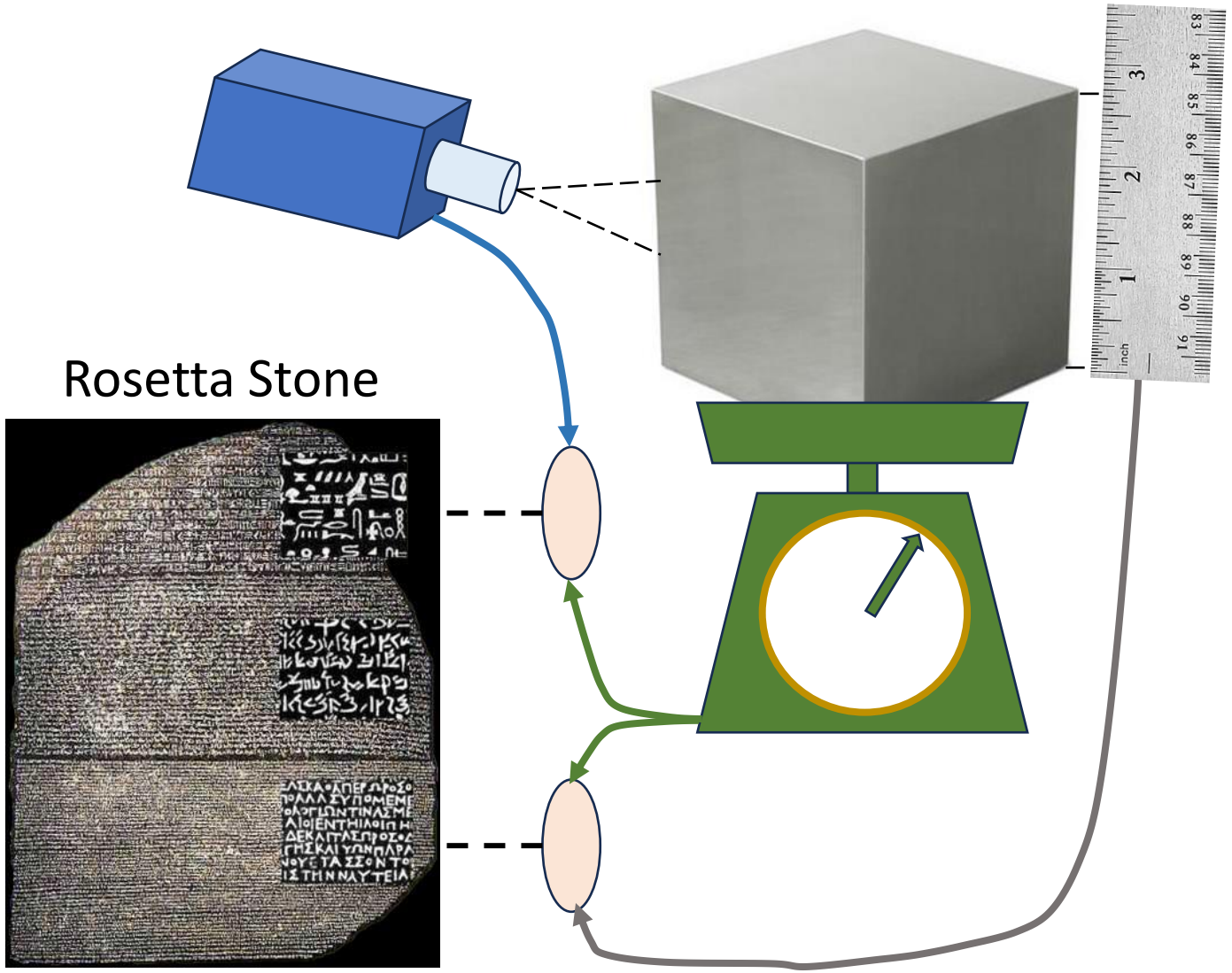
A Cross-Society Collaboration Project:
Mapping Consistency Confirmation Frameworks of Different Communities



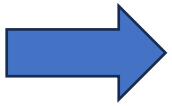
Phase 1 Project Report

Olivia Fischer [1], Mat French [1,2]
Joe Hightower [3], Alex Karl [4]
John Matlik [1], Laura Pullum [3]
Bill Schindel [1,2,3], Guodong Shao [3]
Nigel Taylor [1,3]

1 – AIAA Digital Engineering Integration Committee
2 – INCOSE/OMG MBSE Patterns Working Group
3 – ASME VV50 Model Life Cycle Working Group
4 – NAFEMS Simulation Governance Working Group

V2.1.5

Contents



- Introduction to the Rosetta Stone Project
- Phase 1 Project Report
- Supplemental Example

Disciplines are not isolated-- so their metrics should not be

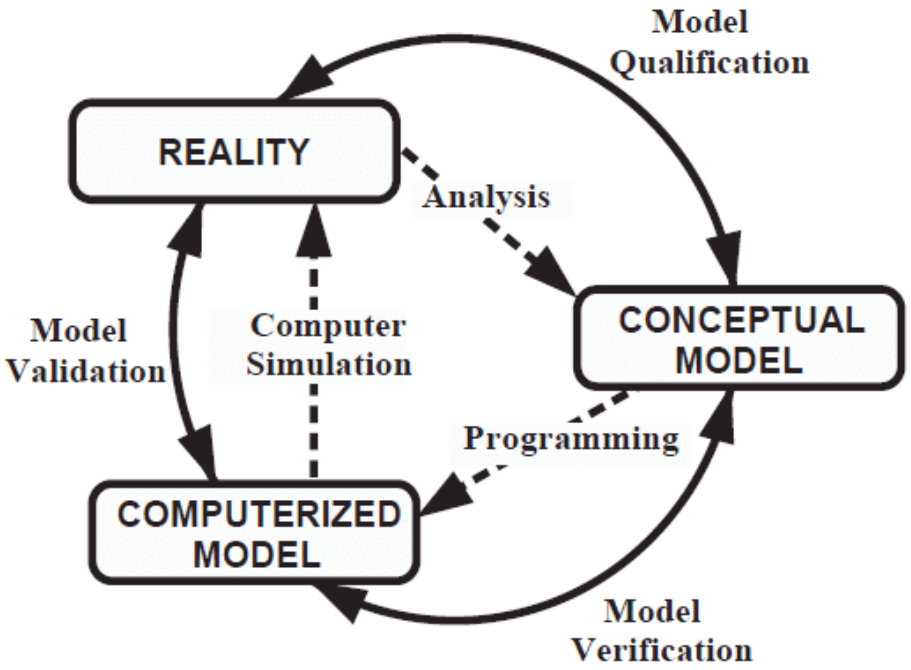


- We increasingly rely on computational models, but practices for related development still vary across disciplines.
- Example: Computational models are sometimes part of larger systems:
  - e.g., A smart milling machine with built-in model, estimating tool wear.
- Designers of those systems include practitioners across multiple disciplines, who must effectively communicate and work together.
- That includes their methods and metrics used to assess confidence in the resulting integrated system as well as its components.

Disciplines are not isolated--so their metrics should not be



- This story began in contemplating a 1979 (now somewhat dated) overview diagram of computational model V&V relationships [1], whose history is discussed in [2]:
  - How does the “computational modeling” community think about it?
  - How would the “product engineering” community think about it?
- More on this example later herein.



From [1]

Disciplines are not isolated-- so their metrics should not be



- Computational modelers apply standard frameworks developed specifically for establishing confidence in models – e.g., ASME VVUQ Standards VVUQ-1, 10, etc. [3], [4]
- Others use standards frameworks for establishing confidence in the overall system design—e.g., ISO 15288, IEEE 1012, etc. [5]
- There are good reasons for the contents of each of these frameworks.

Disciplines are not isolated-- so their metrics should not be



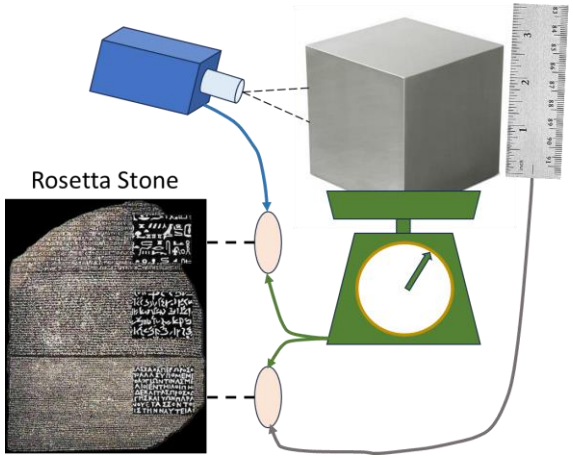
- In spite of using some of the same “V and V” terms, these frameworks appear to assign different meanings to them, and have different perspectives:
  - Different **terms** for the same concept.
  - Different **concepts** labeled with the same term.
  - Different **relationships** between concepts.
- *For integrated work on a single system*, how do these different frameworks function together?

Observation



- While preparing an ASME VV50 guideline about managing confidence in advanced manufacturing computational models across their entire life cycles [6] . . .
- . . . the authoring team has treated the computational model as an engineered subsystem of the larger evolving system into which it is integrated, . . .
- . . . invoking the related engineering V&V standards, along with computational modeling V&V standards.
- We observed this has been confusing for computational modeling specialists used to a different V&V framework.
- This combination has given us some important insights.
- We believe that clearer mapping between these frameworks would be beneficial.

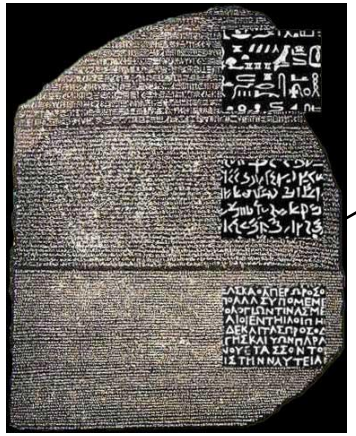
Making comparisons: A project

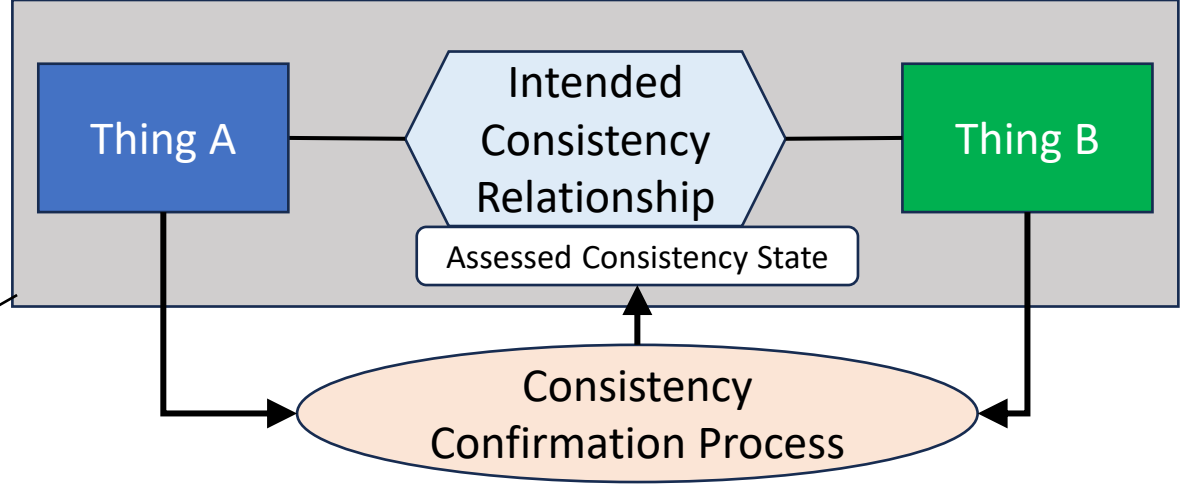


- We are <u>not</u> suggesting that any of these frameworks replace the others.
- Rather, we have started a preliminary project, collaborating across working groups from several technical societies, to <u>establish a mapping between the frameworks</u>, facilitating improved communication between communities.
- This project involves working group representation from:
  - ASME VV50 (Model Life Cycle Working Group)
  - AIAA Digital Engineering Integration Committee (Confidence in Models Subcmtee)
  - INCOSE/OMG MBSE Initiative (MBSE Patterns Working Group)
  - NAFEMS (Systems Modeling & Simulation Working Group)
- Mapping different frameworks using a shared abstraction “Rosetta Stone” . . .

