Traceable Engineering of Fault-Tolerant SoSs

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SoSECIE webinar: 09/15/2015

Outline

- Introduction
- Engineering Fault-Tolerant SoSs
- Conclusions

Outline

- **Introduction**
  - **Systems of Systems**
  - **Systems of Systems and Dependability**
  - **The Fault Modelling and Analysis Method**
- Engineering Fault-Tolerant SoSs
- Conclusions

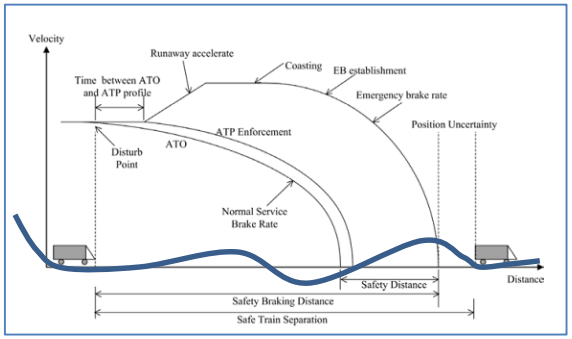
Our Research …

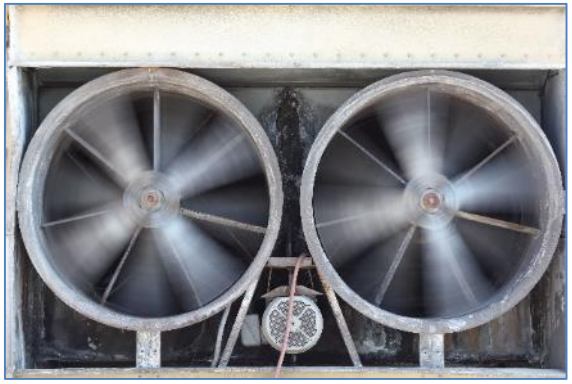
Design technology (foundations, methods, tools) for:

- Systems of Systems (SoS)
- Cyber-Physical Systems (CPS)

We focus on model-based design:

- Models as a basis for collaborative development
- Machine-assisted analysis of models as a means of managing development risk





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Current Projects

- Strongly supported by European Union
- Current Priorities:
  - *Research*: development of sound toolchains for verifying global properties of CPSs (INTO-CPS)
  - *Innovation Support*: creating ecosystems in model-based engineering for CPS (CPSE Labs)
  - *Strategic Actions*: Roadmaps and Transatlantic Research Agenda (Road2CPS, TAMS4CPS)

www.into-cps.au.dk
@IntoCps

www.cpse-labs.eu
@CPSE_Labs

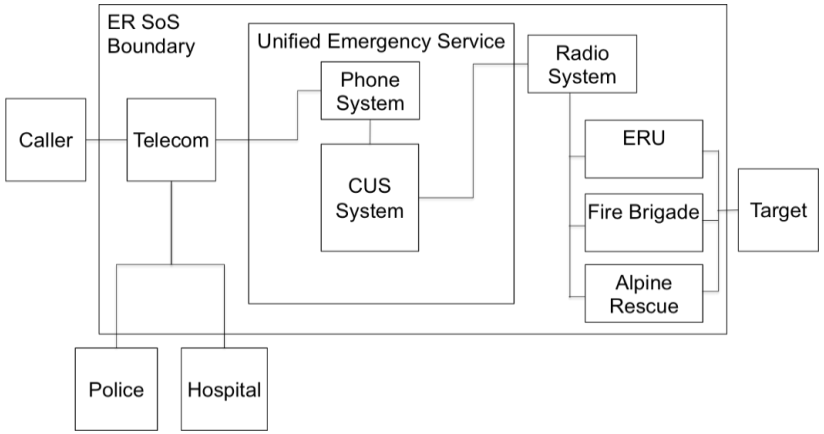
www.road2cps.eu
@ROAD2CPS

www.tams4cps.eu
@TAMS4CPS

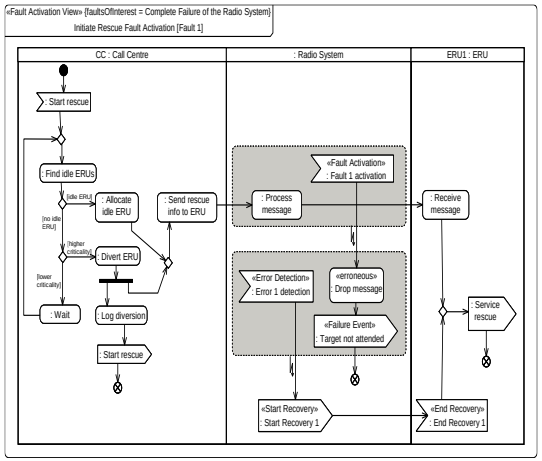
Systems of Systems

- Assembly and integration of independent “constituent systems” interacting via a networked infrastructure
- Collectively offer a new global (“emergent”) service on which value and reliance is placed.
- Independence
- Distribution
- Evolution
- Emergence

- Model-based SoS Engineering as a way of mastering complexity



COMPASS Technology



Semi-formal Modelling

- SysML used for SoS modelling
- Guidelines for Requirements, Architecture, Integration
- SoS modelling profiles
- Architectural patterns and extensible architectural frameworks (AFs)

