Advanced Virtual Engineering Centre

Systems-of-Systems Design Using Architecture Patterns

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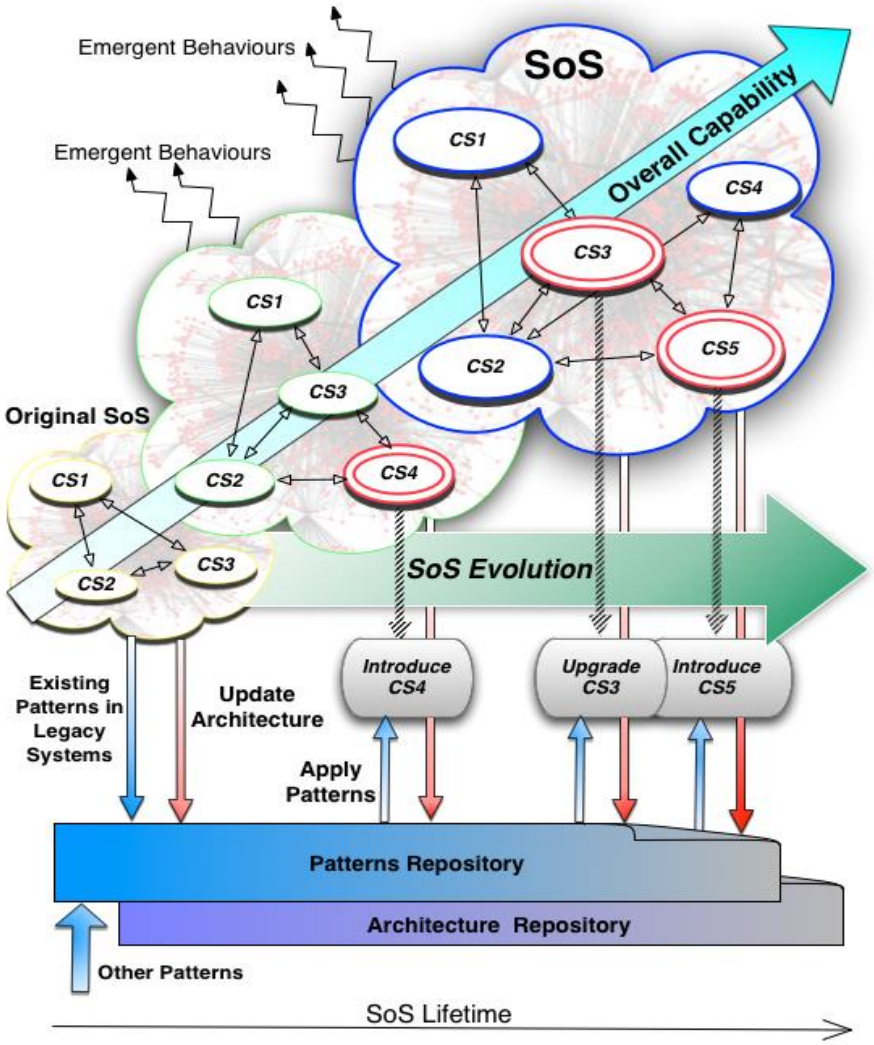
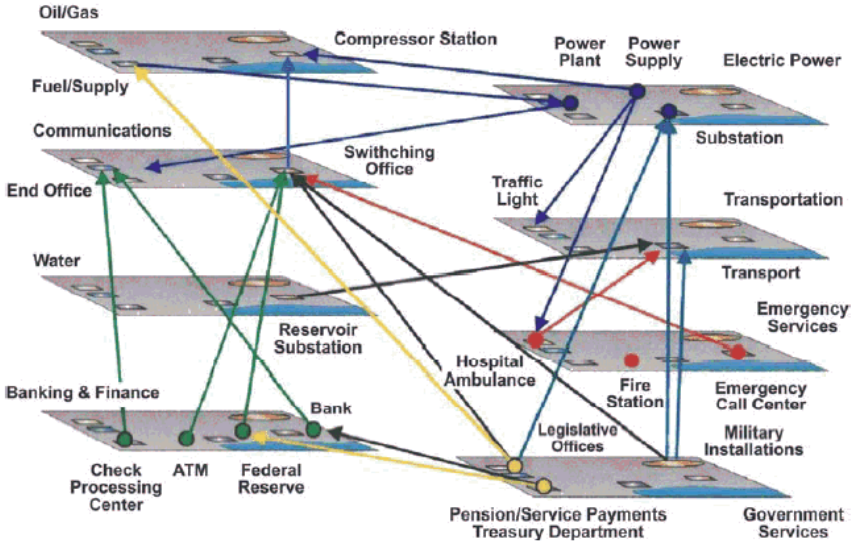
http://www.lboro.ac.uk/research/avrrc/research/currentprojects/modellingandsimulation/

Overview

- **Introduction to Systems of Systems**
  - Systems of Systems
  - Designing For Adaptability and Evolution in Systems of Systems (DANSE Project)
- **Architecture Patterns for SoS Development**
  - Architecture Patterns and SoS Design
  - Mining Architecture Patterns
- **Online Architecture Patterns Repository**
  - Architecture Patterns Classification
  - Architecture Pattern Anatomy
  - Using the Repository
  - Applying Architecture Patterns to an SoS Design Project
- **Architecture Patterns Examples**

Introduction to Systems-of-Systems (SoS)





Some of the complexity issues

- Possibly no conscious knowledge of other systems
- Operational independence,
- Geographically distributed,
- Constantly Evolving,
- Independent Governance, …

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DANSE Project

DANSE - Designing for Adaptability and evolutioN in System of systems Engineering

Nov 2011 – Oct 2014

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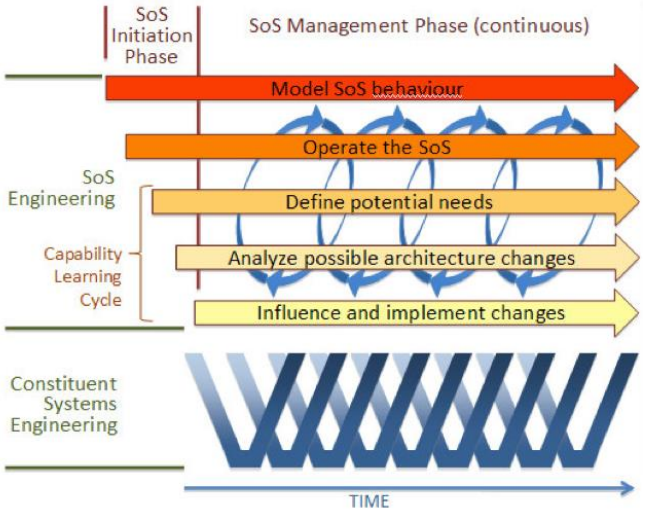
Designing for Adaptability and Evolution in Systems of Systems

DANSE aims at developing new approaches to the design and management of the operation of SoS based on advanced methodologies based on a new evolutionary:

- Adaptive and iterative SoS life-cycle model;
- Semantically sound models based on the notion of contracts;
- Innovative architectures that provide the infrastructure to allow the dynamic affiliation of components so that the behaviour of the ensemble is not disturbed;
- Novel supporting model based tools for analysis, simulation, and optimization;
- Organized in an integrated environment.



DANSE focuses on the development of a new methodology to support evolving, adaptive and iterative SoS life-cycle models based on a formal semantics for SoS inter-operations and supported by novel tools for analysis, simulation, and optimisation.

DANSE Technical Approach

To achieve these challenges DANSE addresses the following innovation points:

•A new evolutionary, adaptive and iterative **SoS life-cycle model**, offering evolutionary simulation, analysis, and development of the SoS in real time.

•Development of **new formal semantics** for SoS modelling based on an architectural framework.

•A formal method for **"correct by evolution"** analysis which constantly guarantees that the SoS evolves towards its current goals.

•High-level behavioural simulation based on **SoS abstraction** using theoretical relationships rather than detailed event-level simulation.

•Methods and tools to allow **optimisation** at the global SoS level and at the local level of constituent systems, in face of possibly contradicting goals.

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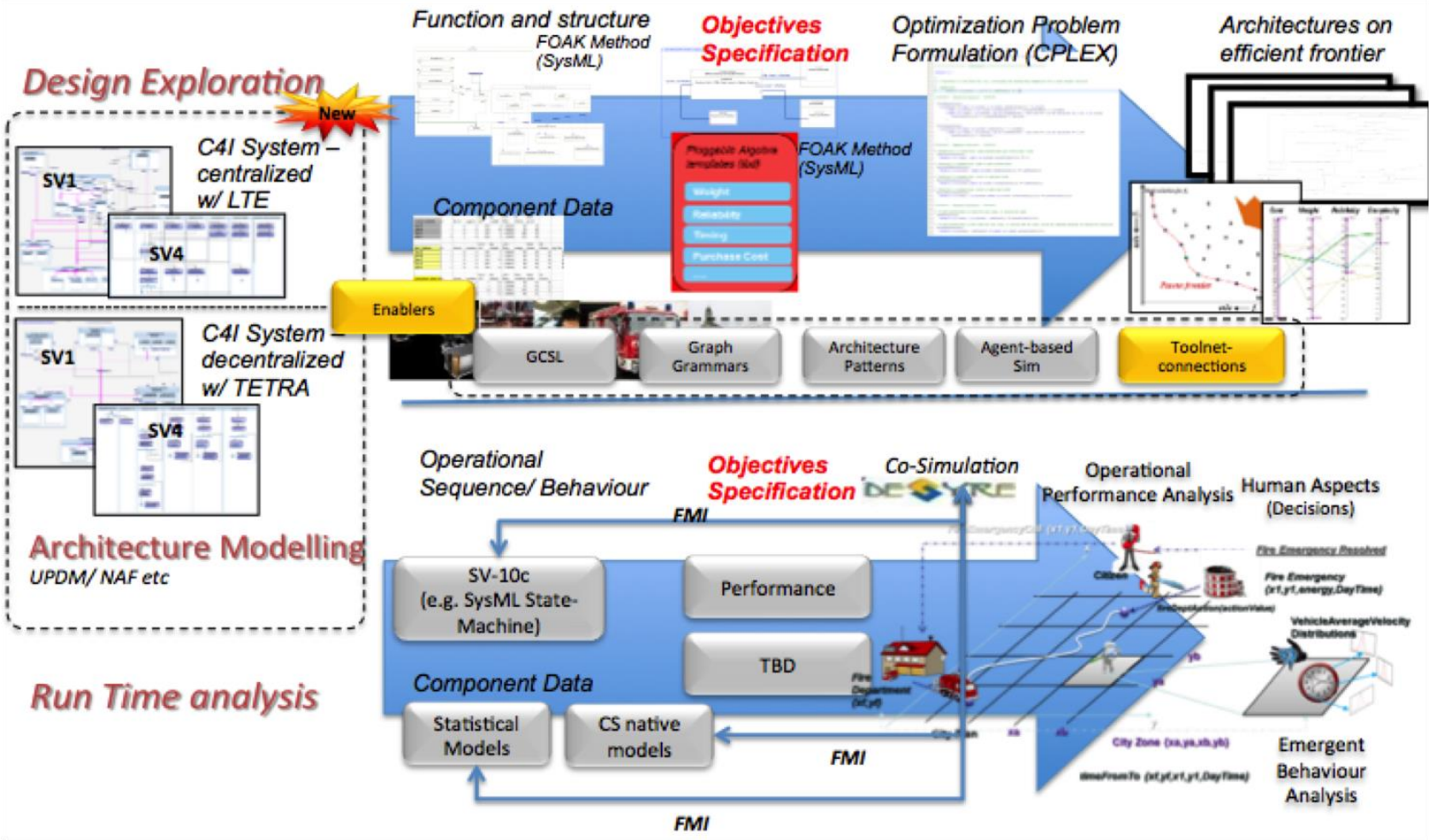
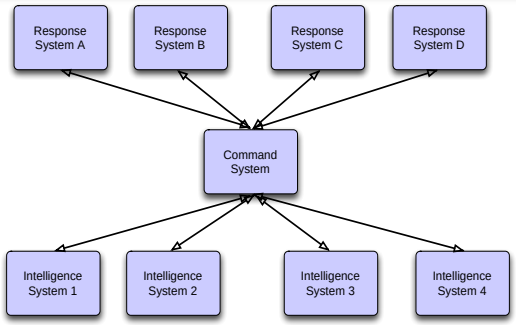
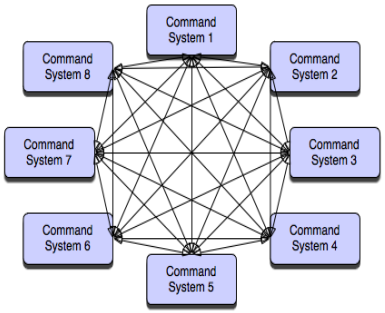
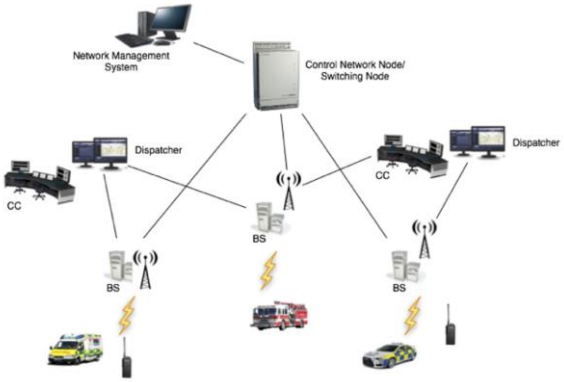
DANSE Technical Approach – Modelling and Simulation