Our “Rosetta Stone” abstraction is “Consistency Management”

Rosetta Stone

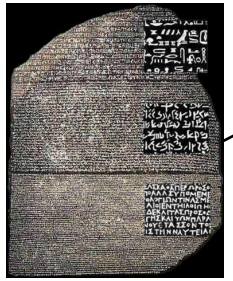


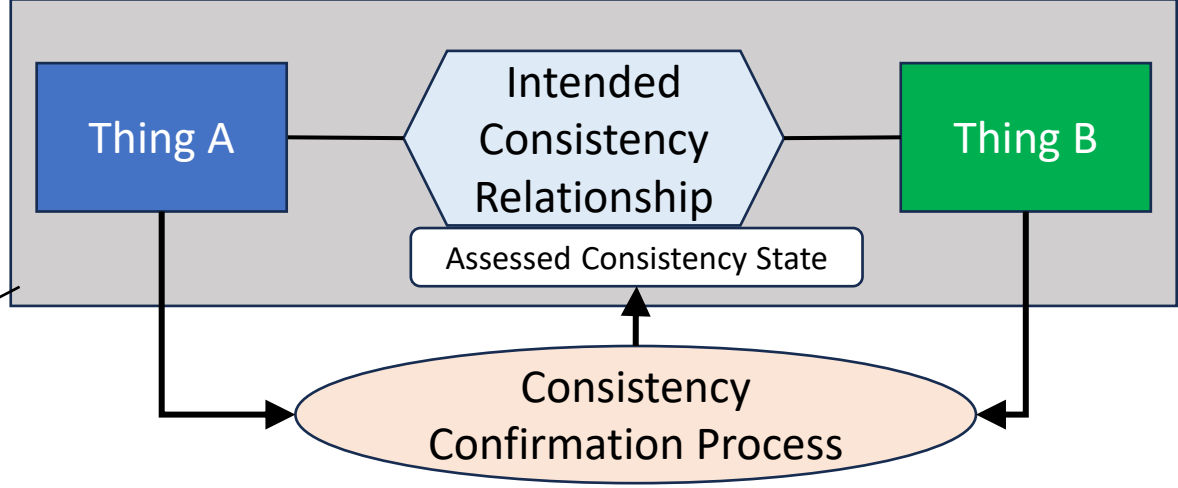


- An abstraction that may be applied equally to each of the different frameworks:
  - All those frameworks check whether pairs of things are “consistent” with each other, where “consistent” has various formally defined types. [2][7][8][9]
- Examples for computational models, (per VVUQ 1-2022) [3]
  - “Verification is the process of establishing the mathematical correctness of the **computational model** with respect to a **referent**.” (e.g., a **mathematical model**)
  - “Validation is the process of determining the degree to which a **model** represents the **empirical data** from the perspective of the context of use.”

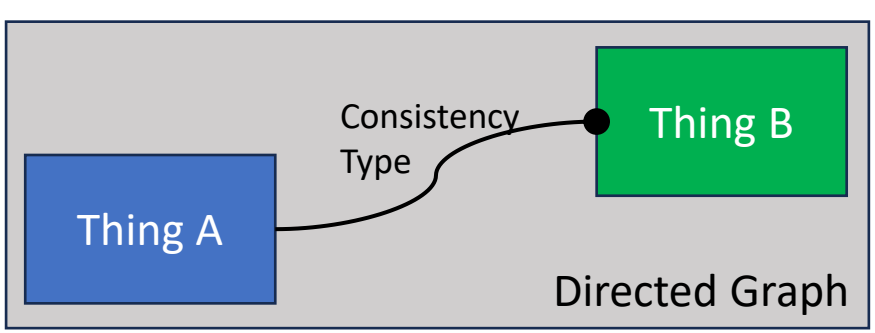
Our “Rosetta Stone” abstraction is “Consistency Management”

Rosetta Stone

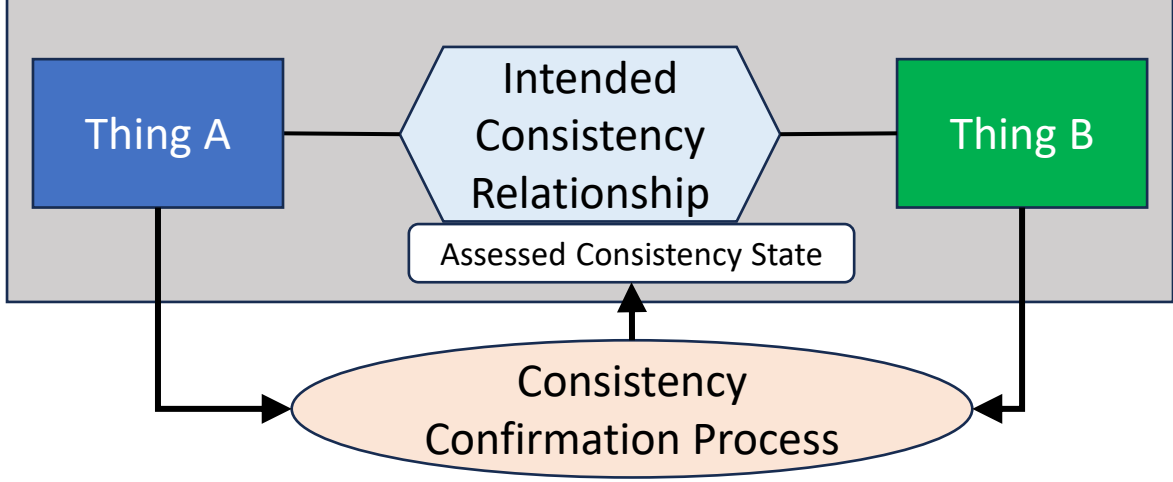




- Likewise, examples for engineered systems, (per ISO 15288) [5]
  - “The purpose of the verification process is to provide objective evidence that a **system, system element, or artefact** fulfils its **specified requirements and characteristics**.”
  - “The purpose of the validation process is to provide objective evidence that the **system, when in use**, fulfils its **business or mission objectives and stakeholder needs and requirements**, achieving its intended use in its intended operational environment.”
  - “Validation is also applicable to the **artefacts (e.g. requirements, architecture, design, design characteristics, or system elements**) produced in the definition and realization of the system.”
  - “The validation process determines that the ‘right solution is built’. The verification process determines that the ‘solution is built right’ “.

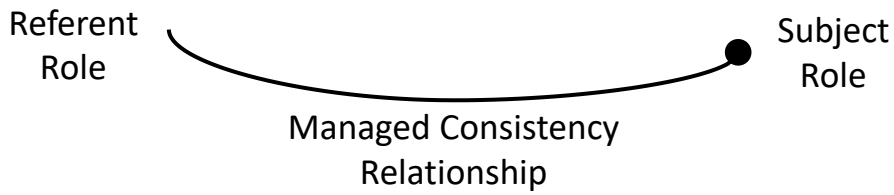


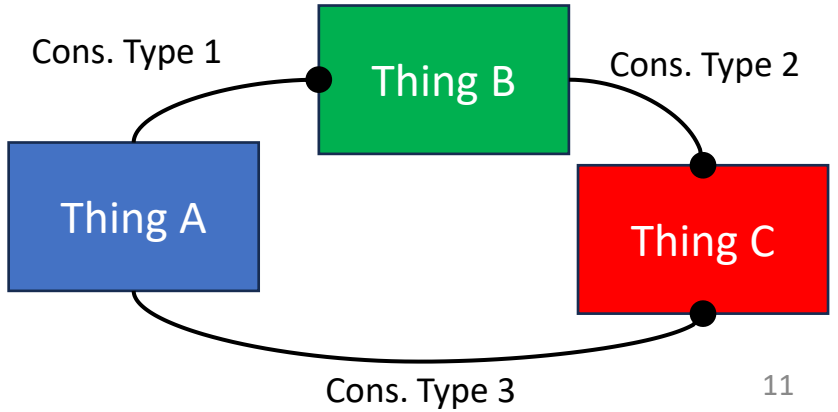
Shorthand Representation



- For any single discipline, the set of all its consistency relationship types (described by the discipline's standard practices) is a "directed graph" of pairwise *intended* consistencies:
  - The graph nodes are the compared things.
  - The graph edges (the linking lines) are the types of consistency sought (the consistency relationship, to be assessed).
  - This is not a process diagram—it is a model of information relationships.

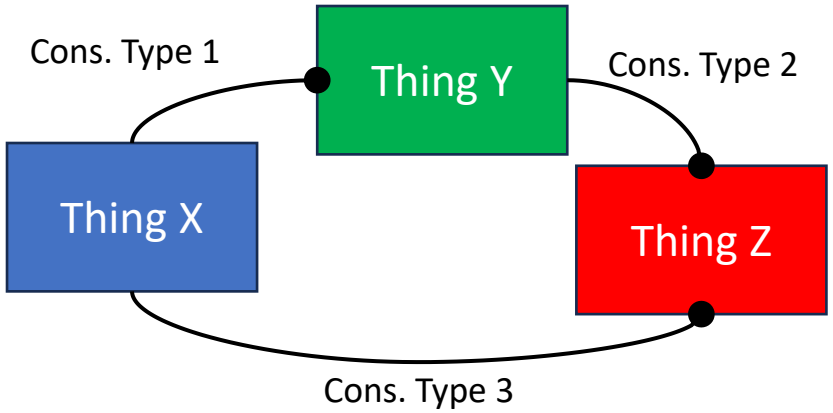
- The graph links are "directed" to differentiate things we are checking (subjects) from what we are checking them against (referents):

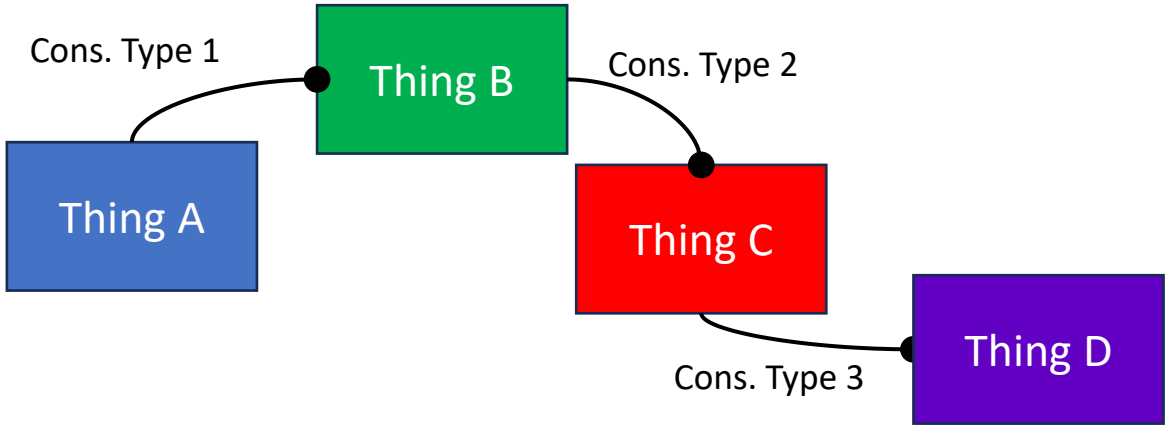




Consistency management: Representation for comparison

- Each such directed graph can be represented by an "N^2 adjacency matrix":
  - Placing the compared things as headings for matrix rows and columns, the links become "consistency type" entries in the matrix cells.





In Computational Modeling community:
- "Referent"
- "Subject"

		From		
		X	Y	Z
To	X			
	Y	Cons. 1		
	Z	Cons. 3	Cons. 2	

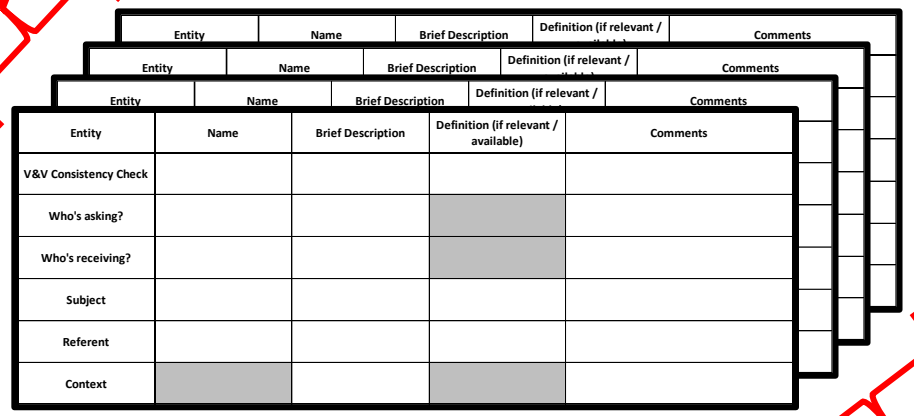
		From			
		A	B	C	D
To	A				
	B	Cons. 1			
	C		Cons. 2		
	D			Cons. 3	

Survey of consistency management frameworks: Data collection and assembly of Rosetta mapping

Survey data collection "card" for a **single managed consistency type**

Entity	Name	Brief Description	Definition (if relevant / available)	Comments
V&V Consistency Check				
Who's asking?				
Who's receiving?				
Subject				
Referent				
Context				

