# Domain Science I: Domain Modelling

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**Abstract**

We present a very short introduction to the concept of *Domain Modelling*, that is, the analysis and both narrative, informal, and formal description of domains.

Domains are here seen as: a *human assisted* reality, i.e., of the world that we daily observe. It includes its **endurants**, i.e., *solid and fluid entities* of **parts** and **living species**, and **perdurants** *Endurants* are either *natural* ["God-given"] or *artefactual* ["man-made"]. and may be considered *atomic* or *compound* parts, or, as in this book, further unanalysed *living species:* **plants** and **animals** – including *humans*. *Perdurants* are here considered to be *actions*, *events* and *behaviours*.

## Contents

# 1 Domain Definition

We repeat the definition of the concept of domains as first given in the abstract.

**Definition 1 Domain:** *By a domain we shall understand a rationally describable segment of a discrete dynamics fragment of a human assisted reality, i.e., of the world that we daily observe. It includes its* **endurants***, i.e., solid and fluid entities of* **parts** *and* **living species***, and* **perdurants** ■

*Endurants* are either *natural* [“God-given”] or *artefactual* [“man-made”]. and may be considered *atomic* or *compound* parts, or, as in this book, further unanalysed *living species:* **plants** and **animals** – including *humans*.

*Perdurants* are here considered to be *actions*, *events* and *behaviours*.

We exclude, from our treatment of domains, issues of ethical, biological and psychological matters.

**Example 1 Domains:** A few, more-or-less self-explanatory examples:

- **Rivers –** with their natural sources, deltas, tributaries, waterfalls, etc., and their man-made dams, harbours, locks, etc. – and their conveyage of materials (ships etc.) [11];
- **Road nets –** with street segments and intersections, traffic lights and automobiles – and the flow of these;
- **Pipelines –** with their wells, pipes, valves, pumps, forks, joins and wells and the flow of fluids [4]; and
- **Container terminals –** with their container vessels, containers, cranes, trucks, etc. – and the movement of all of these [7] ■

The definition relies on the understanding of the terms *‘rationally describable’*, *‘discrete dynamics’*, *‘human assisted’*, *‘solid’* and *‘fluid’*. The last two will be explained later. By **rationally describable** we mean that what is described can be understood, including reasoned about, in a rational, that is, logical manner – in other words **logically tractable**. By **discrete dynamics** we imply that we shall basically rule out such domain phenomena which have properties which are continuous with respect to their time-wise, i.e., dynamic, behaviour. By **human-assisted** we mean that the domains – that we are interested in modelling – have, as an important property, that they possess man-made entities.

This primer presents a *method*, its *principles*, *procedures*, *techniques* and *tools*, for *analysing* &[1] *describing* domains.

## 2 Domain Models

The domain analysis & description method surveyed in this paper has been developed over many years. Several “generations” of domain models have been worked out and their experimental development has led to refinements and simplifications of the method [16]. Several publications on the method has resulted: [6, 8–10, 12, 13].

## 3 A Domain Analysis & Description Ontology

Figure 1 on the following page expresses an ontology[2] for our analysis of domains. Not an taxonomy[3] for any one specific domain.

We refer to Fig. 1 on the next page.

The idea of Fig. 1 on the following page is the following:

[1]We use here the ampersand, ‘&’, as in $A\&B$, to emphasize that we are treating $A$ and $B$ as one concept.

[2]Ontology: See Item **??** on page ??

[3]Taxonomy: See Item **??** on page ??