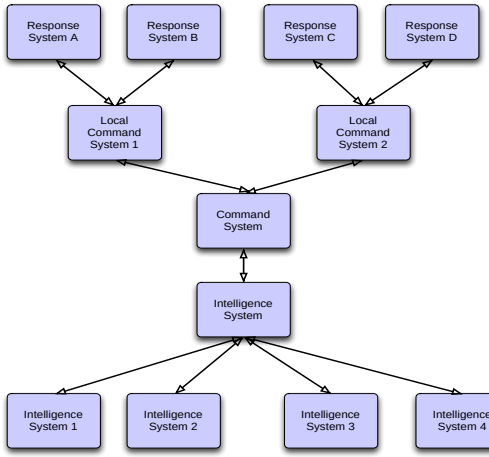


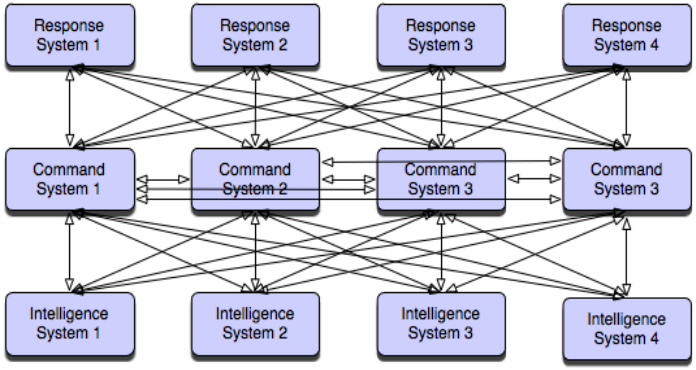
Architecture Patterns

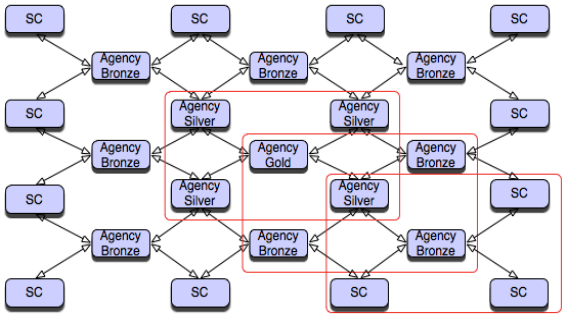


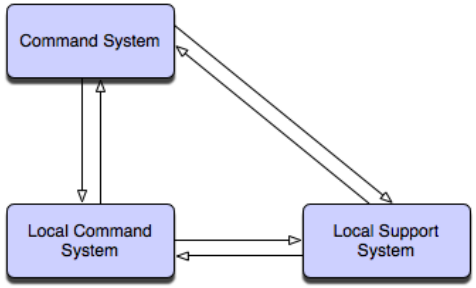


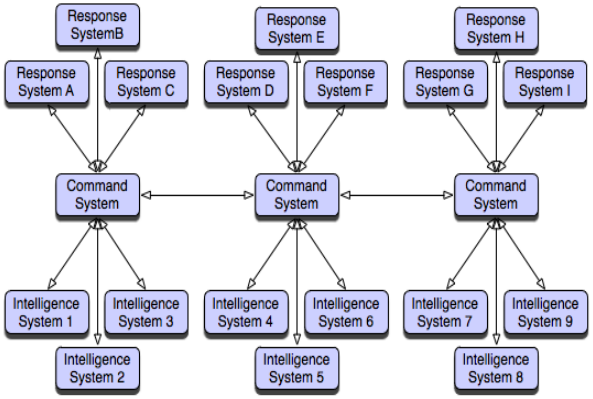






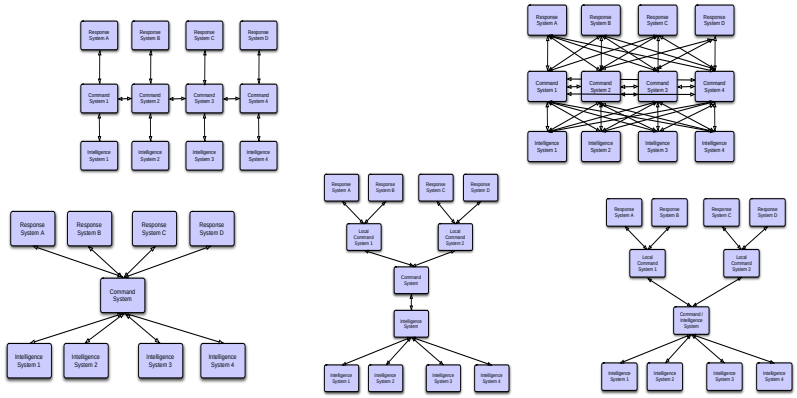






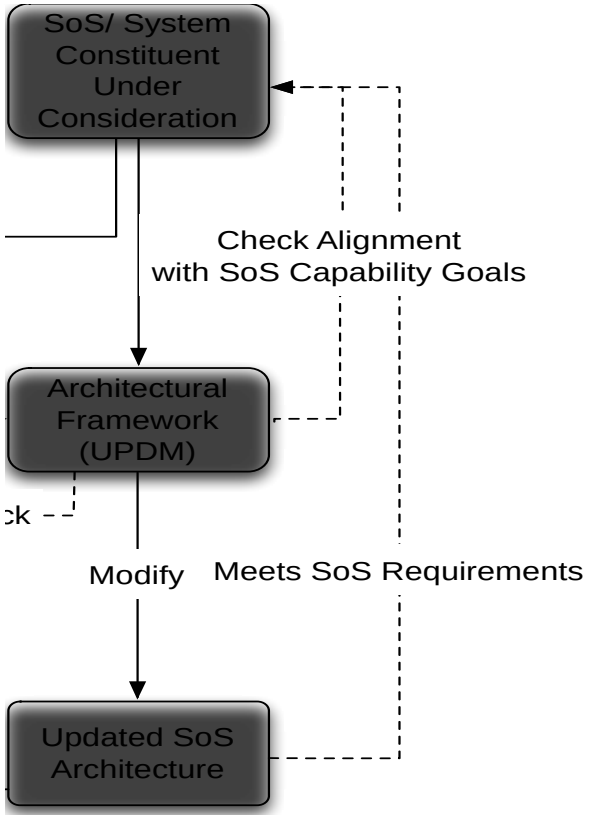
Architecture Patterns

- **Patterns are not new – they have been in existence for centuries**



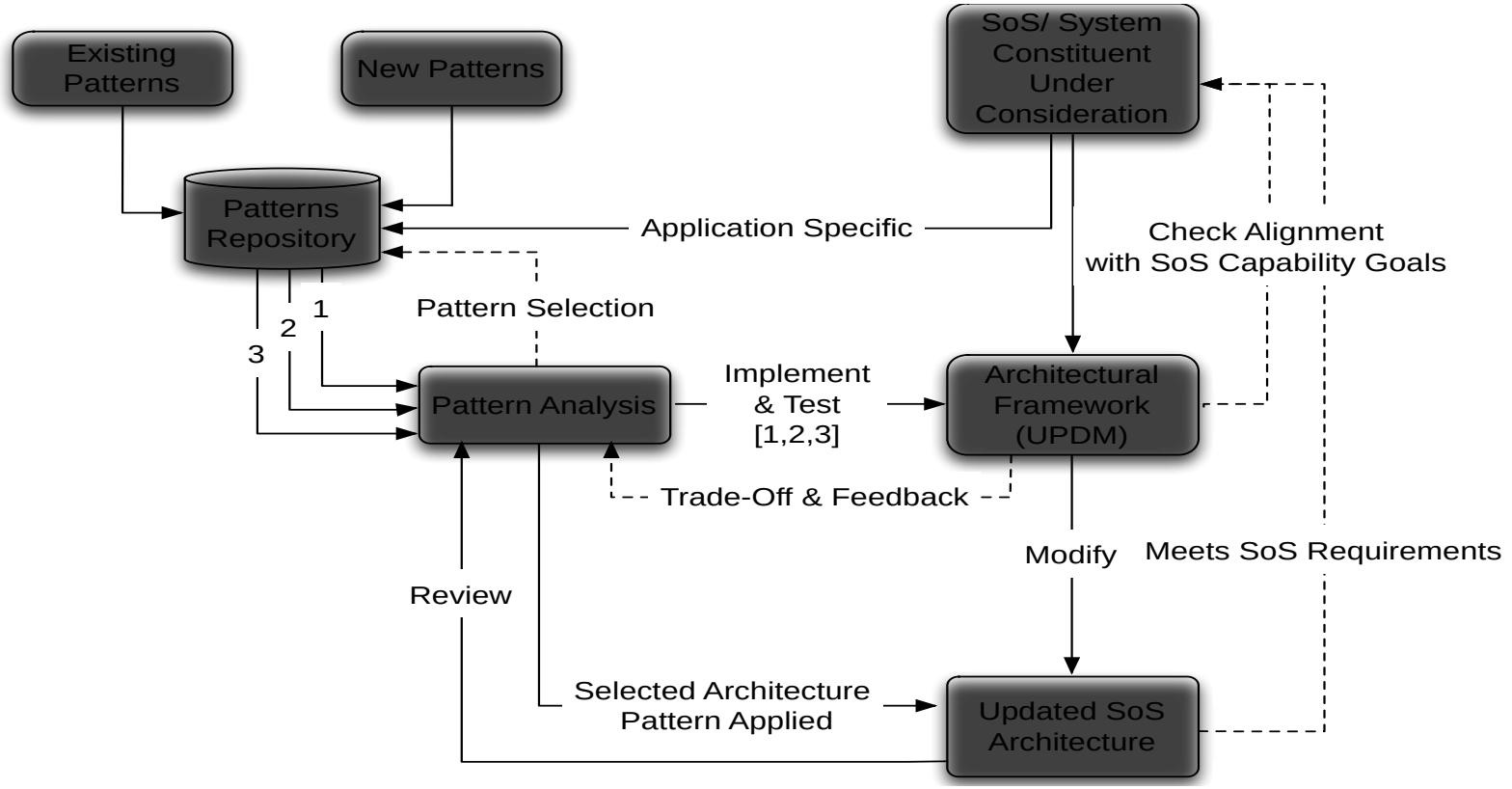
- Design patterns used extensively by software engineering
- However, Architecture Patterns **<u>are new</u>**
- **Patterns encapsulate considerable knowledge from experienced practitioners**
- Patterns are templates or recipes to describe solutions to known problems (relate **Context, Problem & Solution** in a consistent manner)
- Provide **a generalised rule or guideline for realising certain architecture design characteristics**.
- Patterns allow **specification of different architectural approaches**
- Support abstract representations that **facilitate greater understanding** of complex SoS architectures

Architecture Patterns for SoS Development



- SoS is modelled using an architecture framework
- Iterative process until desired global characteristics implemented

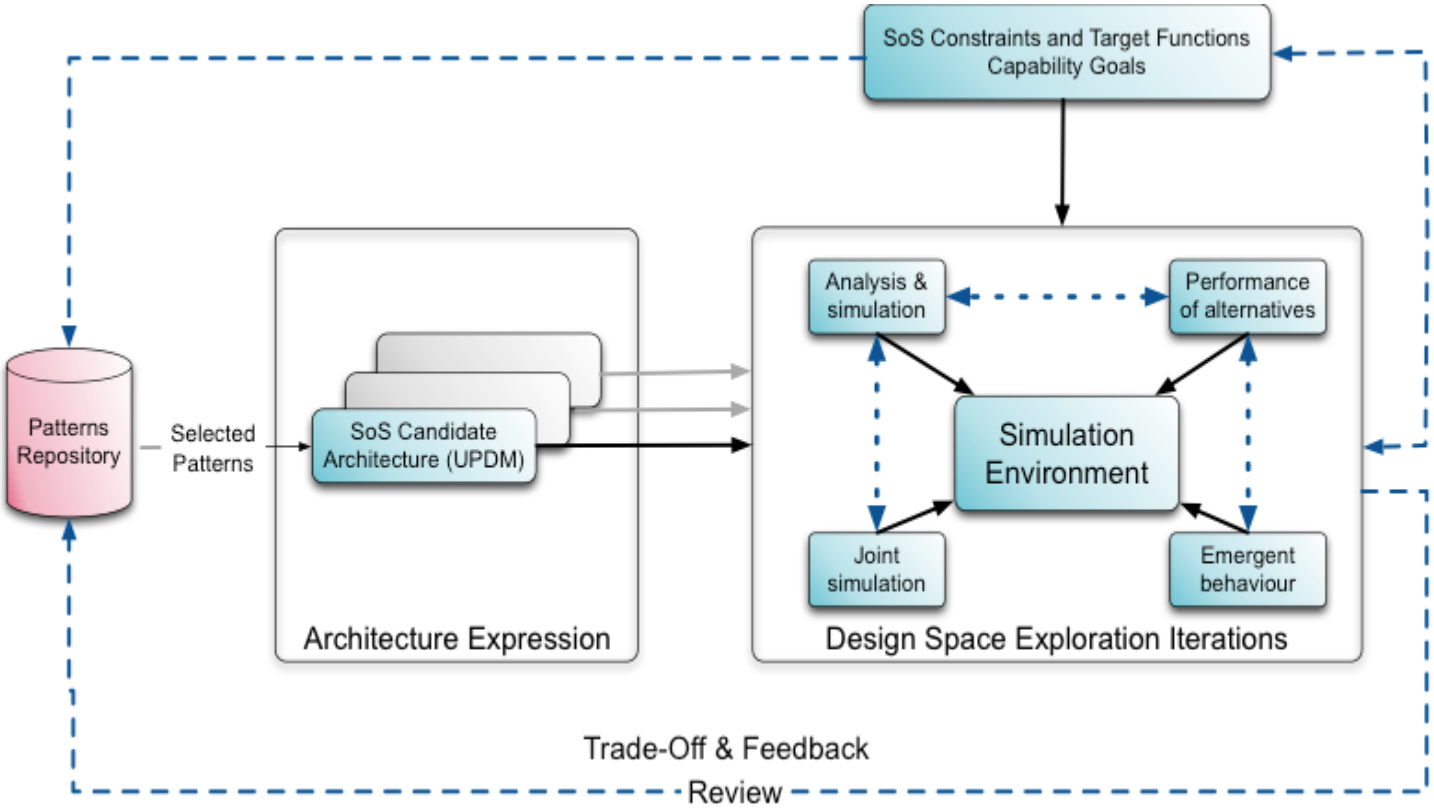
Architecture Patterns for SoS Development



- Architects identify a series of patterns which offer desired qualities and attributes
- Selected patterns implemented in architectural framework and analysed

Architecture Patterns for SoS Development

- Candidate architectures submitted to simulation environment
- Architecture evaluated against a set of SoS constraints and target functions
- Alternative patterns substituted if a particular solution does not converge towards the desired target



