34th Annual INCOSE international symposium

hybrid event

Dublin, Ireland
July 2 - 6, 2024

Advancing Transdisciplinarity from Concept to Practice

James N. Martin, Javier Calvo-Amodio

What is Systems Engineering?

- “Systems Engineering is a transdisciplinary and integrative approach to enable the successful realization, use, and retirement of engineered systems, using systems principles and concepts, and scientific, technological, and management methods.”

[https://www.incose.org/about-systems-engineering/what-is-systems-engineering]

What is Systems Engineering?

- “Systems Engineering is a **transdisciplinary** and **integrative** approach to enable the successful realization, use, and retirement of engineered systems, using systems principles and concepts, and scientific, technological, and management methods.”

[https://www.incose.org/about-systems-engineering/what-is-systems-engineering]

"Crossing boundaries is a defining characteristic of our age."

—Julie Klein, 1996

Transdisciplinary

- This is an approach that “transcends” particular disciplinary boundaries to create an often-new and holistic approach, especially for a uniquely problematic situation

- SE is simultaneously Transdisciplinary and Cross-Disciplinary since it also includes the “Integrative” approach in its application

Crossing Boundaries

- SE not only integrates or crosses disciplines (scientific/technical), but it integrates with and/or crosses domains of application (areas of concern)

Cross-Disciplinary/Domain “Integrative” Approach

- SE helps to integrate across disciplines and domains
  - Mechanical, electrical, software, etc.
  - Manufacturing, testing, integration, etc.
  - Mission, business, logistics, etc.
  - Engineering, management, administration, etc.
- SE uses “Integrated Product Teams” and “Joint Technical Reviews” in solution development

Cross-Disciplinary/Domain “Integrative” Approach

- SE helps to integrate across disciplines and domains
  - Mechanical, electrical, software, etc.
  - Manufacturing, testing, integration, etc.
  - Mission, business, logistics, etc.
  - Engineering, management, administration, etc.
- SE uses “Integrated Product Teams” and “Joint Technical Reviews” in solution development

Transdisciplinarity in Systems Engineering

- “Systems Engineering is a **transdisciplinary** and **integrative** approach to enable the successful realization, use, and retirement of engineered systems, using systems principles and concepts, and scientific, technological, and management methods.”

WHAT, WHY, HOW

Approach Originated in the Social Sciences

- Transcends all of the disciplines and domains involved
- Organizes the effort around a common purpose, shared understanding and “learning together”
- Deals with real-world problems or themes

WHAT, WHY, HOW

The challenge of defining TransDisciplinarity (TD)

- Definitions vary among scholars and disciplines
- Definitions vary among practitioners and domains
- Not yet defined in dictionaries
- Often (mis)used interchangeably with **inter-**disciplinarity and **cross-**disciplinarity
- Sometimes defined metaphorically

WHAT, WHY, HOW

Usable at any level, from complex to simple, from global to personal

- ✓ **Needed when the problem cannot readily be "solved" using a conventional approach**
- ✓ **May only achieve a partial "resolution"**
- ✓ **Involves compromise and synergistic understanding** (*which is not available through their own disciplines in the normal integrative manner*)

WHAT, **WHY**, HOW

The need for TD in SE arises in response to four major concerns:

1. A growing realization about the limitations in current SE approaches for achieving solutions that resolve complex problems
2. The need to evolve our approaches to resolve these problems
3. A realization that contemporary science can neither properly understand nor address these urgent problems
4. The need for more democratic governance of knowledge production

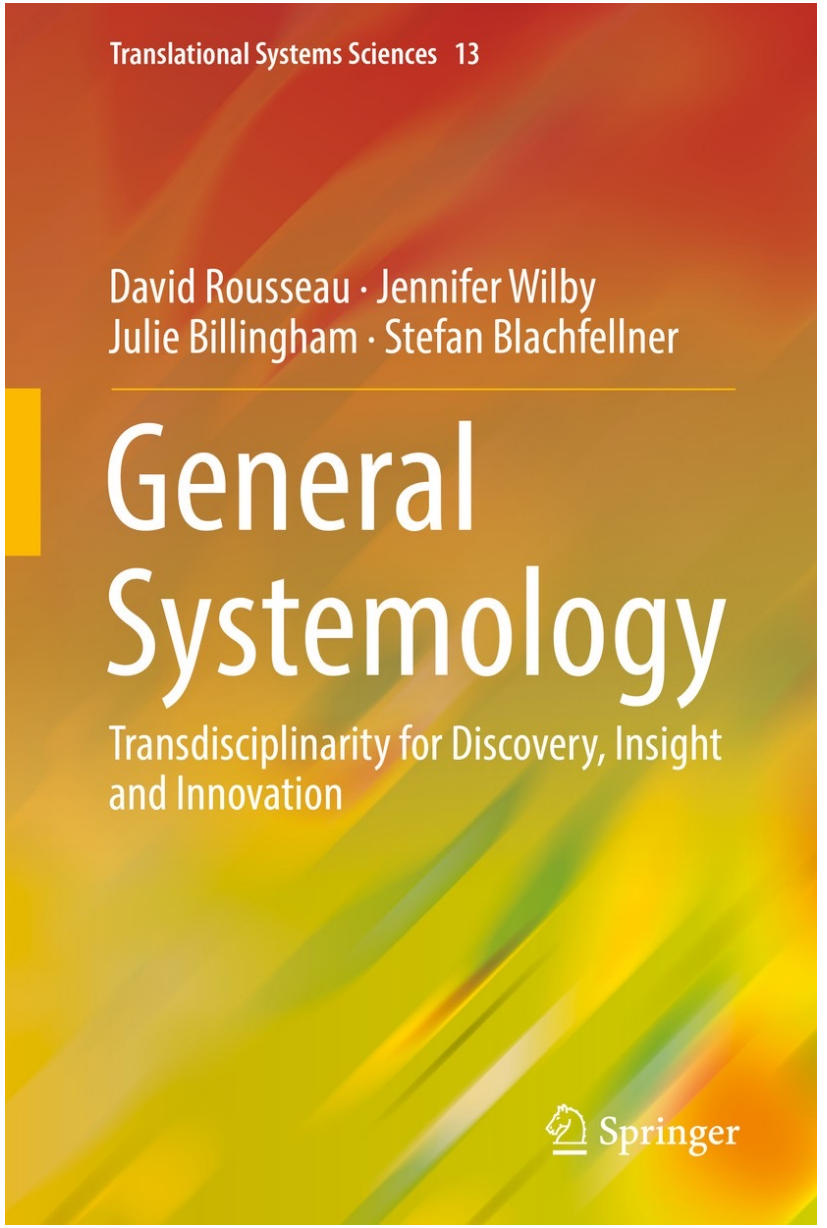
WHAT, WHY, **HOW**

Key characteristics of the TD research model

- Problem-driven
- Action-oriented
- Highly collaborative
- Integrative
- Socially relevant

General Systemology

- Explores the general nature of the systems approach
- Includes key ideas about General Systems Transdisciplinarity (GSTD)

