



*Building the Future.
System by System.*


Use of Capella as Digital Twin to Perform Complex Systems Simulation

Prepared by Prof. Dr. **Christopher Shneider Cerqueira**

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Summary



Context
Who we are...




Concepts
What you are going to find (more or less) in the literature



Our assumptions and characteristics




CapellaSim Add-on
It is on github but the final final real final version release will be made available with the student master thesis.



Quick Example



Connecting Capella to Physical Things
It is not HL (could be), the idea is to have a twin representation of the physical vehicle into the systemic view and track its behavior changes validating it.



Final Considerations



Context

Who we are....



INSTITUTO
TECNOLÓGICO
DE AERONÁUTICA
— 1950 —

<http://www.ita.br>





Some info context

- We are a group of 2 professor (myself -> MBSE and prof. Jonas Fulindi -> STPA)
- We use Capella since 2018 and have the T4C / RAT.
 - Since 2019 we have a graduate course that has around of 30 students (OPM/Capella) per year.
 - Use in 3 undergraduate courses to teach: Verification & Validation, Space Mission Architecture and Space Ground Segment Architecture. Around 30 students per course.
 - Over 15 final works (undergrad/msc) using MBSE.
- Our lab is requested to do some help into strategic projects so we already applied Capella into 6 government acquisition processes.
- We have a funded project to interconnect MBSE with Modelling & Simulation as well as architecture optimization to create a Model based Mission Engineering Framework



Our group

PhD students



Jeanne Samara Lima
(UTM Business Plans /
Systems Eng.)



Priscila Renata
Cardoso (Operational
Research and Systems
Engineering)



Emerson Oliveira
(Verification and
Validation)



Maj. Daniel Pleffken
(Certification)



Maj Leonan Falqueto
(Mission Optimization)



Lt. Col. Guilherme
Moreira (Scenarios and
Formal Methods)

Master's Students



Matheus Cogo
(Architecture
Consistency Check)



Ariane Novais
(Interaction with Digital
Twins)



Cap Bruno Avelino
(Route Optimization)



Ângelo Florentino
(Interaction with
simulation)



Maj Thiago Melo
(Cyber Simulation
Sandbox)



Rebeca Suede Cap
(Requirements)

Collaborators



Ariele Ferraz (Sensor Fusion)



Guilherme Matos (FullStack – VR)



João Cioffi (Machine Learning)



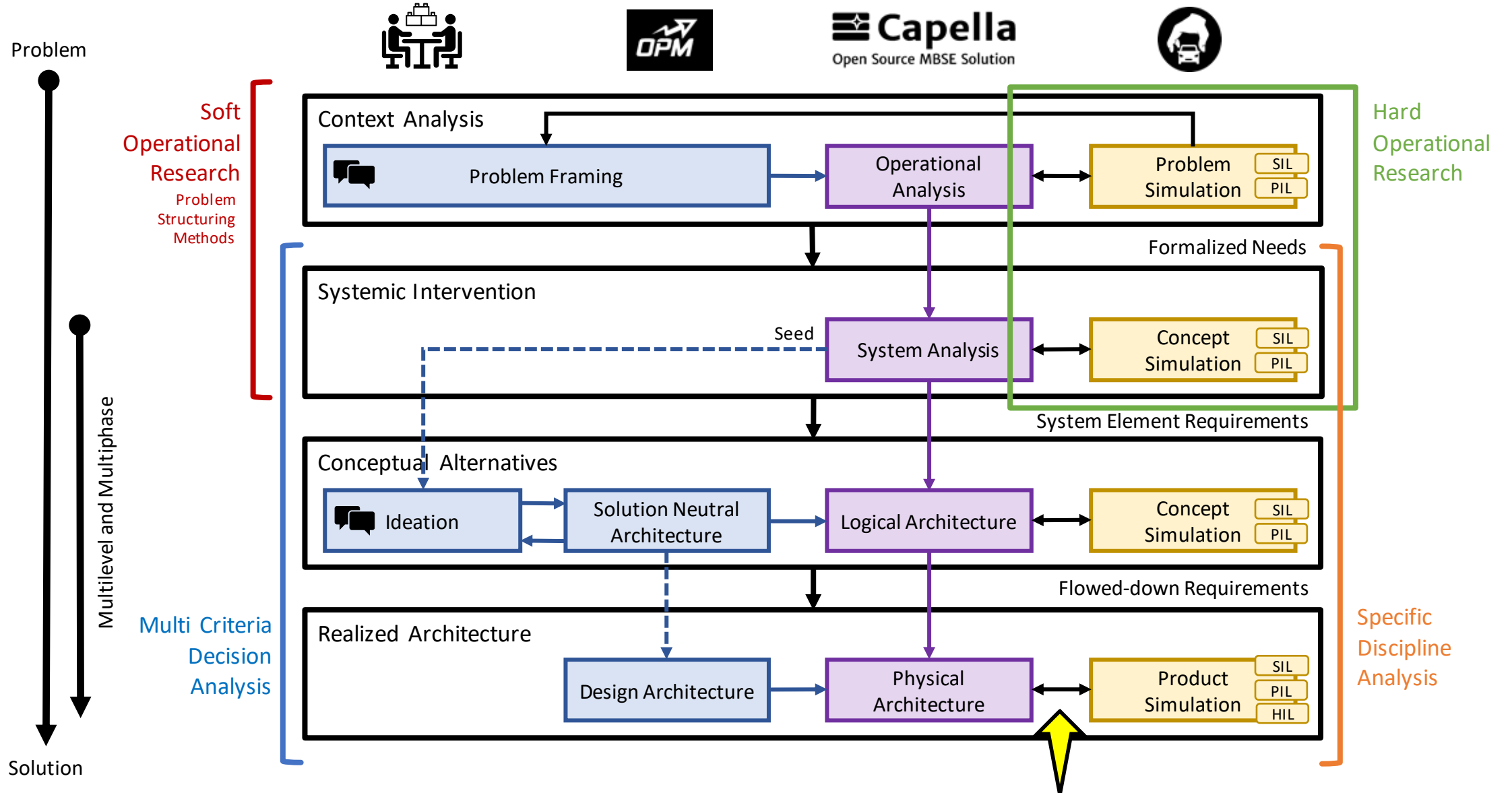
Moara Oliveira (Embedded Design)



Arthur Assis Alves (Simulated UTM
Dev)