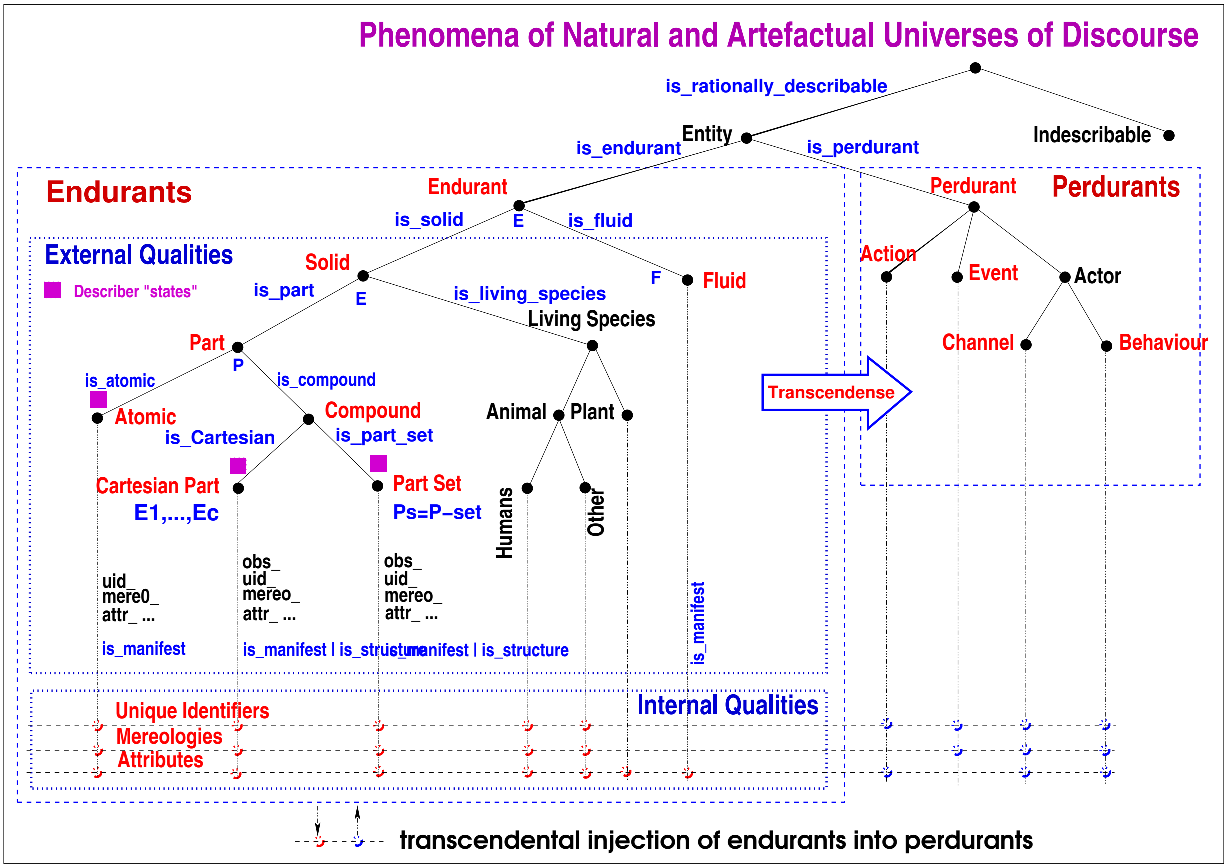


Figure 1: A Domain Analysis & Description Upper Ontology

- It presents a recipe for how to **analyse** a domain.
- You, the *domain* **analyser** *cum describer*, are confronted[4] with, or by a domain.
- You have Fig. 1 in front of you, on a piece of paper, or in Your mind, or both.
- You are then asked, by the domain **analysis** & description method of this chapter, to "start" at the uppermost •, just below and between the '**r**' and the first '**s**' in the main title, Phenomena of Natural and Artefactual Universes of Discourse.
- The **analysis** & description ontology of Fig. 1 then *directs* You to inquire as to whether the phenomenon – whichever You are "looking at/reading about/..." – is an *entity* (`is_rationally_describable`) or is *indescribable*.
- It is Your decision whether the answer to that "query" is yes or no.
- The definitions of the concepts whose names are attached to the •s of Fig. 1 are given in the following sections.

[4]By 'confronted' we mean: You are reading about it, in papers, in books, in postings on the `Internet`, visiting it, talking with domain stakeholders: professional people working "in" the domain.

- Whether they are precise enough to guide You in Your obtaining reasonable answers, "yes" or "no", to the •ed queries is, of course, a problem. I hope they are.
- If Your answer is "yes", then Your **analysis** proceeds down the tree, usually indicated by "yes" or "no" answers.
- If one, or the other is a "leaf" of the ontology tree, You have finished examining the phenomena You set out to **analyse**.
- If it is not a leaf, then further **analysis** is required.
- (We shall, in this book, leave out the analysis and hence description of *living species*.)
- If an **analysis** of a phenomenon has reached one of the (only) three ■'s, then the **analysis** at that • results in the domain describer **describing**, in MoLa, some of the properties of that phenomenon.
- That **analysis** involves "setting aside", for subsequent **analysis & description**, one or more [thus **analysis** etc.-pending] phenomena (which are subsequently to be tackled from the "root" of the ontology).

We do not [need to] prescribe in which order You analyse & describe the phenomena that has been "set aside".

# 4 The Name, Type and Value Concepts

Domain *modeling*, as well as *programming*, depends, in their *specification*, on *separation of concerns:* which kind of *values* are subjectable to which kinds of *operations*, etc., in order to achieve ease of *understanding* a model or a program, ease of *proving properties* of a model, or *correctness* of a program.

## 4.1 Names

We name things in order to refer to them in our speech, models and programs. Names of types and values in models and programs are usually not so-called "first-citizens", i.e., values that can be arguments in functions, etc. The "science of names" is interesting.[5] In `https://botanicalsociety.org.za/the-science-of-names-an-introduction-to-plant-taxonomy/` the authors actually speak of a "science of names" in connection with plant taxonomy: the "art" of choosing such names that reflect some possible classification of what they name.

more to come

[5]The study of names is called *onomastics* or *onomatology*. *Onomastics* covers the naming of all things, including place names (toponyms) and personal names (*anthroponyms*).

### 4.2 Types

The type concept is crucial to programming and modeling.

