MBSE with the ARCADIA Method and the Capella Tool

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Abstract:

Much more than just yet another modelling tool, Capella [1] is a model-based engineering solution that has been successfully deployed in a wide variety of industrial contexts. Based on a graphical modelling workbench, it provides systems, software and hardware architects with rich methodological guidance relying on ARCADIA, a comprehensive model-based engineering method.

The ARCADIA/Capella DSML is inspired by UML/SysML and NAF standards, and shares many concepts with these languages. It is the result of an iterative definition process driven by systems and software architects working in a broad spectrum of business domains (transportation, avionics, space, radar, etc.). It enforces an approach structured on successive engineering phases which establishes clear separation between needs (operational need analysis and system need analysis) and solutions (logical and physical architectures), in accordance with the IEEE 1220 standard.

In this paper, we will explain why a lot of industrial companies, such as Airbus, Airbus DS and Areva, are currently interested in using Capella and running modeling pilot projects with it.

Introduction

Much more than just yet another modelling tool, Capella is a model-based engineering solution that has been successfully deployed in a wide variety of industrial contexts. Based on a graphical modelling workbench, it provides systems, software and hardware architects with rich methodological guidance relying on ARCADIA, a comprehensive model-based engineering method:

- Ensure engineering-wide collaboration by sharing the same reference architecture
- Master the complexity of systems and architectures
- Define the best optimal architectures through trade-off analysis
- Master different engineering levels and traceability with automated transition and information refinement

Referring to the well-known three pillars of MBSE, we could say that ARCADIA provides both a modeling language and a modeling approach, and that Capella knows perfectly the language and the method.

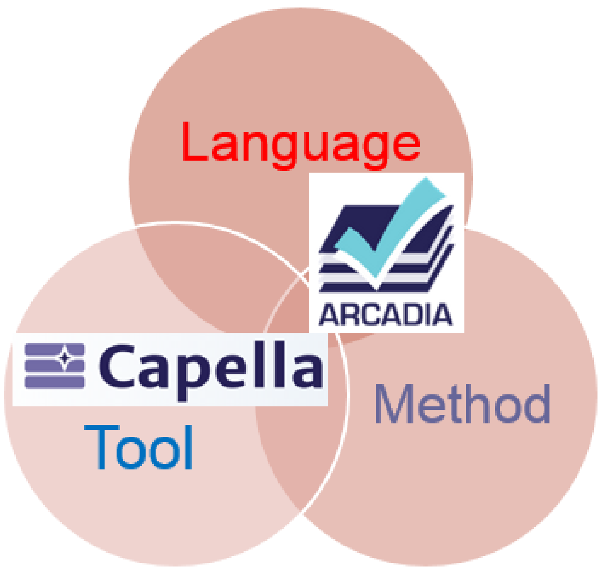


Figure 1: The three pillars of MBSE with ARCADIA/Capella

The ARCADIA Modeling Approach

ARCADIA (ARChitecture Analysis and Design Integrated Approach) is a Model-Based engineering method for systems, hardware and software architectural design. It has been developed by Thales between 2005 and 2010 [2] through an iterative process involving operational architects from all the Thales business domains (transportation, avionics, space, radar, etc.).

It enforces an approach structured on successive engineering phases which establishes clear separation between needs (operational need analysis and system need analysis) and solutions (logical and physical architectures), in accordance with the IEEE 1220 standard.

ARCADIA recommends three mandatory interrelated activities, at the same level of importance:

- Need Analysis and Modeling
- Architecture Building and Validation
- Requirements Engineering

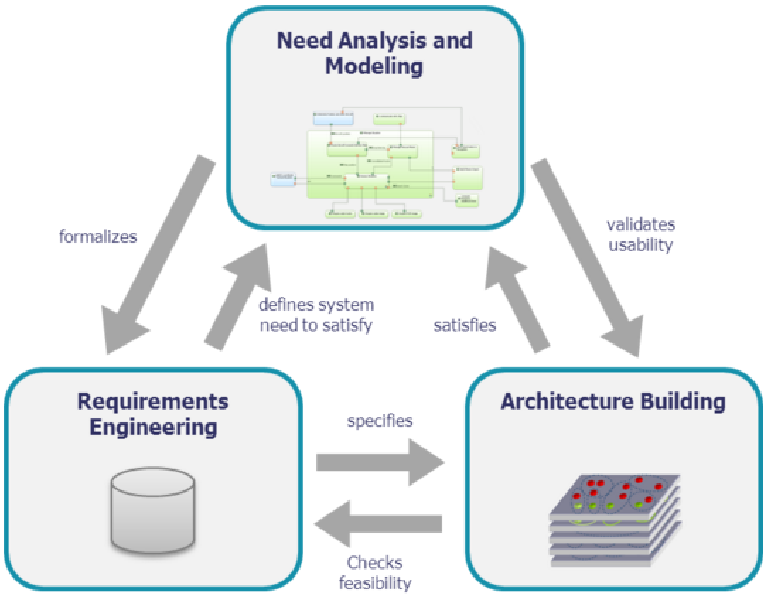


Figure 2: ARCADIA three mandatory interrelated activities

Steps and activities of the method have been defined precisely and tested on real projects inside Thales for several years. To summarize briefly, the main messages are the following ones:

