A Framework for Systems Engineering Research

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Why research?

For an engineering field to be taken seriously amongst other engineering disciplines, (Valedri & Davidz, 2007):

- it must have a solid theoretical basis that
- underpins the system engineering methods and processes as valid and consistent.

What is research?

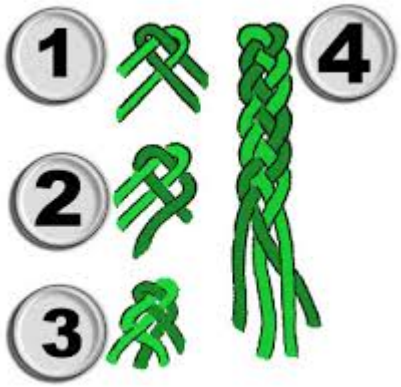
- Research consists of a whole continuum of research designs that cover a spectrum from (Marais 2012):
  - the soft science to that of
  - the hard sciences.

- It is a human activity to gain knowledge about our world
- It is one of the ways in gaining knowledge about our world with a rigid skeptical criticizing function associated with it
- It has a proven method (Scientific Method)

How to do research?

- We already know from various researchers that it is difficult to do research in systems engineering

  (Rhodes & Valderi 2007) (Valderi & Davidz 2009) (Sparrius 2011)



- Do you follow the methods of the hard sciences or that of the soft sciences, in other words,
  - Is systems engineering a hard engineering discipline or is it a management discipline?

Research in Systems Engineering

- Systems engineering has many facets and to choose only one type of research design is naïve and problematic.

- A necessity for hybrid research methods in systems engineering exists (Rhodes & Valderi 2007).

New frontier

Valderi & Davidz (2009) states that empirical research in systems engineering is a new frontier with many challenges that includes:

- Conducting the empirical research in the field.
- Threats to validity associated with data collection.
- Considering empirical mixed-methods research.

What mindset is required?

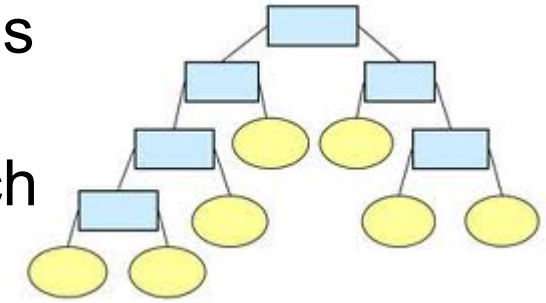
"mindset" *{noun}*

a set of beliefs or a way of thinking that determines one's behavior, outlook and mental attitude.

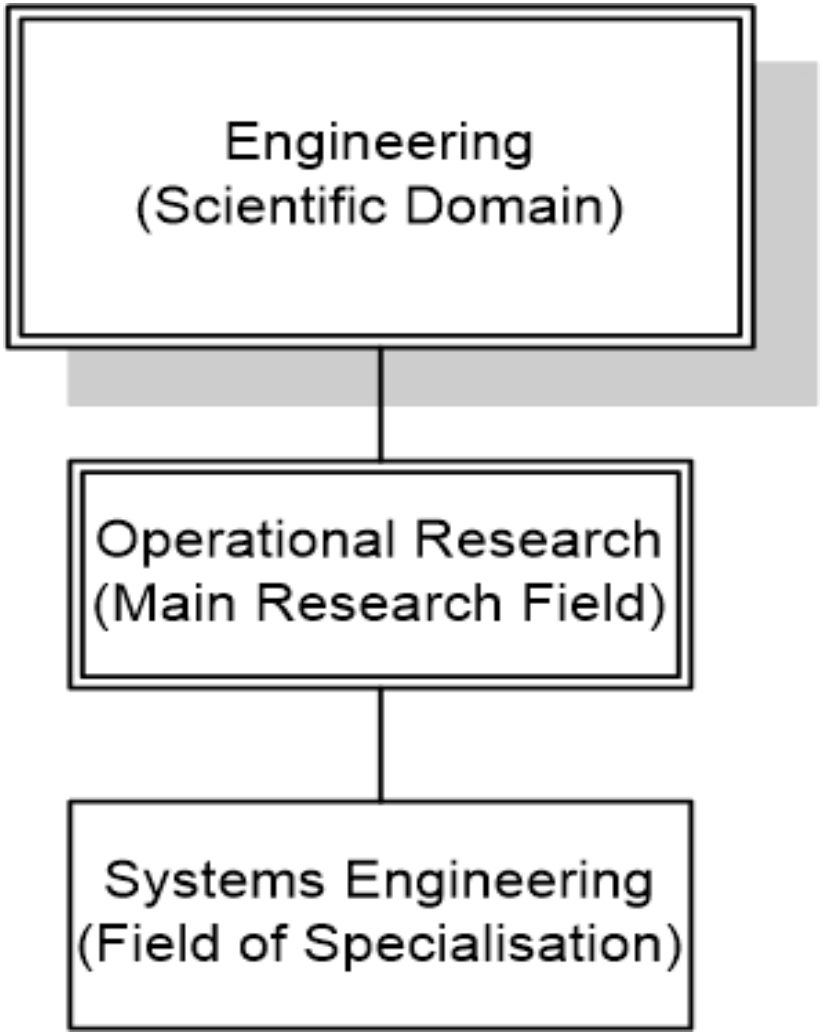
- Systems Engineering requires a post-modernistic mindset in which the measurements are defined relative to the subject under investigation.

