UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL
INSTITUTO DE INFORMÁTICA
PROGRAMA DE PÓS-GRADUAÇÃO EM COMPUTAÇÃO

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A Theory for Ontological Modeling of Events Based on Systems

Thesis presented in partial fulfillment of the requirements for the degree of Doctor of Computer Science

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Porto Alegre
June 2023

CIP — CATALOGING-IN-PUBLICATION

Rodrigues, Fabrício Henrique

A Theory for Ontological Modeling of Events Based on Systems / Fabrício Henrique Rodrigues. – Porto Alegre: PPGC da UFRGS, 2023.

238 f.: il.

Thesis (Ph.D.) – Universidade Federal do Rio Grande do Sul. Programa de Pós-Graduação em Computação, Porto Alegre, BR–RS, 2023. Advisor: Mara Abel.

1. Ontology. 2. Conceptual Modeling. 3. Events. 4. Processes. 5. Occurrents. 6. Auxiliary events. 7. Systems. I. Abel, Mara. II. Título.

ACKNOWLEDGMENTS

Life on Earth is in itself a shared adventure – the fact that each of us is here is nothing more than a sign of the operation of a huge and intricate network of other living beings. We know it from books, we know it in our brains. Still, a few times throughout our lives we have the chance to know it in our hearts. Finishing a doctoral thesis is definitely one of those moments.

This text is already over two hundred pages long. To properly thank everyone that contributed during this journey, I would need no less than another two hundred. Unfortunately, I have only one... I will do my best. First, I thank my parents, Pedro and Oraides, and my brothers, Marcelo and André, for much more than I would ever be able to say in words. I also thank my girlfriend Laura for sharing the ups and downs during the process.

I deeply thank my advisor Mara Abel for the discussions, the challenges, the precise guidance and for believing in me more than myself, and my honorary co-advisor Joel Carbonera for the many expeditions to the endless space of possibilities.

Many thanks to the *Aleatorium Gathering* – my own version of the *Olympia Academy* – and its members Joel Carbonera, Luan Garcia, Cauã Antunes, and Sandro Fiorini for the effervescent stream of ideas that flow unconfined. Many thanks to Lucas Vieira for the various meetings geology-ontology corner, to Nicolau Santos for the partnership on many fronts, to Daniela Schmidt for the providential '*thesis coaching*' sessions, to Luan Garcia for walking down the PhD-road together, and Rafael Manica for his help with the case study. I also thank the BDI group and the PeTwin team for their camaraderie and support. Thank you, Mathias Mantelli, my outlander-quest brother.

I thank Martin Giese for welcoming me abroad and for showing me new perspectives, and David Cameron for the profitable discussions and for the right books at the right times. I also thank all the people from the SIRIUS Center for widening my horizons, in special, Ingrid Yu, Crystal Din, Irina Pene, Leif Harald Karlsen, Oliver Stahl, Farhad Nooralahzadeh, Gianluca Turin, Peyman Rasouli, Adnan Latif, and Arild Waaler.

I thank Rubilar Jardim, André Farias, and Natacha Oliveira for contributing to one of the greatest adventures in my life. I also thank Lúcia Speranza for the understanding and the cheering up, and Paulo do Carmo for the support.

Thank you, Francisco Leite, for guiding me in my inner quest while the outer one was on fire. Thank you, Matheus Martin, for always being there. And finally, thank you so much, Jéssica Lourenço, for the most important '*just go*' ever.

ABSTRACT

In Informatics, an *ontology* is the specification of a system of categories accounting for a certain view of the world. It usually includes categories for the things that *are* in time, which are commonly called *continuants* and include things such as a person, a piece of rock, or a machine. An ontology may also include categories for the things that *happen* in time as a transition through successive situations (*i.e.,* instantaneous snapshots of part of the world). Those entities are usually called *events* or *processes* and include, *e.g.,* a meeting, the erosion of a mountain, or the manufacturing of a good. Despite the usual priority given to continuants, in practical terms, a good model of events can support several ontology-based reasoning activities, such as pre- and post-condition inference or inference of temporal relations.

Accordingly, current ontologies offer powerful modeling constructs that allow us to represent a rich variety of types of events. In contrast, they provide much weaker constraints over the possible models that can be constructed. In special, there are several shortcomings in the current criteria to determine what sequence of situations suitably characterizes the unfolding of a given event and which continuants participate in the event at each of these situations. This lack of clear restrictions on how to model events compromises the ability of such ontologies to guide the modeling process and allows a higher degree of ambiguity in the resulting models. Hence, stricter constraints over the notion of events can be useful to empower modelers to convey the intention behind their models more effectively. Besides that, they can help us to uncover novel relations between events and types of events to account for relevant modeling scenarios.

In view of that, this work presents a theory for ontological analysis and modeling of events based on the notion of *systems* as the invariant element that delimits an event. Under this perspective, an event would be a transition through instantaneous snapshots of an invariant system. We argue that such a constraint captures the observed cohesion among the situations that compose the course of an event. Furthermore, it renders a clearer criterion to decide which objects can be said to participate in an event at each instant as well as which succession of situations can adequately trace out the unfolding of an event. Thus, in this work, we introduce the notion of *system-invariant events* as a type of event whose instances are delimited by systems and derive sub-types according to the type of the system that delimits their instances. Following, we propose an ontological account for the notion of *auxiliary events*, *i.e.,* events that interfere with other events (*e.g.,* by causing the entry/exit of participants into/from other events, by affecting the dynamics of other events), and derive a taxonomy of auxiliary events based on the type of effect they have on other events. Finally, based on the referred taxonomies and on the *principle of ontological conservation* we propose some general guidelines for the modeling of events. We demonstrate this approach with a case study in the domain of Geology (namely, the case of turbidity currents and associated processes such as erosion and deposition).

Keywords: Ontology. Conceptual Modeling. Events. Processes. Occurrents. Auxiliary events. Systems.

Uma Teoria Ontológica para Modelagem de Eventos Baseada em Sistemas

RESUMO

Em Informática, uma *ontologia* é a especificação de um sistema de categorias que representa determinada visão do mundo. Normalmente, uma ontologia inclui categorias para as coisas que *existem* no tempo, comumente chamadas de *continuantes*, tais como como uma pessoa, um pedaço de rocha ou uma máquina. Uma ontologia também pode incluir categorias para as coisas que *acontecem* no tempo na forma de uma transição através de situações sucessivas – ou seja, uma transição através de uma série de configurações instantâneas de parte do mundo. Essas entidades geralmente são chamadas de *eventos* ou *processos* e incluem, por exemplo, uma reunião, a erosão de uma montanha ou a fabricação de um produto. Apesar da prioridade usualmente dada aos continuantes, em termos práticos, um bom modelo de eventos pode apoiar várias atividades de raciocínio baseadas em ontologia, tais como a inferência de condições pré e pós-evento ou a inferência de relações temporais.

Nesse sentido, as ontologias atualmente disponíveis oferecem construtos de modelagem poderosos, que nos permitem representar uma grande variedade de tipos de eventos. Em contraste, tais ontologias fornecem muito menos restrições sobre os possíveis modelos que podem ser construídos.Em especial, existem deficiências nos critérios atuais para determinar que sequência de situações caracteriza adequadamente o desenrolar de determinado evento e quais continuantes participam do evento em cada uma dessas situações. Essa falta de restrições claras sobre como modelar eventos compromete a capacidade dessas ontologias em orientar o processo de modelagem e permite um grau maior de ambiguidade nos modelos resultantes. Portanto, restrições mais rígidas sobre a noção de eventos podem ser úteis para capacitar os modeladores a transmitir a intenção por trás de seus modelos de forma mais eficaz. Além disso, restrições adicionais também podem ajudar a descobrir novas relações entre eventos e novos tipos de eventos que permitam representar cenários de modelagem relevantes que não são adequadamente tratáveis com os recursos atuais.

Diante disso, este trabalho apresenta uma teoria para a análise ontológica e modelagem de eventos baseada na noção de *sistema* como o elemento invariante que delimita um evento. Sob essa perspectiva, um evento seria uma transição através de diferentes configurações instantâneos de um mesmo sistema. Tal restrição permite captar a coesão que se observa entre as situações que compõem o curso de um evento. Além disso, ela proporciona um critério mais claro para decidir quais objetos podem ser considerados participantes de um evento em cada instante, bem como qual sucessão de situações pode traçar adequadamente o desenrolar de um evento.

Assim, este trabalho introduz a noção de *eventos de sistema invariante* como um tipo de evento cujas instâncias são delimitadas por sistemas. Com base nisso, são derivados subtipos evento de acordo com o tipo do sistema que delimita suas instâncias. Este trabalho também propõe um caracterização ontológica para a noção de *eventos auxiliares*, *i.e.,* eventos que interferem em outros eventos (*e.g.,* causando a entrada/saída de participantes em/de outro evento ou afetando sua dinâmica) e apresenta uma taxonomia de eventos auxiliares baseada no tipo de efeito que um evento de certo tipo pode ter sobre outros eventos. Por fim, a partir das taxonomias propostas e do *princípio de conservação ontológica*, este trabalho propõe algumas diretrizes gerais para guiar a tarefa de modelagem conceitual de eventos. A aplicação da teoria proposta é demonstrada em um caso de estudo no domínio de Geologia – mais especificamente, o caso de correntes turbidíticas e seus processos associados, tais como erosão e deposição).

Palavras-chave: Ontologia. Modelagem Conceitual. Eventos. Processos. Ocorrentes. Eventos auxiliares. Sistemas..

LIST OF FIGURES

LIST OF ABBREVIATIONS AND ACRONYMS

BFO	Basic Formal Ontology
DOLCE	Descriptive Ontology for Linguistic and Cognitive Engineering
GFO	General Foundational Ontology
UFO	Unified Foundational Ontology
YAMATO	Yet Another More Advanced Top-level Ontology

CONTENTS

Part I

PRELIMINARIES

1 INTRODUCTION

In informatics, we can regard an *ontology* as an explicit specification of a conceptualization [GRUBER, 1993]. Such specification is intended to restrict the possible interpretations over the terms of a language in order to approximate the set of models allowed by the language to the set of intended models (*i.e.,* allowing as many intended models as possible and ruling out as many unintended models as possible) [GUARINO, 1995] [GUIZZARDI, 2005, p.83].

Ontologies can include concepts to represent both *continuants* and *events* [CASATI; VARZI, 2020]. Continuants[1] are things that *exist*, that *are* in time, and that are wholly present at any time they are present. Conversely, events[2] are things that *happen* or *occur* or *take place*, that *take up* time, and that are only partially present whenever present. As noted in [GALTON; MIZOGUCHI, 2009], there is a widespread view that continuants are ontologically prior to events, *i.e.,* that continuants are all that exist and events represent just the distribution of matter and objects in space and time. Despite this, it seems that a great part of our reality is fundamentally dependent on events (*e.g.,* chemical reactions, business transactions, geological processes, and industrial operations). In any case, representing events is an integral aspect of commonsense reasoning [GRüNINGER, 2009], and there are several advantages in including them in the domain of discourse, such as quantifying over actions and predicating on causality [BORGO; MASOLO, 2009].

In practical terms, good conceptual models of events can support several ontology-based reasoning activities, such as the inference of pre- and post-conditions of an event, the discovery of temporal relations, the inference of missing or implicit events, and the identification of incompatible descriptions of a single event [BORGO et al., 2016]. This support can help in a variety of tasks, which include discrete event simulation [GUIZZARDI; WAGNER, 2010], representation of narratives [TAO et al., 2010], production planning [GRüNINGER; KATSUMI, 2019], scheduling [GRüNINGER; KATSUMI, 2019], causal and temporal reasoning [MELE; SORGENTE, 2011], as well as temporal projection of future states and explanations about past states [GRüNINGER, 2009; GRüNINGER; KATSUMI, 2019]. With that, a number of domains would take advantage of a good ontological analysis of events, including Geology [CARBONERA et al., 2013; DIN et al., 2019], Health Sciences [RODRIGUES et al., 2017; TAO et al., 2010], News [VOSSEN et al., 2016], Social Media [KESKISARKKA; BLOMQVIST, 2013], Man-

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[1] Sometimes referred to as endurants.

[2] Sometimes referred to as occurrents, perdurants, and processes.

ufacturing [GRüNINGER; KATSUMI, 2019], and Enterprise Modelling [GRüNINGER, 2009].

A good model of an event relies on adequate criteria of unity and individuation to determine what sequence of stages suitably characterizes the unfolding of the event and which continuants participate in the event at each of these stages. Besides, building such a model also depends on the availability of suitable modeling constructs to capture all the relevant aspects of the event. However, the current criteria for delineating an event have notable shortcomings and there is a lacking of constructs to account for some modeling scenarios, such as the interaction between events. Given that, this thesis presents our work toward a theory for the ontological analysis and modeling of events that establishes a set of modeling constraints to guide those tasks and offers a set of modeling constructs to deal with facets of events that are still not covered in the literature.

In this chapter, we present the context and motivation for our work (section 1.1), our main hypotheses and objectives (section 1.2), the scope of the work (section 1.3), our main intended contributions (section 1.4), and how the remainder of the document is structured (section 1.5).

1.1 Context and Motivation

It is commonplace in the development of foundational ontologies to define events as things that *happen* in time (*e.g.,* DOLCE [GANGEMI et al., 2002], UFO [GUIZZARDI et al., 2013], BFO [ARP; SMITH; SPEAR, 2015]). However, as argued in [CASATI; VARZI, 2020], it merely shifts the burden to the task of clarifying what it is to "*happen*".

The literature frequently describes events as things that extend in time by having different temporal parts (*e.g.,* [GANGEMI et al., 2002; GUIZZARDI et al., 2013; ARP; SMITH; SPEAR, 2015]). Given this description, we may feel inclined to equate this *extending in time* nature to the idea of *happening*. The problem is that such a description does not fully reveal the nature of what events are. Specifically, even though temporal regions are also extended in time by having different temporal parts, people do not usually say that they *happen* in time. For instance, if we google the sentence "*a century happened*" we will have no exact matches, whereas if we google "*a century passed*" we will have plenty of them. As another example, although BFO defines both temporal regions and events[3] [ARP; SMITH; SPEAR, 2015, p.121-124] as things that are extended in time

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[3] What we refer here as *events* are called *processes* in BFO.

by having temporal parts, it only regards events as things that *happen*. These examples indicate that there must be other factors at play to fully characterize what it is for something to *happen* and, consequently, to fully grasp what events are.

In fact, there are other accounts that shed light on the happening nature of events. A particularly noteworthy one is what we will call the *transition view*, which regards events as transitions through snapshots of a portion of reality or, in other words, transitions through *situations*. We find this view, for example, in UFO (which regards events as mappings between situations in the world) [GUIZZARDI et al., 2013; GUIZZARDI; GUARINO; ALMEIDA, 2016], and in GFO (which regards processes as successions of presential process boundaries) [HERRE, 2010].

The transition view deals with the nature of what happens. Take, for instance, the breaking of a piece of glass onto the ground. The transition view offers a suitable answer to the question of what has happened in this case, *i.e.,* the transition from a situation in which both the glass and the ground were intact to a situation in which the ground is still undamaged, but the glass is broken.

This view also seems to find some support in the etymology of the terms around the notion of events. Events are said to *occur*, which comes from the Latin verb *occurrere* (*ob*- “against, towards” + *currere* “to run”), which means “run to meet, arrive, present itself”[4][5], resembling the idea of a situation arriving to replace a previous state. This idea of superseding situations also seems to have echoes when events are said to *take place*[6][7] (that is a synonym of *happen*[8] and *occur*) and when the verb *happen* is described as “*to come into existence of a situation*”[9].

Moreover, treating events as transitions between situations has some appeal from an informatics/computational perspective. In fact, it seems to be a long-established approach to dealing with the representation of events (*e.g.,* Situation Calculus [MCCARTHY; HAYES, 1969], Statecharts [HAREL, 1987], UML State Machines [RUMBAUGH; JACOBSON; BOOCH, 2004]).

The transition view also arouses pragmatic interest. From an epistemological perspective, these instantaneous situations may be seen as time-stamped data or the result of basic observations [BENEVIDES; MASOLO, 2014], which is arguably a usual way to

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[4] <www.dictionary.com/browse/occur>

[5] <www.etymonline.com/word/occur>

[6] <www.dictionary.com/browse/take--place>

[7] <www.collinsdictionary.com/dictionary/english/take-place>

[8] <www.dictionary.com/browse/happen>

[9] <dictionary.cambridge.org/us/dictionary/english/happen>

record information (*e.g.,* storing the result of a series of measurements of a certain property/quantity at different times instead of its variations). Representing and recognizing events by means of successions of instantaneous snapshots of the world seems to fit this picture.

Such a view is also useful when we record the events themselves instead of snapshots of the world. In such cases, the view of events as transitions allows us to unfold them and identify the world states they link. *E.g.,* given the present state of a store's inventory and the history of sales and purchases, we can infer the number of stored items at different times.

