SYSTEMS ENGINEERING RESEARCH CENTER

Study of Equivalence in Systems Engineering within the Frame of Verification and Systems Theory

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PhD Candidate

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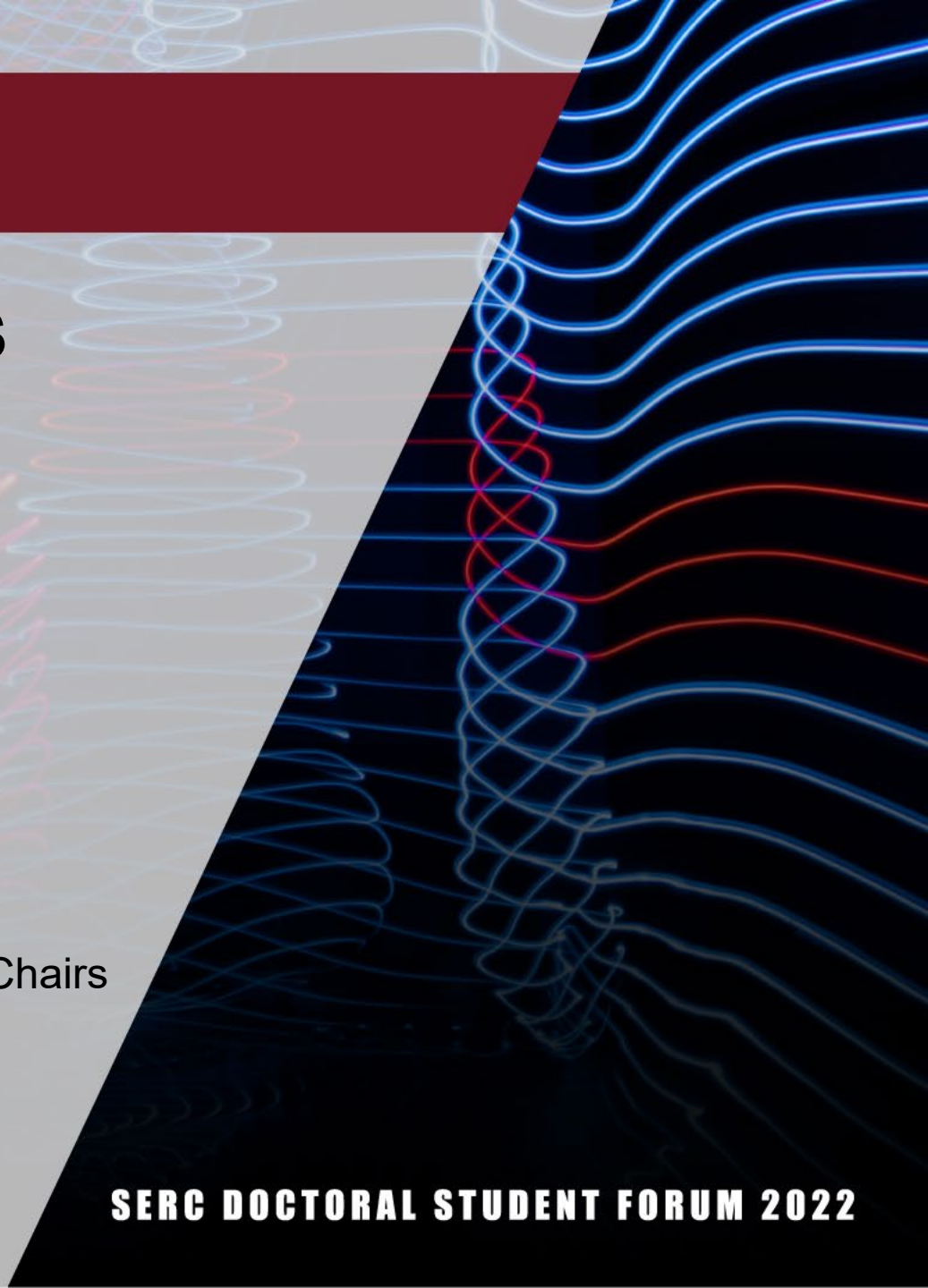
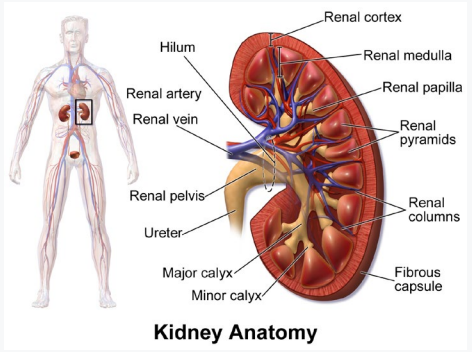
NATIONAL SECURITY INSTITUTE
VIRGINIA TECH



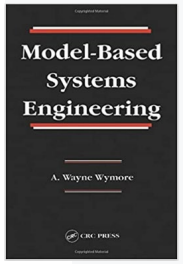
SERC DOCTORAL STUDENT FORUM 2022



Kidney Anatomy

MEDICAL COLLEGE OF GEORGIA AUGUSTA UNIVERSITY 1828

AEROSPACE



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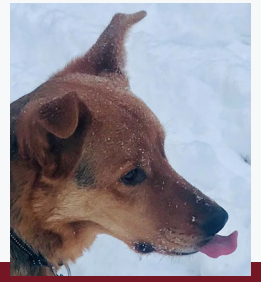
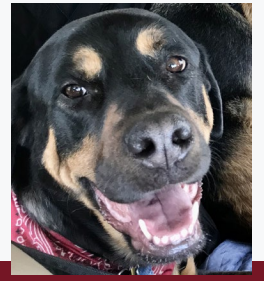
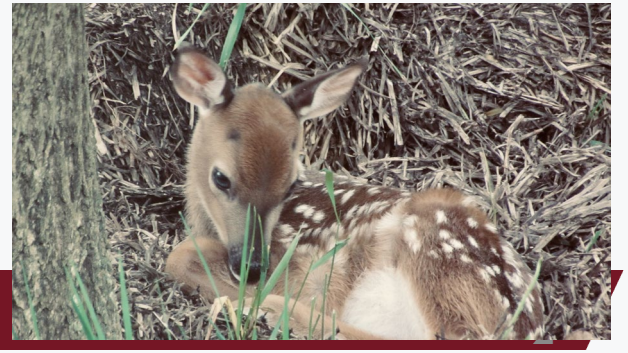
Paul Wach - Visual Bio

EAGLE SCOUT BOY SCOUTS OF AMERICA BE PREPARED







What to do you think when you hear/read…?

