Domain Science & Engineering
A Review of 10 Years Work
The NUS October 2018 Lectures

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Abstract

By a **domain** we shall understand a **rationally describable** segment of a **human assisted** reality, i.e., of the world, its **physical parts**, and **living species**. These are **endurants** ("still"), existing in space, as well as **perdurants** ("alive"), existing also in time. Emphasis is placed on **"human-assistedness"**, that is, that there is *at least one (man-made)* **artifact** and that **humans** are a primary cause for change of endurant **states** as well as perdurant **behaviours**.

- **Lecture 1: Domain Analysis & Description**
  - So that You know what I've been up to!
  - A prelude also to Lectures 2–5.
  - A basis for possible discussions with NUS colleagures.
- **Lecture 2: Domain Facets**
- **Lecture 3: From Domains to Requirements**
- **Lecture 4: Formal Model of Prompts**
- **Lecture 5: A Basis in Philosophy**

Contents

1 Introduction

I survey recent work in the area of *domain science & engineering*[1].

The *triptych dogma* states that before software can be designed we must have a firm grasp on its/their requirements; before requirements can be prescribed we must have a firm grasp on their basis: the domain; and that we therefore see informatics as consisting of

- *domain science & engineering*,
- *requirements science & engineering*, and
- *programming methodology*.

A strict interpretation of the *triptych* of software engineering dogma suggests that software development "ideally" proceeds in three phases:

- First a phase of **domain engineering** in which an analysis of the application domain leads to a description of that domain.
- Then a phase of **requirements engineering** in which an analysis of the domain description leads to a prescription of requirements to software for that domain.
- And, finally, a phase of **software design** in which an analysis of the requirements prescription leads to software for that domain.

We see *domain science & engineering* as a discipline that *need not be justified as a precursor to requirements engineering. Just as physicists study nature, irrespective of engineering, so we can study manifest domains irrespective of computing.*

[1] It is appropriate, at this point, to state that my use of the term 'domain' is not related to that of *Domains and Processes* such as in the *Proceedings of 1st International Symposium on Domain Theory, Shanghai, China, October 1999, eds.: Klaus Keimel, Zhang Guo-Qiang, Liu Ying-Ming and Chen Yi-Chang. Springer Science + Business Media, New York, 2001.*

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1.1 Recent Papers and Reports

Over the last decade I have iterated a number of investigations of aspects of this *triptych* dogma. This has resulted in a number of documents:

- *Manifest Domains: Analysis & Description* (2018, 2014) [1, 2]
- *Domain Facets: Analysis & Description* (2018. 2008) [3, 4]
- *From Domains to Requirements* (2018, 2008) [5, 6]
- *Formal Models of Processes and Prompts* (2014,2017) [7, 8]
- *To Every Domain Mereology a CSP Expression* (2017, 2009) [9, 11]
- *A Philosophy of Domain Science & Engineering* (2018) [10]

1.2 Recent Experiments

Applications of the domain science and engineering outlined in [1]–[6] are exemplified in reports and papers on experimental domain analysis & description. Examples are:

- *Urban Planning* [12],
- *Documents* [13],
- *Credit Cards* [14],
- *Weather Information Systems* [15],
- *The Tokyo Stock Exchange* [16],
- *Pipelines* [17],
- *Road Transportation* [18],
- *Web/Transaction Software* [19],
- *"The Market"* [20],
- *Container [Shipping] Lines* [21],
- *Railway Systems* [22, 23, 24, 25, 26].

1.3 My Emphasis on Software Systems

An emphasis in my work has been on research into and experiments with application areas that required seemingly large scale software. Not on tiny, beautiful, essential data structures and algorithms.

I first worked on the proper application of formal methods in software engineering at the *IBM Vienna Laboratory* in the early 1970s. That was to the formalisation of the semantics of IBMs leading programming language then, *PL/I*, and to a systematic development of a compiler for that language. The latter never transpired.

Instead I got the chance to formulate the stages of development of a compiler from a denotational semantics description to so-called "running code" [27, 1977]. That led, from 1978 onward, to two MSc students and a colleague and I working on a formal description of the *CCITT Communications High Level Language, CHILL* and its compiler [28, 29]. And that led, in 1980, to five MSc students of ours producing a formal description of a semantics for the *US DoD Ada programming language, Ada* [30]. And that led to the formation of *Dansk Datamatik Center* [31] which embarked on the CHILL and Ada compiler developments [32, 33]. **To my knowledge that project which was on time, at budget, and with a history of less that 3% cost of original budget for subsequent error correction over the first 20 years of use of that compiler was a first, large, successful example of the systematic use of formal methods in a medium scale (42 man years) software project.**

1.4 How Did We Get to Domain Science & Engineering ?

So that is how we came from the semantics of programming languages to the semantics of human-centered, manifest application domain software development. Programming language semantics has to do with the meaning of abstract concepts such as programs, procedures, expressions, statements, GOTOs, labels, etc. Domain semantics, for manifest domains, in so far as we can narrate and formalize it, or them, must capture some "meanings" of the manifest objects that we can touch and see, of the actions we perform on them, and of the sentences by means of which we talk about those phenomena in the domain.

1.5 Preliminaries

We need formulate a few characterisations.

1.5.1 Method & Methodology:

By a **method** I understand a set of principles for selecting and applying techniques and tools for constructing a manifest or an abstract artifact.

By **methodology** I understand the study and knowledge of methods.

My contributions over the years have contributed to methods for software design and, now, for the last many years, methods for domain analysis & description.

In my many experiments with domain analysis & description, cf. Sect. 5 on Page 21, I have found that I often let a so-called "streak of creativity" enter my analysis & description – and, as a result I get stuck in my work. Then I recall, ah !, but there are these principles, techniques and tools for analysis & description, and once I apply them, "strictly", i.e., methodically, I am back on the track, and, in my view, a more beautiful description emerges !

1.5.2 Computer & Computing Sciences:

By **computer science** I understand the study and knowledge about the things that can exist inside computing devices.

