Domain Analysis & Description – A Philosophy Basis

DINES BJØRNER*, Technical University of Denmark, Denmark

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This paper consists of two parts: A philosophy part and a terse summary of my April 2019 ACM Trans. on Software Engineering and Methodology paper on Domain Analysis & Description. In the philosophy part, Sect. 2, we outline Kai Sorlander’s philosophy on “what, if anything, is of such necessity, that it can, under no circumstances be otherwise, or: “which are the necessary properties of any possible world” [39, 8 Sept. 2019]. That question is then “narrowed” to the question “which mutually defined basic concepts must be assumed in every possible world description” [39, 8 Sept. 2019]. The two quotes cover the domain analysis respectively the description sections. In Sects. 3–8, we present a new preamble for software engineering, one that precedes requirements engineering. We outline two calculi: one for the analysis of the endurants of human artefact “dominated” domains, and one for their description. By a transcendental deduction endurant domain descriptions are translated into perdurant domain descriptions: manifest parts becoming abstract concepts. We show how the ontology of the second part is basically founded on the necessities of any world description as outlined in the first part — thereby contributing to a philosophy basis for computing.

1 INTRODUCTION

Before software can be designed the programmer must grasp its requirements. Before requirements are prescribed the engineer must grasp an adequate extent of the domain in which that software is to serve. But do software engineers today have a sufficient grasp of their target domains?

Software designs are always formally specified: the program code must be executable by computer – and as such, precise mathematical statements, including properties of computations, as directed by the code, can be expressed, and possibly proved. [2] covers formal software design. Requirements prescriptions are sometimes formally specified. Domain descriptions are introduced in [4, 10, 14, 18]. It is shown in these papers that domain descriptions can be formalised. And in [3, 9] it is shown how formal domain prescriptions can be for “derived” from domain descriptions.

Formal requirements prescriptions and software designs are expressed in a computable formalism. Not so with domain descriptions. The domains they focus on are not (necessarily) computable.

A rôle of requirements prescriptions is to identify and describe relevant computable subsets of the domain. So consistent and complete formal requirements prescriptions and software designs refer, basically, to mathematical objects that do exist in the mathematical universes of their specifications. Domain analysis [& description] does not have this “advantage”!

The present paper, as well as its precedent papers [3–8, 11, 13, 15, 18], lead us to claim that domain science & engineering of offers a compelling new foundation for software development. Physics is the
basis for all branches classical of engineering. So, we claim, [that] domain science, is a basis for all software. We shall, however, cover only a fragment of this basis.

1.1 Domain Science & Engineering

DEF.1: By a domain we shall understand a rationally describable discrete dynamics segment of a human assisted reality. That is, of the world, its physical parts: natural ["God-given"] and artefactual ["man-made"], and living species: plants and animals including, notably, humans.

DEF.2: By a discrete dynamics segment of the world we shall understand a reality whose dynamics “move” in steps, and where possible continuous changes are otherwise ignored.

DEF.3: By rationally describable we mean describable using, for example, the principles, techniques and analysis & description prompts of this paper and detailed in [18].

DEF.4: By human assisted reality we mean a universe of discourse with at least one artefactual phenomenon and as monitored & controlled by at least one human.

We present an essence of two calculi: a calculus of domain analysis prompts and a calculus of domain description prompts. We shall only present the prompts, not their algebra, that is, not the laws of combined uses of prompts.

DEF.5: By a prompt we shall mean an act of encouraging the domain analyser cum describer, that is, a human, to do something, here: to analyse and/or describe.

DEF.6: By domain analysis we mean an inquiry, by domain analysers, i.e., humans, into the make-up of a domain, with the analysis resulting in affirmative answers, to questions like “is, what I am observing, such-and-such”—true or false.

DEF.7: By a domain description we mean a textual document, both informal, the narrative, and formal, the specification.

The narrative is a natural language text which in terse statements introduces the names of the domain, and, possibly, also the definitions, of sorts (types) of syntactic and semantic entities, actions, events and behaviours, and axioms; not anthropomorphically, but by emphasizing their properties. The formal specification is a collection of sort, or type definitions, function and behaviour definitions, together with axioms and proof obligations constraining the definitions. So the problem is to analyse and describe a domain, that is, to describe physical parts, whether natural or man-made, and, in [rare] cases also living species: plants and animals, notably humans. The next many sections shows how we tackle – and hence expect others to tackle – that problem. The approach takes its departure in philosophy. Most decisively in the philosophy of Kai Sørlander.

1.2 Some Issues of Philosophy

The question is: “what, if anything, is of such necessity, that it could under no circumstances be otherwise?” or “which are the necessary characteristics of any possible world?”. We take it as the necessary characteristics of any domain is equivalent with the conceptual, logical conditions for any possible description of that domain. Sørlander puts forward the thesis of the possibility of truth and then basing transcendental deductions on indisputable logical relations to arrive at the conceptual, logical conditions for any possible description of that domain. The starting point, now, in a series of deductions, is that of logic and that we can assert a property, $P$, and its negation $\neg P$; and that these two assertions cannot both be true, that is, that $P \land \neg P$ cannot be true. So the possibility of truth is a universally valid condition. When we claim that, we also claim the contradiction principle. The implicit meaning theory is this: “in assertions there are mutual dependencies between the meaning of designations and consistency relation between assertions”. When we claim that a philosophy basis is that of the possibility of truth, then we assume that this basis include the contradiction principle and the implicit meaning theory. We shall also refer to the implicit meaning theory as the inescapable meaning assignment.