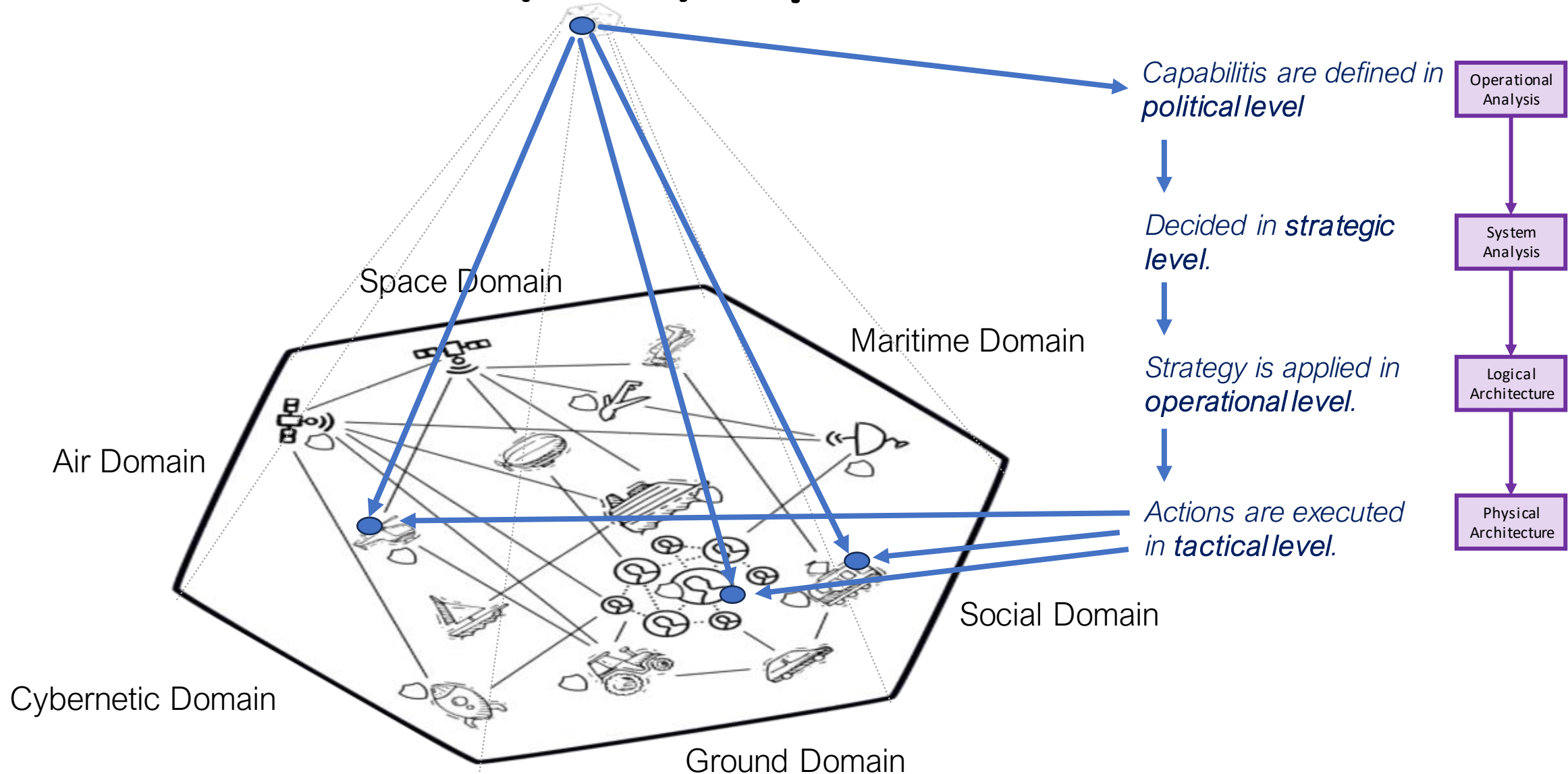


Our Multi Methodology MBSE Framework





Multidomain (SoS) Operations



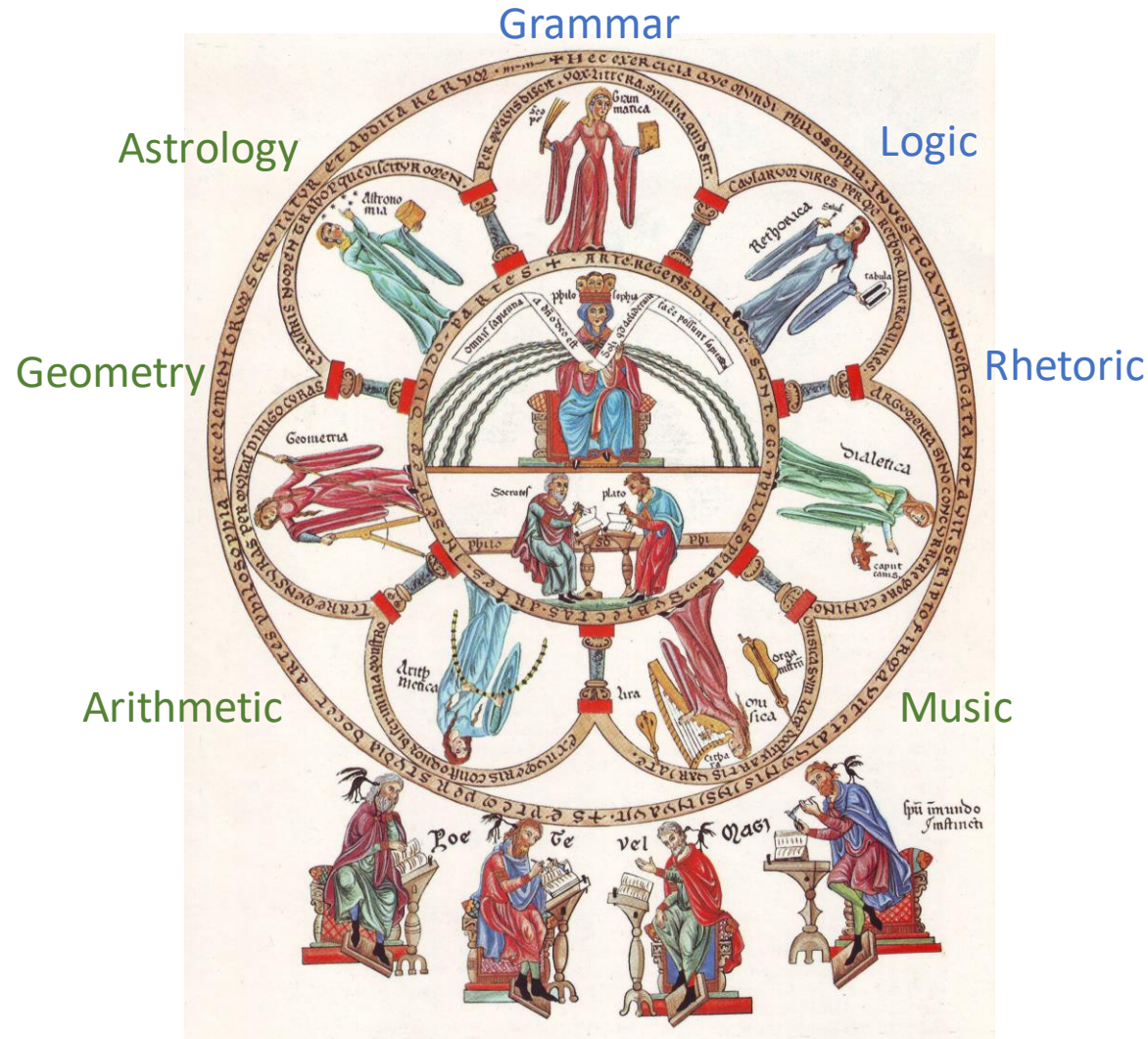


Concepts

What you are going to find (more or less) in the literature

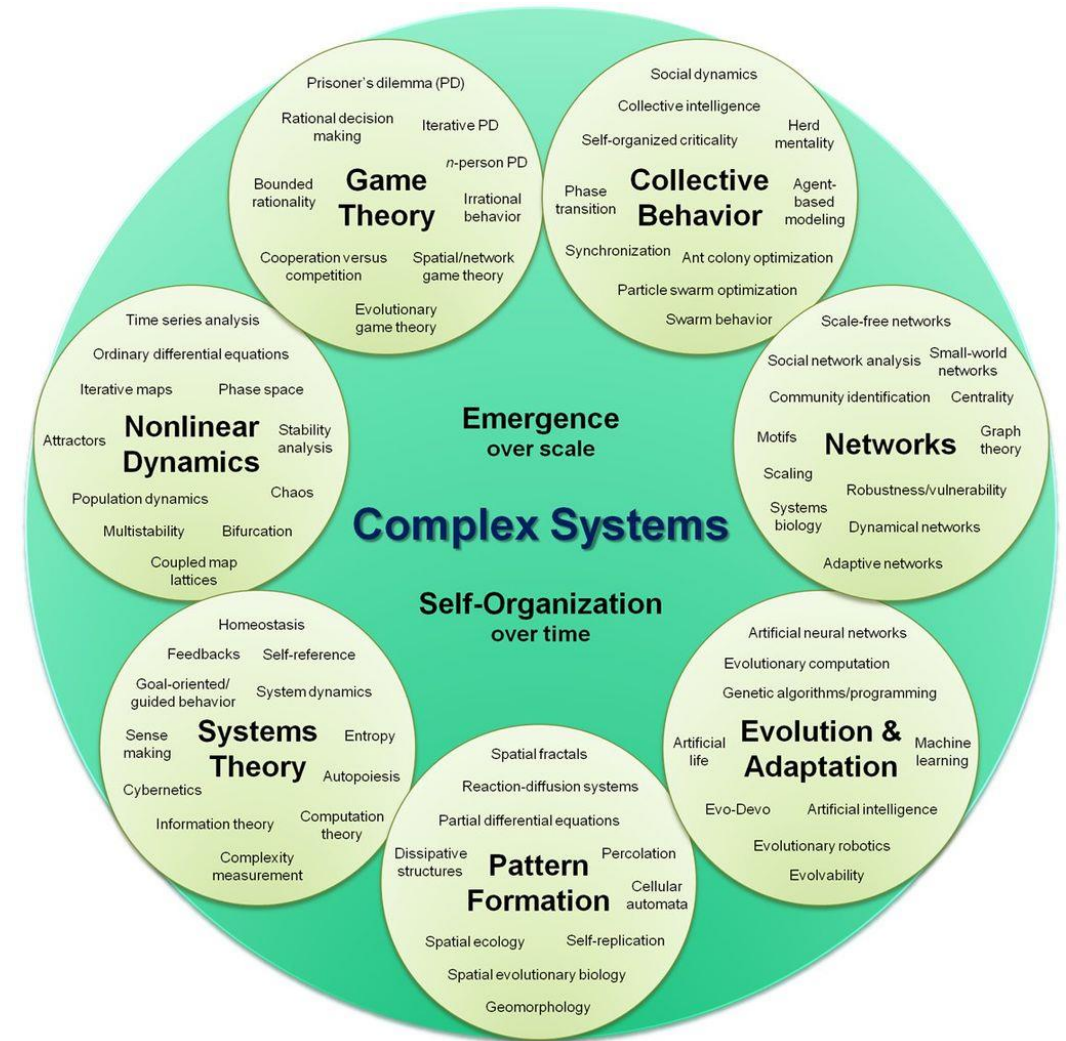


Complex Systems



The Hortus Deliciarum of Herrad of Hohenbourg (Landsberg, 1176-96)

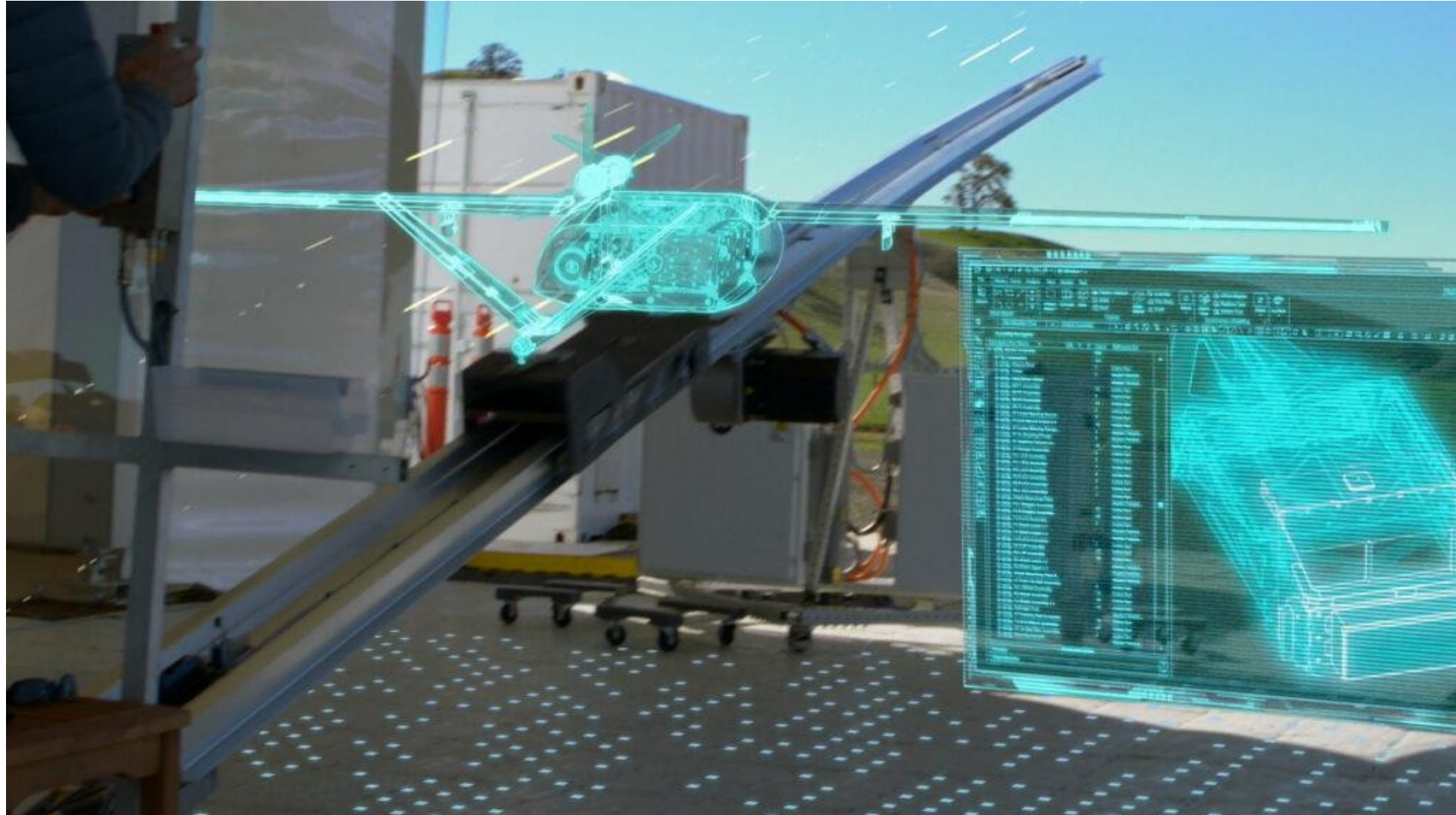
<https://liberalarts.online/trivium-and-quadrivium/>



