Requirements Engineering for Cyber-Physical Systems with the Architecture-Led Incremental System Assurance approach and AADL

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Outline

- AADL
- ALISA Overview
- ALISA Sub-Languages
- Experience Report on Railway Domain
- Conclusion and Perspectives

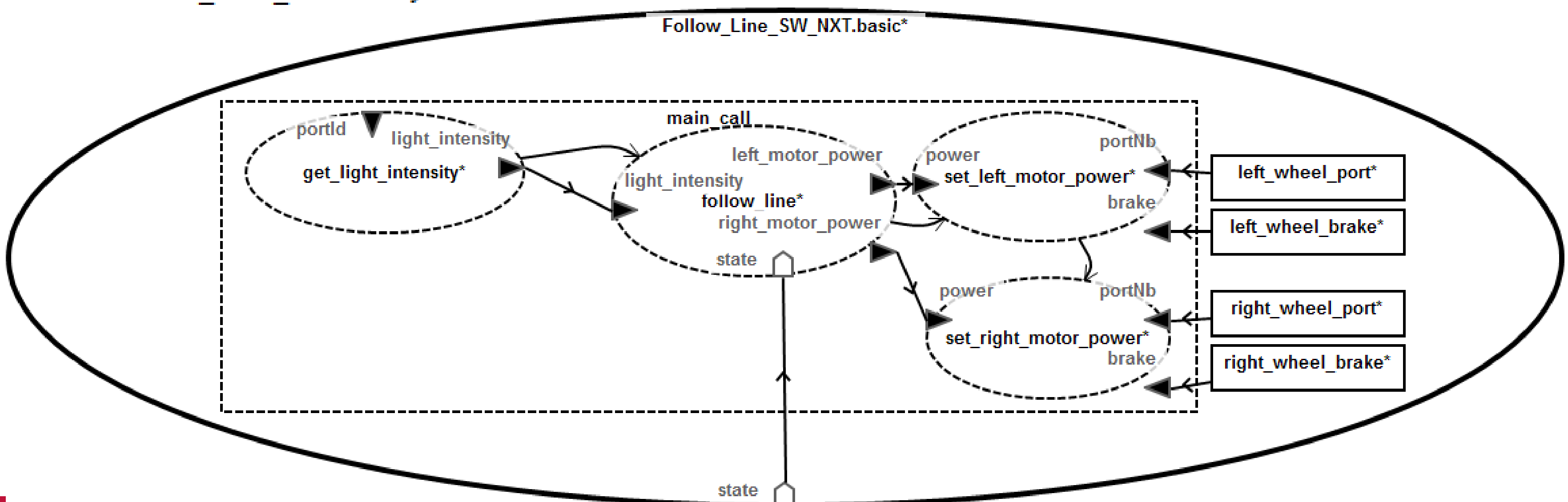
SAE AADL (Architecture Analysis & Design Language)

- **Modeling Language for Safety-Critical Systems**
- **Analysis of properties such as:**
  - Timing, safety, schedulability, fault tolerance, security, functional simulation...
- **Automatic code generation**
- **Component-based, hierarchical**
- **Several mechanism for specifying component libraries**
  - Separation interface and implementation declarations
  - Component extension / refinement

Textual and Graphical Notations

```
subprogram Follow_Line_SW extends Line_Follower_Functions::Follow_Line
    features
        light_intensity: refined to in parameter Light_Intensity_SW;
        left_motor_power: refined to out parameter Power_SW;
        right_motor_power: refined to out parameter Power_SW;
        state: refined to requires data access Robot_State_SW;
    properties
        Classifier_Substitution_Rule => Type_Extension;
end Follow_Line_SW;

subprogram implementation Follow_Line_SW.basic extends Line_Follower_Functions::Follow_Line.basic
    subcomponents
        compute_turn_angle: refined to subprogram Compute_Turn_Angle_SW.pid;
        compute_wheels_motors_power: refined to subprogram Compute_Wheels_Motors_Power_SW.basic;
end Follow_Line_SW.basic;
```