In light of this, the transition view can help in the tasks described before, *e.g.,* discrete event simulation and temporal reasoning. Regarding temporal reasoning, this approach seems to increase in importance with the growing amount of information that is shared in open systems. Let us consider the case of the internet as a large repository that can contain, for any given entity, information regarding its states at distinct instants of time, without any particular structure. With that, recovering reliable information about the state of such an entity at a given point in time becomes a challenging task that may take advantage of the capability of processing events as transitions between situations involving continuants. To give an example, if we search for Arnold Schwarzenegger, we will find him as an actor, a professional bodybuilder, and the Governor of California. In order to know which of these facts are true about him at present we have to understand the events that made him acquire/lose each of these roles (*e.g.,* retiring from sports activities ended his bodybuilder career; by leaving the Governor's Office he is no longer a governor).

Current ontologies provide rich support for modeling events according to the transition view, with plenty of constructs that allow representing a myriad of desired cases. Despite that, they are not so generous in offering constraints over the possible models they allow. To put it another way, we can recollect the purpose of an ontology as constraining a language to approximate the set of models we can represent with the language to the set of models we intend to accept as valid ones. Bearing that in mind, it seems that existing work contributes a great deal to allow representing intended models of events as transitions, but not so much to avoid unintended models.

This limitation raises some questions. If an event is a transition through situations, we can describe it in terms of the succession of situations it brings about as it happens. With that, we face the issue of deciding what successions of situations appropriately describe events. To illustrate the point, we can make an analogy with the persistence of ordinary physical objects. As exposed in [HIRSCH, 1992, p.3-4], we can think of any physical object as something that persists through a career comprising a succession of momentary object-stages.[10]Nevertheless, not every succession of object-stages corresponds to a single persisting object, but just those in which the successive stages are related in some distinctive way. If it were not the case, nothing would prevent us from arbitrarily combining into a single career the early stages of one object with the later stages of a distinct object (*e.g.,* a succession of the stages of the trunk of a tree in the morning followed by the stages of the whole tree in the afternoon).[11]

Analogously, it is not just any succession of situations that corresponds to a genuine event, but only those in which the succeeding situations are related in an adequate manner. To illustrate, we can imagine a succession composed of consecutive situations in which a musician plays chords of a song at a local pub followed by the situation of a runner taking the last step in a sprint race at a stadium next to the pub. Even though it indeed is a sequence of snapshots of part of the world, we would not say that a transition through such snapshots is a real event. On the other hand, we easily recognize the succession of a situation in which a vendor holds a hot dog and a customer holds a dollar bill, followed by the situation in which the vendor holds the dollar bill and the customer holds the hot dog as corresponding to an event of purchasing a hot dog.

The adequacy of a succession of situations as corresponding to an event seems, at least in part, dependent on the continuants that each of the successive situations includes. For example, we seem to have ruled out the “musician-runner” succession of situations on the basis of the presence of an apparently spurious participant (*i.e.,* the runner) in one of the situations. Considering that, deciding whether a succession of situations corresponds to a legitimate event involves deciding which continuants can or cannot be present in each situation in such a succession. That is, it seems to be related to the issue of how to determine what the participants of an event are at each instant.

We would have such an issue, for instance, when a train stops by a station during a trip. This case would raise the question of whether the clerk who checks the tickets at the station participates in the trip. Also, it calls for a decision about whether a person who just entered the train is already participating in the trip or will do so only after the train

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[10] Here, it is not to say that objects have temporal parts. Instead, the notion of object-stage is closer to that of object snapshot in [GUIZZARDI; WAGNER, 2011], *i.e.,* a set of attributions about an object at the time.

[11] Example inspired by [HIRSCH, 1992, p.29].

departs again.

This lack of clear restrictions on which successions of situations can adequately correspond to an event can lead to several shortcomings. The first one relates to the issues of communication and ambiguity of models. Quoting [CARVALHO; ALMEIDA; GUIZZARDI, 2014],

> "*If nothing is said about the conceptualization underlying a language, each language user may interpret a model based on his/her own concepts about reality. Thus, the formal definition of a language's real-world semantics is essential to empower language's users to efficiently communicate about reality*".

Paraphrasing that in our case, if we only have loose constraints over the notion of events as transitions, each modeler/user may build/interpret models based on different assumptions, causing the models to rely on implicit constraints. To illustrate, consider an event described as the transition from a situation in which there is an object x to a situation in which x is not present. In this case, it is up to the user to interpret, *e.g.,* whether x goes out of existence or simply is no longer present at the place. Thus, stricter constraints over this notion can be useful to empower modelers to convey the intention behind their models more effectively. Moreover, crispier borders for events can help us to identify relations between events and to define further event types.

The lack of restrictions is also associated with a weaker ability to guide the modeling process. At each instant, we can arbitrarily break reality down in a practically infinite number of local, instantaneous situations (*e.g.,* a person drinking tea in Tokyo; a bird resting on the top of a skyscraper in São Paulo; or the mereological sum of the previous two situations). With no adequate criteria to determine which combinations of temporally succeeding situations correspond to valid paths for events through this non-stopping stream of new situations, we end up with countless ways to structure what happens in reality. Such a large range of valid models can absorb any possible variation in their elements. As a result, the underlying theory loses the power to spot problematic representations and, consequently, the ability to support approaches to fix them.

Actually, the clash of what the modeler wants to represent against a stricter set of constraints can reveal elements that are implicit in the model. Assuming that the modeler has a good understanding of the type of event s/he wants to represent, some modeling mistakes may be seen as a failure to frame the knowledge about the domain into a definition of a type of event rather than an indication of a flawed view of the domain itself. With that, if the modeler wants to add something to the model that does not fit the constraints over the notion of event, it is probably not the case that s/he is mistaking reality by seeing something that does not really exist. Instead, it is more likely that s/he is trying to “store it in the wrong box”, *i.e.,* identifying the entity as an instance of the wrong category and/or incorrectly relating it to the event.

For example, consider the modeling of the event of sculpting a statue. Now, imagine that the modeler represents the people that come to check out the progress as new participants engaging in the process rather than external observers. Here, it is not that there are no people coming to verify the progress. Instead, it was just the modeler mistaking their role in the case. Thus, constraints that cut such possibility can, at once, avoid the pollution of the model (*i.e.,* avoiding the inclusion of spurious participants) while providing a basis to infer that there must be some sort of element associated with the event that can accommodate what the modeler wants to include.

Conversely, if the modeler makes a model of an event that violates some constraint by lacking some element, again, it is probably not that s/he does not understand the type of event of interest. Rather, it may just be that s/he mistakes the requirements for an event itself, in such a way that what is missing is something that s/he takes for granted so deeply that it does not come to his/her mind (*e.g.,* neglecting the generation of by-products when modeling the process of fuel burning). Therefore, making such constraints explicit can also help to reveal important overlooked elements that, otherwise, would not make their way into the model.

Beyond the lack of constraints, even though the transition view arguably reveals a core aspect of the nature of events, there are not many upper types derived from this aspect, especially in comparison to the variety of types regarding other aspects. Besides, the currently proposed types are not always explicitly defined in terms of situations (*e.g.,* the semantic functions defined in [KANEIWA; IWAZUME; FUKUDA, 2007]). Moreover, a good collection of types should allow additional inferences about properties other than those used to classify the instance [PARSONS; WAND, 2008]. Despite that, the existing types majorly cover representational purposes, not supporting additional inference once the instance is classified (or, at least, not having a clear definition of necessary and sufficient properties).

This thesis deals with such limitations of the current modeling approaches in determining which participants are involved in an event at each time, as well as which succession of situations appropriately traces out its occurrence. In particular, we aim to identify further modeling constraints and explore their implications to derive useful modeling structures. With that, we believe we can contribute to the task of ontological analysis and modeling of events by providing modeling constructs and enabling novel inferences over such models. Also, this enhancement may provide the basis for the systematic verification of models of events, identifying overlooked participants, misclassified entities, inconsistent sequences of situations, and other modeling problems. The next section details our main research hypotheses and the objectives of this work.

1.2 Hypothesis and Objectives

Assuming that the transition view is a faithful account of the nature of events as things that happen, we based this work on the following main hypotheses considered for material domains:

(I) What participates in an event is not an arbitrary, epistemological choice, but instead there are ontological constraints for something to participate in an event;

(II) The succession of situations that corresponds to a genuine event is not an arbitrary mereological sum of temporally ordered situations, but rather there are ontological constraints for a succession of situations to correspond to an event;

(III) It is possible to derive useful types of events from those constraints that can reveal distinct general structures of events along with distinct consequences for analyzing and modeling events.

Given that, the main objectives of this work are:

(1) Determining unifying criteria for events based on the constraints mentioned in hypotheses (I) and (II);

(2) Deriving types of events and relations between events from the unifying criteria referenced in (1) and other related ontological constraints;

(3) Outlining general rules on how to employ the findings from (1) and (2) to guide the analysis and modeling of events, as well as the conceptual verification of these models.

1.3 Scope of the Thesis

This study focuses on events that are changes (or unchanges) on concrete, material objects (*e.g.,* trees, companies, human beings, atoms) rather than abstract ones (*e.g.,* numbers, propositions, the letter ‘A’). With that, we intend to cover events such as the production of a good, a business transaction, the writing of a document, or a geological process, but not events such as the addition of two numbers or the development of a theorem. Moreover, we aim our work at multiple-participant events, intending to cover events such as the interaction between two objects, but not, for example, the independent movement of a single material object.

1.4 Intended Contributions

The major intended contribution of this work is providing a reference conceptual framework for the ontological analysis and modeling of events that can impose certain constraints to guide those tasks and that provides a set of useful modeling constructs, including novel types and relations to account for some facets of events that are still not covered in the literature.

In other words, given the modeler’s initial assumptions about a particular event or class of events of interest, we intend our framework to bring to light a set of consequences of such assumptions so that the modeler can check whether or not such consequences fit her/his modeling intentions. Then, if they turn out to be undesired consequences, the framework can lead the modeler to pay attention to the problematic aspects of the model. Alongside, our framework was conceived to offer additional constructs that can help in amending the identified modeling problems by allowing the unveiling and adequate categorization of missing elements, as well as providing means to accommodate relevant modeling situations, such as the interference between events.

With that, we expect that this framework can be the basis for developing methodological guidelines for analyzing and modeling events, as well as for assessing the correctness of models and fixing problematic ones.

1.5 Thesis Structure

The remainder of this thesis proposal is structured as follows:

- In chapter 2, we review the theoretical background for our proposal, including the notions of ontology, situation, constitution, disposition, and system;
- In chapter 3, we review related work concerning the Ontology of events;
- In chapter 4, we begin our contribution by defining some grounding notions underlying our proposal (such as the notion of *basic ontological substrate* and the *principle of ontological conservation*) and by presenting a basic account of events according to the transition view based on what was already proposed in the literature;
- In chapter 5, we discuss the shortcomings of the presented basic account, delineate our strategy to extend this account and achieve the objectives of this work (*i.e.,* use the notion of *system* to delimit events), and develop the notion of *system-invariant event*;
- In chapter 6, we explore the implications of delimiting events with systems, defining the notions of *open event* and *closed event*, as well as further types of events, relations between them, and some modeling constraints;
- In chapter 7, we present a case study in Geology, applying our approach to model the case of turbidity currents;
- In chapter 8, we discuss the strengths and limitations of our approach, as well as further directions for the research;
- Finally, in chapter 9, we present our concluding remarks.

2 THEORETICAL BACKGROUND

This chapter presents the theoretical basis upon which our work is built. In particular, we review some basic notions underlying the remainder of the text (section 2.1), the views we adopted for the notions of ontology (section 2.2), situation (section 2.3), material constitution (section 2.4), disposition (section 2.5), and system (section 2.6).

2.1 Basic Assumptions and Terminology

This work is built upon some basic assumptions:

- A sharp division between continuants and events, grounded on a *endurantist* or *three-dimensionalist* view, *i.e.,* the view that concrete, physical objects have no temporal parts and are wholly present whenever they exist, whereas events have temporal parts and are only partially present whenever present [EMERY; MARKOSIAN; SULLIVAN, 2020, sec.7] [HAWLEY, 2020, sec.2];
- A particularist view of events, *i.e.,* that events are legitimate, unrepeatable individuals located in spacetime [BORGHINI; VARZI, 2006; BENNETT, 2002; SAVELLOS, 1992; BRAND, 1976; LOMBARD, 1979; DAVIDSON, 1969];
- The existence of event universals of which such particular occurrences of events are instances.
- A realist view of the world, assuming that the entities we consider here (including events) and the properties that characterize them exist independently of anyone's beliefs, linguistic practices, conceptual views, and so on [MILLER, 2019].
- A distinction between concrete and abstract objects according to which abstract objects are causally inefficacious and have no location in spacetime [ROSEN, 2020].

Given that, the next section clarifies the terminology adopted throughout the text.

2.1.1 Basic Notions

We will use the terms ***universal***, ***category***, and ***type*** to refer to abstract entities (*i.e.,* with no spatiotemporal location [ROSEN, 2020]) that can be concretely exemplified in the world (*e.g., person*, *festival*, *building*). Thus, a universal corresponds to certain invariants in reality that its instances have in common [SMITH, 2004]. Complementarily, we will use the terms ***particular***, ***individual***, or ***instance*** to refer to exemplifications of universals (*e.g., Julia Roberts*, *Woodstock*, the *Eiffel Tower*).

We will refer to individuals simply using the name of the universal that they exemplify preceded by an article "*a/an/the*" or expressions that emphasize their particular nature, such as "*an instance of*". Examples of such references include "*a person*", "*the meeting*", and "*an instance of building*". To refer to universals, we will use their names along with the qualifiers *universal*, *type*, or *category*. To illustrate, we would use "*the person universal*" to refer to a universal whose instances are people, "*the type 'meeting'*" for a universal whose instances are meetings, and "*the building category*" for a universal whose instances are buildings.

We choose the term ***continuant*** to unspecifically refer to anything that exists in time, being wholly present whenever it is present (which some works refer to as *endurant*). In this work, we assume that continuants do not include space itself or space regions. ***Substantial*** or ***object*** will be used to refer to existentially independent continuants (*e.g.,* a person, a building).

Event will be the term employed to unspecifically refer to anything that happens in time, that cannot be wholly present at a single time point (which some works refer to as *process*, *occurrent*, or *perdurant*). Again, in our view, events do not include time or spacetime themselves, nor temporal or spatiotemporal regions. We will also use ***occurrence*** to refer to instances of event universals (*e.g.,* an occurrence of *Running*). We will further explore these notions in chapter 3.

We will use the term ***property*** to refer to the notion of *particularized property*, corresponding to *moments* in [GUIZZARDI, 2005, 212-213] and *specifically dependent continuants* in [ARP; SMITH; SPEAR, 2015]. Hence, properties are particulars that existentially depend on other entities and determine the ways that such entities are (*e.g.,* their colors, masses, relationships). Then, we say that properties *inhere in* or *characterize* those entities and that such entities *have*, *bear*, or *exhibit* properties. We also assume that there are property universals or types of properties of which particular properties are instances (*e.g.,* the particular color that inheres in a given emerald is an instance of the universal *Color*).

Intrinsic properties, *i.e.,* those that inhere in a single entity, include ***qualities*** (*i.e.,* properties structured as attributes that have a value on some dimension, *e.g.,* color or size), ***dispositions*** (*i.e.,* realizable properties, *e.g.,* magnetic attraction, solubility), and other general ***modes*** of being (*i.e.,* a thought, a fever). ***Relationship*** will be employed to refer to *relational properties*, *i.e.,* those that inhere in a group of entities that jointly bear the property, representing a connection among such entities (*e.g.,* a chemical bond, a mutual commitment). We will use ***relation*** for referring to entities that also link other entities in some sense, but that do not inhere in their relata (*e.g., greater than*, *in front of*, *instantiates*).

Situation will refer to some configuration of a given portion of the world at a given time point, defined in terms of the objects and properties they present (*e.g.,* an anesthetized patient and a surgical team in an operating room right before a surgery procedure). In addition, we will use the term ***prolonged situation*** to refer to situations that are extended in time. We will detail the notion of situation that we adopt in this work in section 2.3.

We will adopt ***temporal region***, and ***time instant*** or ***time point*** to refer to the distribution or position of things in time. ***Spatial region*** and ***spatial point*** will be used to refer to distribution and position of things in 3-dimensional space. ***Spatiotemporal region*** and ***spatiotemporal point*** will be used analogously with respect to 4-dimensional space.