By **computing science** I understand the study and knowledge about how to construct the things that can exist inside computing devices. Computing science is also often referred to as *programming methodology*. **My work is almost exclusively in computing science.**

1.5.3 A Triptych of Informatics – Continued

This paper contributes to the establishment of *domain science & engineering*, while hinting that *requirements science & engineering* can benefit from the relation between the two [5, 6]. *How much of a domain must we analyse & describe* before we attempt the second and third phases of the triptych ?. When this question is raised, after a talk of mine over the subject, and by a colleague researcher & scientist I usually reply: *As large a domain as possible !* This reply is often met by this *comment* (from the audience) *Oh ! No, that is not reasonable !* To me that comment shows either or both of: the questioner was not asking as a researcher/scientist, but as an engineer. Yes, an engineer needs only analyse & describe up to and slightly beyond the "border" of the domain-of-interest for a current software development – but a researcher cum scientist is, of course, interested not only in a possible requirements engineering phase beyond domain engineering, but is also curious about the larger context of the domain, in possibly establishing a proper domain theory, etc.

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1.6 The Papers

IM^{2}HO I consider the first of the papers reviewed, [1], **my most important paper.** It was conceived of last[2], after publication of three of the other papers [4, 6, 36]. Experimental evidence then necessitated extensive revisions to these other papers, resulting in [3, 5, 37].

1.7 Structure of This Paper

Section 2 reviews [1, 2, *Analysis & Description Prompts*], and Sect. 3 reviews related science and methodology papers. [3, *Domain Facets*] (Sect. 3.1), [5, *From Domains to Requirements*] (Sect. 3.2), [7, *An Analysis & Description Process Model*] (Sect. 3.3), and [9, *From Mereologies to Lambda-Expressions*] (Sect. 3.4), Finally, Sect. 4 briefly reviews [10, *A Philosophy Basis*] *work-in-progress*.

2 Manifest Domains: Analysis & Description [1, 2]

This work grew out of many years of search for principles, techniques and tools for systematically analyzing and describing manifest domains. By a manifest domain we shall understand a domain whose entities we can observe and whose endurants we can touch!

2.1 A Domain Ontology

2.1.1 Parts, Components and Materials:

The result became a calculus of analysis and description prompts[3]. These prompts are tools that the domain analyser & describer uses. The domain analyser & describer is in the domain, sees it, can touch it, and then applies the prompts, in some orderly fashion, to what is being observed. So, on one hand, there is the necessarily informal domain, and, on the other hand, there are the seemingly formal prompts and the *"suggestions for something to be said"*, i.e., written down: narrated and formalised. Figure 1 on the next page suggests a number of **analysis** and **description** prompts. The domain analyser & describer is "positioned" at the top, the "root". If what is observed can be conceived and described then it **is an entity**. If it can be described as a "complete thing" at no matter which given snapshot of time then it **is an endurant**. If it is an entity but for which only a fragment exists if we look at or touch them at any given snapshot in time, then it **is a perdurant**. Endurants are either **discrete** or **continuous**. With discrete endurants we can choose to associate, or to not associate *mereologies*[4]. If we do we shall refer to them as **parts**, else we shall call them **components**. The continuous endurants we shall also refer to as *(gaseous or liquid)* **materials**.

Parts are either **atomic** or **composite** and all parts have *unique identifiers*, *mereology* and *attributes*. Atomic parts *may* **have** one or more **components** and/or one or more **materials**

If the observed part, p:P, is composite then we can observe the part sorts, $P_1, P_2, ..., P_m$ of p: **observe_part_sorts**(p) which yields the informal and formal description: **Narrative:** ... **Formal: type** $P_1, P_2, ..., P_m$, **value** obs_P$_i$: $P \rightarrow P_i$, repeated for all m part sorts P_is"!

Part sorts may have a concrete type: **has_concrete_type**(p) in which case **observe_concrete_part_type**(p) yields **Narrative:** ... **Formal: type:** $T = P$**-set**, **value** obs_T: $P \rightarrow K$**-set** – where K**-set** is one of the concrete type forms, and where K is some sort.

[2] Publication [34, 35] is a predecessor of [2] which is then a predecessor of [1].

[3] Prompt, as a verb: to move or induce to action; to occasion or incite; inspire; to assist (a person speaking) by *"suggesting something to be said"*.