Mass mock-up

Pedigree

Breadboard

Verification Model

Fidelity

Prototype

Based on what relationships do we define verification models?

Are the relationships explicit/implicit and/or descriptive/analytical?

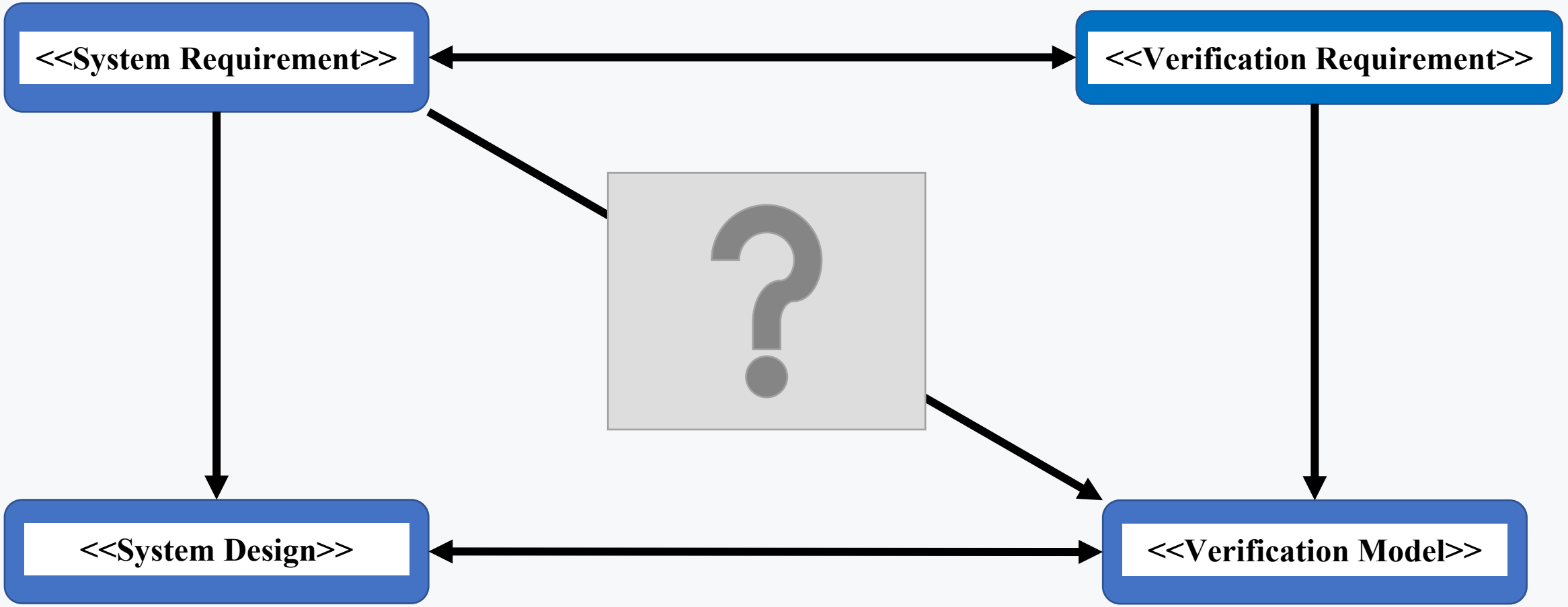
What is verification?

*Is this intuitively consistent with current SE practice?

**Do we mathematically define these relationship?

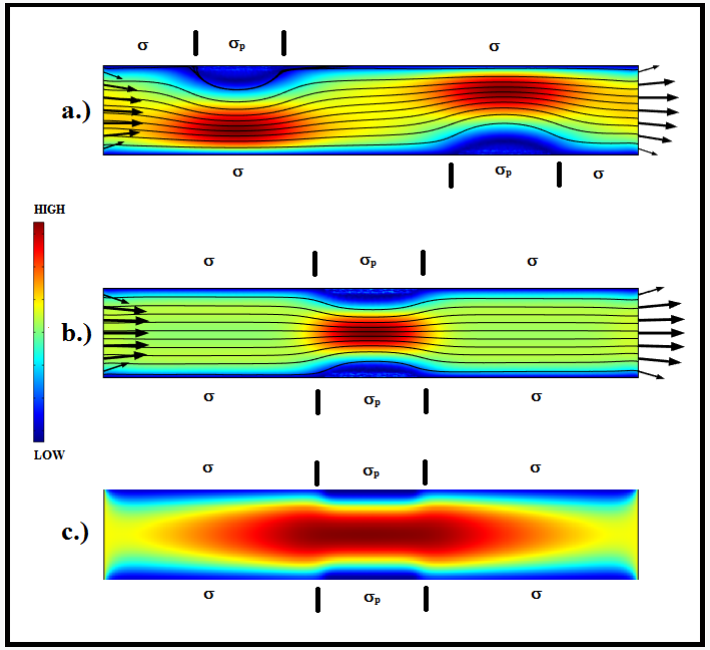
**What assumptions are made?

Base on what relationships do we define verification models?

