Ontological Foundations of General Systems Theory

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Abstract

This paper establishes an ontological foundation for General Systems Theory by clarifying the nature of existence, entities, structure, and causality. Adopting an empirically grounded physicalist stance, it assumes that all observed phenomena occur within space-time and that there is no evidence of non-physical entities interacting with the physical universe. On this basis, reality is understood as comprising physically instantiated entities distinguished by boundaries and organised within space-time.

The paper develops a systematic account of key ontological concepts. Entities may be considered individually or as sets, exhibiting duality between whole and parts. Abstract entities are reconceptualised as distributed physical configurations, understood both as sets of instances and as characteristics defining classes of entities. Structure is distinguished from configuration as the organised arrangement of entities and their relationships, and information is defined ontologically as non-random, recurring structure in space-time. Relationships are classified as configurational or causal, corresponding respectively to structural arrangement and transfer of matter, energy, or information. Events are defined as time-bounded causal interactions, and networks as interconnected systems of such events.

Causality is further analysed through two complementary representations: process–transfer–process (PTP), emphasising relational interactions between systems, and transfer–process–transfer (TPT), emphasising internal transformation within systems. Finally, entities are described in terms of characteristics and states, with change understood as variation in these characteristics over time.

Together, these concepts provide a coherent and physically grounded ontology that supports the analysis of systems, processes, and dynamics, and establishes a foundation for subsequent developments in structure, information, thermodynamics, and social systems theory.

1. Introduction

General Systems Theory requires a clear account of what is meant by *existence* before it can describe systems, processes, and causality. This paper sets out that ontological foundation.

It brings together concepts relating to space-time, physical existence, entities, structure, and relationships. The aim is not to introduce new theoretical constructs, but to clarify the basic nature of reality upon which all subsequent systems concepts depend.

The stance adopted is empirically grounded (Bhaskar, 1975; Carroll, 2016). All observed phenomena occur within space-time, and there is no empirical evidence of any non-physical entity interacting with the physical universe. If non-physical entities exist, they have no demonstrated causal influence on physical systems. On this basis, the ontology developed here is restricted to physically instantiated entities, relationships, and processes.

2. Space-Time and Physical Existence

Reality is understood as a single continuum comprising three dimensions of space and one of time (Einstein, 1916). All entities, interactions, and processes are realised within this space-time framework.

The term *physical* is used to denote anything that exists within, or constitutes, space-time. This includes matter, energy, and the fields and structures that occupy or define it. Even apparently empty regions of space are physical in this sense.

From this follows a foundational principle:

Everything that exists does so in a region or regions of space-time.

This principle reflects the current empirical situation. All observed entities and interactions are realised within space-time, and no evidence has been found of any causal influence originating outside it (Carroll, 2016).

3. Entities and Boundaries

An entity is any identifiable portion of physical reality. Entities include objects, fields, relationships, events, and more complex distributed phenomena.

Entities are distinguished by boundaries, which demarcate what is part of the entity and what is not. A boundary may be sharp, as in the surface of a solid object, or diffuse, as in the case of atmospheric or ecological systems. A boundary may also be continuous, forming a single connected demarcation, or discontinuous, comprising multiple separated regions treated as belonging to the same entity. In all cases, the boundary enables the distinction between an entity and its environment.

Two broad forms of entity may be distinguished.

Concrete entities are those whose components form a continuous region of space-time and can, in principle, be observed in their entirety. Examples include physical objects such as a rock, a machine, or a human body.

Abstract entities, by contrast, are physically real but cannot be apprehended as a single bounded object. They are distributed across space-time and will be examined in more detail in Section 5. For example, wealth is not located in a single place but is distributed across assets, accounts, and transactions over time; it is real and measurable, yet cannot be perceived in its entirety at once as a single object.

4. Collections, Sets, and Aggregation

Entities may be grouped into collections. A *collection* is any plurality of entities, while a *set* is a collection treated as a single entity. For example, a number of trees may be considered as a collection of individual trees, or as a single set described as a *forest* (von Bertalanffy, 1968).