[Introduction to the Modeling and Analysis of Complex Systems - Milne Open Textbooks \(opensuny.org\)](#)



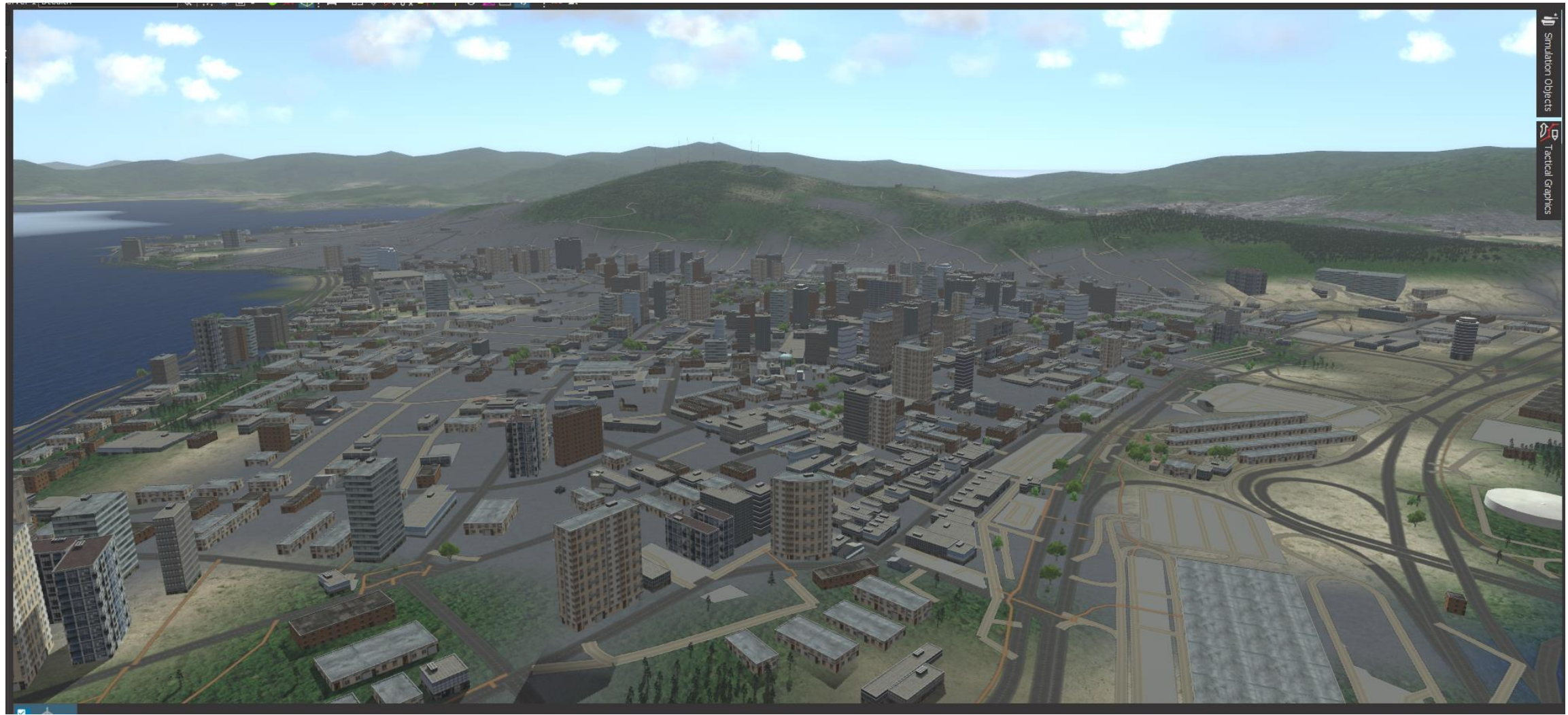
Digital Twin



<https://blogs.sw.siemens.com/xcelerator/2020/07/07/drones-deliver-critical-supplies-to-communities-in-need/>



Simulation



Scenery from Florianópolis City at Brazil, from OpenStreetMap seen at MAK's VR-Forces

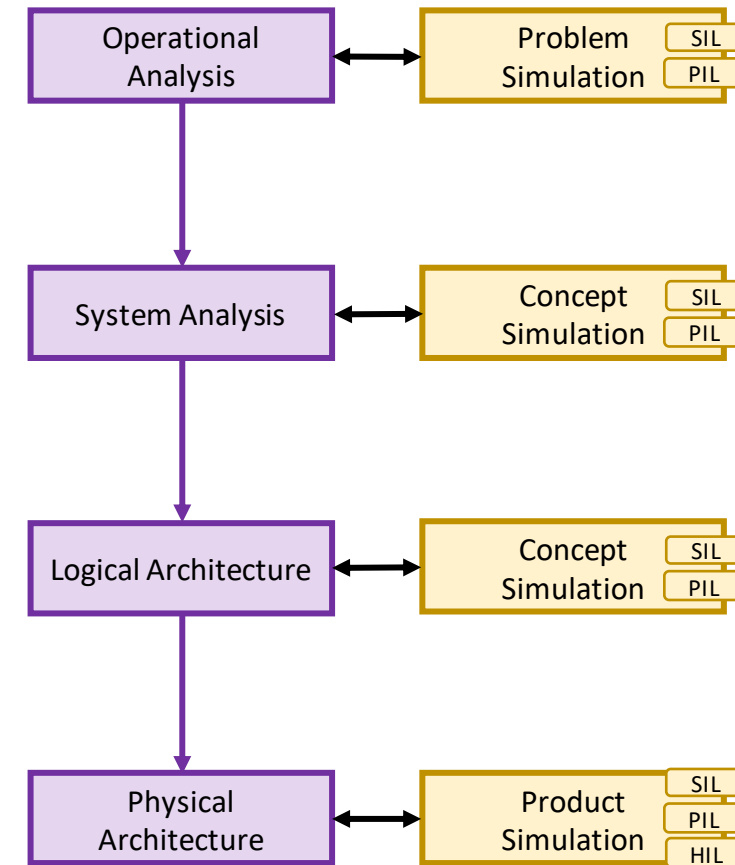


Our assumptions and characteristics



On how could we add simulation into Capella? And if we should do that...

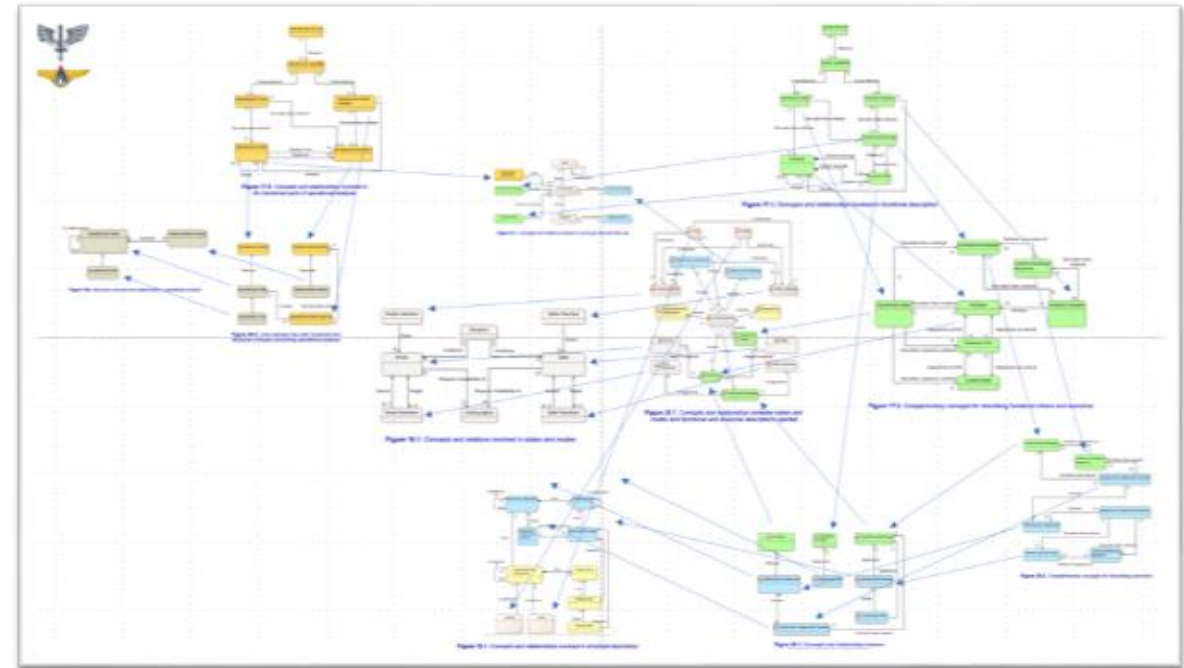
- Decide on the approach:
 - **Read the model** and **moves** the parameters: [RCE](#)
 - The simulation tool **imports and parse the model**: Python / OpenModelica / Scilab
 - Create a addon that **exports the model** and maintain it sync: Python / OpenModelica / Scilab
 - **Embed into Capella.**
- Why do we simulate?
 - Verify/Validate... the architecture (behavior or structure) / the model / concepts / CONOPs





On how does the Capella Model needs to be? And the amount of changes...