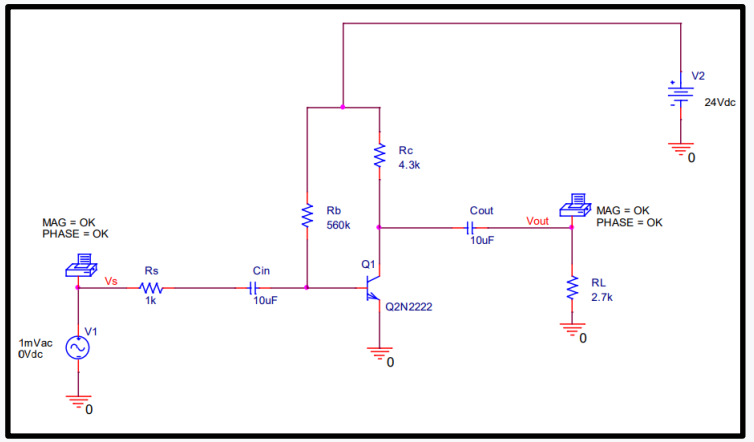


Why is this important?
Mathematical Theory in Other Domains

- Current forms of MBSE are descriptive and do not have theoretical foundations
- Other engineering domains have theoretical foundations upon which software platforms are implemented
- Reinvigorated calls for theoretical foundations of SE

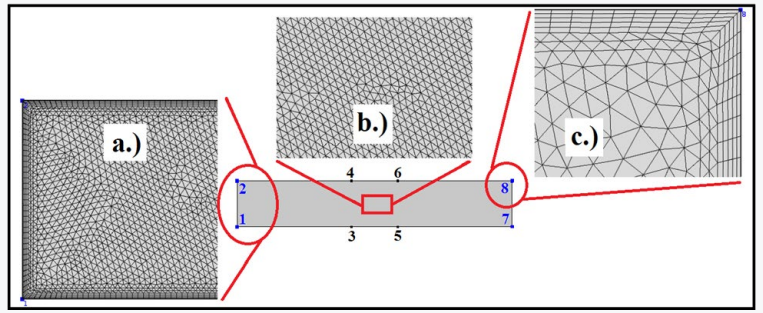


PSpice



https://engineering.purdue.edu/~ee255/lecturesupp_files/PSpice-Tutorial.pdf

<< Computational fluid dynamics



^ Finite element analysis ^

Define research question → [1] Literature Review → Characterize current state, including gaps

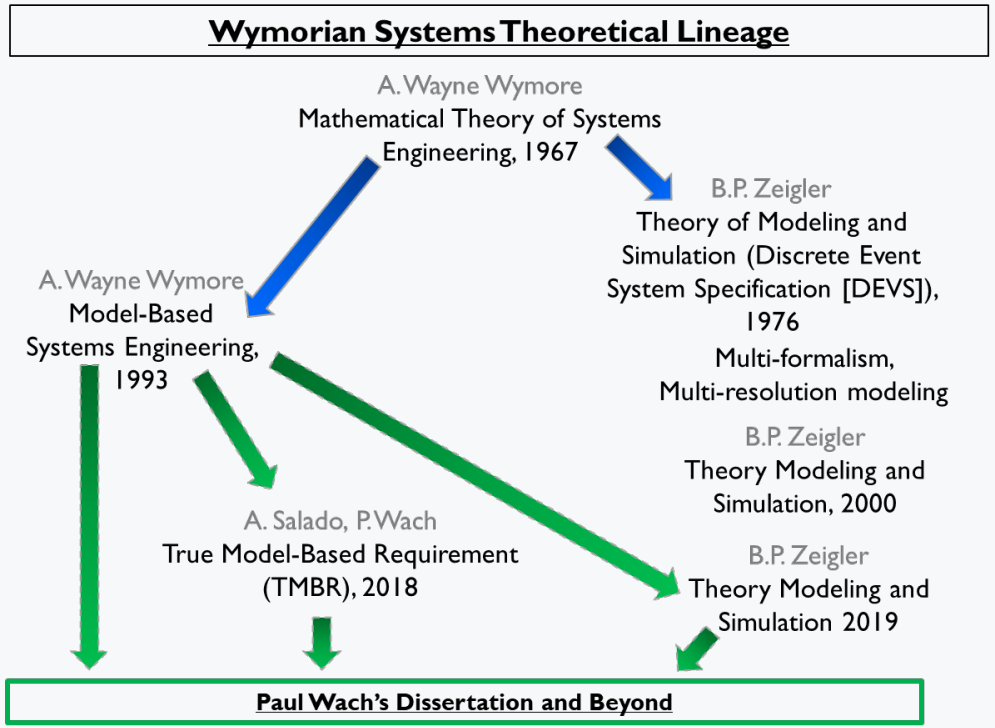
Based on what relationships should we define verification models?

Hypothesis:

We should define **verification models (VM)** based on theoretical relationships to/from/between:

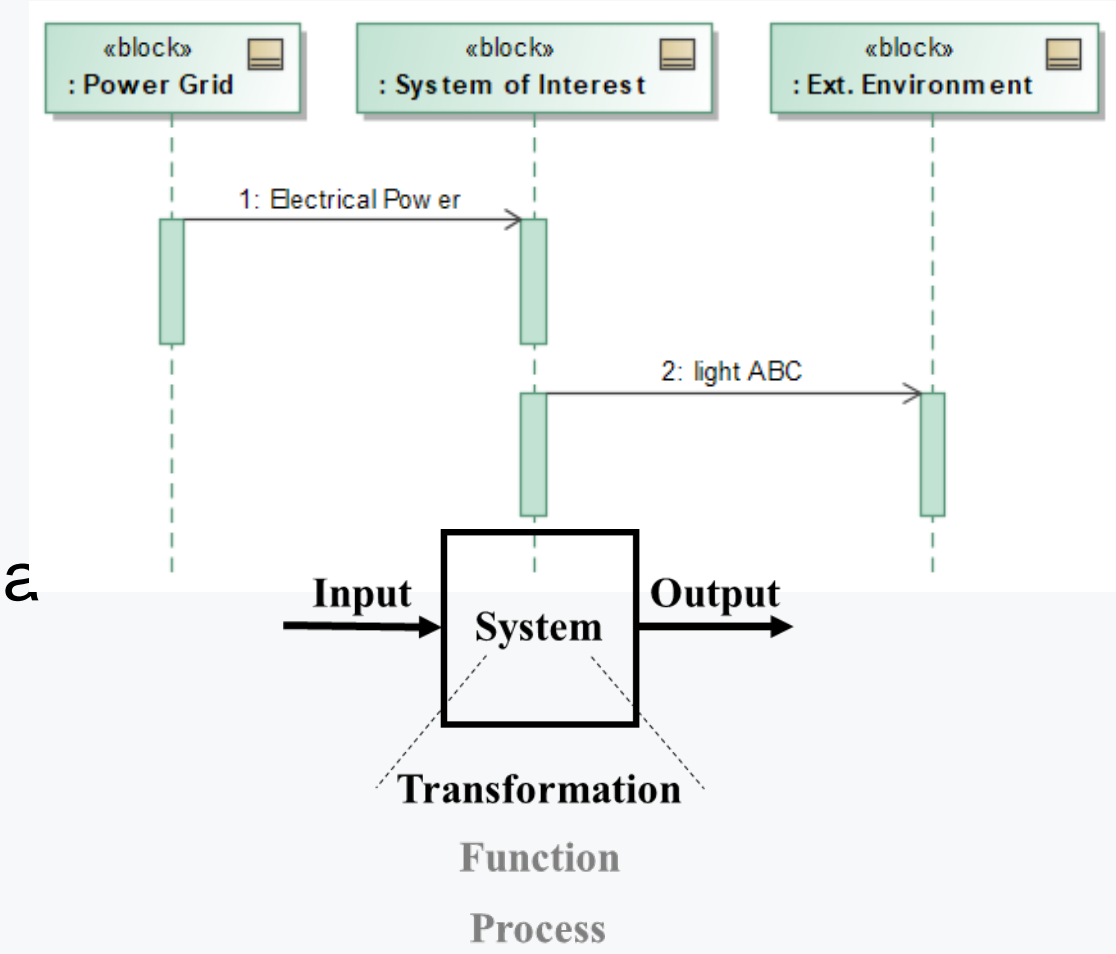
- **System Requirements (SR)**
- **Verification requirements (VR)**
- **System Designs (SD)**

Review of the literature reveals gaps as well as potential theoretical foundations



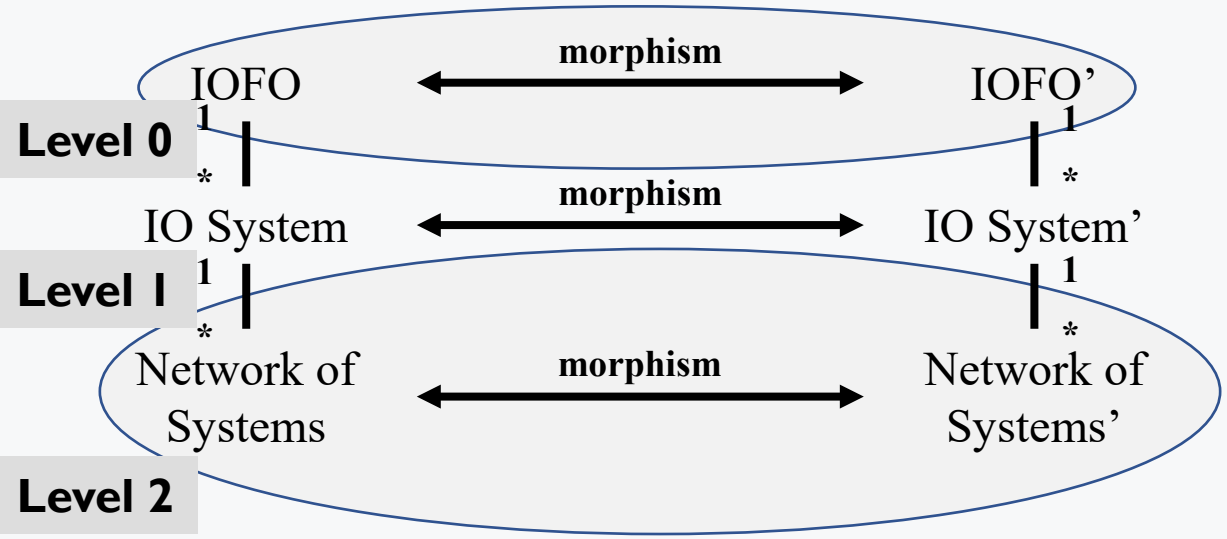
Theory of Problem Spaces of Functions

- WymorianSystems Theory:
  - An open system is defined as a transformation of inputs into outputs
- All **system requirements** can be modeled as required transformations of inputs into outputs
- Dissertation adds that aspects of a verification requirement may be captured problem spaces of functions
  - **Verification requirement problem spaces (VRPS)**