[4] — 'mereology' will be explained next

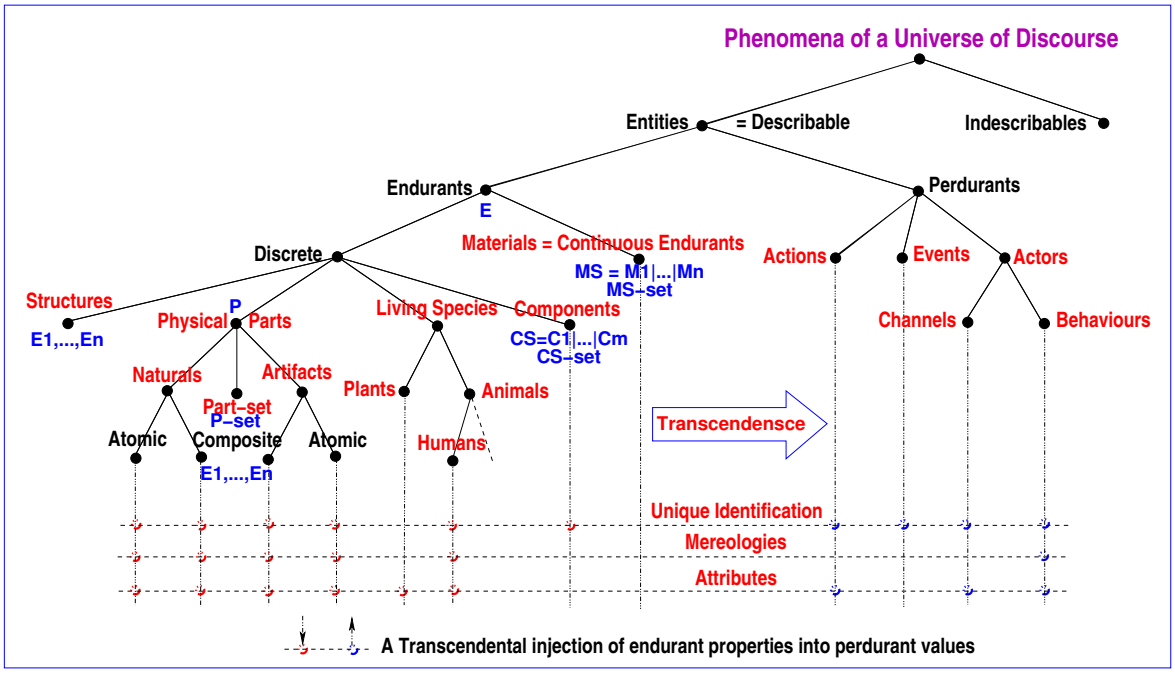

Figure 1: Domain Ontology

Materials have types (i.e., are of sorts): M_i. Observing the (one) material, of type M, of an endurant e of sort E is expressed as **obs_materials**(e) which yields some narrative and some formal *description text:* **Narrative:** ... **Formal: type** M **value** obs_M: $E \to M$. The narrative text (...) narrates what the formal text expresses[5].

Components, i.e., discrete endurants for whom we do not consider possible mereologies or attributes, can be observed from materials, $m : M$, or are just observed of discrete endurants, $e : E$: **obs_components**(em) which yields the informal and formal description: **Narrative:** ... **Formal: type:** $C_1, C_2, ..., C_n$ **value** obs_C_i: $(E|M) \to C_i$ repeated for all n component sorts Cs" to the formal text!

• • •

The above is a pedagogic simplification. As shown in Fig. 1 there are not only parts. There are also *living species: plants* and *animals*, including *humans*. And, because there are humans in the domains, parts and materials are either *natural* or *artifacts* (man-made). Humans create artifacts, usually with an *intent*. Humans have *intents*, and artifacts "possess" *intents*. Intents are like *attributes*, see below.

• • •

We have just summarised the analysis and description aspects of endurants in *extension* (their "form"). We now summarise the analysis and description aspects of endurants in *intension* (their "contents"). There are three kinds of intensional *qualities* associated with parts, two with

[5]– not how it expresses it, as, here, in the `RAISE [38] Specification Language, RSL` [39].

components, and one with materials. Parts and components, by definition, have *unique identifiers*; parts have *mereologies*, and all endurants have *attributes*.

2.1.2 Unique identifiers:

Unique identifiers are further undefined tokens that uniquely identify parts and components. The description language observer **uid_P**, when applied to parts p:P yields the unique identifier, π:Π, of p. The **observe_part_sorts(p)** invocation yields the description text: ... [added to the narrative and] **type** $\Pi_1, \Pi_2, ..., \Pi_m$; **value** uid_Π_i : $P_i \rightarrow \Pi_i$, repeated for all m part sorts P_is and added to the formalisation.

2.1.3 Mereology:

Mereology is the study and knowledge of parts and part relations. The mereology of a part is an expression over the unique identifiers of the (other) parts with which it is related, hence **mereo_P:** $P \rightarrow \mathcal{E}(\Pi_j, ..., \Pi_k)$, $\mathcal{E}(\Pi_j, ..., \Pi_k)$ is a type expression. The **observe_part_sorts**(p) invocation yields the description text: ... [added to the narrative and] **value** mereo_P_i : $P_i \rightarrow \mathcal{E}_i(\Pi_{i_j}, ..., \Pi_{i_k})$ [added to the formalisation]
Example: The mereologies, (i, o), of pipe units in a pipeline system thus express, for each kind of pipe unit, whether it is a well, a linear pipe, a fork, a join, a pump, a valve, or a sink, the identities of the zero, one or two pipe units that it is "connected" to on the input, i, respectively the output, o, side: for well $(0, 1)$, for pipe $(1, 1)$, for fork $(1, 2)$, for join $(2, 1)$, for valve $(1, 1)$, for pump $(1, 1)$, for sink $(1, 0)$ units

2.1.4 Attributes:

Attributes are the remaining qualities of endurants. The analysis prompt **obs_attributes** applied to an endurant yields a set of type names, $A_1, A_2, ..., A_t$, of attributes. They imply the additional description text: **Narrative:** ... **Formal: type** $A_1, A_2, ..., A_t$ **value** attr_A_i: $E \rightarrow A_i$ repeated for all t attribute sorts A_is! **Examples:** Typical attributes of a person are Gender, Weight, Height, Birth date, etcetera. Dynamic and static attributes of a pipe unit include current flow into the unit, per input, if any, current flow out of the unit, per output, if any current leak from the unit, guaranteed maximum flow into the unit, guaranteed maximum flow out of the unit, guaranteed maximum leak from the unit et cetera. Michael A. Jackson [40] categorizes attributes as either *static* or *dynamic*, with dynamic attributes being either *inert*, *reactive* or *active*. The latter are then either *autonomous*, *biddable* or *programmable*. This categorization has a strong bearing on how these (f.ex., part) attributes are dealt with when now interpreting parts as behaviours.

2.2 From Manifest Parts to Domain Behaviours

[2] then presents an interpretation, τ, which to manifest *parts* associate *behaviours*. These are then specified as CSP [41] *processes*. This interpretation amounts to a *transcendental deduction !*

2.2.1 The Transcendental Deduction Idea — by means of an example:

The term *train* can have the following "meanings": The *train*, as an *endurant*, parked at the railway station platform, i.e., as a *composite part*. The *train*, as a *perdurant*, as it "speeds" down the railway track, i.e., as a *behaviour*. The *train*, as an *attribute*,

2.2.2 Atomic Parts:

Atomic parts translate into their core behaviours: $b^{p_{\mathsf{atom}}}_{\mathsf{core}}$. The *core* behaviours are tail recursively defined, that is, are cyclic. $b^{p_{\mathsf{atom}}}_{\mathsf{core}}(...) \equiv (.... \ ; \ b^{p_{\mathsf{atom}}}_{\mathsf{core}}(...))$ where (...) indicate behaviour (i.e., function) arguments.