SoS Design Space Exploration

Architecture Patterns for SoS Development

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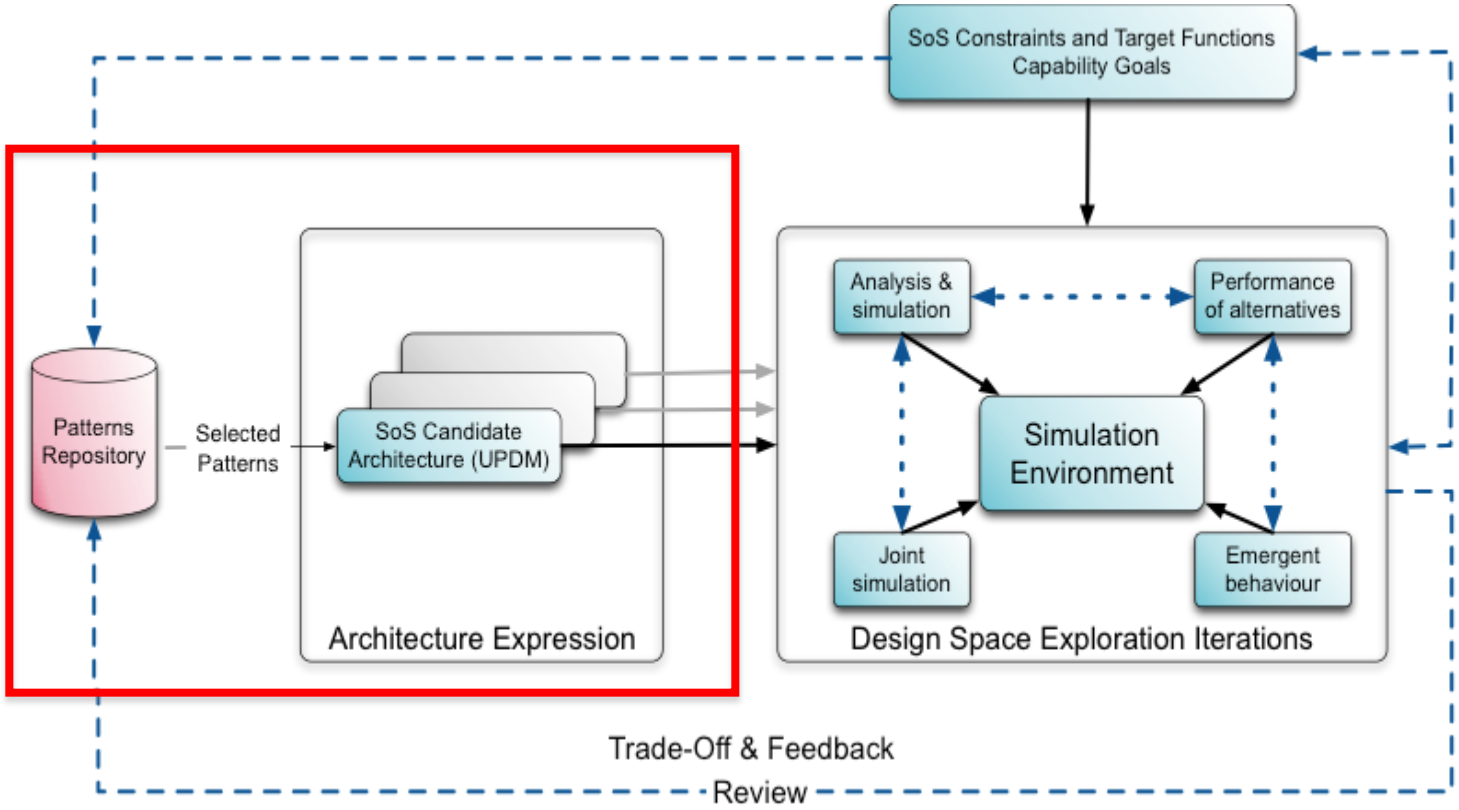

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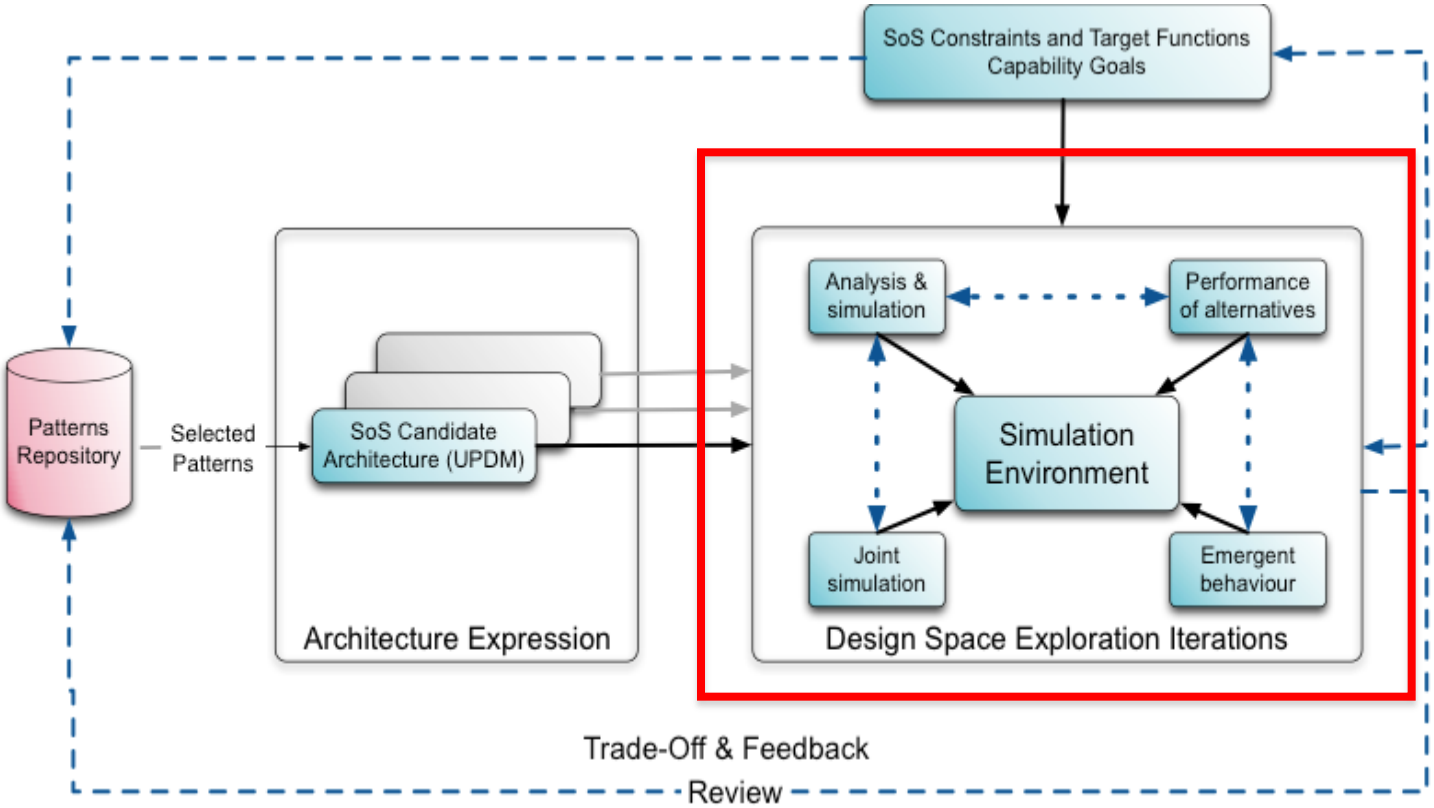


SoS Design Space Exploration

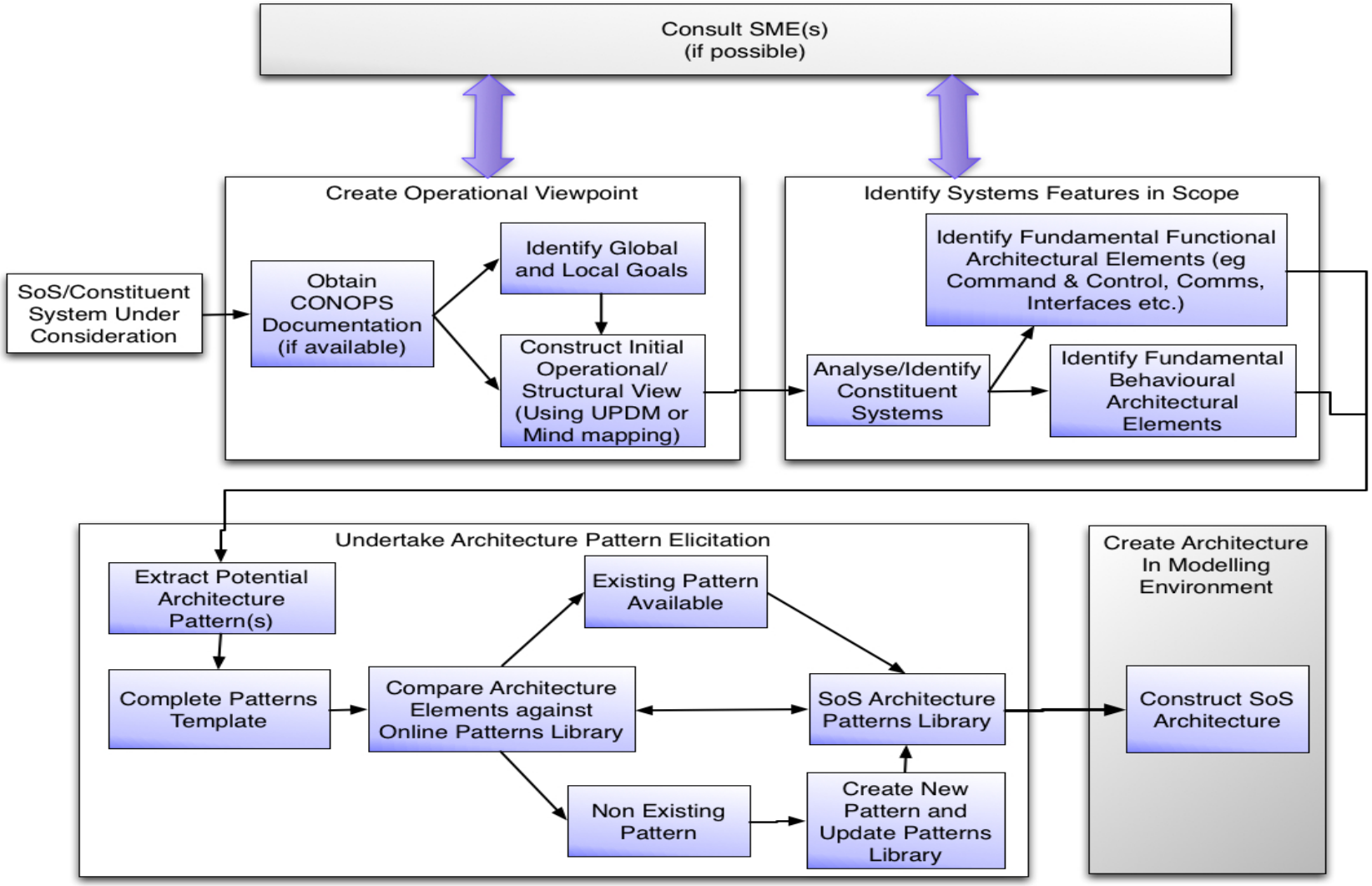
Mining Architecture Patterns

- **Mining patterns is an iterative process**
  - There is an art to mining patterns
  - Patterns have structure
  - Remember **patterns are small reusable elements** that are generally repeatable in structure
- **Think simple** - an elegant pattern is characterized by its simplicity

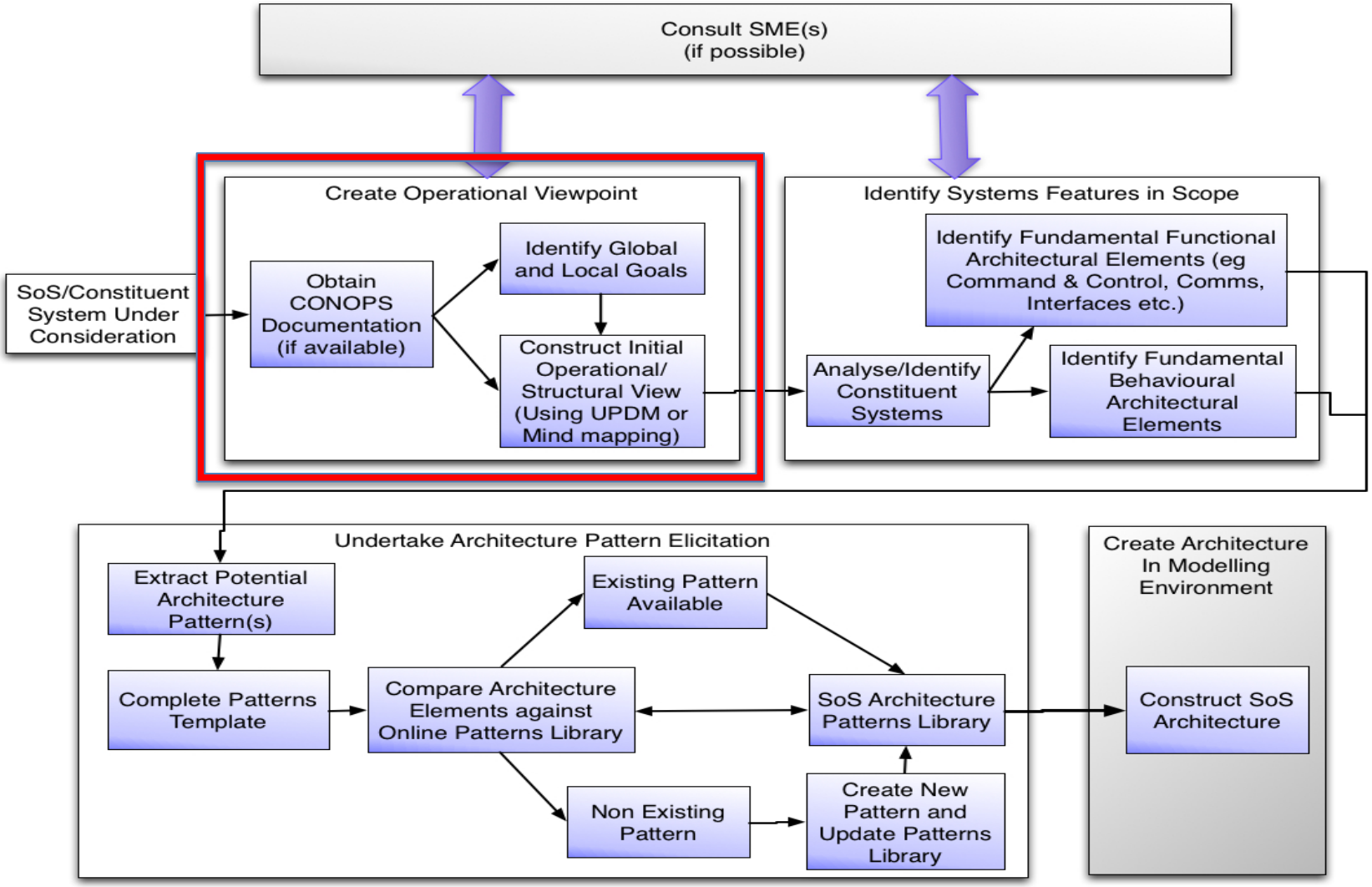
- **Architecture Patterns are abstractions**
  - Don't go into specific implementation details
  - This is too deep
- Note some patterns may look similar but can actually be radically different