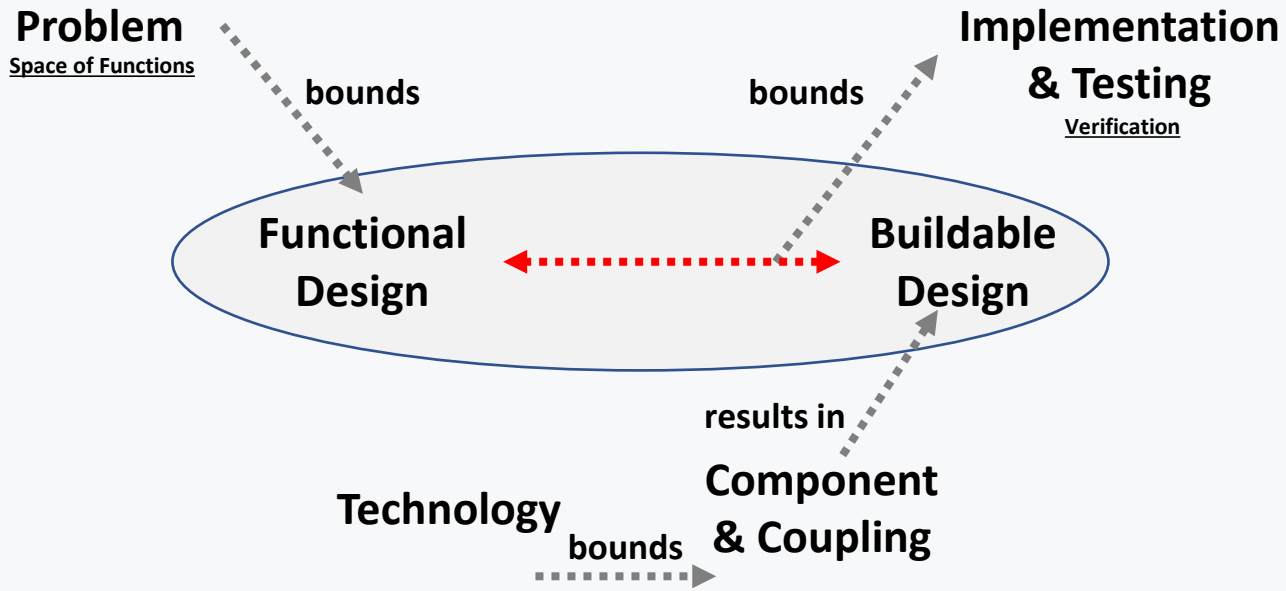


Further Wymorian Systems Theory

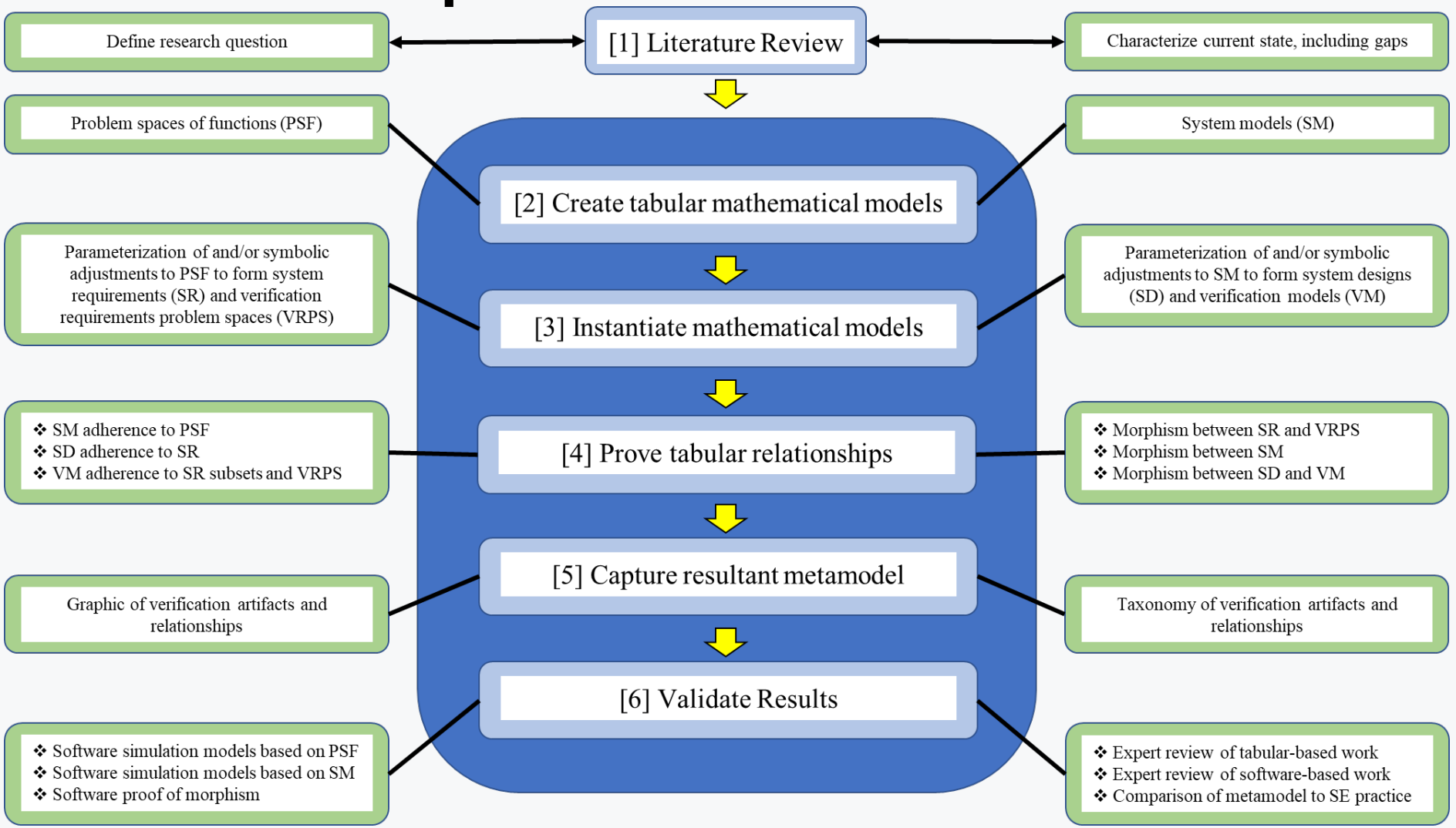
Theory of Modeling and Simulation (DEVS)…computational systems theory