This gives rise to an important duality. The same grouping may be regarded either as a plurality of individual entities or as a single aggregate entity. The choice of perspective determines whether relationships are described at the level of the whole or of the parts. In everyday language, sets are often referred to using *collective nouns*, such as a *team*, *family*, or *fleet*, which reflect the treatment of multiple entities as a single unit.

Aggregation refers to the treatment of a collection as a set, while *disaggregation* refers to the reverse operation. These complementary processes underpin systems analysis, allowing movement between levels of organisation. For example, a football team may be analysed as a single unit when considering its overall performance, or disaggregated into individual players when examining roles and interactions.

5. Abstract Entities as Distributed Physical Configurations

Abstract entities are often treated as non-physical. However, within this framework they are understood as *physically instantiated configurations distributed across space-time* that cannot be apprehended in their entirety at a single moment.

An abstract entity may be understood in two complementary ways.

First, as a *distributed set of concrete entities or events*. For example, justice may be understood as a set of actions, decisions, and institutional practices distributed across different locations and times. No single observation captures the whole.

Second, as a *characteristic or property* that defines a class of entities sharing a common feature. This may be expressed logically or symbolically and identifies the conditions under which an entity belongs to the class (Ladyman et al., 2007; Floridi, 2010).

In this sense, characteristics can be understood as *fields of occurrence across space-time*, where the presence or absence of the characteristic defines the structure of the field. A characteristic may be defined directly, by identifying instances that possess it, or indirectly, by reference to its complement. That is, the spatio-temporal aggregate of entities that do not possess the characteristic.

These two perspectives are equivalent. The extensional description identifies the instances, while the intensional description defines the rule by which those instances are included.

Abstract entities are therefore not non-physical. They are *distributed physical configurations* whose apparent abstraction arises from the limits of perception and representation.

6. Configuration, Structure, and Information

Entities exist in relation to one another within space-time.

Configuration refers to the spatial and temporal arrangement of entities with respect to one another, without implying interaction. For example, a set of particles distributed within a volume has a configuration defined by their positions, regardless of whether they are interacting.

Structure is the organisation of entities and their relationships within a configuration. Structure may be static, persisting over time, or dynamic, undergoing non-random change over time. For example, the arrangement of atoms in a crystal forms a stable structure, whereas the arrangement of vehicles in traffic constitutes a dynamic structure that changes over time.

A key distinction is drawn between random and non-random structure. Randomness refers to a condition in which interactions are unconstrained or insufficiently recurrent to give rise to non-random, recurring structure. For example, the positions of molecules in a gas at equilibrium approximate a random configuration, whereas the ordered arrangement of atoms in a crystal exhibits non-random structure.

Within this framework:

Information is defined as non-random, recurring structure in space-time (Shannon, 1948; Floridi, 2010).

For example, the sequence of nucleotides in DNA or the arrangement of symbols in a written sentence constitutes information because it exhibits stable, non-random structure.

This definition is ontological rather than interpretive. Information exists as structured pattern independently of whether it is observed or interpreted by an agent.

7. Relationships: Causal and Configurational

Entities are connected through physical relationships, which can be of two types (von Bertalanffy, 1968).

Causal relationships involve the transfer of matter, energy, or information between entities. They are processual in nature and occur over time. For example, heat flowing between objects or information being transmitted between agents are instances of causal relationships.

Configurational relationships arise from the configuration of entities in space-time. They do not involve transfer and are purely spatio-temporal associations. For example, the relative positions of components within a structure or the membership of elements within a set constitute configurational relationships.

These two forms are complementary. Configurational relationships determine the conditions under which interactions may occur, while causal relationships describe the processes through which change takes place.

Both forms are physically instantiated. Causal relationships are realised through transfers between entities, whereas configurational relationships are realised through the spatio-temporal arrangement of entities within space-time.

8. Events and Networks

An *event* is a time-bounded instance of a causal relationship involving transfer, resulting in a change of state of the participating entities. Every event is therefore a causal relationship actualised in time, though not every causal relationship is confined to a single event. For example, when a ball strikes the ground, energy is transferred and the motion of the ball changes; this constitutes an event.