- New patterns can be created or evolve from pre-existing patterns

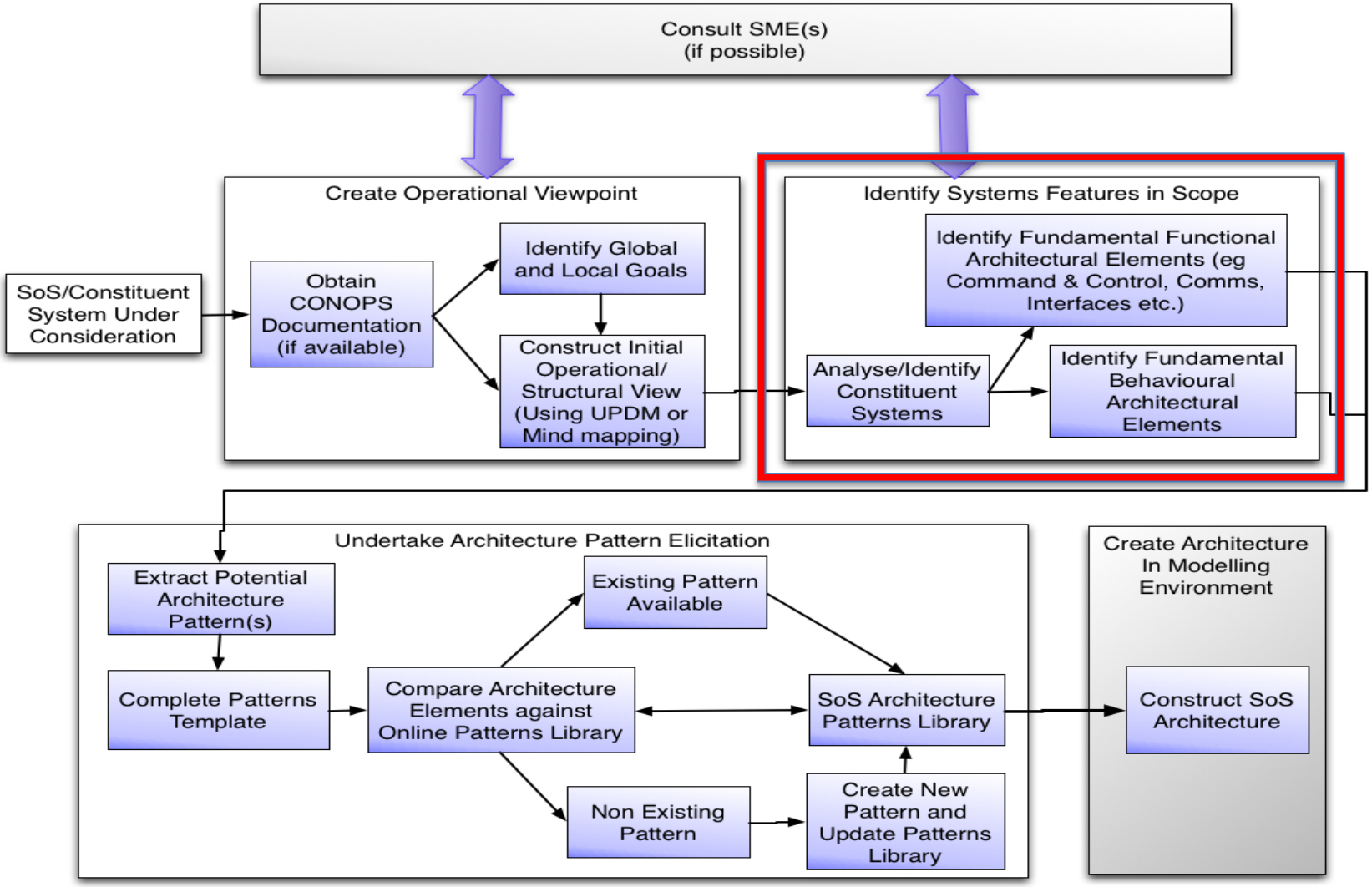
Mining Architecture Patterns



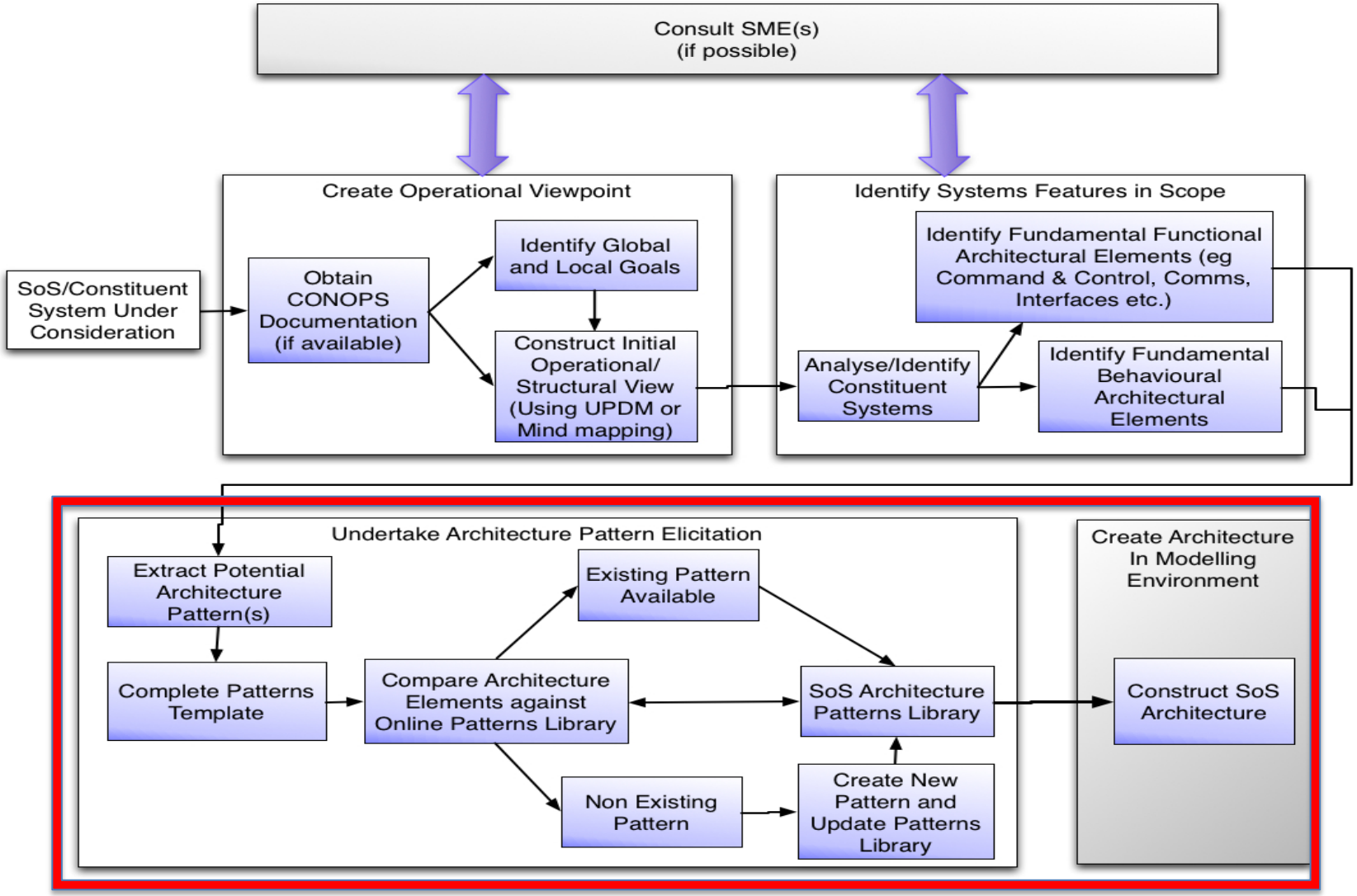
Mining Architecture Patterns



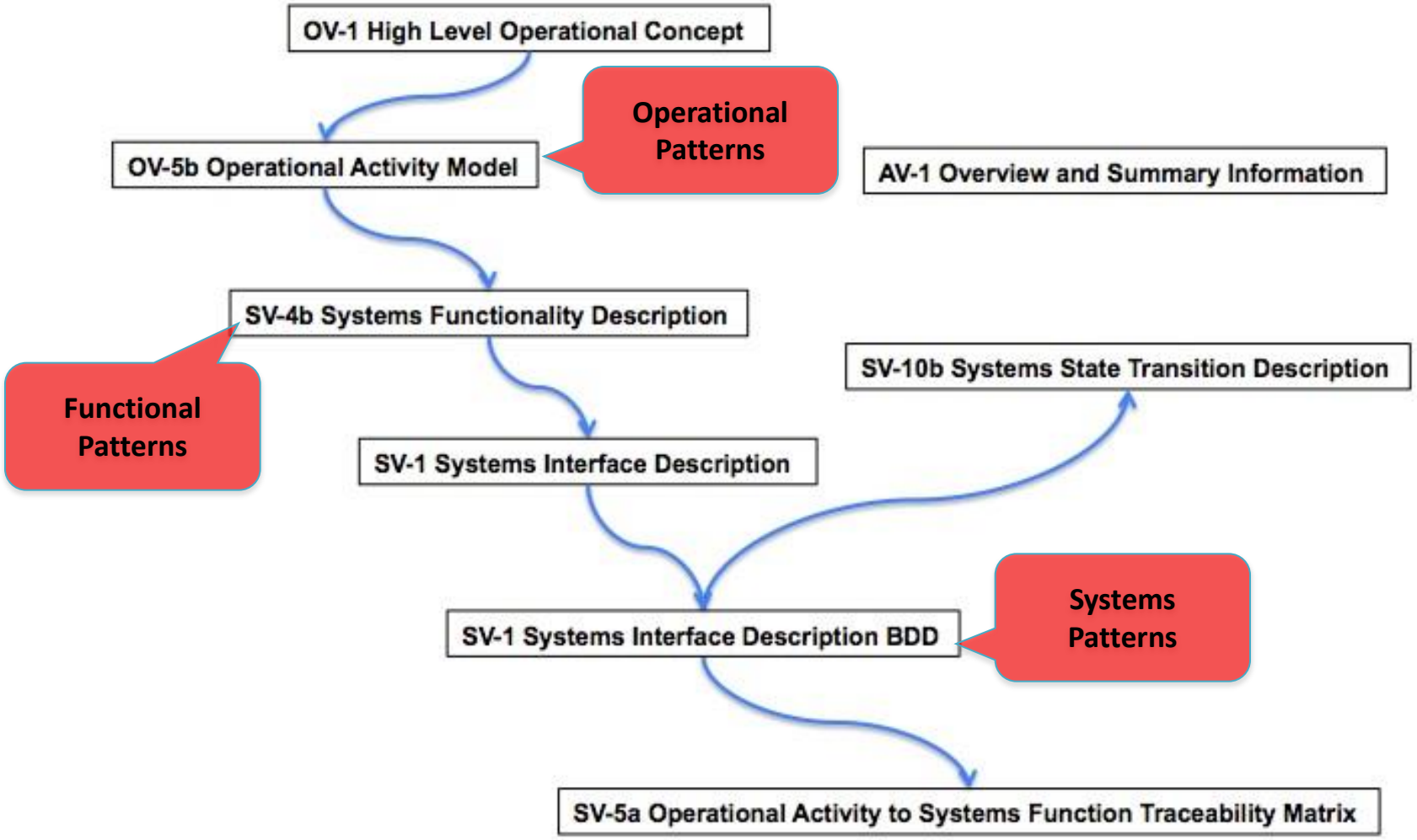
Mining Architecture Patterns



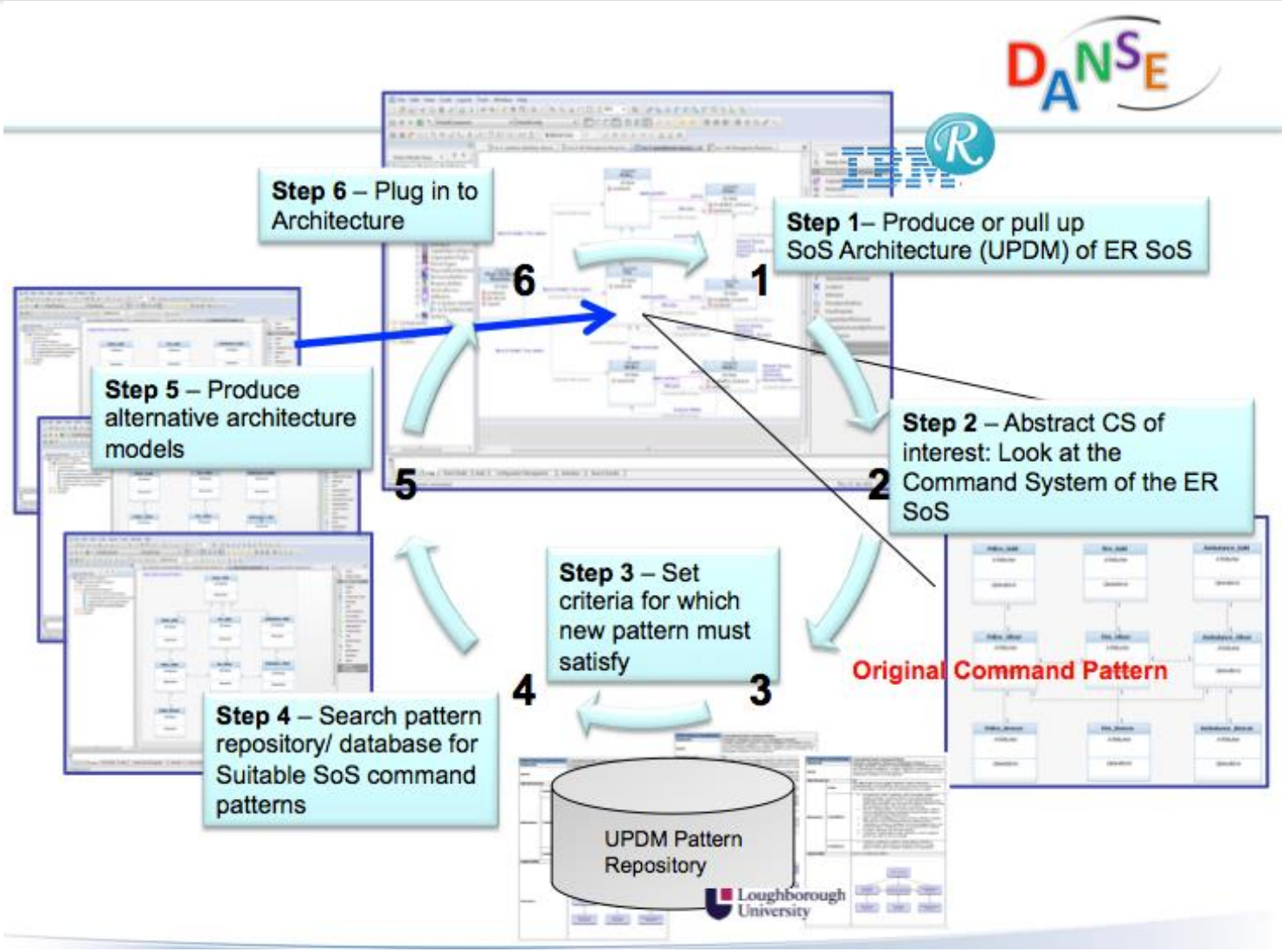
Mining Architecture Patterns



Operational, Functional and Systems Patterns Use within Architectural Framework

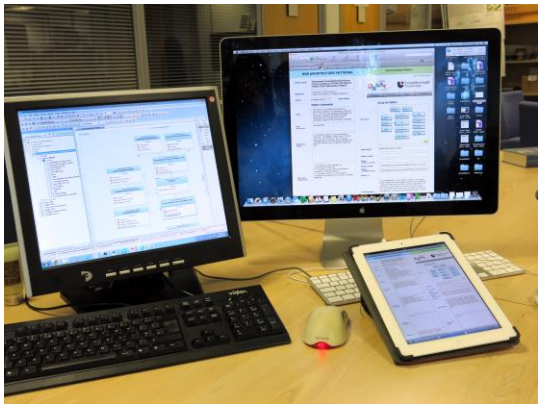


Process


Step 6 – Plug in to Architecture
Step 1– Produce or pull up SoS Architecture (UPDM) of ER SoS
Step 5 – Produce alternative architecture models
Step 2 – Abstract CS of interest: Look at the Command System of the ER SoS
Step 3 – Set criteria for which new pattern must satisfy
Step 4 – Search pattern repository/ database for Suitable SoS command patterns
Original Command Pattern
UPDM Pattern Repository
Loughborough University

Architecture Patterns Repository

- Architecture Patterns repository includes larger catalog of patterns
  - e.g. UPDM, SysML,Test Cases etc.
- Sophisticated online repository for architecture patterns with powerful search capabilities, option to store new patterns.
- The repository exists itself in three forms;
  - a document-based repository,
  - a repository of IBM Rhapsody profiles, and
  - an online searchable repository with the option to download IBM Rhapsody SysML/UPDM profiles for inclusion in DANSE Tool-net.



- Accessed via:
  - Conventional web browser (all popular browsers supported),
  - Apple iPad running the free FileMaker App – FileMaker Go.
  - User run-time version of FileMaker

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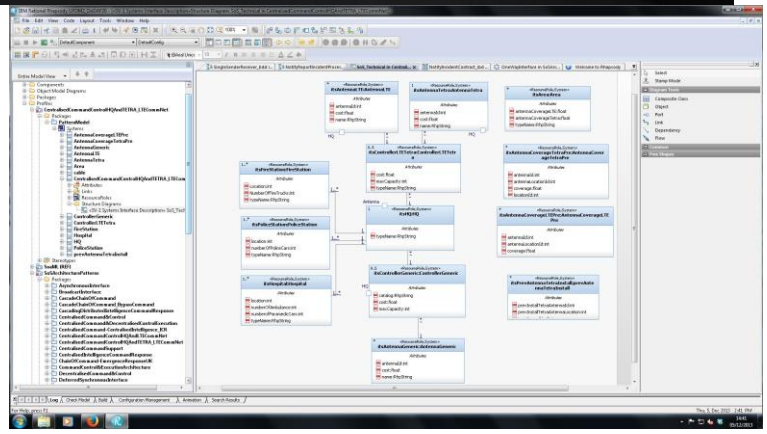
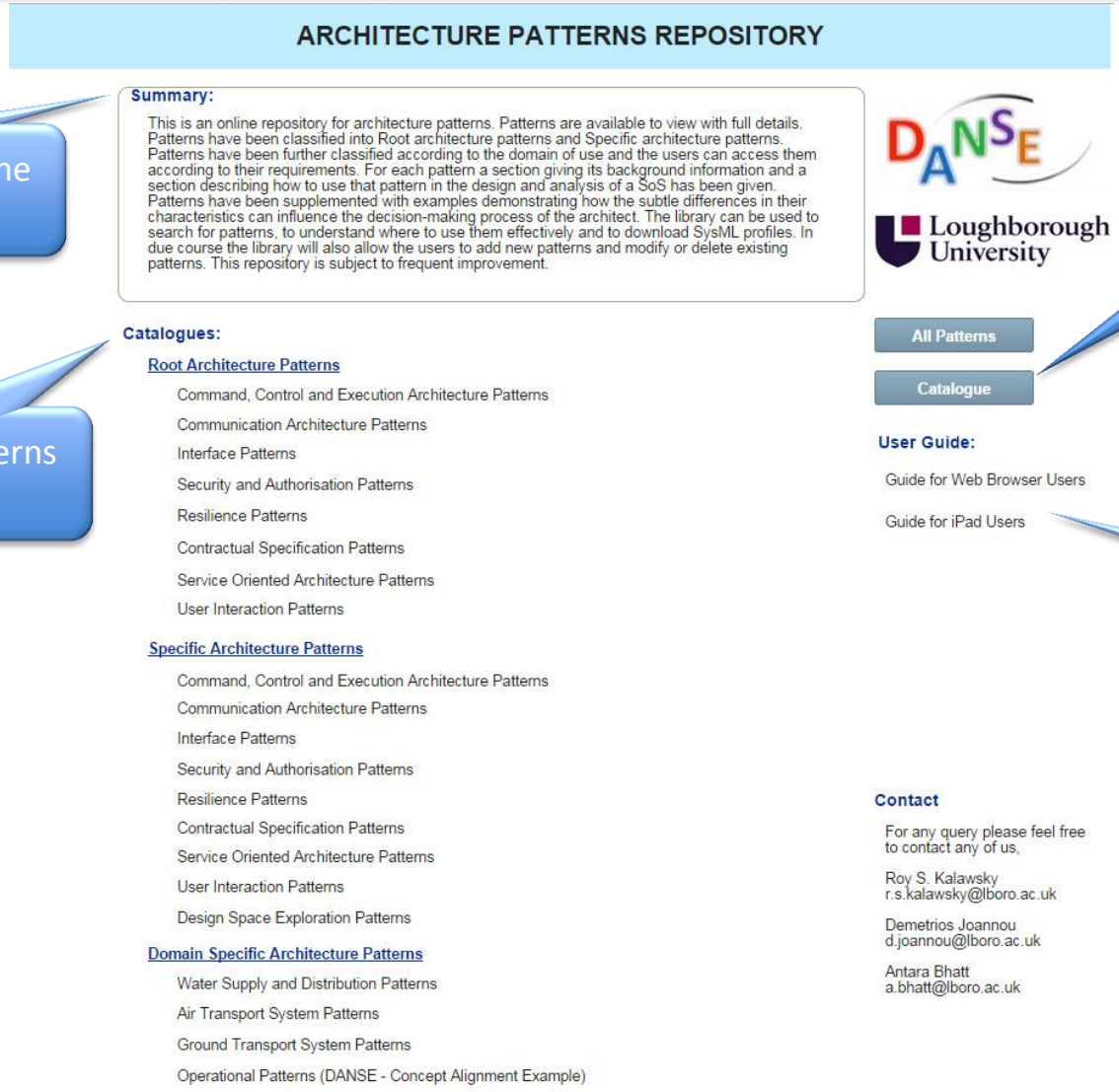
Online Architecture Pattern Repository



Patterns Catalogues



Summary of Online Repository

Architecture Patterns Catalogues

Catalogue navigation pages

User Guides

Loughborough University
Advanced VR Research Centre

Architecture Pattern Anatomy

Any key words that may appear in the pattern that will be useful when looking up the pattern in a repository.

The Author of the Pattern

This refers to the problem and why you would use the pattern to address the issue.

Also known as.

Statement of why the pattern would be utilised to address the design problem or situation. It will help understand the structure and consequences later in the pattern.

Name of Pattern

Diagram of Pattern's Structure

Rhapsody Models Available for Download

ARCHITECTURE PATTERNS REPOSITOR — **Control and Execution Architecture Patterns**

Go to Printing Layout

Catalogue | Previous | Next | All Patterns

Pattern Name: Centralised Command and Control Pattern

Keywords: Command, Centralised, Control

Author: Loughborough Uni — New Pattern

Pattern Information

Intent: Exercise of authority (invention, advice, opinion, influence, or command) and direction by a control system over assigned resources to achieve accomplishment of the specified mission. The Central Command/Control System governs and exercises full authority over resources.

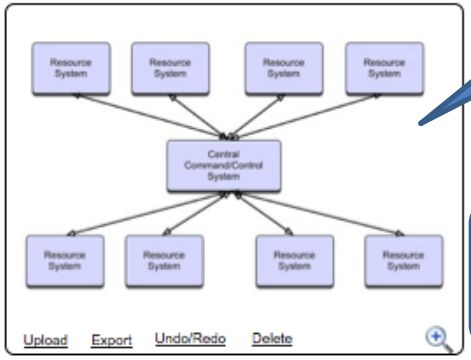
Also Known: CCC, C3

Motivation: Goals: The pattern allows for a single command centre, which has unquestionable overall authority.

Motivation: Capabilities:
1. Many points of intelligence access the Centralised Command System, allowing for a more informed decision making process.
2. Centralised command facilitates for all knowledge to be in one central location, resulting in more accurate decision making.

Using the Pattern

Structure



Applicability: Root Architecture Patterns

Model (SysML): SoSArchitecturePatter Export Delete Upload

Model (SysML+Concise): Upload

Model (UPDM): Upload

Model (UPDM+Concise): Upload

Model (Other): Upload

Pattern Anatomy (Cont.)

Describes what the pattern has to offer to the user and the characteristics which it possessed which will be of benefit to the pattern implementer.

Motivation: Capabilities

1. Many points of intelligence access the Centralised Command System, allowing for a more informed decision making process.

2. Centralised command facilitates for all knowledge to be in one central location, resulting in more accurate decision making.

3. Excellent planning and tasking potential.

4. Command System able to rank requests in order of highest priority and able to act accordingly.

Refers to the restrictions of the pattern.

Motivation: Limitations

1. For Command/Control to be effective, the command and control information network must be "interoperable, sustainable, and survivable".

2. A single command/control system is subject to serious common mode failure and is completely dependent on the Command/Control System being available.

3. A single command/control system is extremely cost effective in terms of interfaces but due to point 2 above it may be necessary to consider alternative more resilient architecture variants

The elements that are involved within the pattern.

Participants

Central Command System, Command Systems

Collaborators