2.2 Ontologies

In Philosophy, the term *Ontology* (with capital “O”) traditionally refers to the study of what are the things that exist (*i.e.,* the stuff reality is made out of) as well as the most general features of and relations among these things [HOFWEBER, 2021]. More recently, the term *ontology* (with lowercase “o”) is also employed to designate an inventory of what exists in reality [BAKER, 2007] or, at least, of what are the entities to which we commit when adopting a given theory or system of thought [LOWE, 2005] [KRAUSE, 2017, p.17].

In the field of informatics, the term *ontology* is commonly defined as “*an explicit specification of a conceptualization*” [GRUBER, 1993]. Here, *conceptualization* refers to an abstract and simplified view of the world that we want to represent for a particular purpose [GRUBER, 1993].

Despite its widespread use, this definition of ontology is somewhat controversial, mainly due to the notion of *conceptualization* that grounds it. This notion is based on [GENESERETH; NILSSON, 1987], in which the authors affirm that “*conceptualizations are our inventions, and their justification is based solely on their utility*”. Furthermore, they do not commit themselves to any correspondence between a conceptualization and entities in reality, attributing this view to an "*essential ontological promiscuity of AI*" [GENESERETH; NILSSON, 1987, p.13].

With that, the resulting definition of ontology in [GRUBER, 1993] leaves room for too many possible interpretations [SMITH; WELTY, 2001]. Particularly, with no guarantee of pursuing a correspondence between the specified conceptualization and the real world, an ontology ends up as nothing more than a specification of the concepts in people's minds rather than an account of entities in reality.

Such a perspective conflicts with the strong position that, following the philosophical view on ontologies, defends that an ontology should refer to the very entities in reality instead of our concepts or knowledge about them [GUARINO, 1995; SMITH, 2004; GUIZZARDI, 2005]. This position comes from a perception of the benefits of anchoring ontologies in the *a priori* nature of reality as it exists beyond our concepts [GUARINO, 1995; SMITH, 2004].

Indeed, concepts are frequently useful tools for gaining cognitive access to the corresponding entities in reality [SMITH, 2004]. Some may even argue that the view of ontologies as simply specifying concepts is appropriate for computer systems since it defines the kinds and structures of the entities *that exist in the system* [SMITH; WELTY, 2001]. However, the lack of grounding in external reality can be a source of problems.

For example, suppose we have two agents that use the same vocabulary but with distinct conceptualizations underlying it. In this case, communication is only possible if the sets of intended models associated with their conceptualizations overlap [GUARINO, 1998]. Moreover, the better such models reflect the reality about which the agents need to talk, the easier their interaction will become [GUARINO, 1995]. Analogously, if we have systems with different conceptual models but overlapping semantics, we need to refer to the common world to which they relate in order to integrate them [SMITH; WELTY, 2001].

Besides that, since knowledge acquisition is a notoriously expensive task, it is advisable to maximize the reuse of its products. Thus, a knowledge specification acquires value *per se* to the extent in which it corresponds to the real world [GUARINO, 1995], for such common ground can enhance its potential for reuse.

Given the importance of such a link with reality, [GUARINO; GIARETTA, 1995] revises the notion of conceptualization to define it as an *intensional* semantic structure that encodes the implicit rules constraining the structure of a piece of reality. Further, [GUARINO, 1998] equates *conceptualization* to the philosophical reading of the term *ontology*, defining it as a particular system of categories accounting for a certain view of the world, which does not depend on a particular language. In other words, a conceptualization describes the set of all possible states of affairs considered admissible regarding a given domain [GUIZZARDI, 2005, p.82].

Then, based on both the revised account of conceptualization and the AI view of ontologies as artifacts, Guarino [1998] defines an *ontology* as a logical theory accounting for the intended meaning of a formal vocabulary by reflecting the ontological commitment of this vocabulary to a particular conceptualization of the world. Ideally, given a language L with a vocabulary V, an ontology O that determines the ontological commitment of V to a conceptualization C is a set of axioms designed in a way to constrain the set of models allowed by L[1] to the set of models accepted by C [GUARINO, 1998].

With that, ontologies can provide real-world semantics to such languages and resulting models [CARVALHO; ALMEIDA; GUIZZARDI, 2014], which can limit the possibility of stating something that is reasonable for the system but not reasonable in the real world [GUARINO, 1995]. Additionally, the ontological axioms allow inferring information not explicitly represented in the models [CARVALHO; ALMEIDA; GUIZZARDI, 2014]. This can facilitate knowledge integration, since, as stated in [GUARINO, 1994],

> "*while the choice of a particular axiomatisation is still up to the user, its consequences are formalised in such a way that another user can understand the meaning of the choice itself, and possibly agree on it on the basis of its semantics.*

Nevertheless, it may not be possible to find the right set of axioms, so that an ontology will usually admit some non-intended models and/or fail to admit some of the intended ones. Therefore, the purpose of an ontology is to approximate as best as possible the set of models allowed by a language to the set of intended models [GUIZZARDI, 2005, p.83]. That is to say, its goal is making the language allow as many as possible of the models we intend to accept as valid while rejecting as many as possible of the ones we consider invalid.

Further on that, paraphrasing [GUIZZARDI, 2005, p.94], an *ontology* is the representation, in a concrete artifact, of theories that describe knowledge about reality in a way that is independent of language, of particular states of affairs, and of epistemic states of knowledgeable agents. In this sense, it tries to characterize as accurately as possible the conceptualization it refers to and focuses on representation adequacy regardless of the

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[1] *I.e.,* a particular extensional interpretation of language L [GUIZZARDI, 2005, p.79].

consequent computational costs. In practical terms, it can be seen as a representational artifact, comprising a taxonomy as proper part, whose representations are intended to designate some combination of universals, defined classes, and certain relations between them [ARP; SMITH; SPEAR, 2015].

2.3 Situations

A *situation* is a particular configuration of a portion of reality that is understood as a whole [BARWISE, 1989; HERRE, 2010; GUIZZARDI et al., 2013; ALMEIDA; COSTA; GUIZZARDI, 2018]. Some works use the term situation exclusively to refer to instantaneous configurations of reality (*e.g.,* the health status of John at the time instant t) [HOEHNDORF, 2005; GUIZZARDI et al., 2013]. Others also use it to refer to entities that are prolonged in time and that can endure changes (*e.g.,* the situation of "John being sick", which extended itself for two weeks with different degrees of seriousness) [BARWISE, 1989; ALMEIDA; COSTA; GUIZZARDI, 2018]. Since we are investigating the nature of events as transitions, we adopted the view of ***situation*** as *an instantaneous, particular configuration of a portion of reality* so that we can highlight such a transition nature by contrasting distinct entities superseding one another at each time.

This configuration is given in terms of *states of affairs* (*SOAs*)[2] . SOAs are attributions about certain objects that describe them as bearing or failing to bear certain properties (intrinsic and/or relational) and/or as standing or failing to stand in certain formal relations [BARWISE, 1989; COSTA et al., 2006; GUIZZARDI; WAGNER, 2013; HERRE, 2010]. Moreover, the identity of a SOA is associated with the objects, properties, and relations it refers to, *i.e.,* two SOAs are identical iff they are attributions of the same properties and/or formal relations to the same objects. Thus, given a set Q of SOAs describing a set of objects O, a situation defined by Q is the configuration of the objects in O at a time t according to the description of the SOAs in Q. Moreover, given a situation s defined by a set of SOAs Q, we say that s supports every SOA q in Q. With that, we define the relations of inclusion and presence between situations and objects as follows:

Definition 1 ***includes***(s,x) $=_{def}$ *A binary relation between a situation* s *and an object* x *such that* s *supports a SOA* q *that refers to* x.

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[2] Several works use the term *infon* for referring to this notion, *e.g.,* [BARWISE, 1989; GINZBURG, 2005; HOEHNDORF, 2005; DEVLIN, 2006].

Definition 2 ***present_at***$(x,s) =_{def}$ *A binary relation between an object* x *and a situation* s *such that* $includes(s,x)$ *(*i.e., *the reverse of* $includes(s,x)$*).*

For example, given the objects a and b, we can have the SOAs q_1 such that "a is on top of b", q_2 such that "a is not larger than b" and q_3 such that "b is round". Then, we can have a situation s defined by q_1, q_2, and q_3 as "a is on top of b, a is not larger than b, and b is round at t". In this case, we say that s includes both a and b.

Each SOA refers to at least one object and one property (either intrinsic or relational), and each situation supports at least one SOA [HOEHNDORF, 2005]. Finally, for every consistent set of SOAs (*i.e.,* a set that does not contain contradictory SOAs, *e.g.,* describing an object as exhibiting contradictory properties), we have a possible situation defined by such a set (*i.e.,* a configuration of a portion of reality covering all and only the objects and properties referred by those SOAs) [HOEHNDORF, 2005; ZALTA, 1993; BARWISE, 1989].

2.3.1 Coincidence, Qualitative Equivalence, and Identity of Situations

Situations are instantaneous and exist only at a single time point. Thus, we can define the relation of temporal coincidence between situations as follows:

Definition 3 ***t-coincides***$(s_1,s_2) =_{def}$ *A binary relation between two situations* s_1 *and* s_2 *such that both* s_1 *and* s_2 *exist at the same time instant* t*.*

Besides that, we can define a relation of qualitative equivalence between situations in terms of the SOAs that define them as follows:

Definition 4 ***q-equivalent***$(s_1,s_2) =_{def}$ *A binary relation between two situations* s_1 *and* s_2 *such that both* s_1 *and* s_2 *are defined by the same set of SOAs.*[3]

Two situations are numerically identical iff they are both temporally coincident and qualitatively equivalent [ZALTA, 1993; HOEHNDORF, 2005; GUIZZARDI et al., 2013]. That is

Axiom 1 (Identity of Situations) $s_1 = s_2 \Leftrightarrow t\text{-}coincides(s_1, s_2) \wedge q\text{-}equivalent(s_1, s_2)$.

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[3] This relation is called informational equivalence in [BARWISE, 1989].

It is noteworthy that, with this criterion of identity, we can distinguish situations that are co-located in spacetime, but defined in terms of different attributes (*e.g.,* with differences in granularity or focus of their descriptions of a part of reality). We can also distinguish qualitatively equivalent situations that are bound to different time instants (*e.g.,* when things remain as they are from an instant to the next)

2.3.2 Mereology of Situations

In this work, we follow the view that situations may be part of other situations and that only situations can be part of other situations [ZALTA, 1993]. Particularly, a situation *s'* is part of a situation *s* iff both are temporally coincident and *s'* is defined by a subset of the set of SOAs that defines *s*. That is

Axiom 2 (Mereology of Situations) $\forall s,s'\ part\_of(s',s) \Leftrightarrow t\text{-}coincide(s',s) \wedge (\forall q\ supports(s',q) \Rightarrow supports(s,q))$.

2.4 Material Constitution

Constitution is the relation between something (which we will call *constituted individual*) and what it is made of (which we will call *constituent*) [EVNINE, 2011; GARCIA et al., 2019]. Among the different views regarding this notion, in this work we adopt the so-called *Constitution View* [WASSERMAN, 2017], more specifically as proposed in [BAKER, 2004; BAKER, 2007]. Moreover, we will focus on the case of material objects, resulting in the notion of *material constitution* [WASSERMAN, 2017; GARCIA et al., 2019] (which, in this work, for short, we will simply call *constitution*).

According to this view, constitution is an irreflexive, asymmetric, and transitive relation that is time-dependent, *i.e.,*x may constitute y at one time point, but not at another). Also, constitution is distinct from the relation of composition, *i.e.,* if x is part of y, then x does not constitute y, as well as if x constitutes y, then x is not part of y (axioms 3 and 4).

Axiom 3 (components are not constituents) $\forall x,y\ part\_of(x,y) \Rightarrow \neg constitutes(x,y)$.

Axiom 4 (constituents are not components) $\forall x,y\ constitutes(x,y) \Rightarrow \neg part\_of(x,y)$.

Besides that, Baker poses six main requirements for an individual to constitute another at a given time point, which we rephrase here as follows:

(1) The constituent and the constituted individual are instances of distinct primary kinds;

(2) The constituent and the constituted individual are spatially coincident, and the constituent can be spatially coincident to only one thing of the primary kind of the constituted individual at the time;

(3) There must exist a set of favorable circumstances that the constituent must meet for the constitution relation to exist;

(4) Whenever the constituent meets the favorable circumstances, the constitution relation must exist;

(5) There must exist a possible situation where the constituent is not constituting anything of the same primary kind as the constituted entity, that is, whenever it is not in favorable circumstances;

(6) Constitution only holds between things of the same basic kind of stuff (material things to material things, immaterial things to immaterial ones *etc.*).

This account of constitution is mainly grounded on the notions of *primary kind* and *favorable circumstances*. A *primary kind* is a universal that determines what the individual most fundamentally is, and every existing individual is an instance of exactly one primary kind. A primary kind is essential for its instances, *i.e.,* an individual cannot cease to be an instance of its primary kind without going out of existence. In addition, it determines a principle of identity for them, *i.e.,* a criterion to judge whether two instances of the type are numerically identical or not [GUIZZARDI, 2005]. Besides that, it also determines the persistence conditions for its instances, *i.e.,* the requirements for an individual to remain in existence or to cease to exist altogether (not just for being or ceasing to be an instance of a given type), with each primary kind defining its own corresponding set of persistence conditions. [4] Given that, it is precisely when a primary kind is instantiated that a new individual comes into existence. Moreover, ceasing to be of the primary kind is sufficient for the individual to cease to exist at all.

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[4] Given these features, primary kinds resemble substance sortals [GRANDY; FREUND, 2020], although the latter are associated with counting principles for their instances, while the former do not).

An example of a primary kind is *Person*. It is arguably an essential type for its instances, *i.e.,* a person cannot cease to be a person without ceasing to exist. Additionally, it provides an identity criterion for them (*e.g.,* depending on the adopted theory, personal identity involves some sort of psychological continuity [OLSON, 2021]) as well as further persistence conditions (*e.g.,* being alive). Primary kinds may be of various sorts, including types of functional complexes (*e.g.,* person, statue, spaceship), amounts of different types of material (*e.g.,* silver, marble, clay), regular collections (*e.g.,* an aggregate of atoms of gold, an aggregate of grains of sand), or even heterogeneous mereological sums (*e.g.,* a set of school supplies composed by a pencil, a rubber eraser, and a notebook). It is noteworthy that not all types are primary kinds, notably those that are not essential for its instances, such as the type *Student* since an individual can cease to be a student and remain existing as the very same person.

Favorable Circumstances represent the necessary and sufficient conditions for the establishment of a constitution relation between two individuals (requirements (3) and (4)). That is, favorable circumstances are a set of conditions F such that if we submit an individual x of a primary kind A to F, it makes the case that a distinct individual y of another primary kind B comes into existence without the x ceasing to exist. For example, the favorable circumstance for an aggregate of atoms of gold to constitute a portion of gold is their sharing of detached electrons to establish a metallic bond.

Favorable circumstances are also contingent conditions (requirement (5)). Therefore, if an instance x constitutes y at time t_1 by virtue of being submitted to a set of favorable circumstances F, it must be possible for x not to be in the circumstances F. This implies that it must be possible that x does not constitute y at some other time. For instance, the favorable circumstances for an amount of gold g to constitute a ring r include being solid and being molded in an annular shape. Both of them are contingent conditions since it is always possible for a goldsmith to melt g down and/or reshape it in a different manner, *e.g.,* to make a pendant.

The constituent is spatially coincident with only one thing of the primary kind of the constituted individual during the time the constitution relation holds (requirement (2)). With that, for every primary kind A, any object x can be the constituent of at most one individual of type A at a time. Despite that, x can be the constituent of different individuals of a primary kind at different times. For example, an amount of clay c can constitute a statue s_1 at t_1 and a different statue s_2 at t_2 after the smashing of s_1 and reshaping of c.

Besides, the constituent may vary in time so that an individual y can be constituted of an individual x at a time t_1 and constituted of a distinct individual w at time t_2. As an illustration, the biceps muscle of a person p is constituted of different collections of cells during the lifetime of p.

Even so, as asserted in axioms 3 and 4, for every object x composed of proper parts $[p_1, ..., p_n]$, none of such parts is a constituent of x. For example, *e.g.,* given a table formed by four wooden legs directly fitted in a tabletop, the table is not constituted of the top and constituted of each of the legs. Instead, it is constituted of the aggregate of top and legs, which is in the table-favorable circumstances of being assembled in a particular way [BAKER, 2007, p.188,193].

Different individuals of a given primary kind may have constituents of diverse primary kinds, *e.g.,* a statue may be constituted of an amount of clay, or an amount of marble, or an amount of gold, or an aggregate of amounts of various types. There may be different sets of favorable circumstances for each different type of potential constituent. For instance, the circumstances for an amount of matter to constitute a statue include being in a solid state and maximally self-connected; for an aggregate of amounts of different types to constitute a statue, the circumstances also include a connection between such separate amounts. The primary kinds of a constituted individual and that of its constituent are in different ontological levels (*i.e.,* levels of reality), being, respectively, lower- and higher-level types in relation to each other.