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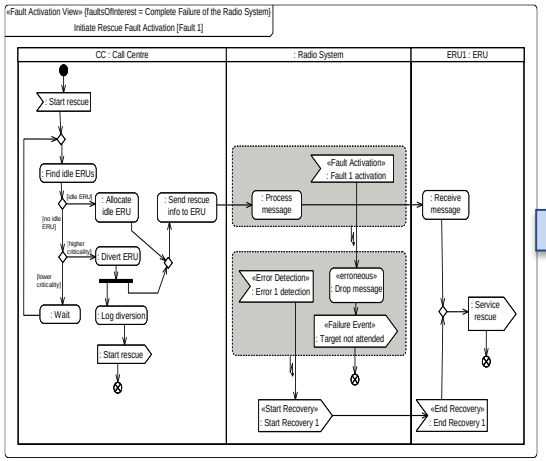


```
process CallCentreProc = begin
...
actions
 MERGE1(r) =
  (dcl e: set of ERUId @ e := findIdleERUs();
   if  e = {}
   then DECISION2(r)
   else
     (dcl e1: ERUId @ e1 :=
       allocateIdleERU(e, r); MERGE2(e1, r)))
    ...


process InitiateRescue = CallCentreProc
          [| SEND_CHANNELS |] RadioSystemProc
          [| RCV_CHANNELS |] ERUsProc
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Formal Modelling

- CML allows representation of behavioural semantics of the SoS
- Supports contract specification
- Describes functionality, object-orientation, concurrency, real-time, mobility.
- Can be extended to new paradigms

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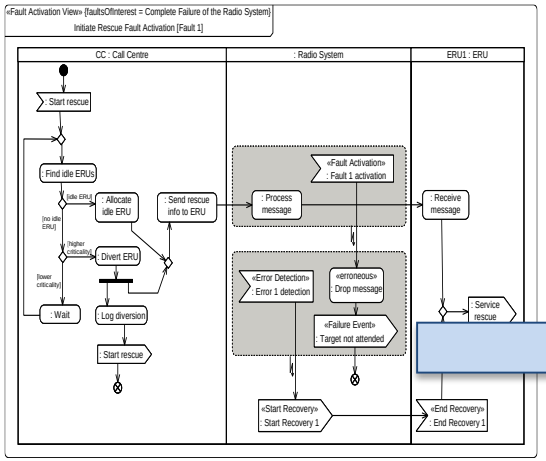


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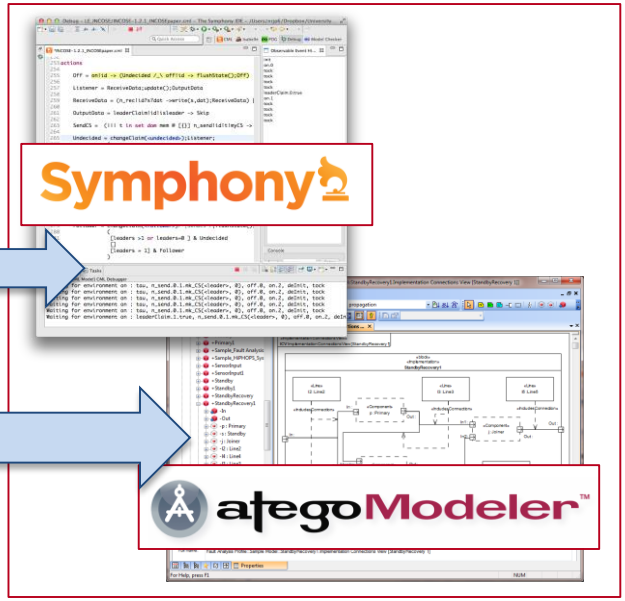

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Tool-supported Analysis

- Model-checker
- Automated proof
- Static Fault Analysis
- Test generation
- Simulation
- Model-in-Loop Test
- Exploration of design space

SoS and Dependability

Independence

Distribution

Evolution

Emergence

Challenge:

CSs are *autonomous* and *independent*, responsibility for preventing SoS failure when a CS fails or withdraws from the SoS is unclear

Approach:

Record explicitly where responsibility for fault tolerance lies

SoS and Dependability

Independence

Distribution

Evolution

Emergence

Challenge:

Networking technology that SoS-level functionality relies on may introduce faults

Approach:

Model-based support for exploration of recovery strategies that can be applied when networking failures occur

SoS and Dependability

Independence

Distribution

Evolution

Emergence

Challenge:

CSs evolve independently, need to preserve dependability under evolutions of the SoS

Approach:

Model-based traceability facilitates impact analysis to understand the impact of unexpected changes

SoS and Dependability

Independence

Distribution

Evolution

Emergence

Challenge:

Need to analyse the emergent dependability of the SoS, but constituents systems may be black boxes

Approach:

Document fault assumptions for constituents and provide tool support for analysis of emergent dependability properties

SoS and Dependability

SoS failure *"a deviation of the service provided by the SoS from expected (correct) behaviour"*

SoS error *"the part of the SoS state that can lead to its subsequent service failure"*

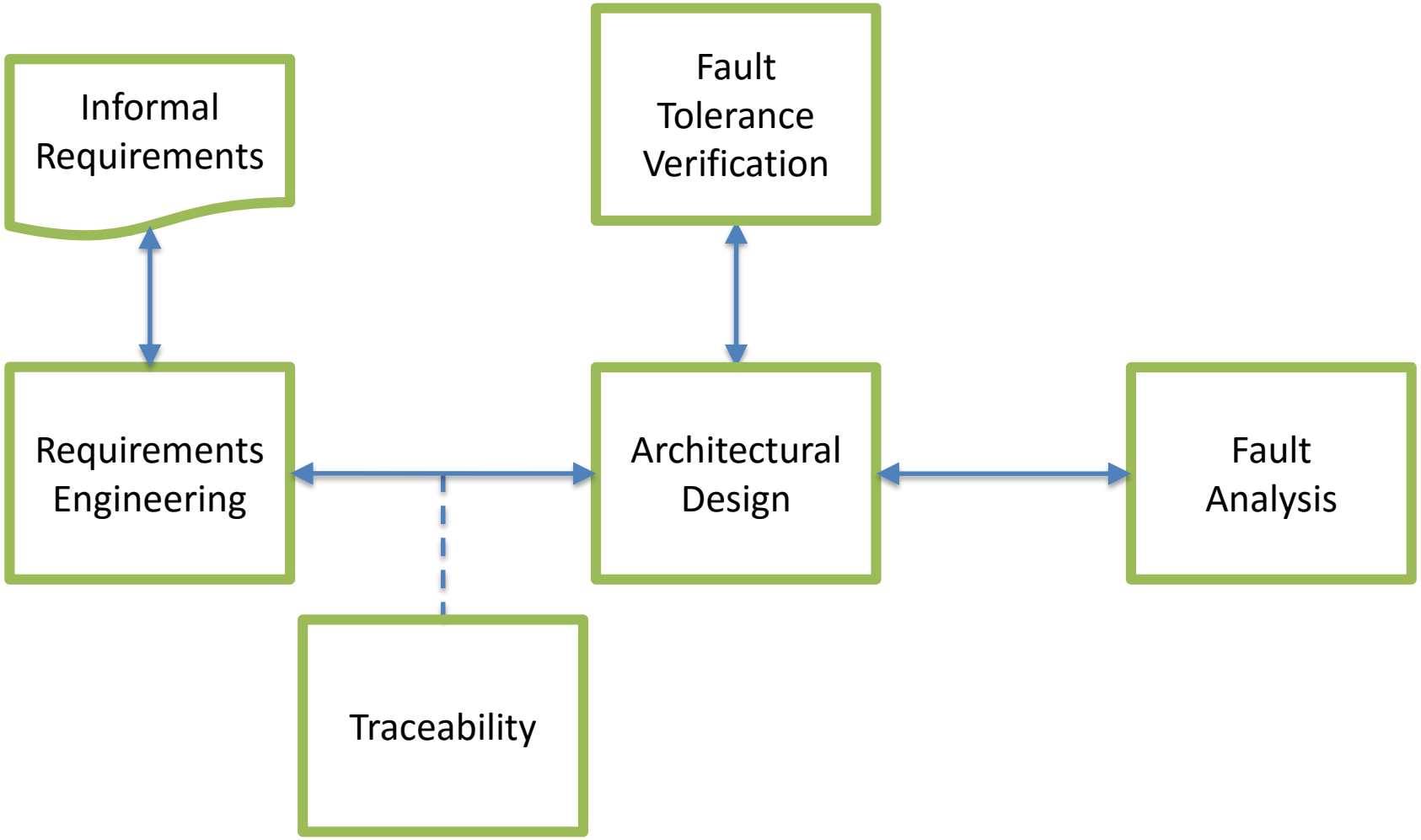
SoS fault *"the adjudged or hypothesised cause of an error"*

The focus of our work is on **fault-tolerant SoSs**

- preventing SoS failures from arising in the presence of faults
- achieved by detecting errors and conducting system recovery

Avizienis, A.; Laprie, J.-C.; Randell, B. & Landwehr, C., "Basic concepts and taxonomy of dependable and secure computing," *Dependable and Secure Computing, IEEE Transactions on* , vol.1, no.1, pp.11,33, Jan.-March 2004.

Methodology



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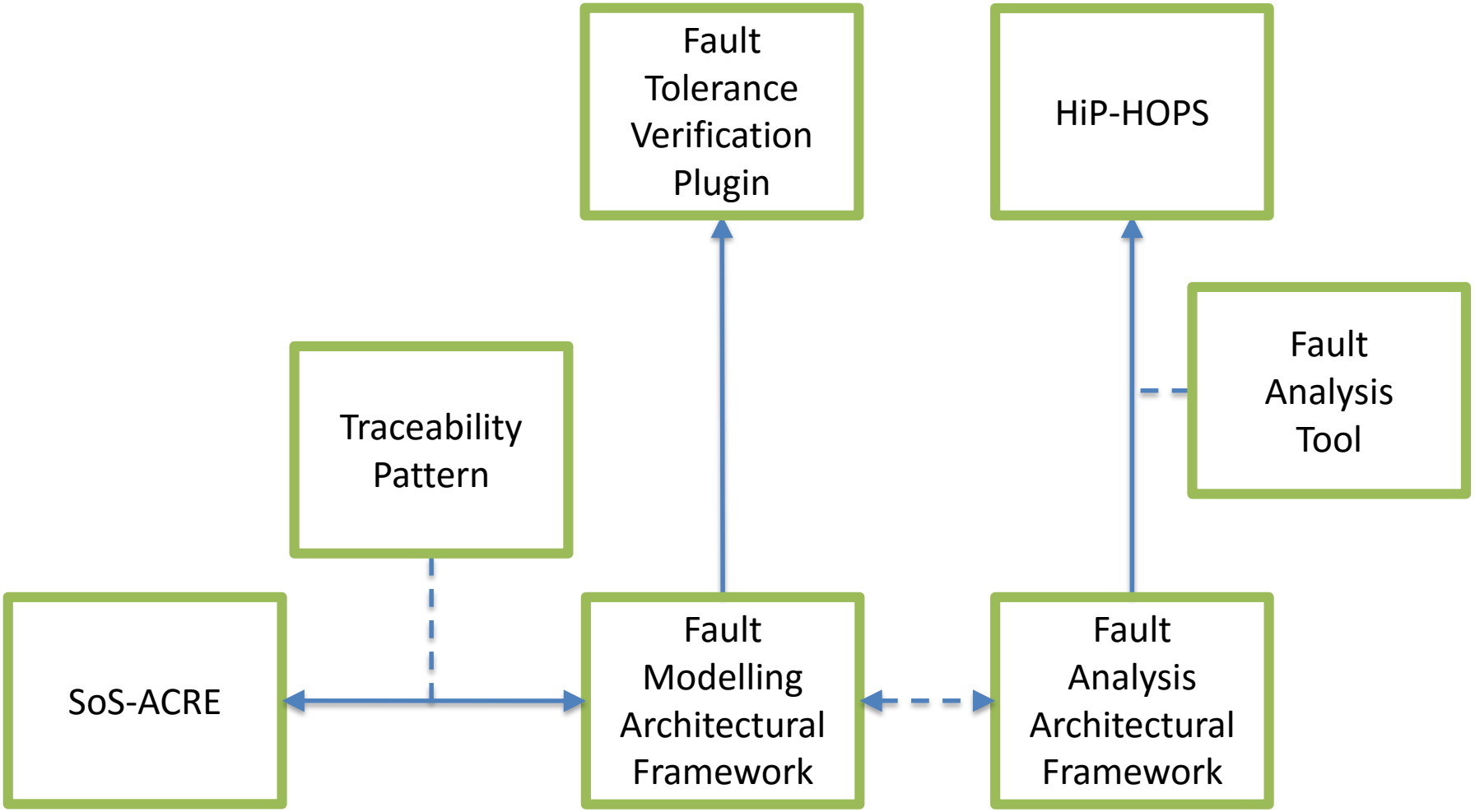

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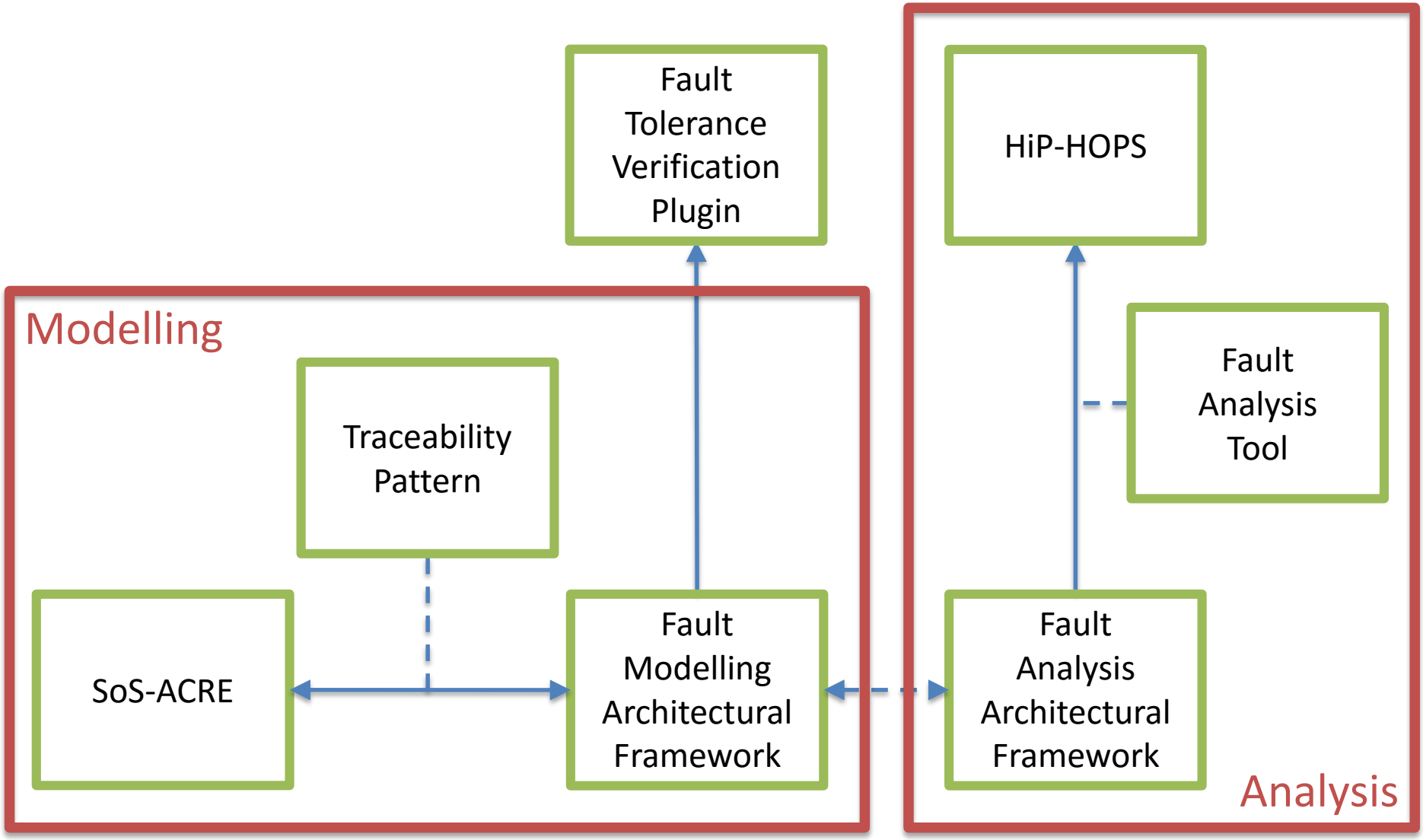