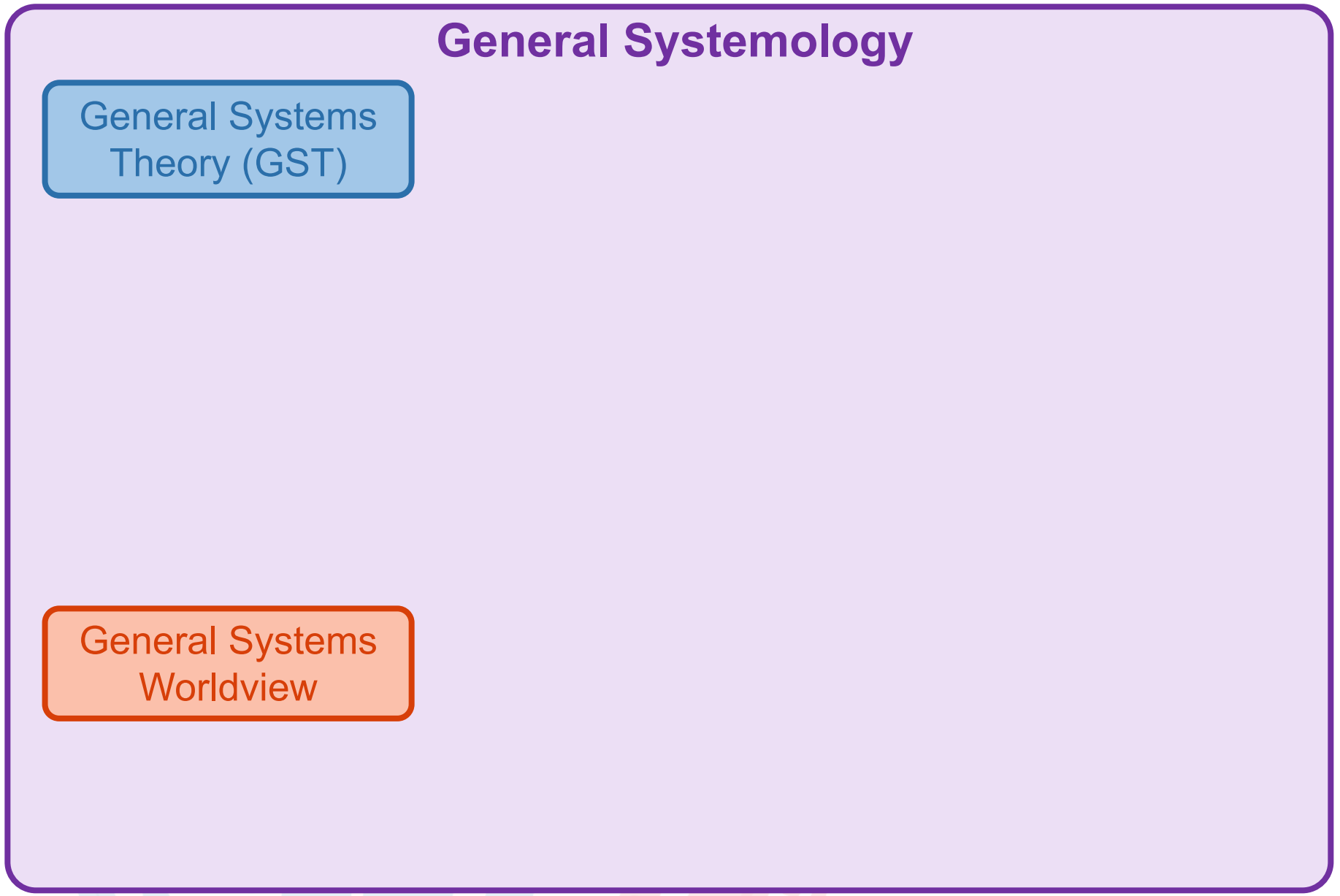


General Systems Transdisciplinarity

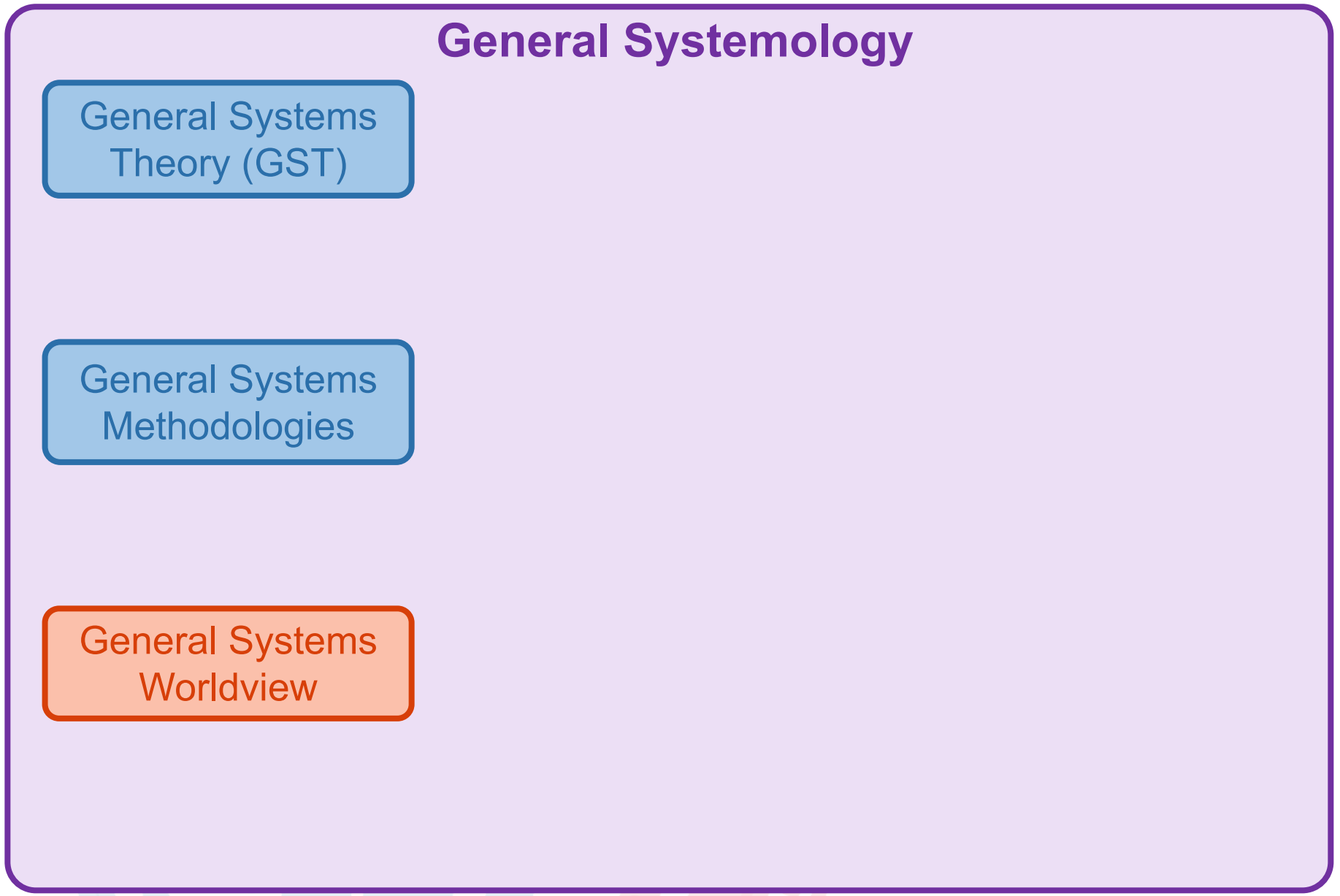
General Systemology

General Systems Theory (GST)