**Definition 2 Type:** *A type is a class of values ("of the same kind")* ■

We name types.

**Example 2 Type Names:** Some examples of type names are:

- RT – the class of all road transport instances: the *Metropolitan London Road Transport*, the *US Federal Freeway System*, etc.
- RN – the class of all road net instances (within a road transport).
- SA – the class of all automobiles (within a road transport) ■

You, the domain describer, choose type names. Choosing type names is a "serious affair". It must be done carefully. You can choose short (as above) or long names: Road_Transport, Road_Net, etc. We prefer short, but not cryptic names, like X, Y, Z, ... . Names that are easy to *memorize*.

### 4.3 Values

Values are what programming and modeling, in a sense, is all about". In programming, values are the *data* "upon" which the program code specifies computations. In modeling values are, for example, what we observe: the entities in front of our eyes.

## 5 Phenomena and Entities

**Definition 3 Phenomena:** *By a phenomenon we shall understand a fact that is observed to exist or happen* ■

Some phenomena are rationally describable – to some degree[6] – others are not.

**Definition 4 Entities:** *By an entity By an entity we shall understand a more-or-less rationally describable phenomenon* ■

**Example 3 Phenomena and Entities:** Some, but not necessarily all aspects of a river can be rationally described, hence can be still be considered entities. Similarly, many aspects of a road net can be rationally described, hence will be considered entities ■

[6] That is: It is up to the domain analyser cum describer to decide as to how many rationally describable phenomena to select for analysis & description. Also in this sense one practices abstraction by "abstracting away" [the analysis & description of] phenomena that are irrelevant for the "current" (!) domain description.

# 6 Endurants and Perdurants

## 6.1 Endurants

**Definition 5 Endurants:** *Endurants are those quantities of domains that we can observe (see and touch), in space, as "complete" entities at no matter which point in time – "material" entities that persists, endures* ■

**Example 4 Endurants:** Examples of endurants are: a street segment [link], a street intersection [hub], an automobile ■

## 6.2 Perdurants

**Definition 6 Perdurants:** *Perdurants are those quantities of domains for which only a fragment exists, in space, if we look at or touch them at any given snapshot in time* ■

**Example 5 Perdurant:** A moving automobile is an example of a perdurant ■

# 7 External and Internal Endurant Qualities

## 7.1 External Qualities

**Definition 7 External Qualities:** *External qualities of endurants of a manifest domain are, in a simplifying sense, those we can see, touch and have spatial extent. They, so to speak, take form.*

**Example 6 External Qualities:** An example of external qualities of a domains is: the Cartesian[7] of sets of solid atomic street intersections, and of sets of solid atomic street segments, and of sets of solid automobiles of a road transport system where the Cartesian, sets, atomic, and solid reflect external qualities ■

### 7.1.1 Discrete or Solid Endurants

**Definition 8 Discrete or Solid Endurants:** *By a solid [or discrete] endurant we shall understand an endurant which is separate, individual or distinct in form or concept, or, rephrasing: have 'body' [or magnitude] of three-dimensions: length, breadth and depth [17, Vol. II, pg. 2046]* ■

**Example 7 Solid Endurants:** Examples of sold endurants are the wells, pipes, valves, pumps, forks, joins and sinks of pipelines are solids. [These units may, however, and usually will, contain fluids, e.g., oil, gas or water] ■

**Type Naming:** When, in a domain analysis, we encounter a solid, for the first time, we name its type, i.e., anticipating the upcoming solid description, as for parts, i.e., atomic, compound, Cartesian and part set parts (or for living species)[8], see below, we "set aside", somehow, say in our mind, or on a piece of paper, or in a computer document, that or those type names[9].

[7] Cartesian after the French philosopher, mathematician, scientist René Descartes (1596–1650)

[8] – whose further analysis we shall not cover in this book

[9] Cf. Sect. **??** on page ??

#### 7.1.2 Fluids

**Definition 9 Fluid Endurants:** *By a fluid endurant we shall understand an endurant which is prolonged, without interruption, in an unbroken series or pattern; or, rephrasing: a substance (liquid, gas or plasma) having the property of flowing, consisting of particles that move among themselves [17, Vol. I, pg. 774]* ■

**Example 8 Fluid Endurants:** Examples of fluid endurants are: water, oil, gas, compressed air, smoke ■

Fluids are otherwise liquid, or gaseous, or plasmatic, or granular[10], or plant products, i.e., chopped sugar cane, threshed, or otherwise[11], et cetera. Fluid endurants will be analysed and described in relation to solid endurants, viz. their "containers".

**Type Naming:** When, in a domain analysis, we encounter a fluid, for the first time, we name its type, i.e., anticipating the upcoming fluid description, we "set aside", somehow, say in our mind, or on a piece of paper, or in a computer document, that or those type names[12].

#### 7.1.3 Parts

**Definition 10 Parts:** *The non-living species solids are what we shall call parts* ■

Parts are the "work-horses" of man-made domains. That is, we shall mostly be concerned with the analysis and description of endurants into parts.