When multiple causal relationships connect entities, they form *networks*. These networks underpin processes, system behaviour, and the emergence of higher-level organisation (Barabási, 2016; Mitchell, 2009). For example, in an ecosystem, energy is transferred through a sequence of interactions from plants to herbivores to predators, forming a network of causal relationships rather than a single isolated event.

9. Causality: PTP and TPT

Causal relationships in systems may be understood in two complementary ways.

First, as *process-transfer-process (PTP)* relationships, in which matter, energy, or information is transferred between systems or processes. This representation emphasises the relational structure of interactions, describing events and extended causal interactions.

Second, as *transfer-process-transfer (TPT)* structures, in which a system receives inputs, transforms them through internal processes, and produces outputs. This representation emphasises internal transformation.

For example, a heater converting electrical energy into heat may be described as a TPT process, while the transfer of heat from the heater to the surrounding air may be described as a PTP relationship.

These two representations describe the same underlying causal reality from different analytical perspectives. They differ only in perspective: PTP describes transfers between systems, while TPT describes transformations within systems. The PTP form highlights connections between systems, while the TPT form highlights the transformation of inputs into outputs within systems.

Any causal network can be described in PTP terms, while the behaviour of individual systems can be described in TPT terms.

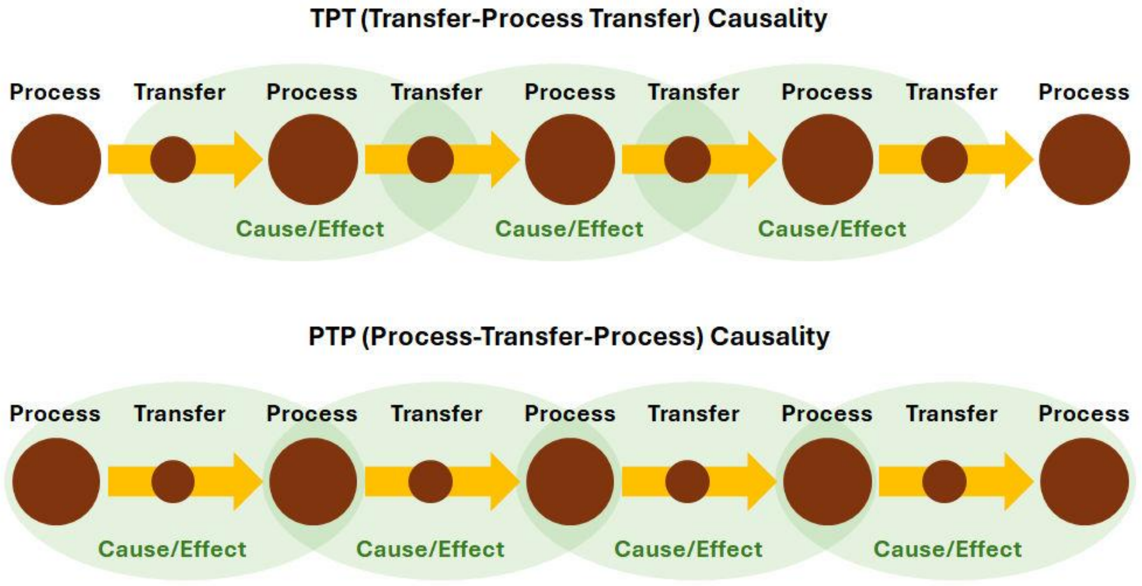

Figure 1: *Complementary representations of causality as PTP (between systems) and TPT (within systems).*

10. Characteristics, States, and Change

Entities are described in terms of their characteristics or properties.

The state of an entity is the set of characteristics that apply to it at a given time. A change of state occurs when this set changes. For example, water in a container may be described by characteristics such as temperature and phase; as heat is applied, its temperature increases, and when a threshold is reached it changes from liquid to gas, representing a change of state.

Some changes occur gradually and continuously, eventually producing observable transformation, such as the steady increase in temperature of the water. Others may be discrete, involving a transition between qualitatively different states, such as the change from liquid to gas during boiling. These concepts provide the basis for understanding system dynamics and evolution (Meadows, 2008).