As an example of what “goes into” the inescapable meaning assignment, we bring, albeit from the world of computer science, that of the description of the stack data type (its endurants and operations).

An Inescapable Meaning Assignment Example, Narrative

The meaning of designations:

1. $E, S$

value

2. $\text{empty}_S : \text{Unit} \to S$

3. $\text{is_empty}_S : S \to \text{Bool}$

4. stack: $E \times S \to S$

5. unstack: $S \to S$

6. top: $S \to E$

The consistency relations:

7. $\text{empty}(\text{empty}_S(1)) = \text{true}$

8. $\text{is_empty}(\text{stack}(e,s)) = \text{false}$

9. $\text{top}((\text{stack}(e,s))) = e$

An Inescapable Meaning Assignment Example, Formalisation

The meaning of designations:

1. $E, S$

value

2. $\text{empty}_S : \text{Unit} \to S$

3. $\text{is_empty}_S : S \to \text{Bool}$

4. stack: $E \times S \to S$

5. unstack: $S \to S$

6. top: $S \to E$

The consistency relations:

7. $\text{empty}(\text{empty}_S(1)) = \text{true}$

8. $\text{is_empty}(\text{stack}(e,s)) = \text{false}$

9. $\text{top}((\text{stack}(e,s))) = e$

1.3 Transcendence

DEF.8: By transcendental “we shall understand the philosophical notion: the a priori or intuitive basis of knowledge, independent of experience”.

DEF.9: By a transcendental deduction “we shall understand the philosophical notion: a transcendental ‘conversion’ of one kind of knowledge into a seemingly different kind of knowledge”.

Transcendental philosophy, with Kant and Sørlander, seeks to find the necessary conditions for experience, recognition and understanding. Transcendental deduction is then the “process”
based on the principle of contradiction and the implicit meaning theory by means of which – through successive concept definitions one can deduce a system of base concepts which must be assumed in any possible description of the world. The subsequent developments of the logical connectives, modalities, existence, identity, difference, relations, numbers, space, time and causality, are all transcendental deductions.

2 OVERVIEW OF THE SØRLANDER PHILOSOPHY

In this section we shall give a very terse summary of main elements of Kai Sølander’s philosophy. We shall primarily base this overview on [38]. It is necessarily a terse summary. What we overview is developed in [38] Sølander over some 50 pages. Sølander’s books [31, 32, 34, 38], relevant to this overview, are all in Danish. Hence the need for this section.

2.1 Logical Connectives

Negation: \( \neg \) The logical connective, negation (\( \neg \)), is defined as follows: if assertion \( \mathcal{P} \) holds then assertion \( \neg \mathcal{P} \) does not hold. That is, the contradiction principle understood as a definition of the concept of negation.

Conjunction and Disjunction: \( \land \) and \( \lor \) Asserting \( \mathcal{P} \land \mathcal{Q} \) holds, i.e., is true, if both \( \mathcal{P} \) and \( \mathcal{Q} \) holds. Asserting \( \mathcal{P} \lor \mathcal{Q} \) holds, i.e., is true, if either \( \mathcal{P} \) or \( \mathcal{Q} \) or both \( \mathcal{P} \) and \( \mathcal{Q} \) holds.

Implication: \( \rightarrow \) Asserting \( \mathcal{P} \rightarrow \mathcal{Q} \) holds, i.e., is true, if the first assertion, \( \mathcal{P} \), holds, \( t \), and the second assertion, \( \mathcal{Q} \), is not false, \( \neg t \).\( [(\mathcal{P}, \mathcal{Q}), \mathcal{P} \rightarrow \mathcal{Q}] : [(t,t), [(t,f), f], [(f,t), f], f] \).

2.2 A Philosophy Basis for Physics and Biology

In a somewhat long series of deductions we shall, based on Sørlander’s Philosophy, motivate the laws of Newton and more, not on the basis of empirical observations, but on the basis of transcendental deductions and rational reasoning.

Possibility and Necessity Based on logical implication we can transcendentially define the two modal operators: necessity and possibility. \( \Box \) An assertion is necessarily true if its truth follows from the definition of the designations by means of which it is expressed. \( \Diamond \) An assertion is possibly true if its negation is not necessary.

Empirical Assertions There can be assertions whose truth value does not only depend on the definition of the designations by means of which they are expressed. Those are assertions whose truth value depend also on the assertions referring to something that exists independently of the designations by means of which they are expressed. We shall call such assertions empirical.

Existence With Sørlander we shall now argue that there exist many entities in any world. [38, pp145] “Entities, in a first step of reasoning, that can be referred to in empirical assertions do not necessarily exist. It is, however, an empirical fact that they do exist; hence there is a logical necessity that they do not exist. In a second step of reasoning, these entities must exist as a necessary condition for their actually being ascribed the predicates which they necessarily befit in their capacity of of being entities referred to in empirical assertions.”

Identity, Difference and Relations [38, pp146] “An entity, referred to by A, is identical to an entity, referred to by B, if A cannot be ascribed a predicate, in-commensurable with a predicate ascribed to B.” That is, if A and B cannot be ascribed in-commensurable predicates. [38, pp146] “Entities A and B are different if they can be ascribed in-commensurable predicates.” [38, pp147] “Identity and difference are thus transcendally derived through these formal definitions and must therefore be presupposed in any description of any domain and must be expressible in any language.” Identity and difference are relations. [38, pp147] “As a consequence identity and difference imply relations. Symmetry and asymmetry are also relations: A identical to B is the same as B identical to A. And A different from B is the same as B different from A. Finally transitivity follows from A identical to B and B identical to C implies A identical to C.”