Managed consistency Type cards for a **single discipline**



Merge

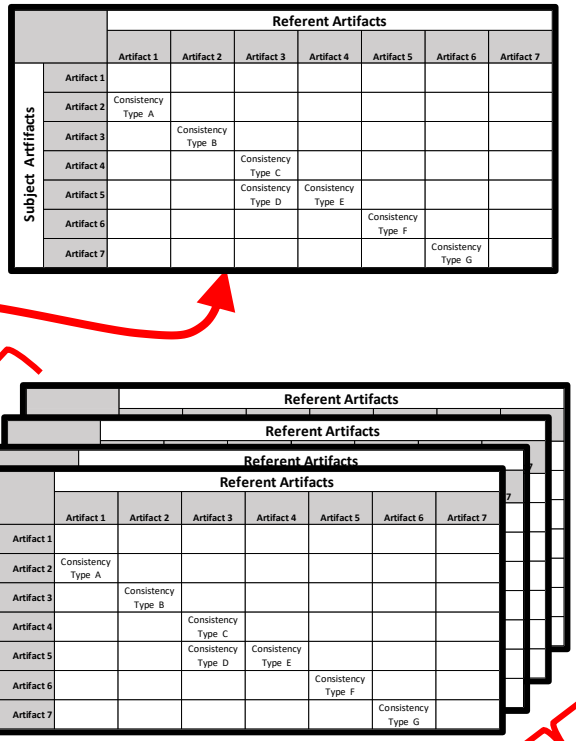
N^2 matrix of consistencies for a **single discipline**

Subject Artifacts \ Referent Artifacts	Artifact 1	Artifact 2	Artifact 3	Artifact 4	Artifact 5	Artifact 6	Artifact 7
Artifact 1							
Artifact 2	Consistency Type A						
Artifact 3		Consistency Type B					
Artifact 4			Consistency Type C				
Artifact 5			Consistency Type D	Consistency Type E			
Artifact 6					Consistency Type F		
Artifact 7						Consistency Type G	

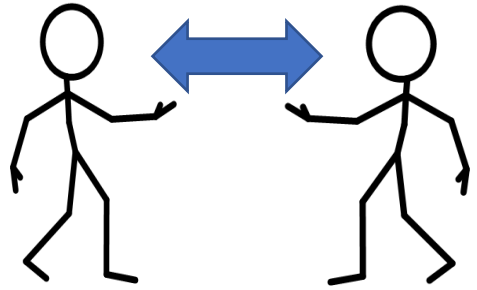
Multiple disciplines

Merge

Rosetta Stone: Multiple disciplines mapping



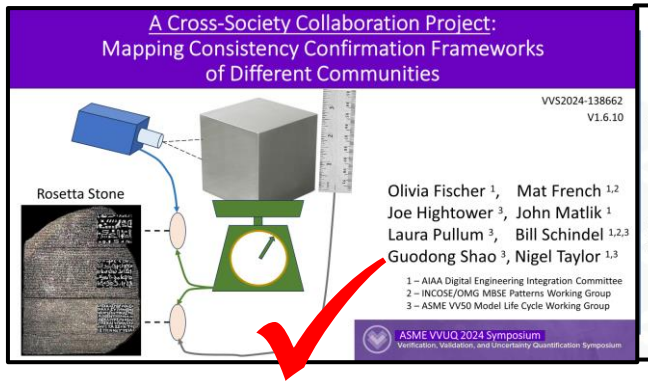
Our collaborative project



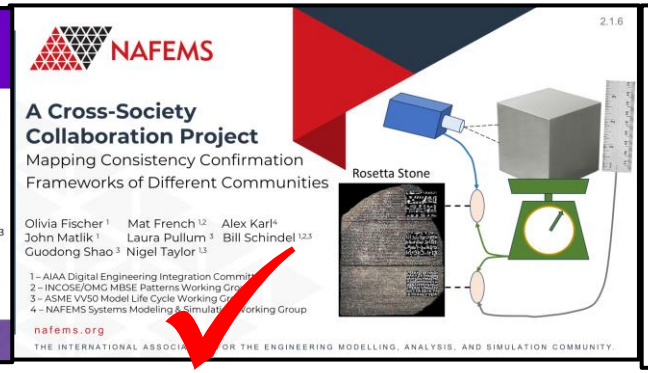
- Not so hard: This approach does not require any changes to discipline methods or nomenclatures!
- It simply captures them in a common, shared (matrix) representation(s) that makes their coverages and relationships evident.
- So, it need not be extremely difficult.
- But it does encourage objective conversation between the disciplines. [13]
- Accordingly, our “social strategy” was to carry this out as a collaboration between the technical societies associated with the disciplines.
- Our deliverable is the reference mapping, targeted across 2024 to cover Computational Model and ISO15288 Engineering communities.
- We reported on progress over 2024, at meetings of ASME, AIAA, NAFEMS, and INCOSE.

2024: Describing the Project Across Four Societies

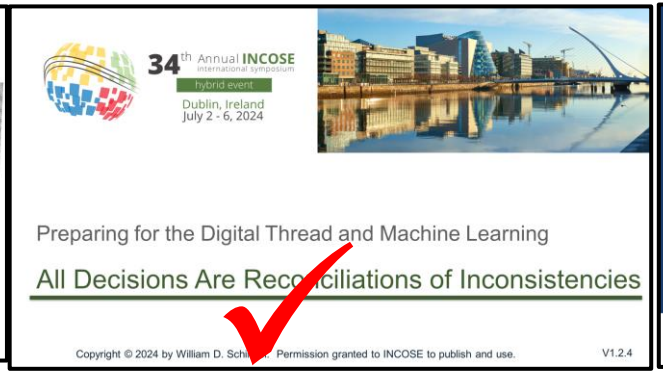
- **<u>Cross-Societies "V&V Rosetta Stone" Collaboration Project:</u>**
  - Mapping between the consistency management frameworks (V&V et al) of different engineering disciplines and communities: [3], [5], [10], [14].
  - Especially mapping between [computational modeling V&V] and [ISO 15288 V&V].
  - Authored by members of AIAA, INCOSE, ASME, NAFEMS.
  - Team presented project at four tech societies' 2024 conferences, below.
  - Standards data collected, analyzed, and now mapped for four targeted standards.
  - End report Jan, 2025; presenting it at four tech societies' 2025 conferences.



<u>ASME VVUQ2024: May, 2024</u>
Bill Schindel



<u>NAFEMS Americas 2024: July</u>
Alex Karl



<u>INCOSE IS2024: July</u>
Bill Schindel

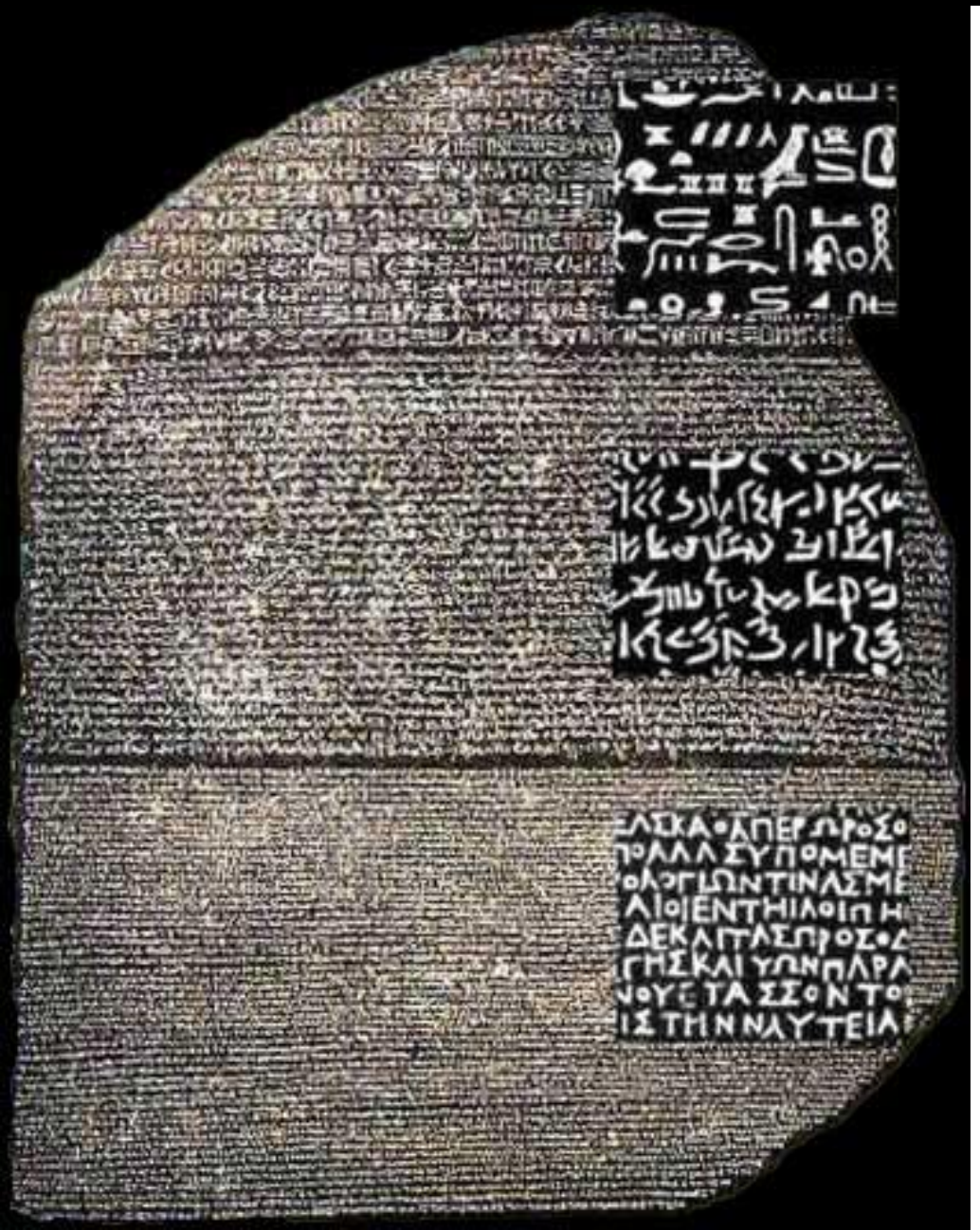


<u>AIAA Aviation 2024: July-Aug</u>
Nigel Taylor

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The Rosetta Stone—Multiple languages in a single shared context



What have we learned from comparing four V&V frameworks for a computational model (CM)?

- ISO 15288 (general systems, including CM) [5]
- ASME VVUQ-1 (CM) [3]
- NAFEMS ESQMS (CM) [10]
- AIAA-G077 (CM) [14]

V&V grounded in characterizing accuracy for a computational model:

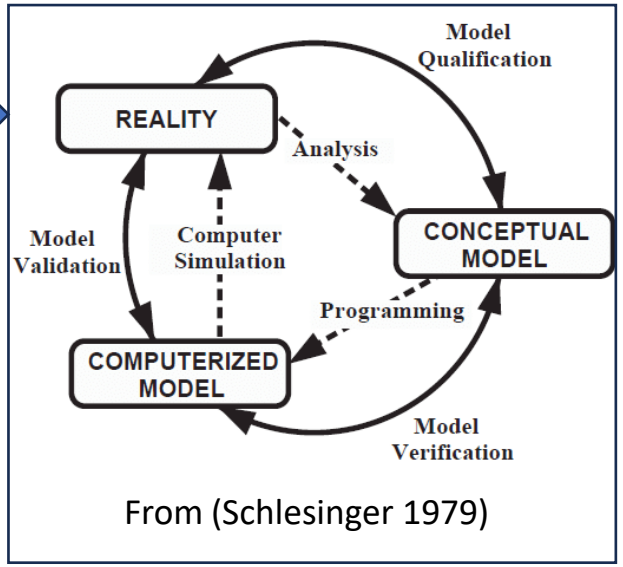
- ASME VVUQ-1
- AIAA-G077

V&V grounded in application requirements for a computational model:

- ISO 15288 (Systems in general, including computational models)
- NAFEMS ESQMS (Engineering simulations in particular)

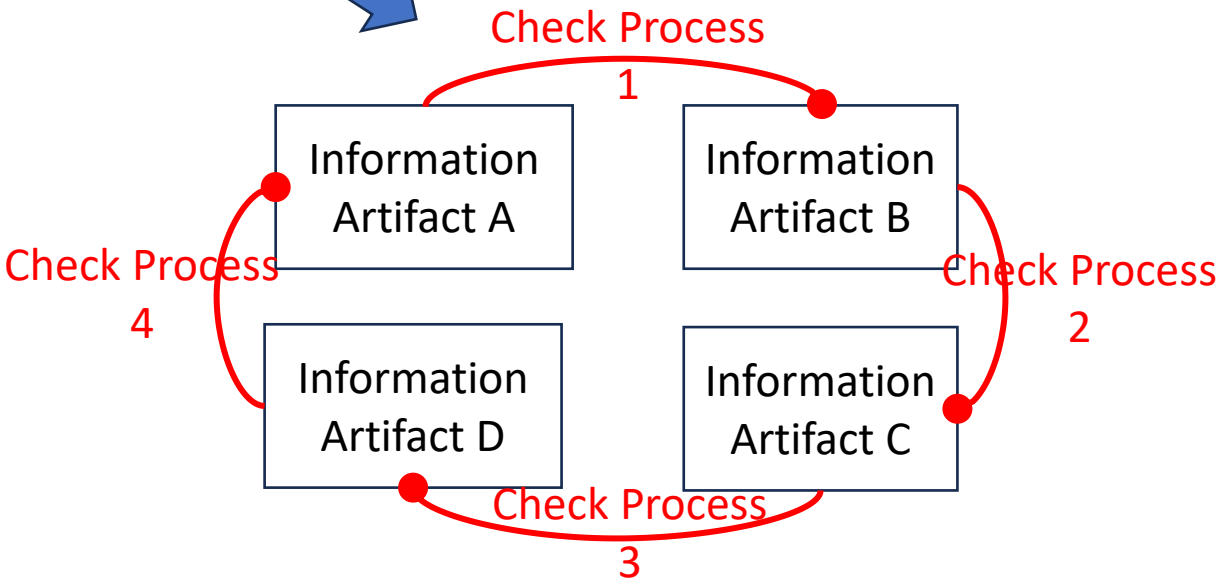
Representing " consistency management" frameworks

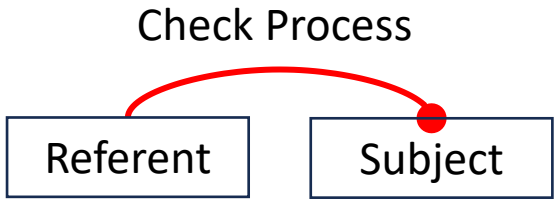
Inspired by Schlesinger's 1979 diagram.