**Example 9 Parts:** The previous example of solids was also an example of parts ■

We distinguish between atomic and compound parts.

##### 7.1.3.1 Atomic Parts

**Definition 11 Atomic Part, I:** *By an atomic part we shall understand a part which the domain analyser considers to be indivisible in the sense of not meaningfully consist of sub-parts* ■

**Example 10 Atomic Parts:** Examples of atomic parts are: a hub, i.e., a street intersection; a link, i.e., the stretch of road between two neighbouring hubs; and an automobile ■

**7.1.3.2 Compound Parts** We, pragmatically, distinguish between Cartesian product- and set-oriented parts.

**Definition 12 Compound Part, I:** *Compound parts are those which are observed to [potentially] consist of several parts* ■

**Example 11 Compound Parts:** An example of a compound parts is: a road net consisting of a set of hubs, i.e., street intersections or "end-of-streets", and a set of links, i.e., street segments (with no contained hubs), is a Cartesian compound; and the sets of hubs and the sets of links are part set compounds ■

[10] This is a purely pragmatic decision. "Of course" sand, gravel, soil, etc., are not fluids, but for our modelling purposes it is convenient to "compartmentalise" them as fluids!

[11] See footnote 10.

[12] Cf. Sect. **??** on page ??

#### 7.1.3.3 Cartesians.

**Definition 13 Cartesians:** *Cartesian parts are those compound parts which are observed to consist of two or more distinctly sort-named endurants (solids or fluids)* ■

**Example 12 Cartesians: Road Transport:** A road transport is observed to consist of an aggregate of a road net and a set of automobiles, where the road net is observed, i.e., abstracted, as a Cartesian of a set of hubs, i.e., street intersections (or specifically designated points segmenting an otherwise "straight" street into two such), and a set of links, i.e., street segments between two "neighbouring" hubs.

Once a part has been analysed into a Cartesian, say c, we inquire, **Cartesian_parts**, as to the number of endurants of which it consists. The inquiry: **Cartesian_parts**(c:C), we decide, then yields the type of the constituent parts.

**Example 13 Cartesian Parts:** The *Cartesian part*s of a road transport, rt:RT, is thus observed to consists of

- an aggregate of a road net, rn:RN, and
- an aggregate set of automobiles, sa:SA:

that is:

- **Cartesian_parts**(rt:RT) = {RN,SA}

where the type names rt:RT were and RN and SA are coined, i.e., more-or-less freely chosen, by the domain analyzer cum describer[13] ■

#### 7.1.3.4 Part Sets.

**Definition 14 Part Sets:** *Part sets are those compound parts which are observed to consist of an indefinite number of zero, one or more parts* ■

Once a part has been analysed into a part set, say s, we inquire, **part_set_parts**, as to the number of endurants of which it consists. The inquiry: **part_set_parts**(s:S), we decide, then yields the the type of the constituent parts.

**Example 14 Part Sets: Road Transport:** The road transport contains a set of automobiles. The part set type name has been chosen to be SA. It is then determined (i.e., analyzed) that SA is a set of Automobile of type A

- **part_sets_part**(sa:SA) = {A}

where the value and type names sa:SA were and the type name A is coined, i.e., more-or-less freely chosen, by the domain analyzer cum describer[14] ■

• • •

So far we have only touched upon the 'External Qualities' labeled, dotted-dashed box of the 'Endurants'-labeled dashed box of Fig. 1.

[13] Cf. Sect. **??** on page ??
[14] Cf. Sect. **??** on page ??

### 7.1.4 Observer Functions

Once the domain analyser cum describer has decided upon the names of atomic and compound parts, **obs**_erver functions can be applied to Cartesian, c:C, respectively part set, ps:PS, parts:

**value**
  **let** {P1,P2,...,Pn} = **Cartesian_parts**(c:C) **in**
  **"type** P1, P2, ..., Pn; **value obs**_P1: C→P1, **obs**_P2: C→P2,...n **obs**_Pn: C→Pn **"**
  [respectively:]
  **let** {Ps, P} = **part_set_parts**(ps:PS) **in**
  **"type** Ps = P-**set**, **value obs**_Ps: C→Ps **"**
  **end end**

The **"..."** texts are the MoLa texts "generated", i.e., written down, by the domain describer. They are *domain model specification units*.

The "surrounding" MoLa-like texts are not written down as phrases, elements, of the domain description. They are elements of the domain describers' "notice board", and, as such, elements of the development of domain models.

We have thus introduced a core domain modeling tool the **obs**_... observer function, one to be "applied" mentally by the domain describer, and one that appears in (MoLa) domain descriptions

The **obs**_... observer function is "applied" by the domain describer, it is not a computable function.

### 7.1.5 Validity of Endurant Observations

We remind the reader that the **obs**_erver functions, as all later such functions: **uid**_-, **mereo**_- and **attr**_-functions, are applied by humans and that the outcome of these "applications" is the result of human choices, and possibly biased by inexperience, taste, preference, bias, etc.