- Besides requirement engineering, drive an operational need analysis, describing final user expectations, usage conditions, and realistic IVVQ conditions, and a system need analysis, describing both the requested behavior of the system under study and its external interfaces
- Structure the system and build a logical architecture, by searching for the best compromise between design drivers and non-functional constraints. Each viewpoint deals with a specific concern such as functional consistency, interfaces, performances, real time, safety, security, integration, reuse, cost, risk, schedule, and the ease of adaptation
- Secure development and IVVQ through a physical architecture which deals with technical and development issues, favoring separation of concerns, efficient and safe component interaction

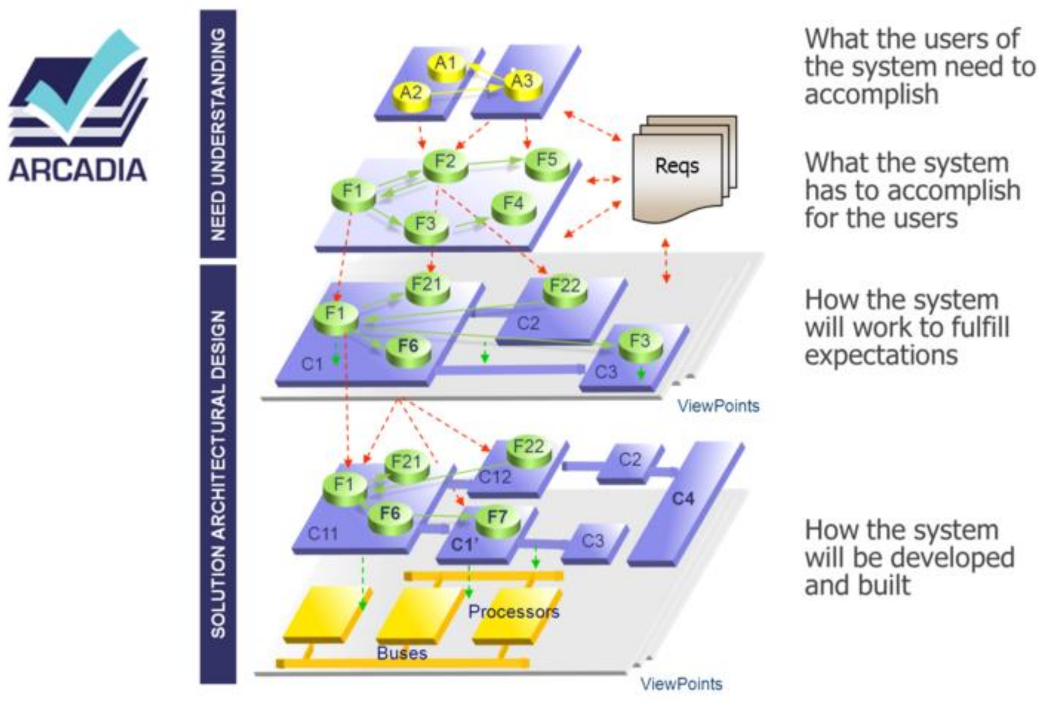

ARCADIA
NEED UNDERSTANDING
SOLUTION ARCHITECTURAL DESIGN
A1
A2
A3
Reqs
F1
F2
F3
F4
F5
F21
F22
C1
C2
C3
F6
ViewPoints
C11
C12
C1'
C4
F7
Processors
Buses
What the users of the system need to accomplish
What the system has to accomplish for the users
How the system will work to fulfill expectations
How the system will be developed and built

Figure 3: ARCADIA engineering levels

Of course, these messages are very similar to the recommendations of the INCOSE SE Handbook [3].

The ARCADIA Domain Specific Modeling Language (DSML)

The ARCADIA DSML is inspired by UML/SysML and NAF standards, and shares many concepts with these languages. But a Domain-Specific Modeling Language was preferred in order to ease appropriation by all stakeholders. ARCADIA is mostly based on functional analysis, and then allocation of the functions to components [4].

The richness of the ARCADIA DSML is comparable to SysML [5] with about ten different diagram types including data flow diagrams, scenario diagrams, states and modes diagrams, component breakdown diagrams, functional breakdown diagrams, etc. Let us give a few examples of concepts and diagrams proposed by ARCADIA at different levels on a simple case study in the meteorological domain:

Operational Analysis

A very important diagram at this level is called the Operational Architecture Blank diagram (OAB). It captures the allocation of Operational Activities to Operational Entities.

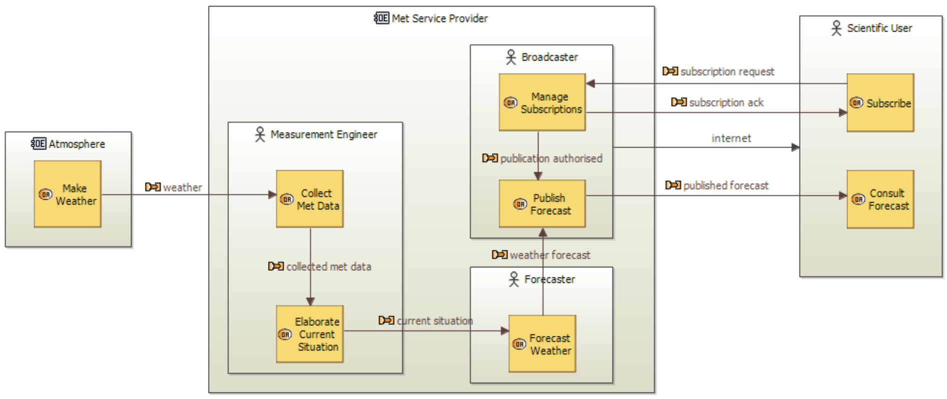


Figure 4: Operational Architecture Blank diagram (OAB) example

System Analysis

Dataflow diagrams are available in all Arcadia engineering levels. They represent information dependency between functions. These diagrams provide rich mechanisms to manage complexity: Computed simplified links between high-level Functions, categorization of Exchanges, etc. Functional Chains can be displayed as highlighted paths.