Tricotyledon Theory of System Design (T3SD)…MBSE



HarnessingWymorian Systems Theory to address the research questions

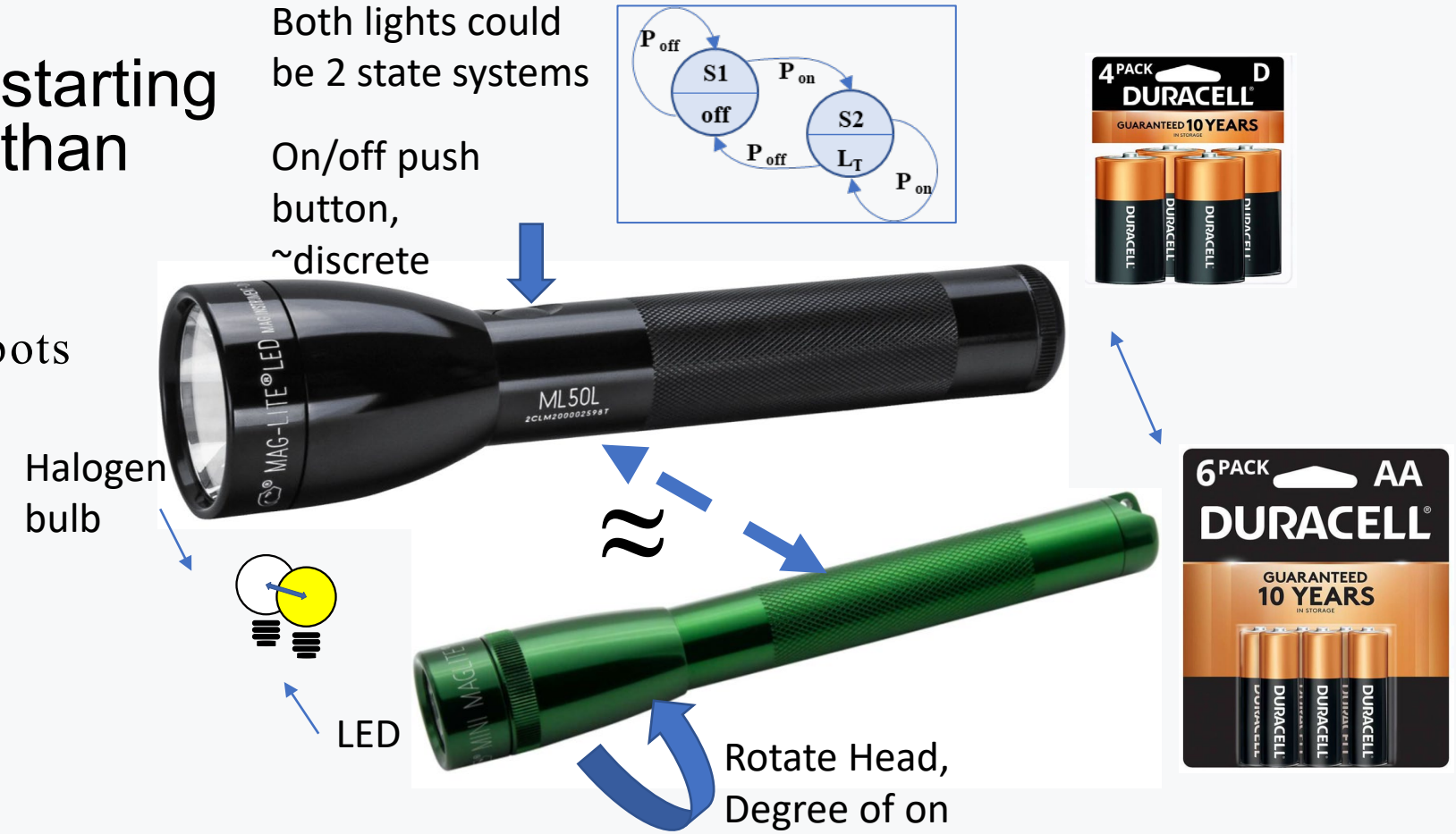


- Mathematical structures are independent of domain instantiation
- Manual:
  - Mathematical proof
  - Expert and software validation
- Metamodel summarizes outcome

‘Out of simplicity arises complexity’

-Systems Thinking Made Simple, Derek Cabrera

- “There be dragons” of starting with complexity rather than simplicity
  - Considered:
    - LEGO/Arduino-based robots
    - Drones/UAVs
- Focused on:
  - Simple
  - Discrete
  - Deterministic
  - Open systems



Tabular mathematical models and their instantiation

Problem spaces of functions (PSF) and System requirements (SR)

- PSF
  - Seven subsets of one superset
  - Defined at Level 0
- SR
  - Instantiated superset of PSF
  - On/off-commands
  - Yellow-light
  - Water-resistances
- SR subsets
  - Explore assumptions of treating individual SR as orthogonal

PSF and Verification requirement problem spaces (VRPS)

- VRPS
  - Instantiated subsets of PSF
  - VRPS1 – pizza
  - VRPS2 – on/off/yellow-light
  - VRPS3 – water resistance
  - VRPS4 – on/off/blue-light
  - VRPS5 – 0/1

Tabular mathematical models and their instantiation

System Models (SM)

- SM
  - Thirteen SM
  - Seven defined at Level 1 (no-components defined)
  - Six defined at Level 2 (components and coupling)

System Designs (SD)

- SM instantiated to form SD
  - SD1 – 2-state, L1
  - SD2 – 3-state, L2
  - SD3 – paired with SD1
  - SD4 – paired with SD2