Finally, constitution is a relation that stands between two individuals by virtue of their primary kinds. Thus, the possible spatial coincidence of an individual of a primary kind (*e.g.,* a person) and an individual of a non-primary kind (*e.g.,* a student) is not a matter of the first constituting the latter by being in certain favorable circumstances. Rather than that, it is just a case of the first contingently instantiating the non-primary kind in virtue of acquiring certain properties to fulfill its criterion of application (*e.g.,* being enrolled in an educational institution).

2.4.1 Derivative and Non-Derivative Properties

Even though constitution is not identity, a constituted object may borrow some properties of its constituent and vice versa during the time the constitution relation holds [BAKER, 2007, p.37-38]. Then, according to Baker, there are two ways in which an object can have a property: it may have the property *non-derivatively*, *i.e.,* independently of its constitution relations, or *derivatively*, *i.e.,* in virtue of a constitution relation to something that has the property non-derivatively [BAKER, 2007, p.166-169].

For example, a dollar coin is constituted of a portion of a certain alloy cut in a circular shape. Thus, such a coin non-derivatively has the property of being worth one dollar while it derivatively has the properties of having a certain weight and being circular in shape; conversely, the portion of alloy non-derivatively has the properties of having a certain weight and being circular, but derivatively has the property of being worth one dollar.

As another example, we can take a portion of gold constituted of an aggregate of atoms of gold when metallic bonds are tying together such atoms. The portion of gold has its mass derivatively, borrowed from the underlying aggregate of atoms (*i.e.,* its mass is simply the sum of the masses of each of the atoms). In contrast, the portion of gold non-derivatively has the properties of electrical conductivity and malleability since such properties only arise when the aggregate of atoms is constituting a portion of gold (*i.e.,* when a metallic bond gathers the atoms).

A last remark is that certain types of property cannot be had derivatively, such as those that are rooted outside the times they are had, which includes historical properties (*e.g.,* "*having been recovered from an ore mine*" may be a property of a portion of gold, but not of the gold ring it is constituting now).

2.5 Dispositions

Dispositions are particularized properties that inhere in and are specifically dependent on particular objects (*i.e.,* the bearers of the dispositions), to which we usually broadly refer as potentialities, propensities, capacities, capabilities, tendencies, liabilities, and so on [CHOI; FARA, 2018; BARTON; JANSEN; ETHIER, 2017; GUARINO; GUIZZARDI, 2016; GUIZZARDI et al., 2013; GUIZZARDI; WAGNER, 2013; RöHL; JANSEN, 2011]. These properties have the distinctive feature of presenting characteristic manifestations under some stimulus conditions [GUIZZARDI; WAGNER, 2013; CHOI; FARA, 2018]. With that, dispositions are associated with two types of events.

- ***Triggering Event***. An event that brings about a situation gathering the stimulus conditions needed to activate some disposition [TOYOSHIMA; BARTON, 2018; GUIZZARDI; WAGNER, 2013; GUIZZARDI et al., 2013; RöHL; JANSEN, 2011].

- ***Realization/Manifestation Event***. An event in which the disposition is manifested and that has its bearer as a participant [TOYOSHIMA; BARTON, 2018; BARTON; JANSEN; ETHIER, 2017; GUIZZARDI; WAGNER, 2013; GUIZZARDI et al., 2013; RöHL; JANSEN, 2011].

A prototypical example is that of the fragility of a piece of glass, *i.e.,* the disposition to break in response to being struck [BARTON; JANSEN; ETHIER, 2017]. In this case, the triggering event would be that of striking the glass, which brings about a situation that gathers the required stimulus conditions, *i.e.,* a hard object exerting pressure over the glass. Then, this situation would lead to the corresponding realization/manifestation event, that is, the breaking of the glass. Other typical examples of dispositions are the solubility of a chemical substance (*i.e.,* the disposition to dissolve when put in some other substance, *e.g.,* the solubility of salt in water) and magnetic attraction of magnets (*i.e.,* the disposition to attract certain metals and unlike poles of other magnets within a certain distance) [GUIZZARDI et al., 2013; BARTON et al., 2018; TOYOSHIMA; BARTON, 2018; RöHL; JANSEN, 2011]. Dispositions have also been used to formalize diseases, risks, and probabilities [BARTON; JANSEN; ETHIER, 2017].

Dispositions may be either *single-track* or *multi-track.* A *track* is a pair composed of a type of triggering event for a disposition and a corresponding type of manifestation. Thus, a disposition is single-track if it is triggered by events of a single type and manifested in events of only one type as well. For example, we can regard *solubility* of salt in water as a single-track disposition triggered only by putting salt in contact with water and manifested only by the breaking of the ionic bonds that hold chloride and sodium ions of the salt.

Conversely, a multi-track disposition can be triggered by more than one type of event and can be manifested in events of different types too. For instance, the disposition of *fragility* may be construed as a multi-track disposition. Under this account, it may be triggered by a *light struck* event that will lead to a *cracking* event as manifestation, or it may be triggered by a *heavy struck* event that will lead to a *breaking* event as manifestation.

It is a common view that the stimulus conditions for a disposition include some object external to the bearer of the disposition. In other words, the stimulus conditions for a disposition d inhering in an object x include some object y that is external to x and that bears some property that matches d [BUNGE, 1977, p.180], such that y roughly corresponds to what is called “reciprocal dispositional partner” [MARTIN, 2008, p.53].

Additionally, the stimulus conditions include some relationship between x and y so that the matching properties can be exposed to each other (*e.g.,* it is not simply an allergenic substance that triggers an allergic reaction in a patient, but the exposure – by physical contact, for example – between the patient and the allergen) [RöHL; JANSEN, 2011; MARTIN, 2008; BUNGE, 1979].

Still, the triggering event of a disposition may also be internal to the bearer of the disposition [ARP; SMITH; SPEAR, 2015, p.101], which does not involve any object other than the bearer of the disposition (*e.g.,* particle decay, an alarm clock ringing due to the interaction of its components). That is, there may be dispositions whose stimulus conditions do not include any object external to the bearer. Throughout this work we will only consider dispositions activated by the interaction of their bearers with external objects. We will discuss this limitation in chapter 8.

Dispositions exist due to the physical makeup of their bearers [ARP; SMITH; SPEAR, 2015, p.178]. Further, a disposition exists in virtue of a non-dispositional property (or sum of such properties) of the disposition bearer that is called the *categorical basis* [BARTON et al., 2018] or *causal basis* [PRIOR; PARGETTER; JACKSON, 1982] of the disposition. It is such a categorical basis together with the required stimulus conditions that constitute the causally operative sufficient conditions for the manifestation of the disposition [PRIOR; PARGETTER; JACKSON, 1982]. For example, the molecular structure of a piece of glass is the categorical basis of its fragility – that is, it is by virtue of having such a molecular structure that the piece of glass is disposed to break in response to being struck.

Also, dispositions are usually seen as distinct from their categorical basis since the same property (or sum of properties) can be the categorical basis of distinct dispositions (*e.g.,* the arrangement of electrons in a piece of glass is the categorical basis of both its electrical resistivity and its transparency for visible light) [BARTON et al., 2018; PRIOR; PARGETTER; JACKSON, 1982]. Besides that, dispositions of the same type may have categorical bases of various types (*e.g.,* an object may be fragile due to its molecular bonding whereas another may be fragile due to its crystalline structure) [RöHL; JANSEN, 2011; PRIOR; PARGETTER; JACKSON, 1982].

Given those features, dispositions are realizable entities [BARTON; JANSEN; ETHIER, 2017] that may or may not be manifested or even triggered [BARTON et al., 2018; GUIZZARDI; WAGNER, 2013; GUIZZARDI et al., 2013; MARTIN, 2008], but that are still present even if never manifested [BARTON; JANSEN; ETHIER, 2017] (*i.e.,* the fragility of a piece of glass is present even if the glass is never struck and/or never breaks). Moreover, given their relation to possible realization events, dispositions are causal properties [BARTON et al., 2018; RöHL; JANSEN, 2011] relevant for and causally explanatory of the events involving their bearers [RöHL; JANSEN, 2011; GUIZZARDI; WAGNER, 2013].

By this means, dispositions determine the behavior that their bearers will show under certain circumstances [TOYOSHIMA; BARTON, 2018; RöHL; JANSEN, 2011]. With that, dispositions are entities that link the static structure of the world, *i.e.,* the objects that populate it, to its dynamical structure, *i.e.,* the events that can happen to or be performed by such objects [RöHL; JANSEN, 2011].

2.5.1 Mereology of Dispositions

According to [MARTIN, 2008, p.142], dispositions can be complexes of simpler dispositions. This is reflected in the theory of disposition parthood proposed in [BARTON; JANSEN; ETHIER, 2017], for which a complex disposition is a disposition that has some proper disposition part. These complex dispositions follow some constraints:

- The bearer of a disposition part is always a (proper or improper) part of the bearer of the whole complex disposition;
- If a complex disposition is manifested in an event, then at least one of its proper disposition parts is manifested in a part of this event;
- If a complex disposition is triggered, then at least one of its proper disposition parts is also triggered.

On top of that, [BARTON; JANSEN; ETHIER, 2017] presents some special types of disposition parthood. In *mod-parthood*, the complex disposition (*i.e.,* a *mod-complex*) is composed of disposition parts (*i.e., mod-parts*) that correspond to distinct modes through which the *mod-complex* can be manifested. For instance, the ferromagnetic disposition of a magnet is composed of its dispositions to attract unlike poles and to repel like poles of other magnets [BARTON; GRENIER; ETHIER, 2018]. A mod-complex is manifested in an event iff at least one of its mod-parts is manifested in such event. Analogously, a mod-complex is triggered in an event iff at least one of its mod-parts is triggered in such an event.

In *add-parthood*, the complex disposition (*i.e.,* an *add-complex*) is composed of disposition parts (*i.e., add-parts*) whose parallel manifestations compose the manifestation of the whole add-complex. *e.g.,* the solubility of a tablet composed of two halves is composed by the solubilities of both halves of the tablet. If an add-complex is manifested in an event, then each of its add-parts is manifested in a part of such event (*e.g.,* the solubility of the tablet is only manifested if both of its halves are dissolved). Likewise, if an add-complex is triggered by an event, then each of its add-parts is triggered by a part of the event. Finally, for any two dispositions d_1 inhering in b_1 and d_2 inhering in b_2 there is an add-complex d_1+d_2 that inheres in b_1+b_2.

In *chain-parthood*, the complex disposition (*i.e.,* a *chain-complex*) is composed of disposition parts (*i.e., chain-parts*) in such a way that the manifestation of one of its chain-parts triggers another chain-part, creating a causal chain. For example, the *warning ability* of a fire alarm system, *i.e.,* its disposition to set off when smoke is detected, is a chain-complex. The chain-parts that compose it are the alarm's *detecting ability* disposition to produce an internal electrical signal when detecting smoke and its *alarm ability* disposition to emit a loud sound when an internal electrical signal is produced.

Similarly to add-complexes, if a chain-complex is manifested by an event, then each of its chain-parts is manifested in a part of the event. For example, *warning ability* is manifested only in case of the chained manifestation of *detecting ability* and *alarm ability*). In contrast, the triggering event of a chain-complex is the event that triggers one of its chain-parts (arguably, one that is earlier in the causal chain) – *e.g.,* triggering an alarm's *warning ability* boils down to triggering its *detecting ability*. Also dissimilarly to add-parthood, given two dispositions d_1 inhering in b_1 and d_2 inhering in b_2, there is a chain-complex d_1+d_2 inhering in b_1+b_2 only if the class of manifestations of d_1 has as part the class of triggers of d_2.

A further interesting case of complex disposition is the causally equivalent sum of reciprocal dispositions. *Reciprocal dispositions* can be seen as two associated dispositions such that one of them can be manifested only if the other is also manifested in the same event [ARP; SMITH; SPEAR, 2015]. Barton and colleagues [2020] characterize a pair of reciprocal dispositions as two dispositions that are (1) triggered by exactly the same events, that are (2) manifested in exactly the same events, and (3) whose bearers have no common part. A popular example is the disposition d_{key} of a certain key key to open a certain lock $lock$ being reciprocal to the disposition d_{lock} of $lock$ to be opened by key.

Given that, the *causally equivalent sum* of two reciprocal dispositions is an add-complex that has such reciprocal dispositions as add-parts and that inheres in the mereological sum of their bearers [TOYOSHIMA; BARTON, 2018]. Taking again the previous example, the causally equivalent sum of dispositions d_{key} and d_{lock} is the complex disposition d_{key}+d_{lock} that inheres in the object *key+lock*. It is noteworthy that the causally equivalent sum and each of its disposition parts have the same triggering events and the same manifestations, but distinct categorical basis.

2.6 Systems

A *system* is a complex object composed of at least two interrelated components forming an integrated, unitary whole, rather than a mere aggregate of loose things [BUNGE, 1979, p.4] [BERTALANFFY, 1968] [ACKOFF, 1999, p.5,8] [BACKLUND, 2000] [SKYTTNER, 2021, p.53] [KLIR, 2001, p.4]. For instance, a molecule, a human body or a text are systems, whereas a random sample of a biological population and a random collection of words are not. Moreover, there are no independent subcollections of components in a system, in the sense that there is a path from every component of the system to every other component through their relationships [ACKOFF, 1999, p.7] [BACKLUND, 2000].

In general, systems are part of other larger systems and are included in a hierarchy of systems [SKYTTNER, 2021, p.60]. This hierarchy can be viewed as a structure of nested systems, each of them being a subsystem of a higher, larger system (*i.e.,* its supersystem) [BUNGE, 1979, p.12]. Case in point, a hunting pack of wolves is a supersystem that has each of such wolves as a subsystem.

Systems can also be interrelated when in a multilateral structure, *i.e.,* when there is some object that is a component of more than one system simultaneously [SKYTTNER, 2021, p.64].

2.6.1 Concrete Systems

Our focus in this work is on what is called *concrete system*[5], *i.e.,* a system composed of material objects [BUNGE, 1979] (which we will simply call '*system*' throughout this document). In this case, components of a system are not linked by mere relations (*e.g.,* being larger than). Instead, they are linked by what we will call *connections*, *i.e.,* rela-

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[5] Sometimes also called physical system [SKYTTNER, 2021, p.55]

tionships through which (at least) one of the relata affects the behavior of the other (*e.g.,* exerting pressure) [BUNGE, 1979; BERTALANFFY, 1968].

Here, affecting the behavior of a connected object does not mean causing it to perform or undergo some event, but may simply consist in changing the way the object will behave given certain circumstances. In this sense, the existence of a connection between objects a and b implies cutting out or opening up certain possibilities for a and/or b, modifying their/its behavior trajectory or history [BUNGE, 1979], so that their/its behavior is different from that they would exhibit if they were not in such connection [BERTALANFFY, 1968, p.55-56].

With that, the behavior trajectory of the whole system differs from the union of the histories of its isolated components. More than that, it is this interdependence of behaviors that characterizes systems and grants them their emergent properties, which are not shared by any of its components, either individually or in aggregation [MIETTINEN, 2008; BUNGE, 1979] [ACKOFF, 1999, p.8].

2.6.2 Aspects of Systems

Three main facets characterize a system: a definite *composition*, a definite *immediate environment*, and a definite *structure* [BUNGE, 1979; SKYTTNER, 2021]. *Composition* is the collection of components of the system [BUNGE, 1979], *i.e.,* the collection of interrelated objects that compose the system. These components can be systems themselves [BACKLUND, 2000] (*e.g.,* a human eye is a system in itself and it is also part of a human body, which is another, larger system).

Immediate Environment is the collection of objects (*i.e.,* the elements of the immediate environment) that are connected to components of the system or to the system itself as a whole, but that are not themselves components of the system [BUNGE, 1979, p.4,9]. In other words, the immediate environment of a system is the next higher system minus the system itself [SKYTTNER, 2021, p.59]. Along with that, the *Extended Environment* of a system includes every object that is not a component of the system, regardless of its connection with the system or its components. Finally, the environment of every system includes further systems, and every new system is assembled from units supplied by the environment [BUNGE, 1979, p.32-33]. For brevity, throughout the text we will refer to the immediate environment of a system simply as its *environment*, using *extended environment* when appropriate.

Structure comprises the connections and other relationships among the components of the system as well as between these and elements of the environment [BUNGE, 1979]. The structure of a system may include relations of more than one type [BACKLUND, 2000]. We can also distinguish the *internal structure* of a system, *i.e.,* formed by the relations among the system components, from its *external structure*, *i.e.,* formed by the relations between system components and elements of the environment [BUNGE, 1979, p.10].