COMPASS AF Framework (CAFF) Approach

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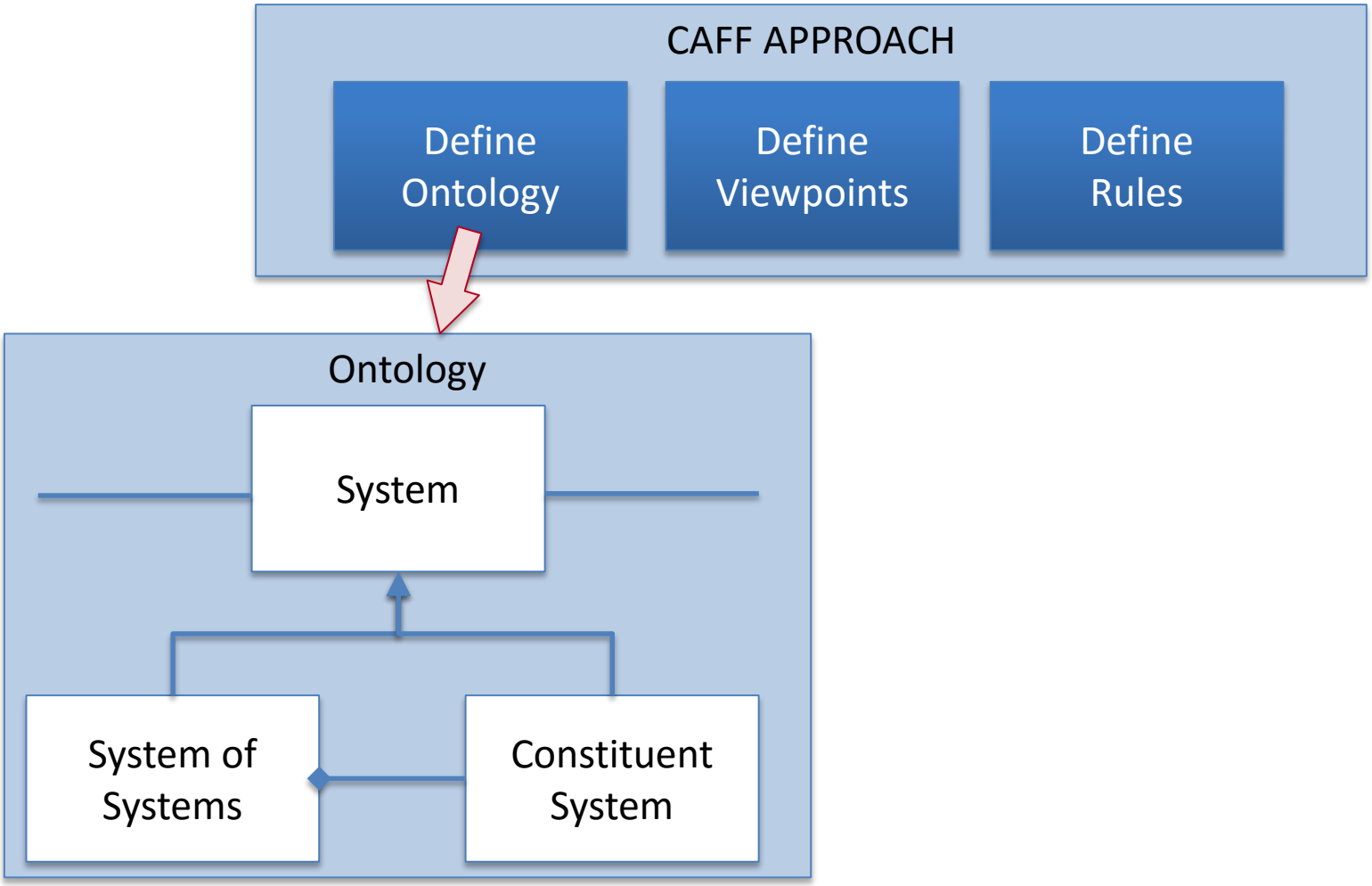

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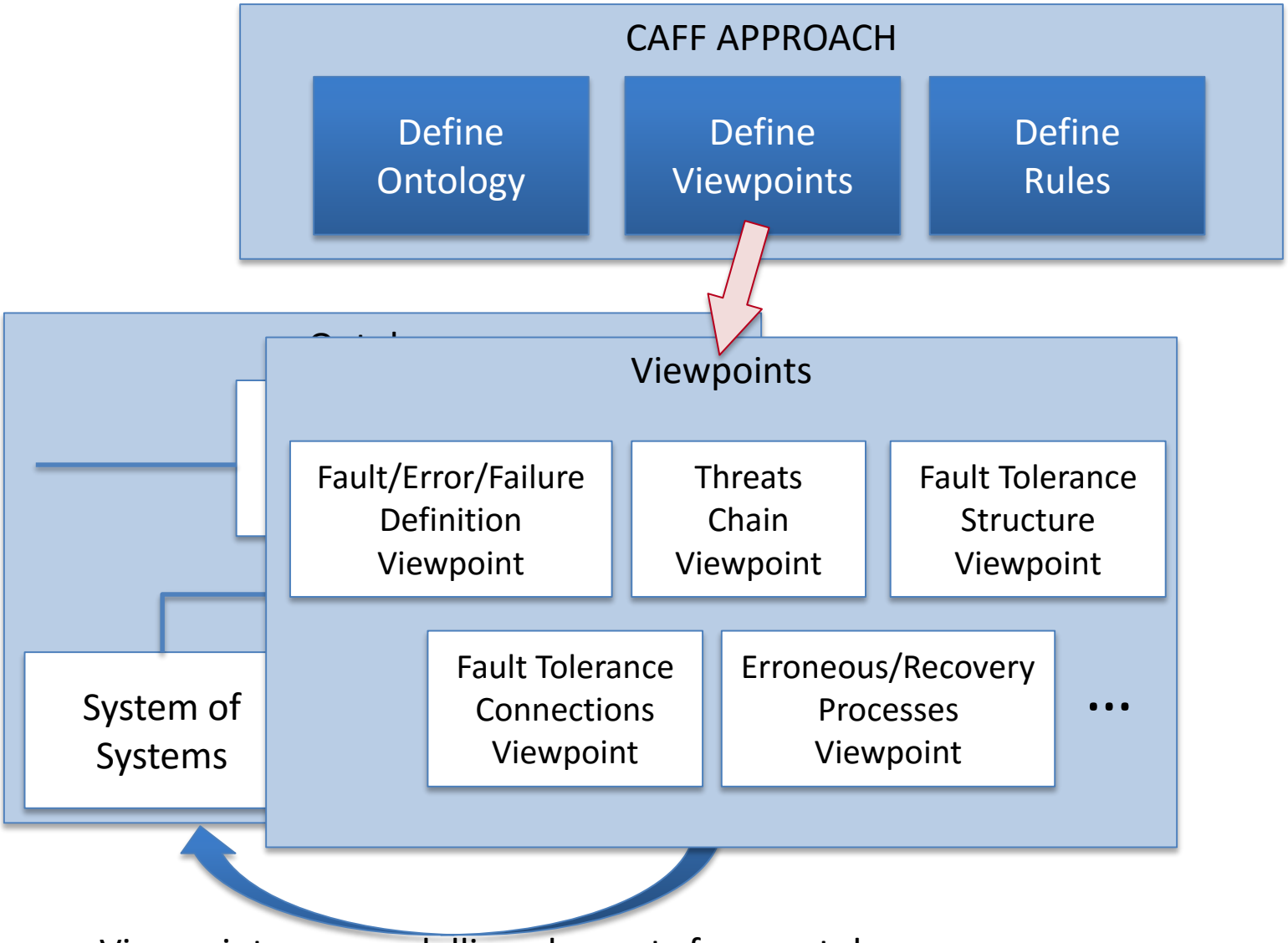
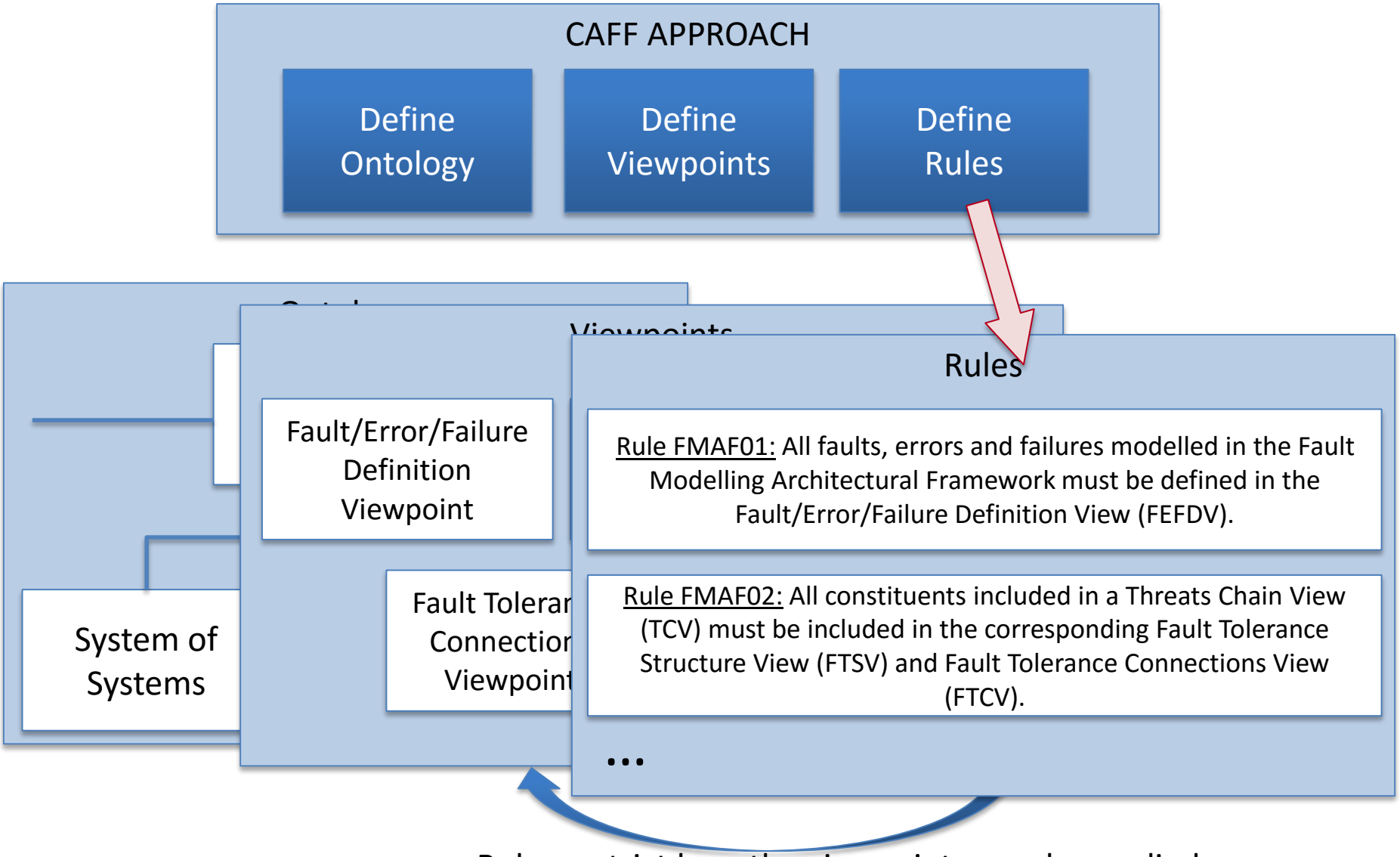


Viewpoints use modelling elements from ontology

COMPASS AF Framework (CAFF) Approach



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- Introduction
- **Engineering Fault-Tolerant SoSs**
  - **Case Study**
  - **Requirements Engineering**
  - **Fault Modelling**
  - **Requirements Tracing**
  - **Fault Analysis**
- Conclusions

Emergency Response SoS

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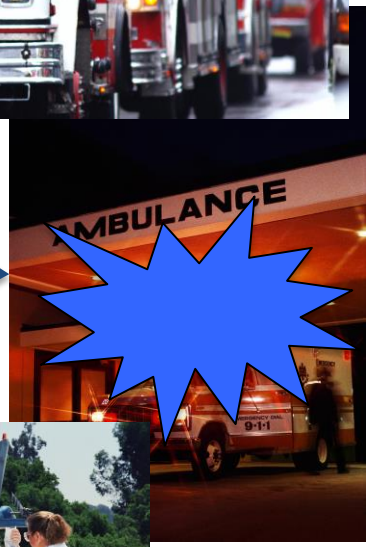
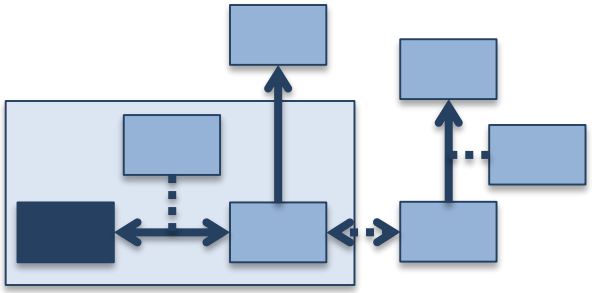


Emergency Response SoS

Requirements Engineering

- Apply SoS-ACRE: a structured way of engineering and managing the requirements of an SoS

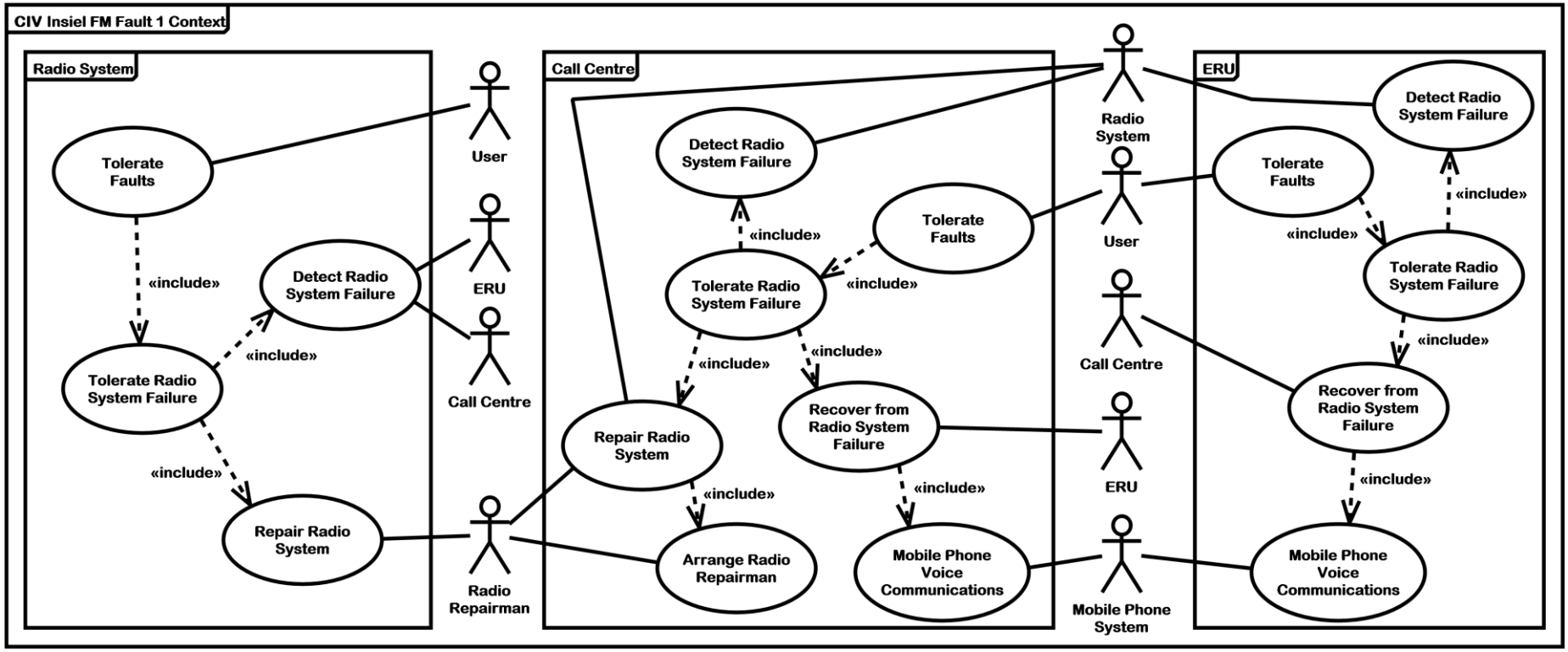


We focus on the requirements *engineering* processes

- Key elements of SoS-ACRE for fault tolerance:
  - define the fault tolerance requirements of the SoS (what faults)
  - examine the fault tolerance requirements in the context of the CSs
  - identify error detection and recovery scenarios

ER SoS: Context Interaction

Requirement: Tolerate Radio System Failure



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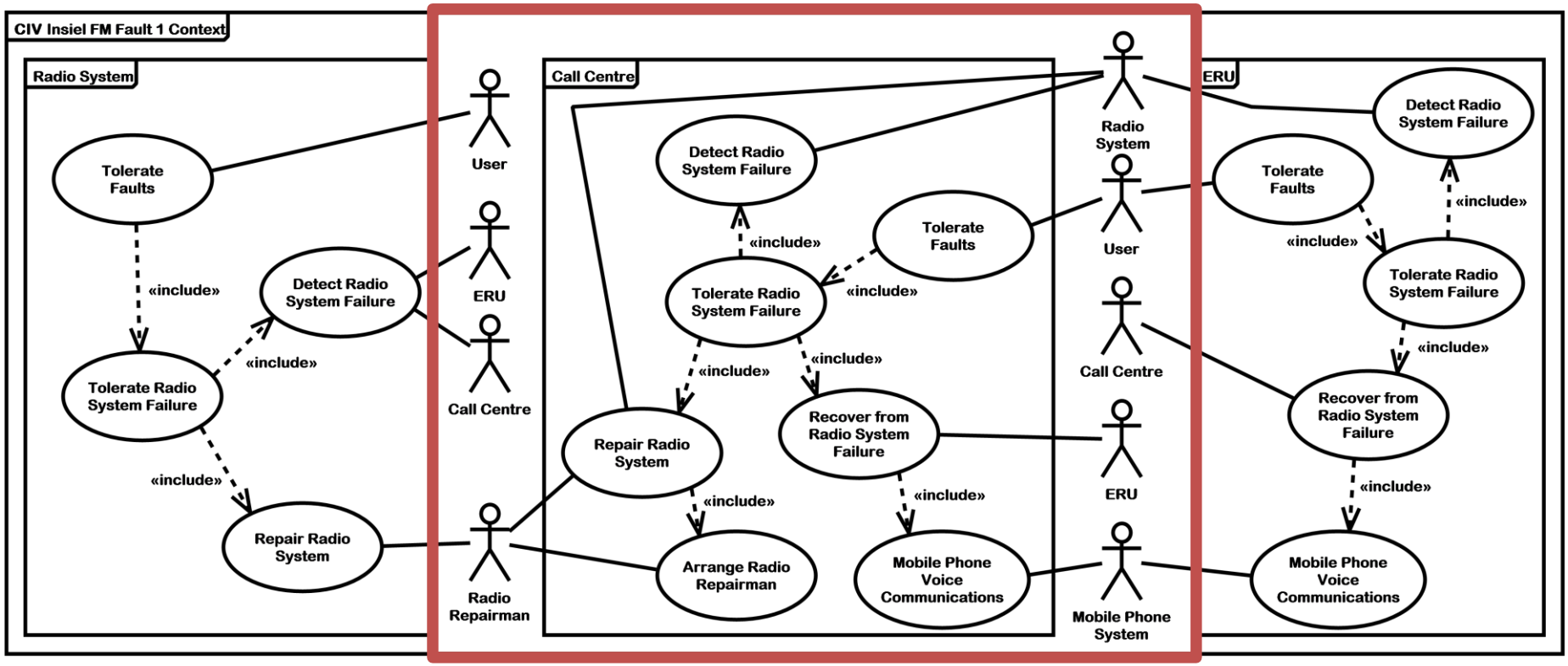

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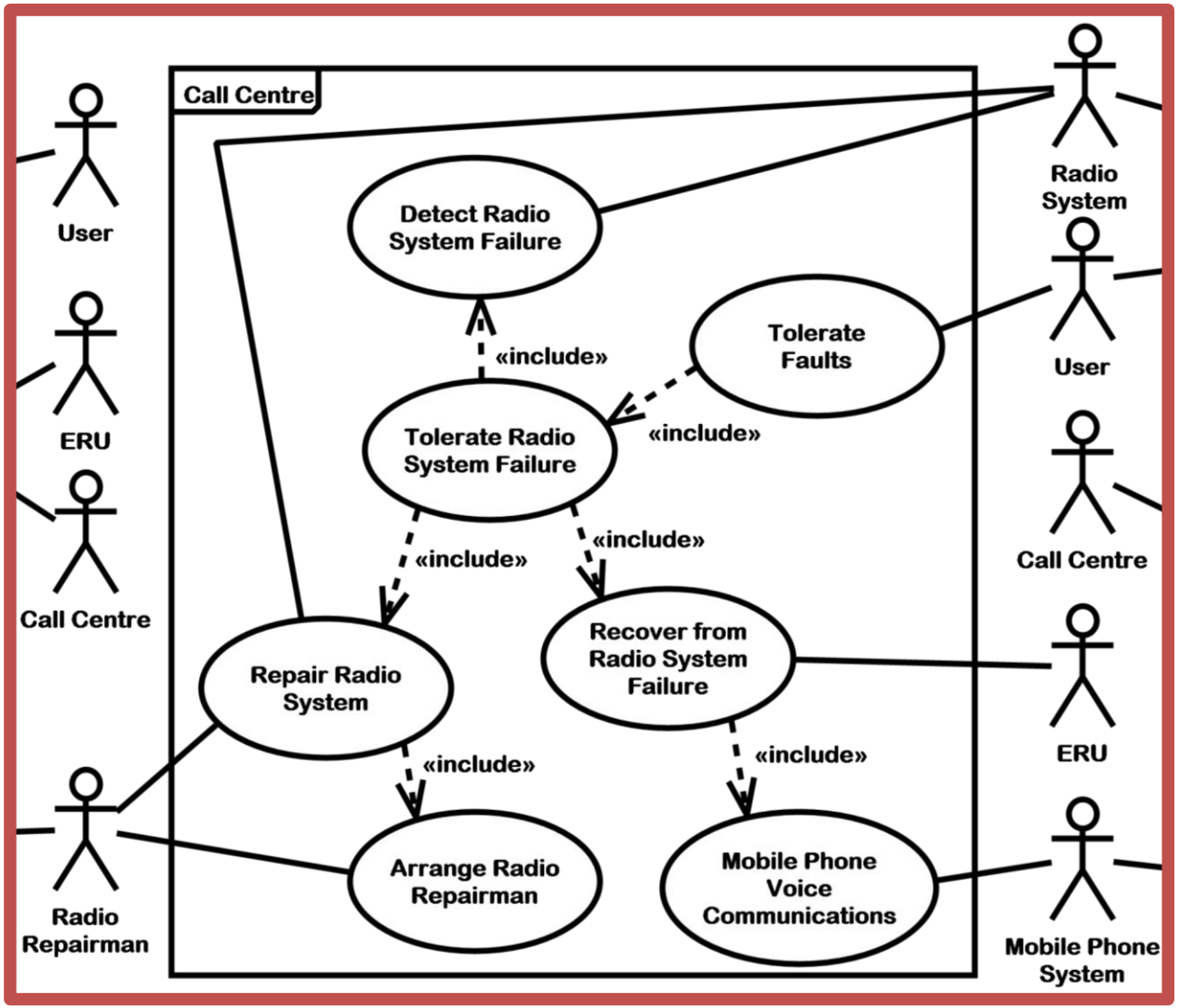
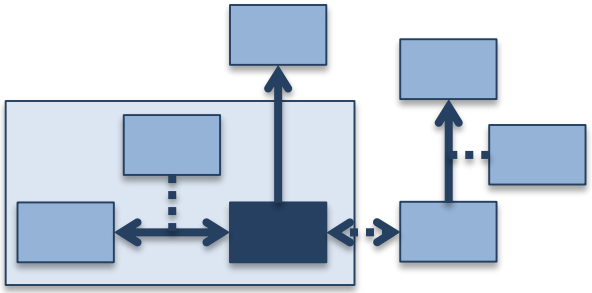
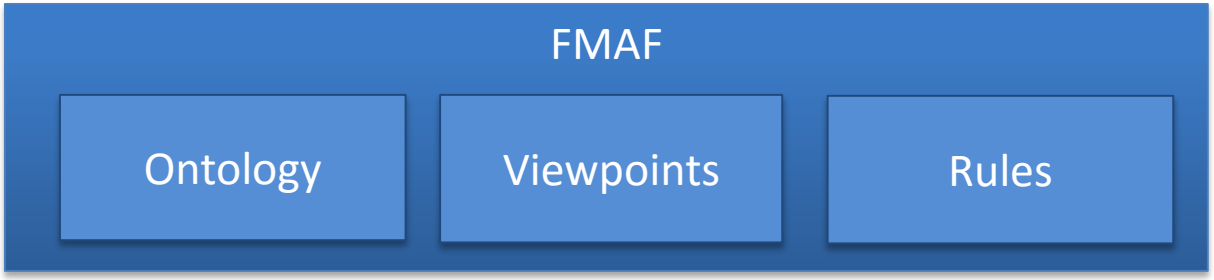


Fault Modelling