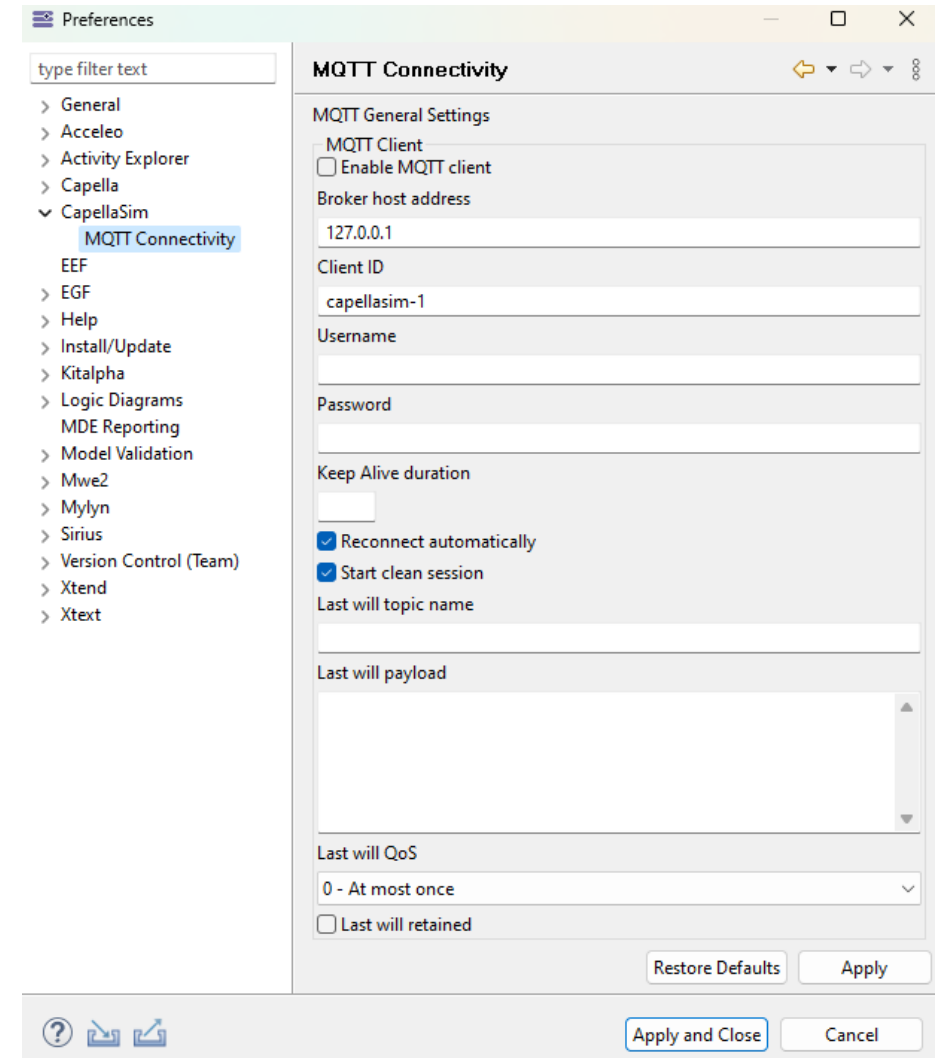
- Regarding the metamodel:
 - There has to be about **zero changes**. *I would not like to change it into our T4C server.*
 - Capella has **behavioral diagrams** (static / reactive).
- To the users?
 - There has to be no change unless it **eases the use**.
 - As new things will appear/be controlled, the **UI design has to follow to the same type of navigation**.





On how to open a running Capella to the rest of world? And interface with it...

- Well... Capella is simulating, executing the reactive model.
- Can we interconnect **simulating Capellas** and integrate it, without actually sharing the model.
 - (the use of S2SS or the T4C are more to the model integration / sharing).
- Distributed Simulation:
 - Hard runtimes: HLA / DIS
 - “Soft” runtime: **ROS**
 - “Even softer” runtime: **MQTT**



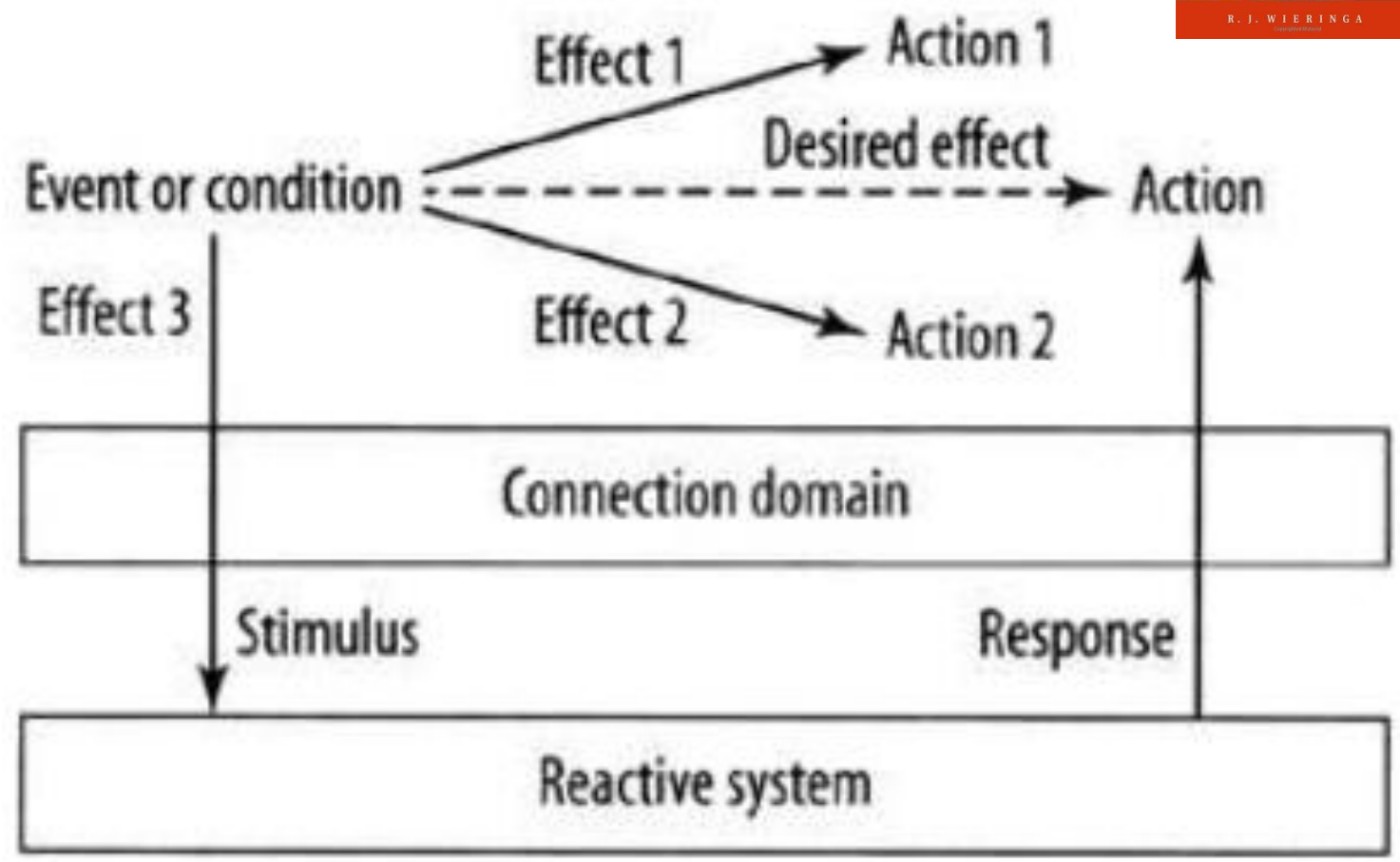
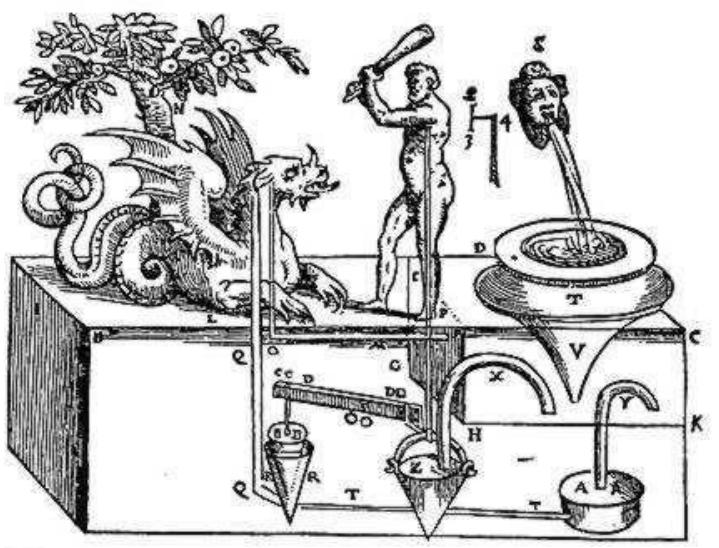
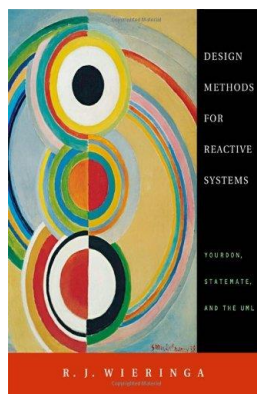