Tabular mathematical models and their instantiation: Verification Models

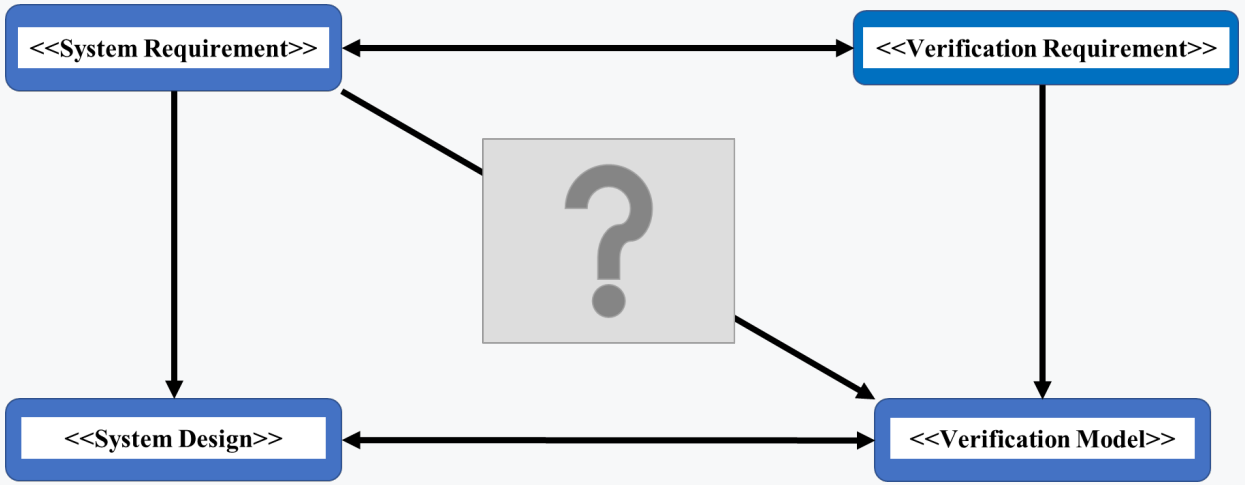
- VM1
  - SD1
- VM2
  - SD2
- VM3
  - SD3
- VM4
  - SD4
- VM5
  - SD1-based, water-proof
- VM6
  - Yellow-light, 2-state
- VM7
  - 0/1
- VM8
  - Blue-light, 2-state
- VM9
  - Blue-light, 3-state
- VM10
  - RGB ink pen
- VM11
  - pizza
- VM12
  - fireflies
- VM13
  - Hand-radio
- VM14
  - Pressure vessel
- VM15
  - Dry-bag
- VM16
  - Dry-bag w/ fireflies
- VM17
  - Water-proof hand-radio
- VM18
  - Submarine w/ yellow-light

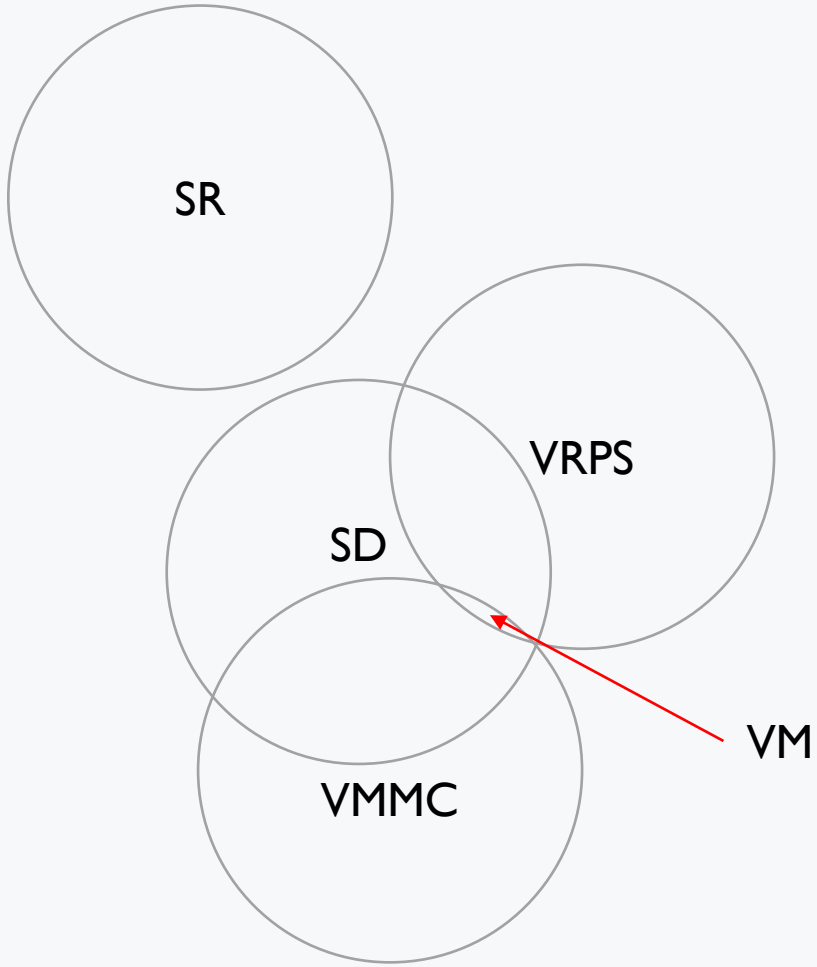
Verification Model Morphic Conditions (VMMC) …for equivalence between VM and SD

Morphisms	Summary description	Notional example
Homomorphism	A mapping of the preservation of equivalence between a pair of system specifications of the same algebraic structure	One mechanical spring to another mechanical spring
Isomorphism	Is a homomorphism with a one-to-one mapping	Mechanical spring to electric circuit
Parameter morphism	A mapping of the preservation of equivalence between parameters spaces of a pair of system specifications	Parameters of the mechanical spring to parameters of the electric circuit
Identity parameter morphism	Is a parameter morphism with an equality between parameter values and units	Parameters of a mechanical spring to parameters same (or potentially another) mechanical spring
Identity isomorphism	Is an isomorphism with equality mapping in underlying mathematical structure and parameter space	The same mechanical spring to the same mechanical spring