Extensibility and Tools

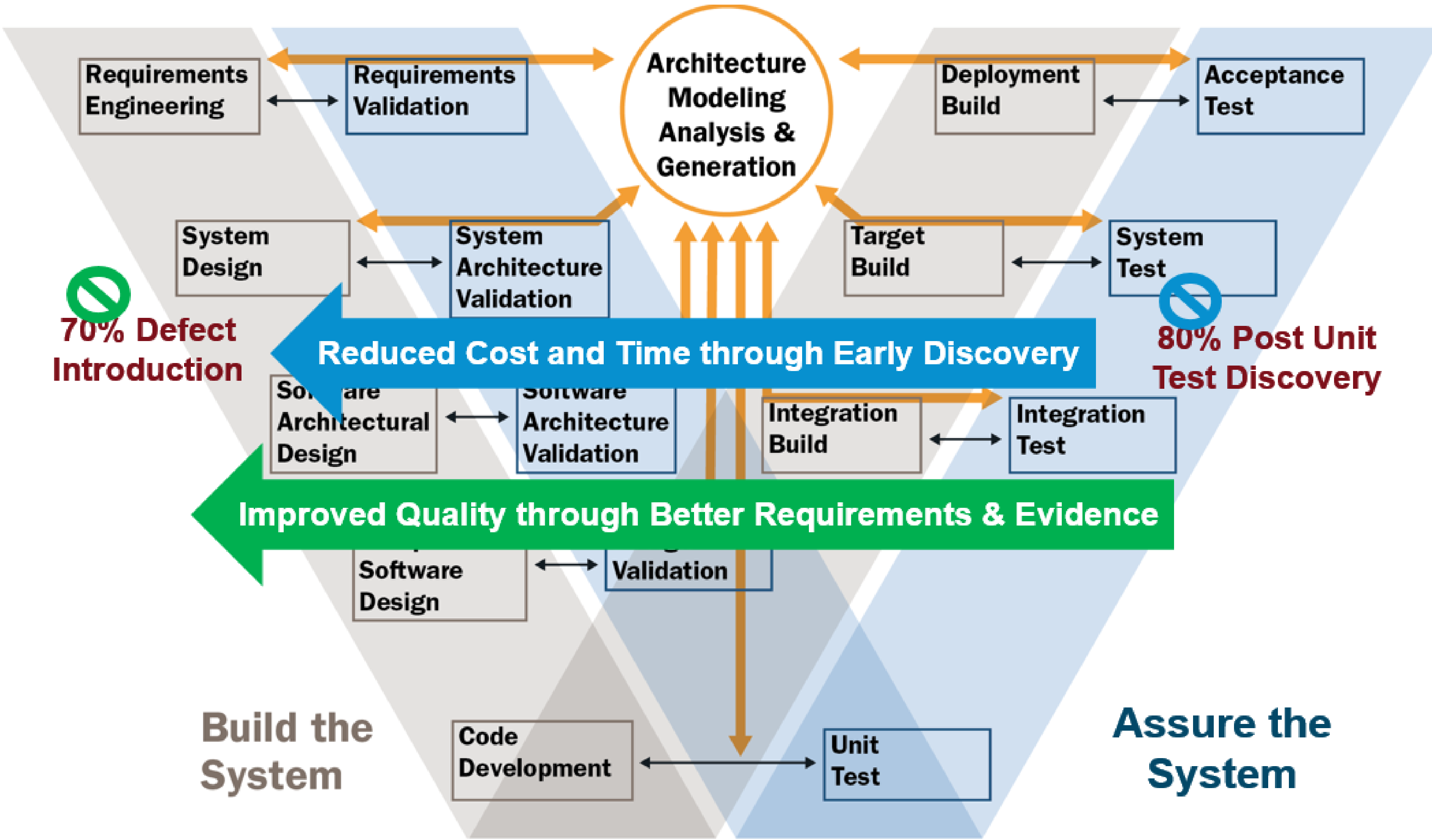
Extensible

- Via user-defined properties and component classifiers
- Standardized annexes (Behavior, Error, Assurance (ALISA))

Ecosystem of tools

- OSATE (reference language implementation)
- Behavior Annex front end
- RAMSES (Refinement of AADL Models for the Synthesis of Embedded Systems)
- Ocarina (code generation)
- Cheddar (Scheduling analysis)
- ALISA framework

ACVIP (Architecture-Centric Virtual Integration Process)



Source: McGregor, Gluch, and Feiler, *Analysis and Design of Safety-critical, Cyber-physical Systems*, 2017.

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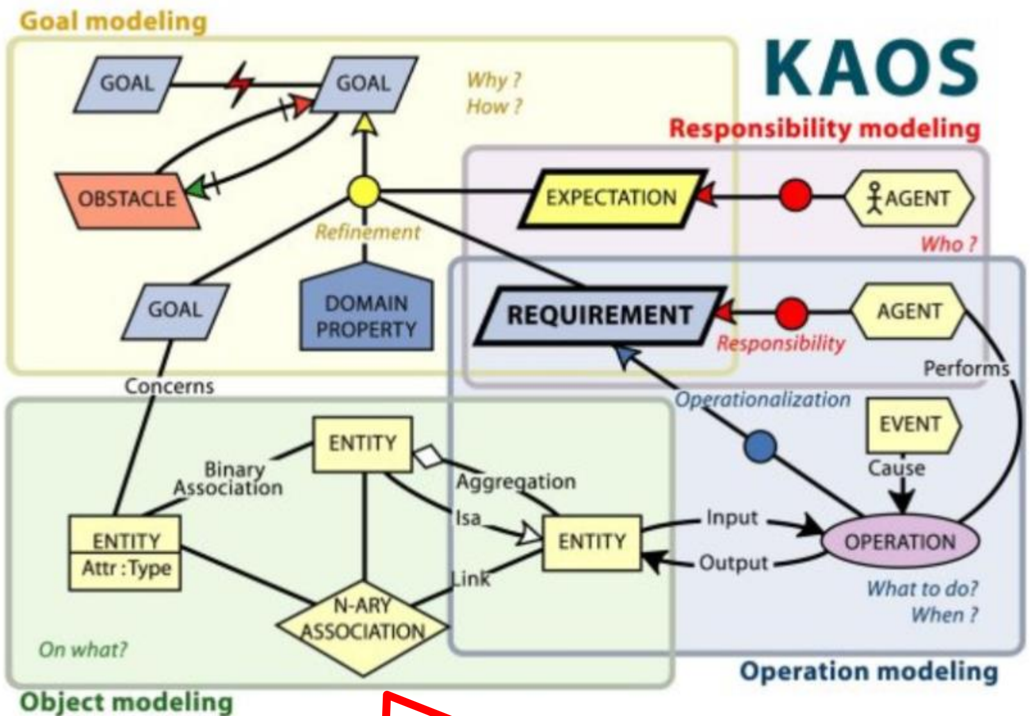
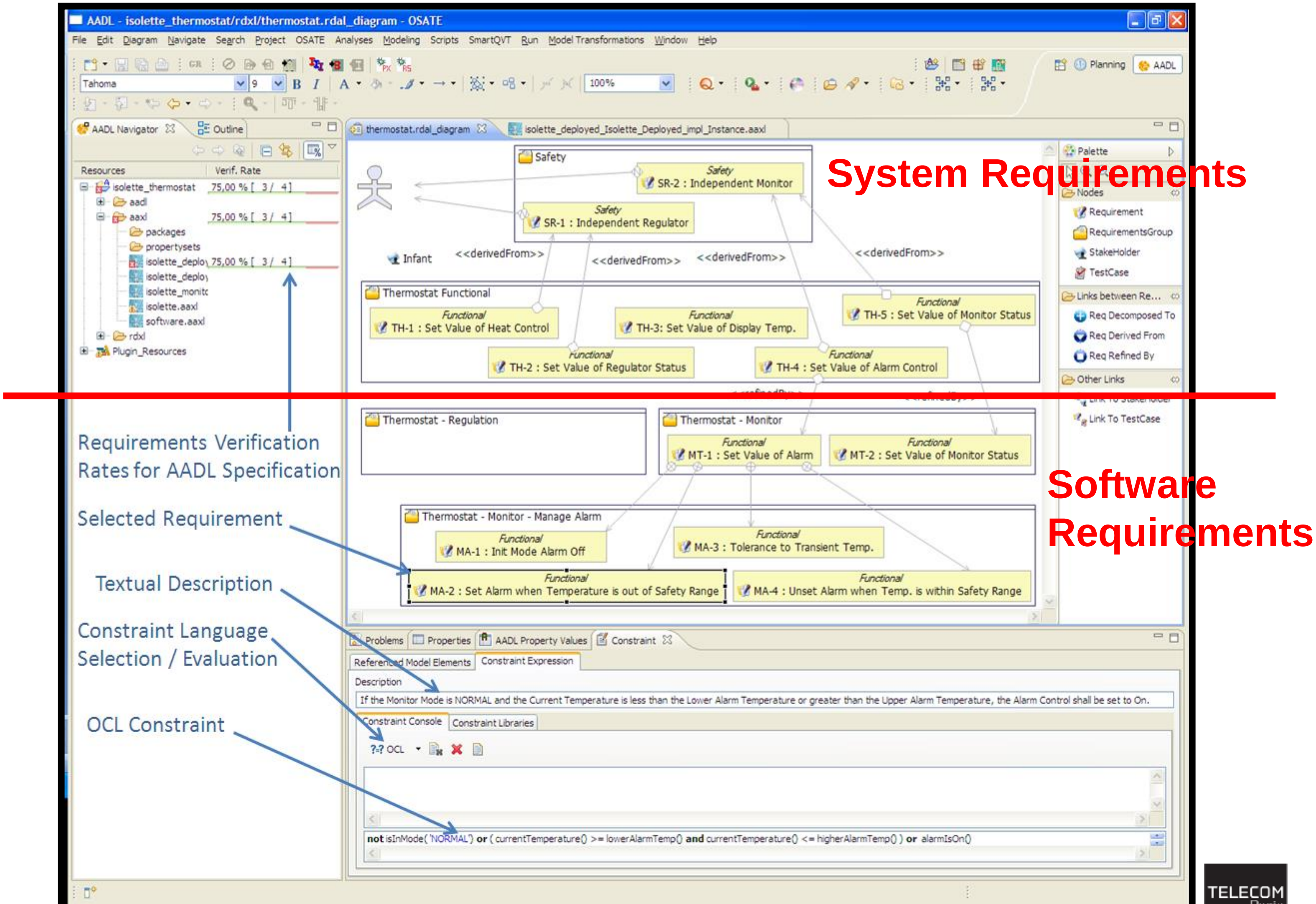
First Inspiration: Goal-Oriented Requirements Engineering (GORE)