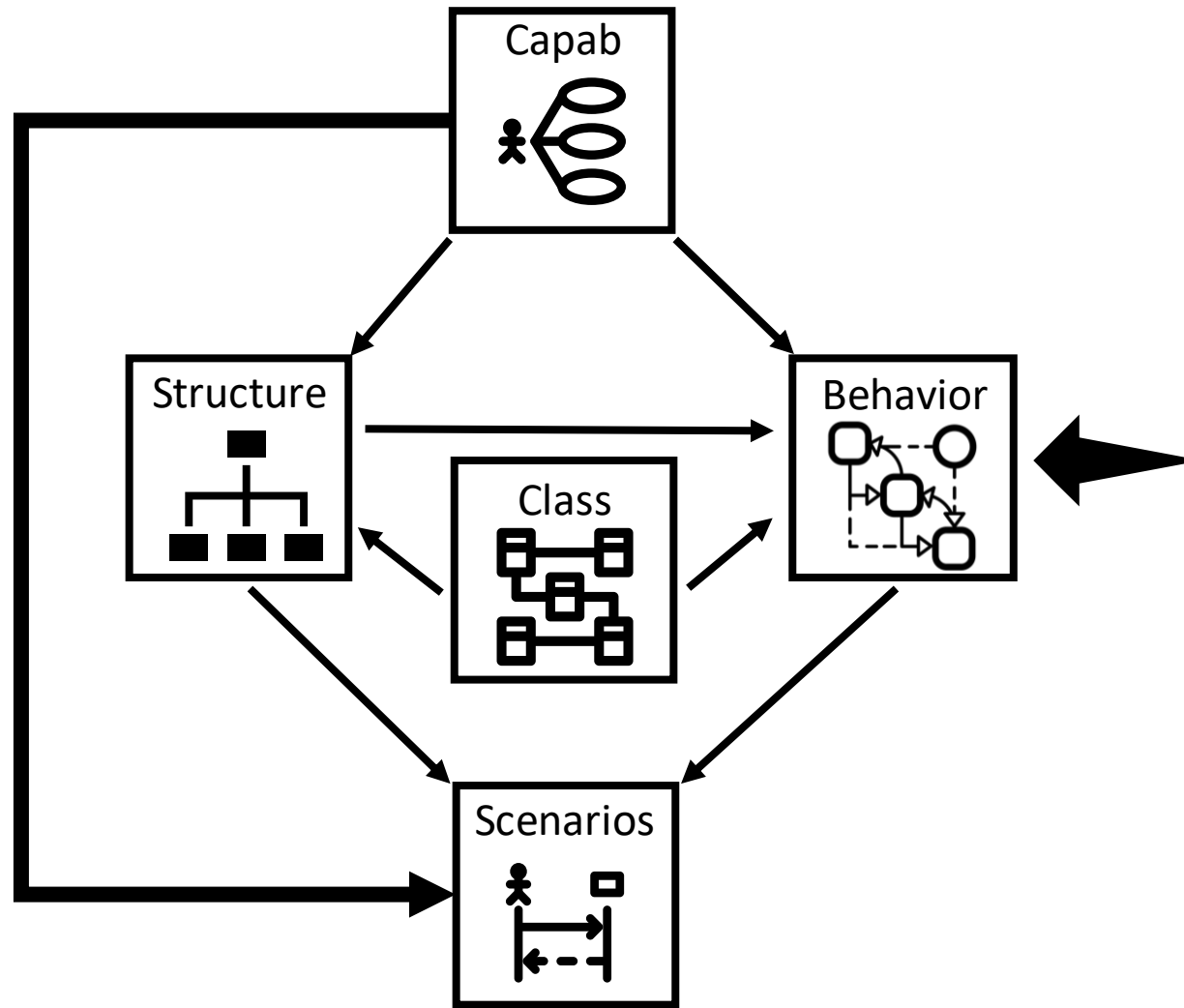
CapellaSim Add-on

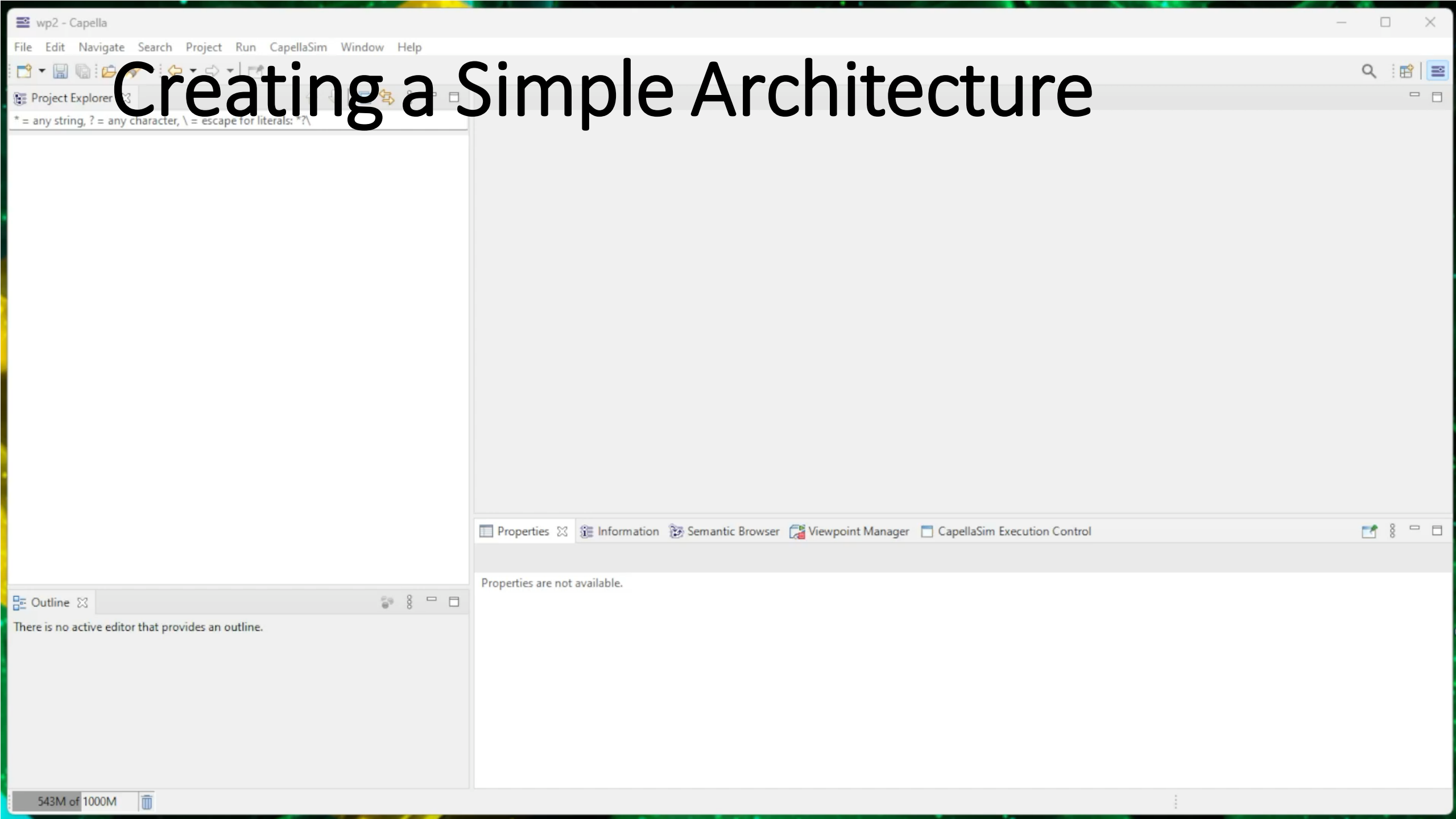
It is on github but the final final real final version release will be made available with the student master thesis.



Statechart - Reactive Simulation







Creating a Simple Architecture

Starting the Simulation

The screenshot displays the Capella software interface for a project named "capellaDays2023". The interface is divided into several main sections:

- Project Explorer (Left):** Shows the project structure, including "capellaDays2023.afm", "capellaDays2023.aird", and "capellaDays2023". Under "capellaDays2023", there are sub-views for "Operational Analysis", "System Analysis", "System Functions", "Capabilities", "Interfaces", "Data", "Structure", "System", "System State Machine", "Default Region", "SA 2", "[SAB] Structure", "Missions", "Logical Architecture", "Physical Architecture", "EPBS Architecture", and "Representations per category".
- System Diagram (Center-Left):** A hierarchical diagram showing a "System" containing "SystemFunction 1" and "SystemFunction 2". A sub-system "SA 2" contains "SystemFunction 3". "FunctionalExchange 1" connects "SystemFunction 1" to "SystemFunction 3", and "FunctionalExchange 2" connects "SystemFunction 2" to "SystemFunction 3".
- State Machine Diagram (Center-Right):** A state transition diagram starting from "Initial 1" and moving to "Mode 2 [region]". From "Mode 2", a transition labeled "FunctionalExchange 1 / SystemFunction 1" leads to "Mode 3 [region]". From "Mode 3", a transition labeled "FunctionalExchange 2 / SystemFunction 2" leads back to "Mode 2".
- Properties Panel (Bottom):** The "(DRepresentation Descriptor) [MSM] Default Region" panel is active. It shows fields for "Name" (set to "[MSM] Default Region") and "Package". Below these are sections for "Contextual Elements" and "Elements of Interest", both currently set to "<undefined>".

At the bottom left, a status bar indicates "207M of 1000M".