How do we know whether a domain analyser & describer's description of domain parts is valid ? Whether relevantly identified parts are modeled reasonably wrt. being atomic, Cartesians or part sets Whether all relevant endurants have been identified ? Etc. The short answer is: we never know. Our models are conjectures and may be refuted[15]. A social process of peer reviews, by domain stakeholders and other domain modelers is needed.

## 7.2 Internal Qualities

**Definition 15 Internal Qualities:** *Internal qualities are those properties [of endurants] that do not occupy space but can be measured or spoken about* ■

**Example 15 Internal qualities:** Examples of internal qualities are the *unique identity* of a part, the *mereological relation* of parts to other parts, and the endurant *attributes* such as temperature, length, colour ■

This section therefore introduces a number of domain description tools:

- **uid**_: the unique identifier observer of parts;

[15] We refer to [18, *Sir Karl Popper*].

- **mereo_**: the mereology observer of parts;
- **attr_**: (zero,) one or more attribute observers of endurants; and
- **attributes_**: the attribute query of endurants.

#### 7.2.1 Unique Identity

**Definition 16 Unique Identity:** *A unique identity is unique identity an immaterial property that distinguishes any two spatially distinct solids* ■

**Example 16 Unique Identities:** Each hub in a road net is uniquely identified, so is each link and automobile ■

#### 7.2.2 Mereology

**Definition 17 Mereology, I:** *Mereology is a theory of [endurant] part-hood relations: of the relations of an [endurant] parts to a whole and the relations of [endurant] parts to [endurant] parts within that whole* ■

**Example 17 Mereology:** Examples of mereologies are that a link is topologically *connected* to exactly two specific hubs, that hubs are *connected* to zero, one or more specific links, and that links and hubs are *open* to specific subsets of automobiles ■

#### 7.2.3 Attributes

**Definition 18 Attributes:** *Attributes are properties of endurants that are not spatially observable, but can be either physically (electronically, chemically, or otherwise) measured or can be objectively spoken about* ■

**Example 18 Attributes:** Examples of attributes are: links that have lengths, and, that at any one time, zero, one or more automobiles are occupying the links[16] ■

# 8 Prompts

## 8.1 Analysis Prompts

**Definition 19 Analysis Prompt:** *An analysis prompt is a predicate or a function that may be posed by humans to a domain. Observing the domain the analyser may then act upon the combination of the particular prompt (whether a predicate or a function, and then what particular one of these it is) thus "applying" it to a domain phenomena, and yielding, in the minds of the humans, either a truth value or some other form of value* ■

[16] Oh yes, it is, of course, spatially observable that a link has a length, but the measurement, say *123 meters* is not; and the number of cars on the link is also not spatially observable.

#### 8.1.1 Analysis Predicate

**Definition 20 Analysis predicates:** *An analysis predicate is an analysis prompt which yields a truth value* ■

**Example 19 Analysis Predicates:** General examples of analysis predicates are: *"can an observable phenomena be rationally described"*, i.e., an entity, *"is an entity a solid or a fluid"*, *"is a solid endurant a part or a living species"* ■

#### 8.1.2 Analysis Function

**Definition 21 Analysis function:** *An analysis function is an analysis prompt which yields some* MoLa-**text** ■

**Example 20 Analysis Functions:** Two examples of analysis functions are: one yields the endurants of a Cartesian part and their respective sort names, another yields the set of a parts of a part set and their common type ■

### 8.2 Description Prompt

**Definition 22 Description Prompt:** *A description prompt is a function that may be posed by humans who may then act upon it: [the human] "applying" it to a domain phenomena, and [the human] "yielding", i.e., writing down, a narrative and formal* MoLa-**text***s describing what is being observed [by that human]* ■

**Example 21 Description Prompts:** Description prompts result in MoLa-**text**s describing for example a (i) Cartesian endurant, or (ii) its unique identifier, or (iii) its mereology, or (iv) its attributes, or (iv) other ■

## 9 Perdurant Concepts

### 9.1 "Morphing" Parts into Behaviours

As already indicated we shall transcendentally deduce (perdurant) behaviours from those (endurant) parts which we, as domain analysers cum describers, have endowed with all three kinds of internal qualities: unique identifiers, mereologies and attributes. Section **??** will show and exemplify (Example **??** on page ??) how.

### 9.2 State

**Definition 23 State, I:** *A state is any set of the parts of a domain* ■

**Example 22 A Road System State:** The domain analyser cum describer may, decide that a road system state consists of the road net aggregate (of hubs and links)[17], all the hubs, and all the links, and the automobile aggregate (of all the automobiles)[18], and all the individual automobiles ■

[17]The road net aggregate, in its perdurant form, may "model" the *Department of Roads* of some country, province, or town.

[18]The automobile aggregate aggregate, in its perdurant form, may "model" the *Department of Vehicles* of some country, province, or town.

