Engineering and Architecting Multidisciplinary Systems

Volume 3

SYSTEMS ARCHITECTURE AND DESIGN

ALAIN FAISANDIER

Practical Guidelines

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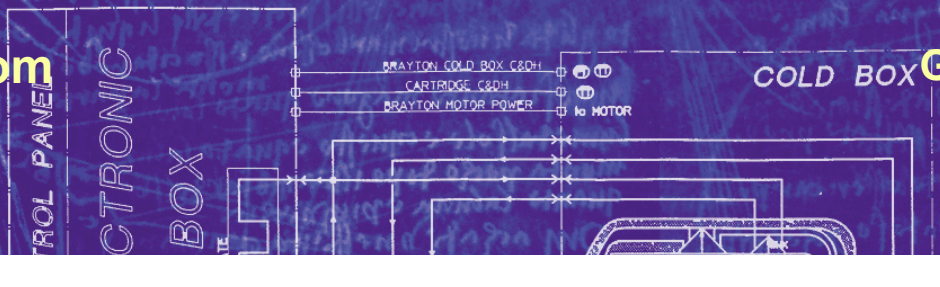

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FOREWORD

Purpose of this volume

This volume, dedicated to Systems Architecture and Design, is part of the series of books entitled “Engineering and Architecting Multidisciplinary Systems”.

This practical guideline is intended primarily for professionals who want to understand and apply daily engineering of systems, and in particular to those who will have to conceptualize and/or design complex or multidisciplinary systems. Here they will find methods, processes, modelling and analysis techniques, reasoning elements, useful recommendations for application, as well as case studies or examples to start using this approach.

Other people having to understand or to exchange with system architects and designers will find simple and concrete explanations. They will then be able to judiciously apply certain precepts and concepts to their own job. For example, they can be responsible for integration, verification and validation, program and project managers, technological study engineers, service developers, etc.

This guideline is most useful to University professors who desire teaching System Architecture Definition or Conceptualization, to university students, and to researchers, as a certain number of topics discussed in this book could possibly lead to more extensive studies, as well as studies which have not yet been tackled by the engineering community.

In this book, the approach used to present processes, activities, methods, and techniques related to systems architecture and design is gradual. It includes definitions, descriptions, discussions; examples and case studies illustrate practices. The case studies explain step by step how to perform the activities and tasks. Readers can directly transpose the step-by-step and use provided templates for their current or future projects.

Content abstract

The present volume contains what is necessary to know for defining the architecture of a system and for designing the system:

- Fundamentals related to the notion of system architecture and system design
- Principles and approaches related to Logical and Physical Architecture Definition processes, activities, and tasks
- The transition from System Requirements to Architecture Definition
- Basic Constructs for modelling a logical architecture
- Some system functional and behavioural patterns often encountered with industrial and service systems
- The description and definition of major system Architectural Characteristics and associated Design Properties
- The separation between Architecture Definition processes and System Elements Design process, and their relationships
- Some applicable methods, modelling techniques, architecture and design considerations, and their utilisation on examples and case studies
- Some pitfalls, proven practices, recommendations and Frequently Asked Questions

CONTENT

3 REMINDERS ABOUT FUNDAMENTALS OF SYSTEM DEFINITION

This chapter provides necessary fundamentals to know about System Definition before reading and studying concepts, principles, approaches and processes dedicated to systems architecture and design. You will find only reminders about those fundamentals here; they are detailed in other volumes: in volume 1 “System Notion and Engineering of Systems” for general approaches, and in volume 2 “Systems Opportunities and Requirements” for requirements definition.

Following subjects are summarized hereafter:

- The notion of life cycle processes and the notion of system – section 3.1
- The top-down and bottom-up engineering approaches – section 3.2
- How these engineering approaches are supported by system development ontology elements – section 3.3

4 GENERAL PRINCIPLES AND CONCEPTS RELATED TO SYSTEM ARCHITECTURE AND SYSTEM DESIGN

You will find in this chapter definitions, principles and concepts related to System Architecture and System Design as well as interesting discussions concerning these subjects.