2.2.3 Composite Parts:

A composite part, p, "translates", τ, into the parallel composition of a core behaviour: $b^{p_{\mathsf{comp}}}_{\mathsf{core}}(...)$, for part p, with the parallel composition of the translations, τ, for each of the parts, $p_1, p_2, ..., p_m$, of p, $(\tau(p_1)\|\tau(p_2)\|...\|\tau(p_m))$ that is: $\tau(p) \equiv b^{p_{\mathsf{comp}}}_{\mathsf{core}}(...)\|(\tau(p_1)\|\tau(p_2)\|...\|\tau(p_m))$

2.2.4 Concrete Parts:

The translation of concrete part set, t, types, $t : T = K$-**set**, is $\tau(t) \equiv \|\{\tau(k_i)|k_i{:}K \bullet k_i \in t\}$.

2.2.5 Translation of Part Qualities (...):

Part qualities, that is: *unique identifiers, mereologies* and *attributes*, are translated into behaviour arguments – of one kind or another, i.e., (...). Typically we can choose to *index* behaviour names, b by the *unique identifier*, id, of the part based on which they were translated, i.e., b_{id}. *Mereology values* are usually static, and can, as thus, be treated like we treat static attributes (see next), or can be set by their behaviour, and are then treated like we treat programmable attributes (see next), i.e., (...). *Static attributes* become behaviour definition (body) constant values. *Inert, reactive* and *autonomous attributes* become references to channels, say *ch_dyn*, such that when an inert, reactive and autonomous attribute value is required it is expressed as *ch_dyn ?*. *Programmable* and *biddable attributes* become arguments which are passed on to the tail-recursive invocations of the behaviour, and possibly updated as specified [with]in the body of the definition of the behaviour, i.e., (...).

2.3 Contributions of [1] – and Open Problems

For the first time we have, now, the beginnings of a calculus for developing domain descriptions. In [34, 35] we speculate on laws that these analysis & description prompts (i.e., their "meanings") must satisfy. With this calculus we can now systematically develop domain descriptions [12–26]. I am right now working on understanding issues of *implicit/explicit* semantics[6] Since December 2017 I have revised [2] extensively: simplified

[6] Cf. http://impex2017.loria.fr/

it, extended it, clarified some issues, provided analysis & description techniques for channels and arguments, et cetera. The revised paper is [1][7].

3 Related Papers

3.1 Domain Facets: Analysis & Description [3, 4]

3.1.1 Overview

By a domain facet we shall understand one amongst a finite set of generic ways of analyzing a domain: a view of the domain, such that the different facets cover conceptually different views, and such that these views together cover the domain.

[3] is an extensive revision of [4]. Both papers identify the following facets: *intrinsics*, *support technologies*, *rules & regulations*, *scripts*, *license languages*, *management & organisation*, and *human behaviour*. Recently I have "discovered" what might be classified as a domain facet: classes of *attribute semantics*: the diversity of attribute semantics resolving the issue of so-called implicit and explicit semantics. I shall not cover this issue in this talk.

3.1.2 Intrinsics

By domain intrinsics we shall understand those phenomena and concepts of a domain which are basic to any of the other facets, with such domain intrinsics initially covering at least one specific, hence named, stakeholder view.

3.1.3 Support Technology

By a domain support technology we shall understand ways and means of implementing certain observed phenomena or certain conceived concepts.

3.1.4 Rules and Regulations

By a domain rule we shall understand some text (in the domain) which prescribes how people or equipment are expected to behave when dispatching their duties, respectively when performing their functions.

By a domain regulation we shall understand some text (in the domain) which prescribes what remedial actions are to be taken when it is decided that a rule has not been followed according to its intention.

3.1.5 Scripts

By a domain script we shall understand the structured, almost, if not outright, formally expressed, wording of a procedure on how to proceed, one that possibly has legally binding power, that is, which may be contested in a court of law.

[7] You can find it on the Internet: http://www.imm.dtu.dk/~dibj/2018/tosem/Bjorner-TOSEM.pdf.

3.1.6 Management & Organisation

By domain management we shall understand such people (such decisions) (i) who (which) determine, formulate and thus set standards (cf. rules and regulations) concerning strategic, tactical and operational decisions; (ii) who ensure that these decisions are passed on to (lower) levels of management and to floor staff; (iii) who make sure that such orders, as they were, are indeed carried out; (iv) who handle undesirable deviations in the carrying out of these orders cum decisions; and (v) who "backstops" complaints from lower management levels and from "floor" staff.
By domain organisation we shall understand (vi) the structuring of management and non-management staff "overseeable" into clusters with "tight" and "meaningful" relations; (vii) the allocation of strategic, tactical and operational concerns to within management and non-management staff clusters; and hence (viii) the "lines of command": who does what, and who reports to whom, administratively and functionally.

3.1.7 Human Behaviour:

By domain human behaviour we shall understand any of a quality spectrum of carrying out assigned work: (i) from careful, diligent and accurate, via (ii) sloppy dispatch, and (iii) delinquent work, (iv) to outright criminal pursuit.

3.1.8 Contributions of [3, 4] – and Open Problems:

[3] now covers techniques and tools for analyzing domains into these facets and for their modeling. The issue of *license languages* are particularly intriguing. The delineations between the listed[8] facets is necessarily not as precise as one would wish: we are dealing with an imprecise world, that of (manifest) domains. License languages are treated in [3].

3.2 From Domains to Requirements [5, 6]

3.2.1 Overview:

[5] outlines a calculus of refinements and extensions which applied to domain descriptions yield requirements prescriptions. As for [2] the calculus is to be deployed by human users, i.e., requirements engineers. Requirements are for a *machine,* that is, the hardware and software to be developed from the requirements. A distinction is made between *domain, interface* and *machine requirements*. I shall briefly cover these in another order.