Classification of Systems Engineering Research

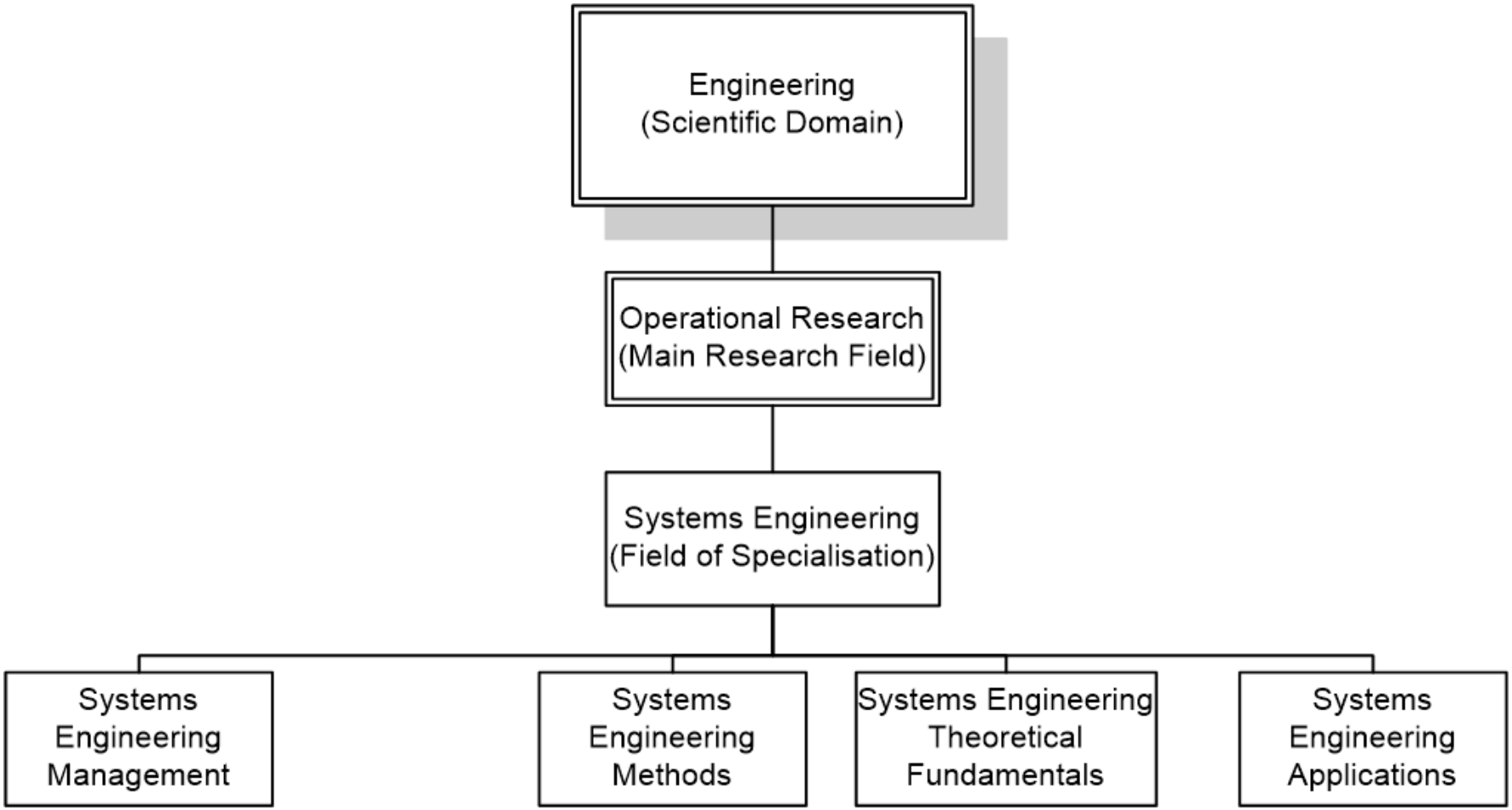
An academic research programme for systems engineering in South Africa needs a classification in terms of the National Research Foundation's (NRF) framework for evaluating research output.