### 9.3 Actors

**Definition 24 Actors:** *An actor is anything that can initiate an action, an event or a behaviour* ■

#### 9.3.1 Action

**Definition 25 Actions:** *An action is a function that can purposefully changes a state* ■

**Example 23 Road Net Actions:** These are some road net actions: The insertion of a new or removal of an existing hub; or the insertion of a new, or removal of an existing link;

#### 9.3.2 Event

**Definition 26 Events:** *An event is a function that surreptitiously changes a state* ■

**Example 24 Road Net Events:** These are some road net events: The blocking of a link due to a mud slide; the failing of a hub traffic signal due to power outage; the blocking of a link due to an automobile accident.

#### 9.3.3 Behaviour

**Definition 27 Behaviours:** *A behaviour is a set of sequences of actions, events and behaviours* ■

**Example 25 Road Net Traffic:** Road net traffic can be seen as a behaviour of all the behaviours of automobiles, where each automobile behaviour is seen as sequence of start, stop, turn right, turn left, etc., actions; of all the behaviours of links where each link behaviour is seen as a set of sequences (i.e., behaviours) of "following" the link entering, link leaving, and movement of automobiles on the link; of all the behaviours of hubs (etc.); of the behaviour of the aggregate of roads, viz. *The Department of Roads*, and of the behaviour of the aggregate of automobiles, viz, *The Department of Vehicles*.

### 9.4 Channel

**Definition 28 Channel:** *A channel is anything that allows synchronisation and communication of values between two behaviours* ■

## 10 Domain Analysis & Description

### 10.1 Domain Analysis

**Definition 29 Domain Analysis:** *Domain analysis is the act of studying a domain as well as the result of that study in the form of* **informal** *statements* ■

### 10.2 Domain Description

**Definition 30 Domain Description:** *Domain description is the act of describing a domain as well as the result of that act in both* **narratives** *and* **formal** MoLa**-text** *form* ■

# 11 Closing

## 11.1 Summary

This paper has introduced the main concepts of domains such as we shall treat (analyse and describe) domains.[19]

## 11.2 Conclusion

to come

# A Bibliography

## References


[1] Dines Bjørner. From Domains to Requirements www.imm.dtu.dk/ dibj/2008/ugo/ugo65.pdf. In *Montanari Festschrift*, volume 5065 of *Lecture Notes in Computer Science (eds. Pierpaolo Degano, Rocco De Nicola and José Meseguer)*, pages 1–30, Heidelberg, May 2008. Springer.

[2] Dines Bjørner. Domain Engineering. In Paul Boca and Jonathan Bowen, editors, *Formal Methods: State of the Art and New Directions*, Eds. Paul Boca and Jonathan Bowen, pages 1–42, London, UK, 2010. Springer.

[3] Dines Bjørner. Domains: Their Simulation, Monitoring and Control – A Divertimento of Ideas and Suggestions. In *Rainbow of Computer Science, Festschrift for Hermann Maurer on the Occasion of His 70th Anniversary.*, Festschrift (eds. C. Calude, G. Rozenberg and A. Saloma), pages 167–183. Springer, Heidelberg, Germany, January 2011. www.imm.dtu.dk/~dibj/maurer-bjorner.pdf.

[4] Dines Bjørner. Pipelines – a Domain www.imm.dtu.dk/~dibj/pipe-p.pdf. Experimental Research Report 2013-2, DTU Compute and Fredsvej 11, DK-2840 Holte, Denmark, Spring 2013.

[5] Dines Bjørner. Domain Analysis: Endurants – An Analysis & Description Process Model www.imm.dtu.dk/ dibj/2014/kanazawa/kanazawa-p.pdf. In Shusaku Iida and José Meseguer and Kazuhiro Ogata, editor, *Specification, Algebra, and Software: A Festschrift Symposium in Honor of Kokichi Futatsugi*. Springer, May 2014.

[6] Dines Bjørner. Manifest Domains: Analysis & Description www.imm.dtu.dk/ dibj/2015/faoc/faoc-bjorner.pdf. *Formal Aspects of Computing*, 29(2):175–225, March 2017. Online: 26 July 2016.

[7] Dines Bjørner. Container Terminals. www.imm.dtu.dk/ dibj/2018/yangshan/maersk-pa.pdf. Technical report, Technical University of Denmark, Fredsvej 11, DK-2840 Holte, Denmark, September 2018. An incomplete draft report; currently 60+ pages.


[19] We have omitted treatment of *living species: plants* and *animals* – the latter including *humans*.

[8] Dines Bjørner. Domain Analysis & Description – Principles, Techniques and Modeling Languages. `www.imm.dtu.dk/ dibj/2018/tosem/Bjorner-TOSEM.pdf`. *ACM Trans. on Software Engineering and Methodology*, 28(2):66 pages, March 2019.