Sending triggers (stimuli)

The screenshot displays the Capella software interface. The main workspace is divided into two panes. The left pane shows a hierarchical system architecture diagram. At the top is a 'SimulatorUnit 1' containing a 'SourceStatechartDiagram [MSM] Defa...'. Below it is a 'System' block containing two 'SystemFunction' blocks: 'SystemFunction 1' and 'SystemFunction 2'. To the left of the 'System' block is a 'SA 2' block containing a 'SystemFunction 3'. Two 'FunctionalExchange' blocks, 'FunctionalExchange 1' and 'FunctionalExchange 2', connect 'SystemFunction 3' to 'SystemFunction 1' and 'SystemFunction 2' respectively. The right pane shows a state machine diagram with an 'Initial 1' state leading to 'Mode 2 [region]'. 'Mode 2' is connected to 'Mode 3 [region]' via 'FunctionalExchange 1 / SystemFunction 1'. 'Mode 3' is connected back to 'Mode 2' via 'FunctionalExchange 2 / SystemFunction 2'. The bottom of the interface features a 'Properties' panel with tabs for 'Information', 'Semantic Browser', 'Viewpoint Manager', and 'CapellaSim Execution Control'. The 'Information' tab is active, showing project details for 'capellaDays2023'.

Name	Version	State
Capella Requirements	0.13.1	Unreferenced
CapellaSim	1.0.0.qualifier	Active

299M of 1000M

Parsing guards (PropertyValues)

The screenshot displays the CapellaSim interface. On the left is the Project Explorer showing the project structure for 'capellaDays2023'. The main workspace is divided into two panes. The left pane shows a 'System' block containing 'SystemFunction 1' and 'SystemFunction 2', connected to an external 'SA 2' block via 'FunctionalExchange 1' and 'FunctionalExchange 2'. The right pane shows a state machine diagram with 'Initial 1' leading to 'Mode 2 [region]', which transitions to 'Mode 3 [region]' via 'FunctionalExchange 1 / SystemFunction 1', and returns via 'FunctionalExchange 2 / SystemFunction 2'. At the bottom, the 'CapellaSim Control Panel' includes a 'Registered Statecharts' section with 'System State Machine' selected, a 'System Triggers' dropdown set to 'FunctionalExchange 2', and buttons for 'Send trigger', 'Next step', 'Start', and 'Stop'. A 'Logger' section shows a list of events such as 'User sent a trigger: OperationalActivity 1'. The simulation status at the bottom indicates 'Simulation has ended' at '00:00:14.384'.



Soon will be public at Github

The screenshot shows a GitHub repository for 'CapellaSim', which is currently private. The repository has 2 watchers, 0 forks, and 0 stars. A notification indicates that the main branch is not protected. The repository contains several files and folders, including 'features', 'plugins', 'tests', '.gitignore', 'LICENSE', 'README.md', and 'View_prototyping.txt'. The most recent commit is by 'mvccogo' with the message 'Change wizard message', dated yesterday, and has 142 commits. The repository also has 4 releases, with the latest being 'CapellaSim v0.1.1-beta2' published 2 days ago. There are no packages published yet.

CapellaSim Private

Edit Pins Watch 2 Fork 0 Star 0

main 3 branches 4 tags

Go to file Add file Code

Your main branch isn't protected
Protect this branch from force pushing or deletion, or require status checks before merging. [Learn more](#) Protect this branch

mvccogo Change wizard message 2d69dc7 yesterday 142 commits

features	Repo restructuring	2 days ago
plugins	Change wizard message	yesterday
tests	Repo restructuring	2 days ago
.gitignore	Ignore .class files	8 months ago
LICENSE	Initial commit	last year
README.md	Update README (UNDER PROGRESS)	2 days ago
View_prototyping.txt	New view prototyping (.txt)	3 months ago

README.md

CapellaSim

About
No description, website, or topics provided.

- Readme
- GPL-3.0 license
- Activity
- 0 stars
- 2 watching
- 0 forks

Releases 4

CapellaSim v0.1.1-beta2 **Latest**
2 days ago

+ 3 releases

Packages
No packages published
[Publish your first package](#)



Quick Example



Applying into a UAV context



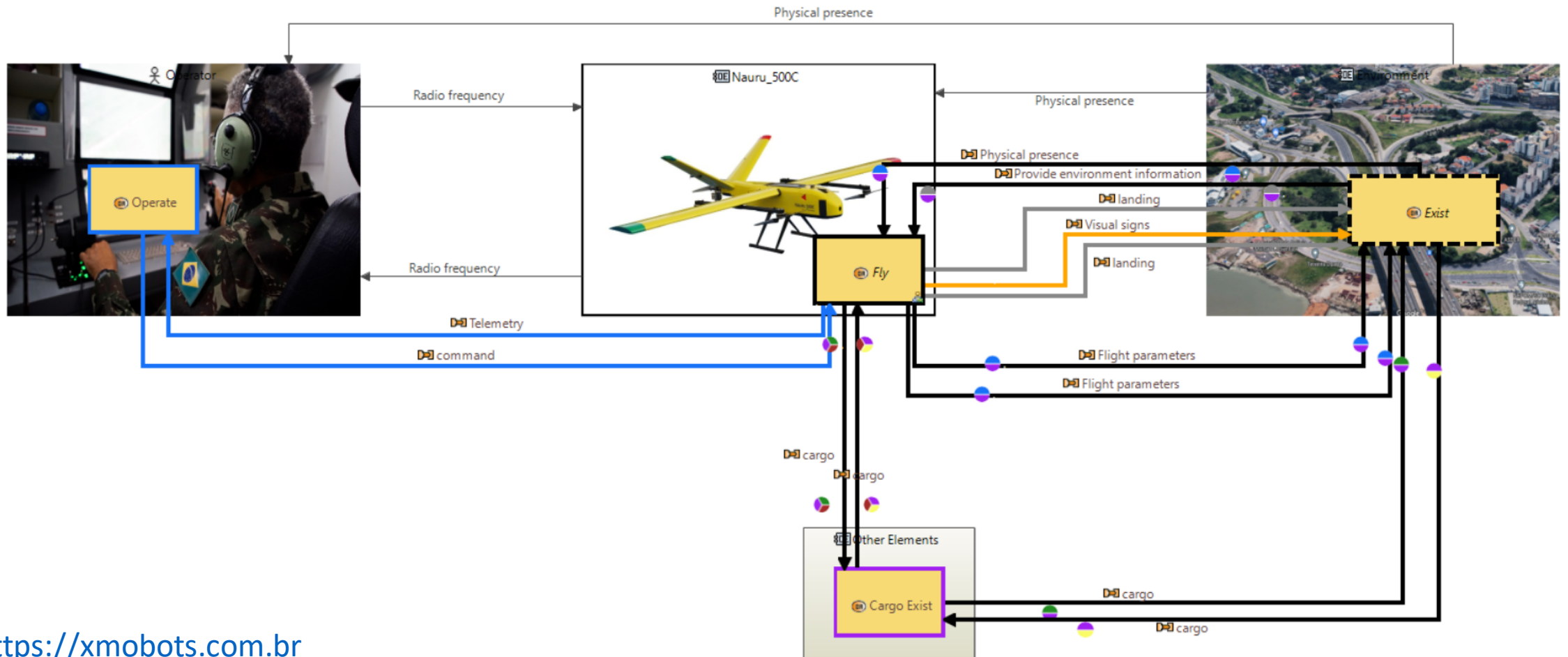


Modelling the Aircraft functions



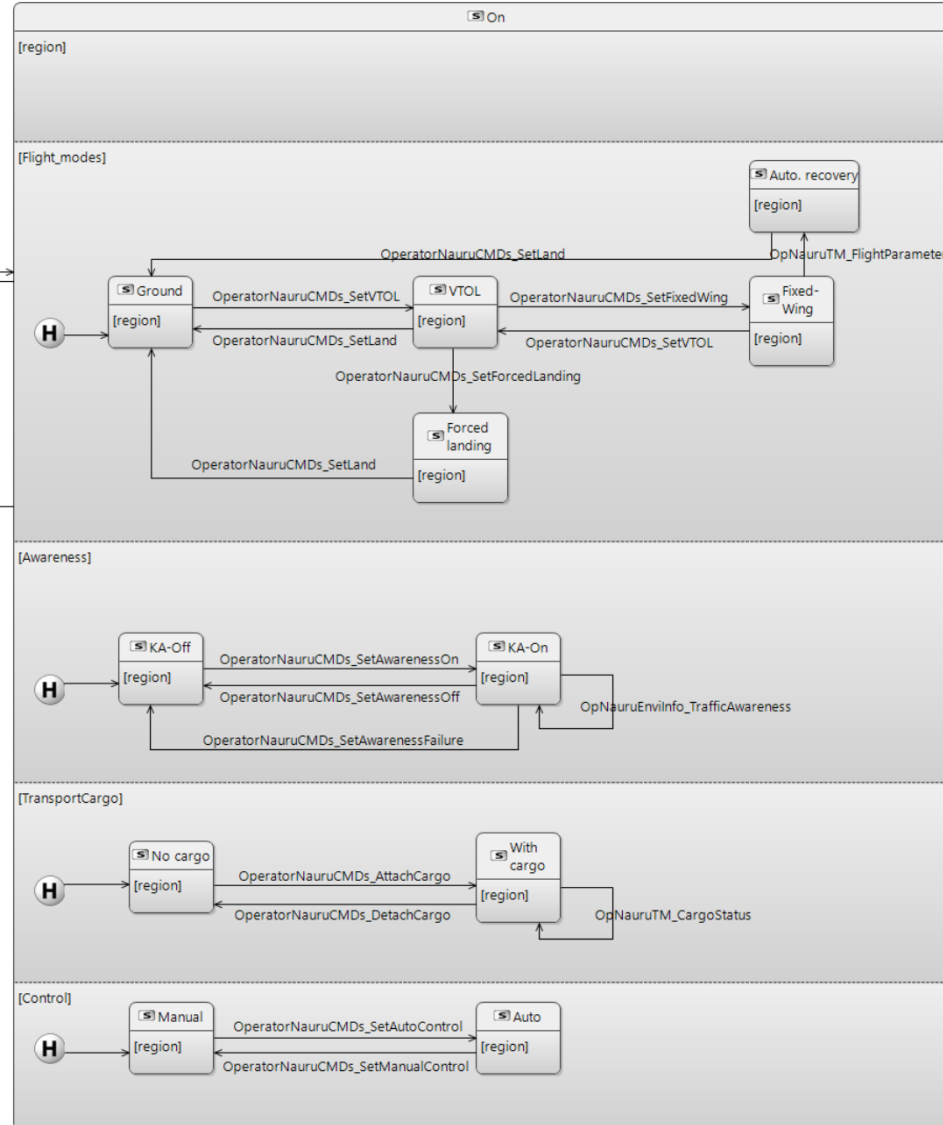
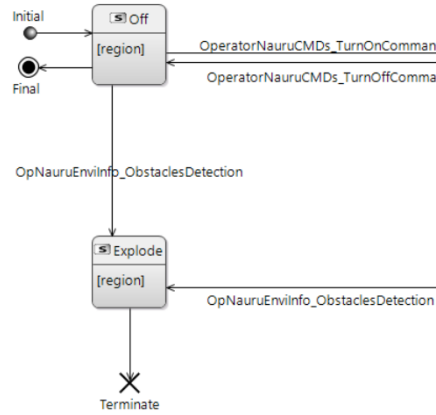
(same approach to all layers)