- Defined a Fault Modelling Architectural Framework (FMAF) + SysML profile



- Prompts an SoS engineer to consider the impact of faults at the early stages of design
- A coherent set of views & concepts for designing fault-tolerant SoSs



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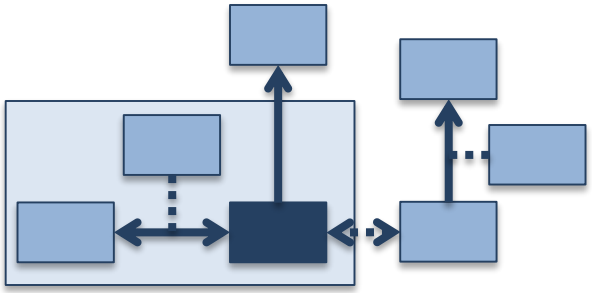

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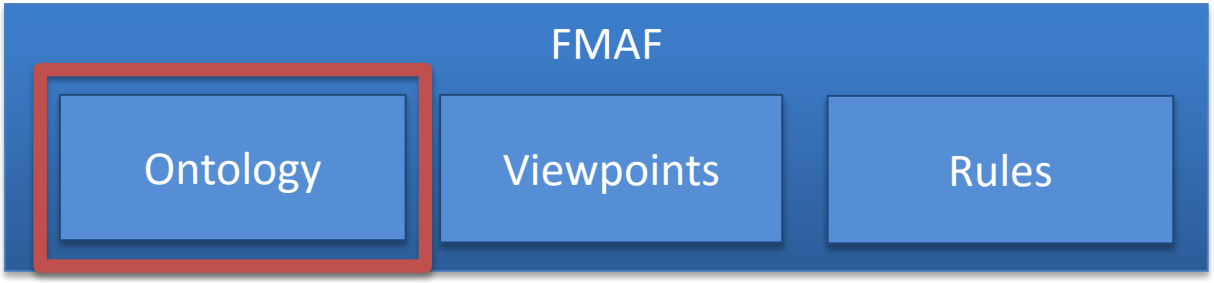
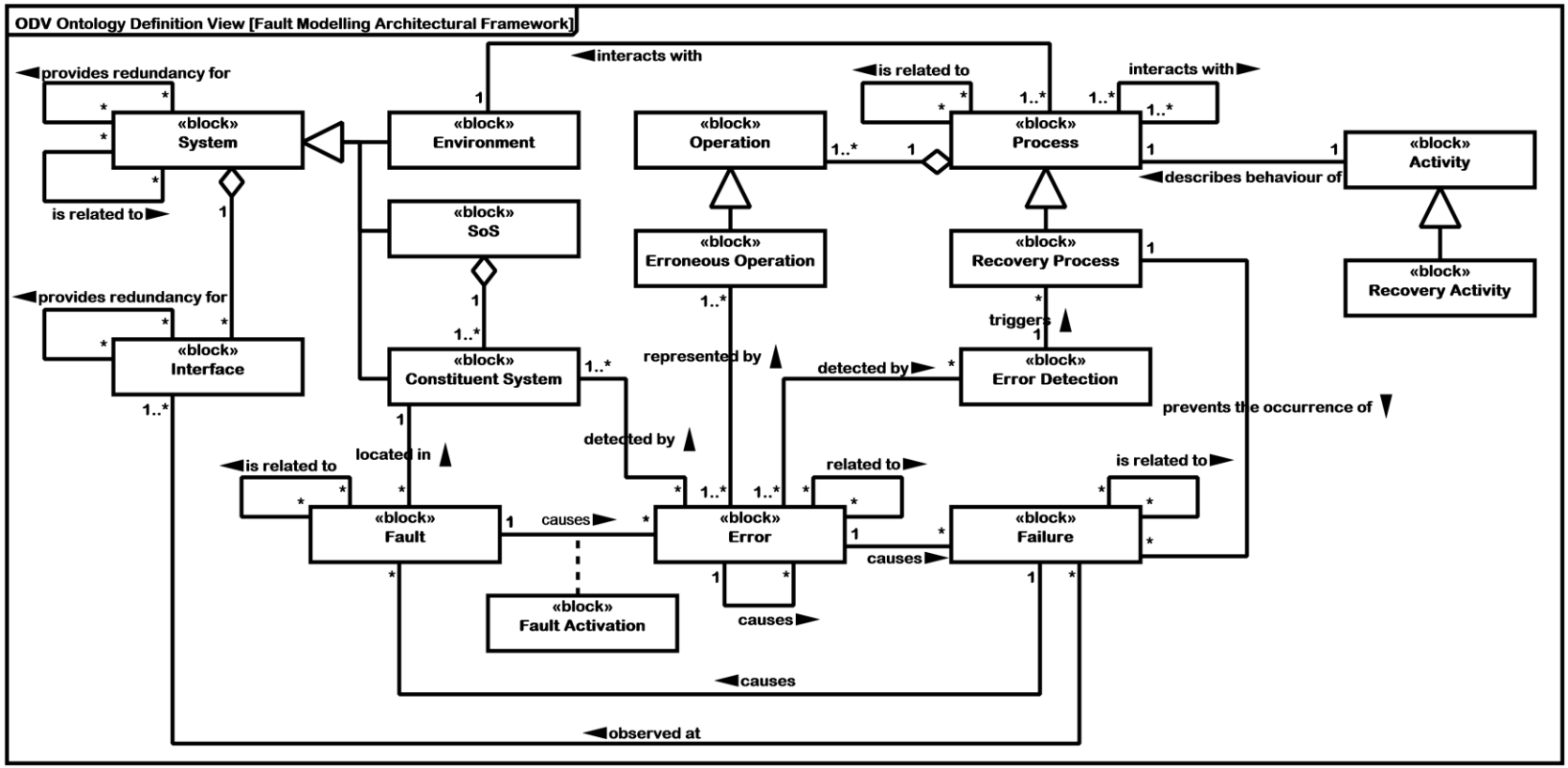


FMAF: Ontology Definition



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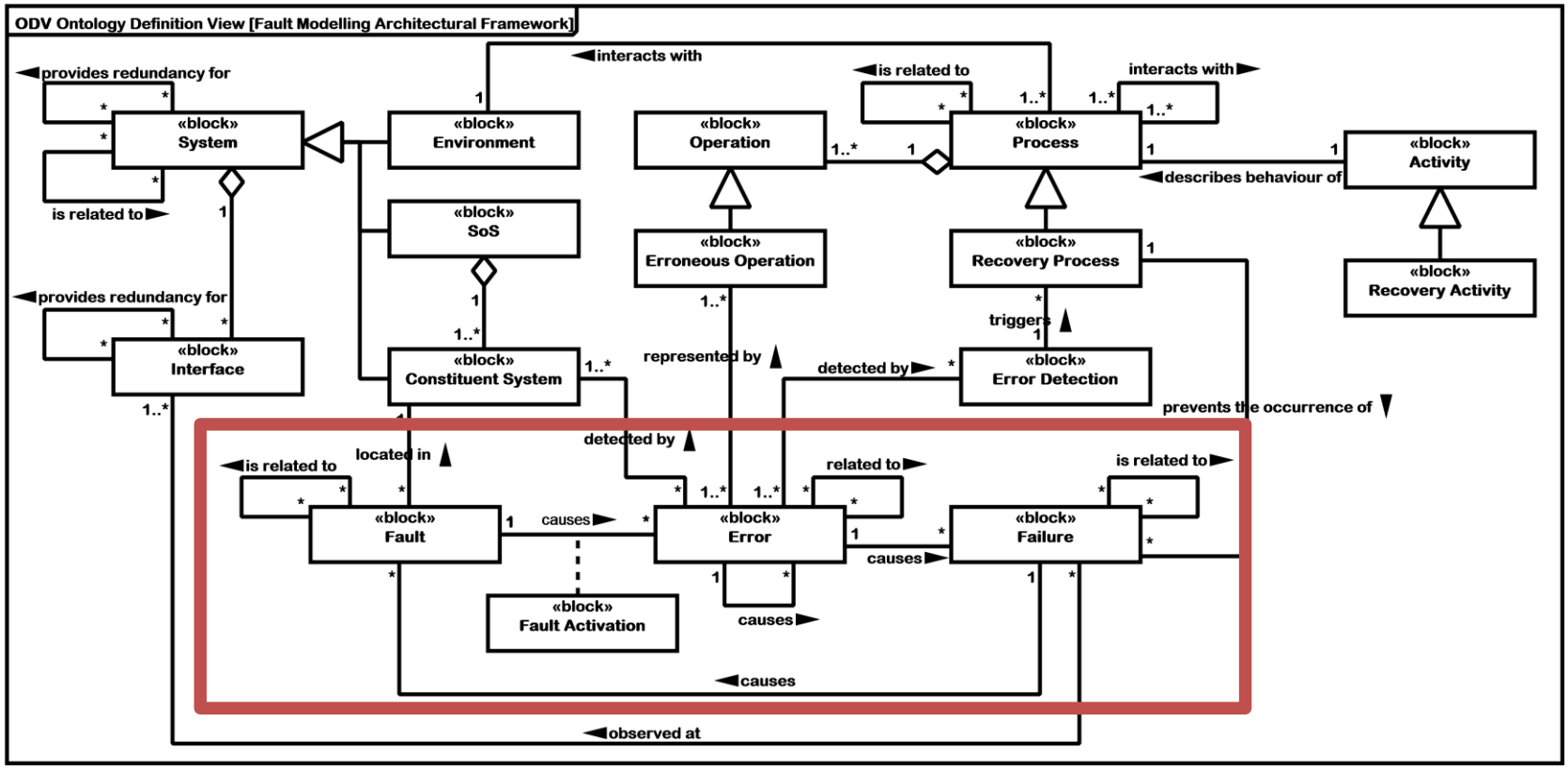

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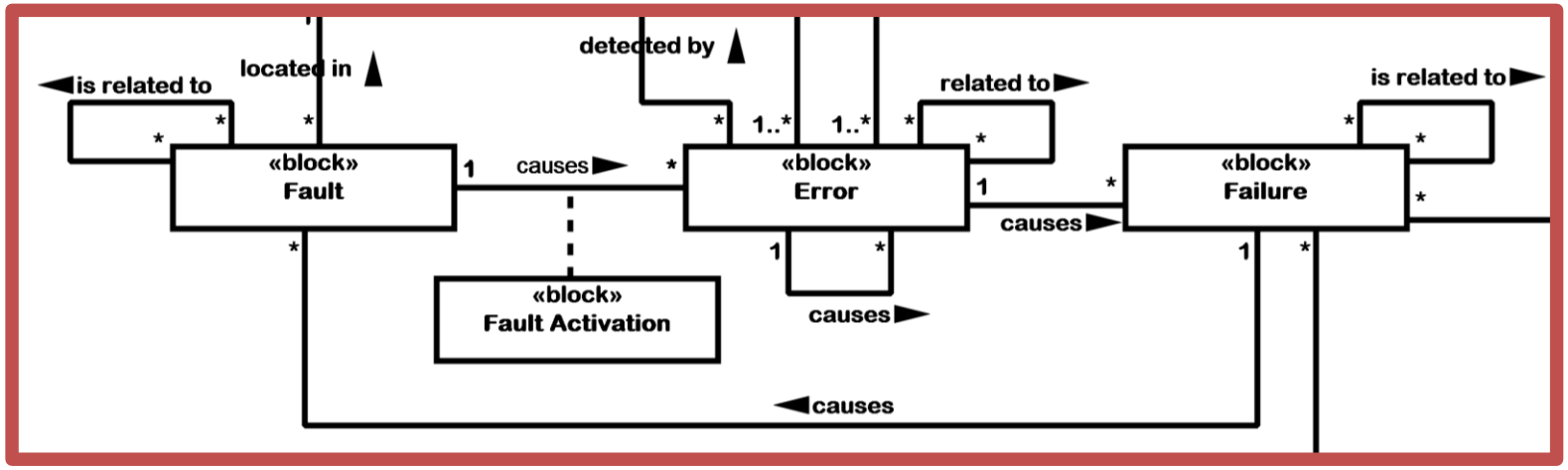

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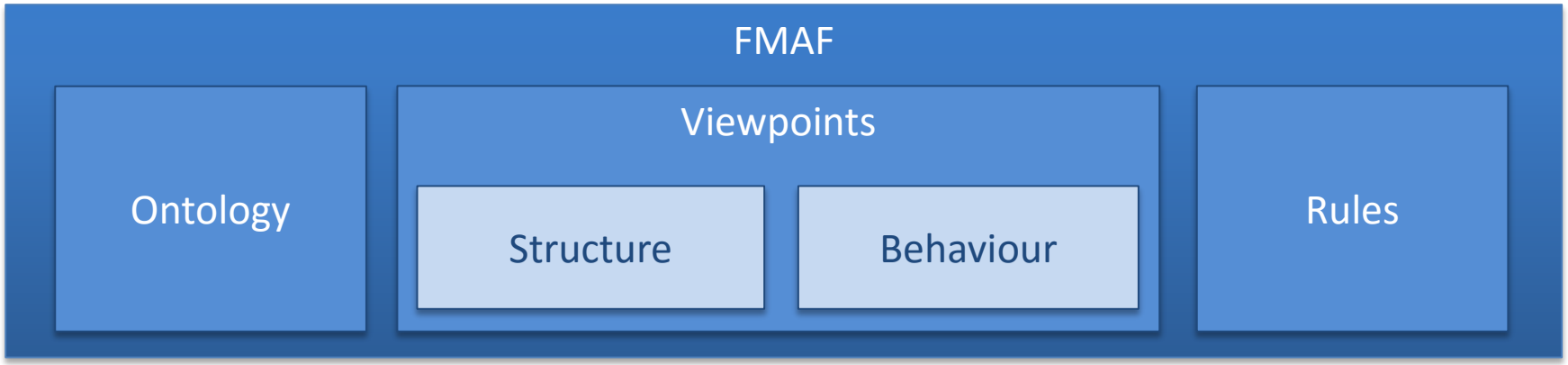
FMAF: Viewpoints



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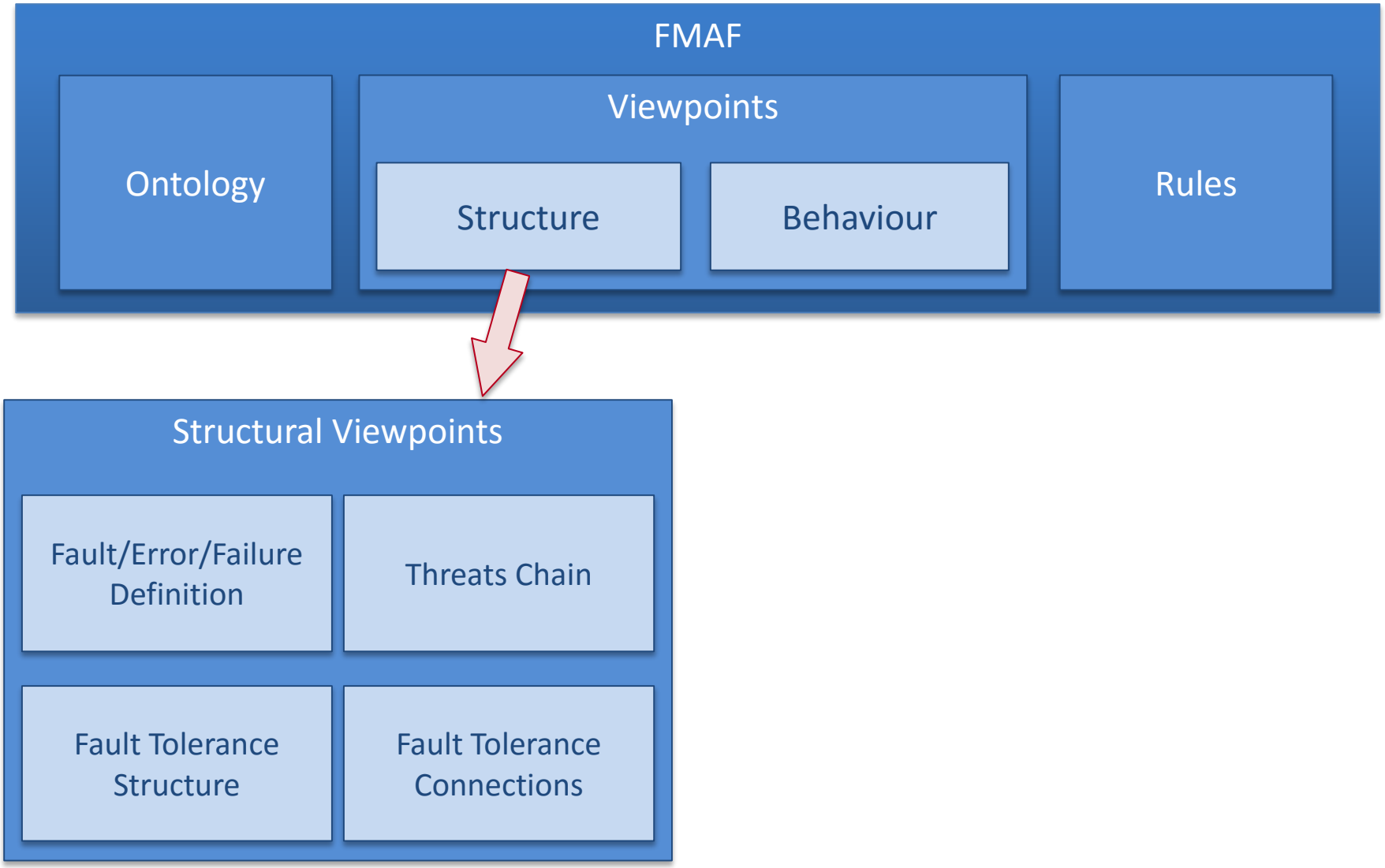

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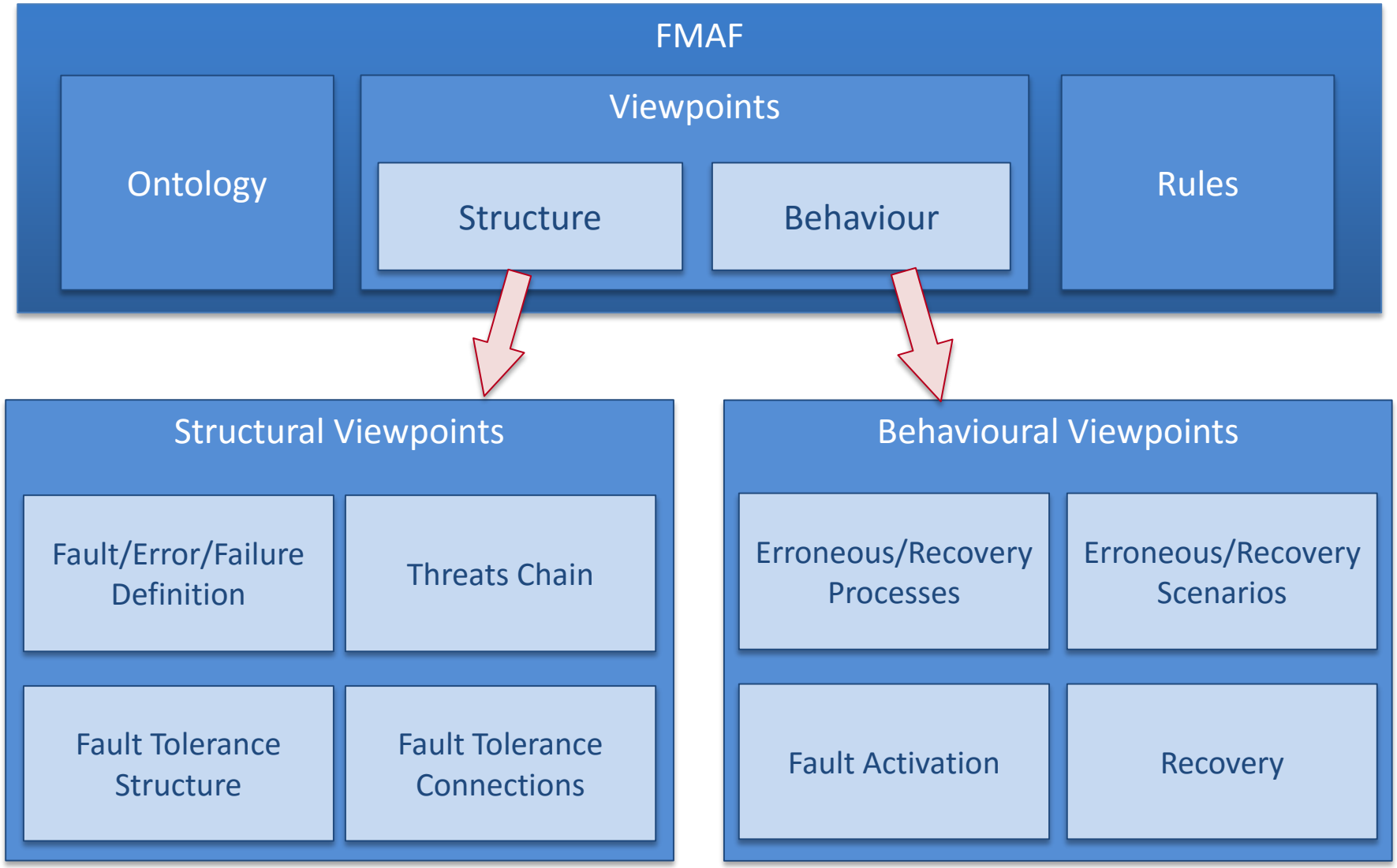

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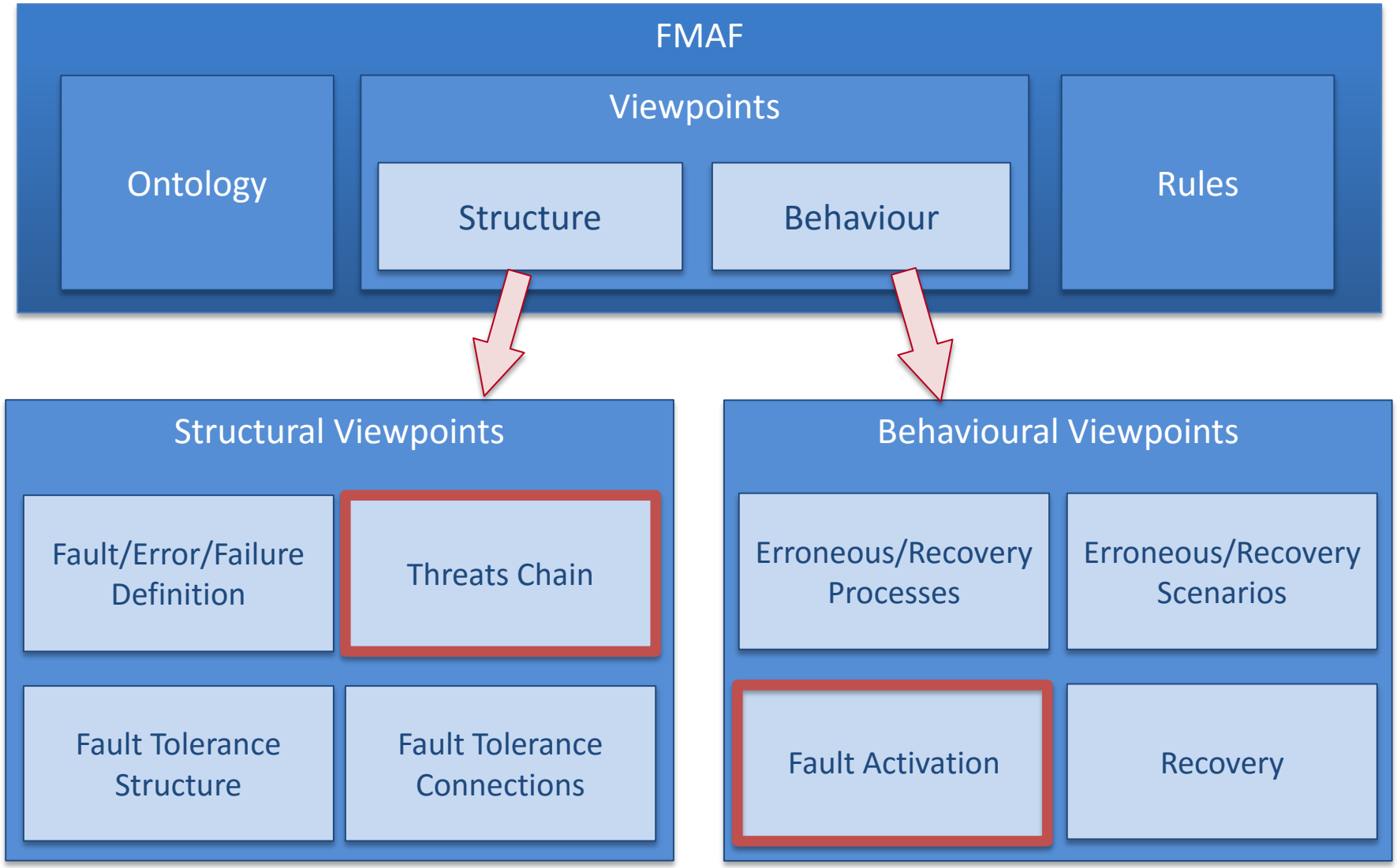
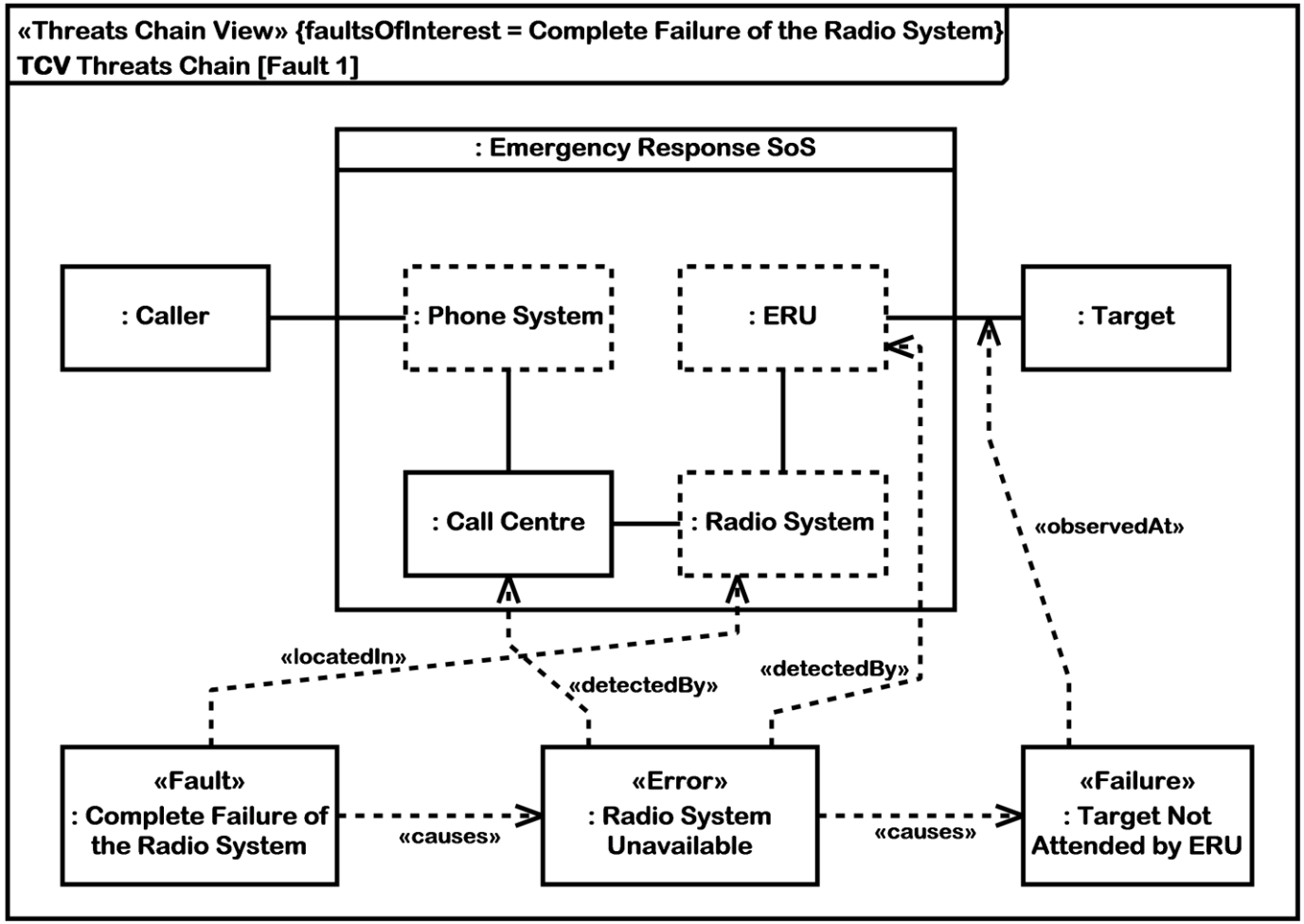


ER SoS: Threats Chain



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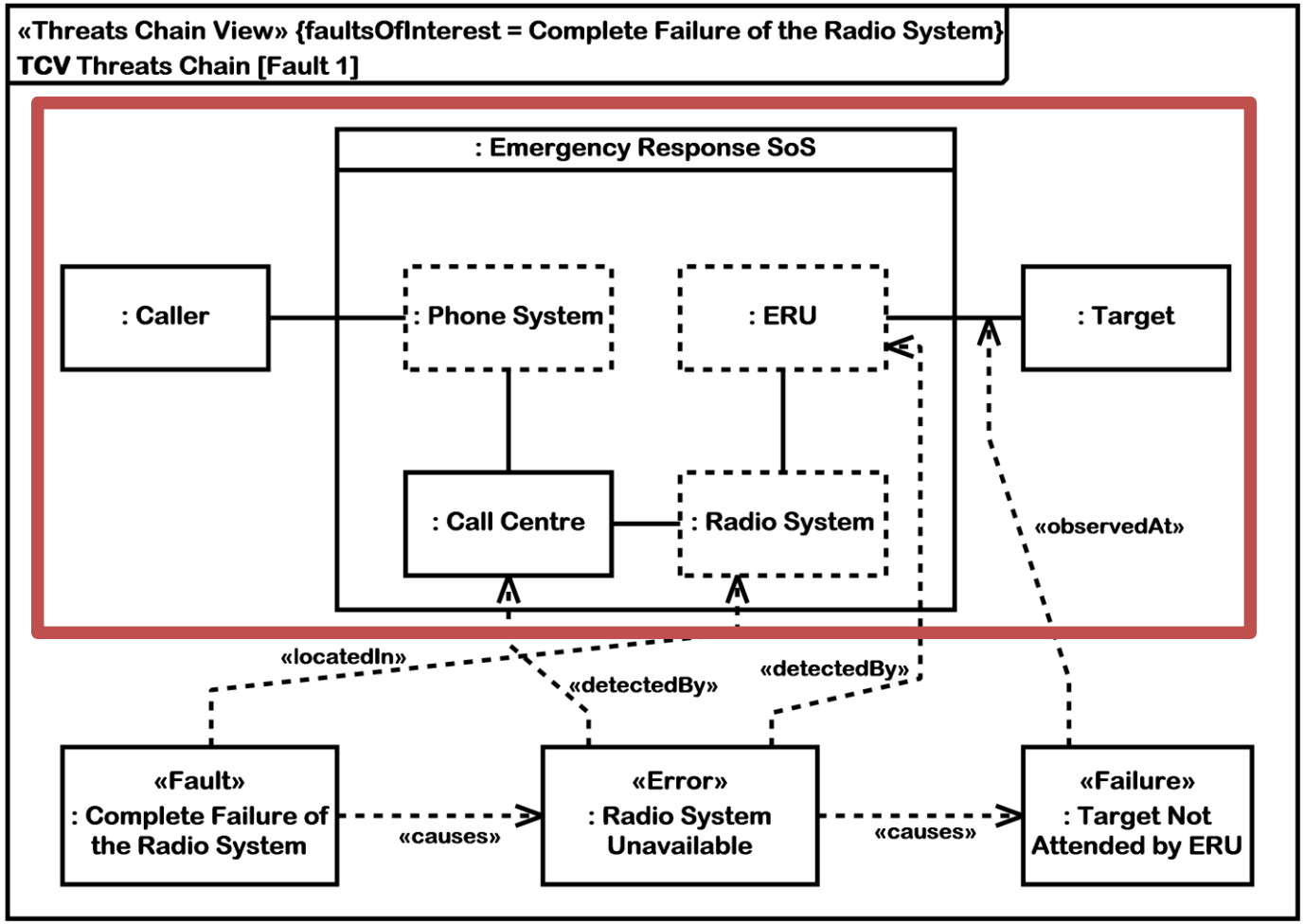

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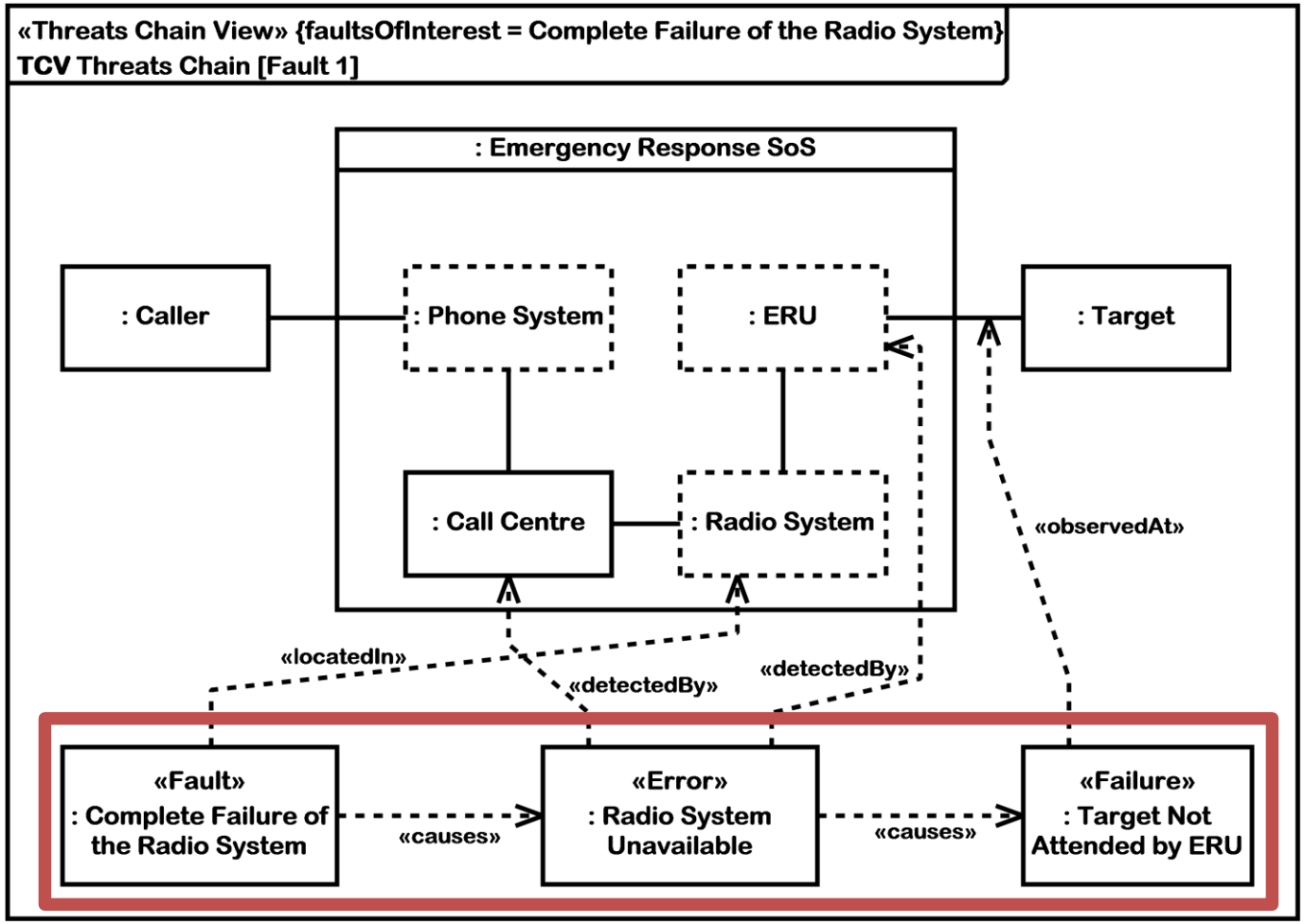
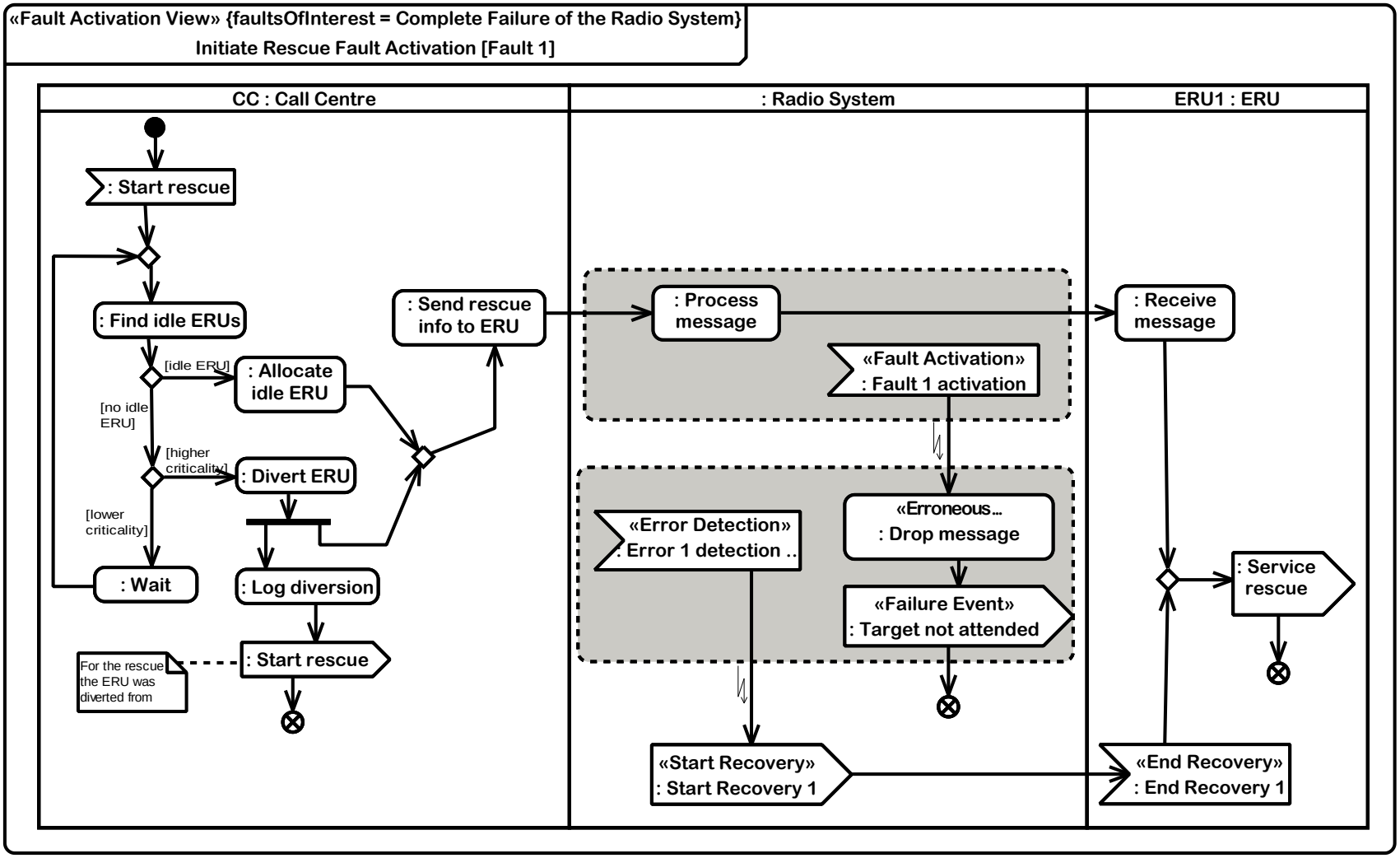


ER SoS: Fault Activation



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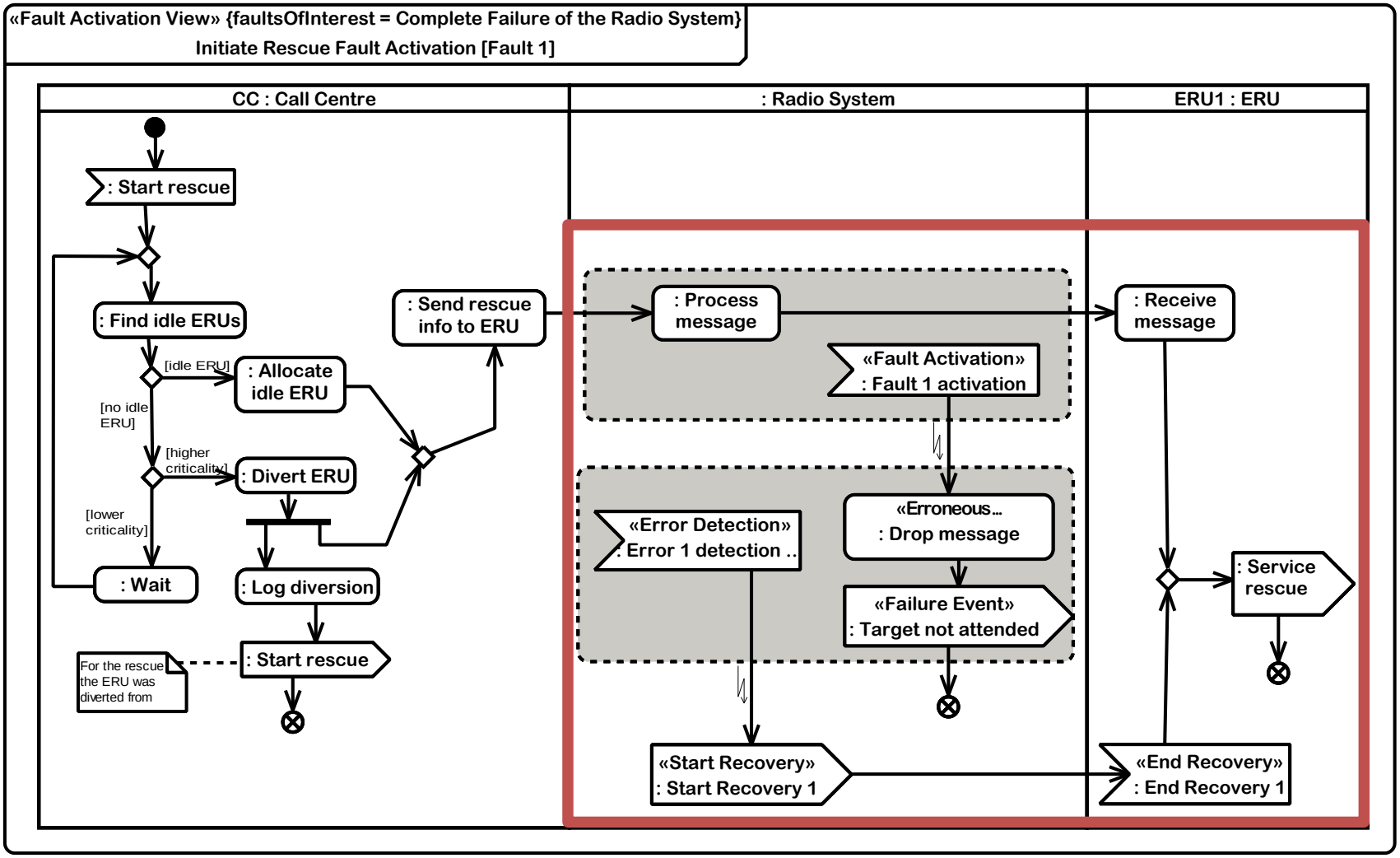

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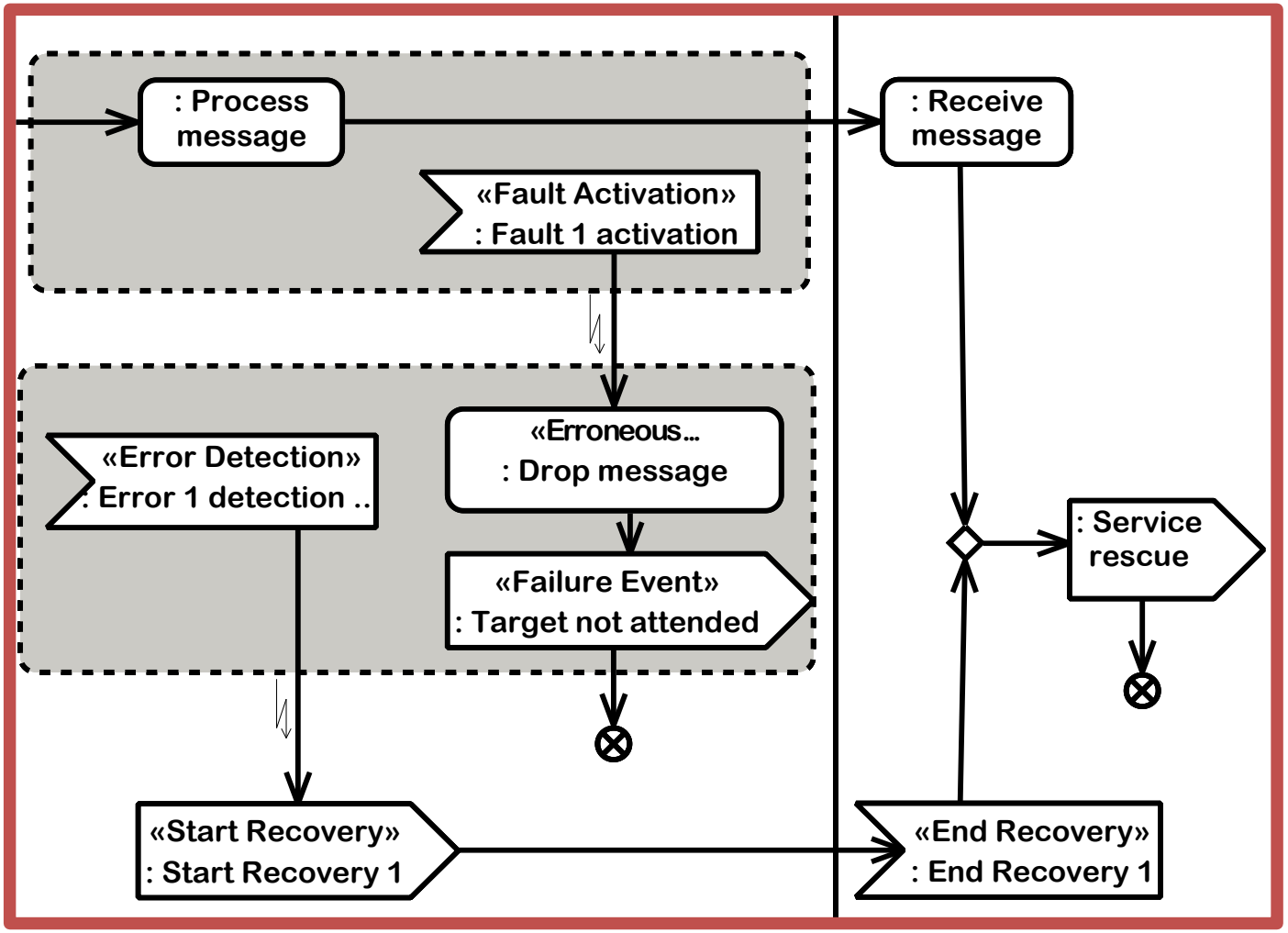