[9] Dines Bjørner. Domain Analysis & Description: Sorts, Types, Intents. `www.imm.dtu.dk/ dibj/2019/ty+so/HavelundFestschriftOctober2020.pdf`. Technical report, Technical University of Denmark, Fredsvej 11, DK-2840 Holte, Denmark, November 2019. Paper for Klaus Havelund Festschrift, October 2020.

[10] Dines Bjørner. *Domain Science & Engineering – A Foundation for Software Development*. EATCS Monographs in Theoretical Computer Science. Springer, 2021. A revised version of this book is [15].

[11] Dines Bjørner. Rivers and Canals. `www.imm.dtu.dk/~dibj/2021/Graphs/Rivers-and--Canals.pdf`. Technical Report, Technical University of Denmark, Fredsvej 11, DK-2840 Holte, Denmark, March 2021.

[12] Dines Bjørner. Domain Modelling. Revised edition of [15]. xii+208 pages. `http://www.imm.dtu.dk/ dibj/2023/DomainModelling/DomainModelling.pdf`, June 2023.

[13] Dines Bjørner. Domain Modelling. In Jonathan Bowen et al., editor, *Theories of Programming and Formal Methods: Essays Dedicated to Jifeng He on the Occasion of His 80th Birthday*, Lecture Notes in Computer Science, Festschrift. Spriger, August 2023.

[14] Dines Bjørner. Domain Modelling – A Primer. A short version of [15]. xii+202 pages[20], May 2023.

[15] Dines Bjørner. Domain Science & Engineering – A Foundation for Software Development. Revised edition of [10]. xii+346 pages[21], January 2023.

[16] Dines Bjørner. Domain Case Studies:

- 2023: *Nuclear Power Plants, A Domain Sketch*, 21 July, 2023 `www.imm.dtu.-dk/~dibj/2023/nupopl/nupopl.pdf`
- 2021: *Shipping*, April 2021. `www.imm.dtu.dk/~dibj/2021/ral/ral.pdf`
- 2021: *Rivers and Canals – Endurants – A Technical Note*, March 2021. `www.imm.-dtu.dk/~dibj/2021/Graphs/Rivers-and-Canals.pdf`
- 2021: *A Retailer Market*, January 2021. `www.imm.dtu.dk/~dibj/2021/Retailer/-BjornerHeraklit27January2021.pdf`
- 2019: *Container Terminals*, ECNU, Shanghai, China `www.imm.dtu.dk/~dibj/2018/-yangshan/maersk-pa.pdf`
- 2018: *Documents*, TongJi Univ., Shanghai, China `www.imm.dtu.dk/~dibj/2017/-docs/docs.pdf`

[20] This book is currently being trasnlated into Chinese by Dr. Yang ShaoFa, IoSCAS, Beijing and into Russian by Dr. Mikhail Chupilko, ISP/RAS, Moscow

[21] Due to copyright reasons no URL is given to this document's possible Internet location. A primer version, omitting certain chapters, is [14]

- 2017: *Urban Planning*, TongJi Univ., Shanghai, China www.imm.dtu.dk/~dibj/-2018/BjornerUrbanPlanning24Jan2018.pdf
- 2017: *Swarms of Drones*, Inst. of Softw., Chinese Acad. of Sci., Peking, China www.imm.dtu.dk/~dibj/2017/swarms/swarm-paper.pdf
- 2013: *Road Transport*, Techn. Univ. of Denmark www.imm.dtu.-dk/~dibj/road-p.pdf
- 2012: *Credit Cards*, Uppsala, Sweden www.imm.dtu.dk/~dibj/2016/credit/accs.-pdf
- 2012: *Weather Information*, Bergen, Norway www.imm.dtu.dk/~dibj/2016/wis/-wis-p.pdf
- 2010: *Web-based Transaction Processing*, Techn. Univ. of Vienna, Austria www.imm.-dtu.dk/~dibj/wfdftp.pdf
- 2010: *The Tokyo Stock Exchange*, Tokyo Univ., Japan www.imm.dtu.dk/~db/to-dai/tse-1.pdf, www.imm.dtu.dk/~db/todai/tse-2.pdf
- 2009: *Pipelines*, Techn. Univ. of Graz, Austria www.imm.dtu.dk/~dibj/pipe-p.pdf
- 2007: *A Container Line Industry Domain*, Techn. Univ. of Denmark www.imm.dtu.-dk/~dibj/container-paper.pdf
- 2002: *The Market*, Techn. Univ. of Denmark www.imm.dtu.dk/~dibj/themarket.-pdf
- 1995–2004: *Railways*, Techn. Univ. of Denmark - a compendium www.imm.dtu.-dk/~dibj/train-book.pdf

Experimental research reports carried out to "discover", try-out and refine method principles, techniques and tools, Technical University of Denmark, Fredsvej 11, DK-2840 Holte, Denmark.

[17] W. Little, H.W. Fowler, J. Coulson, and C.T. Onions. *The Shorter Oxford English Dictionary on Historical Principles*. Clarendon Press, Oxford, England, 1973, 1987. Two vols.