Machine requirements: *Machine requirements* are such which can be expressed using only technical terms of the machine: performance and dependability accessibility, availability, integrity, reliability, safety, security and robustness). and development requirements development process, maintenance, platform, management and documentation). Within *maintenance requirements* there are adaptive, corrective, perfective, preventive,

[8] We have omitted a facet: *license languages*.

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and extensional requirements. Within *platform requirements* there are development, execution, maintenance, and demonstration requirements. Etcetera. [5] does not cover these. See instead [42, Sect. 19.6].

Domain Requirements: *Domain requirements* are such which can be expressed using only technical terms of the domain. The are the following domain-to-requirements specification transformations: *projection, instantiation, determination, extension* and *fitting*. **I consider my work on the domain requirements issues the most interesting.**

1: Projection: By a *domain projection* we mean *a subset of the domain description, one which projects out all those endurants: parts, materials and components, as well as perdurants: actions, events and behaviours that the stake-holders do not wish represented or relied upon by the machine.*

2: Instantiation: By *domain instantiation* we mean *a refinement of the partial domain requirements prescription (resulting from the projection step) in which the refinements aim at rendering the endurants: parts, materials and components, as well as the perdurants: actions, events and behaviours of the domain requirements prescription more concrete, more specific.*

3: Determination: By *domain determination* we mean *a refinement of the partial domain requirements prescription, resulting from the instantiation step, in which the refinements aim at rendering the endurants: parts, materials and components, as well as the perdurants: functions, events and behaviours of the partial domain requirements prescription less non-determinate, more determinate.*

4: Extension: By *domain extension* we understand *the introduction of endurants and perdurants that were not feasible in the original domain, but for which, with computing and communication, and with new, emerging technologies, for example, sensors, actuators and satellites, there is the possibility of feasible implementations, hence the requirements, that what is introduced becomes part of the unfolding requirements prescription.*

5: Fitting: Often a domain being described "fits" onto, is "adjacent" to, "interacts" in some areas with, another domain: *transportation* with *logistics*, *health-care* with *insurance*, *banking* with *securities trading* and/or *insurance*, and so on. The issue of requirements fitting arises when two or more software development projects are based on what appears to be the same domain. The problem then is to harmonize the two or more software development projects by harmonizing, if not too late, their requirements developments.

Interface Requirements: *Interface requirements* are such which can be expressed only by using technical terms of both the domain and the machine. Thus interface requirements are about that which is *shared* between the domain and the machine: *endurants* that are represented in machine storage as well as co-existing in the domain; *actions* and *behaviours* that are performed while interacting with phenomena in the domain; etc.

3.2.2 Contributions of [5, 6]:

[5] does not follow the "standard division" of requirements engineering into systems and user requirements etcetera. Instead [5] builds on domain descriptions and eventually gives a rather different "division of requirements engineering labour" – manifested in the domain, the interface and the machine requirements paradigms, and these further into sub-paradigms, to wit: projection, instantiation, determination, extension and fitting. Some readers have objected to my use of the term *refinement* for the domain-to-requirements transformations.

3.3 Formal Models of Processes and Prompts [7, 8]

3.3.1 Overview:

[1] outlines a calculus of prompts, to be deployed by human users, i.e., the domain analyzers & describers. That calculus builds on the *assumption* that the domain engineers build, *in their mind*, i.e., *conceptually*, a **syntactical** structure of the domain description, although, what the domain engineers can "see & touch" are **semantic** objects. A formal model of the analysis and description prompt process and of the meanings of the prompts therefore is split into a model for the process and a model of the syntactic and semantics structures.

3.3.2 A Summary of Analysis and Description Prompts

The Analysis Prompts :

[a] is_entity	[f] is_part	[k] has_concrete_type
[b] is_endurant	[g] is_component	[l] has_mereology
[c] is_perdurant	[h] is_material	[m] has_components
[d] is_discrete	[i] is_atomic	[n] has_material
[e] is_continuous	[j] is_composite	[o] has_parts

The Description Prompts :

[1] observe_part_sorts	[5] observe_attributes
[2] observe_concrete_type	[6] observe_component_sorts
[3] observe_unique_identifier	[7] observe_part_material_sort
[4] observe_mereology	[8] observe_material_part_sorts

3.3.3 A Glimpse of the Process Model

Process "Management": Domain description involves the "generation" and use of an indefinite number of type (sort) names, Nm. The global, assignable variables αps and νps serve to hold the names of the sorts to be analysed, respectively the names of the

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sorts for which unique identifiers, mereologies and attributes have to be analysed and described.

```
type
        Nm = PNm | MNm | KNm
variable
        αps := [ Δnm ] type Nm-set
        νps := [ Δnm ] type Nm-set
value
        sel_and_remove_Nm: Unit → Nm
        sel_and_remove_Nm() ≡
                let nm:Nm • nm ∈ νps in
                νps := νps \ {nm} ; nm end; pre: νps ≠ {}
```

Some Process Functions: The analyse_and_describe_endurants function is the major function. It invokes a number of other analysis & description functions. We illustrate two:

```
value
        analyse_and_describe_endurants: Unit → Unit
        analyse_and_describe_endurants() ≡
           while ∼is_empty(νps) do
                let nm = sel_and_remove_Nm() in
                analyse_and_describe_endurant_sort(nm,ι:nm) end end ;
           for all nm:PNm • nm ∈ αps do if has_mereology(nm,ι:nm)
                then observe_mereology(nm,ι:nm) end end
           for all nm:Nm • nm ∈ αps do observe_attributes(nm,ι:nm) end

        analyse_and_describe_endurant_sort: NmVAL → Unit
        analyse_and_describe_endurant_sort(nm,val) ≡
           is_part(nm,val) → analyse_and_describe_part_sorts(nm,val),
           is_material(nm,val) → observe_material_part_sort(nm,val),
           is_component(nm,val) → observe_component_sort(nm,val)
```

3.3.4 A Glimpse of the Syntax and Semantics Models

We suggest a syntax and a semantics of domain descriptions.