11. Conclusion: From Ontology to Systems

The ontology developed in this paper establishes a coherent framework for understanding reality in systems terms.

All existence is realised within space-time. Entities are distinguished by boundaries and may be considered individually or as aggregates. Configuration describes the arrangement of entities in space-time, while structure describes the organisation of entities and their relationships within that configuration. Information is defined as non-random, recurring structure. Relationships connect entities either through configuration (structure) or through transfer. Events represent time-bound causal interactions, and networks of such interactions give rise to processes and systems.

Causality may be understood both relationally, as transfers between systems, and functionally, as transformations within systems. These perspectives are complementary and together provide a complete account of causal organisation.

This framework provides the foundation for subsequent papers, in which structure, information, thermodynamics, and systems behaviour will be developed in greater detail.

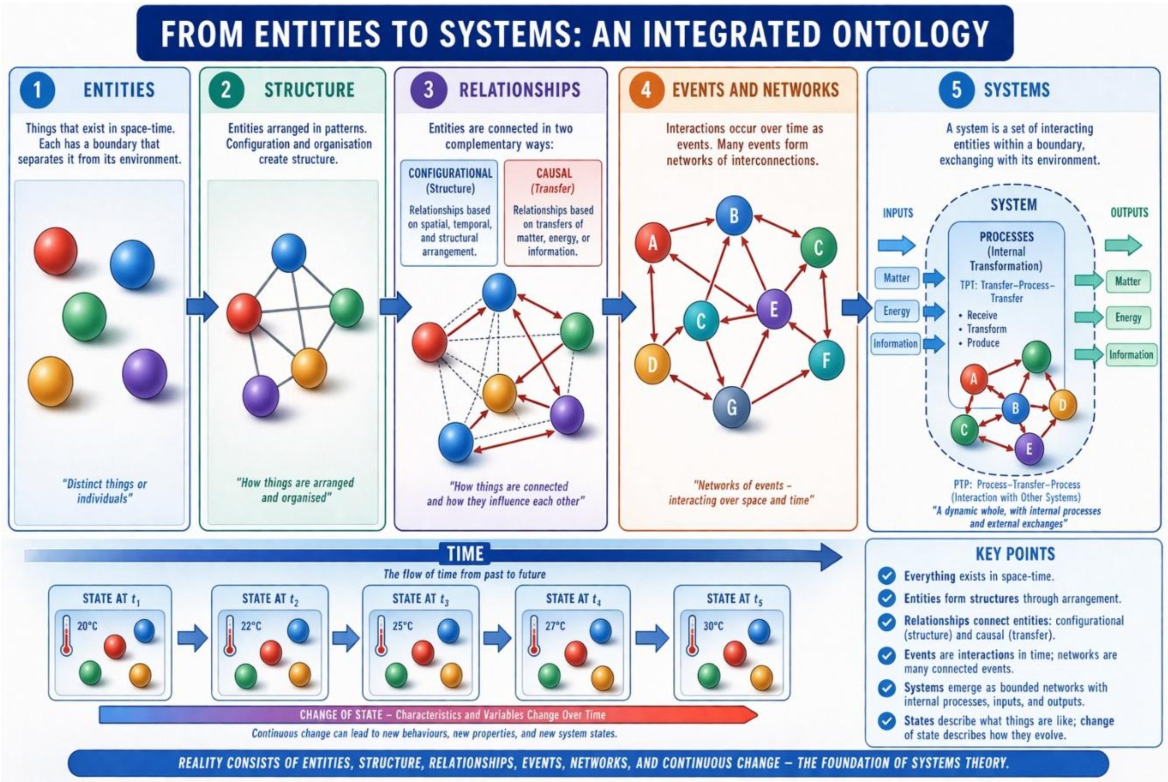

Figure 2: *Integrated Ontology of General Systems Theory showing the progression from entities through structure, relationships, events, and networks to systems and change.*

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Appendix A – Definitions and Propositions

Definitions

D2.1 – Space-Time

A single continuum comprising three dimensions of space and one of time.

D2.2 – Physical

Anything that exists within, or constitutes, space-time, including matter, energy, and the fields and structures that occupy or define it.