- Definition of System Architecture and of System Design – section 4.1
- Approach to System Architecture and Design – section 4.2, including:
  - Simplified categorisation of structural domains – section 4.2.1
  - Purpose of System Architecture and Design – section 4.2.2
  - Properties, characteristics and goals – section 4.2.3
  - Transition from System Requirements to Physical Architecture – section 4.2.4
  - Iterations between Logical and Physical Definition – section 4.2.5
  - Re-use of System Elements and Reverse Engineering – section 4.2.6
- General concepts related to System Architecture and Design – section 4.3, including:
  - System Breakdown Structure and Product Breakdown Structure – section 4.3.1
  - Projection of System Architecture onto realisation technologies – section 4.3.2
  - System Architecture and technological Architectures – section 4.3.3
  - Concept of Interface – section 4.3.4
- Intellectual creation principles – section 4.4

5 SYSTEM LOGICAL ARCHITECTURE DEFINITION

This chapter deals with specific concepts and principles related to System Logical Architecture Definition, and provides *What to do* (the activities and detailed tasks of the process), and *How to do* (concepts, approaches, modelling techniques and practical considerations). Are described and discussed:

- Definitions and purpose of this topic – section 5.1
- Concepts related to System Logical Architecture Definition - section 5.2, including:
  - Functional Architecture concepts: Functions and Input-output Flow, Functional Hierarchy, Control flow and Trigger
  - Behavioural Architecture concepts: Scenario of Functions, Operational Mode, Transition of Modes
  - Temporal Architecture concepts: Synchronous and asynchronous Functions, Temporal hierarchy levels, Temporal Analysis
  - Integration of functional, behavioural and temporal views: Systemic grid
- Approach and principles to define Logical Architectures – section 5.3, including:
  - Where to find and how to define Functions and Input-output Flows?
  - How to define Logical candidate Architectures?
  - Utilisation of Behavioural Constructs and Patterns
- Process approach – What to do? – section 5.4, including:
  - Location of the process in the development cycle
  - Purpose of the process, inputs and outputs
  - Activities of the process
  - Ontology elements
  - Verification and validation of Logical Architecture Definition
  - Documentation templates
- Practice – How to do? – section 5.5, including:
  - Which language to use with design and architecture?
  - Methods and modelling techniques: mainly Functional Flow Block Diagram, and SysML Activity Diagram, Utilisation of behavioural constructs to model scenarios
  - Practical considerations: Pitfalls and Proven Practices, Our strongest Recommendations, Frequently Asked Questions

6 SYSTEM PHYSICAL ARCHITECTURE DEFINITION

This chapter deals with specific concepts and principles related to System Physical Architecture Definition, and provides *What to do* (the activities and detailed tasks of the process), and *How to do* (concepts, approaches, modelling techniques and practical considerations). Are described and discussed:

- Definitions and purpose of this topic – section 6.1
- Concepts related to System Physical Architecture Definition – section 6.2, including:
  - Notions of System Element, Physical Interface, Port, Physical Architecture
  - System life cycle Abilities, Architectural Characteristics and Design Properties
  - Emergent Properties
- Approach and principles for defining Physical Architectures – section 6.3, including:
  - Allocation and partitioning principles
  - Physical Interface focalisation
  - Principles for defining candidate Physical Architectures
  - Selecting the preferred candidate Physical Architecture
- System Elements Definition and Acquisition – section 6.4
- Systems of Systems Architecting – section 6.5
- System Architect and Designer challenges; fields of choice – section 6.6
- Process approach – What to do? – section 6.7, including:
  - Location of the process in the development cycle
  - Purpose of the process, inputs and outputs
  - Activities of the process
  - Ontology elements
  - Verification and validation of Physical Architecture Definition
  - Documentation templates
- Practice – How to do? – section 6.8, including:
  - Methods and modelling techniques: mainly Physical Block Diagram, and SysML Blocks
  - An abstract about Architectural Frameworks
  - Practical considerations: Pitfalls and Proven Practices, Recommendations, Frequently Asked Questions

7 SYSTEM DESIGN AND SYSTEM ELEMENT DESIGN

This chapter deals with general concepts and principles related to System Design and System Elements design, and provides the generic activities and tasks of the corresponding process.