Central Command System – Command System: Centralised Command System passes orders on to the appropriate command system to achieve a specific result, mission or goal. Command Systems may act as a point of intelligence to the Central Command system, collecting "on-scene" information or data to help co-ordinate tasks and to reallocate resources for example if need be.

Here, not only are the participants being shown that make up pattern, but also how, and with which other elements are interacting, describing briefly the relationship between elements which facilitate the tasks they need to conduct.

(SysML+Concise) Upload

Model (UPDM) Upload

Model (UPDM+Concise) Upl

Model (Other) Upl

Implementation

On implementation, consideration should be taken on the following issues:
1. Commands to other command systems need to be unambiguous but also considering how intelligent a command should be, for security concerns.

2. The capacity of command systems a central command system can cope with in a high demanding situation.

3. Whether or not the centralised command pattern will facilitate for a fast or slow response time depending on SoS goals.

Advice/Guidance on the usage of the pattern, providing some considerations to be undertaken when the pattern is applied.

Performance Metrics

Information will be provided after simulation has been run.

Associated metrics e.g. bandwidth, response time, cost, redundancy level, etc.

Emergent Properties

Information will be provided after simulation has been run.

Possible emergent properties which have emerged from simulation

Example(s)

Emergency Response agencies (fire departments departments and medical services) are sometime controlled by a single overarching control centre, authority over all three. Knowledge and intelligen collected and manipulated by the single comman decisions are made as to which resources ought t

Pattern Anatomy (Cont.)

The consequences refer to differing variables that may influence the usage of the pattern. What aspect of the pattern structure does it allow you vary in order to fit your specific application?

Where the pattern has known to be used in real-life scenarios and in which domains. E.g. Military, Emergency Services.

An example where the pattern is in use.

If the pattern has stemmed down from an original pattern, or patterns. Which are these?

Any patterns that may have been form from the pattern.

Catalogue which the pattern belongs to or can be found

URL References to related materials

Collaborators	
Consequences	• Reduced coupling. The pattern frees response systems from receiving commands from multiple command systems. In turn the command system knows exactly what each resource is doing. • Multiple Intelligence systems are required. • High redundancy. • Centralised Command System manages all resources available. • Employs its own intelligence data
Known Uses/ Domain	General command systems, emergency response scenarios, military activities, air traffic control, security systems, ground transport systems, other transport systems, energy management, water management systems etc.
Catalogue	Command, Control and Execution Architecture Patterns
Example(s)	Emergency Response agencies (fire departments, police departments and medical services) are sometimes controlled by a single overarching control centre, which has authority over all three. Knowledge and intelligence is collected and manipulated by the single command HQ and decisions are made as to which resources ought to be
Example(s) Diagrams	 Upload Export Undo/Redo Delete
Related Patterns: Parent Patterns	Not applicable
Related Patterns: Child Patterns	Not applicable
Reference (URL)	http://www.lboro.ac.uk/research/avrrc/ Go

Import Pattern into Rhapsody Project

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Advanced VR Research Centre

SOS ARCHITECTURE PATTERNS

Communication Architecture Patterns

Go to Printing Layout

Pattern Name	**Centralised Command/Control HQ and Communications (TETRA/LTE) Network Pattern [CAE Optimisation Pattern]**
Keywords	Command, Communications, Telecommunications, Emergency Response,
Author	Loughborough Uni ☐ New Pattern

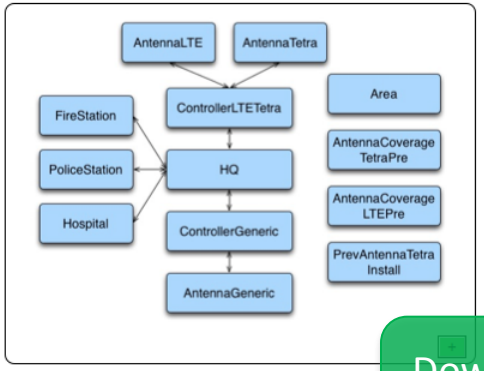
Catalogue | Previous | Next | All Patterns

Pattern Information

Intent	This pattern is to provide the structure of constituent systems in an emergency response SoS in which Concise Modeling stereotypes can be added to perform optimisation activities. Optimisation will consider both how the constituent systems of the emergency response
Also Known As	Not applicable
Motivation: Goals	To provide two options of communications networks – Terrestrial Trunked Radio (TETRA) and Long Term Evolution (LTE) to support message sending and data transfer between the agencies making up an Emergency Response SoS.
Motivation: Capabilities	1. Provides the option between two communications networks. 2. The pattern can be used for optimisation activities in Concise Modelling. 3. The pattern allows for communication coverage for all agencies at all times if optimised effectively.