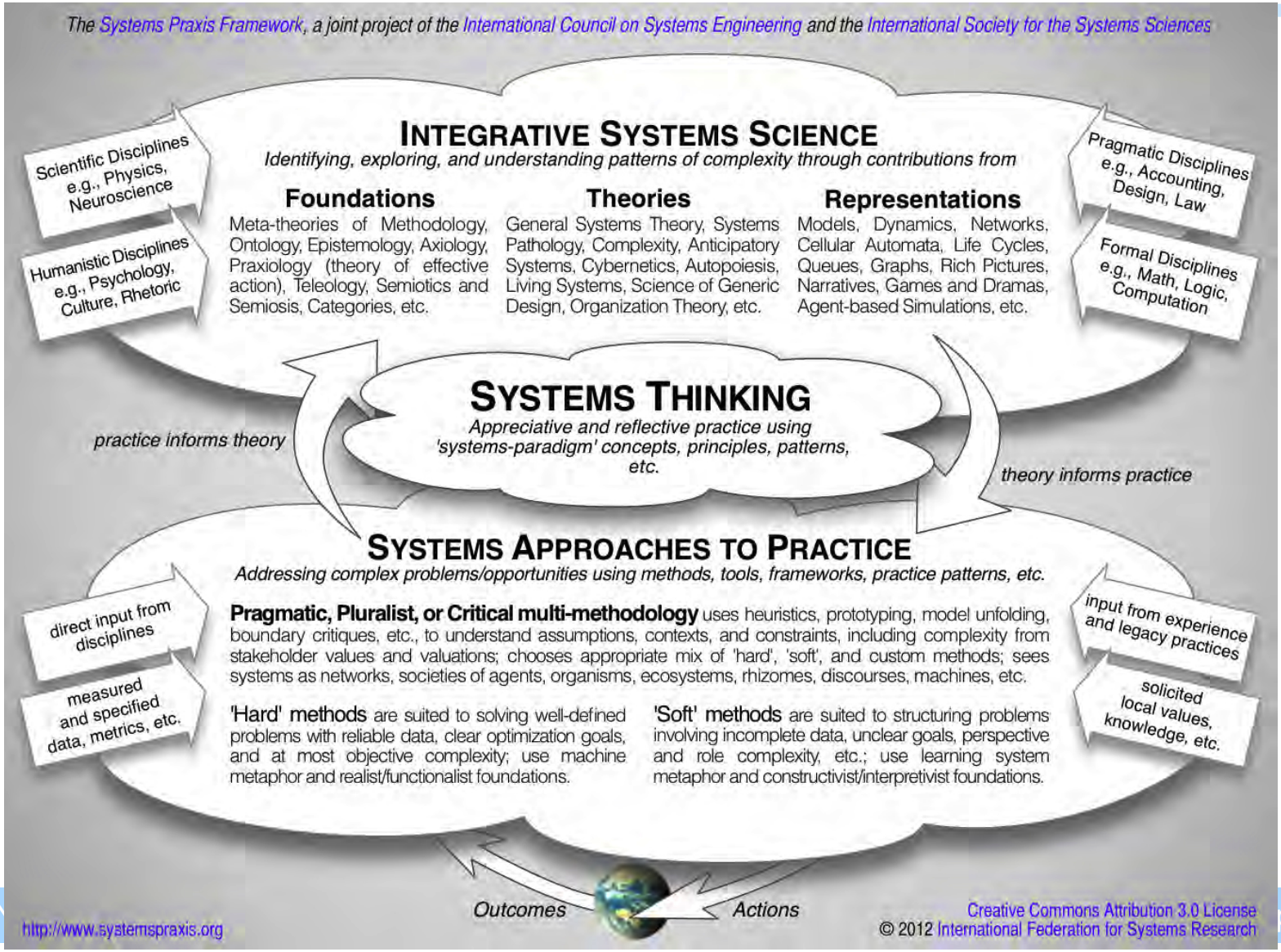
Classification of Systems Engineering Research