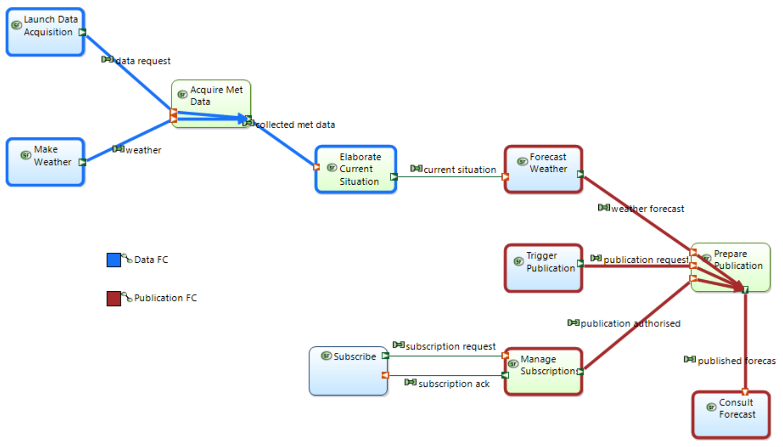


Figure 5: System Data Flow Blank diagram (SDFB) example

Architecture diagrams are used in all Arcadia engineering phases. Their main goal is to show the allocation of Functions onto Components. Functional Chains can be displayed as highlighted paths. In System Need Analysis, these diagrams contain one box representing the System under study plus the Actors.

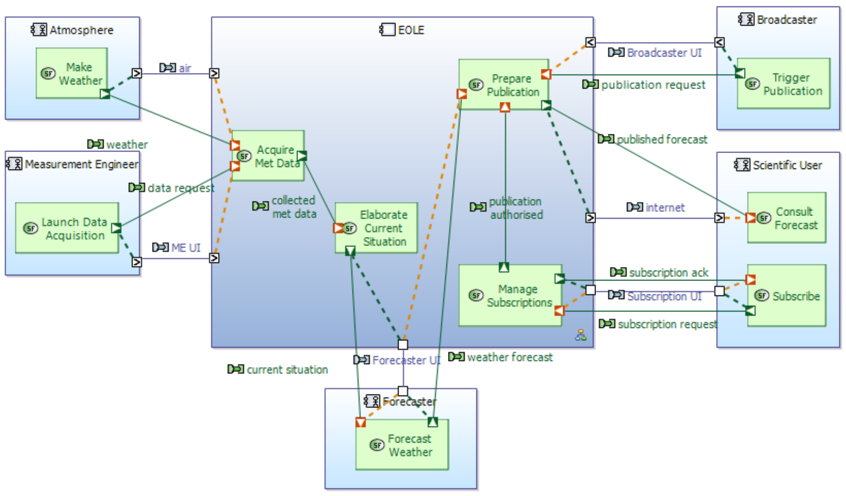


Figure 6: System Architecture Blank diagram (SAB) example

Logical Architecture

To give an example of a different diagram type, let us switch to a Scenario Diagram.

ARCADIA defines several kinds of scenario diagrams: Functional Scenarios (lifelines are Functions), Exchange Scenarios (lifelines are Components/Actors while sequence messages are Functional or Component Exchanges), Interface Scenarios (lifelines are Components/Actors while sequence messages are Exchange Items). Modes, States and Functions can also be displayed on these diagrams, which are also available at all engineering levels.

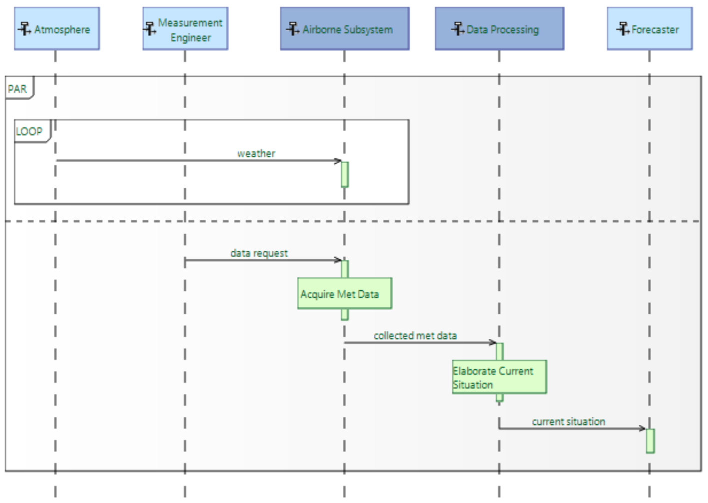


Figure 7: Logical Exchange Scenario diagram (LES) example

Physical Architecture

At this level, we also use the preceding types of diagrams, but we will show different types once again. Tree diagrams represent breakdowns of either Functions or Components.