D2.3 – Metaphysical

Not existing in space-time, i.e. not physical.

D2.4 – Entity

Any identifiable portion of physical reality, including objects, fields, relationships, and events.

D2.5 – Boundary

A demarcation that separates an entity from what is not the entity.

D2.6 – Concrete Entity (Object)

A physical entity that occupies a bounded region of space-time and can, in principle, be apprehended as a single entity.

D2.7 – Abstract Entity

A physically instantiated configuration distributed across space-time that cannot be apprehended in its entirety at a single moment. Such entities may be understood either as sets of instances or as characteristics defining those instances.

D2.8 – Collection

Any plurality of entities.

D2.9 – Set

A collection of entities treated as a single entity.

D2.10 – Aggregation

The conversion of a collection into a set.

D2.11 – Disaggregation

The conversion of a set into a collection.

D2.12 – Set Duality

A set may be regarded either as a single entity or as a plurality of constituent entities (a collection), depending on the analytical perspective.

D2.13 – Configuration

The spatial and temporal arrangement of entities with respect to one another, without implying interaction.

D2.14 – Structure

The organisation of entities and their relationships within a configuration, including the causal relationships that connect them.
Note: Structure is a form of configuration; all structures are configurations, though not all configurations are structured.

D2.15 – Static Structure

A structure that persists over time.

D2.16 – Dynamic Structure

A structure undergoing non-random change.

D2.17 – Randomness

A condition in which variation across configurations does not stabilise into recurring structure.
Note: Structure is a form of configuration; all structures are configurations, though not all configurations are structured.

D2.18 – Information (Ontological)

Non-random, recurring structure in space-time.

D2.19 – Relationship

A physically instantiated connection between entities arising either from configuration (structure) or from transfer.

D2.20 – Configurational Relationship

A relationship arising from the configuration (arrangement) of entities in space-time, without transfer.

D2.21 – Causal Relationship

A physically instantiated process involving the transfer of matter, energy, or information between entities.

D2.22 – Event

A time-bounded instance of a causal relationship resulting in a change of state.

D2.23 – Network

A group of causally interconnected entities or relationships.

D2.24 – Characteristic (Property)

A feature common to entities used to classify or distinguish them.

D2.25 – Variable

A characteristic capable of taking different values.

D2.26 – State

The set of characteristics that apply to an entity at a given time.

D2.27 – Change of State

A change in the set of characteristics that apply to an entity.

D2.28 – Continuum Change of State

A gradual change of state that culminates in observable transformation.

Propositions

P2.1 – Space-Time Existence Proposition

Everything that exists does so in a region or regions of space-time.

P2.2 – Empirical Closure Proposition

There is no empirical evidence of any non-physical entity interacting with the physical universe. All observed entities, relationships, and events are mediated through physical processes within space-time.

P2.3 – Abstract Entity Proposition

Abstract entities are physical in existence but cognitively abstract due to the distributed nature of their instantiation and the limits of perception and representation.

P2.4 – Relationship Proposition

Relationships may be configurational or causal; both forms contribute to the organisation of systems.

P2.5 – Transfer Proposition

A causal relationship involves the transfer of matter, energy, or information between entities.

P2.6 – Relationship Ontology Proposition

Relationships are physically instantiated within space-time.

P2.7 – Causal Relationship–Disposition Proposition

A causal relationship involves transfer, whereas configuration does not.

P2.8 – Event Proposition

Every event is a causal relationship actualised in time, but not every relationship is confined to a single event.

P2.9 – Dual Representation of Causality Proposition

Causal processes may be represented either as transfers between systems (process-transfer-process, PTP) or as transformations within systems involving inputs and outputs (transfer-process-transfer, TPT). These are complementary representations of the same causal structure.

P2.10 – Hierarchical Causality Proposition

A causal relationship or process, whether represented in PTP or TPT form, may be decomposed into component causal relationships or processes, which may themselves be represented in PTP or TPT form.

P2.11 – Causal Relationship Composition Proposition

A causal relationship consists of participating entities and the matter, energy, or information transferred between them, forming a physically instantiated process in space-time.