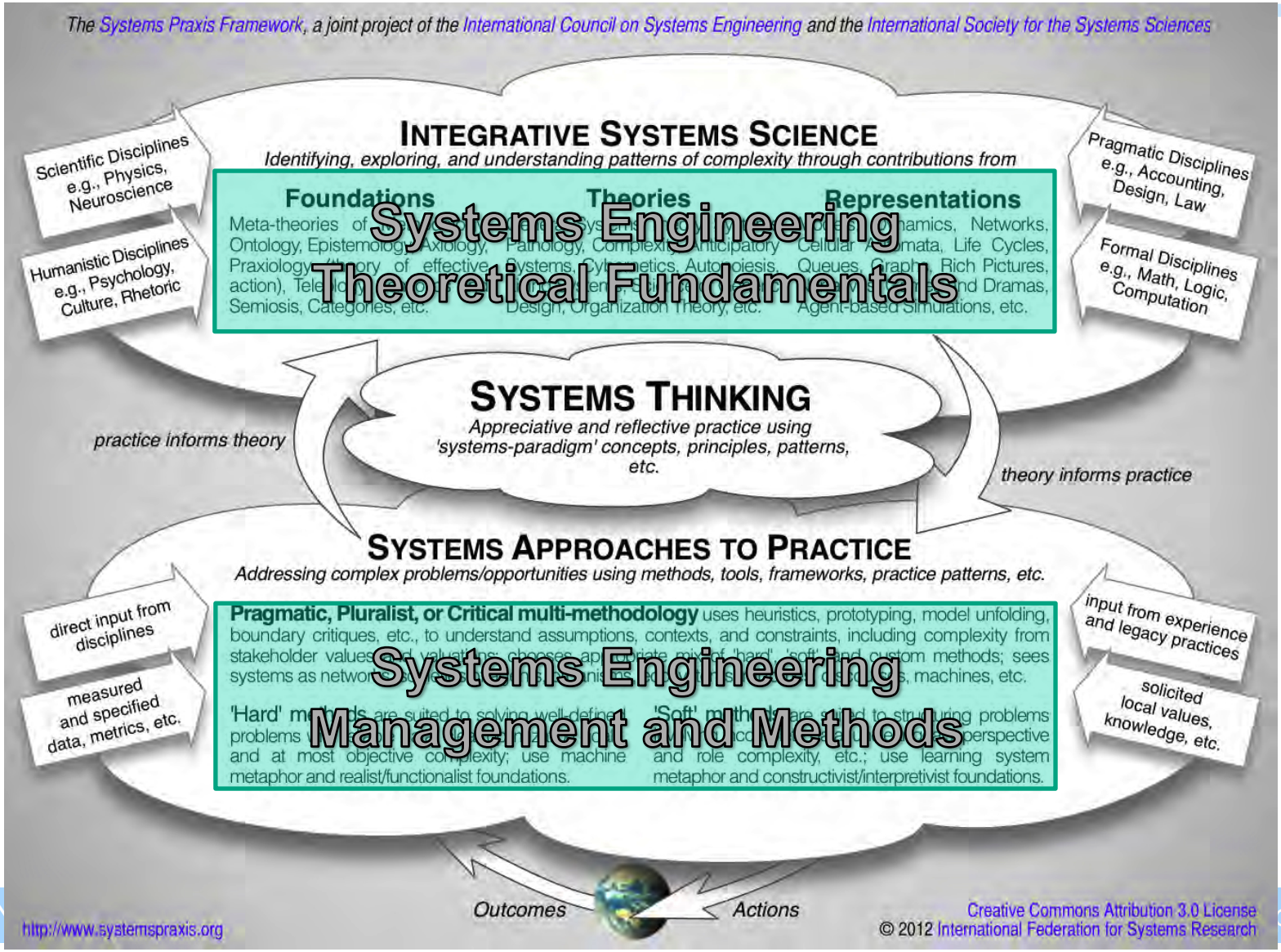
Research Areas

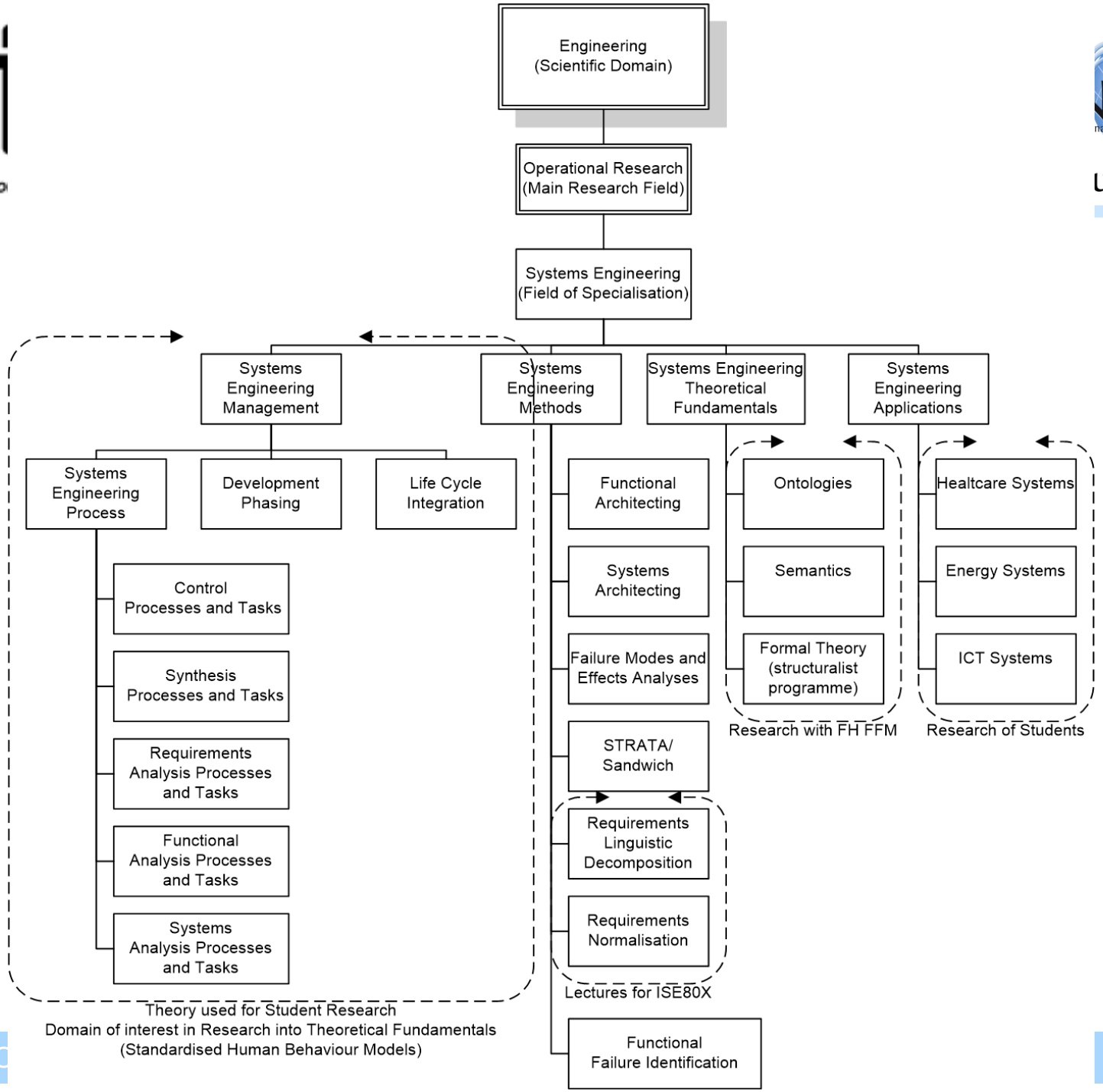


Systems Praxis Framework



Systems Praxis Framework




Engineering
(Scientific Domain)
Operational Research
(Main Research Field)
Systems Engineering
(Field of Specialisation)
Systems Engineering Management
Systems Engineering Methods
Systems Engineering Theoretical Fundamentals
Systems Engineering Applications
Systems Engineering Process
Development Phasing
Life Cycle Integration
Control Processes and Tasks
Synthesis Processes and Tasks
Requirements Analysis Processes and Tasks
Functional Analysis Processes and Tasks
Systems Analysis Processes and Tasks
Functional Architecting
Systems Architecting
Failure Modes and Effects Analyses
STRATA/ Sandwich
Requirements Linguistic Decomposition
Requirements Normalisation
Functional Failure Identification
Ontologies
Semantics
Formal Theory (structuralist programme)
Healtcare Systems
Energy Systems
ICT Systems
Research with FH FFM
Research of Students
Lectures for ISE80X
Theory used for Student Research
Domain of interest in Research into Theoretical Fundamentals
(Standardised Human Behaviour Models)

Research Method Used

- Structuralist philosophy of science

  (Balzer, Moulines & Sneed, 1987)

- Not to be confused with structuralism

- It is the method used by Nobel Prize winners since 1970's

Formal Theory

Definition 4 (Theory)

$$T(x) \iff x =< < O_1, ..., O_n >, < R_1, ..., R_m, f_1, ..., f_k >, A >$$

with

O_i *representing a set of objects,*

R_i *representing relations,*

f_i *representing functions and mappings, and*

A *representing the axioms of the theory.*

In the above definition A is the axioms, and O_i, R_i as well as f_i are part of the inference rules in figure 1.2 on p. 8.