Sets: We can, as a consequence of two or more different entities satisfying a same predicate, say \( \mathcal{P} \), define the notion of the set of all those entities satisfying \( \mathcal{P} \). And, as a consequence of two or more entities, \( e_1, \ldots, e_j \), all being distinct, therefore implying in-commensurable predicates, \( \mathcal{D}_1, \ldots, \mathcal{D}_j \), but still satisfying a common predicate, \( \mathcal{P} \), we can claim that they all belong to a same set. The predicate \( \mathcal{P} \) can be said to type that set. And so forth: following this line of reasoning we can introduce notions of cardinality of sets, finite and infinite sets, existential (\( \exists \)) and universal (\( \forall \)) quantifiers, etc.; and we can in this way transcendally deduce the concept of (positive) numbers, their addition and multiplication; and that such are an indispensable aspect of any domain. We leave it then to mathematics to study number theory.

Space and Geometry \( \text{DEF.12: Space} \) [38, pp154] “The two relations asymmetric and symmetric, by a transcendental deduction, can be given an interpretation: the relation (spatial) direction is asymmetric; and the relation (spatial) distance is symmetric. Direction and distance can be understood as spatial relations. From these relations are derived the relation in-between. Hence we must conclude that primary entities exist in space. Space is therefore an unavoidable characteristic of any possible world.” [38, pp155] “Entities, to which reference can be made in simple, empirical assertions, must exist in space; they must be spatial, i.e., have a certain extension in all directions; they must therefore “fill up some space”, have surface and form.” From this, by further reasoning one can develop notions of points, line, surface, etc., i.e., Euclidean as well as non-Euclidean geometry.

States We introduce a notion of state. [38, pp158–159] “Entities may be ascribed predicates which it is not logically necessary that they are ascribed. How can that be possible? Only if we accept that entities may be ascribed predicates which are in-commensurable with predicates that they are actually ascribed.” That is possible, we must conclude, if entities can exist in distinct states. We shall let this notion of state further undefined – till Sect. 5.3.4.

Time and Causality \( \text{DEF.13: Time} \) [38, pp159] “Two different states must necessarily be ascribed different incompatible predicates. But how can we ensure so? Only if states stand in an asymmetric relation to one another. This state relation is also transitive. So that is an indispensable property of any world. By a transcendental deduction we say that primary entities exist in time. So every
possible world must exist in time.” So space and time are not phenomena, i.e., are not entities. They are, by transcendental reasoning, aspects of any possible world, hence, of any description of any domain. In a concentrated series [38, 160-163] of logical reasoning and transcendental deductions, Sørlander, introduce the concepts of the empirical circumstances under which entities exist, implying non-logical implication between one-and-the-same entity at distinct times, leading to the notions of causal effect and causal implication – all deduced transcendally. Whereas Kant’s causal implication is transcendally deduced as necessary for the possibility of self-awareness. Sørlander’s causal implication does not assume possibility of self-awareness. The principle of causality is a necessary condition for assertions being about the same entity at different times.

Kinematics [38, pp 164] “Entities are in both space and time; therefore must be assumed that they can change their spatial properties; that is, are subject to movement. An entity which changes location is said to move. An entity which does not change location is said to be at rest.” In this way [38] transcendally introduces the notions of velocity and acceleration, hence kinematics.

Dynamics [38, pp 166] “When combining the causality principle with dynamics we deduce that when an entity changes its state of movement then there must be a cause, and we call that cause a force.” [38, pp 166] “The change of state of movement must be proportional to the applied force; an entity not subject to an external force will remain in its state of movement: This is Newton’s 1st Law.”

[38, pp 166] “But to change an entity’s state of movement, by some force, must imply that the entity exerts a certain resistance to that change; the entity must have a mass. Changes in an entity’s state of movement besides being proportional to the external force, must be inverse proportional to its mass. This is Newton’s 2nd Law.”

[38, pp 166-167] “The forces that act upon entities must have as source other entities: entities may collide; and when they collide the forces they exert on each other must be the same but with opposite directions. This is Newton’s 3rd Law.”

[38, pp 167-168] “How can entities be the source of forces? How can they have a mass? Transcendentally it must follow from what we shall refer to as gravitational pull. Across all entities of mass, there is a mutual attraction, universal gravitation.” [38, pp 168-169] “Gravitation must, since it has its origin in the individual entities, propagate with a definite velocity; and that velocity must have a limit, a constant of nature, the universal speed limit.”

2.2.2 Purpose, Life and Evolution [38, pp 174] “For language and meaning to be possible there must exist entities that are not constrained to just the laws of physics. This is possible if such entities are further subject to a “purpose-causality” directed at the future. These entities must strive to maintain their own existence.” We shall call such entities living species. Living species must maintain and also further develop their form and do so by an exchange of materials with the surroundings, i.e., metabolism, with one kind of living species subject only to development, form and metabolism, while another kind additionally move purposefully. The first we call plants, the second animals. Animals, consistent with the principle of causality, must possess sensory organs, a motion apparatus, and instincts, feelings, promptings so that what has been sensed, may be responded to [through motion]. The purpose-directness of animals must be built into the animals. Biology shows that that is the case. The animal genomes appear to serve the purpose-directness of animals. [38, pp 178] “Biology shows that it is so; transcendental deduction that it must be so.”