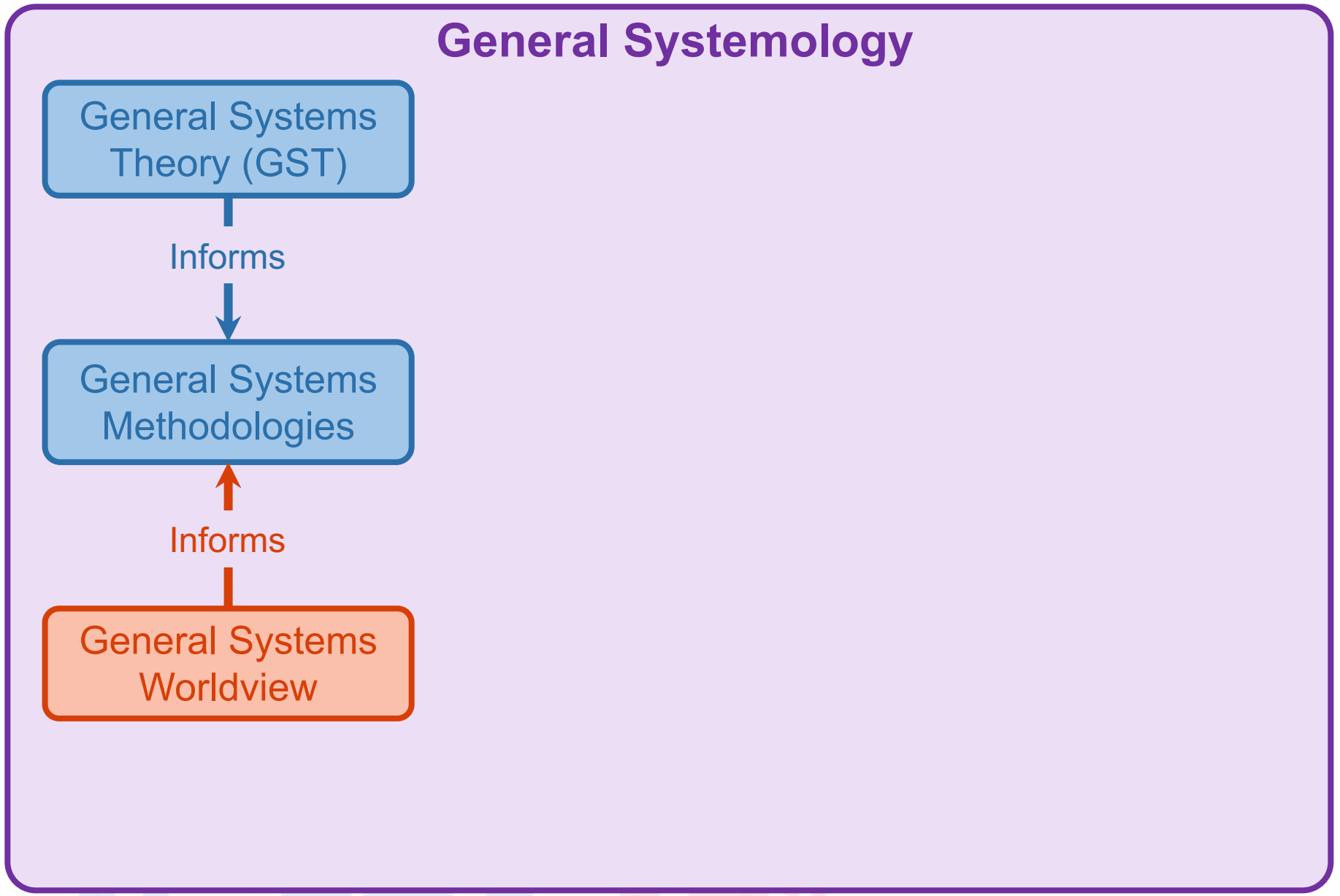
General Systems Transdisciplinarity



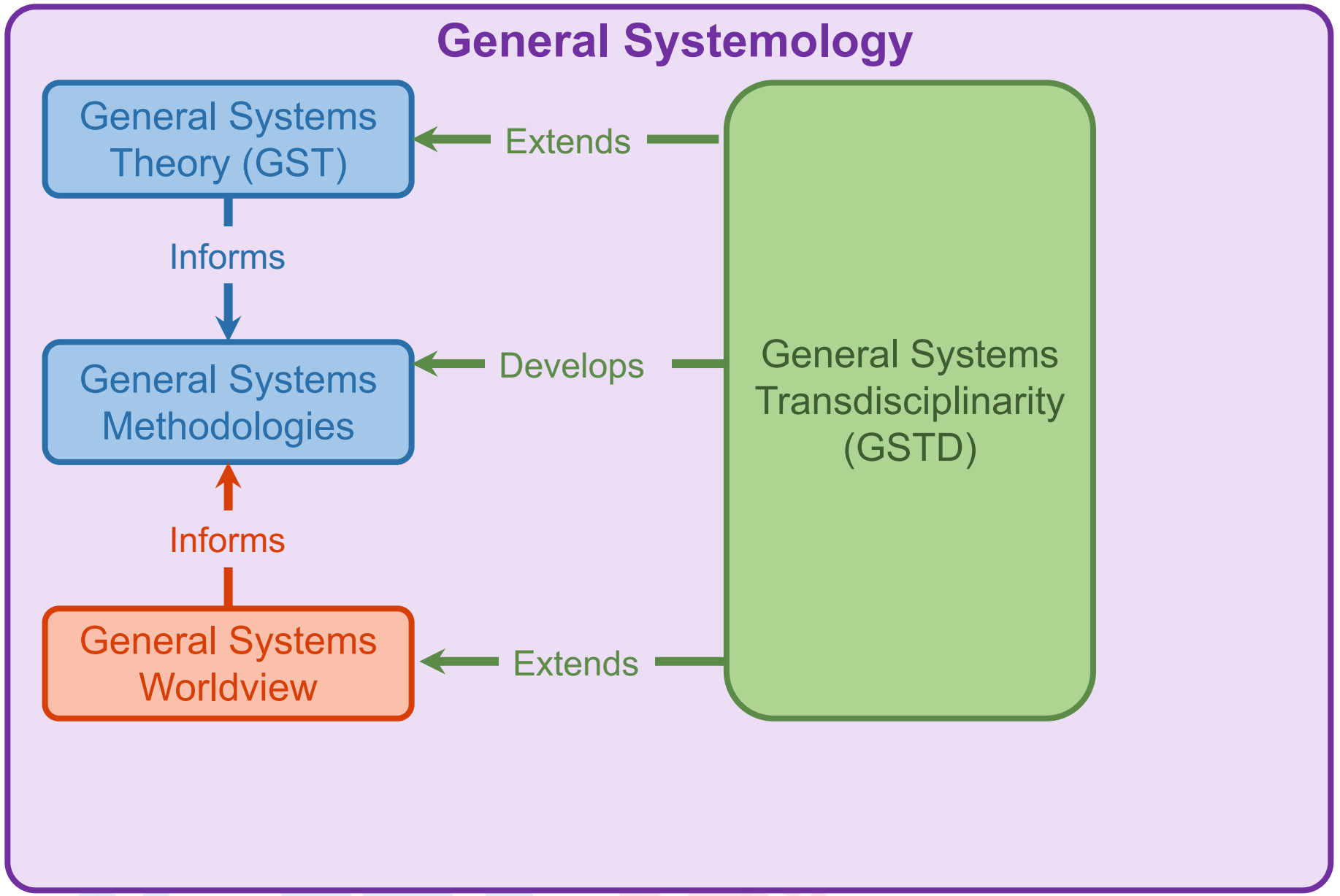
General Systems Transdisciplinarity



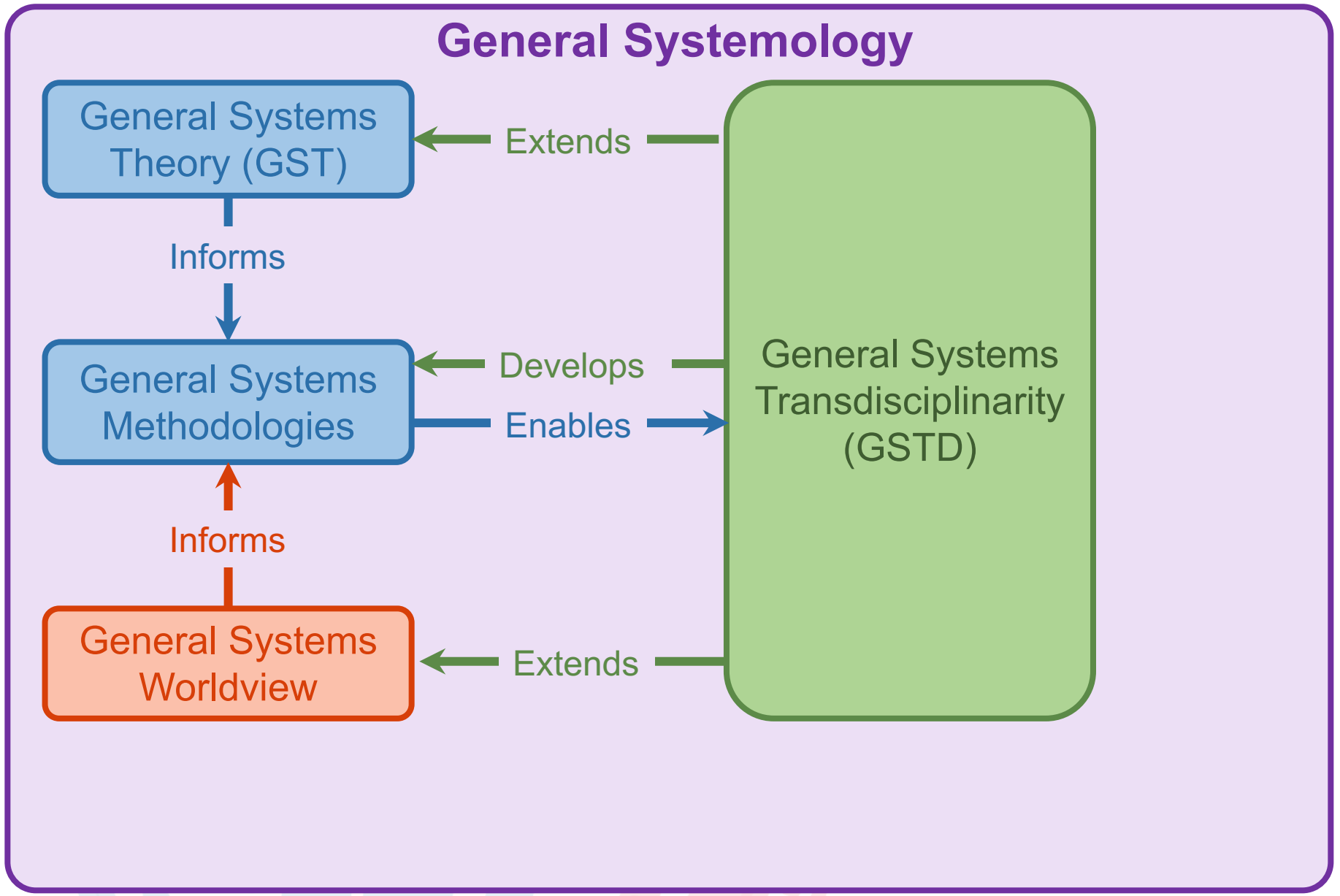
General Systems Transdisciplinarity



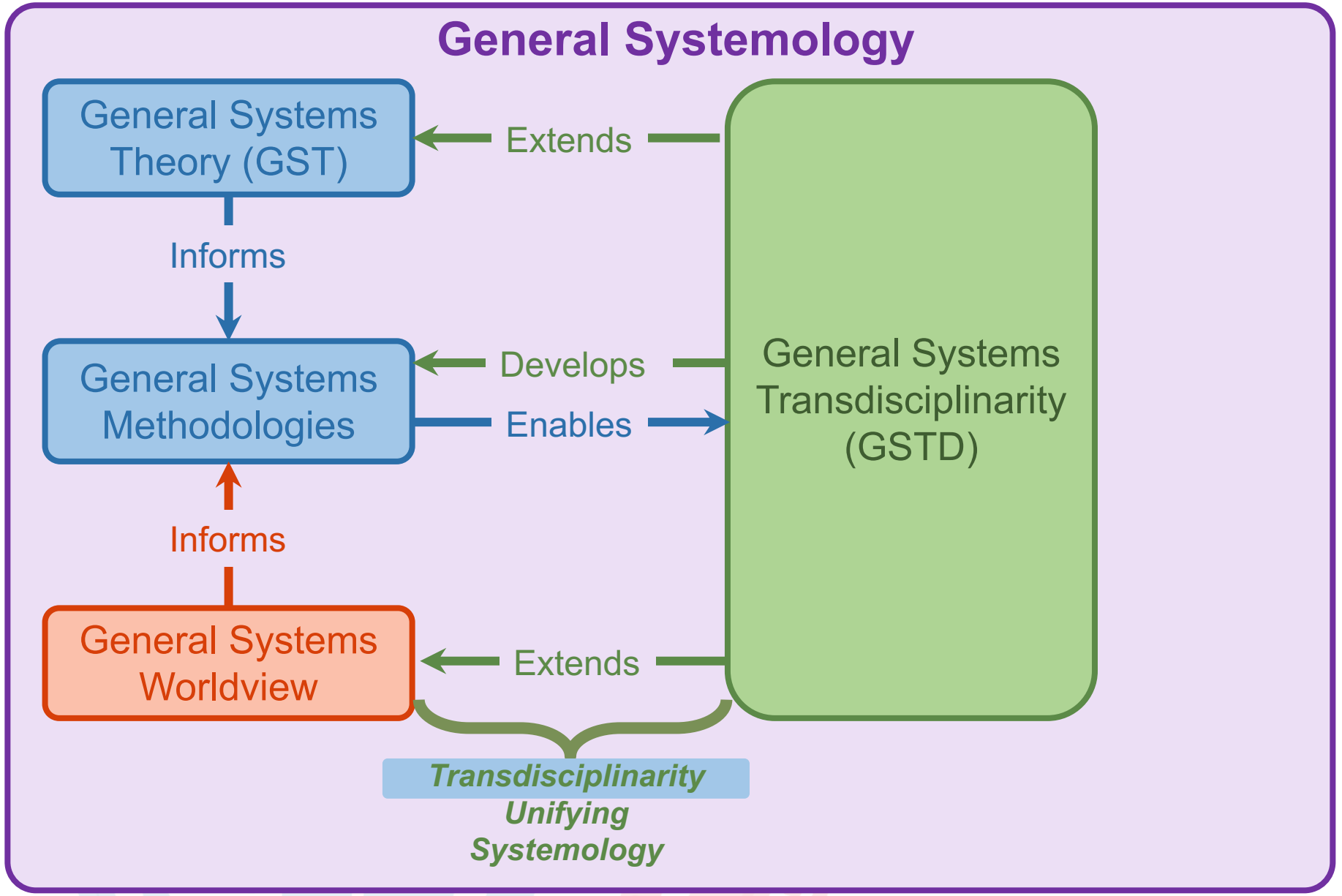
General Systems Transdisciplinarity



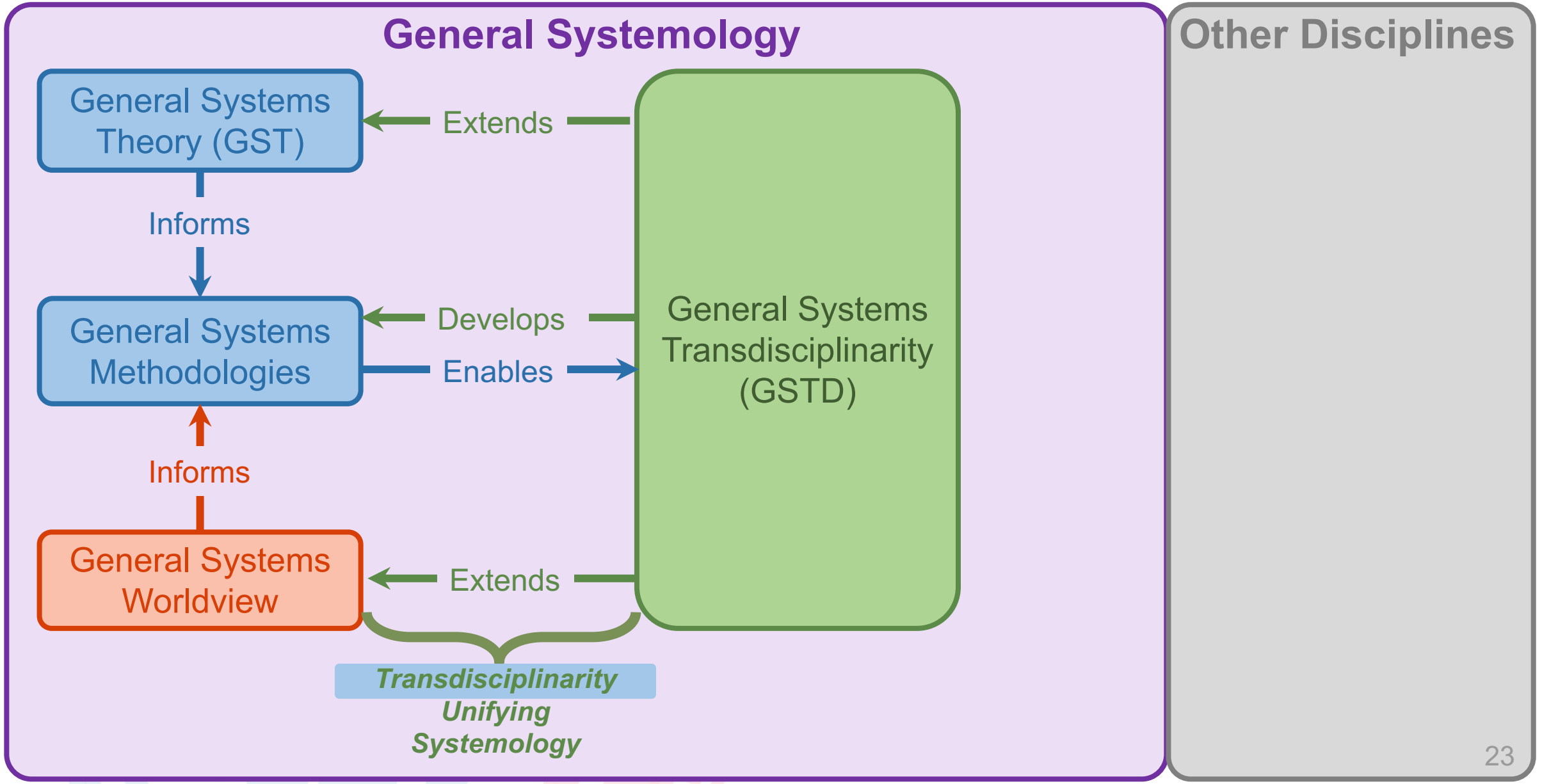
General Systems Transdisciplinarity



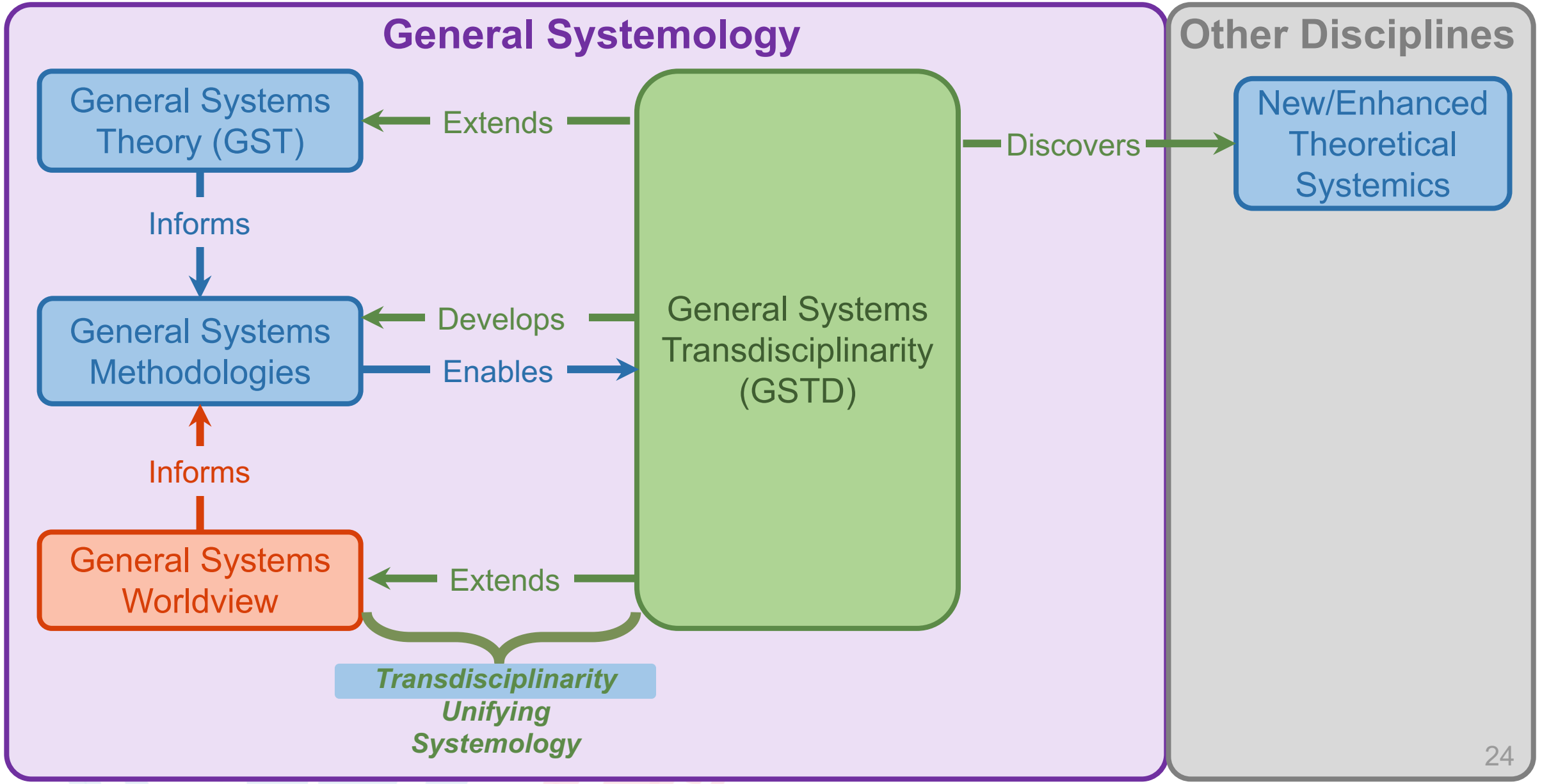