For every relation or function, a type can be given by stating the structure of either the set or sets to which it belongs, [36, 35], e.g.

$$\begin{aligned} R_i &\subseteq O_1 \times \mathbf{2}^{(O_1 \times O_2)} \\ f_j &\subseteq \mathbf{2}^{(O_1 \times O_2)} \times O_3 \end{aligned}$$

The axioms describe laws or definitions in the domain of the theory's objects and relations [36, 35], e.g.

1. Laws: $(\forall x, y)(P(x) \wedge C(y) \Rightarrow X(x, y))$
2. Definitions: $(\forall x)(f(x) = \{y | F(x, y)\})$.

The theory T, on its own, is a pure formal theory with no connection to empirical reality. To establish such a relationship, data D is needed. D is written in a data representation language L', which should be a subset of the formal language L, thus $L' \subset L$ [36, 35].

Definition 6 (System)

$$Systems = \{x | SYSTEM(x)\} \quad \wedge$$
$$SYSTEM(x) \iff$$
$$x \in \{ < x_1, x_2 > \mid x_1 =< O_1, ..., O_m > \wedge x_2 =< R_1, ..., R_n > \} \quad \wedge$$
$$obj(x) = x_1 \quad \wedge$$
$$rel(x) = x_2 \quad \wedge$$
$$states(x) = \mathbb{S} \subseteq obj(x) \quad \wedge$$
$$\mathbb{S} \cap Systems = \emptyset$$

3.2 Formal system breakdown structure

In systems engineering, a system breakdown structure (SBS) is used as a structure to define and manage a system and its life cycle [81, 44, 77, 11].

Formally, it can be said that

$$SBS = \{(x, y) | y \in \mathbf{2}^S, S \in Systems, \exists x \in \mathbf{2}^S, y \subsetneq x\} \tag{3.1}$$

where S is the system with lowest level of resolution that is of interest.

The subsystems and components of S are S_s, thus

$$S_s \subset S \tag{3.2}$$

S is an environment for the subsystems S_s. Each sub-system in S_s is again a system which consists of subsystems and components. This is repeated until the necessary level of resolution is reached.