- Transport cargo process
- Load cargo process
- Anti-collision lighting process
- Automatic recovery process
- Parachute process
- Remoted Operated process
- Unload cargo process
- Relationship process
- Forced landing process

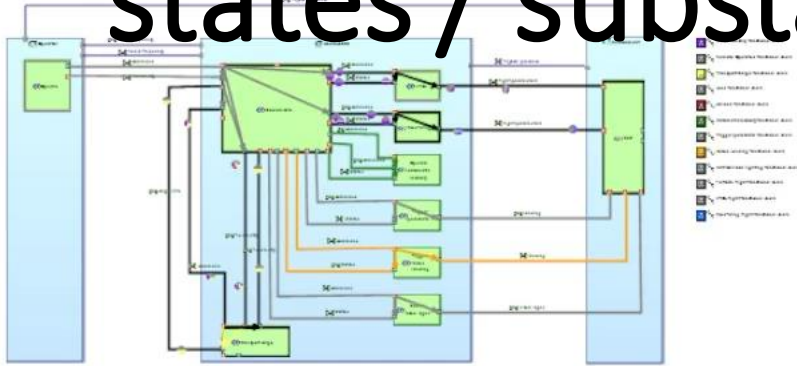




Modelling the State Machine



Simulating the commands and changing the states / substates



CapellaSim Execution Control

CapellaSim Control Panel

Registered Statecharts

- StateMachine 1

System Triggers

Send trigger

Next step

Start

00:00:00.000

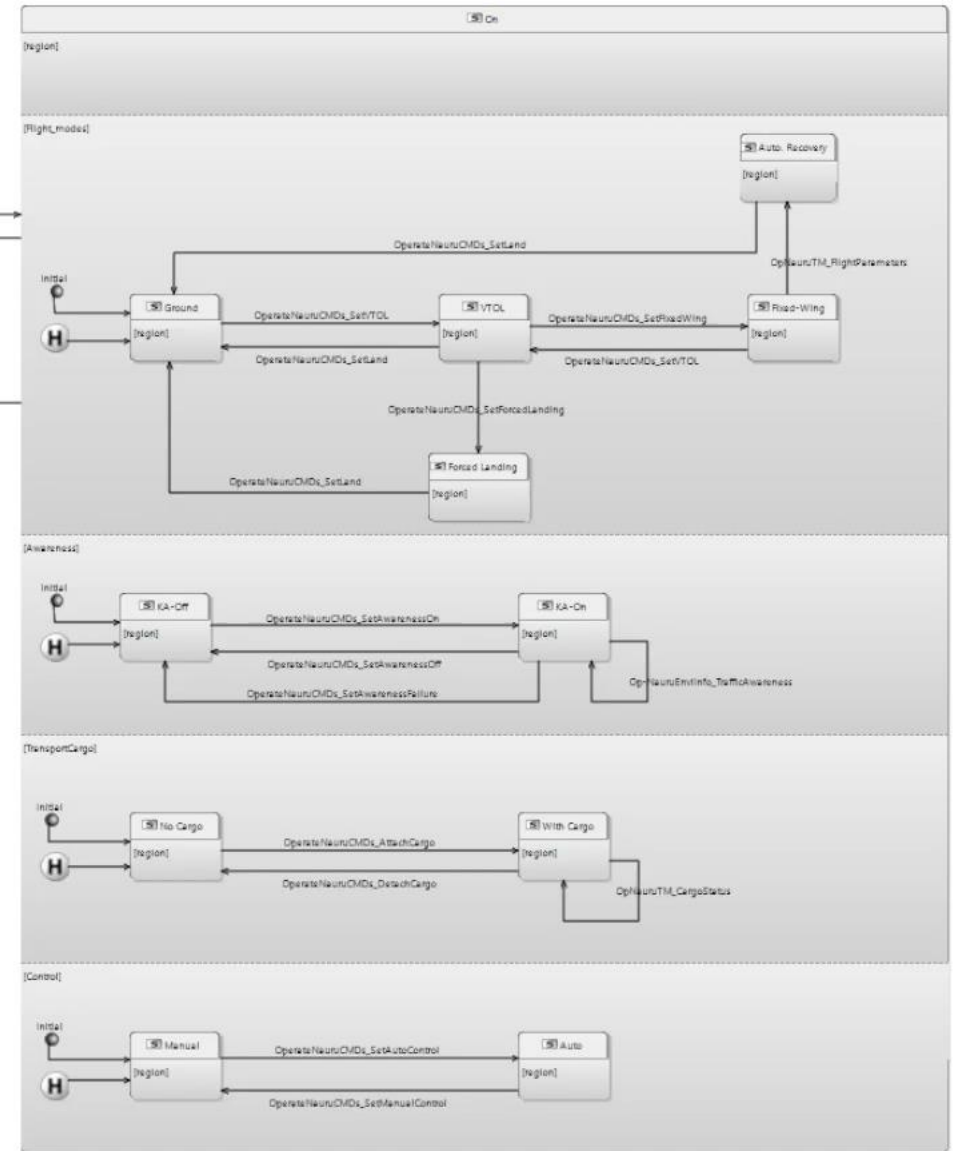
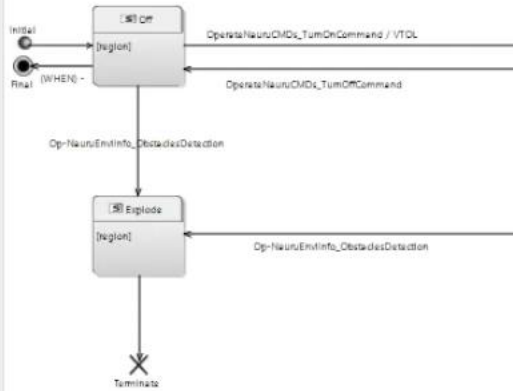
Simulator not loaded

Logger

Stop

Simulation status:

Publish PropertyValues





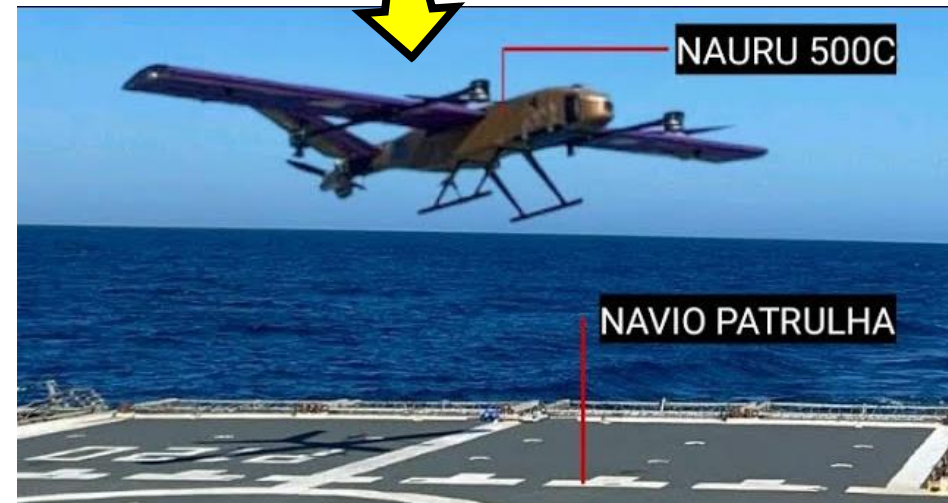
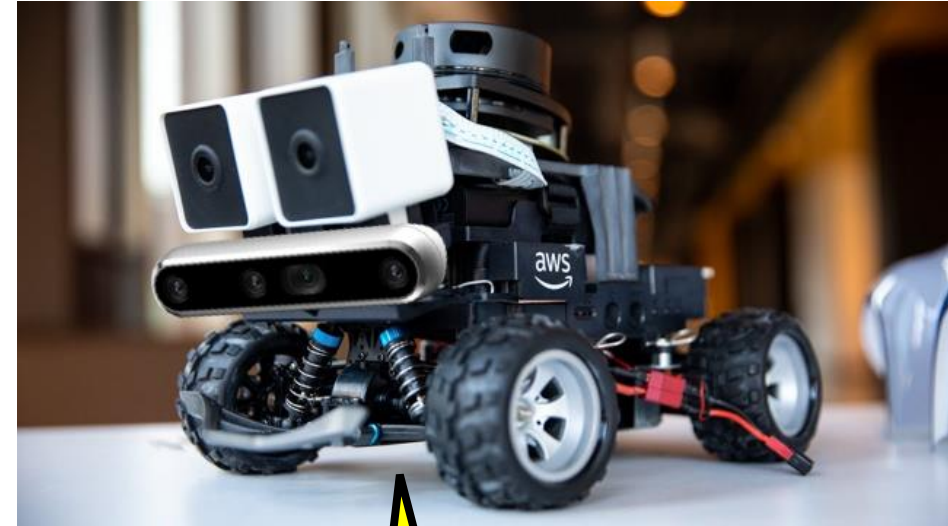
Connecting Capella to Physical Things

It is not HIL (could be), the idea is to have a twin representation of the physical vehicle into the systemic view and track its behavior changes validating it.