From (Schlesinger 1979)

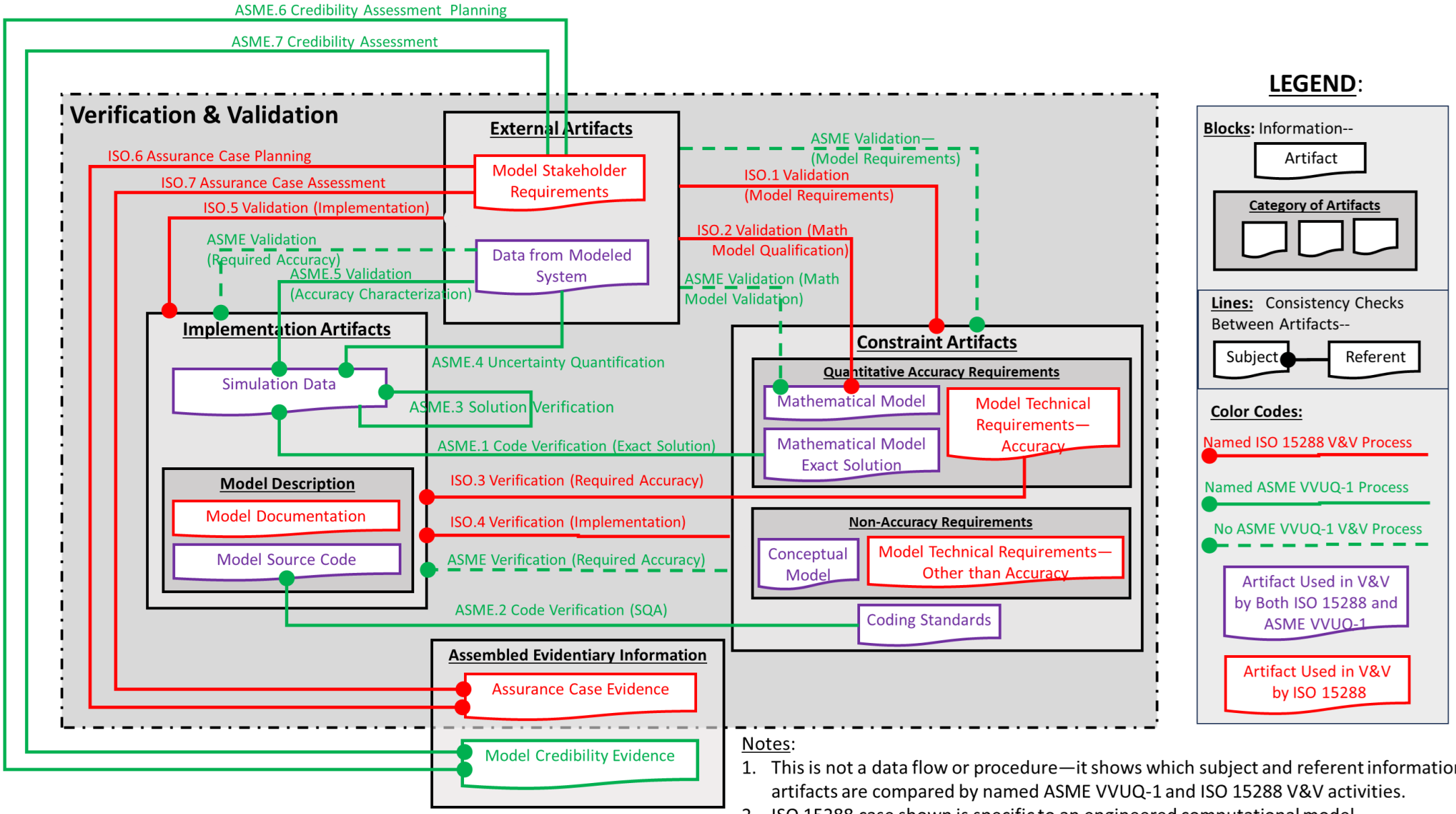
Showed what information entities (blocks) were *checked for subject-artifact consistency* by different "V&V" processes (connecting lines).





Requires identification of information artifact types and the consistency checks performed on (subject-referent) pairs of them.

Comparing ISO15288 and ASME VVUQ-1 (see definitions table and [3], [5])



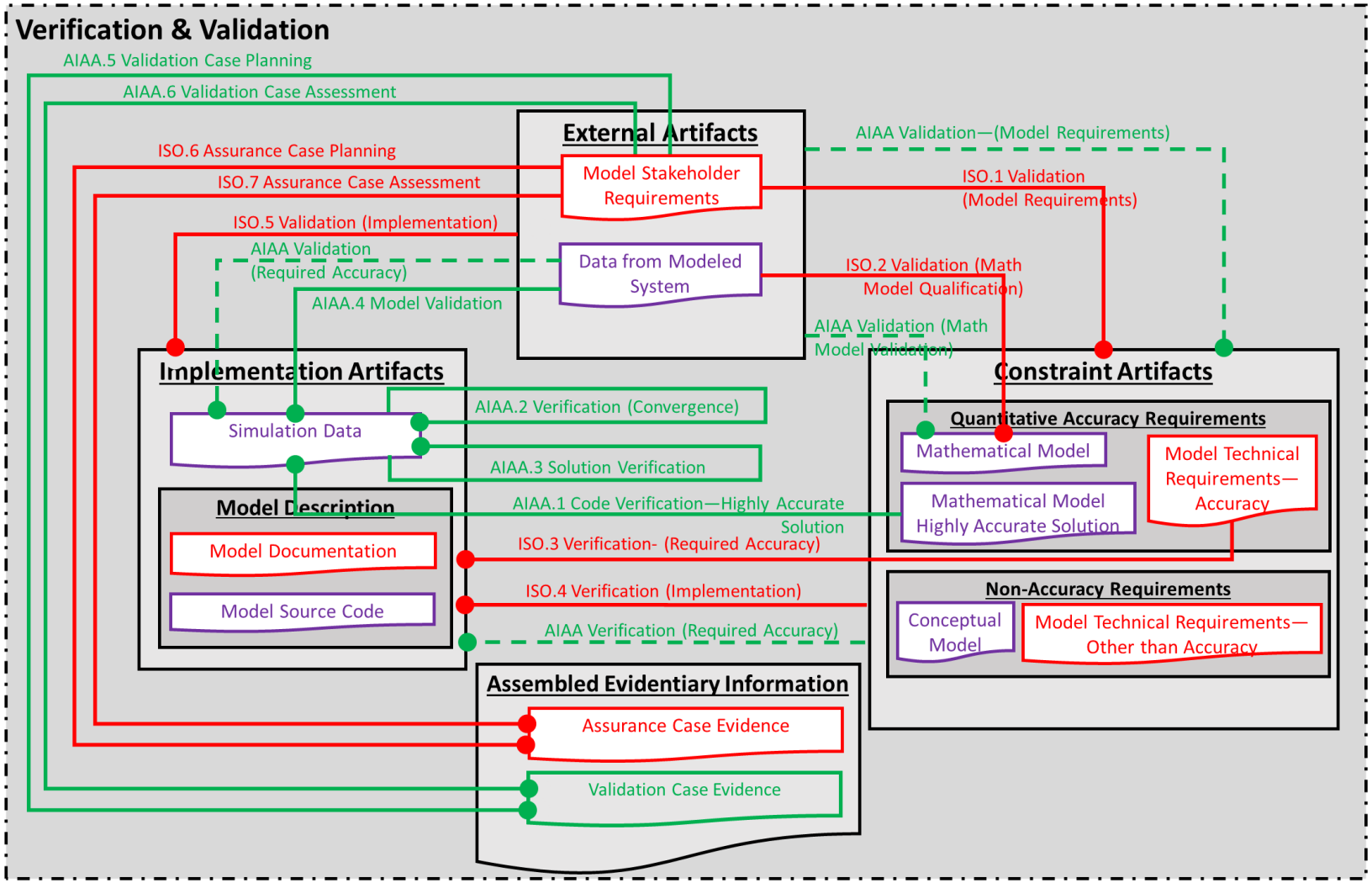
Notes:

1. This is not a data flow or procedure—it shows which subject and referent information artifacts are compared by named ASME VVUQ-1 and ISO 15288 V&V activities.
2. ISO 15288 case shown is specific to an engineered computational model.
3. Not all of ISO 15288 V&V applicabilities to that case are illustrated

Comparing definitions: ISO15288 and ASME VVUQ-1 (see [3], [5])