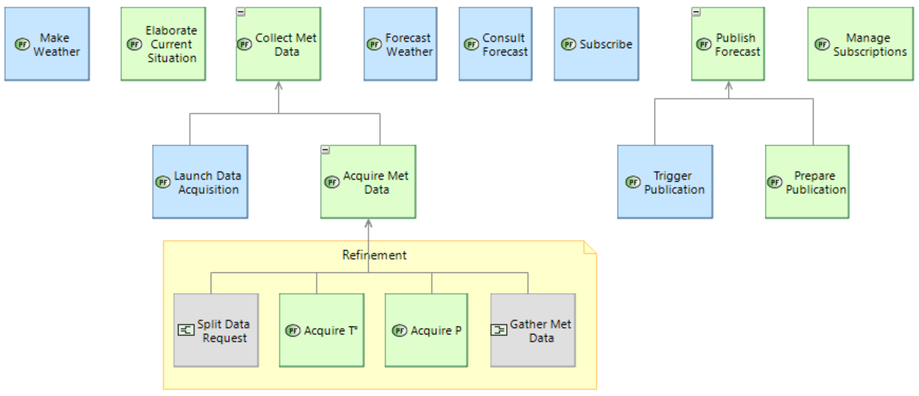
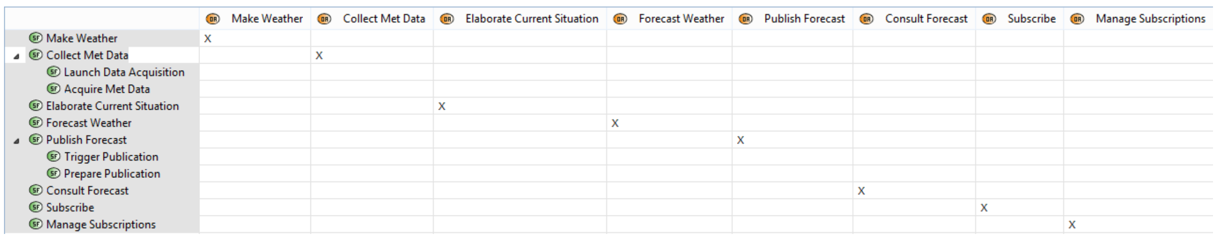


Figure 8: Physical Functional Breakdown diagram (PFBD) example

Matrix views are also available to display the different kinds of relationship between model elements. At each level, for example, two matrices are available showing the realization relationship to the upper level elements.



	Make Weather	Collect Met Data	Elaborate Current Situation	Forecast Weather	Publish Forecast	Consult Forecast	Subscribe	Manage Subscriptions
Make Weather	x							
Collect Met Data		x						
Launch Data Acquisition								
Acquire Met Data								
Elaborate Current Situation			x					
Forecast Weather				x				
Publish Forecast					x			
Trigger Publication								
Prepare Publication								
Consult Forecast						x		
Subscribe							x	
Manage Subscriptions								x

Figure 9: System Functions / Operational Activities Matrix example

To summarize, the ARCADIA DSML covers all aspects of standard architecture modelling in each engineering phase including:

- Capability-driven model organization with scenarios and functional chains
- Functional analysis and allocation to components and resources
- Interfaces, bit-precise data models, behaviors, etc.

An overview of the ARCADIA main concepts through the engineering levels is given by the next figure. Additional important concepts such as scenarios, states and modes, classes, capabilities, etc. are not shown but also available to the modeler.

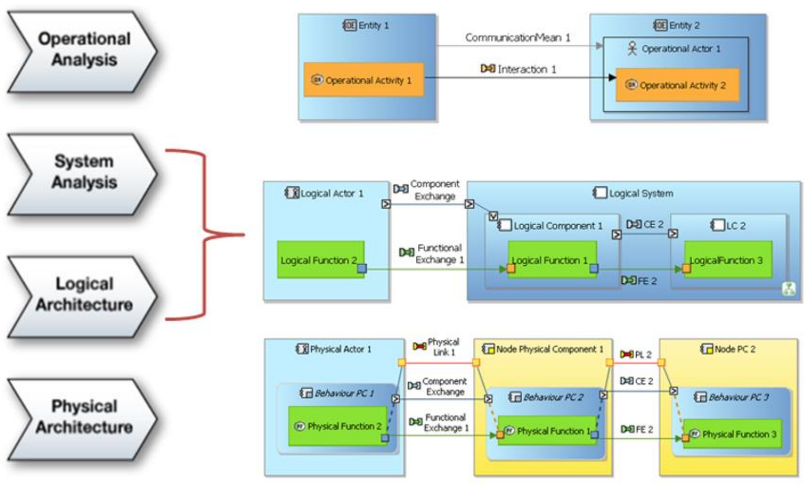
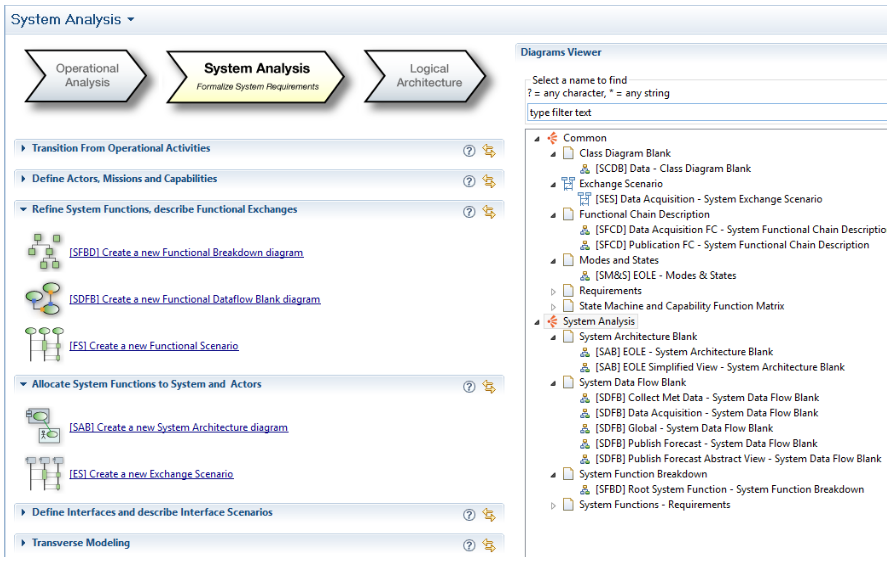