General Systems Transdisciplinarity



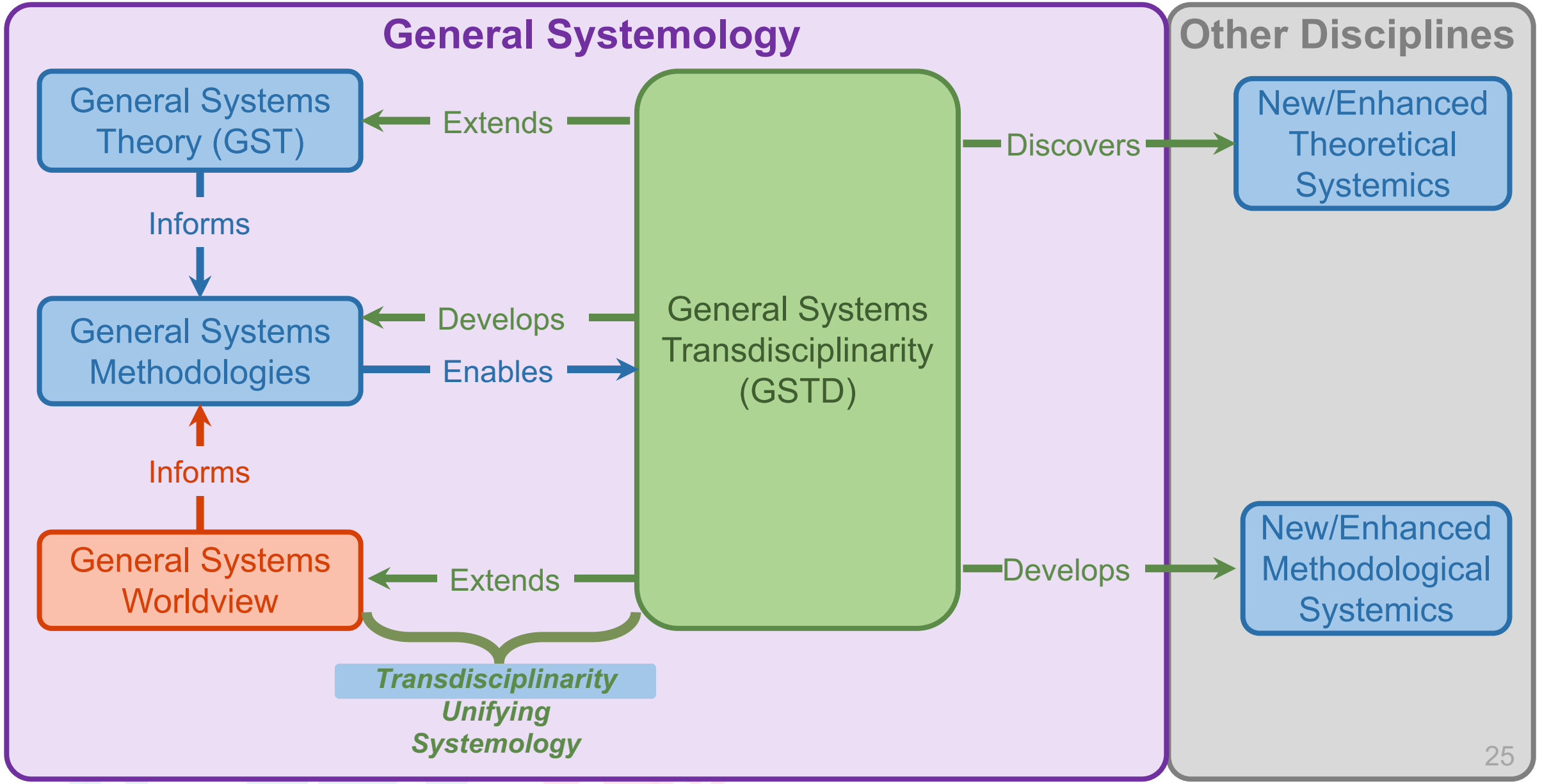
General Systems Transdisciplinarity



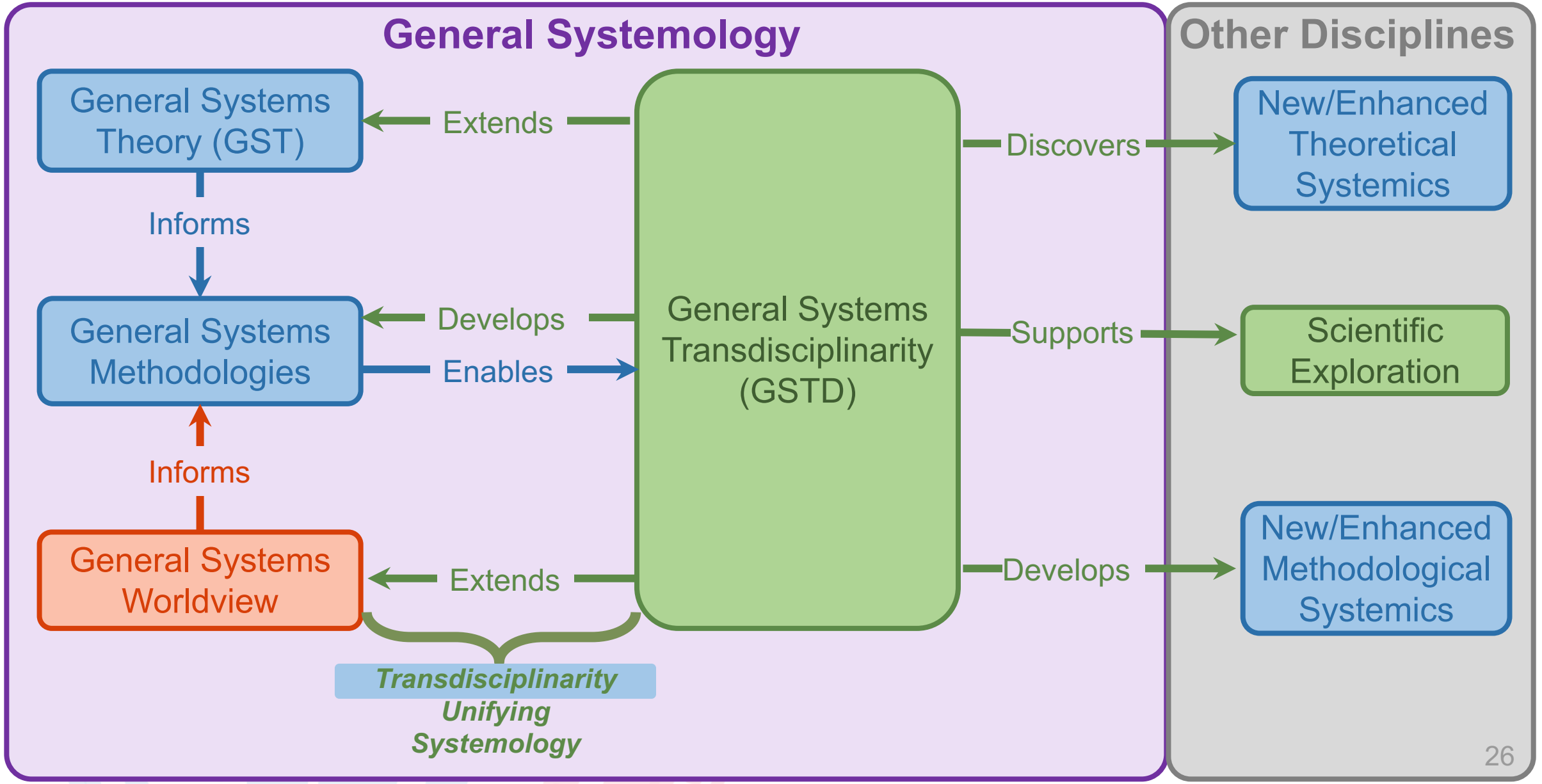
General Systems Transdisciplinarity



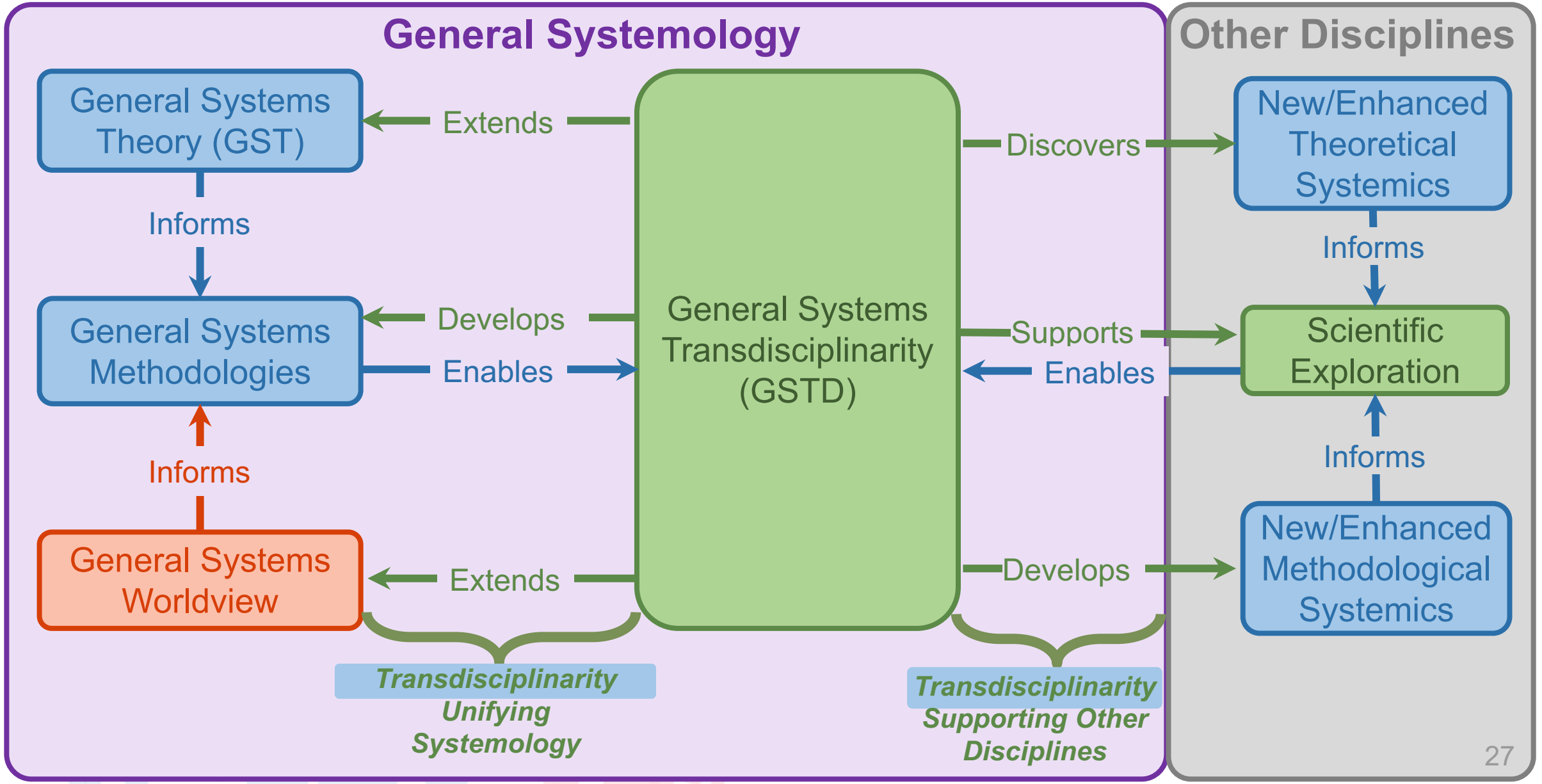
General Systems Transdisciplinarity



General Systems Transdisciplinarity



General Systems Transdisciplinarity



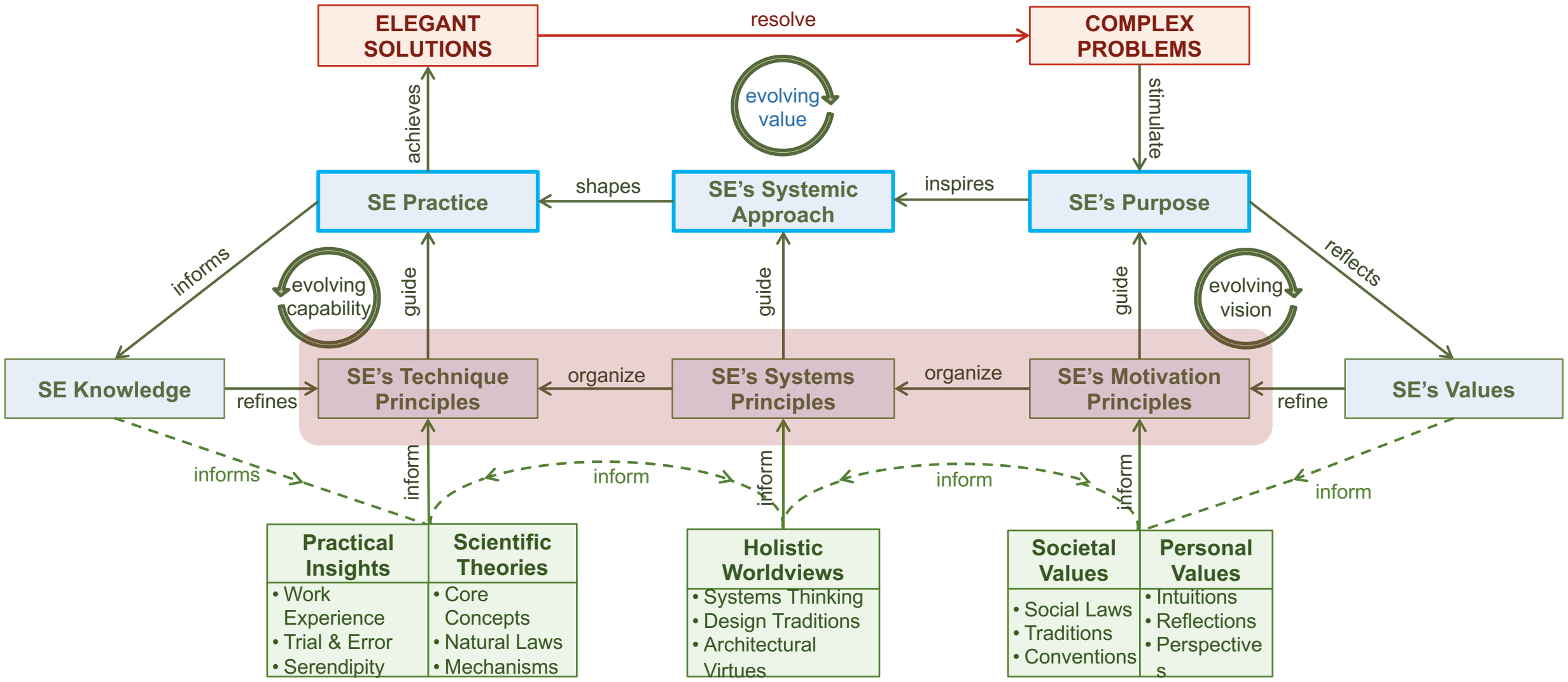
Systems Science as a Transdisciplinary Basis for SE

- Transdisciplinarity is not a one-size fits all
  - It is about communicating, leading, and solving real-world problems with a purpose within a context (or interrelated contexts)
    - We must embrace differences in the level of abstraction, purpose, and contexts
      - Within and across disciplines
      - Within and across domains of application

Systems Science as a Transdisciplinary Basis for SE

- Transdisciplinarity is not a one-size fits all
  - Principles will play a key role in how we should evolve the SE practice and can achieve goals in the INCOSE's Vision 2035
    - ✓ They serve as the foundations to pursue our purpose
    - ✓ They serve as the foundations for our practice
    - ✓ They are the bridge between our purpose and our practice

Future of Systems Engineering (FuSE) Initiative – Links SE Principles to SE Practice