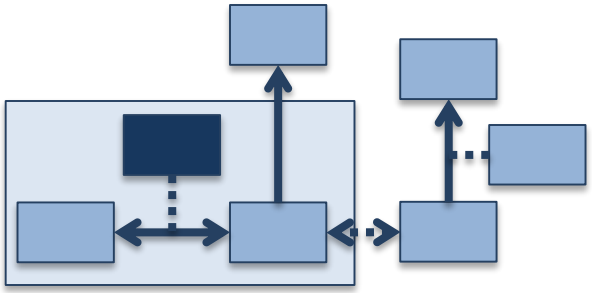
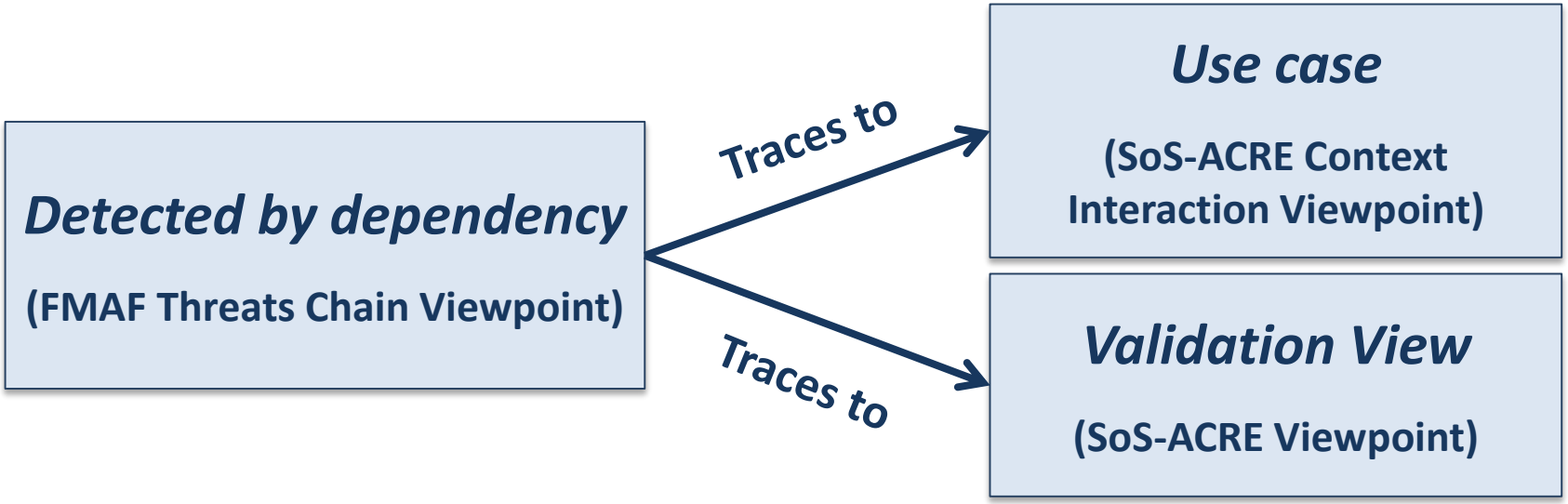


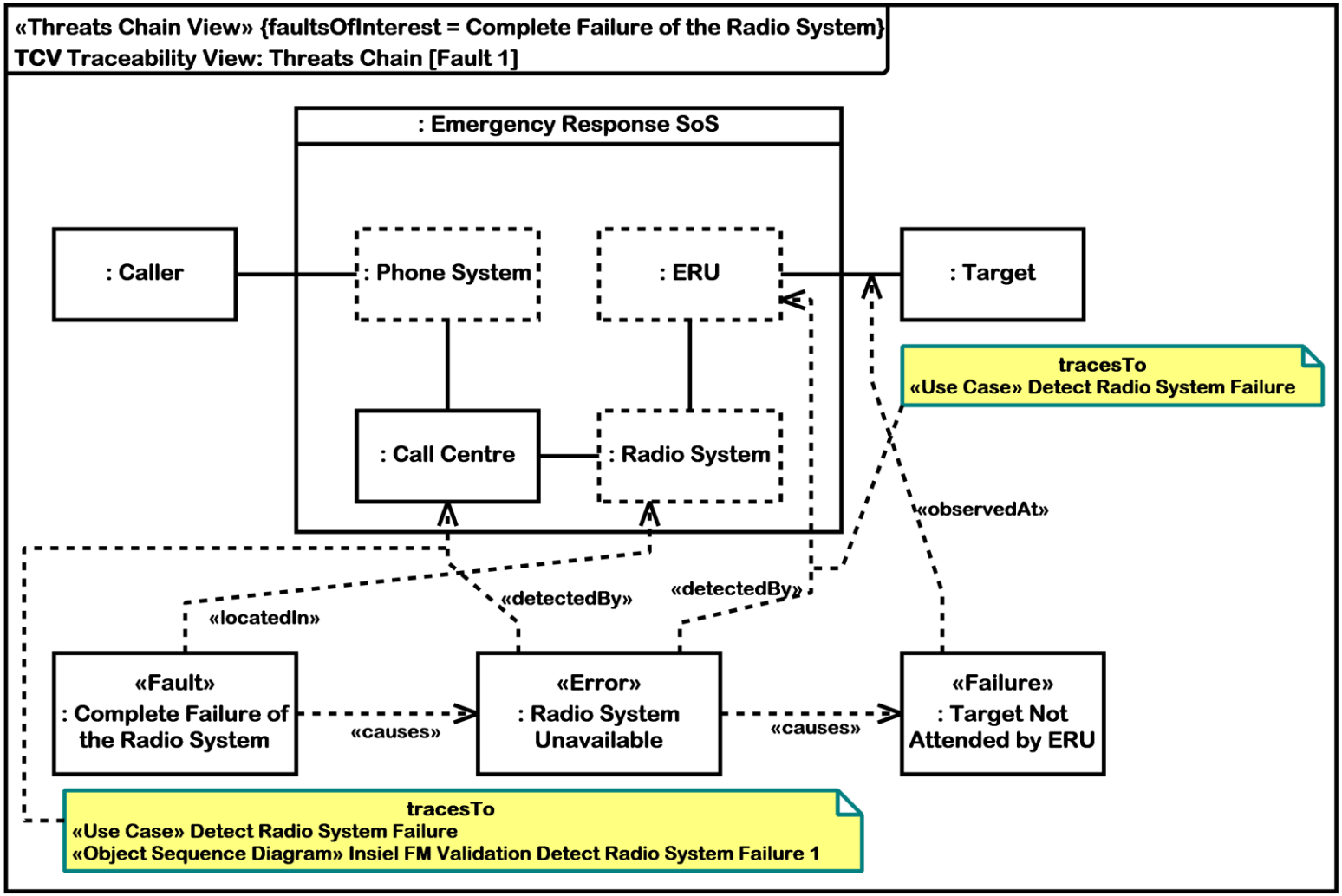
Requirements Tracing

- Traceability Pattern
  - a structured way of defining traceability
  - in this case we will use it for fault tolerance requirements traceability



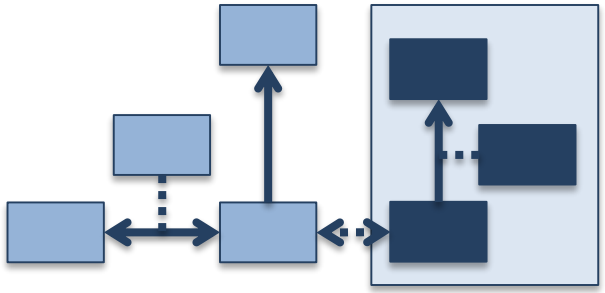


Requirements Tracing (ER SoS)



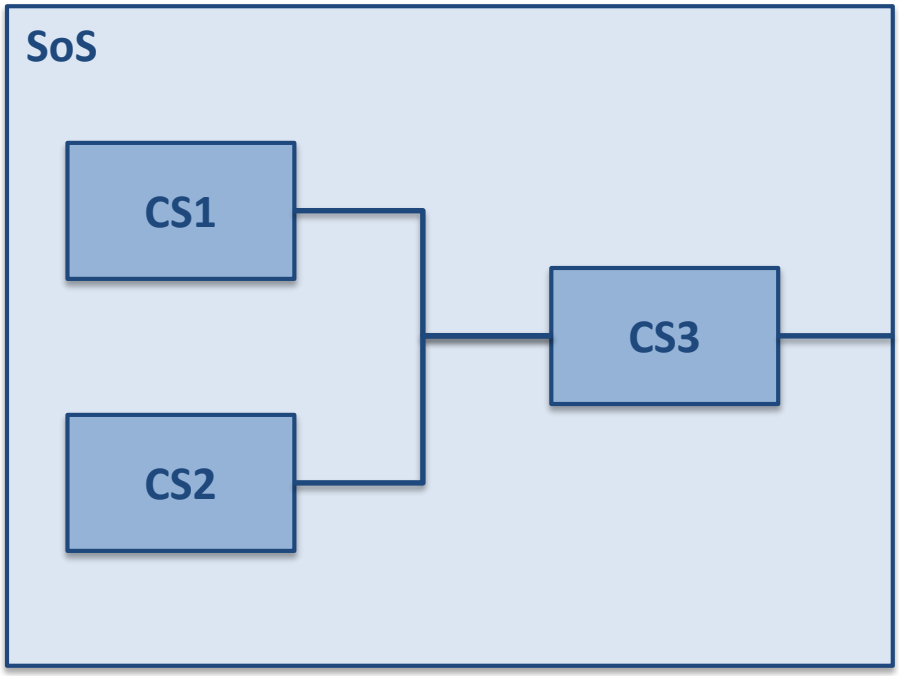
Fault Analysis

- Assists an SoS engineer in analysing the impact of CS/component level faults on SoS functionalities



- Provide modelling and tool support for static fault analysis
  - Fault Analysis Architectural Framework (FAAF) + SysML profile
  - 'Ergonomic profile' and translation tool for Atego Modeler
- Fault analysis capabilities provided by HiP-HOPS tool
  - Fault Tree Analysis
  - Failure Modes and Effects Analysis

Fault Analysis: Example



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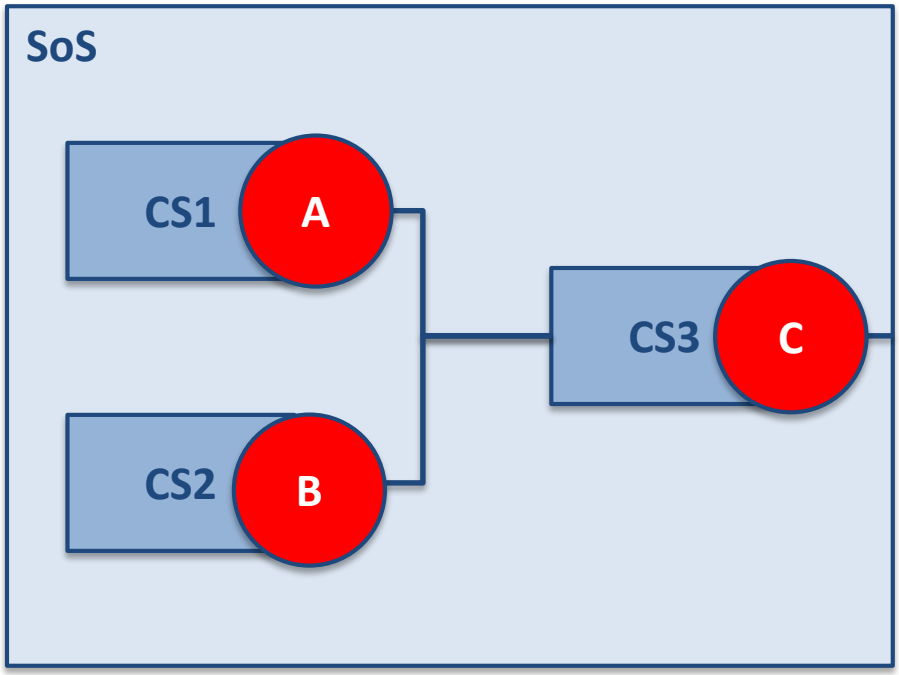

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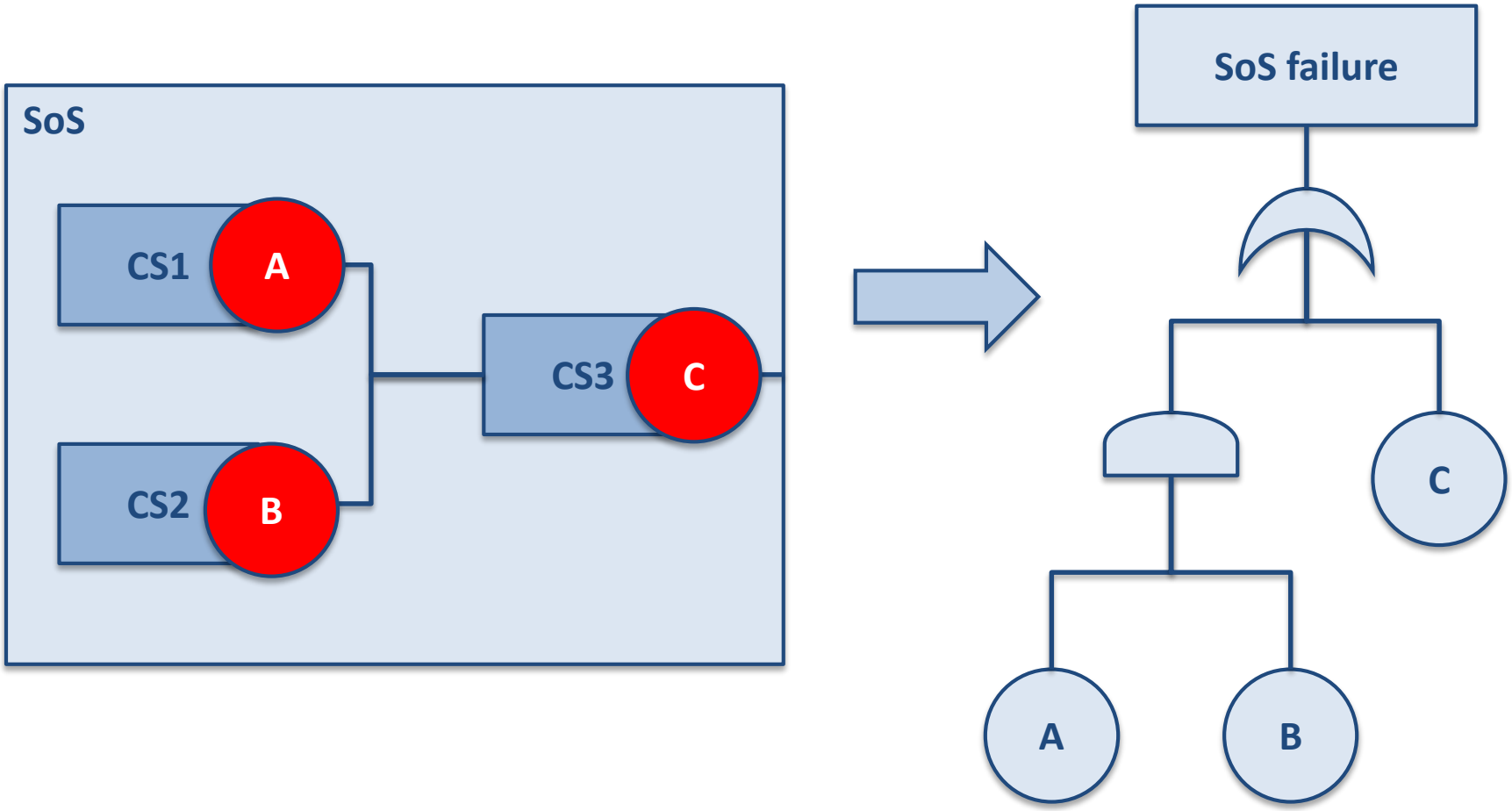
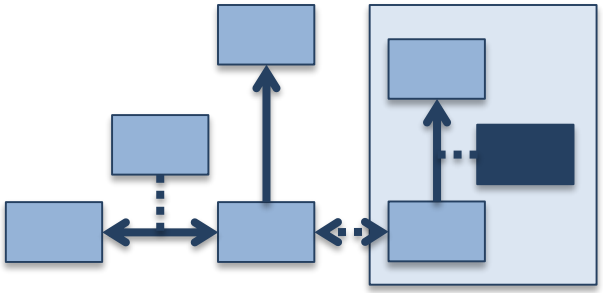
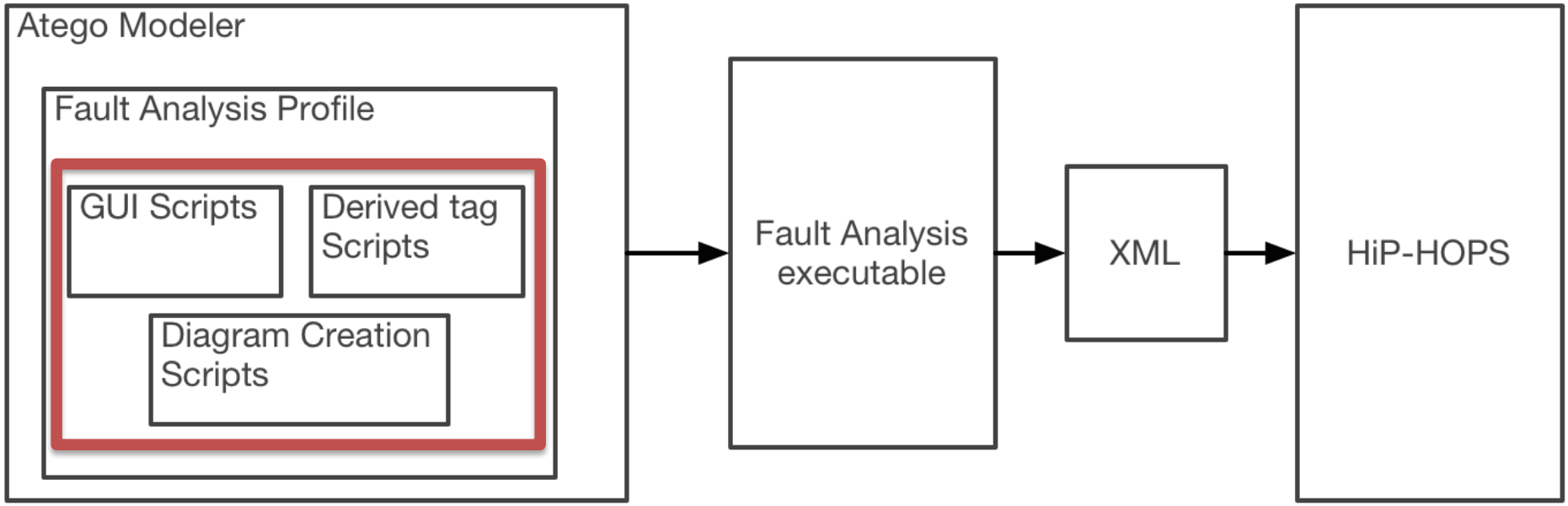


Tool Overview

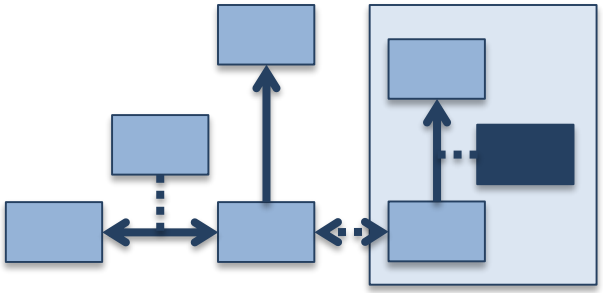
1. Ergonomic profiling

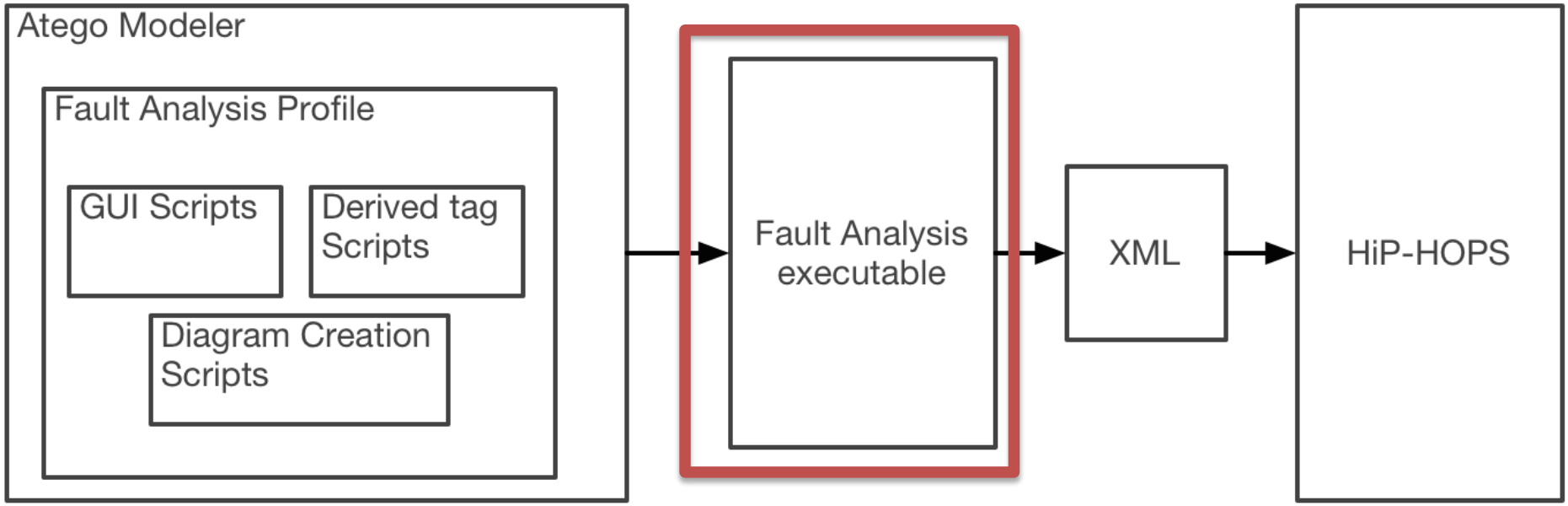




Tool Overview

1. Ergonomic profiling
2. **Exporting models for analysis**





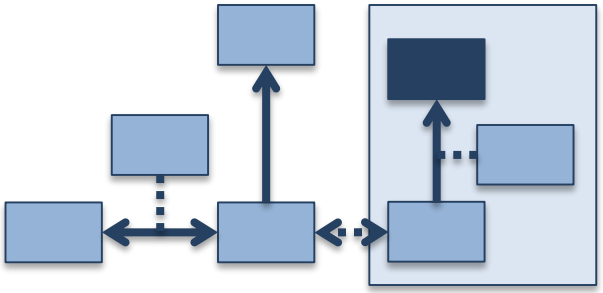
Fault Tree View: Value-Country_A_TMS.actOutA

FaultTrees | **FMEA**

Top Event (Effect)	Value-Country_A_TMS.actOutA
Description	N/A
System Unavailability	0.263319
Severity	0

Fault Trees | **Cut Sets**

- FaultTrees
  - Value-Country_A_TMS.actOutA