Label in Rosetta Stone Diagram	Consistency Check	Brief Definition/Description	Subject (What Is Being Checked?)	Referent (What Is the Check Against?)	Reference in Standard/Guideline; Additional Discussion
ISO.1 Validation (Model Requirements)	System Requirements Validation against Stakeholder Requirements	Confirmation that System Requirements artifact is consistent with Stakeholder Requirements artifact.	Requirements (On Model) Artifact(s)	Stakeholder Requirements Artifact(s)	ISO15288 Section 6d.4.11.1 Note 2: "Validation is also applicable to the artefacts (e.g., requirements, architecture, design, design characteristics, or system elements) produced in the definition and realization of a system."
ISO.2 Validation (Math Model Qualification)	Mathematical Model Validation against Stakeholder Requirements	Confirmation that Mathematical Model artifact is consistent with Stakeholder Requirements artifact.	Mathematical Model Artifact	Stakeholder Requirements Artifact(s)	ISO15288 Section 6d.4.11.1 Note 2: "Validation is also applicable to the artefacts (e.g., requirements, architecture, design, design characteristics, or system elements) produced in the definition and realization of a system."
ISO.3 Verification (Required Accuracy)	System Design Verification by Analysis	The system (model) design is subjected to analysis, based on first principles, judgment against experience, standards, or other types of knowledge.	Model Design Artifact(s)	Model Technical Requirements Artifact(s)	ISO15288 Section 6.4.9.1 Note 1: "The verification process determines that the 'solution is built right'. The validation process determines that the 'right solution is built'. The verification process identifies anomalies in any artefact (e.g., system requirements, architecture description, or design description), implemented system elements, or life cycle processes, using appropriate methods, techniques standards, or rules."
ISO.4 Verification (Implementation)	System Design Verification by Testing	The actual operational performance of the implemented system design is compared to test outcomes demanded by the system requirements.	Simulation Data	Requirements (On Model) Artifact(s)	ISO 15288 Section 6.4.9.3 (3) NOTE 3: "Verification methods include: inspection (including peer review), analysis (including modelling, simulation, and analogy/similarity), demonstration, and testing. The selection of one or more verification methods is made according to the type of system, the needs of the item being verified, the objectives of the project, and the acceptable risks. Selected methods and success criteria are coordinated with relevant stakeholders to help ensure the verification strategy is acceptable."
ISO.5 Validation (Implementation)	System In Service Validation	The system is observed in service and compared to stakeholder expectations.	Simulation Data	Model Stakeholder Requirements	ISO15288 Section 6.4.11.1 "The purpose of the validation process is to provide objective evidence that the system, when in use, fulfils its business or mission objectives and stakeholder needs and requirements, achieving its intended use in its intended operational environment."
ISO.6 Assurance Case Planning	Planning of Assurance Case	Planning for framework to organize objective evidence	Assurance Case Plan	Model Stakeholder Requirements	ISO 15288 Section 5.10: "Assurance is often provided through activities to construct an assurance case. An assurance case is an auditable artefact that provides a convincing and valid argument for a claim on the basis of tangible evidence under a given context."
ISO.7 Assurance Case Assessment	Assessment of Assurance Case	Justifies confidence gained through system verification and validation activities and evidence	Assurance Case Evidence	Model Stakeholder Requirements	ISO 15288 Section 6.4.9.1 NOTE 2: "Construction of an assurance case (see 5.10) can be helpful to provide insight for verification activities and to present verification results."
ASME.1 Code Verification (Exact Solution)	Consistency Check on Simulation Results versus Exact Solution of Mathematical Model	"Code verification is the process of determining that the mathematical models are correctly implemented in the computer code and of identifying errors in the software." (ASME VVUQ 1-2022 Definition 3.3.3.1 page 6)	Results from the Computational Model	Exact Solutions of the Mathematical Model	ASME VVUQ 1-2022 Definition 3.3.3.1 page 6: "Code verification is an error identification process through the evaluation of whether the computational model is consistent with the underlying mathematical model. . . . . Techniques for code verification include the use of analytical solutions and the method of manufactured solutions."
ASME.2 Code Verification (SQA)	Consistency Check on Simulation Source Code Design versus Software Quality Assurance (SQA) Standards of Guidance	"Code verification is the process of determining that the mathematical models are correctly implemented in the computer code and of identifying errors in the software." (ASME VVUQ 1-2022 Definition 3.3.3.1 page 6)	Source Code	Code Syntax requirements, Requirements for data representation and storage Interface Design Requirements	ASME VVUQ 1-2022 Definition 3.3.3.1 page 6: "Code verification relies on having a robust software quality assurance program to minimize the occurrence and severity of "bugs" in the software."
ASME.3 Solution Verification	Consistency check on the computational model output versus estimates of exact mathematical solution	"Solution verification is the process of determining the accuracy of a particular numerical solution relative to an estimate of the exact solution of the computational model." (ASME VVUQ 1-2022 Definition 3.3.3.2 page 7)	Results from the Computational Model	An estimate of the exact solution to the Mathematical Model	An estimate of the exact solution to the mathematical model is created by comparing (to each other) repeated numerical solutions produced by the computational model at different discretizations of time, space, or other variables, use of different computer precisions, and for different numbers of iterations.
ASME.4 Uncertainty Quantification	Quantifying the degree of uncertainty in simulation results.	"In the context of verification and validation, uncertainty quantification is the mathematical assessment of the uncertainties that arise from all sources of uncertainty in the simulation, experimentation, and real-world systems and processes." (ASME VVUQ 1-2022 Section 3.4 page 7)	Results from the Computational Model	Data from Modeled System	"Uncertainty Quantification (UQ) requires models that represent the uncertainty in the value of specific quantities. This uncertainty can result from inherent variability but may also result from lack of knowledge. The main aspect of UQ is the characterization of uncertainty; it may include propagating that uncertainty. Characterization of uncertainty focuses on representing or modeling the uncertainty in a given quantity. An example of characterization is collecting sample data and estimating statistics or fitting probability distribution models to those data. Propagation of uncertainty focuses on determining the impact of uncertainty on the quantities of interest. Examples of propagation methods include Monte Carlo sampling and Taylor Series sensitivity analysis." (ASME VVUQ 1-2022 Definition 3.4.3 page 8)
ASME.5 Validation (Accuracy Characterization)	Characterization of the Accuracy of a Computational Model (not relative to a required accuracy).	"Validation is the process of determining the degree to which a model represents the empirical data from the perspective of the context of use. " (ASME VVUQ 1-2022 Section 3.3.4 Page 7)	Results from the Computational Model	Data from Modeled System	"The primary outcome of validation is an assessment of the modeling error for a specific condition or set of conditions and not a pass-fail statement. That assessment should be a quantitative measure(s) of the level of agreement between empirical data and simulation results. Acceptance of a model can lead to claims of a "validated model"; however, no computational model should be considered broadly "validated." Instead of saying "the model is validated," it is better to say "the model is valid to predict the quantities of interest (X1, X2, X3 …) each with a specified uncertainty (U1, U2, U3) in the context of use (Y)." (ASME VVUQ 1-2022 Section 3.3.4 Page 7.) Satisfaction of accuracy requirements for an application is not part of ASME VVUQ-1 V&V, but instead part of ASME VVUQ-1 Model Credibility Assessment.

Comparing ISO15288 and AIAA G-077 (see definitions table and [5], 14])



LEGEND:

Blocks: Information--

Artifact

Category of Artifacts

Lines: Consistency Checks Between Artifacts--

Subject — Referent

Color Codes:

Named ISO 15288 V&V Process

Named AIAA G-077 V&V Process

No AIAA G-077 V&V Process

Artifact Used in V&V by Both ISO 15288 and AIAA G-077

Artifact Used in V&V by ISO 15288

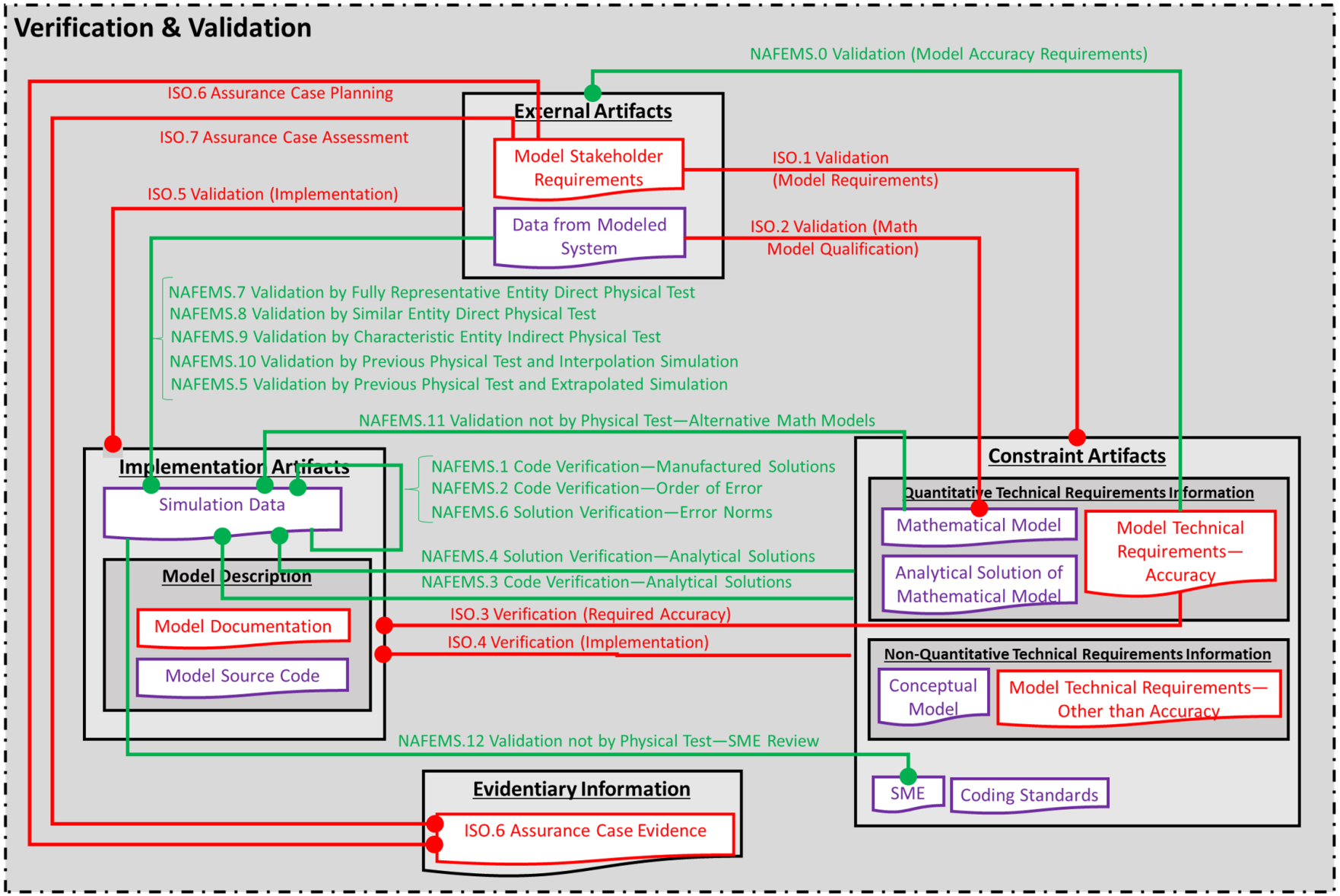
Notes:

1. This is not a data flow or procedure—it shows which subject and referent information artifacts are compared by named AIAA G-077 and ISO 15288 V&V activities.
2. ISO 15288 case shown is specific to an engineered computational model.
3. Not all of ISO 15288 V&V applicabilities to that case are illustrated

Comparing definitions: ISO15288 and AIAA G-077 (see definitions table and [5], 14])

Label in Rosetta Stone Diagram	Consistency Check	Brief Definition/Description	Subject (What Is Being Checked?)	Referent (What Is the Check Against?)	Reference in Standard/Guideline; Additional Discussion
ISO.1 Validation (Model Requirements)	System Requirements Validation against Stakeholder Requirements	Confirmation that System Requirements artifact is consistent with Stakeholder Requirements artifact.	Requirements (On Model) Artifact(s)	Stakeholder Requirements Artifact(s)	ISO15288 Section 6d.4.11.1 Note 2: "Validation is also applicable to the artefacts (e.g., requirements, architecture, design, design characteristics, or system elements) produced in the definition and realization of a system."
ISO.2 Validation (Math Model Qualification)	Mathematical Model Validation against Stakeholder Requirements	Confirmation that Mathematical Model artifact is consistent with Stakeholder Requirements artifact.	Mathematical Model Artifact	Stakeholder Requirements Artifact(s)	ISO15288 Section 6d.4.11.1 Note 2: "Validation is also applicable to the artefacts (e.g., requirements, architecture, design, design characteristics, or system elements) produced in the definition and realization of a system."
ISO.3 Verification (Required Accuracy)	System Design Verification by Analysis	The system (model) design is subjected to analysis, based on first principles, judgment against experience, standards, or other types of knowledge.	Model Design Artifact(s)	Model Technical Requirements Artifact(s)	ISO15288 Section 6.4.9.1 Note 1: "The verification process determines that the 'solution is built right'. The validation process determines that the 'right solution is built'. The verification process identifies anomalies in any artefact (e.g., system requirements, architecture description, or design description), implemented system elements, or life cycle processes, using appropriate methods, techniques standards, or rules."
ISO.4 Verification (Implementation)	System Design Verification by Testing	The actual operational performance of the implemented system design is compared to test outcomes demanded by the system requirements.	Simulation Data	Requirements (On Model) Artifact(s)	ISO 15288 Section 6.4.9.3 (3) NOTE 3: "Verification methods include: inspection (including peer review), analysis (including modelling, simulation, and analogy/similarity), demonstration, and testing. The selection of one or more verification methods is made according to the type of system, the needs of the item being verified, the objectives of the project, and the acceptable risks. Selected methods and success criteria are coordinated with relevant stakeholders to help ensure the verification strategy is acceptable."
ISO.5 Validation (Implementation)	System In Service Validation	The system is observed in service and compared to stakeholder expectations.	Simulation Data	Model Stakeholder Requirements	ISO15288 Section 6.4.11.1 "The purpose of the validation process is to provide objective evidence that the system, when in use, fulfils its business or mission objectives and stakeholder needs and requirements, achieving its intended use in its intended operational environment."
ISO.6 Assuance Case Planning	Planning of Assurance Case	Planning for framework to organize objective evidence	Assurance Case Plan	Model Stakeholder Requirements	ISO 15288 Section 5.10: "Assurance is often provided through activities to construct an assurance case. An assurance case is an auditable artefact that provides a convincing and valid argument for a claim on the basis of tangible evidence under a given context."
ISO.7 Assurance Case Assessment	Assessment of Assurance Case	Justifies confidence gained through system verification and validation activities and evidence	Assurance Case Evidence	Model Stakeholder Requirements	ISO 15288 Section 6.4.9.1 NOTE 2: "Construction of an assurance case (see 5.10) can be helpful to provide insight for verification activities and to present verification results."
AIAA.1 Code Verification (Highly Accurate Solution)	Verification by Highly Accurate Solutions	Comparison of a numerical solution to a highly accurate solution. NB: Verification is defined as the process of determining that a model implementation accurately represents the developer's conceptual description of the model and the solution to the model.	A numerical solution.	A highly accurate solution. Can be an analytical solution, a benchmark numerical solution to an ODE, or a benchmark numerical solution to a PDE.	This is one aspect of what would now widely be referred to as Code Verification. Contemporary Code Verification includes a number of consistency checks that are not described in G-077 - AIAA has recently published a Recommened Practice on this subject (AIAA R-141-2021); a Standard is in the process of being published.
AIAA.2 Verification (Convergence)	Verification by Iterative Convergence and Consistency Checks	Numerical solutions are compared over a range of adjacent iterations, or a single solution is checked within the difference equation, or a conserved quantity or symmetry is checked, to estimate residual error of iteration. NB: Verification is defined as the process of determining that a model implementation accurately represents the developer's conceptual description of the model and the solution to the model.	A numerical solution at given iteration.	A (usually the same) numerical solution at a subsequent iteration.	Now more commonly referred to as Verification of Numerical Convergence (a check to establish the adequacy of the solution of the governing equations). In contrast to the Solution Verification, this typically applies to the analysis of the behavior of a single simulation.
AIAA.3 Solution Verification	Verification by Grid and Time-Step Convergence	Rate of convergence as grid and time step sizes are reduced allows estimation of spatial and time discretization error. NB: Verification is defined as the process of determining that a model implementation accurately represents the developer's conceptual description of the model and the solution to the model.	A numerical solution at given grid and time step sizes.	Numerical solutions at different (finer) grid and time step sizes.	Now commonly referred to as Solution Verification. Typically involves analysis of multiple (carefully coordinated) simulations. The numerical processes involved in solving the governing equations introduce (spatial and time) discretization errors. This check allows the (spatial and time) discretization error of a numerical solution to be estimated. (see G-077 Section 3.1).
AIAA.4 Model Validation	Validation (Multiple Hierarchical Levels)	The 1998 G-077 publication describes hierarchical (bottom up) validations, at Unit, Benchmark, Subsystem, and System levels, not detailed in this summary. NB: Validation is defined as the process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model.	Numerical Model Outputs, at a given hierarchical level	Experimental Measurements at a given hierarchical level	Since its publication, the hierarchy of validation cases described in G-077 has become the subject of much debate (and controversy). While the need for progressive accumulation of validation evidence is not in doubt, and many of the "building" (or learning) principles set out herein appear sound, several aspects are more questionable (for instance, the primary system being modelled by the CFD governing equations is the fluid; not the mechanical hardware bounding it - G-077 says nothing about constitutional relations or the need to differentiate on the basis of scales relevant to the flow being simulated: M, Re, Kn, Pr ..., etc.) Further comment (or critique) is considered beyond the scope of this summary.
AIAA.5 Validation Case Planning	Validation Case Planning	Plan for a set of validation checks at multiple levels, re-usable for future applications. NB: Validation is defined as the process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model.	Validation Case Plan	Model Stakeholder Requirements	Establish overall credibility of validation case, as well as reusable validation case assets. G-077 Section 4.1.
AIAA.6 Validation Case Assessment	Validation Case Assessment	As assembled set of validation checks at multiple levels, re-usable for future applications. NB: Validation is defined as the process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model.	Validation Case Evidence	Model Stakeholder Requirements	