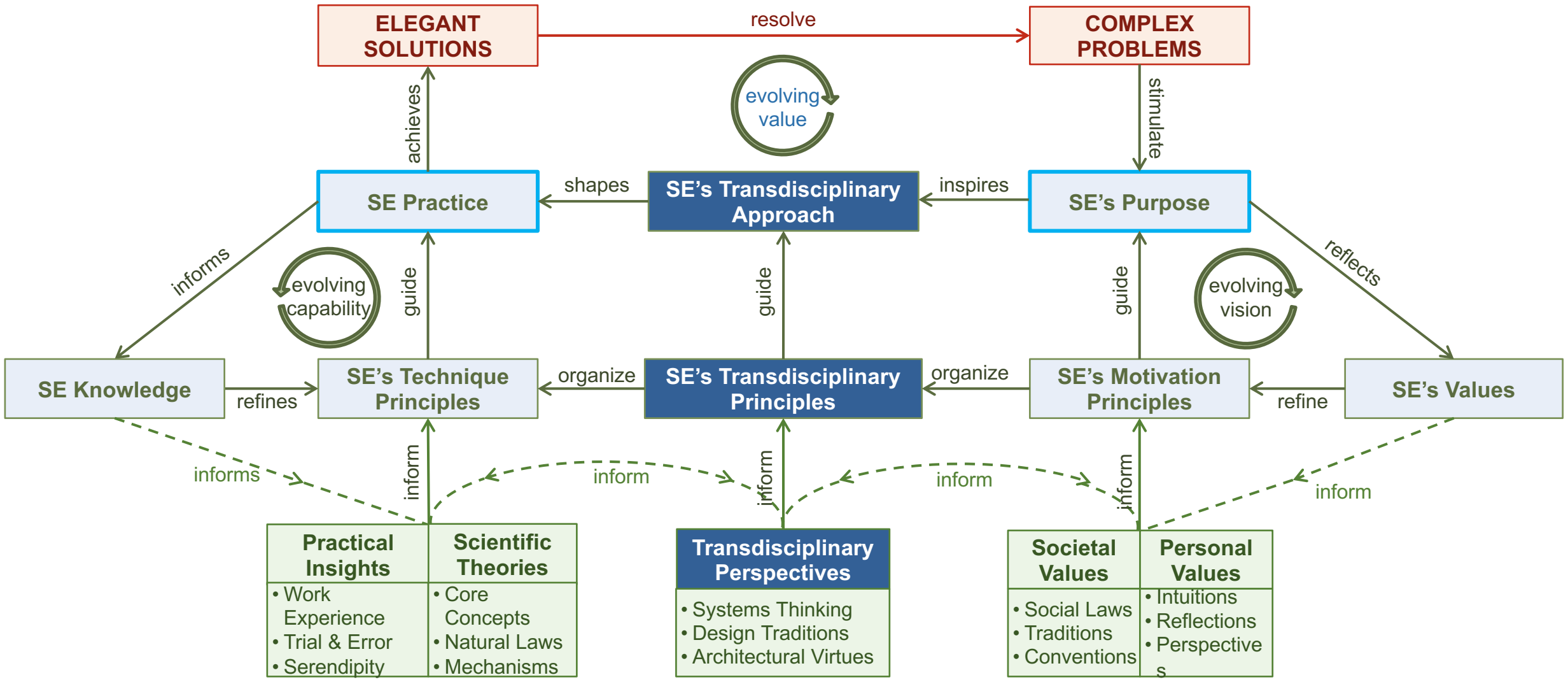


How we do it
- Execute systematically
- Leverage methods, tools, processes

What we do
- Think systemically
- Apply systems thinking to engineering

Why we do it
- Build a better world (sustainable, equitable, …)
- Achieve elegant solutions to complex problems

Transdisciplinary Principles from Future of Systems Engineering Initiative (FuSE)



How we do it
- Execute systematically
- Leverage methods, tools, processes

What we do
- Think systemically
- Apply systems thinking to engineering

Why we do it
- Build a better world (sustainable, equitable, …)
- Achieve elegant solutions to complex problems

The nature of systems

- We learn and interact with systems by engaging the following aspects:
  - About the system
    - Ontological complexity
    - Cognitive complexity
  - About how we engage with the system
    - Restricted complexity
    - General complexity

Morin, E. (1992). From the concept of system to the paradigm of complexity. *Journal of social and evolutionary systems*, *15*(4), 371-385.
Rescher, N. (1998). *Communicative pragmatism and other philosophical essays on language*. Rowman & Littlefield.

The nature of systems

- Ontological complexity
  - Refers to the variety of behaviors and meanings exhibited by real-world systems due to:
    - quantity of parts/elements (constituents)
    - variety of parts/elements (constituents)
    - elaborateness of interrelationships (how togetherness happens)

Rescher, N. (1998). *Communicative pragmatism and other philosophical essays on language*. Rowman & Littlefield.

The nature of systems

		Low	Medium	High
Ontological complexity Variety exhibited by the system of interest	Number and kind of parts and interrelations in system of interest	Real-world system exhibits a small number of parts and/or interrelations	Real-world system exhibits a moderate number of parts and/or interrelations	Real-world system exhibits a large variety in number and in kind of parts and interrelations
	Number of disciplines and domains that are required to understand the system of interest	Only one or two disciplines/domains that closely related	Two or more disciplines/domains that are related	Many that may or may not be closely related

- Depending on the ontological complexity, there is often more than one discipline and domain that is relevant to understanding the system of interest

How we perceive the nature of systems

- Cognitive complexity
  - Refers to the different ways in which the world is viewed
    - This is affected by:
      - The maturity of our approaches
      - How well our approaches match the scope of application

Rescher, N. (1998). *Communicative pragmatism and other philosophical essays on language*. Rowman & Littlefield.

How we perceive the nature of systems

		Low		Medium		High	
Cognitive Complexity The approach matches the kind of ontological complexity exhibited by the system of interest	Approach matches in scope of application	YES	NO	YES	NO	YES	NO
	The approach matches in terms of maturity (how trustworthy it is)	YES	NO	YES	NO	YES	NO

- Depending on the ontological complexity, we must strive to match as best as possible our abilities and ways in which we see the world

		Low		Medium		High	
Ontological complexity Variety exhibited by the system of interest	Number and kind of parts and interrelations in system of interest	Real-world system exhibits a small number of parts and/or interrelations		Real-world system exhibits a moderate number of parts and/or interrelations		Real-world system exhibits a large variety in number and in kind of parts and interrelations	
	Number of disciplines and domains that are required to understand the system of interest	Only one or two disciplines/domains that closely related		Two or more disciplines/domains that are related		Many that may or may not be closely related	
Cognitive Complexity The approach matches the kind of ontological complexity exhibited by the system of interest	Approach matches in scope of application	**YES**	**NO**	**YES**	**NO**	**YES**	**NO**
	The approach matches in terms of maturity (how trustworthy it is)	**YES**	**NO**	**YES**	**NO**	**YES**	**NO**

- Our combined approaches should bridge the gap between ontological and cognitive complexity

How we deal with the nature of systems

- restricted complexity
  - computational modelling techniques – remain “within the epistemology of classical science”
  - systemic reductionist arguments are better suited

		Low	Medium	High
Kind of Solution Solution and/or approach needed	Number of contributing disciplines (scientific discipline) that are available	Only one or two disciplines that are closely related	Two or more disciplines that are related	Many that may or may not be closely related
	Approach needed	Mono-disciplinary or multi-disciplinary	Cross-disciplinary or inter-disciplinary	Interdisciplinary and transdisciplinary
	Nature of approach	Restricted complexity; relies on systemic reductionist arguments	A mix of restricted and general complexity and of systemic reductionist and holistic arguments	Leverages restricted and general complexity; leverages BOTH systemic reductionist and holistic arguments

Morin, E. (1992). From the concept of system to the paradigm of complexity. *Journal of social and evolutionary systems*, *15*(4), 371-385.

How we deal with the nature of systems

- general complexity
  - resists universal truths; fundamental problem “is epistemological, cognitive, paradigmatic”
  - Systemic holistic arguments are better suited

		Low	Medium	High
Kind of Solution Solution and/or approach needed	Number of contributing disciplines (scientific discipline) that are available	Only one or two disciplines that are closely related	Two or more disciplines that are related	Many that may or may not be closely related
	Approach needed	Mono-disciplinary or multi-disciplinary	Cross-disciplinary or inter-disciplinary	Interdisciplinary and transdisciplinary
	Nature of approach	Restricted complexity; relies on systemic reductionist arguments	A mix of restricted and general complexity and of systemic reductionist and holistic arguments	Leverages restricted and general complexity; leverages BOTH systemic reductionist and holistic arguments

Morin, E. (1992). From the concept of system to the paradigm of complexity. *Journal of social and evolutionary systems*, *15*(4), 371-385.