2.2.3 Awareness, Learning and Language [38, pp 180] “Animals, to learn from experience, must be able to feel inclination and disinclination, and must be able to remember that it has acted in some way leading to either the feeling of inclination or disinclination. As a consequence, an animal, if when acting in response to sense impression, experiences the positive feeling of inclination (desire), then it will respond likewise when again receiving sense impression 1, until it is no longer so inclined. If, in contrast, the animal feels the negative feeling of disinclination (dislike), upon sense impression 1, then it will avoid responding in this manner when receiving sense impression 1.” [38, pp 181] “Awareness is built up from the sense impressions and feelings on the basis of, i.e., from what the individual animal has learned. Different animals can be expected to have different levels of consciousness; and different levels of consciousness assume different biological bases for learning. This is possible, biology tells us, because of there being a central nervous system with building blocks, the neurons, having an inner determination for learning and consciousness.” [38, pp 181-182] “In the mutual interaction between animals of a higher order of consciousness these animals learn to use signs developing increasingly complex sign systems, eventually “arriving” at languages.” It is thus we single out humans. [38, pp 183] “Any human language which can describe reality, must assume the full set of concepts that are prerequisites for any world description.”

We have concluded the presentation of a major issue of this paper, that of a philosophy that may be a possible basis for domain science & engineering. We now “apply” this, Kai Sørlander’s, Philosophy to the problem of domain analysis & description.

3 PHENOMENA AND ENTITIES

DEF 14: By an entity, is_entity, we shall understand a phenomenon, i.e., something that can be observed, i.e., be seen or touched by humans, or that can be conceived as an abstraction of an entity; alternatively, a phenomenon is an entity, if it exists, it is “being”, it is that which makes a “thing” what it is: essence, essential nature [26,
An entity is what we can analyse and describe using the analysis & description prompts outlined in this paper. Many of the entities that we are concerned with are those with which Kai Sørlanders Philosophy is likewise concerned. They are the ones that are unavoidable in any description of any possible world.

Before main Sects. 4–8, we introduce two categories of entities: endurants and perdurants.

3.1 Endurants

**Def.15:** By an endurant we shall understand an entity that can be observed, or conceived and described, as a “complete thing” at no matter which given snapshot of time; alternatively an entity is endurant if it is capable of enduring, that is persist, hold out [26, Vol. I, pg. 656]. Were we to “freeze” time we would still be able to observe the entire endurant. **Endurants:** A train wagon, a rail track and a railway station. We suggest that the concept of endurants can be seen as a transcendental deduction based on the inescapable fact that there is a multitude of entities, and that considering these as existing in just space, are the endurants. But note that endurants are [to be] observed.

3.2 Perdurants

**Def.16:** By a perdurant we shall understand an entity for which only a fragment exists if we look at or touch them at any given snapshot in time. Were we to freeze time we would only see or touch a fragment of the perdurant, alternatively an entity is perdurant if it endures continuously, over time, persists, lasting [26, Vol. II, pg. 1552]. **Perdurants:** are entities that only exists partially at any given point in time. **Ex.1. Perdurant:** a train ride. We suggest that the concept of perdurants can be seen as a transcendental deduction based on the inescapable fact that there is a multitude of entities, and that considering these as existing in both space and time, are the perdurants.

Sections 4–6 and Sect. 8 reviews the complex, conceptual “universes” of endurants, respectively perdurants. Section 7 unveils, by a transcendental deduction, the link between endurants and perdurants: that perdurant parts transcend into behaviours. Figure 1 suggests a structuring of endurants, perdurants and their relations.

4 ENDURANTS: EXTERNAL QUALITIES

Observable qualities of endurants are those that can be touched. We choose, it may seem arbitrarily, to analyse endurants into either discrete (solid) or continuous (non-solid) endurants. That is, we claim that endurants can be so analysed either of one kind, or of the other, but not both! We justify the distinctions based on physics.

4.1 Discrete and Continuous Endurants

**Def.17:** By a discrete endurant (a solid) we shall understand an endurant which is separate, individual or distinct in form or concept [26, OED]. **Ex.3. Discrete Endurants:** a particular canal lock, a particular canal link between two specific adjacent locks, a particular barge. **Def.18:** By a continuous endurant (a non-solid) we shall understand an endurant which is prolonged, without interruption, in an unbroken series or pattern [26, OED]. We think of a non-solid to be either a gas or a plasma or a liquid. **Ex.4. Continuous Endurant:** water (in a specific canal), air (in a specific ventilator pump), beer (in a specific bottle). Note, and please accept, the OED definitions. They are not precise in the sense of mathematics. We are not dealing with an exact ‘world’. We are dealing with real worlds.

4.2 Solids

Solids, i.e., discrete endurants, are either physical parts, or living species, or structures. We shall motivate the first two categories of solids on the background of Sørlander’s philosophy. Structures are motivated pragmatically.

4.2.1 Physical Parts and Living Species: **Def.19:** By a physical part we shall understand a discrete endurant existing in space and time and subject to laws of physics, including the causality principle and gravitational pull – and which is not a living species or an animal. **Ex.5. Physical parts:** a pipeline system, a specific pipeline, units of a specific pipeline: a specific pipe, a specific valve, a specific pump, etc. **Def.20:** By a living species we shall understand a discrete endurant, subject to laws of physics, and additionally subject to causality of purpose. **Ex.6. Living Species:** a specific garden, a specific flower bed, a specific rhodendron, a specific bird, a specific human. In this paper we shall not elaborate on the possibility of natural versus man-made living species.