The Syntactical Structure of Domains: First the syntax of domains – divided into the syntax of endurants parts, materials and components.

```
TypDef    =  PTypes ∪ MTypes ∪ KTypes
PTypes    =  PNm →m PaTyp
MTypes    =  MNm →m MaTyp
KTypes    =  KNm →m KoTyp
ENDType   =  PaTyp | MaTyp | KoTyp
PaTyp     == AtPaTyp | AbsCoPaTyp | ConCoPaTyp
AtPaTyp   :: mkAtPaTyp(s_qs:PQ,s_omkn:({|"nil"|}|MNn|KNm))
AbsCoPaTyp :: mkAbsCoPaTyp(s_qs:PQ,s_pns:PNm-set)
axiom        ∀ mkAbsCoPaTyp(pq,pns):AbsCoPaTyp • pns ≠ {}
ConCoPaTyp :: mkConCoPaTyp(s_qs:PQ,s_p:PNm)
MaTyp     :: mkMaTyp(s_qs:MQ,s_opn:({|"nil"|}|PNm))
KoTyp     :: mkKoTyp(s_qs:KQ)
```

Then the syntax of the internal qualities of endurants:

```
PQ      =  s_ui:UI×s_me:ME×s_atrs:ATRS}
UI
ME      == "nil"|mkUI(s_ui:UI)|mkUIset(s_uil:UI)|...
ATRS    =  ANm →m ATyp
ANm, ATyp
MQ      =  s_atrs:ATRS
KQ      =  s_uid:UI × s_atrs:ATRS
```

The Semantical Values of Domains: Corresponding, homomorphically, to these syntaxes are their semantics types:

```
ENDVAL    =  PVAL | MVAL | KVAL
PVAL      == AtPaVAL|AbsCoPVAL|ConCoPVAL
AtPaVAL   :: mkAtPaVAL(s_qval:PQVAL,
              s_omkvals:({|"nil"|}|MVAL|KVAL-set))
AbsCoPVAL :: mkAbsCoPaVAL(s_qval:PQVAL,s_pvals:(PNm →m PVAL))
axiom     ∀ mkAbsCoPaVAL(pqs,ppm):AbsCoPVAL•ppm≠[]
ConCoPVAL :: mkConCoPaVAL(s_qval:PQVAL,s_pvals:PVAL-set)
MVAL      :: mkMaVAL(s_qval:MQVAL,s_pvals:PVAL-set)
KVAL      :: mkKoVAL(s_qval:KQVAL)
```

Qualities: Semantic Types

```
PQVAL     =  UIVAL×MEVAL×ATTRVALS
UIVAL
MEVAL     == mkUIVAL(s_ui:UIVAL)|mkUIVALset(s_uis:UIVAL-set)|...
ATTRVALS  =  ANm →m AVAL
ANm, AVAL
MQVAL     =  ATTRVALS
KQVAL     =  UIVAL×ATTRVALS
```


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3.3.5 From Syntax to Semantics and "Back Again!"

We define mappings from sort names to the possibly infinite set of values of the named type, and from endurant values to the names of their sort.

```
type
  Nm_to_ENDVALS =
    (PNm →m PVAL-set)∪(MNm →m MVAL-set)∪(KNm →m KVAL-set)
  ENDVAL_to_Nm =
    (PVAL →m PNm )∪(MVAL →m MNm)∪(KVAL →m KNm)
value
  typval: TypDef ~→ Nm_to_ENDVALS
  typval(td) ≡ let ρ =
    [ n↦M(td(n))(ρ)|n:(PNm|MNm|KNm)•n ∈ dom td ] in ρ end

  valtyp: Nm_to_ENDVALS ~→ ENDVAL_to_Nm
  valtyp(ρ) ≡
    [ v↦n|n:(PNm|MNm|CNm),v:(PVAL|MVAL|KVAL)•
      n ∈ dom ρ∧v ∈ ρ(n) ]

  M: (PaTyp→ENV~→PVAL-set)|
    (MaTyp→ENV~→MVAL-set)|
    (KoTyp→ENV~→KVAL-set)
```

The environment, ρ, of typval is the least fix point of the recursive equation. The crucial function is **M**, in the definition of typval. Examples of its definition, by part category, is given below.

```
value
  ι nm:Nm ≡ iota(nm)
  iota: Nm → TypDef → VAL
  iota(nm)(td) ≡
    let val:(PVAL|MVAL|KVAL)•val∈(typval(td))(nm)
    in val end
```

Analysis Functions: We exemplify the semantics functions for three analysis prompts.

```
value
  is_endurant: Nm×VAL → TypDef ~→ Bool
  is_endurant(_,val)(td) ≡ val ∈ dom valtyp(typval(td));
      pre: VAL is any value type

  is_discrete: NmVAL → TypDef ~→ Bool
  is_discrete(_,val)(td) ≡ (is_PaTyp|is_CoTyp)(td((valtyp(typval(td)))(val)))

  is_part: NmVAL → TypDef ~→ Bool
  is_part(_,val)(td) ≡ is_PaTyp(td((valtyp(typval(td)))(val)))
```

Description Functions: We exemplify the semantics of one of the description prompts. The generated description **RSL-text** is enclosed within [" ... "].

```
variable
    τ := [ ] Text-set
value
    observe_part_sorts: Nm×VAL → TypDef → Unit
    observe_part_sorts(nm,val)(td) ≡
        let mkAbsCoPaTyp(_,{P1,P2,...,Pn})
            = td((valtyp(typval(td)))(val)) in
        τ := τ ⊕ [" type P1,P2,...,Pn;
                    value
                        obs_part_P1: nm→P1
                        obs_part_P2: nm→P2
                        ...,
                        obs_part_Pn: nm→Pn;
                    proof obligation
                        D; " ]
        ‖ νps := νps ⊕ ([" P1,P2,...,Pn " ] \ αps)
        ‖ αps := αps ⊕ [" P1,P2,...,Pn " ]
        end
    pre: is_AbsCoPaTyp(td((valtyp(typval(td)))(val)))
```

.