		Low	Medium	High
Ontological complexity Variety exhibited by the system of interest	Number and kind of parts and interrelations in system of interest	Real-world system exhibits a small number of parts and/or interrelations	Real-world system exhibits a moderate number of parts and/or interrelations	Real-world system exhibits a large variety in number and in kind of parts and interrelations
	Number of disciplines and domains that are required to understand the system of interest	Only one or two disciplines/domains that closely related	Two or more disciplines/domains that are related	Many that may or may not be closely related
Cognitive Complexity The approach matches the kind of ontological complexity exhibited by the system of interest	Approach matches in scope of application	**YES** / **NO**	**YES** / **NO**	**YES** / **NO**
	The approach matches in terms of maturity (how trustworthy it is)	**YES** / **NO**	**YES** / **NO**	**YES** / **NO**
Kind of Solution Solution and/or approach needed	Number of contributing disciplines (scientific discipline) that are available	Only one or two disciplines that are closely related	Two or more disciplines that are related	Many that may or may not be closely related
	Approach needed	Mono-disciplinary or multi-disciplinary	Cross-disciplinary or inter-disciplinary	Interdisciplinary and transdisciplinary
	Nature of approach	Restricted complexity; relies on systemic reductionist arguments	A mix of restricted and general complexity and of systemic reductionist and holistic arguments	Leverages restricted and general complexity; leverages BOTH systemic reductionist and holistic arguments

		Low	Medium	High
Ontological complexity Variety exhibited by the system of interest	Number and kind of parts and interrelations in system of interest	Real-world system exhibits a small number of parts and/or interrelations	Real-world system exhibits a moderate number of parts and/or interrelations	Real-world system exhibits a large variety in number and in kind of parts and interrelations
	Number of disciplines and domains that are required to understand the system of interest	Only one or two disciplines/domains that closely related	Two or more disciplines/domains that are related	Many that may or may not be closely related
Cognitive Complexity The approach matches the kind of ontological complexity exhibited by the system of interest	Approach matches in scope of application	**YES** / **NO**	**YES** / **NO**	**YES** / **NO**
	The approach matches in terms of maturity (how trustworthy it is)	**YES** / **NO**	**YES** / **NO**	**YES** / **NO**
Kind of Solution Solution and/or approach needed	Number of contributing disciplines (scientific discipline) that are available	Only one or two disciplines that are closely related	Two or more disciplines that are related	Many that may or may not be closely related
	Approach needed	Mono-disciplinary or multi-disciplinary	Cross-disciplinary or inter-disciplinary	Interdisciplinary and transdisciplinary
	Nature of approach	Restricted complexity; relies on systemic reductionist arguments	A mix of restricted and general complexity and of systemic reductionist and holistic arguments	Leverages restricted and general complexity; leverages BOTH systemic reductionist and holistic arguments

		Low	Medium	High
Ontological complexity Variety exhibited by the system of interest	Number and kind of parts and interrelations in system of interest	Real-world system exhibits a small number of parts and/or interrelations	Real-world system exhibits a moderate number of parts and/or interrelations	Real-world system exhibits a large variety in number and in kind of parts and interrelations
	Number of disciplines and domains that are required to understand the system of interest	Only one or two disciplines/domains that	Two or more disciplines/domains that are related	Many that may or may not be closely related
Cognitive Complexity The approach matches the kind of ontological complexity exhibited by the system of interest	Approach matche… scope of applica…		YES / NO	YES / NO
	The approach … in terms of ma… (how trustwor…		YES / NO	YES / NO
Kind of Solution Solution and/or approach needed	Number of contributing disciplines (scientific disci… that are available		Two or more disciplines that are related	Many that may or may not be closely related
	Approach needed	…linary or multi-disciplinary	Cross-disciplinary or inter-disciplinary	Interdisciplinary and transdisciplinary
	Nature of approach	Restricted complexity; relies on systemic reductionist arguments	A mix of restricted and general complexity and of systemic reductionist and holistic arguments	Leverages restricted and general complexity; leverages BOTH systemic reductionist and holistic arguments

		Low	Medium		High	
Ontological complexity Variety exhibited by the system of interest	Number and kind of parts and interrelations in system of interest	Real-world system exhibits a small number of parts and/or interrelations	Real-world system exhibits a moderate number of parts and/or interrelations		Real-world system exhibits a large variety in number and in kind of parts and interrelations	
	Number of disciplines and domains that are required to understand the system of interest	Only one or two disciplines/domains that	Two or more disciplines/domains that are related		Many that may or may not be closely related	
Cognitive Complexity The approach matches the kind of ontological complexity exhibited by the system of interest	Approach matche scope of applica		**YES**	**NO**	**YES**	**NO**
	The approach in terms of ma (how trustwor		**YES**	**NO**	**YES**	**NO**
Kind of Solution Solution and/or approach needed	Number of contributing disciplines (scientific disci that are available		Two or more disciplines that are related		Many that may or may not be closely related	
	Approach needed	inary or multi-disciplinary	Cross-disciplinary or inter-disciplinary		Interdisciplinary and transdisciplinary	
	Nature of approach	Restricted complexity; relies on systemic reductionist arguments	A mix of restricted and general complexity and of systemic reductionist and holistic arguments		Leverages restricted and general complexity; leverages BOTH systemic reductionist and holistic arguments	

		Low	Medium		High	
Ontological complexity Variety exhibited by the system of interest	Number and kind of parts and interrelations in system of interest	Real-world system exhibits a small number of parts and/or interrelations	Real-world system exhibits a moderate number of parts and/or interrelations		Real-world system exhibits a large variety in number and in kind of parts and interrelations	
	Number of disciplines and domains that are required to understand the system of interest	Only one or two disciplines/domains that	Two or more disciplines/domains that are related		Many that may or may not be closely related	
Cognitive Complexity The approach matches the kind of ontological complexity exhibited by the system of interest	Approach matche scope of applica		YES	NO	YES	NO
	The approach in terms of ma (how trustwor		YES	NO	YES	NO
Kind of Solution Solution and/or approach needed	Number of contributing disciplines (scientific disci that are available		Two or more disciplines that are related		Many that may or may not be closely related	
	Approach needed	inary or multi-disciplinary	Cross-disciplinary or inter-disciplinary		Interdisciplinary and transdisciplinary	
	Nature of approach	Restricted complexity; relies on systemic reductionist arguments	A mix of restricted and general complexity and of systemic reductionist and holistic arguments		Leverages restricted and general complexity; leverages BOTH systemic reductionist and holistic arguments	

		Low	Medium	High
Ontological complexity Variety exhibited by the system of interest	Number and kind of parts and interrelations in system of interest	Real-world system exhibits a small number of parts and/or interrelations	Real-world system exhibits a moderate number of parts and/or interrelations	Real-world system exhibits a large variety in number and in kind of parts and interrelations
	Number of disciplines and domains that are required to understand the system of interest	Only one or two disciplines/domains that	Two or more disciplines/domains that are related	Many that may or may not be closely related
Cognitive Complexity The approach matches the kind of ontological complexity exhibited by the system of interest	Approach matches scope of applica		YES / NO	YES / NO
	The approach in terms of ma (how trustwort		YES / NO	YES / NO
Kind of Solution Solution and/or approach needed	Number of contributing disciplines (scientific disci that are available		Two or more disciplines that are related	Many that may or may not be closely related
	Approach needed	inary or multi-disciplinary	Cross-disciplinary or inter-disciplinary	Interdisciplinary and transdisciplinary
	Nature of approach	Restricted complexity; relies on systemic reductionist arguments	A mix of restricted and general complexity and of systemic reductionist and holistic arguments	Leverages restricted and general complexity; leverages BOTH systemic reductionist and holistic arguments

		Low	Medium	High	
Ontological complexity Variety exhibited by the system of interest	Number and kind of parts and interrelations in system of interest	Real-world system exhibits a small number of parts and/or interrelations	Real-world system exhibits a moderate number of parts and/or interrelations	Real-world system exhibits a large variety in number and in kind of parts and interrelations	
	Number of disciplines and domains that a…derstan… sy…	Only one or two …s/domain… …ed	Two or more …lines/domains that …	Many that may or may not be closely related	
Cognitive Com… The approach … kind of ontolog… complexity exh… the system of …			NO	YES	NO
			NO	YES	NO
Kind of Solution… Solution and/or approach needed	…tha…	…ated	…sciplines …ed	Many that may or may not be closely related	
	Approach needed	Mono-disciplinary or multi-disciplinary	Cross-disciplinary or inter-disciplinary	Interdisciplinary and transdisciplinary	
	Nature of approach	Restricted complexity; relies on systemic reductionist arguments	A mix of restricted and general complexity and of systemic reductionist and holistic arguments	Leverages restricted and general complexity; leverages BOTH systemic reductionist and holistic arguments	

So what?

- We need to change our Processes (what), Methods (how), Tools (with what), and People (who)
- How should these things change to accommodate the transdisciplinary approach?
  - How to improve SE education and training
  - How to do better workforce development
  - How to make the world better through the systems approach…

“Transdisciplinary attitude”

- Open-mindedness
- Intellectual flexibility
- Combinatorial creativity
- Capacity for dialog and collaboration
- Intellectual humility

So, How do we proceed?

- **Transdisciplinary Approach**
  - Bring stakeholders *into* the process
  - *Continuous* engagement with non-technical groups and individuals
- **Servant Leadership**
  - SE doesn't have all the answers
  - We don't even have all the questions!

Conclusion

"Transdisciplinarity is not a single form of knowledge but a dialogue of forms."

– Kate Maguire, 2015

34th Annual INCOSE international symposium

hybrid event

Dublin, Ireland
July 2 - 6, 2024

Advancing Transdisciplinarity from Concept to Practice

James N. Martin, Javier Calvo-Amodio