4.2.2 Natural Parts and Artefacts: **Def.21:** By a natural part we shall understand physical parts, i.e., that are in space and time, are subject to the laws of physics, and also subject to the principle of causality and gravitational pull, but are not man made and not living species. **Ex.7. Natural Parts:** a particular landscape, a particular lake, a particular forest, a particular mountain. **Def.22:** By an artefact we shall understand physical parts that are man made with one or more intents. We shall explain the notion of intent later. **Ex.8. Artefacts:** a specific road network, with specific automobiles, specific hubs (at road intersections), specific links (between two adjacent hubs), specific routes (contiguous sequences of zero, one or
Atomic or Composite Parts: **DEF 23.** By an atomic part we shall understand a part which, in a given context, deemed to not contain of meaningful, separately observable proper sub-part, A sub-part is a part. **EX 9.** Atomic Artefacts: hubs, links, automobiles. We shall not consider natural parts as other than that, neither atomic, nor composite in this paper. **DEF 24.** By a composite part we shall mean physical parts which, in a given context, are deemed to indeed consist of meaningful, separately observable proper sub-parts. **EX 10.** Composite Artefacts: road nets, pipeline systems, railway systems. **EX 11.** Elements of a Composite Artefact: The domain of road transport is assumed to contain a road net which then contains a set of links, a set of hubs, a set of automobiles, a set of zero, one or more road maintenance departments, and a set of zero, one or more automobile clubs. It may contain other parts.

Concrete Type Artefacts: In addition to atomic and composite artefacts there are concrete type artefacts. The analysis into this variety of three kinds is based on pragmatic grounds. **DEF 25.** By a concrete type artefact we shall, simplifying, mean a set of endurants, all of the same sort. **EX 12.** Concrete Type Artefacts: a specific set of hubs, a specific set of links, a specific set of automobiles.

Plants, Animals and Humans: Living species are either plants or animals. **DEF 26.** By a plant, animal and human we shall understand what Kari Sørlande’s Philosophy transcendentially arrives at as such. We omit examples!

Structures: **DEF 27.** By a structure we shall understand a discrete endurant which the domain engineer chooses to describe as consisting of one or more endurants, whether discrete or continuous, but to not endow with internal qualities: unique identifiers, mereology or attributes. Structures are “conceptual endurants”. A structure “gathers” one or more endurants under “one umbrella”, often simplifying a presentation of some elements of a domain description. Sometimes, in our domain modelling, we choose to model an endurant as a structure, sometimes as a physical part; it all depends on what we wish to focus on in our domain model. As such structures are “compounds” where we are interested only in the (external and internal) qualities of the elements of the compound, but not in the qualities of the structure itself.

Non-solids

En entity may thus be a non-solid. A composite part, p, natural or man-made, may have one or more non-solid entities, though with at least one solid entity — in which case has_non_solids(p).

The Analysis Prompts

We summarise the analysis prompts informally introduced in this section.

ENDURANTS: INTERNAL QUALITIES

Internal qualities of endurants are those qualities that cannot be touched but can be either conceptualised or measured. We consider the following internal qualities: unique identifiers, mereology, and attributes. Physical parts have the full set of internal qualities. Structures are endurants for which the domain analyser cum describer had decided to not endow with internal qualities. We shall not, in this paper, be concerned with the internal qualities of living species.

Unique Identifiers

It is based on the philosophy idea of identity, cf. Sect. 2.2, that we associate with each solid a unique identifier. **EX 13.** Road Net Links and Hubs: The road net of a transport system consists of links, i.e., street segments, and hubs, i.e., street intersections. Links of any road net have unique identifiers. (Links of all road nets are distinctly identified.) Hubs of any road net are distinctly identified.

Mereology

**DEF 28.** Mereology is the study of parts and the wholes they form. Mereology, as here put forward, is due to the Polish philosopher/logician/mathematician Stanisław Leśniewski [21, 27]. There are basically two relations that can be relevant for part-hood (i) a topological one, and (ii) a temporal one. (i) Physically two or more parts may be adjacent to one another or one within another. (ii) Temporally some parts “relate”, over time, to a “therefrom physically distinct” part. **EX 14.** Topological Mereology: The mereology of links of a road net is a set of two distinct hub identifiers of that net, and of hubs of a road net is a set of zero, one or more link identifiers of that net. The mereology thus defines a concept of routes of a road net, and must be such that there is at least one route from any hub to any other hub of a road net. **EX 15.** Temporal Mereology: The mereology of an automobile (of a road transport system) identifies the hubs and links that it may, over time, traverse and the zero, one or more automobile clubs it may be a member of and may contact, over time. The mereology of a hub and a link, (of a road transport system) in addition to what has already been ascribed to hubs and links, identifies one road maintenance department that, over time, maintains hubs and links.

We may model the mereology of a part, p, as a triplet: an input set of unique identifiers of parts from which p “receives input” in a sense not further described here; a pair of input/output sets of unique identifiers of parts from which p “receives input” and to which “delivers output” in a sense not further described here; and an output set of unique identifiers of parts to which p “delivers output” in a sense not further described here.
5.3 Attributes

Unique identifications and mereologies form abstract concepts. Although topological mereologies may be observed, and unique identification, are not manifest – although they can be the quantities that are referred to in empirical assertions. Attributes are measurable properties of endurants, properties that can be referred to in empirical assertions — they, so-to-speak, give “flesh and blood”; that is, substance to endurants. Endurants are typically recognised because of their spatial form and are otherwise characterised by their intangible, but measurable attributes. We equate all endurants which, besides possible type of unique identifiers and possible type of mereologies, have the same types of attributes, with one sort. Removing a quality from an endurant makes no sense: the endurant of that type either becomes an endurant of another type or ceases to exist (i.e., becomes a non-entity)!