Using the Pattern

Structure

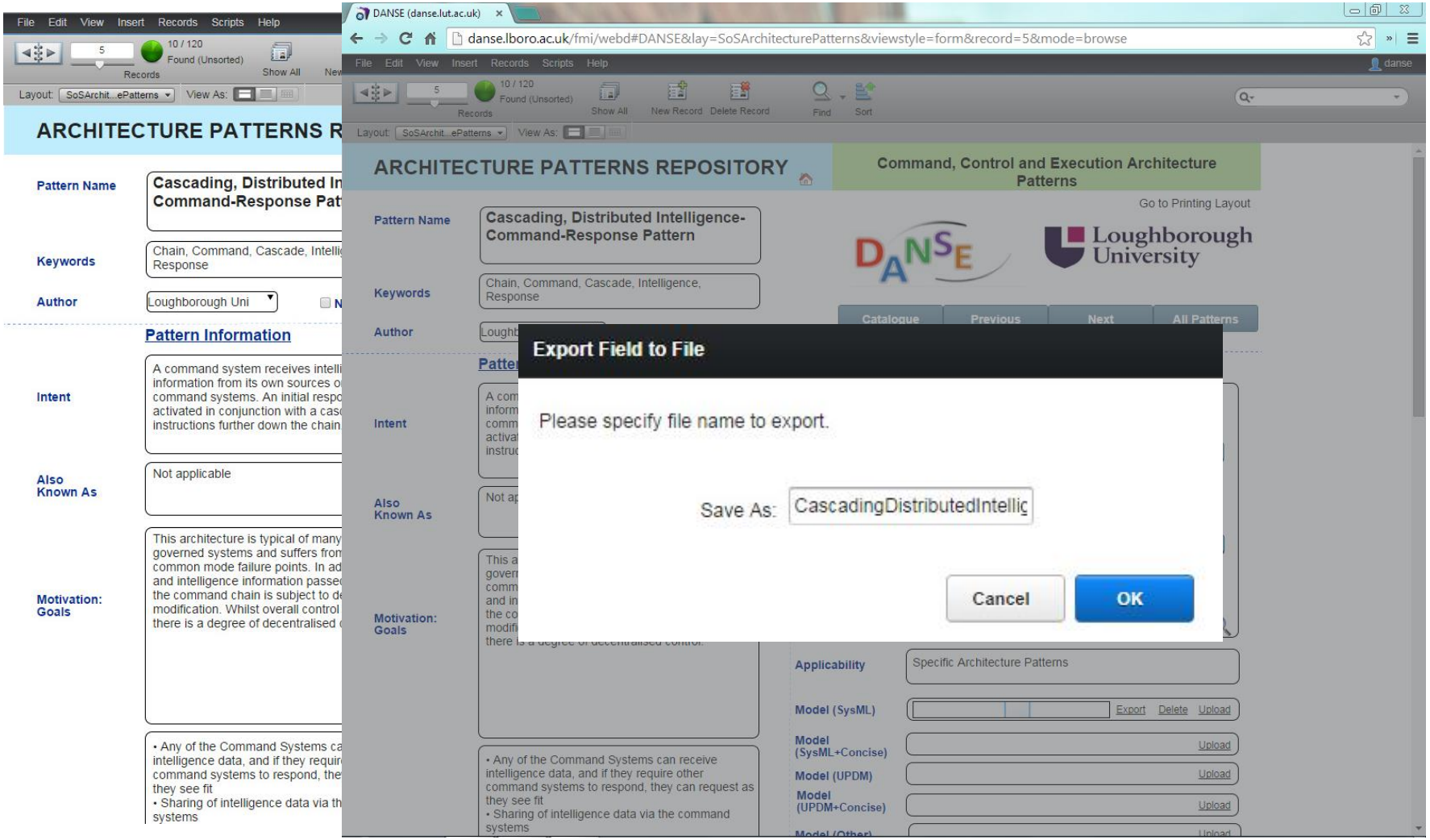


Applicability	Specific Architecture Patterns
Model (SysML)	
Model (SysML+Concise)	
Model (UPDM)	CentralisedCommandControlHQAndTETRA_LTEComm
Model (UPDM+Concise)	CentralisedCommandControlAndTETRA_LTECommuni
Model [v]	

The implementation of this pattern is likely to be multiple phase process as existing legacy systems may already be in place, for example, command centres, base station and

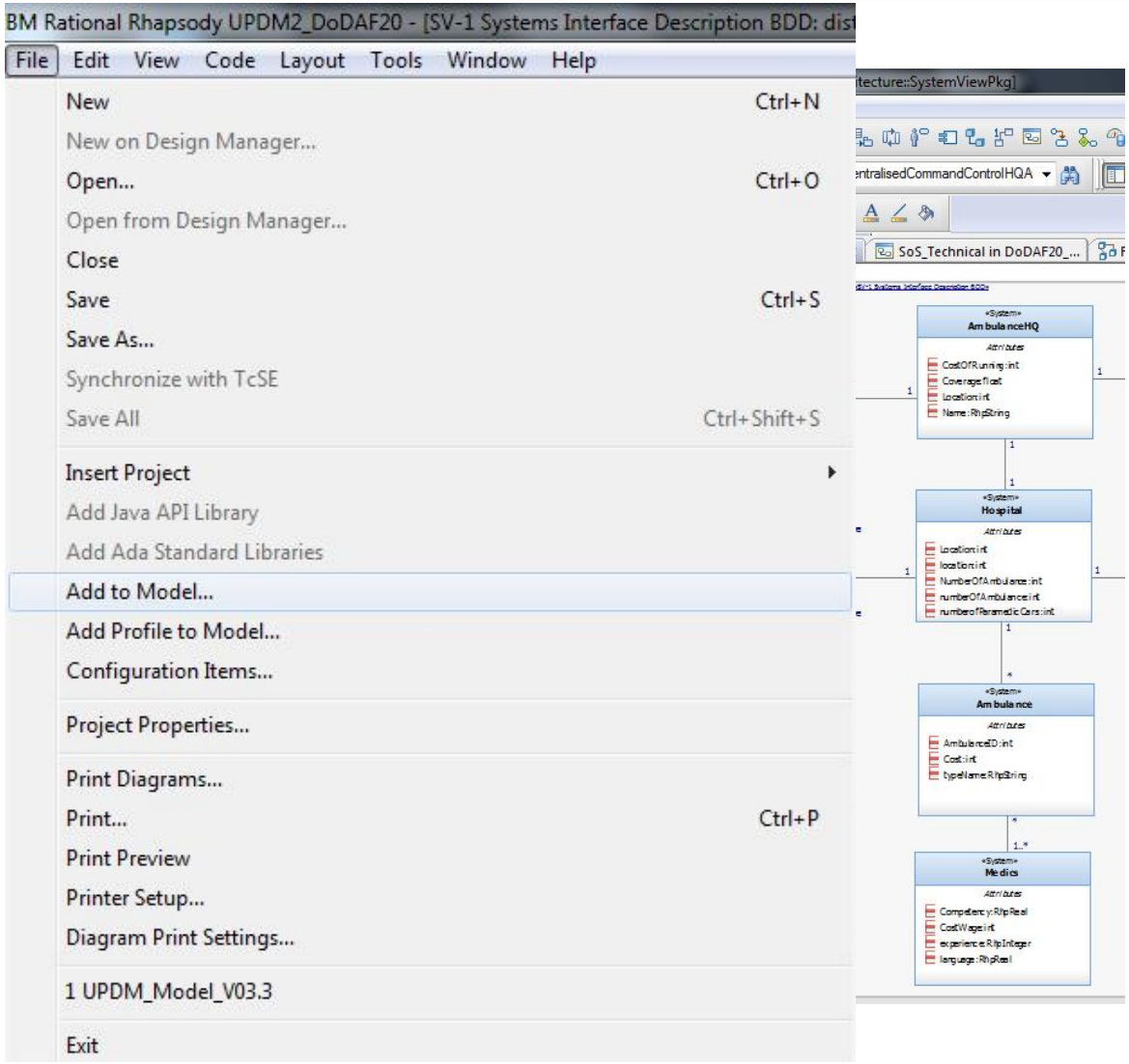
Downloadable Models (Profiles)

Easy Deployment from Repository to Rhapsody



Pattern Application Process

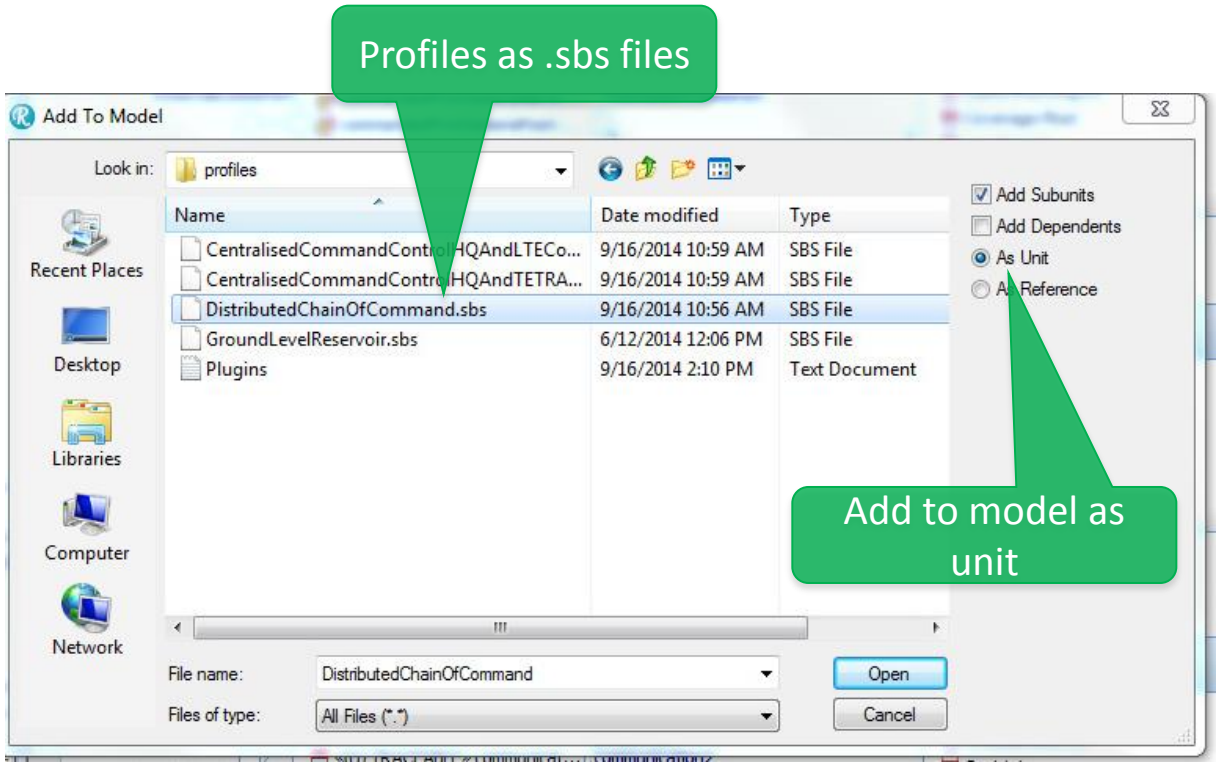
- To import patterns profile into Rhapsody, the following steps are followed:
- Step 1 Download the pattern from the patterns repository to the local machine
- Step 2: In Rhapsody project, select "**File**"-->"**Add to Model**".



Pattern Application Process

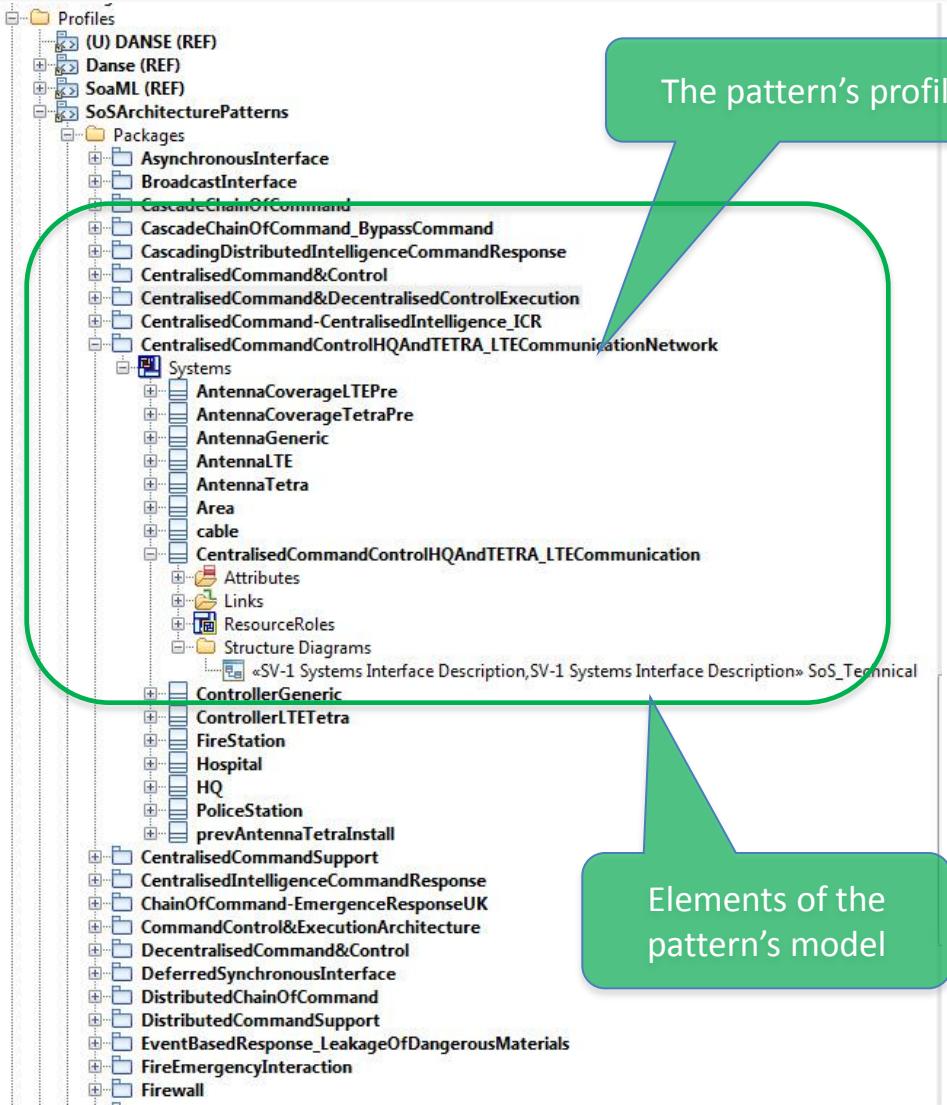
• Step 3: In **Add to Model dialogue**, select the .sbs file of the pattern that needs to be imported and choose "**As Unit**" at right hand side instead of “As Reference”, then click the "Open" button.