    - Value-Country_A_TMS.actOutA ()
      - Value-Country_A_TMS.actOutA (69)
        - Country_A_TMS.CountryA_CommsFailure (66)
        - Country_A_TMS.Country_A_Actuator_1.Actuator_Failure_A (91)
        - Country_A_TMS.Country_A_TCC.TCC_Failure_A (77)
        - Country_A_TMS.Country_A_Sensor_2.Sensor2_Failure_A (98)
        - Country_A_TMS.Country_A_Sensor_1.Sensor1_Failure_A (74)
        - Country_B_TMS.CountryB_CommsFailure (1)
        - Country_B_TMS.Country_B_TCC.TCC_Failure_B (11)
        - Country_B_TMS.Country_B_Sensor_1.Sensor1_Failure_B (5)
        - Country_A_TMS.Country_A_Actuator_2.Actuator_Failure_A (101)
        - Country_A_TMS.Country_A_Actuator_3.Actuator_Failure_A (108)
        - Country_A_TMS.Country_A_Actuator_4.Actuator_Failure_A (115)



Outline

- Introduction
- Engineering Fault-Tolerant SoSs
- **Conclusions**

Conclusions

Systems of systems have characteristics that motivate a structured approach to fault modelling and analysis of SoSs:

- Modelling support for requirements engineering, architectural design, requirements tracing of fault-tolerant SoSs
- Modelling and tool support for fault tolerance verification and static fault analysis

Future directions:

- Tool-supported integration of the fault modelling and fault analysis architectural frameworks and SysML profiles
- Support for modes of operation, either functional modes or degraded modes (e.g. partial functionality in presence of errors)
- Multi-objective optimisation, trading off attributes such as dependability, cost and energy consumption