Figure 10: Summary of ARCADIA main concepts

The Capella Modeling Tool

The Capella workbench is an Eclipse application implementing the ARCADIA method providing both a Domain Specific Modeling Language (DSML) and a dedicated toolset.

A very interesting feature of Capella consists in an embedded methodology browser, reminding ARCADIA principles to the user and providing efficient methodological guidance. This activity browser provides a methodological access to all key activities of Capella, and thus to the creation of all main diagrams, level by level. It is the main entry point to a model and is both meant for beginners and power users.


System Analysis

Operational Analysis | System Analysis *Formalize System Requirements* | Logical Architecture

- Transition From Operational Activities
- Define Actors, Missions and Capabilities
- Refine System Functions, describe Functional Exchanges
  - [SFBD] Create a new Functional Breakdown diagram
  - [SDFB] Create a new Functional Dataflow Blank diagram
  - [FS] Create a new Functional Scenario
- Allocate System Functions to System and Actors
  - [SAB] Create a new System Architecture diagram
  - [ES] Create a new Exchange Scenario
- Define Interfaces and describe Interface Scenarios
- Transverse Modeling

Diagrams Viewer

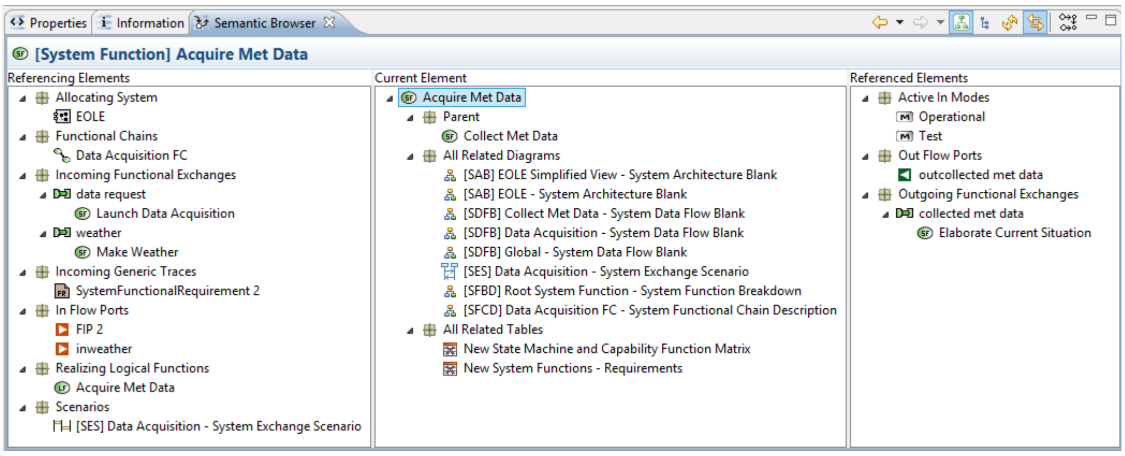
Select a name to find
? = any character, * = any string
type filter text

- Common
  - Class Diagram Blank
    - [SCDB] Data - Class Diagram Blank
  - Exchange Scenario
    - [SES] Data Acquisition - System Exchange Scenario
  - Functional Chain Description
    - [SFCD] Data Acquisition FC - System Functional Chain Descriptio
    - [SFCD] Publication FC - System Functional Chain Description
  - Modes and States
    - [SM&S] EOLE - Modes & States
  - Requirements
  - State Machine and Capability Function Matrix
- System Analysis
  - System Architecture Blank
    - [SAB] EOLE - System Architecture Blank
    - [SAB] EOLE Simplified View - System Architecture Blank
  - System Data Flow Blank
    - [SDFB] Collect Met Data - System Data Flow Blank
    - [SDFB] Data Acquisition - System Data Flow Blank
    - [SDFB] Global - System Data Flow Blank
    - [SDFB] Publish Forecast - System Data Flow Blank
    - [SDFB] Publish Forecast Abstract View - System Data Flow Blank
  - System Function Breakdown
    - [SFBD] Root System Function - System Function Breakdown
  - System Functions - Requirements

Figure 11: Capella Methodological Activity Browser

As graphical representations of elements play a key role in communication, Capella relies on a consistent color scheme. In particular, all function-related elements are green, and all component-related elements are blue. This favors enhanced model readability for all stakeholders (architects, V&V practitioners, specialty engineers, managers, etc.).