The M Function

1 The meaning of an atomic part type expression,

- mkAtPaTyp((ui,me,attrs),omkn) in
- mkAtPaTyp(s_qs:PQ,s_omkn:({|"nil"|}|MNn|KNm)),
- is the set of all atomic part values,
  mkAtPaVAL((uiv,mev,attrvals),omkval) in
- mkAtPaVAL(s_qval:(UIVAL×MEVAL×(ANm $\overrightarrow{m}$ AVAL)),
  s_omkvals:({|"nil"|}|MVAL|KVAL-set)).
  a uiv is a value in UIVAL of type ui,
  b mev is a value in MEVAL of type me,
  c attrvals is a value in (ANm $\overrightarrow{m}$ AVAL) of type (ANm $\overrightarrow{m}$ ATyp), and
  d omkvals is a value in ({|"nil"|}|MVAL|KVAL-set):
    i either ''nil'',
    ii or one material value of type MNm,
    iii or a possibly empty set of component values, each of type KNm.

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1. M: mkAtPaTyp((UI×ME×(ANm $\overrightarrow{m}$ ATyp))×({|"nil"|}|MVAL|KVAL-**set**))
1. →ENV$\xrightarrow{\sim}$PVAL-**set**
1. M(mkAtPaTyp((ui,me,attrs),omkn))(ρ) ≡
1. { mkATPaVAL((uiv,mev,attrval),omkvals) |
1a. uiv:UIVAL•type_of(uiv)=ui,
1b. mev:MEVAL•type_of(mev)=me,
1c. attrval:(ANm $\overrightarrow{m}$ AVAL)•type_of(attrval)=attrs,
1d. omkvals: **case** omkn **of**
1(d)i. "nil" → "nil",
1(d)ii. mkMNn(_) → mval:MVAL•type_of(mval)=omkn,
1(d)iii. mkKNm(_) →
1(d)iii. kvals:KVAL-**set**•kvals⊆{kv|kv:KVAL•type_of(kval)=omkn}
1d. **end** }

Formula terms 1a–1(d)iii express that any applicable uiv is combined with any applicable mev is combined with any applicable attrval is combined with any applicable omkvals.

2 The meaning of an abstract composite part type expression,

- mkAbsCoPaTyp((ui,me,attrs),pns) in
- mkAbsCoPaTyp(s_qs:PQ,s_pns:PNm-**set**), is the set of all abstract, composite part values,
- mkAbsCoPaVAL((uiv,mev,attrvals),pvals) in
- mkAbsCoPaVAL(s_qval:(UIVAL×MEVAL×(ANm $\overrightarrow{m}$ AVAL)),
  s_pvals:(PNm $\overrightarrow{m}$ PVAL)).

a uiv is a value in UIVAL of type ui: UI,

b mev is a value in MEVAL of type me: ME,

c attrvals is a value in (ANm $\overrightarrow{m}$ AVAL) of type (ANm $\overrightarrow{m}$ ATyp), and

d pvals is a map of part values in (PNm $\overrightarrow{m}$ PVAL), one for each name, pn:PNm, in pns such that these part values are of the type defined for pn.

2. M: mkAbsCoPaTyp((UI×ME×(ANm $\overrightarrow{m}$ ATyp)),PNm-**set**)
2. → ENV $\xrightarrow{\sim}$ PVAL-**set**
2. M(mkAbsCoPaTyp((ui,me,attrs),pns))(ρ) ≡
2. { mkAbsCoPaVAL((uiv,mev,attrvals),pvals) |
2a. uiv:UIVAL•type_of(uiv)=ui
2b. mev:MEVAL•type_of(mev)=me,
2c. attrvals:(ANm $\overrightarrow{m}$ ATyp)•type_of(attrsval)=attrs,
2d. pvals:(PNm $\overrightarrow{m}$ PVAL) •
2d. pvals∈{[pn↦pval|pn:PNm,pval:PVAL•pn∈ pns∧pval∈ρ(pn)]} }

3.3.6 Contributions of [7]

The contributions of [7] are to suggest and carry through a "formalisation" of the *conceptual, syntactical* and *semantical* structures *perceived* by the domain engineer, to formalise the *meaning of the informal* analysis & description prompts, and to formalise the possible sets of sequences of valid prompts.

3.4 To Every Manifest Domain Mereology a CSP Expression [9]

3.4.1 Overview

In [2] we have shown how parts can be endowed with mereologies. Mereology, as was mentioned earlier, is the study and knowledge of *"part-hood":* of how parts are related parts to parts, and parts to *"a whole"*. Mereology, as treated by us, originated with the Polish mathematician/logician/philosopher Stanislaw Lešhniewski.

An Axiom System for Mereology :

$$
\begin{array}{rrcl}
\text{part\_of:} & \mathbb{P} : & \mathcal{P} \times \mathcal{P} & \rightarrow \textbf{ Bool} \\
\text{proper\_part\_of:} & \mathbb{PP} : & \mathcal{P} \times \mathcal{P} & \rightarrow \textbf{ Bool} \\
\text{overlap:} & \mathbb{O} : & \mathcal{P} \times \mathcal{P} & \rightarrow \textbf{ Bool} \\
\text{underlap:} & \mathbb{U} : & \mathcal{P} \times \mathcal{P} & \rightarrow \textbf{ Bool} \\
\text{over\_crossing:} & \mathbb{OX} : & \mathcal{P} \times \mathcal{P} & \rightarrow \textbf{ Bool} \\
\text{under\_crossing:} & \mathbb{UX} : & \mathcal{P} \times \mathcal{P} & \rightarrow \textbf{ Bool} \\
\text{proper\_overlap:} & \mathbb{PO} : & \mathcal{P} \times \mathcal{P} & \rightarrow \textbf{ Bool} \\
\text{proper\_underlap:} & \mathbb{PU} : & \mathcal{P} \times \mathcal{P} & \rightarrow \textbf{ Bool}
\end{array}
$$