Comparing ISO15288 and NAFEMS ESQMS (see definitions table and [5], [10])



Notes:

1. This is not a data flow or procedure—it shows which subject and referent information artifacts are compared by named NAFEMS ESQMS and ISO 15288 V&V activities.
2. ISO 15288 case shown is specific to an engineered computational model.
3. Not all of ISO 15288 V&V applicabilities to that case are illustrated

Comparing definitions: NAFEMS ESQMS (see [10])

Label in Rosetta Stone Diagram	Consistency Check	Brief Definition/Description	Subject (What Is Being Checked?)	Referent (What Is the Check Against?)	Reference in Standard/Guideline; Additional Discussion
NAFEMS.0 Validation (Model Accuracy Requirements)	Validation (Model Accuracy Requirements)	Establishment of stakeholder and technical requirements for models, in the context of application intended. This may include accuracy requirements but also other requirements, such as execution speed, user interface, or otherwise.	Model Technical Requirements -- Accuracy	Model Stakeholder Requirements	NAFEMS ESQMS Section 8.2
NAFEMS.1 Code Verification--Manufactured Solutions	Code Verification--Manufactured Solutions	Verifying the coherence of simluation outputs with a reverse solution of the computational model, by introducing a forcing function.	Output of implemented simulation.	Output of manfactured solution.	NAFEMS ESQMS Annex C Section C.1.2
NAFEMS.2 Code Verification--Order of Error	Code Verification--Order of Error	Verifying that the rate of convergence of a mesh-based simulation, as mesh size is refined, agrees with the theoretical order of error of model with respect to mesh size.	Output of an implemented mesh-based simulation, for different levels of mesh refinement.	Theoretical predicted order of error for the simulation, with respect to mesh size.	NAFEMS ESQMS Annex C Section C.1.1. (Assumes that the simulation is finite element mesh-based, as in FEA models.)
NAFEMS.3 Code Verification -- Analytical Solutions	Code Verification--Analytical Solutions	Verifying the convergence of a series of simluation outputs with progressively refined meshes, to analytical solution.	Output of an implemented mesh-based simulation, for different levels of mesh refinement.	Analytical solution and Model Technical Requirements for Accuracy	NAFEMS ESQMS Annex C Section C.1.3
NAFEMS.4 Solution Verification -- Analytical Solutions	Solution Verification--Analytical Solutions	Verifying the convergence of a series of simluation outputs with progressively refined meshes, to analytical solution.	Output of an implemented mesh-based simulation, for different levels of mesh refinement.	Analytical solution and Model Technical Requirements for Accuracy	NAFEMS ESQMS Annex C Section C.2.2
NAFEMS.5 Validation by Previous Physical Test and Extrapolation Simulation	Validation Indirectly Supported by Physical Test--Extrapolated Simulations	"Comparison of simulation results with extrapolated results from previously validated simulations of similar systems. Should be supported by a critical peer review within the quality system."	Output of implemented simulation.	Extrapolated results from previously validated simulations of similar systems, supported by critical peer review within quality system. Model Technical Requirements for Accuracy.	NAFEMS ESQMS Annex D Section D.2.3
NAFEMS.6 Solution Verification -- Error Norms	Solution Verification--Error Norms	Uses metrics on the discontinuities in the field between adjacent finite elements to estimate discretization error.	Metrics on the discontinuities in the field between adjacent finite elements, to estimate discretization error.	Model Technical Requirements for Accuracy	NAFEMS ESQMS Annex C Section C.2.1
NAFEMS.7 Validation by Fully Representative Entity Direct Physical Test	Validation Directly Supported by Physical Test--Fully Representative EntityTest Measurements	"Comparison of simulation results with specific physical test measurements for a physical entity that is fully representative for the entity of interest including the environment of interest."	Output of implemented simulation.	Specific physical test measurements of physical entity that is fully representative of the entity of interest, including environment of interest. Model Technical Requirements for Accuracy.	NAFEMS ESQMS Annex D Section D.1.1
NAFEMS.8 Validation by Similar Entity Direct Physical Test	Validation Directly Supported by Physical Test--Similar Entity Physics	"Comparison of simulation results with experimental measurements for a physical entity that is physically and geometrically representative of the entity of interest and which has a similar entity physics of interest."	Output of implemented simulation.	Experimental measurements of physical entity that is physically and geometrically similar to the entity of interest, and is characteristic of the entity of interest. Model Technical Requirements for Accuracy.	NAFEMS ESQMS Annex D Section D.1.2
NAFEMS.9 Validation by Characteristic Entity Indirect Physical Test	Validation Indirectly Supported by Physical Test--Similar and Characteristic Entity	"Comparison of simulation results with experimental measurements for a physical entity that is physically and geometrically similar to the entity of interest and is characteristic of the entity physics of interest."	Output of implemented simulation.	Experimental measurements of physical entity that is physically and geometrically similar to the entity of interest, and is characteristic of the entity of interest. Model Technical Requirements for Accuracy.	NAFEMS ESQMS Annex D Section D.2.1
NAFEMS.10 Validation by Previous Physical Test and Interpolation Simulation	Validation Indirectly Supported by Physical Test--Interpolated Simulations	"Comparison of simulation results with interpolated results from previously validated simulations of similar systems."	Output of implemented simulation.	Interpolated results from previously validated simulations of similar systems. Model Technical Requirements for Accuracy.	NAFEMS ESQMS Annex D Section D.2.2
NAFEMS.11 Validation Not by Physical Test--Alternative Math Models	Validation Not Supported by Physical Test--Alternative Math Models	"Comparison of simulation results with those from alternative mathematical models."	Output of implemented simulation.	Output of simulation results from alternative mathematical models. Model Technical Requirements for Accuracy.	NAFEMS ESQMS Annex D Section D.3.1
NAFEMS.12 Validation Not by Physical Test -- SME Review	Validation Not Supported by Physical Test--SME Review	"Expert Review by subject matter experts."	Output of implemented simulation.	Knowledge of subject matter experts. Model Technical Requirements for Accuracy.	NAFEMS ESQMS Annex D Section D.3.2

How to obtain a copy of the 2024 project report

1. Scan this QR Code
2. Download report

Questions, discussion

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References

[1] Schlesinger, S., “Terminology for Model Credibility”, *Simulation*, 32(3), 103-104, 1979.

[2] Oberkampf, W. and Roy, C., *Verification and Validation in Scientific Computing*, Cambridge U. Press, 2010.

[3] ASME VVUQ 1-2022: Verification, Validation, and Uncertainty Quantification Terminology in Computational Modeling and Simulation”, 2022.

[4] ASME V&V 10-2019: “Standard for Verification and Validation in Computational Solid Mechanics”, 2019.

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[8] “Consistency Management as an Integrating Paradigm for Digital Life Cycle Management with Learning”. Download from -- https://www.omgwiki.org/MBSE/lib/exe/fetch.php?media=mbse:patterns:aselcm_pattern_--_consistency_management_as_a_digital_life_cycle_management_paradigm_v1.3.1.pdf

[9] “All Decisions Across Life Cycles of Systems Are Reconciliations of Inconsistencies”, INCOSE North Texas Program, August, 2023. Download from -- https://www.omgwiki.org/MBSE/lib/exe/fetch.php?media=mbse:patterns:incose_north_texas_pgm_08.08.2023_v1.2.2.pdf

[10] Rogers, C., et al, “Engineering Simulation Quality Standard”, NAFEMS, UK, 2020.

[11] Walden, D., et al, eds., *INCOSE Systems Engineering Handbook*, Fifth Edition, International Council on Systems Engineering, San Diego, Ca, 2023.

[12] Schindel, W., “Innovation Ecosystem Dynamics, Value and Learning I: What Can Hamilton Tell Us?”, accepted for appearance in *Proc of INCOSE 2024 International Symposium*, Dublin, Ireland.

[13] Taylor, N., and Schindel, W., “CFD Validation: Illustrations of Mutual Accountability and Validation Dialog throughout the Engineering Lifecycle”, in *Proc of AIAA 2024 SciTech Conference*, Orlando, FL.

[14] Oberkampf, W., et al, “Computational Fluid Dynamics Simulations” (AIAA G-077-1998(2002)), Reston, VA, Published Online: 24 Sep 2014, https://doi.org/10.2514/4.472855.001

Acronyms

- AIAA - American Institute of Aeronautics and Astronautics
- ASELCM – Agile Systems Engineering Life Cycle Model
- ASME – American Society of Mechanical Engineers
- CAF – Credibility Assessment Framework
- DEIC – Digital Engineering Integration Committee
- EE – Electrical Engineering or Electrical Engineer
- INCOSE – International Council on Systems Engineering
- ISO – International Standards Organization
- ME – Mechanical Engineering or Mechanical Engineer
- MBSE – Model-Based Systems Engineering
- N^2 – N x N, indicating a square matrix with common headings on rows and columns
- NAFEMS – National Agency for Finite Element Methods and Standards
- V&V – Verification and Validation
- VVUQ – Verification, Validation and Uncertainty Quantification
- WG – Working Group

Contents

- Introduction to the Rosetta Stone Project
- Phase 1 Project Report
- Supplemental Example