It is also noteworthy that what could be part of a system depends very much on what relationships are considered [BACKLUND, 2000]. To illustrate this, imagine the security system of a building: if we only consider electrical connections, the system would only include things such as cameras, wires, and monitoring panels; if we also consider certain social connections and commitments, guards would also be components of the system. Thus, as a last remark, although those are important facets for the definition of a system, it is not always clear what the composition of a system is and, consequently, what its environment would be [BUNGE, 1979, p.8].

2.6.3 Open and Closed Systems

Systems are usually classified as either *open* or *closed* systems, although this distinction can be based on diverse criteria. In [BERTALANFFY, 1968, p.141], a system is said to be open if it exchanges matter with its environment by means of importing and exporting, as well as building up and breaking down of its material components – otherwise, it is said to be closed. For [ACKOFF, 1999, p.7], a system is open if it requires certain environmental conditions in order to carry out its defining function and is closed if it can carry out its function completely independent of the environment it is in.

According to [BUNGE, 1979, p.9,10] a system is open iff it can affect the behavior of some element of its environment or vice-versa, *i.e.,* iff there is some connection between the system or its components and elements in the environment. Let us consider a system s, its environment e, and a type of property P. Then, s is open in respect to P at time t iff, at time t, some component of s (or s itself) is connected to some element of e through an instance of P; otherwise, s is closed in the respect P at t [BUNGE, 1979, p.10,17,18]. Given that, a system can be open or closed in different respects depending on the types of connections it has with its environment. *E.g.,* a system may be open to the influence of gravity (*e.g.,* by virtue of some connection exposing its mass to the mass of some element of the environment) but closed to electrical influence (*e.g.,* for the absence of connections exposing its electrical charge to elements of the environment).

It is notable that, to some extent, the later (Bunge's) criterion apparently generalizes the previous ones. For example, a system that is open for importing/exporting matter is one whose external structure includes connections that allow the exchange of matter between the system and its environment. Hence, if we consider that such connections are associated with certain properties of their relata – in special, with properties of the system components –, then the issue of being open to the exchange of matter boils down to the issue of being open with respect to such properties.

As another example, a system that is open in the sense of depending on environmental conditions to "work" seems to be a system that needs environmental elements to provide stimulus conditions for activating certain dispositions of its components. In this case, we can view the system as open with respect to those dispositions.

3 RELATED WORK

In this chapter, we review some ontological accounts of events focusing on the aspects related to the problem we propose to treat in this work. First, we examine different proposals about the nature of events and then we examine the support for events in some foundational ontologies.

3.1 What Events Are

Events are usually defined as things that happen (or occur or take place) in time, involving continuants as participants. This is a customary view both in Philosophy (*e.g.,* [CASATI; VARZI, 2020; BENNETT, 2002; CRESSWELL, 1986; HACKER, 1982; BUNGE, 1977; KIM, 1976; DAVIDSON, 1969]) as well as in Formal Ontology (*e.g.,* [RODRIGUES; ABEL, 2019; BORGO et al., 2016; ARP; SMITH; SPEAR, 2015; GUIZZARDI et al., 2013; GANGEMI et al., 2002]). Additionally, events are often regarded as entities that persist by having different temporal parts (sometimes called *stages*) at different times, which entails that an event is only partially present at any time instant it is present since some of their proper parts (e.g., past or future stages) will not be present [CASATI; VARZI, 2020; MASOLO et al., 2003].

As a consequence, it is also broadly understood that events cannot change in time [GUIZZARDI et al., 2013; GANGEMI et al., 2002]. Thus, if an event seems to present some property at a time and another incompatible property at a later time, it is not the case that the event has changed – it is just two different temporal parts of it exhibiting different properties. For example, if a talk is boring during its first half and becomes interesting later on, the talk suffered no change, it was always the same: a talk whose first half is boring and whose last half is interesting.

Another prevalent position is the *particularist* view of events, according to which they are spatiotemporally locatable, particular, unrepeatable entities [BORGHINI; VARZI, 2006; BENNETT, 2002; SAVELLOS, 1992; LOMBARD, 1979; BRAND, 1976; DAVIDSON, 1969]. Opposed to that, we have an *universalist* view of events, *e.g.,* in [CHISHOLM, 1970], according to which what particularists would regard as individual occurrences of a given event type would be reduced to the very same (universal) event occurring at different times. In this work, as in several foundational ontologies for events (*e.g.,* UFO, DOLCE, BFO), we adopt a particularist view of events.

Along with that, events are commonly viewed as entities directly related to time and derive their spatial characteristics from the objects that participate in them [BORGHINI; VARZI, 2006; QUINTON, 1979; KIM, 1976]. Moreover, it is also common the view that, although events happen at a place in space, they do not fill such a space so that it is possible to have two distinct events happening to the same substance at the same time and place (*e.g.,* a sphere simultaneously rotating and heating up) [BENNETT, 2002; LOMBARD, 1998; HACKER, 1982]. In this case, they simply consist of one object suffering two distinct changes at the same time [LOMBARD, 1998; HACKER, 1982]. This is the view we adopt in this work.

For the sake of completeness, it is worthy to mention the divergent position is adopted by Quine [QUINE, 1960, p.156], who regards an event as "*the content, however heterogeneous, of some portion of space-time, however disconnected and gerrymandered*". Under this perspective, an event completely fills the space it occupies and, then, at most one event can occur in a given place and time. For some criticism about this view see [LOMBARD, 1998, p.283-284].

In summary, in this work, we regard events as particular entities that happen in time involving continuants as participants and such that distinct events can happen to the same participants at the same spatiotemporal region. Still, this view leaves some open issues. In particular, defining events as *things that happen* seems to simply move the task of defining what events are to the problem of clarifying what it is to *happen* [CASATI; VARZI, 2020]. Some accounts go further on this issue and, among them, we identify two non-exclusive, complementary views that shed some light on the happening nature of events, which we will call the *transition view* and the *manifestation view* of events. We present such views in the following sections.

3.2 The Transition View of Events

We regard the *transition view* of events as the idea that events are transitions through successive snapshots of reality (sometimes referred to as states, states of affairs, situations, and similar terms). This view permeates several works in different degrees of explicitness.

Some of them are very clear about that. In [GUIZZARDI et al., 2013], an event is a transformation of a portion of reality from one situation to another. In [BENEVIDES; MASOLO, 2014] an event is considered to correspond to a set of states that exist at different times, grouped according to some definitory unity criterion, being viewed as a trajectory across such states. For [BARWISE; PERRY, 1983, p.56], every event can be seen as corresponding to a course of events (*i.e.,* a set of states of affairs, each assigned to a distinct spatiotemporal location).

In other cases, the transition view lies in a frequent association between the notion of event and that of change, regarded as the replacement of one (static) property[1] of a (concrete) object by another (or the acquisition/loss of such a property by the object) [LOMBARD, 1998; HACKER, 1982; QUINTON, 1979; KIM, 1976; DAVIDSON, 1969]. Here we can apprehend the transition view from the contrast between the different properties of the involved object at different times. In some cases, it is even referred to as a transition from the object having one to having another property [LOMBARD, 1998], a transition or transformation between states of the changing object/thing [BUNGE, 1977, p.221] [HACKER, 1982] or the replacement of one state by another [QUINTON, 1979]. It is also described as the moving of an object through a quality space[2] [LOMBARD, 1998] or as a trajectory in the state space of changing things [BUNGE, 1979, p.22]. It is also worthy to note that, despite this association between events and changes, several works also include *unchanges* (*i.e.,* the permanence of certain static conditions over time) into their inventory of events (*e.g.,* [GUARINO; GUIZZARDI, 2016; QUINTON, 1979; BUNGE, 1977; KIM, 1976]), while others do restrict events to changes (*e.g.,* [LOMBARD, 1998]).

Besides that, the transition view also seems to fill a role in the interplay between the experiential and historical perspectives of the world. According to [GALTON, 2008], the experiential perspective describes the world as we experience it at each instant, *i.e.,* a world that constantly changes from one snapshot to the next. Thus, this perspective concerns entities that are fully present at each time they are present and that can change in time. In other words, it concerns entities that exhibit characteristics typically associated with continuants.

Conversely, the historical perspective depicts a historical record of the world, comprising the succession of instantaneous experiential snapshots (*i.e.,* the sequences of changes in the experiential world from one snapshot to another). Hence, the historical perspective encompasses entities that are extended in time by having temporal parts

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[1] Static property is here understood as a property whose possession by an object does not imply that the object has changed, is changing, or will change [LOMBARD, 1998, p.290,293]

[2] Quality spaces are here understood as classes of static properties such that all the members of a given class will be contraries [LOMBARD, 1998, p.289-290]

and that cannot themselves undergo change. In other words, it encompasses the events that are built up out of sequences of snapshots of the world (which reveals an underlying transition view of events).

3.2.1 Experiential Changes in Events and the Transition View

The divide between these two perspectives has been employed to deal with the problem of apparent change in ongoing events from the experiential point of view (*e.g.,* a battle can become fiercer, the speed and direction of a flight can change, the score of a soccer match can be increased) [GALTON; MIZOGUCHI, 2009; GALTON, 2016; GUARINO, 2017]. As pointed out in [GALTON; MIZOGUCHI, 2009, p.7], "*in order for there to be change, there must be something that does not change*", that is, for an entity to undergo a change from an instant to another such an entity (the subject of change) must remain the same at the two times, *i.e.,* keeping its identity in face of changes in its accidental properties. Thus, in order to account for events that undergo change, the experiential perspective must include some corresponding entity to be the bearer of such a change. Different approaches were adopted for that and give us further insight into the nature of events as transitions.

In [GALTON; MIZOGUCHI, 2009], the authors resort to the notion of *process*. It is a special type of *occurrent*[3] that is entirely present within a temporal window large enough to encompass the minimal amount of change required to characterize the going on of the process. *e.g.,* for the process of *walking*, the size of the temporal window is the interval needed for a sequence of two steps, one with each leg. This temporal window continuously moves forward in time, framing sequential intervals. At each of these intervals we have a different stage in the lifetime of the process.

Thus, such processes can change in time (*e.g.,* a person can change the speed or the direction of the walking) and, in some respects, it is more similar to continuants than to occurrents (being even referred to as *continuant-like processes* [GALTON; MIZOGUCHI, 2009; GALTON, 2016]). Moreover, given an appropriate temporal granularity, the temporal window can be seen as points in the temporal line. Therefore, along with traditional continuants, these processes are included among the entities concerned by experiential perspective, rendering the snapshots of the world as inherently dynamic

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[3] In their terminology, occurrent refers to the topmost category of things that happen, corresponding to the notion of event employed in this work.

(*i.e.,* with processes present here and now) [GALTON, 2016].

Complementarily, this account also includes another type of occurrent, disjoint from processes, which they call *event*. Whereas a process can be seen as ongoing stuff, an event is a temporal individual with definite beginning and ending points. With that, it is said that events are constituted of processes. The simplest type of event can be seen as a mere chunk or an episode of some process, *i.e.,* a process beginning, going for a while, and then stopping. For example, the event of a *walk* can be seen as a chunk of *walking*, with someone starting to walk, walking for a while, and then stopping walking. Most events are more complex than that, involving structured sequences of distinct chunks of process (*e.g.,* a journey composed of episodes of walking intercalated with episodes of resting).

As we have seen, in [GALTON; MIZOGUCHI, 2009] we have *processes* as surrogate entities that are the subject of the apparent change in *events* (*i.e.,* in occurrents that are not processes). In [GUARINO, 2017] we find a distinct approach in respect to changes in *events* (understood as the topmost category of entities that happen in time). Guarino proposes that, from the experiential point of view, ongoing and future events do themselves change. To achieve that, he resorts to the notion of variable embodiment.

A *variable embodiment* is an entity that can undergo a replacement of its constituting material or of its parts while keeping its identity [MOLTMANN, 2020, p.369, 370]. With that, it may have different material manifestations at different times, having properties derivatively from such manifestations [MOLTMANN, 2020, p.369, 370, 371][4]. Thus, it is associated with a *variable embodiment principle* that determines which is the material manifestation of the variable embodiment (*i.e.,* the matter that constitutes it) at each time instant [FINE, 1999, p.69] [MOLTMANN, 2020, p.370]. Such a principle may involve various conditions, such as shape and spatiotemporal continuity [MOLTMANN, 2020, p.372]. Organisms and artifacts are typical examples of variable embodiments (*e.g.,* a human body is constituted of different collections of cells at different times; a car may have some components replaced during its existence) [FINE, 1999, p.61, 69] [MOLTMANN, 2020, p.370].

Although the notion of variable embodiments is usually applied to material objects, Fine [FINE, 1999, p.72] suggests that events may also be taken to be variable embodiments, whose successive manifestations are the different stages of the event. With that, Guarino defines ongoing and future events as variable embodiments, so that they can

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[4] Which is in line with the idea that a constituted individual has properties derivatively based on its constituent at the time [BAKER, 2007, p.166-169], as discussed in section 2.4.

change by *embodying* distinct temporal parts as time passes by, which accumulate with the previously embodied parts.

A third approach is brought by Galton [GALTON, 2016; GALTON, 2018], proposing that processes are not themselves occurrences, but rather abstract patterns of occurrence that are concretely realized as particular occurrences. More precisely, from the experiential perspective, a process is realized, at a given instant, as an instantaneous state, given by the values of the attributes of the involved objects at each time. Conversely, from the historical view, a process is realized over a time interval as a discrete, temporally delimited event corresponding to a succession of the referred instantaneous states. For instance, we can take the process of someone's *walking* as a pattern of movement of body parts that results in an overall forward movement of the body. From the experiential point of view, it is realized as successive instantaneous *walking states* (*i.e.,* the characteristic spatial arrangement and state of motion of the person's body parts when walking). Complementarily, from the historical point of view, the process is realized as a discrete event consisting of someone's starting walking, walking for a while, and then stopping.

Patterns can be either open or closed [GALTON, 2016; GALTON, 2018]. A pattern is open when its specification contemplates its repetition character (*i.e.,* specifying a motif that is repeated when the pattern is realized) but does not include any criterion to bind its realizations (i.e, the pattern can ideally be extended indefinitely in a single realization, with the boundaries being imposed from outside). An example of an open pattern is a wallpaper in which some geometrical figure is continuously repeated along the paper until the borders of the wall (which impose the boundaries for the repetition). In contrast, a pattern is closed when it specifies an arrangement of components and the boundaries of such arrangement (*i.e.,* it is part of the specification of the pattern directions on how to define the limits of a realization), but repetition is not intrinsic to the pattern (*i.e.,* the pattern just specifies a single unit and repetition comes from multiple realizations of the pattern). An example of a closed pattern is a product specification, which specifies the arrangement of the parts that compose a unit of the product, that could be repeatedly concretized in several units.

Consequently, there are two types of processes [GALTON, 2016; GALTON, 2018]. An *open process* is an open pattern of occurrence that specifies a motif to be repeated over time when it is realized, but that does not specify how its realizations should be temporally bounded. Thus, a realization of it could ideally be continued in the same way indefinitely, being terminated by external factors. *Walking*, for instance, is an open process consisting in the repetition of alternate swings of the legs and that terminates due to external factors that are not part of the specification of the process (*e.g.,* the walker getting tired or arriving at the desired destination). Analogously, a closed process is a *closed pattern* of occurrence that specifies a structured, finite sequence of activities that lead to a completion. An example of a closed process is that of *filling an application form* since it specifies a structured sequence of activities (*i.e.,* filling a field, then another, and so on) with an intrinsic criterion of termination (*i.e.,* the realization of the process ends when the form is filled).

3.3 The Manifestation View on Events

The *manifestation view* of events comes from the idea that potency is prior to act and that actuality is the unfolding of potentiality, such that the disposition (in the sense of possibility) to do x is then prior to doing x [BUNGE, 1977, p.180, 183]. With that, the potentiality of an event happening must exist as concrete properties of continuants [GUIZZARDI; GUARINO; ALMEIDA, 2016]. Therefore, we can say that events are manifestations (or realizations) of such potentiality that inheres in objects in the form of dispositions (in the sense exposed in section 2.5).

This view is present when regarding events as manifestations of dispositions or other individual qualities of their participants [GUIZZARDI et al., 2013; GUARINO; GUIZZARDI, 2016]. It also seems related to the ‘property exemplification account’ of events, according to which events are the exemplifying of properties by objects at a time [KIM, 1976; LOMBARD, 1998], which could be understood as the manifesting of such properties. This is especially evident when events of change are described in terms of an object exemplifying some ‘dynamic property’, *i.e.,* that implies changes in the object (*e.g.,* fading in color, falling, and freezing) [KIM, 1976; LOMBARD, 1998], rather than in terms of a transition of successive snapshots.