- **4 complementary and interrelated views on the system:**
  - Goals (owners, users, business managers, regulations, etc.)
  - Responsible agents
    - Human and automated
    - System or environment
  - Problem domain
    - Concepts and their relationships
  - Behaviors
    - In order to achieve goals



Missing Domain-Specific Vocabulary

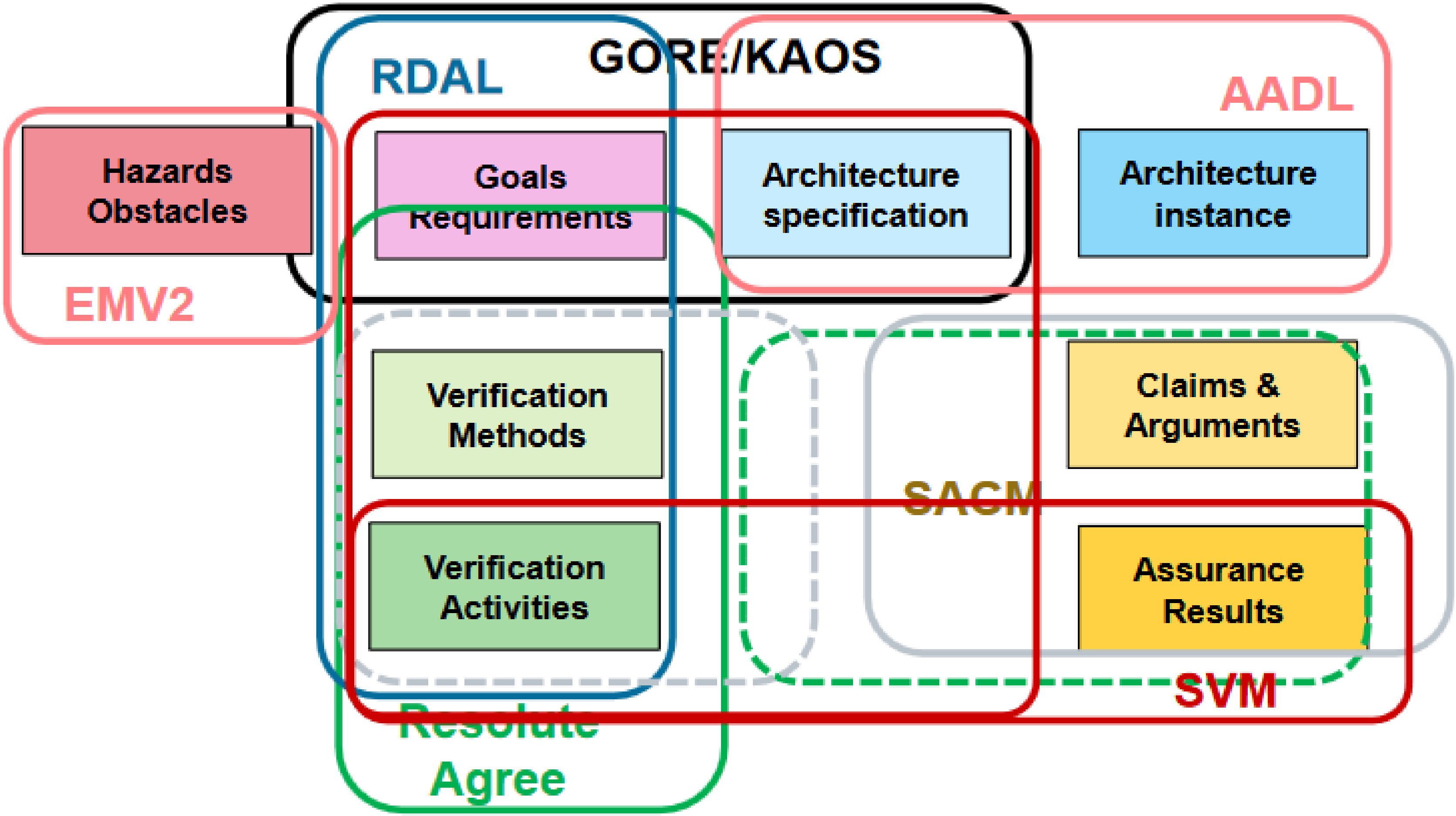
RDAL (Requirements Definition and Analysis Language) coupled with AADL