Another very useful feature of Capella is the capability to navigate inside the model elements (independently of the diagrams) through a contextual semantic browser. More practical than the standard hierarchical view of the model, the semantic browser instantaneously provides the context of model elements trough meaningful queries. It is the preferred way to navigate in models and diagrams and to quickly analyze the relationships between model elements.



[System Function] Acquire Met Data

Referencing Elements
- Allocating System
  - EOLE
- Functional Chains
  - Data Acquisition FC
- Incoming Functional Exchanges
  - data request
    - Launch Data Acquisition
  - weather
    - Make Weather
- Incoming Generic Traces
  - SystemFunctionalRequirement 2
- In Flow Ports
  - FIP 2
  - inweather
- Realizing Logical Functions
  - Acquire Met Data
- Scenarios
  - [SES] Data Acquisition - System Exchange Scenario

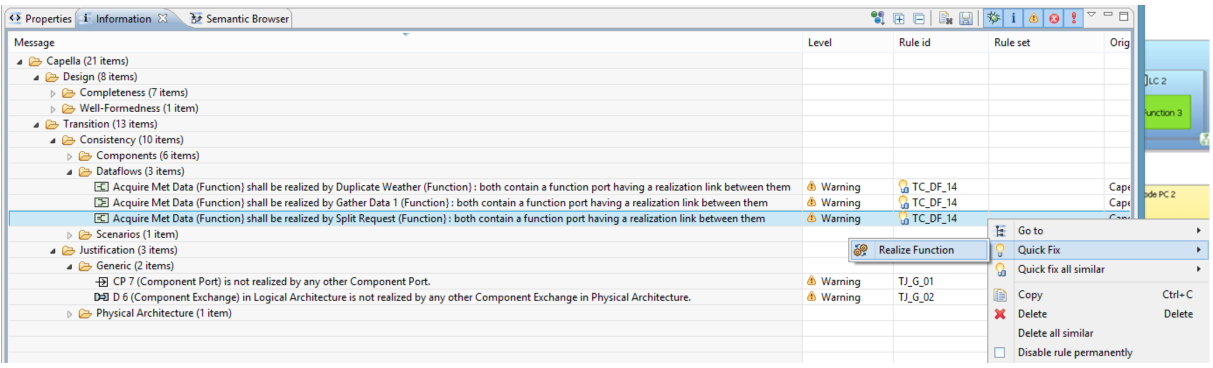
Current Element
- Acquire Met Data
  - Parent
    - Collect Met Data
  - All Related Diagrams
    - [SAB] EOLE Simplified View - System Architecture Blank
    - [SAB] EOLE - System Architecture Blank
    - [SDFB] Collect Met Data - System Data Flow Blank
    - [SDFB] Data Acquisition - System Data Flow Blank
    - [SDFB] Global - System Data Flow Blank
    - [SES] Data Acquisition - System Exchange Scenario
    - [SFBD] Root System Function - System Function Breakdown
    - [SFCD] Data Acquisition FC - System Functional Chain Description
  - All Related Tables
    - New State Machine and Capability Function Matrix
    - New System Functions - Requirements

Referenced Elements
- Active In Modes
  - Operational
  - Test
- Out Flow Ports
  - outcollected met data
- Outgoing Functional Exchanges
  - collected met data
    - Elaborate Current Situation

Figure 12: Capella Contextual Semantic Browser

Capella can go further than traditional modeling tools thanks to its knowledge of ARCADIA. For instance, the tool will check that each model element at a given engineering level is realized by a similar element at the next engineering level.

Capella organizes model checking rules in several categories: integrity, design, completeness, traceability, etc. Architects can define validation profiles focusing on different aspects. Whenever possible, quick fixes provide fact and automated solutions.



Message	Level	Rule id	Rule set	Orig
Capella (21 items)				
Design (8 items)				
Completeness (7 items)				
Well-Formedness (1 item)				
Transition (13 items)				
Consistency (10 items)				
Components (6 items)				
Dataflows (3 items)				
Acquire Met Data (Function} shall be realized by Duplicate Weather (Function} : both contain a function port having a realization link between them	Warning	TC_DF_14		Cape
Acquire Met Data (Function} shall be realized by Gather Data 1 (Function} : both contain a function port having a realization link between them	Warning	TC_DF_14		Cape
Acquire Met Data (Function} shall be realized by Split Request (Function} : both contain a function port having a realization link between them	Warning	TC_DF_14		
Scenarios (1 item)				
Justification (3 items)				
Generic (2 items)				
CP 7 (Component Port) is not realized by any other Component Port.	Warning	TJ_G_01		
D 6 (Component Exchange) in Logical Architecture is not realized by any other Component Exchange in Physical Architecture.	Warning	TJ_G_02		
Physical Architecture (1 item)				

Figure 13: Capella Model Checking results example

As Capella was progressively specified and enhanced by using earlier versions of the tool on Thales internal projects, it contains a lot of very efficient features such as:

- Automatic computation of graphical simplifications (for instance information exchanges between lower-level functions can be automatically displayed on higher-level functions)
- Automated contextual diagrams: content is automatically updated according to preselected model elements and predefined semantic rules
- Filters: enable the user to show simplified views of a given diagram by selecting display options and automatically hiding / showing specific model elements

Another advanced feature of Capella is the ability to create reusable model elements, either simple ones like types and classes, or complex ones, such as complete physical components with ports, functions, etc. A Replicable Elements Collection (REC, for Record) is a definition of an element which can be reused in multiple contexts / models. A Replica (RPL, for Replay) is an instantiation of a REC. RECs can be packaged in external libraries, which can be shared between several projects.