•Step 4: Under profiles folder of the Rhapsody project, a package of the same name as the pattern is added. The patterns profile is ready to use now.



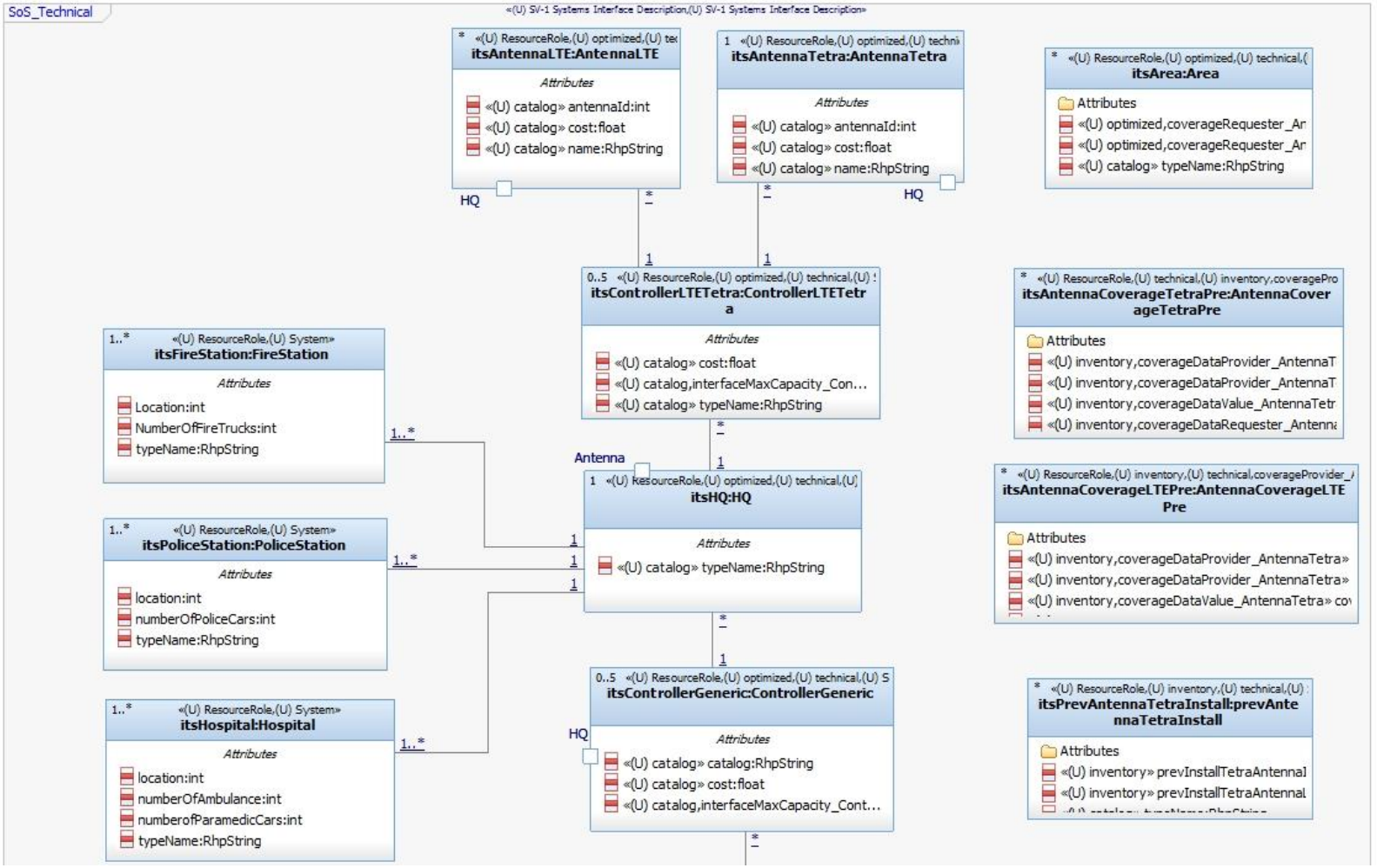
Application Example: Emergency Response SoS

- SoSArchitecturePatterns.sbs has been downloaded from the repository and imported into to the CAE UPDM model using ‘Add to model’.
- SoSArchitecturePatterns package is added under ‘profiles’.
- The structure of CentralisedCommandControlHQAndTETRA/LTECommunicationNetwork pattern is represented here



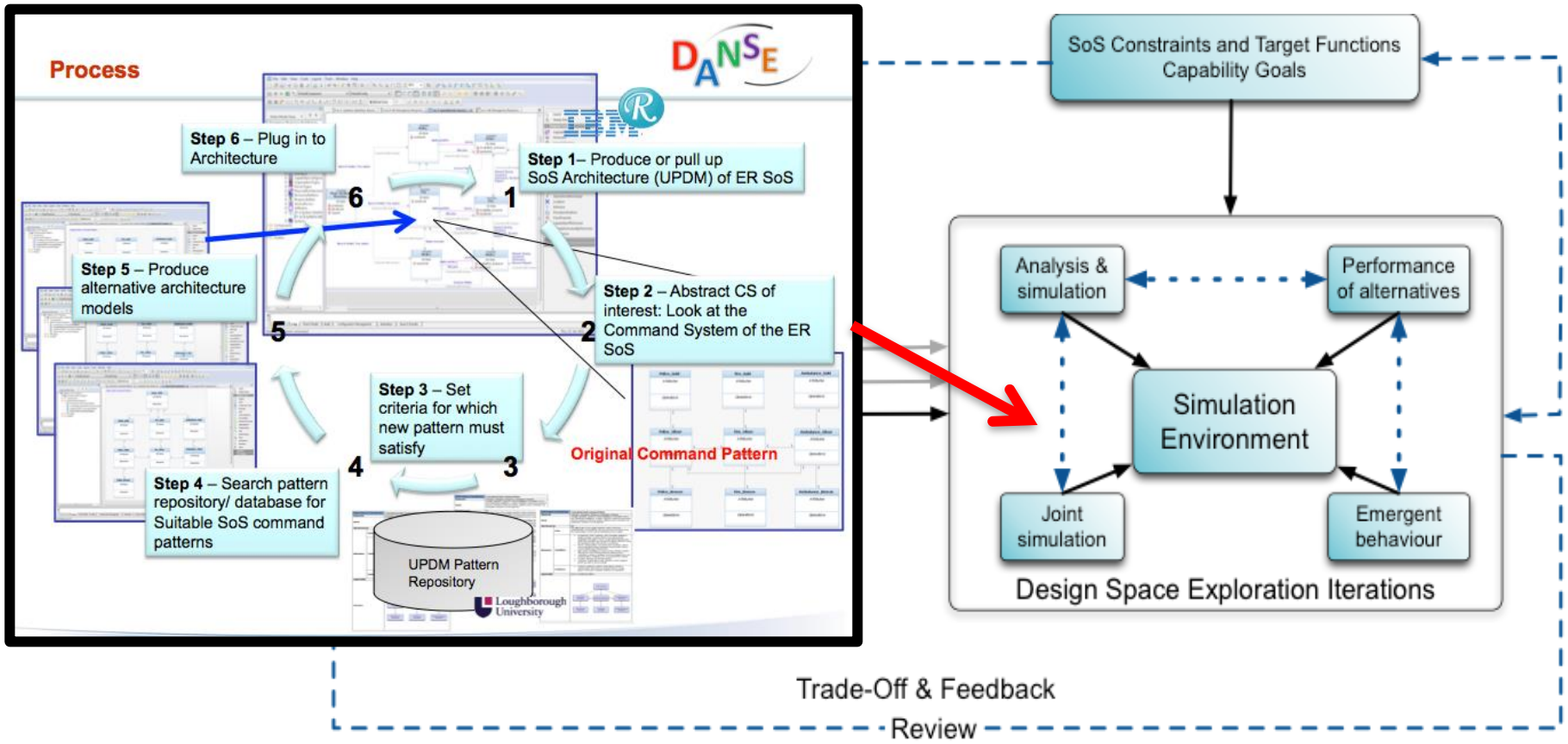
Application Example: Emergency Response

Main structure diagram in CentralisedCommandControlHQAndTETRA/LTECommunicationNetwork pattern



Architecture Patterns for SoS Development

- Candidate architectures submitted to simulation environment
- Architecture evaluated against a set of SoS constraints and target functions
- Alternative patterns substituted if a particular solution does not converge towards the desired target



SoS Design Space Exploration

Architecture Pattern Examples

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Water Supply Strategic Grid Architecture Patterns

DANSE (danse.lut.ac.uk)

danse.lboro.ac.uk/fmi/webd#DANSE&lay=SoSArchitecturePatterns&viewstyle=form&record=6&mode=browse

File Edit View Insert Records Scripts Help

ARCHITECTURE PATTERNS REPOSITORY

Water Supply and Distribution Patterns

Go to Printing Layout

Pattern Name: Water Grid with Borehole- Demand management between borehole and transmission mains supply

Keywords: Borehole, water grid

Author: Loughborough Uni New Pattern

Catalogue | Previous | Next | All Patterns

Pattern Information

Intent: Transfer of water to a demand centre through water supply grid that carries purified water. Water is also supplied through a borehole located near the demand point. The pattern could be used for water supply grids for transferring water from one region to the other

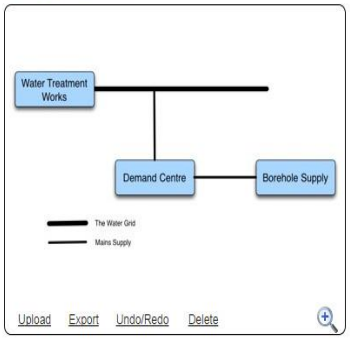
Also Known As: Not applicable

Motivation: Goals: Supply and distribution of water to a demand center through a water supply grid. The water treatment works supplies water directly to the water supply grid which is distributed to different demand points. The demand center also receives supply from a borehole.

- The grid carries purified water
- Supply can be managed between the borehole and the transmission main depending on the demand

Using the Pattern

Structure:



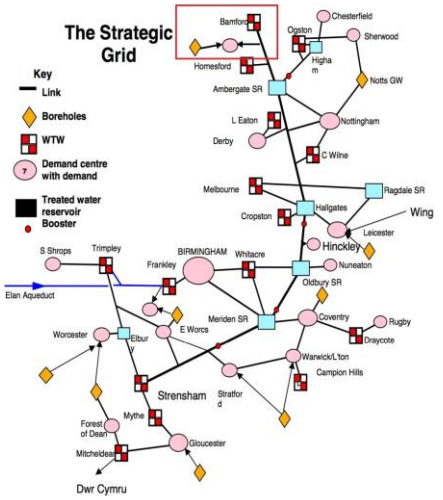
Applicability: Domain Specific Architecture Patterns