ALISA (Architecture-Led Incremental System Assurance)

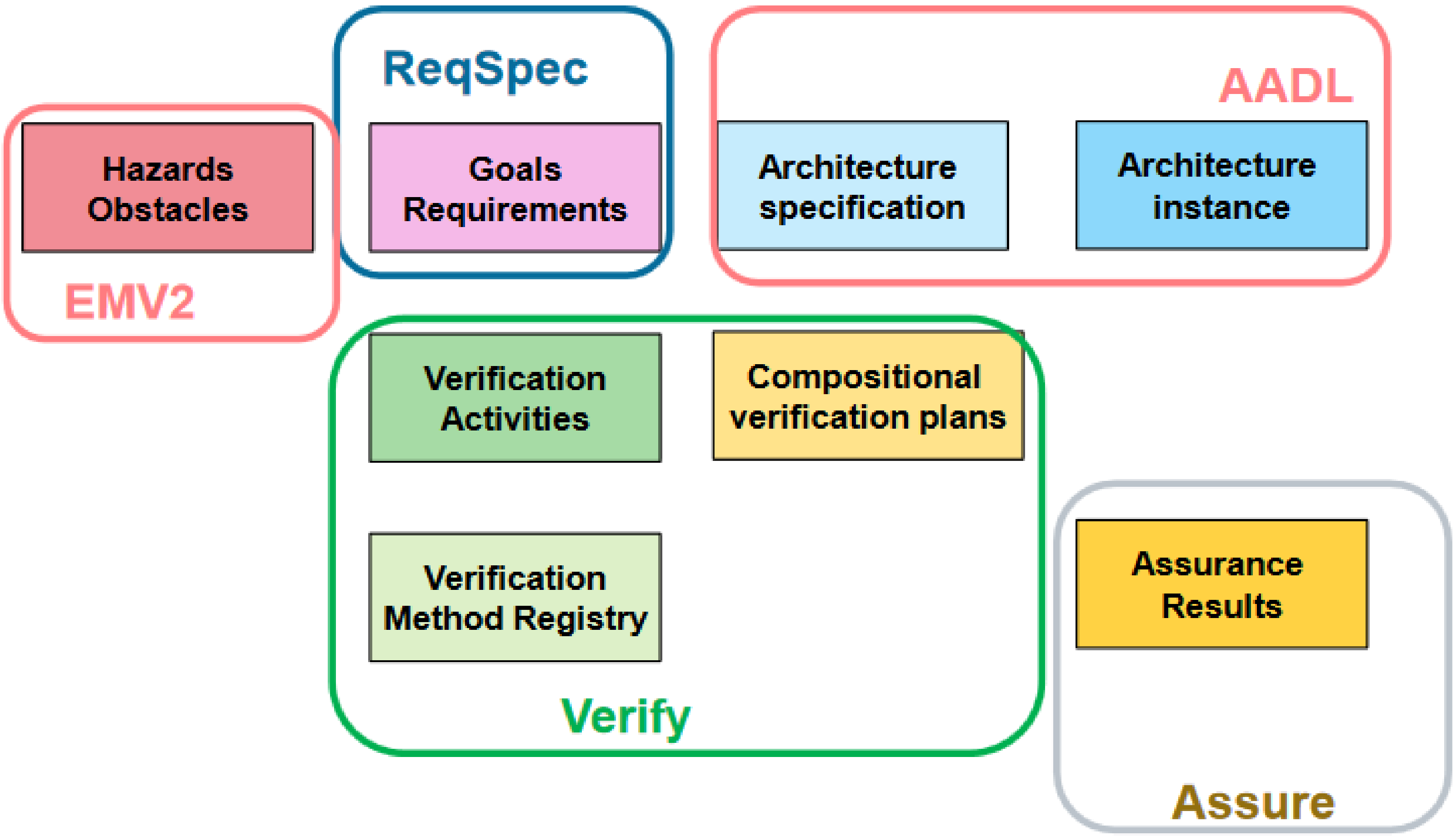
- Reimplementation of RDAL by SEI (Peter Feiler)
- Grammar based like AADL / OSATE
- Strongly coupled with AADL (extension of AADL grammar)
- Development of verification activity concepts
- Added assurance case modeling
- Link with error model annex (*mitigates* construct)

Languages and Concepts Basis for ALISA



Source: Peter Feiler, *ALISA Tutorial*, 2018.