Insight gained from a simple warm-up example

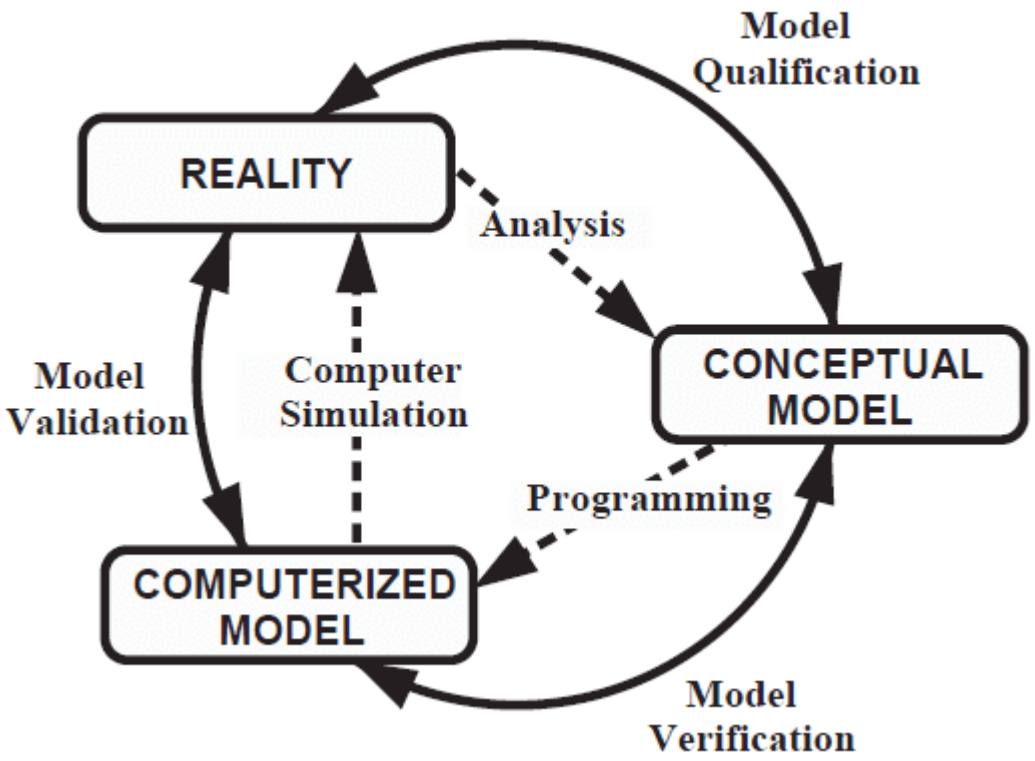
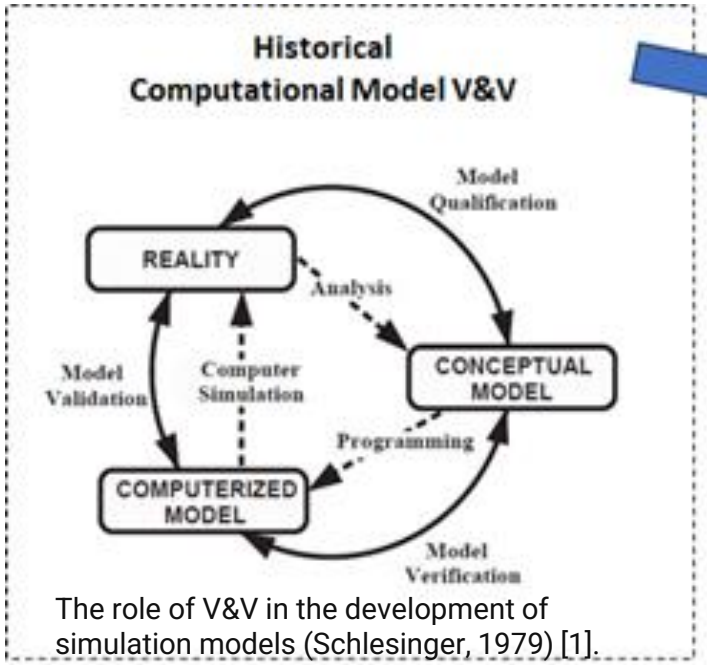
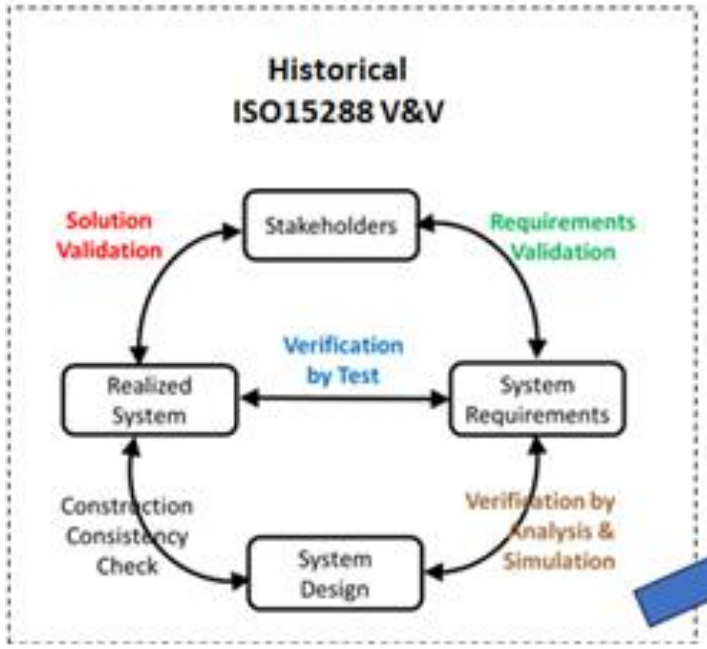


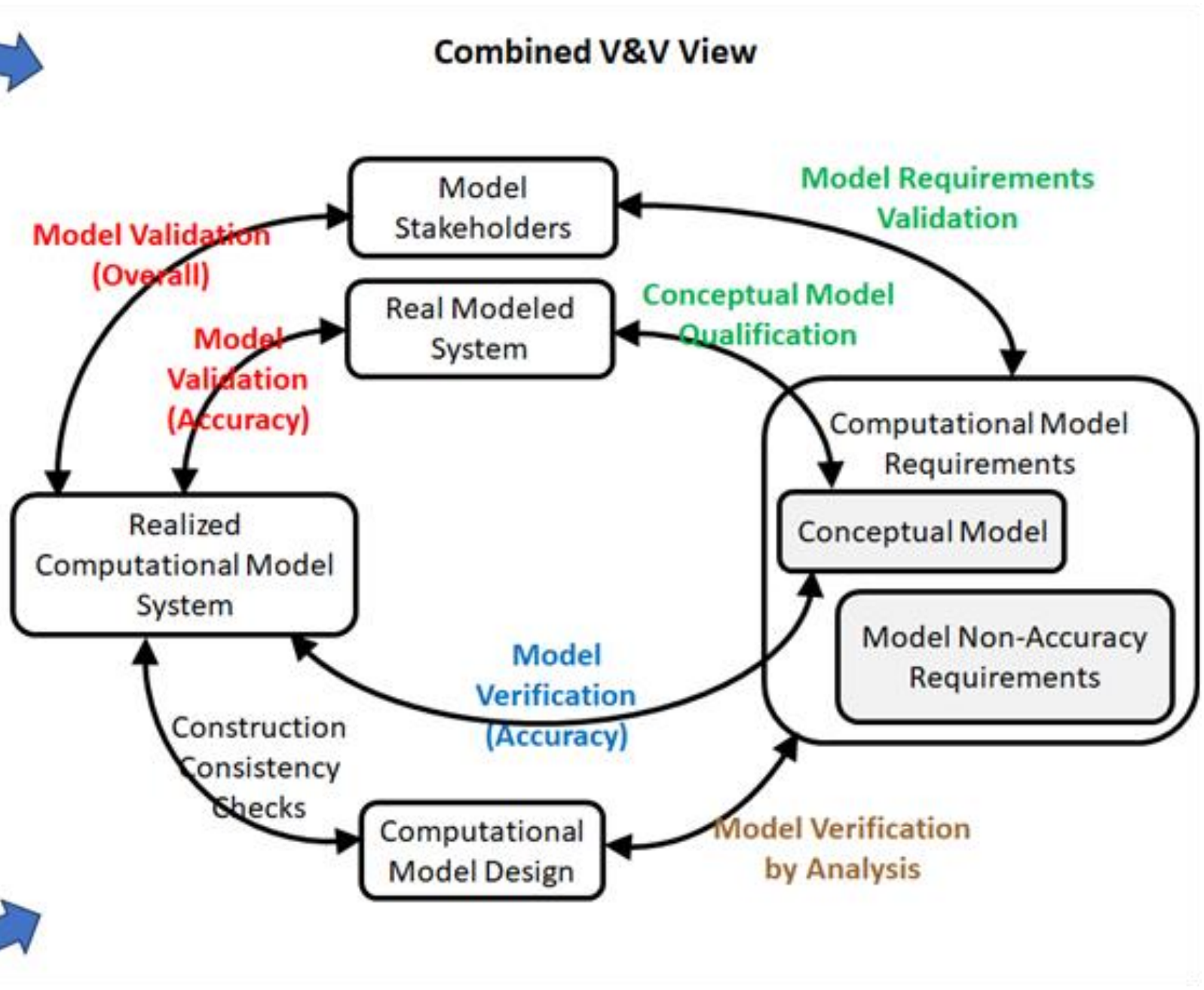
Diagram: The role of V&V in the development of simulation models (Schlesinger, 1979) [1].

- This 1979 graph diagram is somewhat dated, but is a simple example with key ideas that continue to apply.
- An informative discussion of this diagram and subsequent history is in Oberkampf and Roy (2010) [2], pp 22 and its following sections.



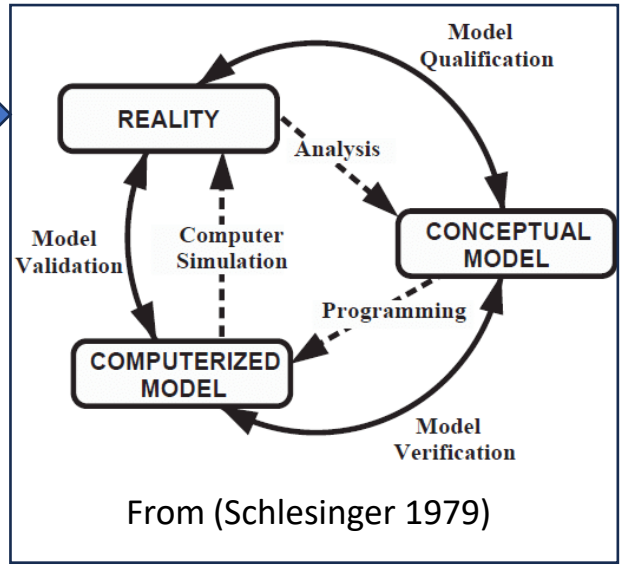
The role of V&V in the development of simulation models (Schlesinger, 1979) [1].





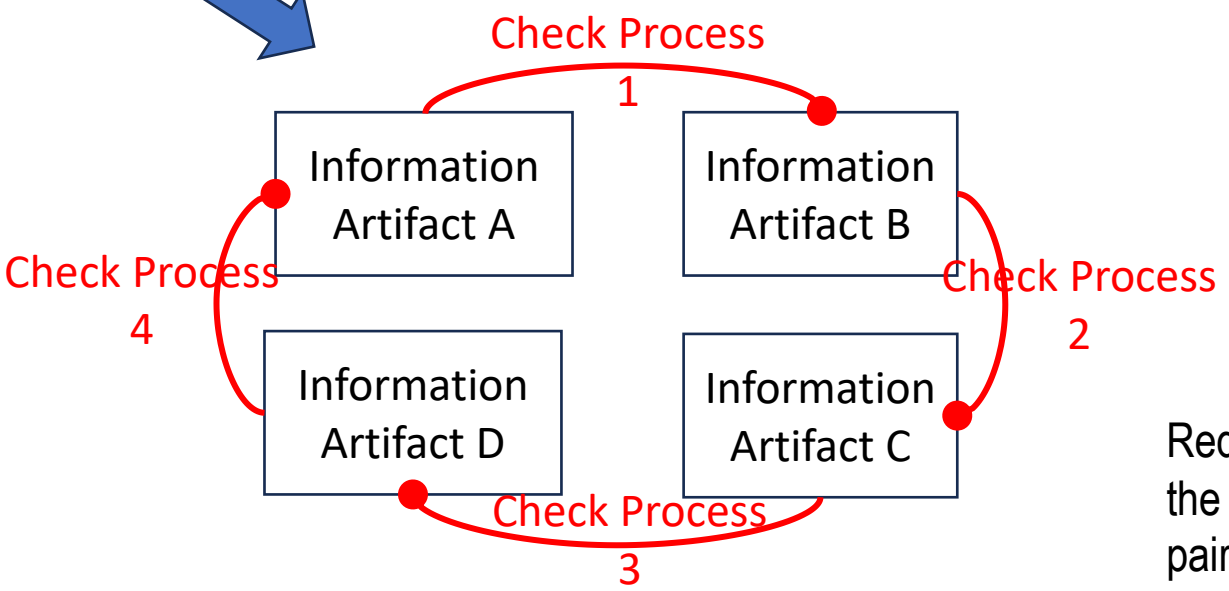
Representing " consistency management" frameworks

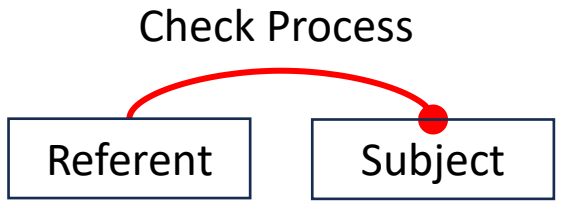
Inspired by Schlesinger's 1979 diagram.



From (Schlesinger 1979)

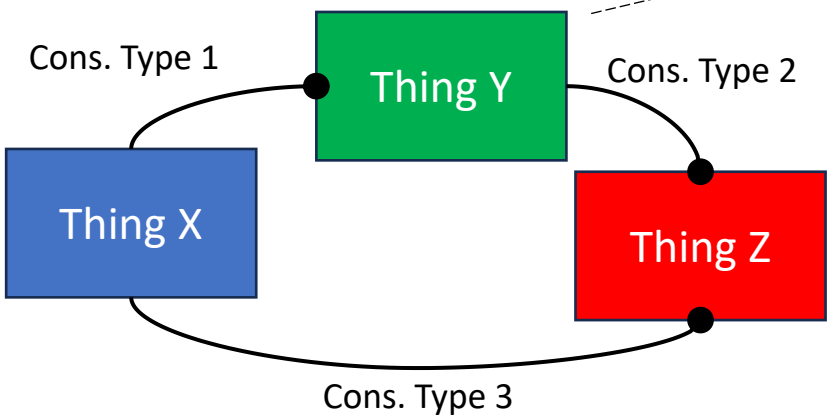
Showed what information entities (blocks) were *checked for subject-artifact consistency* by different "V&V" processes (connecting lines).