Are described and discussed:

- Definitions and purpose of this topic – section 7.1
- Principles and concepts related to System Element Design – section 7.2
- Process approach – section 7.3, including:
  - Location of the process in the development cycle
  - Purpose of the process, inputs and outputs
  - Activities of the process
  - Ontology elements discussion

8 SOME REFERENCES

Some references cited or used in this volume are listed below. The reader can read some of the following books and documents related to the subject of the present volume.

Books in English:

- [ALE 77] Alexander, Christopher; Sara Ishikawa, Murray Silverstein, Max Jacobson, Ingrid Fiksdahl-King, Shlomo Angel. 1977. A Pattern Language: Towns, Buildings, Construction. New York: Oxford University Press.
- [CHE 99] Checkland, P. B. 1999. Systems Thinking, Systems Practice. Chichester, UK: John Wiley & Sons Ltd.
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- [GAM 95] Gamma, Erich; Richard Helm, Ralph Johnson, and John Vlissides. 1995. Design Patterns: Elements of Reusable Object-Oriented Software. Addison-Wesley.
- [LAW 10] Lawson Harold.2010. Systems Thinking and Systems Engineering series. Volume 1, A Journey Through the Systems Landscape. King's College London, UK. College Publications.
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- [THO 93] Thome, B. 1993. Systems engineering, principles & practice of computer-based systems engineering. New York, NY: Wiley.
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- [VIT 99] Vitruvius. 1999. Ten Books on Architecture, translated by Ingrid D. Rowland. Cambridge University Press.

Standards:

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- [OMG 10] OMG Systems Modeling Language – specification - version 1.2 – July 2010 - http://www.omg.org/technology/documents/spec_catalog.htm
- MOD Architecture Framework, UK MOD, version 1.2.004 available from UK MOD at

  http://www.mod.uk/DefenceInternet/AboutDefence/WhatWeDo/InformationManagement/MODAF/
- DOD Architecture Framework, DOD, version 2.02 available from US DOD at http://cio-nii.defense.gov/sites/dodaf20/

Handbooks:

- [INC 11] INCOSE Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities". 2011. San Diego, CA, USA: International Council on Systems Engineering (INCOSE), INCOSE-TP-2003-002-03.2.1.
- [NAS 07] NASA. 2007. Systems engineering handbook. Washington, D.C.: National Aeronautics and Space Administration (NASA), NASA/SP-2007-6105.
- [SEB 12] Guide to the Systems Engineering Body of Knowledge – version 1 – 2012 – http://www.sebokwiki.org

Books in French:

- [MEI 98] Meinadier Jean-Pierre. 1998. Ingénierie et intégration des systèmes. Paris: Hermes.
- [MEI 02] Meinadier Jean-Pierre. 2002. Le metier d'intégration des systèmes. Paris: Hermes-Lavoisier.
- [PEN 97] Penalva Jean-Michel. 1997. La modélisation par les systèmes en situation complexe. Thèse Université. Paris XI Orsay.
- [ROQ 09] Roques, Pascal. 2009. SysML par l'exemple. Paris: Eyrolles.

9 CASE STUDIES

Case studies are presented in the form of exercises. The reader is invited to do the exercises using material included in the previous chapters. Elements of solutions are provided afterwards. The exercises have the goal to illustrate what should be done and how to obtain progressively the outcomes of the engineering activities. The goal is not to provide here complete solutions.