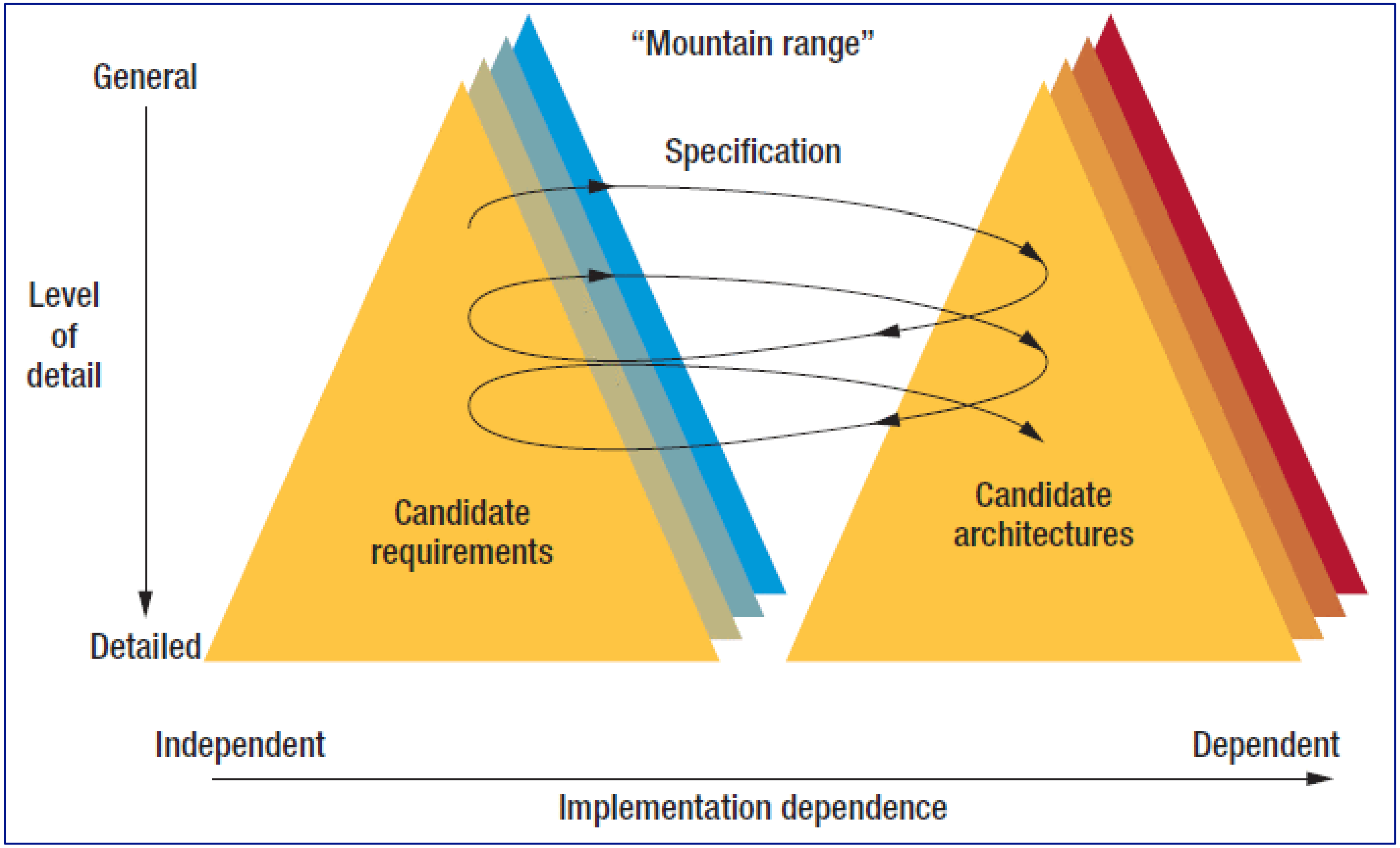
ALISA Unified Concepts



Source: Peter Feiler, *ALISA Tutorial*, 2018.

ALISA Incremental Process (Architecture-Led Incremental System Assurance)

- **Requirements and architecture "Twin Peaks" model**



Source Cleland-Huang et al., *The Twin Peaks of Requirements and Architecture*, IEEE Software, 2013

ALISA Sub-Languages

- **Organization**: Defines the stakeholders of a project
- **ReqSpec: Stakeholder goals, system requirements**
  - Architecture-led
  - Verifiable
  - Coverage and uncertainty
- **Verify: Verification plans of verification activities**
  - Reasoning on how verification activities satisfy requirement
  - Verification methods (manual, automated)
  - Assumptions, preconditions on verification method
- **Alisa: Composition of verification plans into assurance cases**
  - Verification of AADL model artifacts across system architecture
  - Assurance tasks as filtered views of assurance plans
- **Assure: Manage assurance case instance execution and results**
  - Multi-valued logic evaluation of verification action & results
  - Acceptable risk factors (e.g., design assurance levels)
  - Filtered execution of assurance plans (based on category tags)

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ReqSpec: Stakeholder Goals

```
stakeholder goals Line_Follower_Robot_Perf for Line_Follower_Robot_Cps::Line_Follower_Robot_Cps [

    goal G_Perf_1 : "Minimal Cost" [
        description "The cost of producing the robot should be minimal."
        stakeholder Tartempion_Warehouse_Equipments_Ltd.Customer Tartempion_Warehouse_Equipments_Ltd.Marketing
        rationale "The robot should be cheap so that it is competitive on the market."
        category Quality.Cost
    ]

    goal G_Perf_2 : "Minimal_Transportation_Time" [
        description "The time taken to carry objects should be minimal."
        stakeholder Tartempion_Warehouse_Equipments_Ltd.Customer Tartempion_Warehouse_Equipments_Ltd.Customer
        rationale "The robot should be fast to meet the needs of customers."
        category Quality.Performance
    ]
]
```

ReqSpec: Requirements

- **Decomposition: reference(s) to requirements of an enclosing system that this requirement is derived from**

```
requirement R_Behav_1 : "Carry_Object_Function" [
    description
        "The robot shall carry an object between two specified points by following a predefined trajectory in the warehouse."
    see goal Line_Follower_Robot_Behavior.G_Behav_1
    category Quality.Behavior
]

    requirement R_Behav_1_1 : "Pick_Up_Object_Function" for pick_up_object [
        description "At the beginning of the path, the robot shall pick up an object on the floor."
        category Quality.Behavior
        decomposes R_Behav_1
    ]

    requirement R_Behav_1_2 : "Follow_Line_Function" for follow_line [
        description "The robot shall follow a line on the floor of the warehouse."
        category Quality.Behavior
        decomposes R_Behav_1
    ]
```

- **Refinement: provides a more detailed specification for the same system. Requirements are refined until they become verifiable.**

```
requirement ETCS_OB01_evc_2oo3_design_redundancy : "All CPUs of the EVC shall execute the same functions" [
  refines ETCS_OB01_evc_2oo3_design
  category Quality.Safety
]
```

ReqSpec: Verifiable Requirements

Via predicate

```
requirement ERA_5_2_1_1_evc : "EVC response time" for message_processing_flow [

   decomposes ERA_5_2_1_1

   compute SystemOperationMode: string
   compute MinLatency : Time
   compute MaxLatency : Time
   val MaxLatencyInMs : real = (MaxLatency%us / (1 us)) / 1000
   val PipelinePeriod : real = (#Middleware_Properties::Default_Hyper_Period%us / (1 us)) / 1000
   description "Delay between reception of an input data message and output command dispatch."
   "Delay shall be < " MaxEVCResponseTime
   value predicate MaxLatency < MaxEVCResponseTime
   category Quality.Latency
]
```

Via verification activity

```
requirement ETCS_OB01_evc_2oo3_design_redundancy : "All CPUs of the EVC shall execute the same functions" [
   refines ETCS_OB01_evc_2oo3_design
   category Quality.Safety
]
claim ETCS_OB01_evc_2oo3_design_redundancy [
   activities
   redundancy : Resolute.allFunctionsAreRedounded ( )
]
```