5.3.1 Attribute Categories: Attributes [25] are either of static value, i.e., does change value, or of monitorable value, i.e., dynamic inert or reactive: monitorable values can change, or of controllable value, i.e., dynamic biddable or programmed: biddable values can be prescribed, but prescription may fail; programmable values can be set. Ex.16. Link Attributes: Typical link attributes could be: location (e.g., as a Bézier curve) [static], length [static], road condition (icy, dry, ...) [monitored], state — as a set of pairs of adjacent hub identifiers [controllable], state spaces — as set of all such states [static], and automobile history: recordings of which automobiles have been on the link, at which position and time. Ex.17. Hub Attributes: Typical hub attributes could be: location [static], state — as set of pairs of adjacent link identifiers [controllable], and automobile history: recordings of which automobiles have been on the hub, and at which time. States are abstractions of traffic signals. Ex.18. Automobile Attributes: Typical automobile attributes could be: position (on hub or link), velocity, etc., road net history: recordings of the hubs and links on which the automobile has been, at which position and time.

5.3.2 Artefact Intents: With artefacts we can associate intents. Ex.29. By an intent of an artefact we shall understand a simple label which informally indicates the purpose for which the artefact is intended. An artefact may be ascribed more than one intent. Artefacts are usually ascribed at least one intent. Ex.19. Intents of Automobiles and Road Nets: To automobiles we may ascribe the intent that they are located on the road net, i.e., on hubs and links; and to hubs and links we then ascribe the intent that they accommodate automobiles.

5.3.3 Intentional Pull: Gravitational pull, cf. Sect. 2.2, follows from Newton’s Third Law. Intentional pull “follows” from the fact that pairs or triples, etc., of artefacts of different sorts, may be ascribed commensurate intents. Ex.20. Intentional Pull between Automobiles and Road Net: If an automobile’s road net history records that is has visited a road net unit at time t and position π, then that road net unit’s automobile history records that very same fact! And vice versa. It cannot be otherwise!

5.3.4 States: By a state we shall understand any collection of endurants for which any one endurant has at least one dynamic, i.e., non-static, attribute. By the state of a behaviour we shall understand its current program point, that is, its point of execution, and the collection of its monitorable and controllable variables, that is, of their current values.

6 ENDURANTS: DESCRIPTION PROMPTS

So far we have outlined a number of domain analysis prompts, cf. Sect. 4.4. We now summarise some description prompts. We refer to Fig. 1. The “analysis states” marked with magenta colored square boxes, ■, correspond, left-to-right in the ontology graph to the following description prompts: observe_endurant_sorts, observe_concrete_part, observe_component_sort, observe_structure_components and observe_non_solids. Sections 3–4 can be summarised formally:

In any specific domain analysis & description the analyst may describe which subset of composite sorts to analyse & describe. That is: any one domain model emphasises certain aspects and leaves out many “other” aspects. A similar observer is defined for concrete type parts, cf. Sect. 4.2.4:

Typically P may be a sort expression: P1|P2|...|Pn where Pi are sorts. We refer to [18] for observers of structures and non-solids.

The above covered the prompts for describing external qualities. Prompts for describing internal qualities are: observe_unique_identifier, observe_mereology and observe_attributes. Section 5 can be summarised formally:

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One and “seemingly” the same domain may give rise to different analyses & descriptions. Each of these emphasize different aspects.

**Example: Road Net**: In one model of a road net emphasis may be on automobile traffic (aiming, eventually, at a road pricing system). Another model of “the same” road net emphasis may be on the topological layout (aiming, eventually, at its construction). Yet a third model “over” a road net emphasis may be on traffic control. For each such “road net” model the domain analyser cum describer selects different overlapping sets of attributes.

### 7 FROM PARTS TO BEHAVIOURS

It is often said “every noun can be verbed” and “every verb can be nounced”. That may be so. In any case we shall perform the following one-way transcendental deduction: “to every [endurant] physical part” “we shall associated a perdurant behaviour.” That deduction is “inspired” by the following observations: (i) there is the train, as an endurant entity, as it stands, there, on the platform, statically observable, over time; (ii) there is the train, as a perdurant behaviour, as it “speeds” down the railway track, only a part of it visible at any given point and time; and (iii) there is the train, as a railway system attribute, as it “appears” in a time table; programmable.

By an **action** we shall understand a function which, among its arguments, take a state and delivers an updated state, and where that action has been knowingly, willfully applied. By an **event** we shall understand a state change for which we do not seek its origin, i.e., an endurant entity, as as it stands, there, on the platform, statically observable, over time; that deduction works! Each have a crucial rôle!