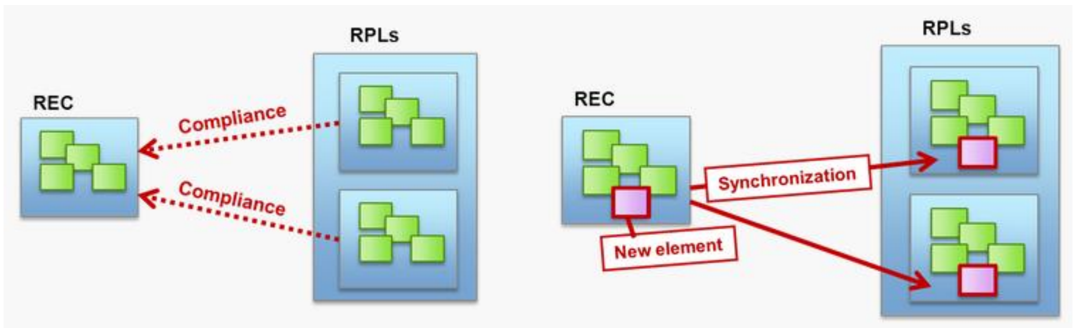


Figure 14: Capella Replicable Elements Mechanism

To widen the perspective, Capella does not work in isolation, but on the contrary fits into a wider engineering landscape, as many bridges can be developed to:

- Initialize Capella models from upstream engineering outputs (typically coming from Architecture Frameworks such as NAF)
- Confront architecture models to specialty engineering tools (performance, safety, etc.)
- Iteratively populate downstream engineering (subsystems, code generation, etc.)

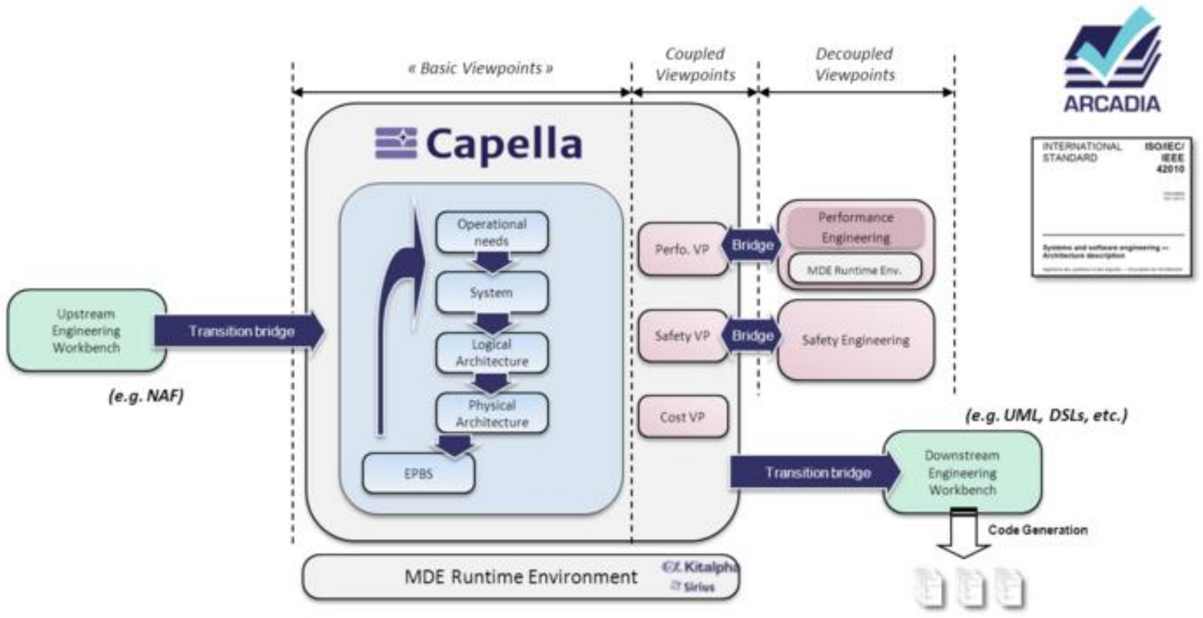


Figure 15: Capella "Big Picture"

SysML with a tool vs ARCADIA / Capella: elements of comparison

As we explained earlier, the ARCADIA DSML is inspired by UML/SysML and NAF standards, and shares many concepts with these languages. But a Domain-Specific Modeling Language was preferred in order to ease appropriation by all stakeholders, usually not familiar with general-purpose, generic languages such as UML or SysML. Previous experiments inside Thales proved that system engineers not coming from software were not at ease with the object-oriented concepts proposed by UML (and subsequently by SysML). So ARCADIA is mostly based on functional analysis, and then allocation of the functions to components. The vocabulary of the DSML has proven to be easily understood by system engineers.