ReqSpec: Verifiable Environmental Assumptions

Requirements that constrain the environment of the system

```
system requirements Line_Follower_Robot_Env_Assumptions for Line_Follower_Robot::Warehouse_Robots.normal [

    requirement EA_1: "Minimum Warehouse Luminosity" for light_source [
        description "The power of the light source shall not be less than the Minimum Illuminance value"
        rationale "Otherwise the light sensor of the robot will not be able to give proper readings given its sensitivi
        category Kind.Assumption
        val Minimum_Illuminance = 100.0 lx
        value predicate #Physics_Properties::Illuminance >= Minimum_Illuminance
    ]

    requirement EA_2: "Minimum Curvature Radius" for line [
        description "The curvature radius of the line to be followed by the robot shall not be lower than TODO"
        rationale "Otherwise the robot given its speed, mass and response time will not be able to follow the line."
        category Kind.Assumption
        val Minimum_Curvature_Radius = 100.0 mm
        value predicate #Physics_Properties::Curvature_Radius >= Minimum_Curvature_Radius
    ]
]
```

Organization of requirements:

- Requirements and goals can be declared into sets (packages)
- Global sets can be declared that can be reused across systems

Verify: Methods and Registry

- **Reusable verification methods on models and other artifacts**
  - OSATE Analysis plugins, Java methods, Python Scripts, Resolute claim functions, Junit-based code tests

```
verification methods KPIs [
    method Save(component, value: real): "Save a KPI, name and value" [
        java fr.irt_systemx.pst.alisa.kpi.Persistence.save(double value)
        description "Save a KPI, name and value"
    ]

    method Compute(component, value: real) returns (value: real): "Compute a KPI" [
        java fr.irt_systemx.pst.alisa.kpi.Persistence.compute(double value)
        description "Compute a KPI"
    ]
```

```
verification methods Resolute [

    method allFunctionsAreRedounded ( ) : "Functions shall be redounded" [
        description "Check that all functions running on the CCP2 are the same" resolute
                Middleware_2oo3.Design_2oo3_Verification.Middleware_2oo3.Design_2oo3_Verification_publi
    ]

    method cpusAreOfSameType ( ) : "CPUs shall be of same type" [
        description "Check that CPUs are of same type" resolute
                Middleware_2oo3.Design_2oo3_Verification.Middleware_2oo3.Design_2oo3_Verification_publi
    ]
```

Verify: Verification Plans

- Made of claims aligned with system requirements
  - Contain verification activities invoking verification methods of registry

```
verification plan ETCS_OnBoard_Safety_Verification for ETCS_OnBoard_Safety_Requirements [

    claim ETCS_OB01 [
        activities
        persistence: KPIs.Save(kpi)
    ]

    claim ETCS_OB01_evc [
        claim ETCS_OB01_evc_2oo3_design [
            claim ETCS_OB01_evc_2oo3_design_redundancy [
                activities
                redundancy : Resolute.allFunctionsAreRedounded ( )
            ]

            claim ETCS_OB01_evc_2oo3_design_cpus_make_and_model [
                activities
                consistency : Resolute.cpusAreOfSameType ( )
            ]
        ]
    ]
]
```

Verify: Multi-Valued Verification Activity Results

- Verification activity result states
  - Success, fail, error, tbd

- Compositional argument expressions
  - All: a collection of independent Vas
  - Va1 then Va2: Execution of Va2 dependent on success of Va1
  - Va1 else Va2: Execute Va2 only if Va1 produces negative result
  - Va1 else [fail: Va21 timeout: Va22 error: Va23]

- Mode specific verification activities

- Parameterized verification activities (data sets as input)

Assure: Assurance case, plans and tasks

- Assurance plan: configuration of assurance case:
  - Which part(s) of architecture to be verified using which verification plans
- Assurance plan instantiation & execution
  - Automated verification activity execution
  - Tracking of result state and reports
- Assurance Task
  - Filtered assurance plan instances based on requirement, verification, and verification activity selection categories

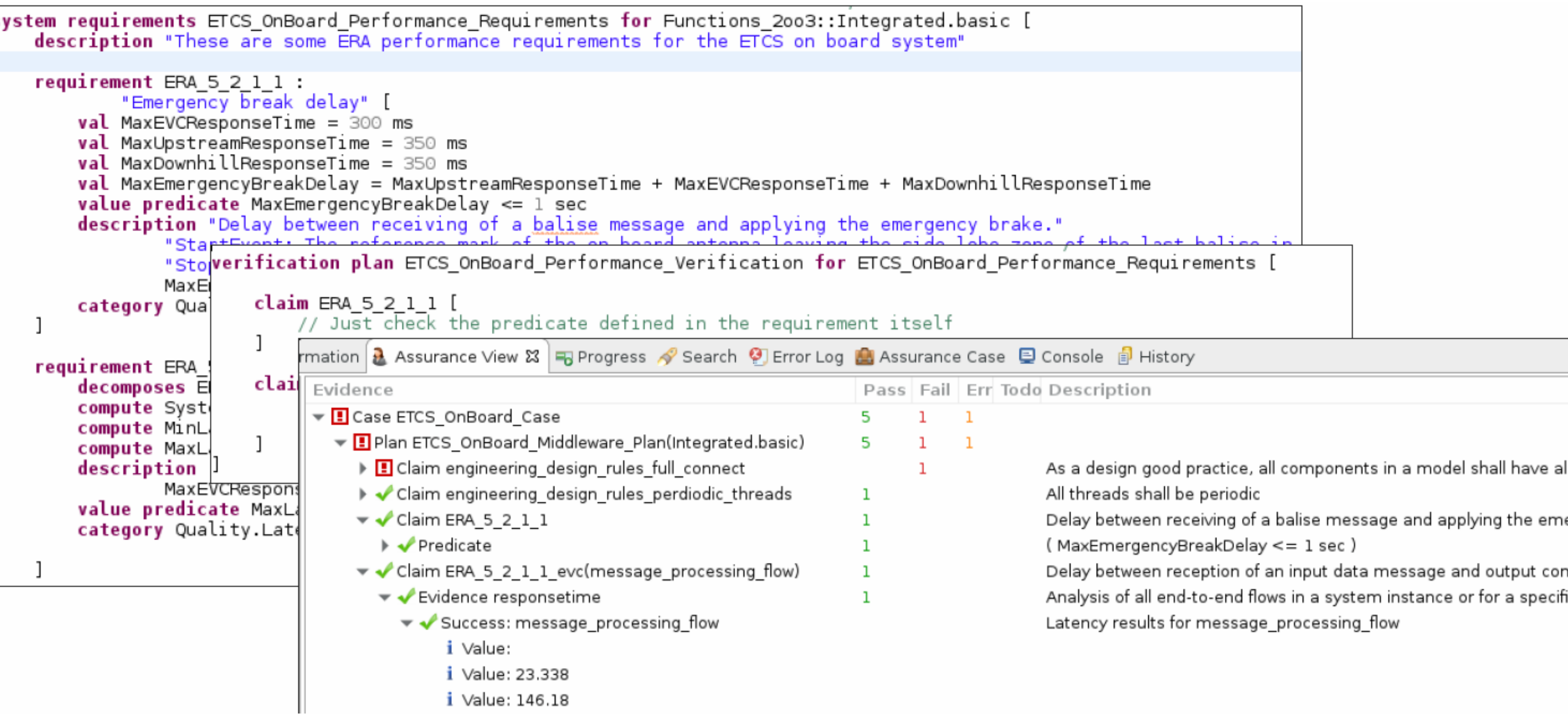
```
assurance case ETCS_OnBoard_Case for Middleware_2oo3::Integrated [

    assurance plan ETCS_OnBoard_Middleware_Plan for Middleware_2oo3::Integrated.basic [
        description "Assurance plan for ETCS on board functions and software"
        assure subsystem all
        assure ETCS_OnBoard_Design_Rules_Verification ETCS_OnBoard_Performance_Verification ETCS_OnBoard_Safet
    ]

]
```