A component can be defined as follows:

$$\begin{aligned} &Components = \{x \mid COMPONENTS(x)\} \quad \wedge \\ &COMPONENTS(x) \iff x \cap Systems \neq \emptyset \quad \wedge \\ &obj(x) \cap Systems = \emptyset \quad \wedge \\ &rel(x) \cap Systems \neq \emptyset \end{aligned}$$

Each level of resolution is indicated by a number. The highest level of resolution is system level one. If a system consists of seven levels of resolution, then the lowest level of resolution will be number 7 and the highest resolution level will be 1. From this description, it follows that if $S^{(i)}$ is the subsystems and components of system level $i + 1$ and ℓ is the number of system levels of interest, then

$$S^{(1)} \subset S^{(2)} \subset ... \subset S^{(\ell)} = S$$

If $S^{(i)}$ is the subsystems and components of system level $i + 1$, then

$$\forall x \in S^{(i)}, \exists y \in S^{(i+1)}, \ni x \subset y$$

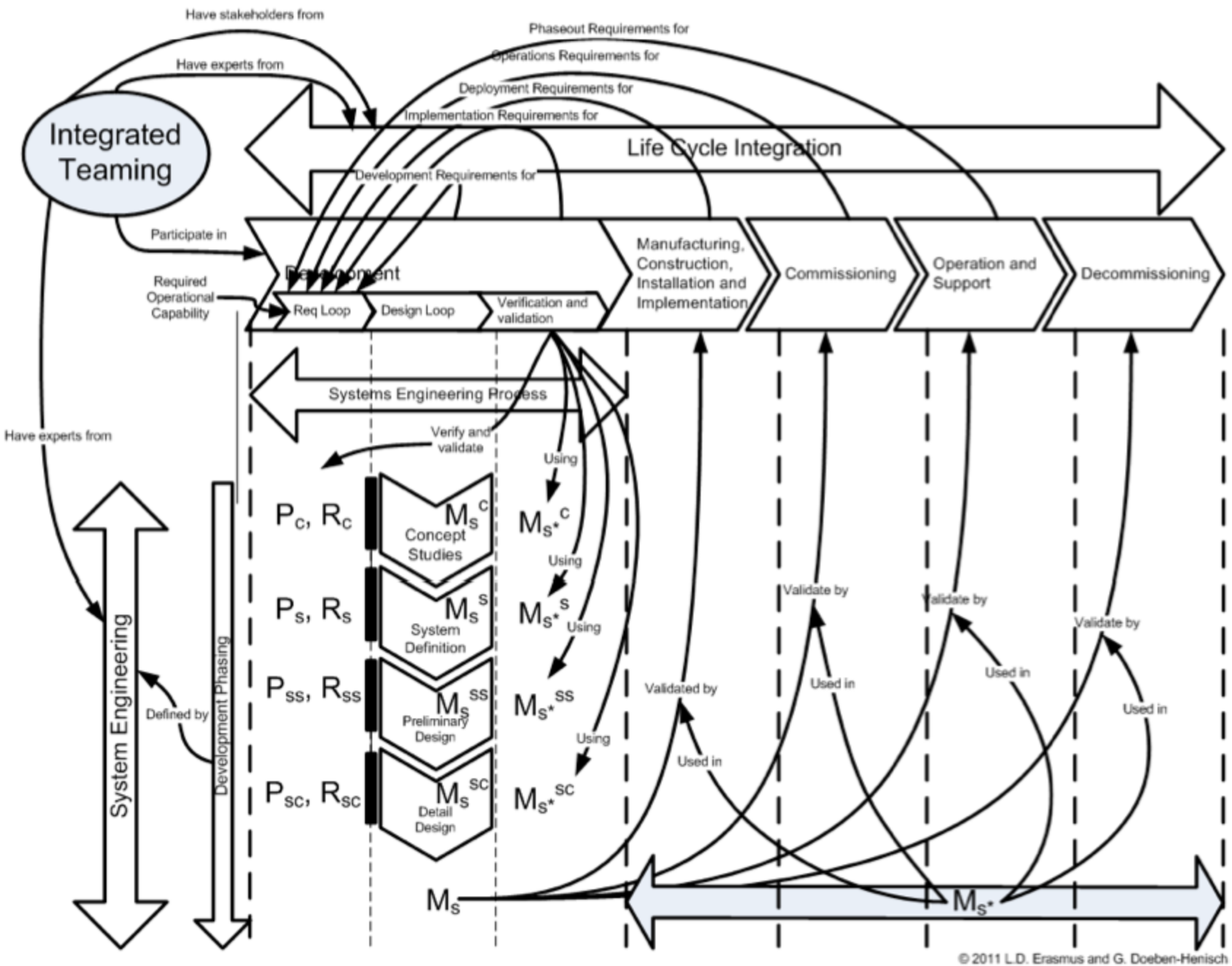
SEMBASE

$$\Sigma(x) \iff x \in \langle \mathcal{S}, \mathcal{E}, \mathcal{A}, \mathcal{D}, \mathcal{P}, \mathcal{M}_{\mathcal{R}}, \mathcal{M}_{\mathcal{S}}, \mathcal{M}_{\mathcal{S}*}, \rho, \delta, \iota \rangle$$

where the operators are abbreviated as follows:

$$\begin{aligned} \rho &:= requirements \\ \delta &:= design \\ \iota &:= implement \end{aligned}$$

Erasmus, L. D. and Doeben-Henisch, G. 2011. A Theory of the System Engineering Process. In *10th AFRICON Conference: Sustainable Energy & Communications Development for Africa*, Livingston, Zambia.