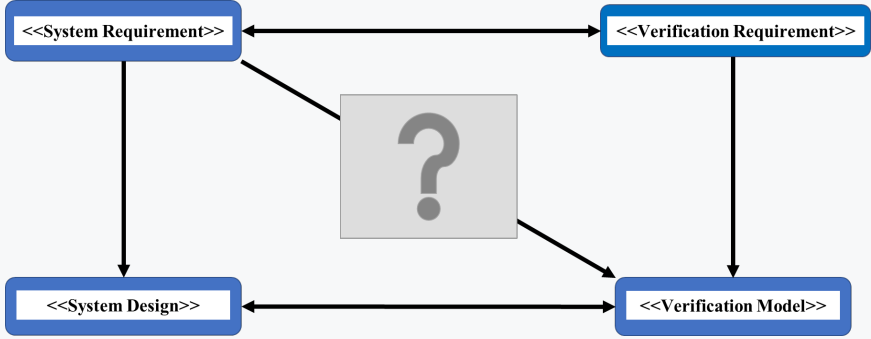
- Morphism(s) may occur at:
  - L0 between PSF/SR/VRPS
  - L1/L2 between SM/SD/VM
- Parameters are associated with:
  - input/output (I/O) items
  - physical interfaces (IF)
- VMMC define conditions of desired pedigree between the VM and SD; examples:
  - L1 homomorphism
  - L2 identity isomorphism
- Note(s):
  - Equivalence vs equality
  - Pedigree vs fidelity

Resultant Metamodel of Verification Artifacts?





Resultant Metamodel of Verification Artifacts



<<Verification Requirement>>

<<System Requirement>>

<<Morphism>>

<<Verification Requirement Problem Space>>

<<Refers to>>

<<Bounds>>

<<Verification Model Morphic Condition>>

<<Bounds>>

<<Sets conditions for>>

<<Adheres to>>

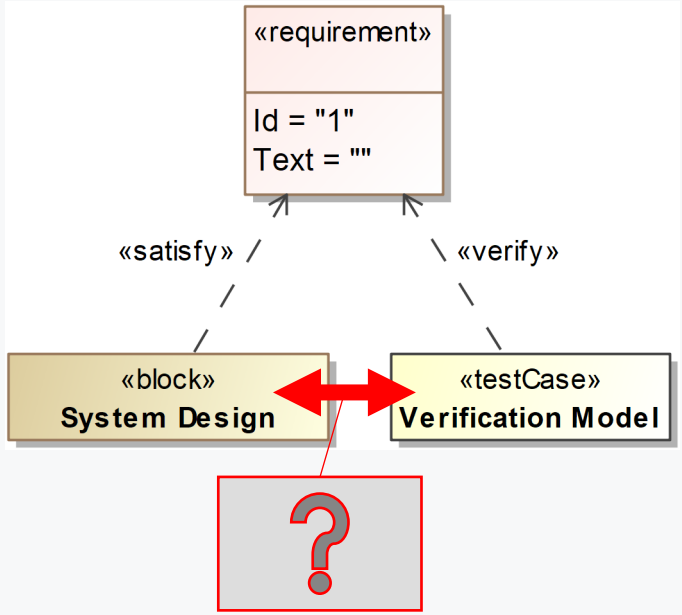
<<Morphism>>

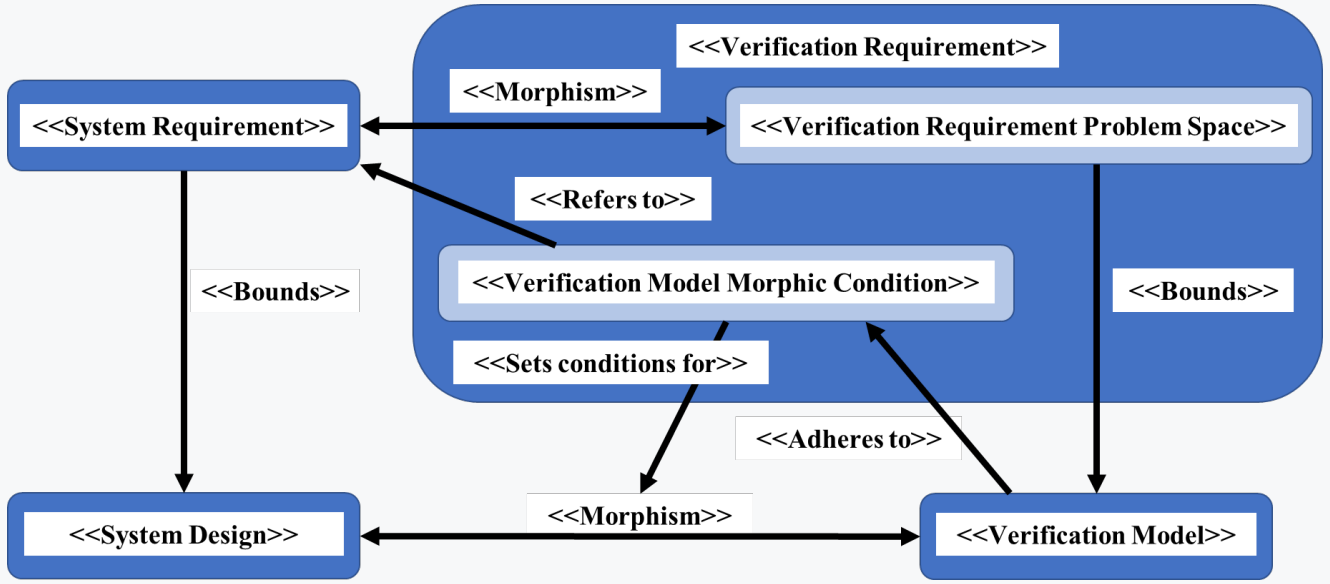
<<System Design>>

<<Verification Model>>

Research Outcome

- Comparison to state of SE practice confirms uniqueness of research
  - E.g.; SysML v1.6 implicit/descriptive versus explicit/analytical
- The results suggest that VM should be defined based on:
  - Mathematically characterized interrelationships between SR, SD, and VR consisting of VRPS and VMMC
- Gap in SE research/practice identified and new area of study opened





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THANK YOU

Stay connected with us online.

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