Assure: Assurance Case Execution and Results

- Assurance view in OSATE to execute assurance cases



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Experience Report on using ALISA for Railway Software Systems

Engineering Railway Systems with an Architecture-Centric Process Supported by AADL and ALISA: an Experience Report

Paolo Crisafulli[1], Dominique Blouin[2], Françoise Caron[3], and Cristian Maxim[1]

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- Many of the ALISA examples taken from this work

Towards an Agile Engineering Process

- Reuse the continuous integration paradigm from software development
- Define ALISA requirements for major design choices
- Implement continuous requirements verification to maintain design within the solution space shaped by the set of requirements
- KPIs computation and charting to qualify in terms of performance the evolution of design and alternatives over time
  - Provide KPI charts

Building Blocks

Osate/ALISA/AADL Inspector
AADL parsing, analysis and verification platform

Git/Repo
Versioning system for the comprehensive source of all artifacts:

- Requirements
- Models and Code
- Verification activities
- Dockerfiles

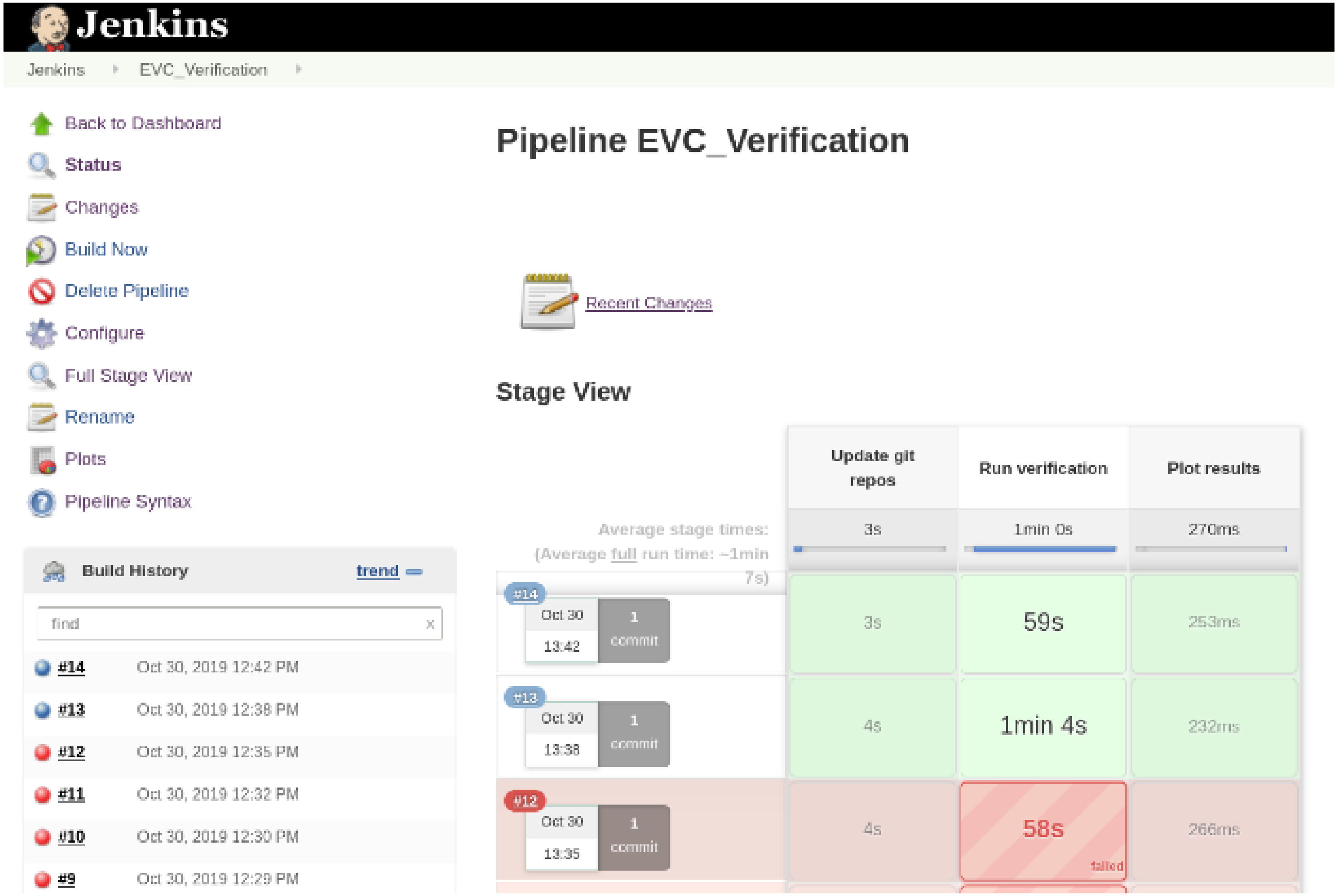
Jenkins
Continuous integration

Triggers verification check on any change to the artifacts

Docker
Container platform

Configuration management of the development, build and test environments