Have stakeholders from
Have experts from
Integrated Teaming
Phaseout Requirements for
Operations Requirements for
Deployment Requirements for
Implementation Requirements for
Development Requirements for
Life Cycle Integration
Participate in
Development
Required Operational Capability
Req Loop
Design Loop
Verification and validation
Manufacturing, Construction, Installation and Implementation
Commissioning
Operation and Support
Decommissioning
Systems Engineering Process
Have experts from
Verify and validate
Using
P_C, R_C
M_S^C
Concept Studies
$M_{S^*}^C$
P_S, R_S
M_S^S
System Definition
$M_{S^*}^S$
P_{SS}, R_{SS}
M_S^{SS}
Preliminary Design
$M_{S^*}^{SS}$
P_{SC}, R_{SC}
M_S^{SC}
Detail Design
$M_{S^*}^{SC}$
System Engineering
Development Phasing
Defined by
Validated by
Used in
Validate by
M_S
M_{S^*}
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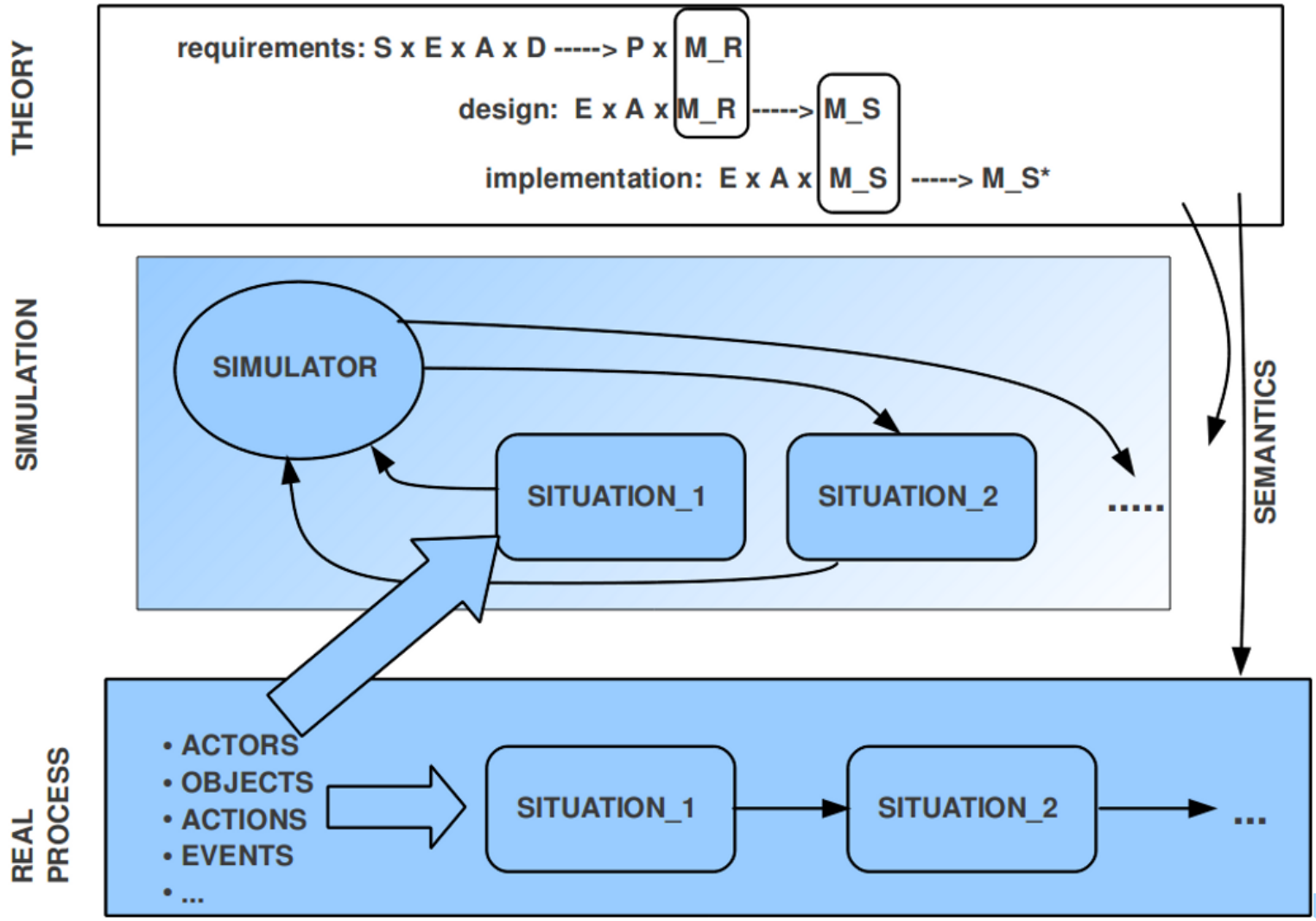