There is a remarkable association between the transition and the manifestation views, which is beautifully captured by Guizzardi and colleagues [GUIZZARDI et al., 2013]: “*These events considered here, as manifestations of dispositions, change the world, by mapping one situation to another. Situations that are brought about by the manifestation of dispositions and can activate other dispositions, making the world ‘tick’*”. Then, we could say that, while the transition view reveals *what* happens (*i.e.,* things were in a given configuration and now they are configured in another way), the manifestation view reveals *how* it happens, *i.e.,* by the meeting of disposition and its stimulus conditions, resulting in the new configuration of the involved participants).

3.4 Unifying Criteria for Events

As stated in [BENEVIDES; MASOLO, 2014], if we consider an event to correspond to a set of snapshots of a part of the world at successive times, there must be a unity criterion to gather such snapshots. Complementarily, there must be an analogous unifying criterion to gather certain objects as participants of the event at each time, which would be those included in the snapshot at the time. There are some alternative approaches to provide this unifying criterion.

In [QUINE, 1960, p. 156], an event is defined as the whole content of a region of space-time, no matter how disconnected and arbitrarily cut this region may be. Interpreting this definition under the transition view, an event would be the succession of three-dimensional snapshots of this region. Thus, the unifying criterion for the succession of snapshots of the event is straightforward, *i.e.,* it would be the collection of the snapshots within the temporal length of the delimited region. Analogously, the participants of the event at a given time would be all the objects within the spatial projection of the region at the time.

Alternatively, the succession of snapshots within an event can be unified by causal or causal-like relations between each pair of successive snapshots. This approach is employed, for instance, in GFO [HERRE, 2010], in which two immediately successive snapshots in an event (*coinciding boundaries of a process* in their terms) must be causally and ontically related (which is detailed in section 3.6). We find a similar view in [GALTON; MIZOGUCHI, 2009], according to which each successive phase in a causal process is caused by its earlier phases. Consequently, the snapshots of an event constituted of such a process are causally related. Following the intuition that for something to change there must be something that remains the same [GALTON; MIZOGUCHI, 2009], another way to come up with the desired unifying criterion is looking for something that remains invariant throughout the unfolding of the event. This invariant element may concern the contents of the snapshots. It may be a single concrete object [LOMBARD, 1998; HACKER, 1982] [BUNGE, 1979, p.22] [BUNGE, 1977, p.221,273] [DAVIDSON, 1969] or a set of objects [KIM, 1976, p.160] that are subject to the event. As proposed in [GUARINO; GUIZZARDI, 2016], the invariant element may instead be a set of focal properties (including relationships among the participants), whose value variation or regularity characterize the event (more on that in section 3.5). In a similar direction, based on [BARTON; TOYOSHIMA; ETHIER, 2020; TOYOSHIMA; BARTON, 2018; BARTON; JANSEN; ETHIER, 2017], an event might also be unified as the manifestation of a single, complex disposition consisting in the sum of the dispositions manifested by each of the participants (*e.g.,* taking the *key-lock* example in section 2.5.1, the opening of the lock l with the key k would be the manifestation of the complex disposition $d_{key}+d_{lock}$ that inheres in the object $key+lock$).

In fact, each of these options of invariant element seems to convey a distinct manner of delimiting the portion of reality that is transformed in virtue of the happening of the event [GUIZZARDI et al., 2013]. In consequence, this approach yields a criterion for determining the participants of an event at each, *e.g.,* the selected object or set of objects, or to the bearers of the selected focal properties.

Alternatively, analogous to one of the unity criteria considered for the notion of *scene* in [ALMEIDA; COSTA; GUIZZARDI, 2018], the invariant element may not itself delimit the portion of reality alone. Instead, it may be regarded as a nucleus for the snapshots in the course of the event, with the remaining participants at each time being the objects within a distance threshold (*i.e.,* in the neighborhood) of the invariant element.

The invariance that unifies the successive snapshots in the course of an event may also come from some source other than the very content of the snapshots. Such snapshots may be unified by being different manifestations of the same variable embodiment that defines the event [GUARINO, 2017]. With that, the participants of an event at a given time would be the set of objects picked out by the associated principle of variable embodiment to compose the manifestation of the embodiment at the time. Similarly to that, we have the notion of processes as abstract patterns of occurrence and the case of events that are the realization of such a pattern over an interval of time [GALTON, 2016; GALTON, 2018]. In this case, the snapshots in the course of such an event are the successive instantaneous/experiential realizations of the pattern at each instant in the interval. Finally, we also have the notion of continuant-like processes and the case of events that are chunks or episodes of a process [GALTON; MIZOGUCHI, 2009; GALTON, 2016], with the successive snapshots within the event being successive stages of the process.

3.5 Unified Foundational Ontology (UFO)

The Unified Foundational Ontology (UFO) [GUIZZARDI, 2005] is a philosophically and cognitively well-founded reference ontology, encompassing both continuants and events. It is subdivided into a series of partial and interconnected ontologies devised to deal with different views of reality. The main ones are UFO-A (an ontology for continuants) and UFO-B (an ontology for events). UFO-B offers deep support to a broad range of aspects of events, including their mereological structure and temporal ordering, causation, participation of objects in events, as well as an explicit account of the happening of events under transition and manifestation views [GUIZZARDI et al., 2013].

In UFO, events are mappings between situations in the world, *i.e.,* a transformation of a portion of reality from one situation to another by means of manifestations of particularized properties, in special dispositions [BENEVIDES et al., 2019; GUIZZARDI; GUARINO; ALMEIDA, 2016; GUIZZARDI et al., 2013]. In this context, *situation* is regarded as a particular configuration of a part of reality that can be understood as a whole, and that is bounded to a single, specific time point (*i.e.,* situations occurring at different time points are numerically distinct), and that comprises some objects and some of their properties and relations at the time [BENEVIDES; ALMEIDA; GUIZZARDI, 2019; GUIZZARDI et al., 2013; GUIZZARDI; WAGNER, 2013; COSTA et al., 2006].[5] Also, the relation of participation of objects in events derives from that of events as manifestations of dispositions, *i.e.,* an object o participates in an event e when e is a manifestation of a disposition of o or when e is composed of such a manifestation [ALMEIDA; FALBO; GUIZZARDI, 2019]. Moreover, the maximal part of an event that is exclusively dependent on a particular endurant is itself an event called *participation* (of that endurant in that event).

Whenever an event happens, there is a unique initial situation that *triggers* the event, that is, a situation that obtains at the initial time point of the event and that satisfies conditions for its occurrence[6], activating dispositions that will be manifested by the event [GUIZZARDI et al., 2013; BENEVIDES et al., 2019]. Similarly, there is a unique, maximal ending situation that the event *brings about*, which obtains at the ending time point of

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[5] In [BENEVIDES; ALMEIDA; GUIZZARDI, 2019] the authors consider the possibility of lifting the restriction of situations being bound to specific time points. Recent related work [ALMEIDA; COSTA; GUIZZARDI, 2018] also seems to point to this direction, regarding situations as able to endure in time.

[6] There are divergent positions regarding this point. In [GUIZZARDI et al., 2013], a situation that triggers an event satisfies all the necessary and sufficient conditions for the happening of the event. Contrary to that, in [BENEVIDES; ALMEIDA; GUIZZARDI, 2019], situations are viewed just as enablers so that the obtaining of a situation can be a necessary but not sufficient condition for the happening of an event.

the event and that embodies all the effects of the event at this ending instant [GUIZZARDI et al., 2013].

Based on that, UFO brings an account of causation between events as a strict partial order relation in terms of the situations mapped by them [GUIZZARDI et al., 2013]. That is, an event e_1 directly causes another event e_2 iff it e_1 brings about a situation that triggers e_2. Moreover, an event e_1 causes another e_2 iff e_1 directly causes e_2 or e_1 causes some other event that causes e_2.

Following the view of events as manifestations of particularized properties, in [GUARINO; GUIZZARDI, 2016] events are defined as "*whatever happens to a suitably selected set of individual qualities in a particular spatiotemporal region*". With that, we have a principle of individuation for events (*i.e.,* an event is determined by a spatiotemporal region and a collection of focal individual qualities), which allows the differentiation of co-localized events (*i.e.,* given two different sets of focal qualities we can have two different occurrents in the same region). Events involving multiple participants (*i.e., relational events* in their terminology) are determined in terms of focal relationships among their participants, which are complexes of qualities that inhere in multiple participants. Those relationships can endure in time and qualitatively change while keeping their identity [GUARINO; GUIZZARDI, 2015]. Thus, a relational event can be seen as the manifestation of the qualities that constitute their focal relationships [GUARINO; GUIZZARDI, 2016].

Finally, UFO has some types of events that are interesting from the transition view standpoint, for they are characterized according to the differences between their initial and ending situations. Such types are *object creation*, *object destruction* (or *termination*), and *object change* [BENEVIDES et al., 2019; GUIZZARDI; GUARINO; ALMEIDA, 2016; GUIZZARDI; WAGNER, 2010], all of them specializations of *participation*. An *object creation* is an event in which an object comes into existence, so that such an object must be present in the ending situation of the event and must not be present in its initial situation. An *object change* is an event in which an object is present in both the initial and the ending situation of the event, and in which the properties of such object are changed (by means of creation, destruction, or change of intrinsic and relational qualities). Finally, an *object destruction* (or *termination*) is an event in which an object goes out of existence, so that such an object must be present in the situation that triggers the event and must not be present in the situation that the event brings about.[7]

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[7] From a conceptual modeling standpoint, in [ALMEIDA; FALBO; GUIZZARDI, 2019] the termination of an object is seen as a change in which the object acquires a historical nature, with immutable properties.

3.6 General Foundational Ontology (GFO)

The General Foundational Ontology (GFO) [HERRE, 2010; HERRE et al., 2007] is a foundational ontology integrating events and continuants in a four-dimensionalist view. With that, *process* (a notion corresponding to that of *event* as adopted in this work) is the most fundamental category in GFO [HERRE, 2015, sec. 2, 7] and *continuants* are regarded as merely creations of the mind, which are not in the same level of objectivity as processes [HERRE, 2015, sec. 1]. In spite of that, GFO commits to an integrative realistic view, assuming the existence of a real world independent from the observers, with independent material entities. Further, these independent entities bear objective dispositions which are realized in some mind to become subjective phenomena, such that of the perception of persistence of continuants through time [HERRE, 2015, sec. 6].

GFO has three major pairwise disjoint types of spatiotemporal individuals, distinguished according to their relation to time, *i.e., presentials*, *processes*, and *continuants* [HERRE, 2015, sec. 1] [HERRE, 2010, ch. 4]. Presentials are individuals whose wholly existence is restricted to a single point in time [HERRE et al., 2006, ch. 6] and cannot suffer changes since any change needs an extended temporal interval to happen [HERRE, 2015, sec. 3.1]. Processes are individuals that are extended over a connected time interval and cannot be wholly present at a time-point [HERRE et al., 2006, ch. 6, 8]. Projections of a process to a point of time are process boundaries, which are presentials [HERRE, 2015, sec. 7]. Finally, continuants are built from a series of presentials which is perceived as an identical individual over time [HERRE, 2015, sec. 7] [HERRE, 2010, sec. 6.1]. For every continuant there is a process such that the set of its process boundaries is equal to the series of presentials that correspond to the continuant, establishing the causal and spatiotemporal connectedness between those presentials [HERRE, 2015, sec. 7] [HERRE et al., 2006, ch. 14].

Presentials existentially depend on processes (*i.e.,* every presential is a whole boundary of a process or a part of such a boundary) [HERRE, 2010, sec. 6.1]. Presentials may be *attributives* (*i.e.,* always inhering on other entities), which include things such as qualities, relationships, and dispositions [HERRE, 2010, sec. 4.5], and material structures (*i.e.,* occupy three-dimensional space regions, being bearer of attributives, but never being attributives of other entities [HERRE et al., 2006, ch. 7]). A special type of presential is that of *presentic situations*, which are presentials comprising configurations of material structures, qualities and relationships [HERRE et al., 2006, ch. 8] [HERRE, 2010, sec.

4.6]. With that, processes in GFO seem to reflect the view of events as transitions through situations.

In addition, a process is not simply the mereological sum of its process boundaries, but must satisfy coherence restrictions [HERRE, 2015, sec. 7] [HERRE, 2010, sec. 4.4.2], which involves the notions of *causality* and *ontical connectedness*. With that, every pair of immediately successive boundaries of a process are linked by a *basic causal relation* (defined in terms of regularity, counterfactual dependency, and manipulability) [MICHALEK, 2009, sec. 5.2], so that they cannot be replaced arbitrarily by another presential [HERRE, 2010, sec. 4.4.2].

Moreover, based on this basic causal relation, there is also an indirect, sequential causal relation between two processes such that the last presential of the '*cause*' process has a basic causal relation to the first presential of the '*effect*' process [MICHALEK, 2009, sec. 5.1/5.2]. Additionally, there is the case of *causal adhesion*, in which two temporally overlapping processes A and B are causally connected throughout this overlap. Thus, for every pair of immediately successive time points in the overlap, there is a processual boundary of A in one of the points that causes a processual boundary of B on the other time point [MICHALEK, 2009, sec. 5.2].

Regarding the notion of *ontical connectedness* in [HERRE, 2010, sec. 4.4.2], it denotes an integrated system of causal and spatiotemporal relationships, which holds between processes or presentials [HERRE, 2010, sec. 5.10] [HERRE et al., 2006, sec. 14.10]. A case of ontical connectedness is the relation of *substrate-connectedness*, holding between material structures that consist of the same amount of substrate (*e.g.,* a statue made of clay at a given time point is substrate-connected with the pieces of clay resulting from the crashing of the statue on a later time point) [HERRE et al., 2006, sec. 14.10]. The authors state that, underlying this relation there is a general ontological law of conservation of substrate or matter [HERRE, 2010, sec. 4.4.2], even though they do not further specify this law.

In GFO, a presential amount of substrate is always a part of the substrate of a material structure [HERRE et al., 2006, ch. 7]. Conversely, every material structure consists of a presential amount of substrate, delimited by some boundaries, exhibiting forms and other qualities (*e.g.,* color, weight), with basic relations bringing these elements together to form the whole of material structure [HERRE et al., 2006, ch. 7]. There may be several sorts of substrates that may be classified as solid, fluid, and gaseous substrates [HERRE et al., 2006, ch. 7] and it might be the case that the substrate that a material structure comprises has non-divisible atoms [HERRE et al., 2006, ch. 7].

Lastly, there are some interesting types of events (in the sense adopted in this work). *Change* [HERRE et al., 2006, sec. 8.2.1] [HERRE, 2010, sec. 4.4.3] refers to a transition between two process boundaries which satisfy contradictory conditions. Thus, the involved process boundaries must be instances of a common universal U (in order to rule out spurious changes, *e.g.,* a change of 20kg to a color of red) as well as they must be instances of distinct, disjoint sub-universals of U in order to characterize the change. Changes are classified according to the temporal distance between the involved boundaries. *Discrete change* (a.k.a. *extrinsic change*) involves a pair of coinciding boundaries. *Continuous change* (a.k.a. *intrinsic change*) involves a pair of boundaries situated at opposite ends of a process of arbitrary extension.

Based on the notion of change, GFO specifies three main types of process [HERRE, 2010, sec. 4.4.4]. *States* are processes such that all of its processual boundaries are instances of the same universal *U*. Additionally, the process is a *strong state* if there are no pair of boundaries instantiating distinct, disjoint sub-universals of *U*. *Continuous processes* are processes that are mereological sums of continuous changes and states, and include no discrete changes. Finally, *discrete processes* are processes made up of alternating sequences of discrete changes and states or continuous processes.

3.7 Kneiwa, Iwazume, and Fukuda's Ontology (KIFO)

The ontology presented in [KANEIWA; IWAZUME; FUKUDA, 2007] – which we will refer to as “KIFO” – is an upper ontology for events proposed as an infrastructure for knowledge bases for events and intended to provide help in tasks such as annotation of event data and detection of relations between events. Events in KIFO include both dynamic entities, which affect objects or environments, changing their properties, as well as the maintenance of static properties.

KIFO describes events both according to structural aspects (*e.g.,* the number and roles of participants, time and location) as well as according to their semantic function (*i.e.,* the effect of the event over its participants), and propose a set of event types based on each of these ways of describing events. It also defines types of relations between events, both in instance-level and type-level (*e.g.,* causal relation, temporal order).

Classification of events based on structural aspects mainly comprise types according to the involved participants (*e.g., Object Event* vs. *Environment Event*, according to the presence of a focal participant, or *Natural Event* vs. *Action*, according to the presence of some agents), not taking into account the transition aspect of events. Even so, it also includes the distinction between *static states* (*i.e.,* events that imply the maintenance of a property in time (*e.g.,* being "hot", "cold", and "fine") and *dynamic states* (*i.e.,* events that imply activity and dynamic change of an object or environment in time, which seems to suggest the maintenance of a pattern of activity of the participant, *e.g.,* "rolling continues", "rising/dropping", "slightly active", "become higher"). In some sense, it reflects the property exemplification account of events in [KIM, 1976; LOMBARD, 1998].