[18] Karl R. Popper. *Conjectures and Refutations. The Growth of Scientific Knowledge*. Routledge and Kegan Paul Ltd. (Basic Books, Inc.), 39 Store Street, WC1E 7DD, London, England (New York, NY, USA), 1963,...,1981.


# B An Example Domain Model: Road Nets

We present the types of a simple **domain model** of road transport.

**The External Qualities of Parts:**

1. There are road transports, RT.
2. From a road transport we can observe an aggregate of a **road net**, RN, and an **aggregate of automobiles**, AA.
3. From an aggregate of a road net we can observe an **aggregate of street intersections**, we shall call them **hubs**, AH, and **street segments**, i.e., **links**, as we shall call them, AL, [directly, immedi-

ately] between two hubs.

4. From an aggregate of automobiles we can observe a **set of automobiles**, As.

5. From an aggregate of hubs we can observe a **set of hubs** Hs.

6. From an aggregate of links we can observe a **set of links** Ls.

7. **Automobiles** A, **hubs** H, and **links** L and are here considered **atomic**, i.e., consists of not further sub-parts.

**type**
1. RT
2. RN
2. AA
3. AH, AL
4. As = A-**set**
5. Hs = H-**set**
6. Ls = L-**set**
7. A, H, L

**value**
2. obs_RN: RT → RN
2. obs_AA: RT → AA
3. obs_AH: RN → AH
3. obs_AL: RN → AL
4. obs_As: AA → As
5. obs_Hs: AH → Hs
6. obs_Ls: AL → Ls

**The Internal Qualities of Parts: Unique Identifiers, Mereologies and Attributes**

**Automobiles:**

8. **Automobiles** have **unique identifiers**,

9. are **mereologically** related to a subset of all hubs and links, and

10. have **attributes** of position, APos, on the road net [programmable], velocity, AVel [programmable], history, AHis, of the times, $\mathbb{TIME}$, they left and entered hubs and links and the road net, and entered the road net, links and hubs.

**Hubs:**

11. **Hubs** have **unique identifiers**,

12. are **mereologically** related to the one[22] or two links it connects (i.e., upon which it is incident), and

13. have **attributes** of current signal state, $\Sigma$ [programmable], signal state space, $\Omega$ [static], and **hub history**, HHis [programmable], i.e., the times automobiles left and entered the hub.

**Links:**

14. **Links** have unique **identifiers**,

15. are **mereologically** related to the one or two hubs upon which they are incident, and

16. have **attributes** of **length**, LEN [static] and **link history**, LHis [programmable], i.e., the times automobiles left and entered the link.

[22] One if the link "loops back" to the hub from which it emanates

**type**

**Unique Identification:**

8. AI
11. HI
14. LI

**value**

8. uid_A: A → AI
11. uid_H: H → HI
14. uid_L: L → LI

**Mereology:**

**type**

9. AM = (HI|LI)-**set**
12. HM = LI-**set**
15. LM = HI-**set**
15. [**axiom** ∀ lm:LM•1≤**card** lm≤2]

**value**

9. mereo_A: A → AM
12. mereo_H: H → HM
15. mereo_L: L → LM

**Attributes:**

**type**

10. APos, AVel
10. AHis = ($\mathbb{TIME}$×(HI|LI))*
13. HΣ = LI-**set**
13. [**axiom** ∀ h:H•**card** 1≤attr_HΣ(h)≤2]
13. HΩ = HΣ-**set**
13. [**axiom** ∀ h:H•attr_HΣ(h)∈attr_HΩ(h)]
13. HHis = ($\mathbb{TIME}$×AI)*
16. LEN
13. LHis = ($\mathbb{TIME}$×AI)*

**value**

10. attr_APos: A → APos
10. attr_AVel: A → AVel
10. attr_AHis: A → AHis
13. attr_HΣ: H → HΣ
13. attr_HΩ: H → HΩ
16. attr_LEN: L → LEN
16. attr_LHis: L → LHis

**Intentions and Intentional Pull:** We narrate, but do not formalize:

**Intentions:**

17. The intentions of road transport is
    (a) for automobiles to drive on roads: entering and leaving hubs and links, driving around hubs and along links, sometimes stopping, and
    (b) for hubs and links to accommodate automobiles: letting them enter and leave, drive around or along.

**Intentional Pull:**

18. For any automobile $a$ in the road net
    (a) if at some time $\tau$ it is leaving a hub $h$ or a link $\ell$,
    (b) then that hub or link has recorded that event.
19. For any hub $h$ [link $\ell$] of the road net
    (a) if at some time $\tau$ it observes an automobile $a$ entering (leaving) that hub [or link]
    (b) then that automobile $a$ has recorded that corresponding event.

• • •

These are the main characteristics of **solid** road transport **endurants**, i.e., **parts**. Other characteristics, such as the **perdurants**, i.e., *behaviour*s, **action**s and **events** will be exemplified later[23] ■

[23] **Editorial Note:** **Remember to develop these examples and insert reference.**