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This work is part of the COMPASS project: research into model-based techniques for developing, maintaining and analysing SoSs

COMPASS

thecompassclub.org

http://sourceforge.net/projects/compassresearch/files/StaticFaultAnalysis/

Further Reading

- Andrews, Z.; Fitzgerald, J.; Payne, R. and Romanovsky, A. "Fault Modelling for Systems of Systems," in *Proceedings of the 11th International Symposium on Autonomous Decentralised Systems (ISADS 2013)*, March 2013, pp. 59–66.
- Andrews, Z.; Payne, R.; Romanovsky, A.; Didier, A. L. and Mota, A. 2013. "Model-based development of fault tolerant systems of systems" *in Proceedings of the* 2013 IEEE International Systems Conference (SysCon 2013).
- Ingram, C.; Riddle, S.; Fitzgerald J.; Al-Lawati, S.A.H.J.; Alrbaiyan, A., "SoS Fault Modelling at the Architectural Level in an Emergency Response Case Study" in Proceedings of the Workshop on Engineering Dependable Systems of Systems, 2014 (EDSoS 2014)
- Andrews, Z.; Ingram, C.; Payne, R.; Plat, N., SysML Fault Modelling in a Traffic Management System of Systems" in Proceedings of the 2014 IEEE International Systems of Systems Engineering Conference (SoSE 2014).
- Andrews, Z.; Ingram, C.; Payne, R.; Romanovsky, A.; Perry, S. & Holt, J., Traceable Engineering of Fault-Tolerant SoSs, *in* "International INCOSE Symposium, Las Vegas, USA", June-July 2014.

- COMPASS Deliverables D24.2, D33.3 and D43.3: http://www.compass-research.eu/
- Fault Analysis Tool: http://sourceforge.net/projects/compassresearch/files/StaticFaultAnalysis/

- Atego Modeler: http://www.atego.com/products/atego-modeler/
- HiP-HOPS: http://hip-hops.eu/