So, basically, ARCADIA was defined first in Thales, from the engineering problems encountered in real projects. Then came the need for a software tool enabling to create and manage ARCADIA models. The first experiments were done using existing UML tools such as Rational Software Modeler, Objecteering and Rhapsody, and defining UML profiles on top of them [2]. At the time of these first tries, the commercial tools were not easy at all to customize, and in particular it was difficult to remove unused commands or menus. So Thales people decided to create their own tool, dedicated to ARCADIA, encouraged by the emergence of enabling technologies based on the Eclipse platform. ARCADIA definition can really be seen as the specification of the Capella modeling tool.

If we try to compare with another possible solution, namely use a standard modeling language, such as SysML, and an existing commercial tool, such as Rhapsody, we can spot several important differences. SysML and Rhapsody (as the other commercial SysML tools) are based on UML, which is a disadvantage for system engineers who have not been exposed to object-oriented concepts (notions of operation, generalization / specialization in block diagrams, and even of object flows and object nodes in the activity diagram). These object-oriented origins are clearly an obstacle to adoption by system engineers who are not familiar with the world of software development [6].

Another big problem is that SysML is only a language, and each company needs to elaborate an adapted modeling strategy. But then, how to teach the method to the modeling tool? Each commercial tool claims it offers an API to build specific add-ons, but this represents clearly a big amount of work. A prototype is provided by IBM with the Harmony for SE toolkit [7], but experiments in Thales proved that this toolkit is not more than a proof of concept and very difficult to use on real projects. For instance, the automated transitions between modeling phases were not iterative and incremental, as is the case with Capella, but merely one-shot.

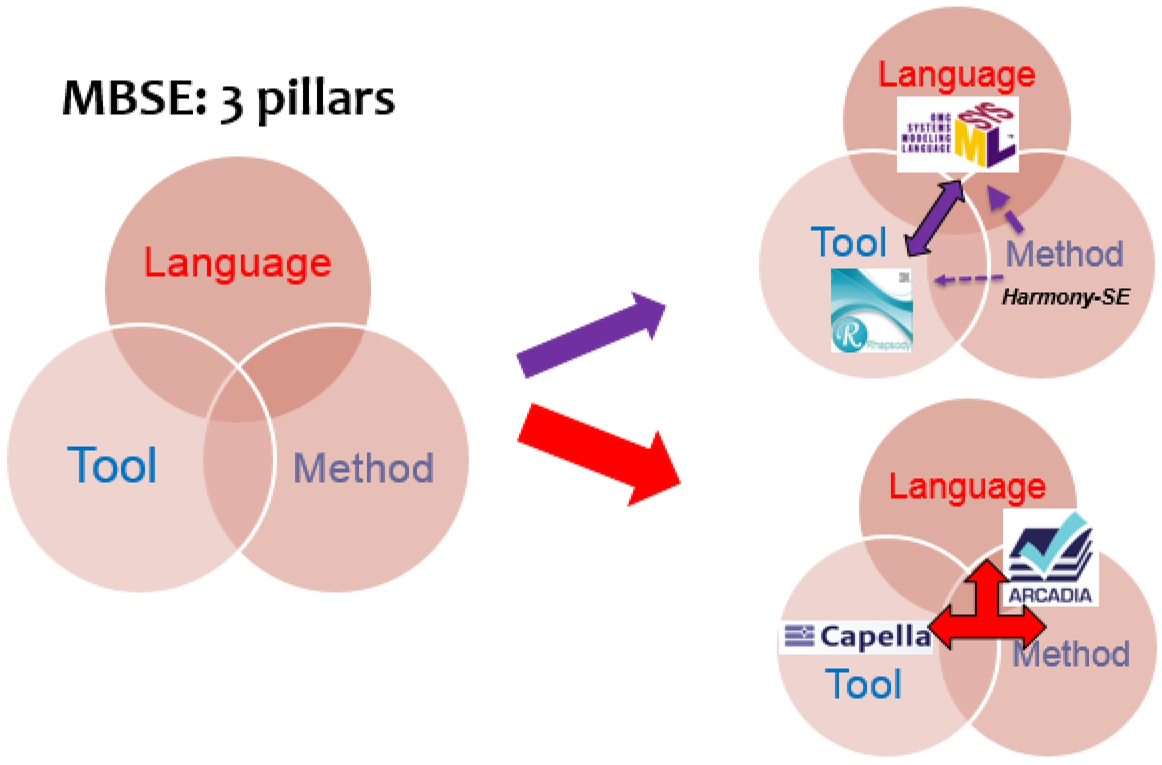


Figure 16: MBSE 3 pillars implementation: a comparison

Conclusion

The development of Capella (called Melody then) started in Thales in 2008 after a few years of experience with development of profile-based UML/SysML solutions. It is now widely deployed on operational projects in all Thales domains worldwide (defense, aerospace, space, transportation, identity and security, etc.).

Growing a community of interest and of users is a major objective of the Capella open sourcing initiative [1]. The goal is to favor the emergence of an ecosystem of organizations, including industries that would drive the Capella roadmap according to operational needs, service and technology suppliers that would develop their business around the solution, and academics that would pave the future of the engineering ecosystem.

The 3-years Clarity consortium [8] is dedicated to building this ecosystem. Since the start of the Clarity project, one year ago, such big industrial companies as Airbus, Airbus DS and Areva have already begun to experiment Capella internally. In the meantime, technology providers such as Artal, All4Tec, Scilab, have also begun to work in order to bridge Capella with simulation tools, safety engineering tools, etc. The rationale behind Clarity is that a strong adoption of this industrial solution will bring a major competitive advantage for industrial actors but also for technology and service providers.

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