On the other hand, classification based on the semantic function of events deals with the nature of the changes on properties of objects or environments, with the types depicting the configurations of the world prior to and after the happening of the event, which is closer related to the transition view of events. *State changes* are changes in the state of an object or environment, *i.e.,* if a property is true, the event yields a different state or property at the next instant (*e.g.,* a sick person becoming healthy). A *comparison* is the change in the value of some attribute of an object (*e.g.,* "raise", "increase", and "decrease"). *Spatial existence changes* are changes in objects regarding their spatial positions. *Object identification change* is an event in which the essential property of an object is changed and, therefore, the object cannot be recognized as the former object at the next time after the occurrence. It means that an object x is changed into another, numerically distinct object y. *Temporal existence change* is a change in the existence of an object according to a change in time (*e.g.,* an object x did not exist in the past but, after the occurrence, it exists now). Finally, *cardinality change* is an event that changes the number of existing objects of a given type or exhibiting a given property (*e.g.,* an event before which there exist 100 guitars and after which there exist 200 of them).

3.8 Descriptive Ontology for Linguistic and Cognitive Engineering (DOLCE)

The Descriptive Ontology for Linguistic and Cognitive Engineering (DOLCE) [GANGEMI et al., 2002; MASOLO et al., 2003; BORGO; MASOLO, 2009] is an upper-level ontology aimed to capture the ontological categories underlying natural language and human common sense. It is intended to capture the intuitive and cognitive bias underlying common sense, looking at reality from the mesoscopic and conceptual level aiming at formally describing a conceptualization of the world rather than objective features of the underlying reality [BORGO; MASOLO, 2009]. Thus, its categories reflect the surface structure of language and cognition, being regarded as cognitive artifacts that group entities according to some cognitively determined principle of classification, not necessarily reflecting the intrinsic nature of the world.

Originally, DOLCE distinguishes three main types of entities [GANGEMI et al., 2002], namely *endurants*, *perdurants*, and *abstracts*.[8] *Endurants* correspond to the notion of *continuant* that we use in this work and include entities that are primarily in space. *Perdurants* correspond to what we refer to as *events* and include entities that are primarily in time. Finally, *abstracts* include entities that are outside time and space, such as facts, sets, and spatial/temporal regions.

In DOLCE, a perdurant is something that happens in time and that, in general, extends itself in time by accumulating different temporal parts that are fixed in time. Hence, a perdurant is only partially present whenever it is present, *i.e.,* some of its proper temporal parts, such as its previous or future stages, are not present [GANGEMI et al., 2002; MASOLO et al., 2003]. Nevertheless, instantaneous snapshots of perdurants are also considered perdurants, though with atomic temporal location and, thus, lacking proper temporal parts [GANGEMI et al., 2002; MASOLO et al., 2003]. Then, under the transition view of events, these instantaneous perdurants seem to align with what we refer to as *situations* in this work (section 2.3).

Only perdurants are parts of perdurants. Then, endurants and perdurants are linked by the primitive relation of *participation*, which corresponds to the intuition that there are endurants 'involved' in a perdurant and that endurants 'live' in time by participating in perdurants [MASOLO et al., 2003; GANGEMI et al., 2002], capturing the mutual existential dependence between endurants and perdurants [BORGO; MASOLO, 2009]. It is a time-indexed relation that accounts for the varieties of participation in time (*e.g.,* temporary and constant participation) [MASOLO et al., 2003].

DOLCE distinguishes some types of perdurant according to three main notions: *cumulativity*, *homeomericity*, and (temporal) *atomicity*. A type of perdurant is cumulative iff it holds for a mereological sum of two of its instances. For example, "running" is a cumulative type of perdurant since two following instances of "running" (involving the same runner) are also an instance of "running". A perdurant is homeomerous iff all of its parts can be described by the very same expression that describes the whole perdurant.

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[8] A later revision of DOLCE called DOLCE-CORE [BORGO; MASOLO, 2009], the ontology is divided into six basic categories of temporal particulars (*i.e.,* located in time): objects, events, individual qualities, regions, concepts, and arbitrary sums. All of these categories are rigid: an entity cannot change from one category to another over time.

For instance, every instance of "being seated" is a homeomerous perdurant since any temporal part of an occurrence of "being seated" is also an occurrence of "being seated". Finally, an event is (temporally) atomic if it has no temporal parts (*e.g.,* an instance of "reaching a mountain").

Based on that, perdurants are first distinguished into *stative*, *i.e.,* a cumulative type of perdurant (*e.g.,* "being seated", "walking"), and *event*, *i.e.,* a non-cumulative type of perdurant (*e.g.,* "traveling from NY to London" since the sum of two instances of this type is not a "traveling from NY to London"). Stative is further specialized into *state*, *i.e.,* a type of perdurant whose instances are homeomerous (*e.g.,* "being seated"), and *process*, *i.e.,* a type of perdurant whose instances are not homeomerous (*e.g.,* "walking", since it has smaller temporal parts that are not "walking", such as "taking a step"). Event is specialized into *achievement*, *i.e.,* a type of perdurant whose instances are atomic (*e.g.,* "reaching the top of a mountain"), and *accomplishment*, *i.e.,* a type of perdurant whose instances have temporal parts (*e.g.,* "making a cake").

3.9 Basic Formal Ontology (BFO)

The Basic Formal Ontology (BFO) [GRENON; SMITH, 2004; ARP; SMITH; SPEAR, 2015; SMITH, 2015] is a relatively small upper-level ontology developed for supporting data integration of scientific research. BFO adopts a realist approach, according to which reality and its constituents exist independently of our representations (*e.g.,* linguistic, conceptual, theoretical) of them [GRENON; SMITH, 2004]. Still, it was also conceived under the idea that there are many views of reality that are equally faithful (*e.g.,* in different domains, or from different perspectives, or on different levels of granularity), and that this plurality of views is needed to do justice to reality as a whole.

In BFO, events (in the sense adopted in this work) are conveyed by the notions of *processes* and *process boundaries*. A process is an entity that happens in time, that always depends on at least one material, independent continuant as participant [ARP; SMITH; SPEAR, 2015, p.121-122,183], and that has proper temporal parts (which are either other processes or process boundaries). Examples of processes are cell divisions and surgeries. A process boundary is also an entity that happens in time, being a temporal part of a process that has no proper temporal parts itself and that marks the beginning, ending, or any cross-section of the process it bounds [ARP; SMITH; SPEAR, 2015, p.123,183] [SMITH, 2015, p.67]. Examples of process boundaries are the final separation of two cells at the end of a cell division and the incision at the beginning of a surgical procedure.

Processes and material, independent continuants are linked by the primitive relation of participation (or *has_participant* in BFO terms), which holds when a continuant is in some way involved in a process [ARP; SMITH; SPEAR, 2015, p.142] [SMITH, 2015, p.71]. Earlier versions of BFO also included more specific types of participation such as *perpetration* (*i.e.,* direct, agentive participation in a process, which may be initiation, *perpetuation*, or *termination* of the process) or its dual, *patiency* (*i.e.,* the participation of what is being acted upon in the process) [SMITH; GRENON, 2005; GRENON; SMITH, 2004]. Earlier versions also included the relation of *involvement*, which is the reverse relation of participation, but whose specializations reveal additional forms of involvement. Examples are *creation* (*i.e.,* when the process brings the involved continuant into being), *sustaining in being* (*i.e.,* when the process contributes to continued existence of the continuant), *destruction* (*i.e.,* when the process puts the continuant out of existence), and *degradation* (*i.e.,* when the process has negative effects upon the continuant, contributing to its eventual destruction) [SMITH; GRENON, 2005].

In addition to participation, BFO also includes the relation of *realization*, which holds between a process and a realizable, dependent continuant (*e.g.,* a disposition), when the bearer of such realizable is a participant of the process and the type of the process is correlated with the type of the realizable, dependent continuant [SMITH, 2015, p.57-58]. This reveals some commitment of BFO to the manifestation view of events.

Besides that, earlier versions of BFO also seem to commit to the transition view of events. Originally, BFO was conceived as a framework combining two sorts of ontologies, namely, *SNAP* ontologies for continuants and *SPAN* ontologies for occurrents (including processes) [GRENON; SMITH, 2004]. A single SNAP ontology would correspond to a snapshot of reality. With that, an account of the world over time from the SNAP perspective would require taking temporally successive SNAP ontologies into account [GRENON; SMITH, 2004, p.156-157].

The link between entities in successive SNAP ontologies is given by the *genidentity* relation, *i.e.,* a relation in which an entity stands to another when the latter is *such-as-to-have-come-forth-from* the former [GRENON; SMITH, 2004; SMITH; GRENON, 2005].[9] *E.g.,* if we cut a piece of wood in two, the sum of the resulting separated pieces of wood is genidentical to the original piece of wood; if we burn a log, the remaining ashes

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[9] The essence of the genidentity relation seems to have been later preserved by the *derives_from* relation, which is defined as a primitive relation between two distinct material continuants such that one succeeds the other across a temporal divide [ARP; SMITH; SPEAR, 2015, p.135].

are partially genidentical to the original log.

Thus, in this account, changes in the world would appear as structures or patterns through these successive snapshots, representing three main types of change: *qualitative*, *locational*, and *substantial*. A *qualitative change* would involve an object (in the sense adopted in this work) presenting contradictory properties in different SNAP ontologies within the succession. It would be a *qualitative creation* if a property that is not present in one ontology appears in later ontologies; a *qualitative destruction* if an object has a property in one ontology, but not in the later ontologies; or a *change in determinables* if an object has different values for a given property in different ontologies in the succession. A *locational change* would involve an object that is in distinct locations in different ontologies within the succession. Finally, in a *substantial change* would involve either an object that is present in an ontology within the succession, but not in earlier ontologies (*i.e.,* corresponding to the creation of the object), or an object that is present in an ontology, but not in later ontologies (*i.e.,* corresponding to the destruction of the object). Substantial changes may happen, *e.g.,* by the division of an object to produce a plurality of other objects or by the merging of a plurality of objects into a single one.

Part II

Contribution

4 GROUND ASSUMPTIONS FOR OUR PROPOSAL

In this chapter, we begin to present our contribution by presenting some grounding assumptions, principles, and notions for our proposal. We start by distinguishing the relations of *constitution*, *direct constitution*, and partial constitution (section 4.1). We also elaborate on the notion of material constitution to define the notion of *basic ontological substrate* (section 4.2). Following that, in section 4.3, we discuss relevant aspects in which systems can be open/closed and define specific types of systems related to that. Then, based on the notions of basic ontological substrate and on the notions of open and closed systems, we propose the *Principle of Ontological Conservation* (section 4.4). In section 4.5, we examine different ways systems can overlap. Finally, in section 4.6, we present a basic account of events mainly composed of definitions that are already present in literature, with adjustments to better describe our proposal.

4.1 Constitution, Direct Constitution and Partial Constitution

In this work, we will employ the notion of constitution (sec. 2.4) by means of the irreflexive, asymmetric, and transitive relations ***constitutes*** and ***constituted of***. Moreover, given the transitive nature of constitution, we can say that an object is constituted of several distinct constituents at the same time, each at a different ontological level. Despite that, the direct constituent of an object (*i.e.,* the one at the immediately lower ontological level) seems to fill a distinctive place in our view of the world.

For example, a gold ring is constituted of a portion of gold that is molded in an annular shape, which is constituted of a collection of atoms tied together by metallic bonds. With that, we can also say that the ring is constituted of a collection of atoms of gold that connected by metallic bonds and spatially disposed in a circular manner. Even so, though we naturally say that a goldsmith creates the ring by handling a portion of gold, it would sound odd to say that the ring was made by handling a collection of atoms. Thus, in order to account for this special status of direct constituents, we define the relations of ***directly constituted of*** and ***directly constitutes*** as follows:

Definition 5 ***directly_constituted_of****(x,c)* $=_{def}$ *A relation between objects x and c such that constituted_of(x,c) and there is no object y such that constituted_of(x,y) and constituted_of(y,c).*

Definition 6 ***directly_constitutes****(c,x)* $=_{def}$ *A relation between objects c and x such that directly_constituted_of(x,c).*

Besides, we adopted a view of constitution as a relation distinct from that of composition (axioms 3 and 4). Thus, for every object *x* composed of different proper parts [p_1, ..., p_n], none of such parts is a constituent of *x*. *E.g.,* given a table formed by four wooden legs directly fitted in a tabletop, the table is not constituted of the top and constituted of each of the legs. Instead, it is constituted of the aggregate of top and legs, which is in the table-favorable circumstances of being assembled in a particular way [BAKER, 2007, p.188,193].

Still, sometimes it may be useful to refer to the *partial constituents* of an object (*e.g.,* when the object derivatively has a property by virtue of some part of its constituent exhibiting such a property, such as when an object is magnetically attractable due to having a part that is constituted of iron). Therefore, to account for that, we define the relations ***partially constituted of*** and ***partially constitutes*** as follows:

Definition 7 ***partially_constituted_of****(x,pc)* $=_{def}$ *A relation between objects x and pc such that there is an object c, constituted_of(x,c), and proper_part_of(pc,c).*

Definition 8 ***partially_constitutes****(pc,x)* $=_{def}$ *A relation between objects pc and x such partially_constituted_of(x,pc).*

4.2 Basic Ontological Substrate

Given the transitive nature of the relation of constitution (sec. 2.4), it comes into question whether this relationship is well-founded, *i.e.,* whether the chain of constitution terminates on an individual constituted by anything else [TAHKO, 2018]. Baker [BAKER, 2007, p.159, 181] acknowledged the possibility of the existence of individuals that are not constituted by anything else (in her words, the *ultimate constituters*).[1] In line with that, we assume the relationship of constitution to be well-founded. Consequently, every object falls into one of two possible categories, being either

1) a ***constituted object***, *i.e.,* an object that is constituted by another object of a lower-level primary kind; or

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[1] Although she considered an empirical question whether such ultimate constituters indeed exist [BAKER, 2007, p.58]

2) an amount of ***basic ontological substrate*** (or ***substrate*** for short), *i.e.,* an object that is not constituted by anything else.

We define the notion of ***substrate*** simply by emphasizing a base case for constitution, *i.e.,* the lowest-level objects upon which chains of favorable circumstances can pile up to constitute the ordinary objects we usually describe. Thus, we do not commit to any particular nature of substrate, be it matter, energy, or whatever else.[2]

Despite that, we do assume that substrate cannot be created or destroyed. We do so to account for the intuition that objects neither come out of nothing nor vanish without a trace (*e.g.,* to prevent odd cases such as that in which we have a bucket full of water, remove a glassful from it and the bucket remains full without any water being added to it as if an amount of substrate was created and come to constitute such additional water).

Along with the notion of basic ontological substrate, we define the relations ***ultimately constituted of*** and ***ultimately constitutes*** as follows:

Definition 9 ***ultimately_constituted_of****(x,b)* $=_{def}$ *A relation between an object x and an amount of substrate b such that, for every y such that constituted_of(x,y), either constituted_of(y,b) or y=b.*

Definition 10 ***ultimately_constitutes****(b,x)* $=_{def}$ *A relation between an amount of substrate b and an object x such that ultimately_constituted_of(x,b).*

Finally, given the notion of basic ontological substrate, we define the *encompasses* relation between a situation and the amount of substrate that ultimately constitutes the collection of objects that are present in the situation, as follows:

Definition 11 ***encompasses****(s,b)* $=_{def}$ *A relation between a situation s and the amount of substrate b such that b is the mereological sum of the amounts of substrate that ultimately constitute each of the objects present at s.*

4.3 Types of Open and Closed Systems

As exposed in section 2.6.3, systems can be open or closed in different respects, depending on the behavior possibilities that are enabled or disabled by its internal and

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[2] For example, Baker [BAKER, 2007] suggested that simple aggregates, especially aggregates of subatomic particles [BAKER, 2007, p.32,165,181,185,186] could fill the role of ultimate constituters, since they only require the commitment to the existence of its parts/members, with no additional circumstances [BAKER, 2007, p.181-186].

external connections. Thus, the notions of openness and closedness of a system seem to be intrinsically associated with possible changes that it is able or unable to undergo, which include:

(1) Exchange of components with the environment;

(2) Exchange of matter with the environment;

(3) Behavior modulation by some influence of elements in the environment.

In this section, we discuss some general aspects in which a system may be open or closed, which are related to the three referred types of change. Moreover, since we regard the openness of a system based on the possible changes it can endure, we have to assume that the system must remain in existence throughout these changes. Thus, we will not consider any exchange or influence that results in the destruction of the system.

4.3.1 Composition-Open and Composition-Closed Systems

We first describe the openness and closedness of a system with respect to its composition, *i.e.,* with respect to the possibility of exchange of components with its extended environment[3].