Let $\mathbb{P}$ denote **part-hood**; p_x is part of p_y, is then expressed as $\mathbb{P}(p_x, p_y)$.[9] (1) Part p_x is part of itself (reflexivity). (2) If a part p_x is part of p_y and, vice versa, part p_y is part of p_x, then $p_x = p_y$ (anti-symmetry). (3) If a part p_x is part of p_y and part p_y is part of p_z, then p_x is part of p_z (transitivity).

$$\forall p_x : \mathcal{P} \bullet \mathbb{P}(p_x, p_x) \tag{1}$$

$$\forall p_x, p_y : \mathcal{P} \bullet (\mathbb{P}(p_x, p_y) \wedge \mathbb{P}(p_y, p_x)) \Rightarrow p_x = p_y \tag{2}$$

$$\forall p_x, p_y, p_z : \mathcal{P} \bullet (\mathbb{P}(p_x, p_y) \wedge \mathbb{P}(p_y, p_z)) \Rightarrow \mathbb{P}(p_z, p_z) \tag{3}$$

We exemplify one of the mereology propositions: **proper underlap**, $\mathbb{PU}$: p_x and p_y are said to properly underlap if p_x and p_y under-cross and p_y and p_x under-cross.

$$\mathbb{PU}(p_x, p_y) \triangleq \mathbb{UX}(p_x, p_y) \wedge \mathbb{UX}(p_y, p_x) \tag{4}$$

A Model for the Axioms [9] now gives a model for parts: atomic and composite, commensurate with [2] and [7], and their unique identifiers, mereology and attributes and show that the model satisfies the axioms.

[9] Our notation now is not RSL but a conventional first-order predicate logic notation.

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3.4.2 Contributions of [9]

[9] thus contributes to a domain science, helping to secure a firm foundation for domain engineering.

4 Domain Science & Engineering: A Philosophy Basis [10]

My most recent work is documented in [10]. It examines the question:

- *What must inescapably be in any domain description ?*

Another formulation is:

- *Which are the necessary characteristics of each and every possible world and our situation in it.*

Recent works by the Danish philosopher Kai Sørlander [43, 44, 45, 46] appears to direct us towards an answer.

Here is how it is done, in brief. On the basis of *possibility of truth*[10] Sørlander establishes the logical connectors and from them the existence of a world with symmetry, asymmetry and transitivity. By a transcendental deduction Sørlander then reasons that *space* and *time*, inescapably, are "in the world"[11]. Further logical reasoning and transcendental deductions establishes the inescapability of *Newton's 1st, 2nd and 3rd Laws*. And from that *kinematics*, *dynamics*, and *gravitational pull*. And so forth. Thus the worlds that can possibly be described must all satisfy the *laws of physics*.

This line of reasoning and deduction thus justifies the focus, in our calculi, on natural parts, components and materials.

But Sørlander goes on and reasons and transcendentally deduce the inescapable existence of *living species: plants* and *animals*, and, among the latter, *humans*. Because of reasoned characteristics of humans we inescapably have *artifacts: man-made parts components* and *materials*. Humans construct artifacts with an *intent*, an attribute of both humans and artifacts. These *shared intents* lead to a notion of *intentional "pull"*[12] and so forth.

This line of reasoning and deduction thus justifies the inclusion, in our calculi, of living species and artifacts.

[10] is presently an approximately 90 page report. As such it is presently a repository for a number of "texts" related to the issue of *"what must inescapably be in any domain description ?"* It may be expected that a far shorter paper may emerge.

[10] Sørlander makes his *logical reasoning* and *transcendental deductions* on the basis of the *possibility of truth* – where Immanuel Kant [47], according to Sørlander, builds on the *possibility of self-awareness*, which is shown to lead to contradictions.

[11] Kant assumes space and time.

[12] We shall here give an example of *intentional "pull":* humans create automobiles and roads. An intention of automobiles is to drive on roads, and an intention of roads is to have automobiles move along roads. We can thus speak of the *traffic history of an automobile* as the time-stamped sequence of vehicle positions along roads, and of the *traffic history of a road* as the time-stamped sequence of vehicle positions along that road. Now, for the sum total of all automobiles and all roads the two consolidate histories must be identical. *It cannot be otherwise.*

5 The Experiments [12–26]

In order to test and tune the domain analysis & description method a great number of experiments were carried out. In our opinion, when applied to manifest domains, they justify the calculi reported in [2] and [7].

- *Urban Planning* [12],
- *A Space of Swarms of Drones* [48],
- *Documents* [13],
- *Credit Cards* [14],
- *Weather Information Systems* [15],
- *The Tokyo Stock Exchange* [16],
- *Pipelines* [17],
- *Road Transportation* [18],
- *Web Transactions* [19],
- *"The Market"* [20],
- *Container [Shipping] Lines* [21],
- *Railway Systems* [22, 23, 24, 25, 26].

6 Summary

We have identified a discipline of domain science and engineering. Its first "rendition" was applied to the semantics of programming languages and the development of their compilers [29, CHILL] and [32, Ada]. Domain science and engineering, as outlined here, is directed at a wider spectrum of "languages": the "meaning" of computer application domains and software for these applications. Where physicists model facets of the world emphasizing physical, dynamic phenomena in nature, primarily using differential calculi, domain scientists cum engineers emphasize logical and both discrete phenomena of man and human institutions primarily using discrete mathematics.

7 Bibliography

7.1 Bibliographical Notes

In the last ten years I have also worked on related topics:

- Domains: Their Simulation, Monitoring and Control, see [36], [37] 2008,
- Compositionality: Ontology and Mereology of Domains[13], [49] 2008,
- Domain Science & Engineering, [34, 35] 2010,
- Computation for Humanity: Domain Science and Engineering, [50] 2012,
- 40 Years of Formal Methods — Obstacles and Possibilities[14], [51] 2014,
- Domain Engineering – A Basis for Safety Critical Software, [52] 2014,

[13] with Asger Eir
[14] with Klaus Havelund

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- Implicit and Explicit Semantics and the Domain Calculi, [53] 2017.

Work on these papers and on the many, extensive experiments has helped solidify the basic domain analysis & description method.

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