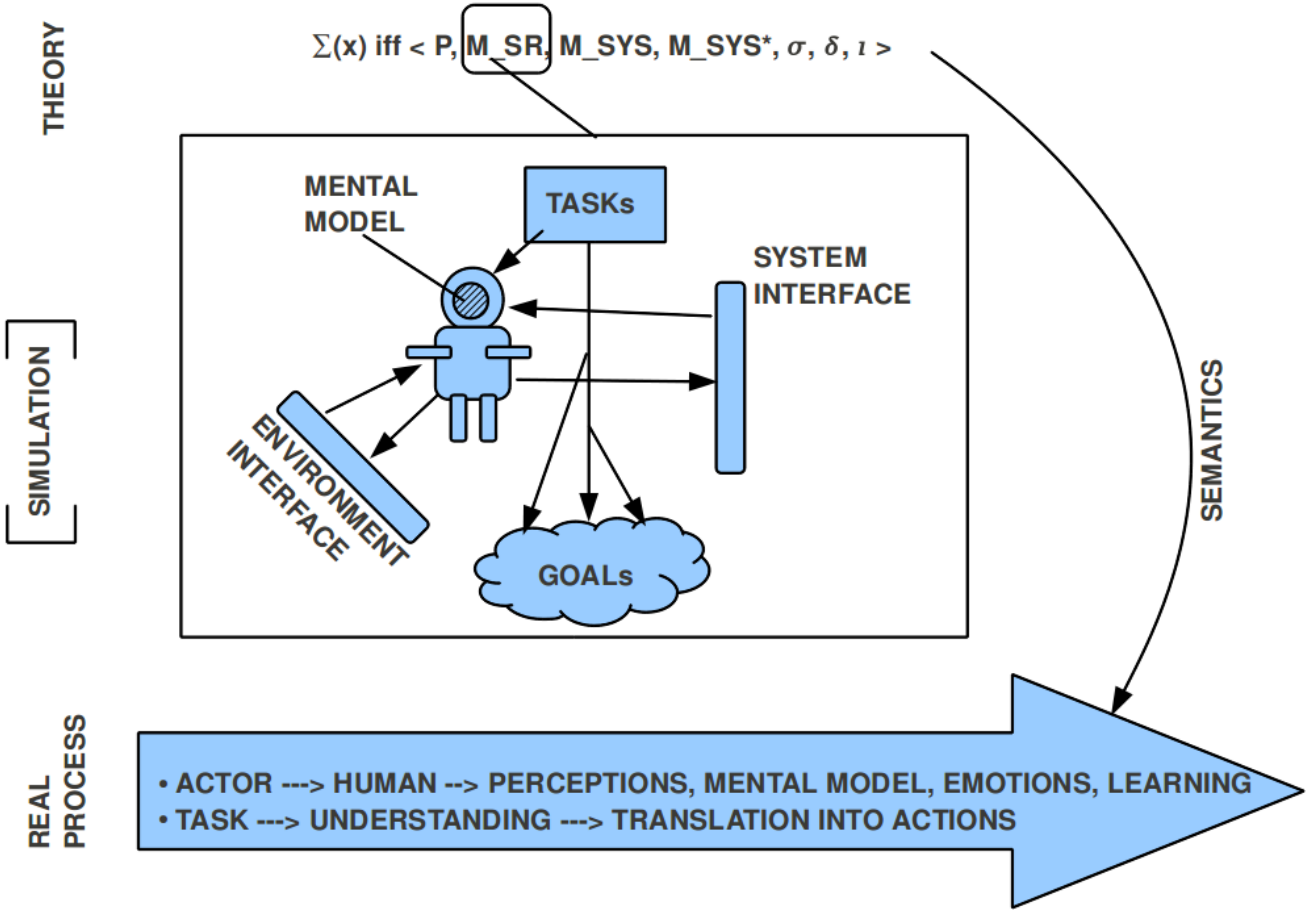
Semantic of theory



Semantic of theory



In summary

- A framework is proposed to perform systems engineering research within South Africa.
- Within the reference of the National Research Foundation (NRF) classification of research, Systems Engineering is classified within:
  - Specific Scientific Domain of Engineering,
  - Main research Field of Operational Research.
- Four categories for systems engineering research in South Africa:
  - Formal Theories for Systems Engineering,
  - Tools for Systems Engineering,
  - Processes for Systems Engineering (Standardised behaviour) and
  - Systems Engineering Applications.


THANK
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GRACIAS
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TASHAKKUR ATU
SUKSAMA
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