#### 8.1 Behaviour Signatures

A behaviour signature, for part \( p \), is of the form:

| value | \( \text{Name: ui:U} \rightarrow (\text{st}_1, \ldots, \text{st}_n): \text{Statics} \rightarrow \text{me:Mereology} \rightarrow \text{ca}_1, \ldots, \text{ca}_n: \text{Programmables} \rightarrow \text{in Monitorables, in}_p \text{Mereology, in}_p \text{out}_p \text{Mereology, out out}_p \text{Mereology} \rightarrow \text{Unit} \) |

We explain this signature: Name is an analyser cum describer chosen name, usually a meaningful mnemonic; \( U \) is the type of the unique identifier for the translated sort, i.e., of part \( p \); Statics designates the zero \((=0)\), one or more static attributes of part \( p \); Mereology designates the triplet mereology of the part, cf. last paragraph of Sect. 5.2; Programmables designates the zero \((=0)\), one or more programmable attributes of part \( p \); Monitorables designates zero, one or more input channel references designating monitorable attributes of part \( p \); in\_Mereology designates zero, one or more input/output channel references designating the parts from whom part \( p \) “receives” input; in\_out\_Mereology designates zero, one or more output channel references designating the parts to whom part \( p \) “delivers” output; and Unit designates that the behaviour goes on forever! Technicalities are given in [18], Sects. 7.4.3–7.4.4.

#### 8.2 Behaviour Definition Bodies: \( \mathcal{B}_p \)

In general the signature expresses that behaviour Name\(\text{(ui)}\) evolves around (i) constant values whose type is given in Statics; (ii) input from monitorable attributes (of values “residing” in part \( p \), but not otherwise expressible) are not expressed in the body of the behaviour definition by the CSP input expression attr\(A_i\)? where \( A \) is a monitorable attribute of \( p \); (iii) input from topologically related parts, \( q \), are expressed by \( ch[ui_p,ui_q] \)?; and (iv) output of values \( v \) to topologically related parts, \( q \), are expressed by \( ch[ui_p,ui_q] \) v. (v) In other words, the channel designations of the signature are of the form: attr\(A_i, \ldots, \text{attr}A_j\) and \( ch[ui_p,ui_q] \). Further technicalities are given in [18], Sect. 7.4.5.

#### 8.3 From Part Descriptions to Behaviour Definitions

| \( \text{Composite parts: type } \text{Translate}^c_p: P \rightarrow \text{RSL}^c+\text{Text} \) |

\[
\begin{align*}
\text{value} & \quad \text{Translate}^c_p: P \rightarrow \text{RSL}^c+\text{Text} \\
\text{Translate}^c_p(p) & = \\
& \quad \text{let } ui = \text{uid}(p), \quad \text{me = mereo}(p), \quad \text{Sects. 5.1, 5.2} \\
& \quad \text{sa = sta(attr)(s)(p), ca = ctrl(attr)(s)(p), \quad \text{Sect. 5.1.1} \\
& \quad \text{MT = mereo}(ys)(p), \quad \text{ST = sta(attr)(ys)(p),} \\
& \quad \text{CT = ctrl(attr)(ys)(p), IOR = calc(attr)(refs)(p))}
\end{align*}
\]
8.5 Concrete System

An instantiation of any given universe of discourse, tod, thus amounts to the parallel, composition of properties, behaviourally one for each composite and each atomic part. [18, Sect. 7.6] illustrates an example.

9 CONCLUSION

In [11, Sect. 3.1.5] we elaborate extensively on the analysis & description process, while giving, in [11, Sect. 5.3], an extensive review of related work. In [18, Sect. 9, Closing] we discuss, extensively, the wider ramifications of the domain science and engineering approach of the present paper. [19] elaborates on issues of sorts, types and intents.

9.1 What Have We Achieved?

We have summarised an essence of Kai Sørland’s Philosophy [38]: recounted how, from a basis of the inescapable meaning theory, the concepts of space, time and Newton’s Laws can be transcendentally deduced, and from these the concepts of living species: plants and animals. And we have summarised the essence of [18]: an ontology of endurants and perdurants, discrete and continuous (non-solid) endurants, physical parts, living species and structures, natural parts and artefacts; and their internal qualities: unique identifiers, mernology and attributes. Finally we have shown, by a transcendental deduction, how discrete endurants can be “morphed” into perdurants, i.e., in this paper CSP behaviours whose signature can be derived from internal qualities of equivalent discrete endurants: unique identifiers, mernology and attributes. Throughout we have related the two areas: philosophy and computing.

The Philosophy aspect of this paper is new. That is, it is, to our knowledge, the first time a serious attempt has been made to strongly relate an area of the science of computing to philosophy. The domain science & engineering of [18] is also new. For the first time we see a straight line from the domain of artefact problems to their solution by computing [3–7, 15]. I find that remarkable. If you have a need for examples, please consult [18] and [20, twelve domain case studies].

9.2 Open Problems

9.2.1 General We shall only focus on issues that relate to Sects.-3-8. The issue of artefacts is not dealt with specifically in Sørland’s Philosophy; and the issue of the intent[s] of artefacts is new. Further studies seem necessary in order to secure the inevitability of the distinction between discreteness and continuity, justify the presence of structures, and the distinction between atomic and composite parts. The transcendental deduction of endurants into perdurants may not exactly satisfy Kai Sørland’s strict criteria for such deductions.

9.2.2 Intentional Pull: Invariants: Intentional pull seems to relate very strongly to the notion of invariants. In [28, Item 4, pp. 4–5] Wolfgang Reisig identifies the issue of invariants, for example, of distributed discrete dynamic systems, such as we transcendently deduce them from composite artefacts, as a central characteristic of, and a hard problem for, such systems. It seems to us that it might be worthwhile to study the point made by Reisig by taking

\[ \mathcal{P}(\text{ui})(\text{sa})(\text{me})(\text{ca}) \] designate the “body” of the definition of behaviour \( \mathcal{P}(\text{ui}) \). For details we refer to the Core Behaviour Schema of [18, Sect. 7.5].