Three case studies are treated:

- Case study 1 – Tank filling, section 9.1
  - This case figures out how logical and physical definition activities are supported by appropriate modelling techniques;
  - As a starting example, few activities of the processes are illustrated.
- Case study 2 – SIBERIA, section 9.2
  - This case provides guidance about the progression of the definition using major activities and tasks of the processes.
  - In particular several behavioural patterns are used with eFFBD and SysML Activity Diagrams.
  - Two physical architectures are defined.
- Case study 3 – FITVEE, section 9.3
  - This case provides also guidance about the progression, using the same guidance template than the previous one. Tasks, models and considerations about the allocated logical architecture are added.
  - Other behavioural patterns are used with eFFBD and SysML Activity Diagrams.
  - Also two physical architectures are defined and their structures are discussed.

10 ANNEXE 1 – GENERIC BEHAVIOURAL CONSTRUCTS

The following representations illustrate the Generic Behavioural **Constructs** and the result of their execution in the form of a timeline as a system architect or designer could expect it.

Two modelling techniques are used to represent these Constructs: Functional Flow Block Diagrams (FFBD) and Activity Diagrams of SysML (AD).

FFBD constructs are using the graphs theory principles; the set of constructs constitutes a "well structured language" mathematically speaking. Timelines have been obtained through the execution of FFBD models.

Activity Diagrams of SysML include simpler and more basic idioms – refer to SysML OMG specification for complete descriptions. As SysML is more a natural language than a formal one (authors said), models presented here are interpretations from the author; other presentations could be acceptable.

The following figures present main generic constructs useful at system engineering level. To understand the figures below you should read before part of sections 5.5.2.2 and 5.5.2.3.

List of constructs:

- Sequence – section 10.1
- Concurrency – section 10.2
- Alternative (selection) – section 10.3
- Iteration – section 10.4
- Multiple exits – section 10.5
- Loop with exit – section 10.6
- Replication without monitoring – section 10.7
- Replication with monitoring – section 10.8

11 ANNEX 2 – BEHAVIOURAL PATTERNS EXAMPLES

This annex presents some examples of general functional / behavioural patterns:

- Sequence of functions – section 11.1
- Parallelism of functions through allocation – section 11.2
- Monitor performance of an operation – section 11.3
- Send and receive a message – section 11.4
- Man Machine Interface (MMI) – section 11.5
- Mutual exchanges – section 11.6
- Monitor transitions of operational modes – section 11.7
- Real time monitoring of processes – section 11.8
- Process threats – section 11.9
- Queue management – section 11.10
- Production – consumption – section 11.11
- Control-command (simple) – section 11.12
- Supervised control-command – section 11.13

16 ANNEX 7 - SYSTEM DESIGN DOCUMENT - TEMPLATE & GUIDELINES

Preliminary

This template is a form to use and fill in for producing the document related to a specific system in the context of a development project.

The "System Design Document" (SysDD) presents the outcomes generated by the performance of the System Logical Architecture Definition Process and of the System Physical Architecture Definition Process.

It contains the selected solution in terms of Logical views of the Architecture of the system XX (functional, behavioural, and temporal architectures or views) and of Physical views of the Architecture of the system XX.

It does not present the justification and rationale of the selected solution; these elements are described in the System Justification Document – refer to the corresponding template in Annex 8.

17 ANNEX 8 - SYSTEM JUSTIFICATION DOCUMENT - TEMPLATE & GUIDELINES

Preliminary

This document is a form to use and fill in for producing the document related to a specific system in the context of a development project.

The "System Justification Document" (SysJD) presents the justification and rationale for selection of main engineering elements. Main engineering elements include the set of Stakeholder Requirements, the set of System Requirements, the architectural and designed elements: Functions, Input-output Flows, Operational Modes, Transition of Modes, Scenarios, System Elements, Physical Interfaces (links/connectors).

It provides the traceability between engineering elements, and the outcomes of cost analysis, effectiveness analysis, risk analysis, dependability analysis, safety analysis, and trade-offs analysis (refer to System Analysis Process) that argue chosen engineering elements.

The purpose can be extended to system integration.