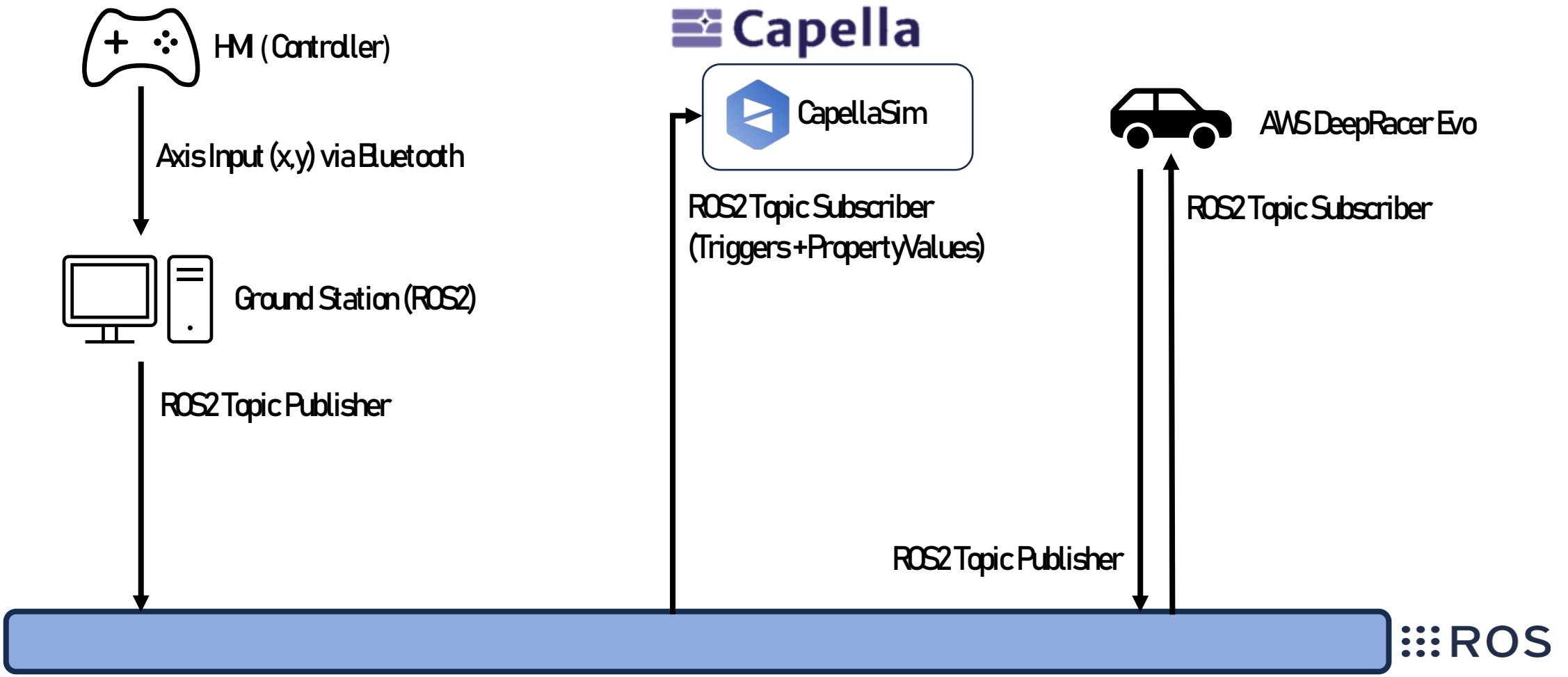
Design of Experiments

- Use a representative of the vehicle to run 2D detect and avoid experiments. Flying crashes are more expensive 😊.
- Use of Capella to track the changes during the simulation.
 - Live Simulation: Commands sent to the vehicle by a HMI should be sent to the Capella, sending triggers to the state-machine should also be sent to the vehicle.





ROS



<https://portal.waraps.org>

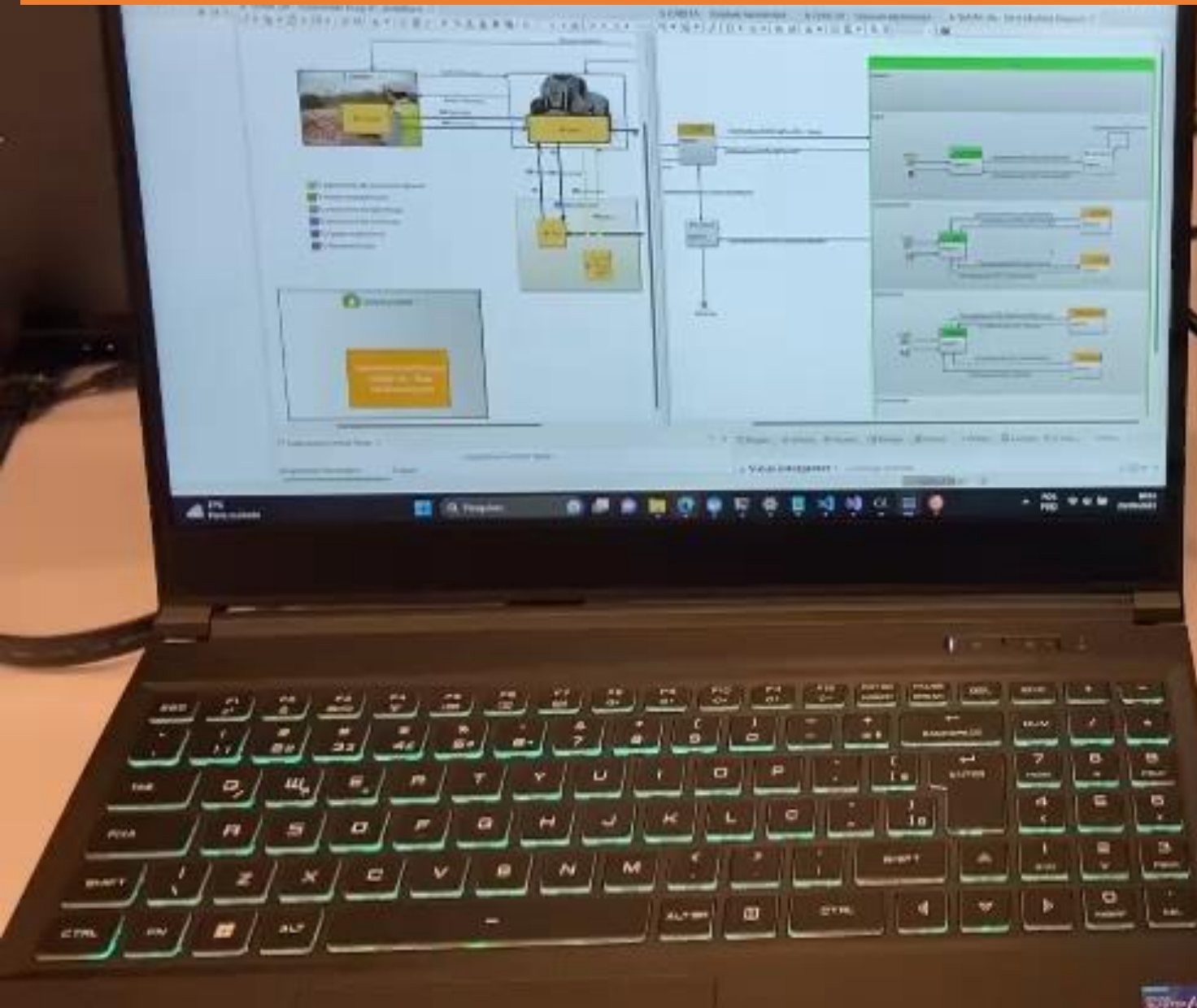


WASP | WALLENBERG AI
AUTONOMOUS SYSTEMS
AND SOFTWARE PROGRAM

WASP RESEARCH ARENAS
Public Safety



Twin in Capella / Equipment





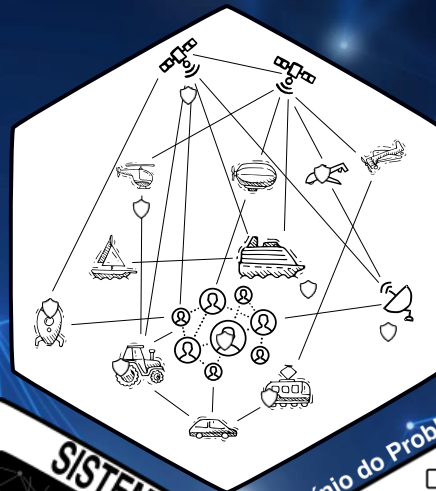
Final Considerations



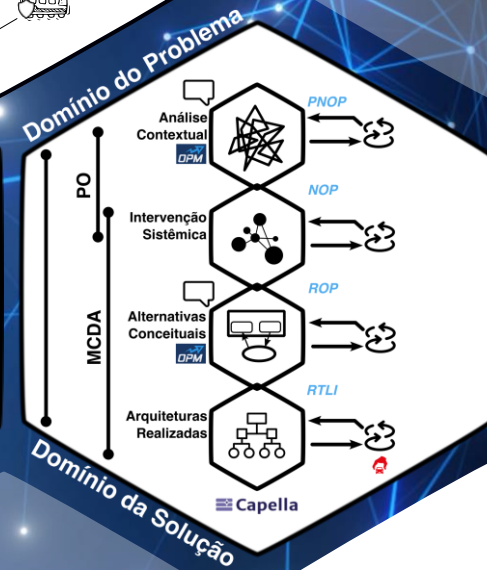
Some on-going developments

- Our lab is working into **multidomain problems** and **Brazilian Air Force Life Cycle Framework**.
- We have a question: “**Is the current Systems Engineering UI Metaphor natural?**”
- In terms of development:
 - Library Management Add-On (ways to better filter elements of the library)
 - Architecture Optimization Add-On (ways to check interfaces and simulation results)
 - Distributed Simulation Add-On (what was presented)
 - Operational Research Add-On (we started with Soft Systems Methodology)
 - simple_OPM Add-On (changes on the block-diagram to be able to show structure/behavior simultaneously)

conceptiolab.dev.br



Thank you!



 **Capella**
Open Source MBSE Solution