Requires identification of information artifact types and the consistency checks performed on (subject-referent) pairs of them.

More on consistency management: How linked are these entities?



		From		
		X	Y	Z
To	X			
	Y	Cons. 1		
	Z	Cons. 3	Cons. 2	

- A single “Thing” can be both a referent and subject – see Thing Y here.
- A single “Thing” can be informed by / compared to more than one referent—see Thing Z here.
- A single “Thing” can be a referent for more than one subject—see Thing X here.
- A referent can be some product of development, observation, a standard, some earlier learned reference pattern, or other suitable kind of reference.

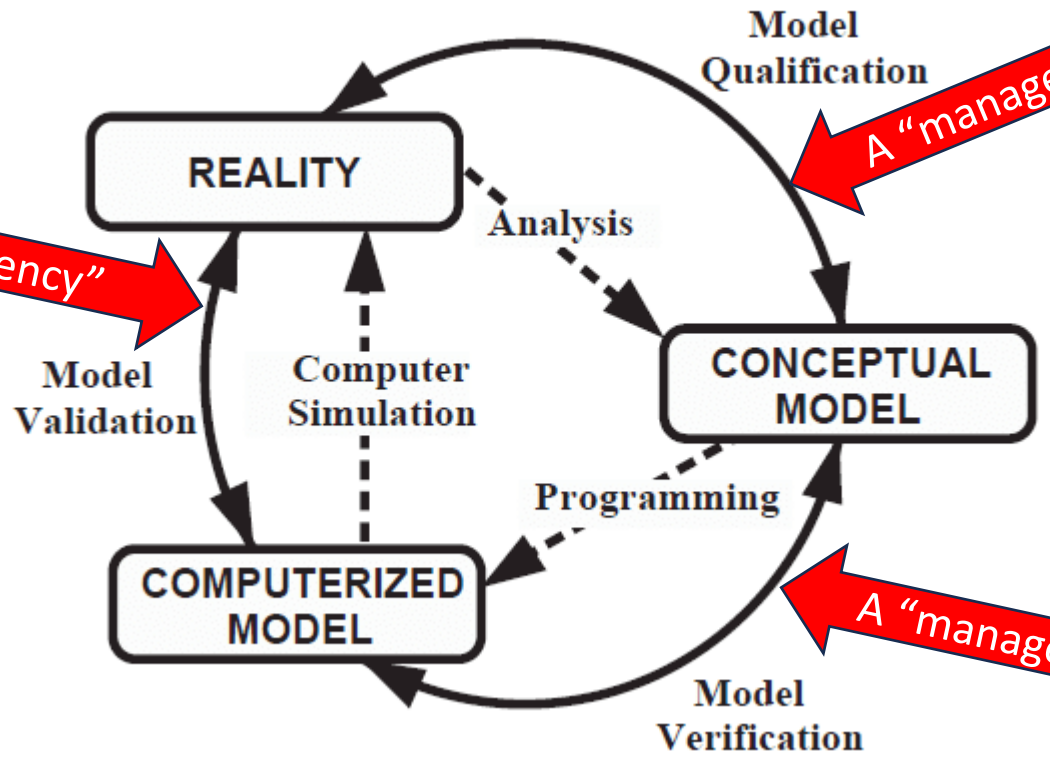
More about the example

Is the Conceptual Model suitable as a model of Reality, for the intended purpose?

A "managed consistency"

A "managed consistency"

Does the Computerized Model agree sufficiently with the Reality system that it describes, for the intended use of the model?

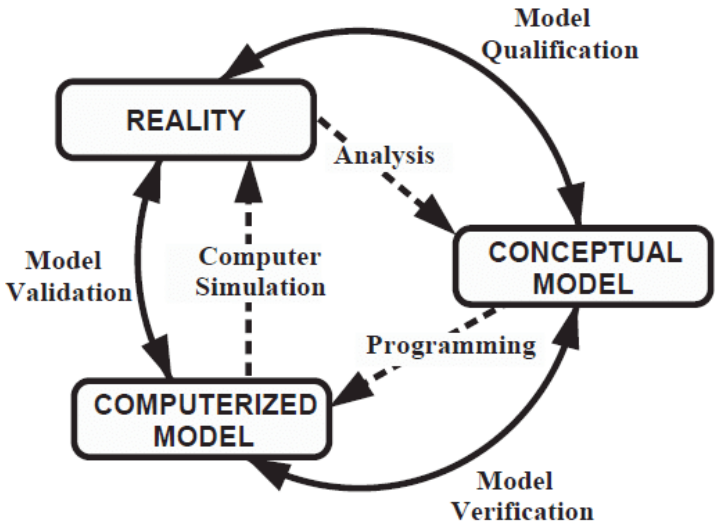


Does the Computerized Model agree sufficiently with the Conceptual Model it is based upon?

A "managed consistency"

Diagram: The role of V&V in the development of simulation models (Schlesinger, 1979) [1].

Example Matrix of Consistency Checks—Computational Model Cases in Diagram

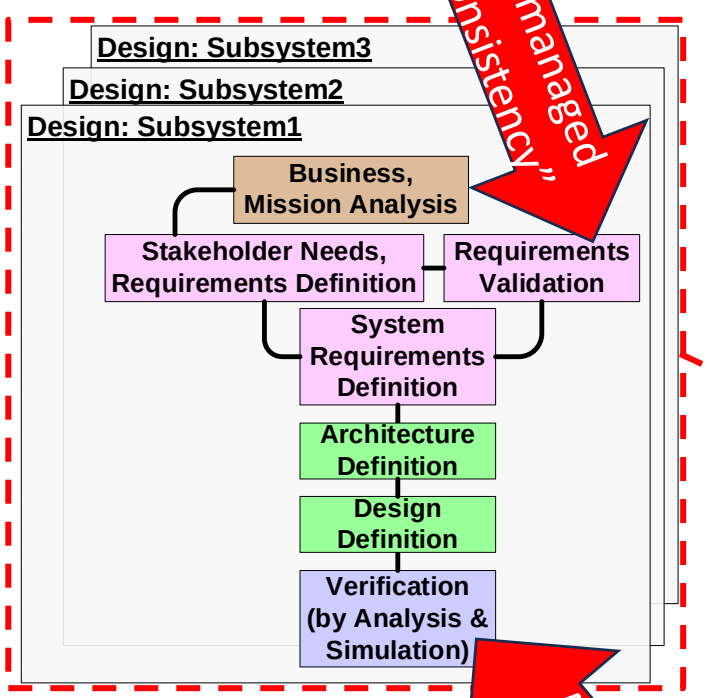


		Upstream						
		Model Stakeholders	Real Modeled System	Computational Model Requirements	Conceptual/ Math Model	Model Non-Accuracy Requirements	Computational Model Design	Realized Computational Model System
Downstream	Model Stakeholders							
	Real Modeled System							
	Computational Model Requirements							
	Conceptual/ Math Model		**Conceptual Model Qualification**					
	Model Non-Accuracy Requirements							
	Computational Model Design							
	Realized Computational Model System		**Model Validation (Accuracy)**		**Model Verification (Accuracy)**			

Do the subsystem requirements represent the stakeholder needs and "flowed down" decomposed allocated requirements adequately for purpose?

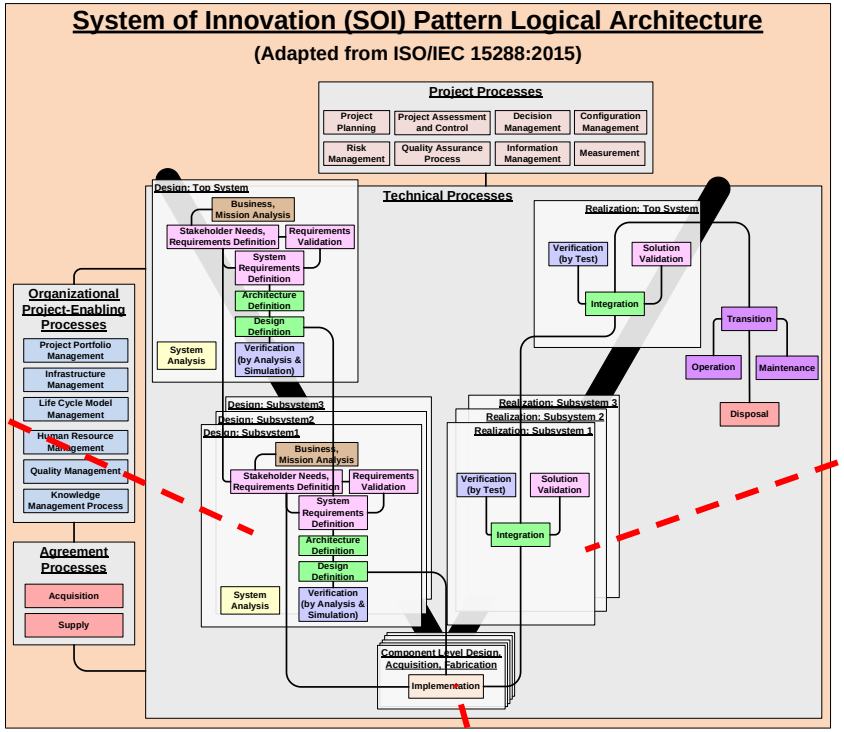
Does the implemented subsystem satisfy its stakeholders?

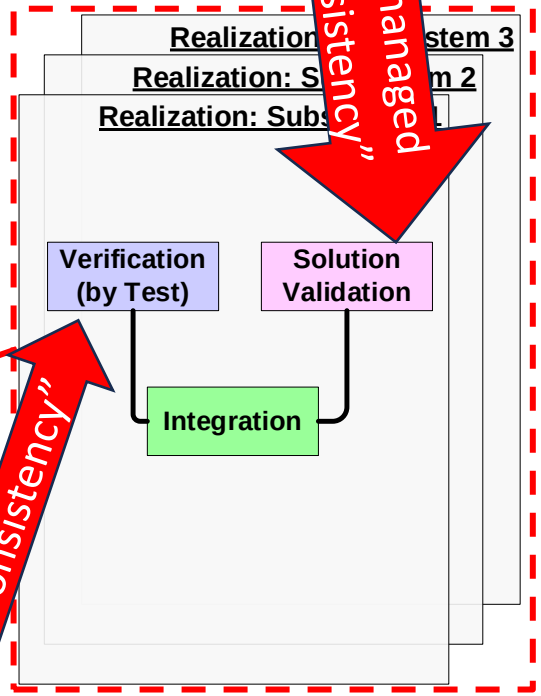
Computation Model As Engineered Subsystem: Systems Engineering "Vee" Perspective on Engineering of Systems (as in ISO15288 [5], INCOSE Handbook [11], etc.)



A "managed consistency"

A "managed consistency"





A "managed consistency"

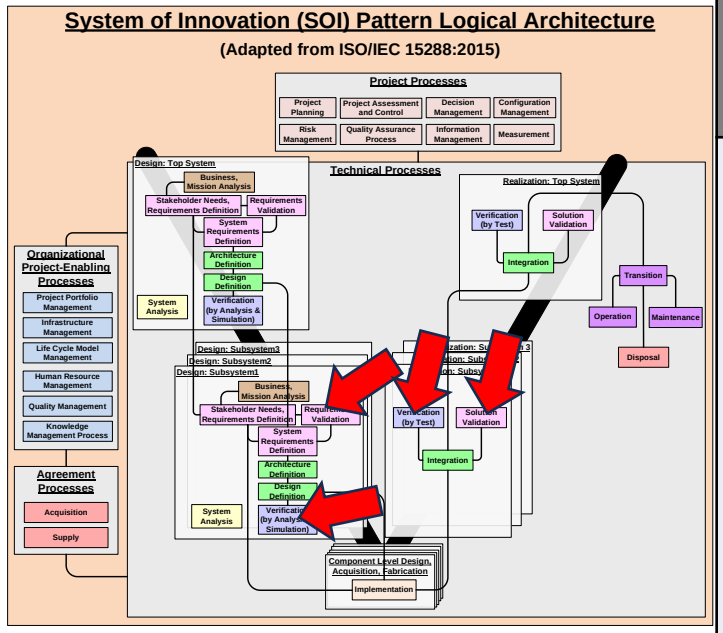
Component Level Design, Acquisition, Fabrication

Implementation

Will the designed subsystem predictably behave in sufficient agreement with its requirements?

Does the implemented subsystem behave in sufficient agreement with its requirements?

Example Matrix of Consistency Checks—Engineered System Cases in Diagram



		Upstream						
		Model Stakeholders	Real Modeled System	Computational Model Requirements	Conceptual / Math Model	Model Non-Accuracy Requirements	Computational Model Design	Realized Computational Model System
Downstream	Model Stakeholders							
	Real Modeled System							
	Computational Model Requirements	**Model Requirements Validation**						
	Conceptual/ Math Model							
	Model Non-Accuracy Requirements							
	Computational Model Design			**Model Verification by Analysis**				
	Realized Computational Model System	**Model Validation (Overall)**					**Construction Consistency Checks**	