8.4 Channel Declarations

Here we shall just mention that the above \texttt{Translate} schemas refer to channels. The channel declaration, in RSL, are of the form

- \texttt{channel \{ui,ui\}: CHMSG}

where \texttt{CHMSG} is a type expression for the values communicated over CSP channels. That is, the channel array indexes are two element sets of unique identifiers of relevant distinct parts as implied by their respective mereologies.

\[ \text{IOD} = \text{calc}_{\text{iod}} \text{rels}_{\text{iod}}(p) \]
\[ \text{channel IOD} \]
\[ \text{value} \]
\[ \mathcal{A}_P: \text{UI} \rightarrow \text{ST} \rightarrow \text{MT} \rightarrow \text{CT} \rightarrow \text{IOR} \text{ Unit} \]
\[ \mathcal{A}_P(\text{ui})(\text{sa})(\text{me})(\text{ca}) = \mathcal{A}_P(\text{ui})(\text{sa})(\text{me})(ca) \]
\[ \begin{array}{c}
\text{Translate}_{\text{iod}}(\text{ods}_{\text{iod}}(p)) \\
\text{Translate}_{\text{iod}}(\text{ods}_{\text{iod}}(p)) \\
\vdots \\
\text{Translate}_{\text{iod}}(\text{ods}_{\text{iod}}(p))
\end{array} \]
\[ \text{end} \]

The above schema specifies the translation of composite parts into RSL Text, where RSL is the RAISE Specification Language. [22]. The \{...,\} designate the texts, ... as written.

Concrete parts: type \texttt{Translate}\(\_\text{c}\) \(P \rightarrow \text{RSL}\) Text

<table>
<thead>
<tr>
<th>type</th>
<th>Qs = Q-set</th>
</tr>
</thead>
<tbody>
<tr>
<td>value</td>
<td>qs:Q-set (= \text{obs}_{qs}(p))</td>
</tr>
<tr>
<td>\text{Translate}(_\text{iod})(p)</td>
<td>let ui = \text{uid}(p), me = \text{mereo}(p), \text{sa} = \text{stat}<em>{\text{atts}}(p), \text{ca} = \text{ctrl}</em>{\text{atts}}(p), \text{ST} = \text{stat}<em>{\text{atts}}(p), \text{CT} = \text{ctrl}</em>{\text{atts}}(p), \text{IOR} = \text{calc}<em>{\text{iod}} \text{rels}(p), \text{IOD} = \text{calc}</em>{\text{iod}} \text{rels}(p) \in \text{channel IOD}</td>
</tr>
<tr>
<td>\text{value}</td>
<td>\mathcal{A}_P: \text{UI} \rightarrow \text{CT} \rightarrow \text{IOR} \text{ Unit}</td>
</tr>
</tbody>
</table>
| \mathcal{A}_P(\text{ui})(\text{sa})(\text{me})(\text{ca}) & \mathcal{A}_P(\text{ui})(\text{sa})(\text{me})(\text{ca}) \]
\[ \{ \ldots \text{Translate}\_\text{iod}(q) : q : Q \equiv q \} \]
\[ \text{end} \]

Atomic parts: type \texttt{Translate}\(\_\text{c}\) \(P \rightarrow \text{RSL}\) Text

| value | \text{Translate}\(\_\text{iod}\)(p) = |
| \text{let} | ui = \text{uid}(p), me = \text{mereo}(p), \text{sa} = \text{stat}_{\text{atts}}(p), \text{ca} = \text{ctrl}_{\text{atts}}(p), \text{ST} = \text{stat}_{\text{atts}}(p), \text{CT} = \text{ctrl}_{\text{atts}}(p), \text{IOR} = \text{calc}_{\text{iod}} \text{rels}(p), \text{IOD} = \text{calc}_{\text{iod}} \text{rels}(p) \in \text{channel IOD} |
| \text{value} | \mathcal{A}_P: \text{P:UI} \times \text{MT} \times \text{ST} \times \text{PT} \rightarrow \text{IOR} \text{ Unit} |
| \mathcal{A}_P(\text{ui})(\text{sa})(\text{me})(\text{ca}) & \mathcal{A}_P(\text{ui})(\text{sa})(\text{me})(\text{ca}) \]
\[ \text{end} \]
into account the philosophical basis that we have proposed in this paper.

Ex.21. Invariants of Distributed Systems: We show some informal examples: Simple Credit Card Systems: For a system of credit cards (surrogates for owners), their honouring banks and accepting shops, one invariant could be: the sum of cash with credit cards (i.e., their owners purses), banks, and shops remain a constant across purchase and refund operations! Simple Market System: For a system of end-use customers (e.g., with credit cards) retailers and wholesalers, one invariant could be: the set of goods with end-use customers, retailers and wholesalers remain unchanged across customer, retailed and wholesale operations. The examples are ‘simple’ in that they, e.g., omit consideration of the advent of new automobiles on the road, new merchandise in wholesalers warehouses and the destruction of merchandise with end-users, retailers, etc.

In [28] Reisig suggests an intriguing list of aspects that appear to form main characteristics of our science.

9.3 Acknowledgment

I am grateful to Kai Srønder for his patience and help in properly understanding his philosophy and for creating that philosophy [31–38]; truly a remarkable feat — as also observed by Georg Henrik von Wright, Wittgenstein’s successor at Cambridge, England (en.wikipedia.org/wiki/Georg_Henrik_von_Wright) [31].

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