Build History



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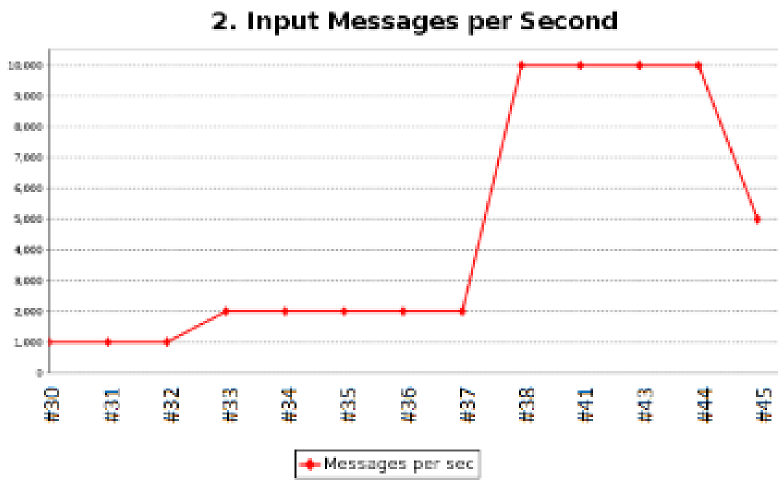

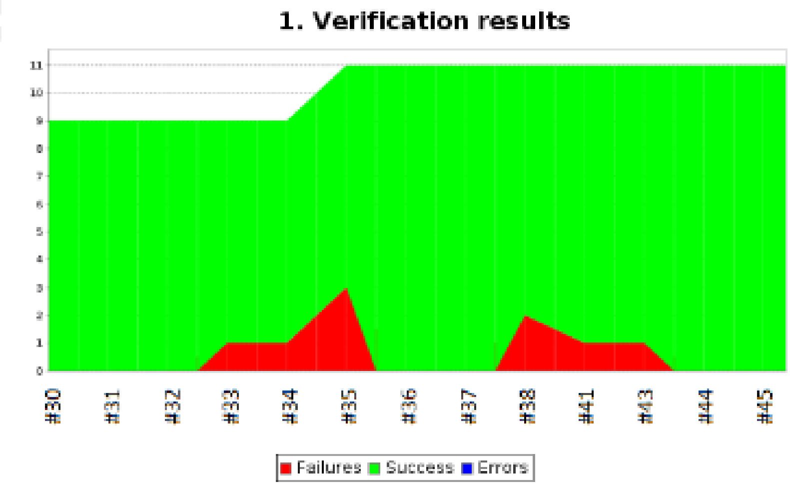

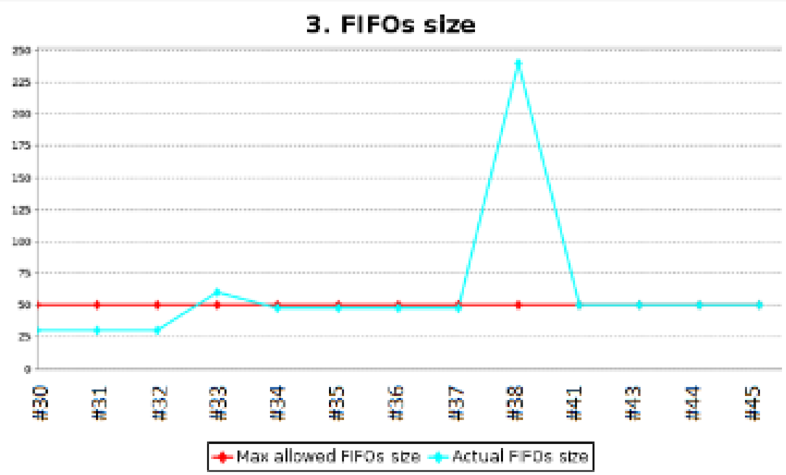

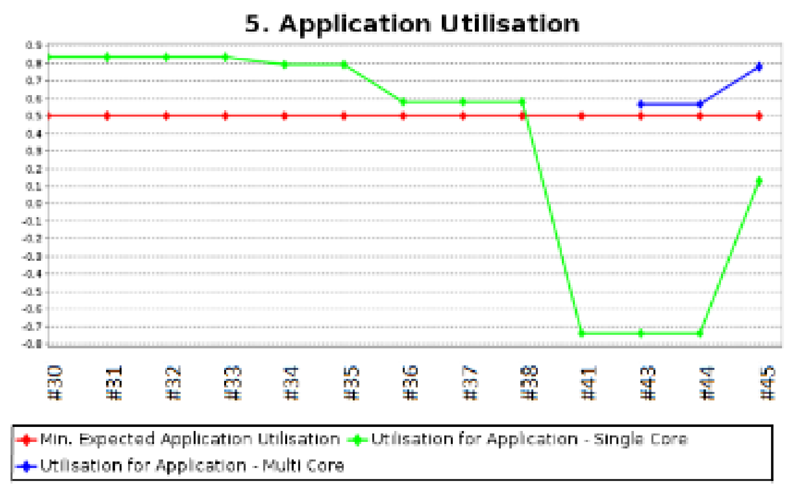

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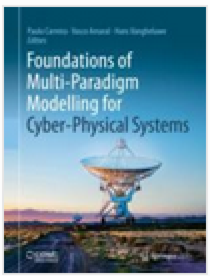
Conclusion and Perspectives

- Demonstrate how AADL and ALISA can support agile architecture-centric engineering process:
  - The continuous verification maintains the design within the solution space shaped by the set of requirements
  - The KPIs computation and charting qualify system performance evolution of design alternatives over time
- ALISA is not yet completely mature:
  - Scalability and multi-organization issues to be addressed
- AADL ecosystem of companion languages and development environments opens the way to agile engineering of highly constrained systems requiring a certification process
- Additional work on the overall system engineering process published at SysCon 2020

More Info on ALISA

- **AADL Tutorial by Peter Feiler: https://apps.dtic.mil/sti/pdfs/AD1084078.pdf**
- **OSATE online help**



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Integration of ALISA into the PST Process

Seamless Integration between Real-time Analyses and Systems Engineering with the PST Approach

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