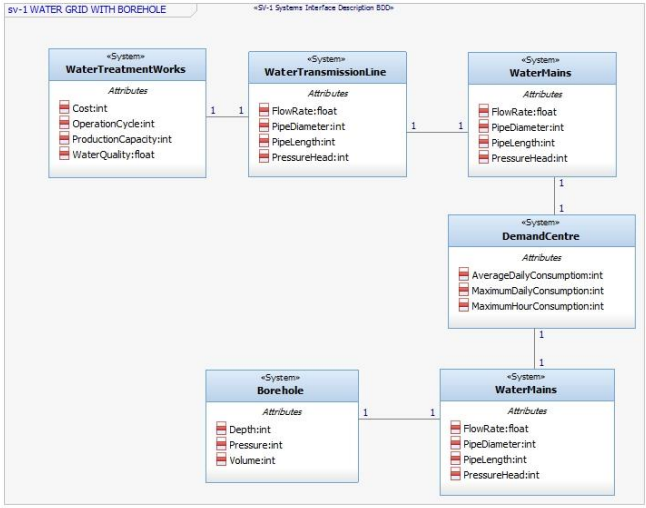
Model (SysML): Upload

Model (SysML+Concise): Upload

Model (UPDM): Export Delete Upload

Model (UPDM+Concise): Upload





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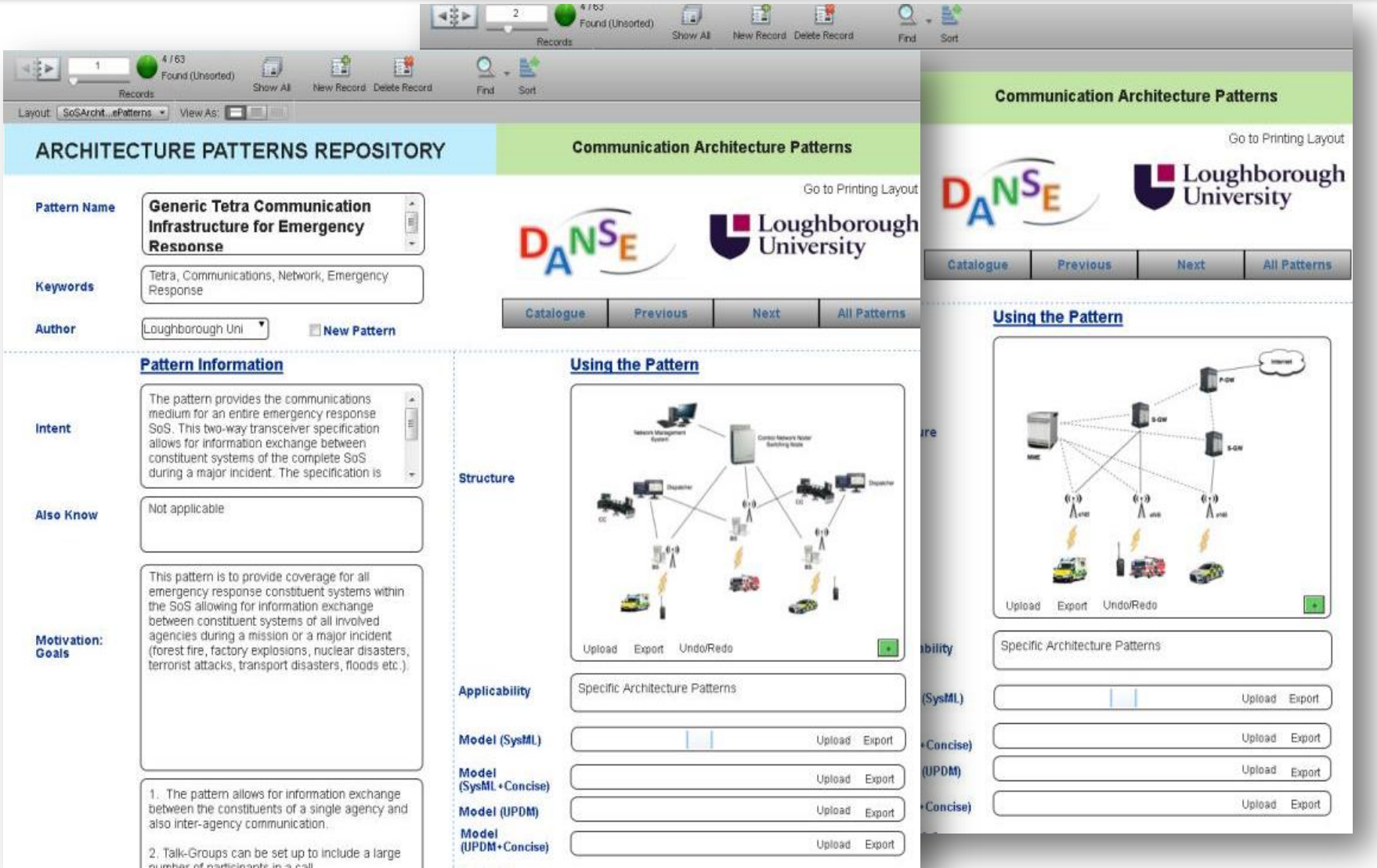
Emergency Response Communication Patterns



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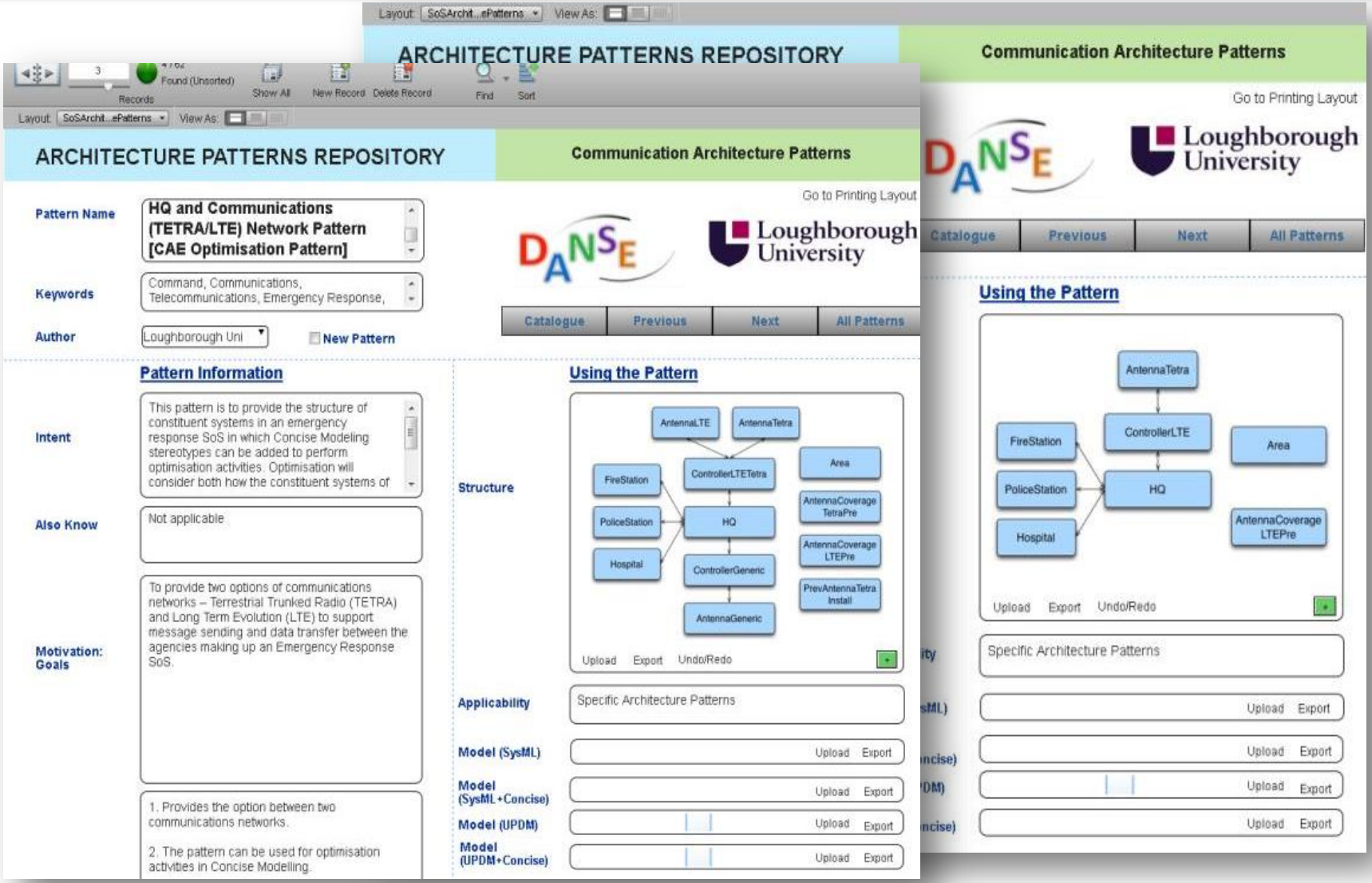
Emergency Response Communication Patterns



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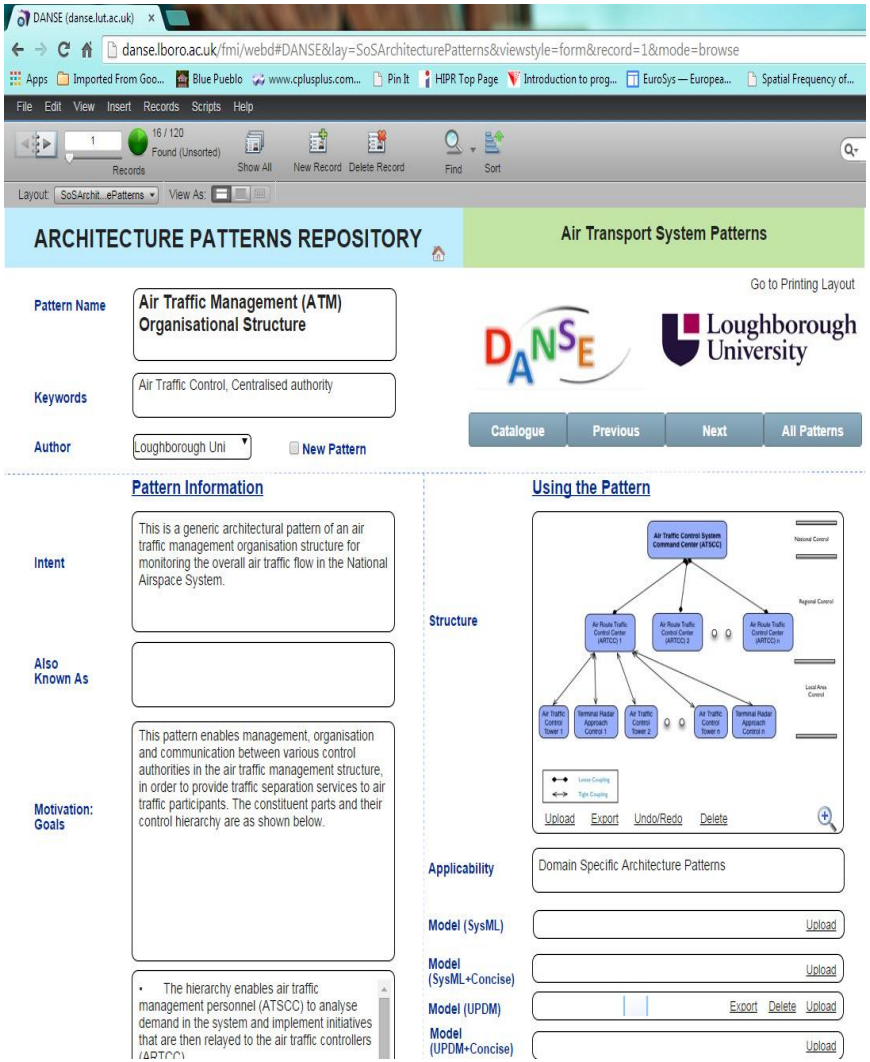
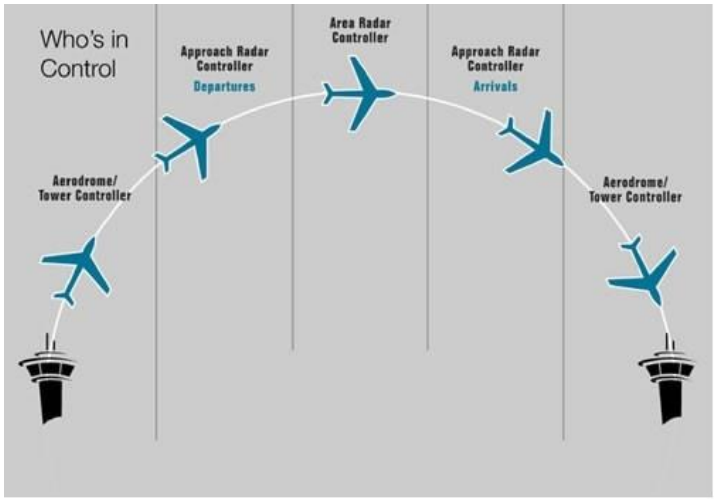
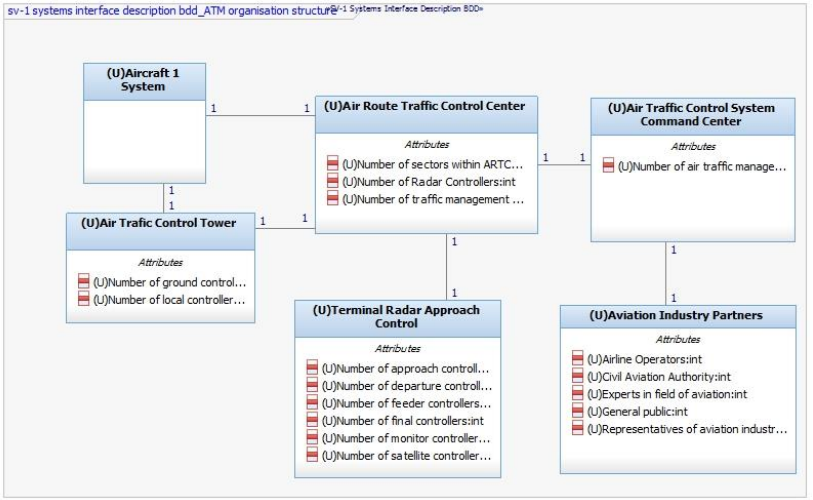
Air Traffic Control Patterns





Air Traffic Control during various flight phases (*Image Courtesy www.ivao.pt*)

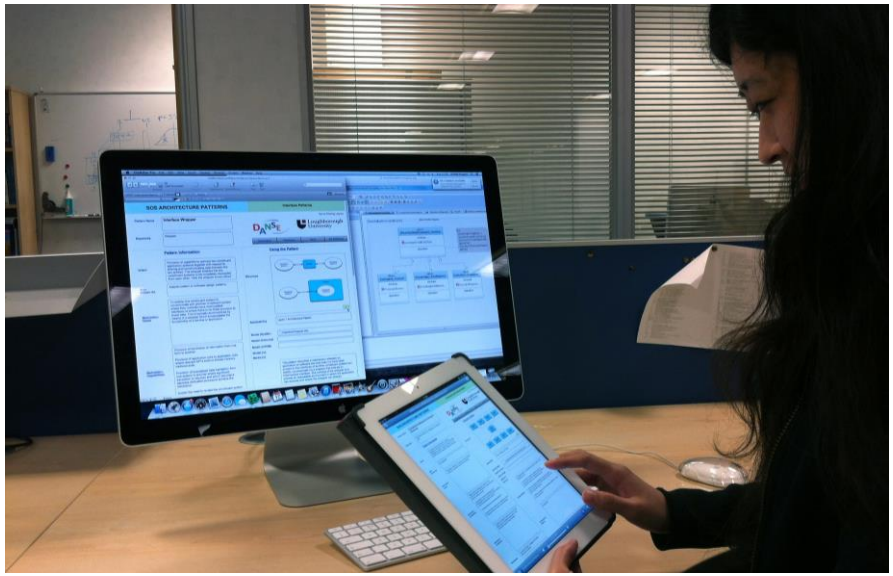


Concluding Remarks

- Architecture patterns are an excellent resource for the SoS architect
- Provide key building elements for SoS architectures
- Integrated with modelling and simulation environments
- Facilitate abstraction of complex systems
- Support SoS design space exploration
- Built from verified and validated designs

On going Research

- Continued development of ontological database for wider integration with other modelling and simulation tools
- Expansion of architecture patterns repository to include further patterns
  - Root patterns
  - Application specific patterns
- Inclusion of additional examples and performance metrics within patterns
- Release of patterns repository (post DANSE project)



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SEVENTH FRAMEWORK PROGRAMME

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Thank you for your attention