A system is open w.r.t. its composition iff it allows the entry of objects into the system and/or the exit of objects from the system. In other words, a system is composition-open iff it allows objects outside the system to acquire the necessary connections to become components of the system and/or it allows objects inside the system to lose the connections that qualify them as components of the system. Thus, a system is composition-open if there are connections between its components or between its components (or the system itself) and elements of its environment that allow the establishment or the ceasing of the connections required for an object to be a component of the system.

With that, in what follows we define the notions of *composition-open system* (*i.e.,* a system that is open w.r.t. the exchange of components) and *composition-closed system* (*i.e.,* a system that is closed w.r.t. the exchange of components).

Definition 12 ***Composition-Open System*** $=_{def}$ *A system* sys *that has a component* c*, that has* e *as an element of its extended environment, and that has internal and external*

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[3] Which includes, as described in section 2.6.2, objects that are not components of the system, regardless of whether they are connected to system components or not.

connections that are associated with dispositions whose manifestations result in some of the following outcomes:

(1) e becoming a component of sys; and/or

(2) c ceasing to be a component of sys.

Definition 13 ***Composition-Closed System*** $=_{def}$ *A system sys that is not a composition-open system.*

Composition-open systems include, for example:

- an industrial hydraulic system composed of many interconnected pipes and valves which can be extended by adding new pipes or valves and which can undergo replacement of old components;
- a joint-stock company composed of many shareholders connected by contractual agreements, which allows the entry of new shareholders and the exit of current ones.

Composition-closed systems include, for example:

- a human circulatory system composed of a heart, various interconnected blood vessels, and an amount of blood that is circulated through such vessels, with none of these components being able to leave the system and none of them being incorporated from the environment;
- a molecule of water composed of two atoms of hydrogen and one of oxygen connected by covalent bonds, to/from which no atom can be added/removed without destroying the system.

It is worth noting that some systems are composition-open or composition-closed only circumstantially, due to their connections with their environments. For example, the referred industrial hydraulic system is considered open to the replacement of its components due to the assumption that its environment includes a maintenance team that actively monitors the system and repairs it when needed. Likewise, the referred circulatory system is considered a composition-closed system assuming the usual environment in which it is placed, *i.e.,* the human body structure that shields it from being harmed, preventing the establishment of connections that would render the system composition-open. However, it could be considered an open system if, analogously to the industrial hydraulic system, the circulatory system was in an environment consisting of a human body laying down on an operating table, with its chest open, and surrounded by a surgery team designated to perform a heart transplant.

On the other hand, some systems are composition-open or composition-closed by logical necessity. For example, a molecule of water is, by definition, composed of three atoms in such a way that removing one of them or adding a fourth one would result in something that is no longer a water molecule. Similarly, a joint-stock company, by definition, allows its shareholders to transfer their shares to other people, consequently allowing the entry and exit of shareholders, without compromising the continued existence of the company.

4.3.2 Constitution-Open and Constitution-Closed Systems

A system may also be open or closed with respect to the constitution of its components, *i.e.,* open or closed to the exchange with its extended environment of the substrate that ultimately constitutes its components. In other words, a system is open w.r.t. constitution iff it allows at least one of its components to:

- incorporate an amount of substrate that totally or partially constitutes one or more elements of the extended environment; and/or
- lose the totality or part of its constituent substrate to the extended environment (*i.e.,* without the substrate being incorporated by any other component of the system) while remaining as a component of the system.

With that, in what follows we define the notions of *constitution-open system* (*i.e.,* a system that is open w.r.t. the exchange of substrate between its components and elements of the extended environment) and *constitution-closed system* (*i.e.,* a system that is closed w.r.t. the exchange of substrate between its components and elements of the extended environment).

Definition 14 ***Constitution-Open System*** $=_{def}$ *A system* sys *that has a component* c*, that has* e *as an element of its extended environment, and that has internal and external connections that are associated with dispositions whose manifestations result in one or both of the following outcomes:*

(1) an amount of substrate that (totally or partially) constitutes e *becomes a (partial or total) constituent of* c*;*

(2) an amount of substrate ceases to (totally or partially) constitute c *and does not become a (total or partial) constituent of any other component of* sys*.*

Definition 15 ***Constitution-Closed System*** $=_{def}$ *A system that is not a constitution-open system.*

It is relevant to note that this definition covers several different ways in which substrate may be exchanged, which include the cases of

- a component of the system incorporating the constituent substrate of an element of the environment without incorporating it as a part (*e.g.,* an animal fed with milk that incorporates the calcium from the milk into its bones);
- a component of the system losing part of its constituent substrate to the environment (*e.g.,* a ship that loses part of the sacrificial metal plates that protect its hull from corrosion);
- part of an object from the extended environment becoming a part of a component of the system (*e.g.,* blood transfusion);
- an object from the extended environment becoming a part of a component of the system (*e.g.,* replacing the lens of one of the cameras that compose a surveillance system);

Constitution-open systems include, for example, a living organism, whose chemical makeup is replaced continuously as needed nutrients are incorporated, and waste products are released.

Conversely, constitution-closed systems include, for example, a sealed battery composed of several electrochemical cells, with connections for powering external electrical devices, but that does not exchange matter with its surroundings.

4.3.3 Exchange-Open and Exchange-Closed Systems

Constitution-closed systems are obviously open to the exchange of substrate with its extended environment. However, composition-open systems are also open to the exchange of substrate by allowing the exchange of whole components, which carry their constituent substrate as they enter and exit the system. With that, we can define the more general categories of *exchange-open* and *exchange-closed* systems as follows.

Definition 16 ***Exchange-Open System*** $=_{def}$ *A system that is a composition-open system, a constitution-open system, or both.*

Definition 17 ***Exchange-Closed System*** $=_{def}$ *A system that is neither a composition-open system nor a constitution-open system.*

4.3.4 Influence-Open and Influence-Closed Systems

Finally, a system may also be open or closed with respect to environmental influence other than the exchange of substrate with its extended environment. That is, a system may be open with respect to the possibility of undergoing qualitative changes due to the interaction of its components (or the system itself) with elements of its environment. Such qualitative changes include changes in the properties of the system, in the properties of its components, and in the relations among its components, which are not the result of an exchange of substrate with the extended environment. With that, we define *influence-open* and *influence-closed* systems in what follows.

Definition 18 ***Influence-Open System*** $=_{def}$ *A system sys that*

(1) bears a quality q with value v; and

(2) has a component c that bears a quality p with value w and that stands in a relation r with another component of sys; and

(3) has e as an element of its environment that has a connection conn with a component of sys; and

(4) conn is associated with some disposition d whose manifestation

  a) does not comprise any exchange of substrate between sys and its environment; and

  b) comprises at least one of the following outcomes:

    i) sys acquires a new quality;

    ii) sys loses q;

iii) q *acquires a value other than* v*;*
iv) c *acquires a new quality;*
v) c *loses* p*;*
vi) p *acquires a value other than* w*;*
vii) *a new connection is established between* c *and some other component of* sys*;*
viii) r *ceases to exist.*

Definition 19 ***Influence-Closed System*** $=_{def}$ *A system that is not an influence-open system.*

Influence-open systems include, for example:

- an automatic illumination system composed of a lamp and a presence sensor such that when a person is within the detection range of the sensor, the lamp is turned on;
- a weighing scale composed of, among other things, a plate, a scale, and a pointer such that when a body is positioned on top of the plate, exerting a force on it, the position of the pointer in relation to the scale changes.

There is hardly any real example of an influence-closed system since every system is arguably liable to environmental influence. Still, we can think about systems that are closed w.r.t. specific types of influences. For example, differently from the automatic illumination system, the weighing scale system is closed to electromagnetic influence, although it is open to mechanical influence.

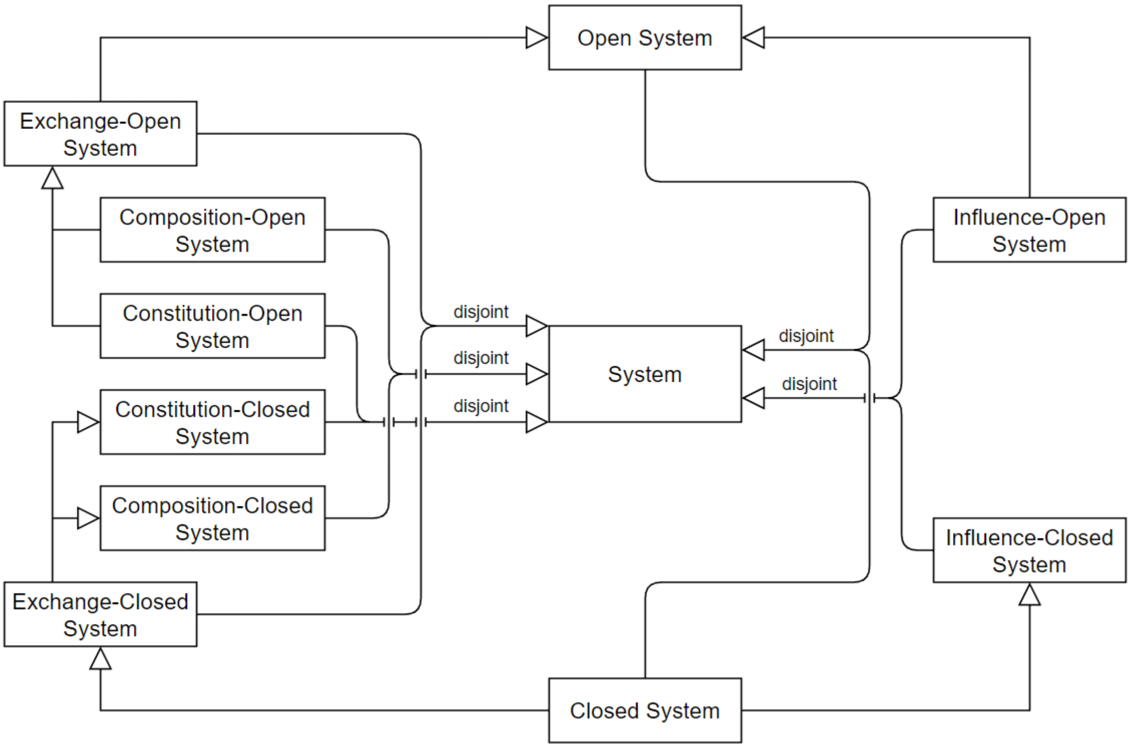
4.3.5 Openness/Closedness-Based Taxonomy of Systems

Based on the previously defined types, we define the notions of ***open system*** and ***closed system*** as follows:

Definition 20 ***Open System*** $=_{def}$ *A system that is a exchange-open system, an influence-open system, or both.*

Definition 21 ***Closed System*** $=_{def}$ *A system that is both an exchange-closed system and an influence-closed system.*

Figure 4.1 – Types of System



Source: the author

This reflects Bunge's view that a system is open if it is open in any respect, but it is closed iff it is closed in every respect [BUNGE, 1979, p.9-10], *i.e.,* ifF it is a *completely* closed systems. It also implies that closed systems cannot be affected by the environment in any way, being even scarcer than influence-closed systems – if existent at all[4].

Therefore, contrasting with open systems, which form a broad category with specializations for each way in which a system may be open, the category of closed systems is very narrow, with no specialization. Instead, it is a conjunction of super-types corresponding to each respect in which a system can be closed (*i.e.,* it is both a *exchange-closed* and an *influence-closed* system). Finally, the types of systems discussed in previous sections – which correspond to various degrees of openness/closedness – can be placed in between these two categories, giving rise to the taxonomy depicted in figure 4.1.

4.4 Principle of Ontological Conservation

In Physics, the notion of *law of conservation* refers to principles that state that certain physical quantities do not change in the course of time within an isolated physical

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[4] In Bunge's words "*The universe is the only system closed at all times [...] for the universe may be defined as that thing which has a void environment (i.e. which is self-contained).*" [BUNGE, 1979, p.9-10].

system [BRITANNICA, 2018]. An example of such principles is the *Law of Conservation of Mass*[5], which states that, in an isolated system[6], the total mass involved in a chemical reaction (taking into account all its reactants and products) remains the same throughout the course of the reaction [STERNER; SMALL; HOOD, 2011] so that no mass is created nor destroyed.

An analogous principle can be stated for the realm of ontology. As exposed in section 4.2, objects are either *constituted objects* or amounts of *basic ontological substrate*. Given the assumption that substrate cannot be created or destroyed, we introduce what we call the ***principle of ontological conservation***, which states that the *amount of basic ontological substrate within an exchange-closed system remains the same over time*. Here it is important to note that what is preserved over time is numerically the same individual amount of substrate, not just distinct amounts of substrate with equivalent quantities. This is analogous to saying that, if we melt a gold coin and mold the gold again into a ring, the amount of gold that constitutes the ring now is numerically identical to the amount of gold that has earlier constituted the coin, and not just two distinct amounts of gold with the same weight and volume.

As presented in section 2.3, for any given consistent set of states of affairs, there is a corresponding situation defined by them. Hence, we can depict a situation that includes all the objects that are components of a given system at a time t and that is defined in terms of states of affairs that describe the properties in virtue of which these objects are components of the system at t. This situation is what we will call a *snapshot* of the system. With that, the situations that supersede one after another as snapshots of a given closed system must encompass the same amount of substrate. Then, given any two situations s_1 and s_2, bound to distinct time points, we can restate the principle as follows:

Axiom 5 (Principle of Ontological Conservation) *If s_1 and s_2 are snapshots of an exchange-closed system at different times, then* $\exists b\ \mathit{Basic\_Ontological\_Substrate}(b) \land \mathit{encompasses}(s_1,b) \land \mathit{encompasses}(s_2,b)$.

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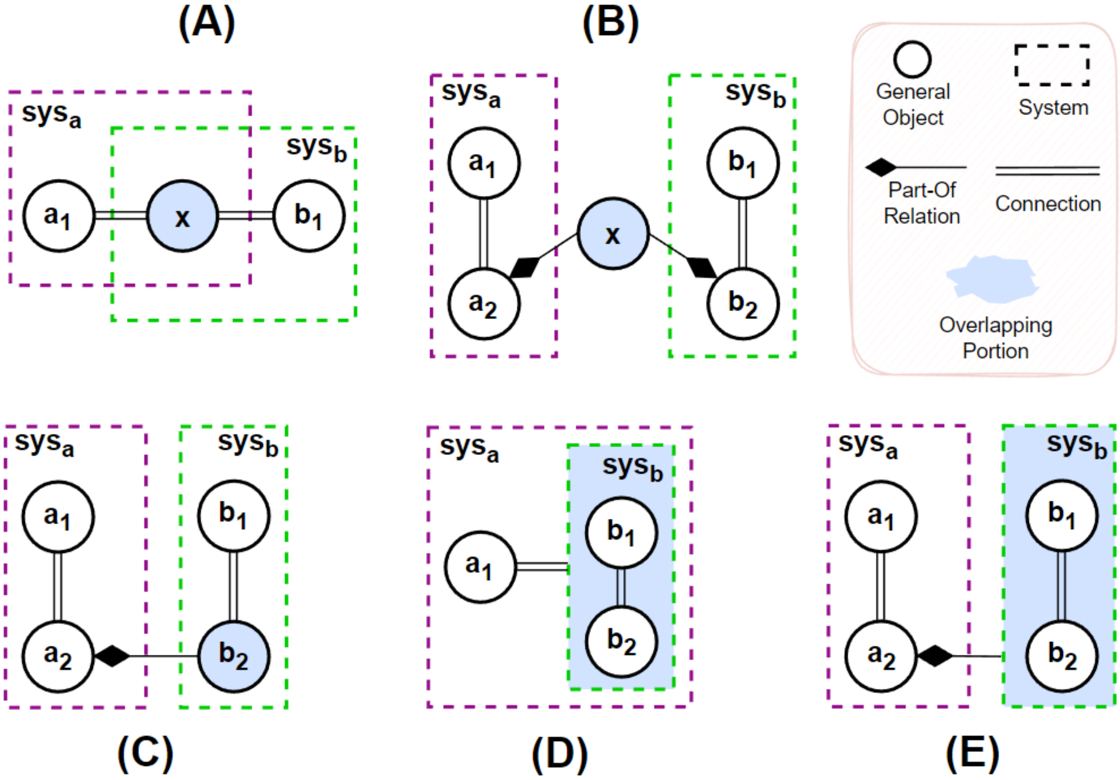
[5] In fact, this is just an approximate law of conservation since mass can be converted into energy [BRITANNICA, 2011]. However, we use it as an illustration of the concept for its simplicity.

[6] Note that the notion of *isolated system* here is not necessarily as strict as our notion of *closed system* (def. 21), but may rather be simply "a system closed to the exchange of mass with the environment".

Figure 4.2 – Types of Overlap between Systems



Source: the author

4.5 Overlapping Systems

Upon the notion of system, we can develop the idea of overlapping systems. As a general intuition, we assume that two things overlap if they have parts in common[7][8] . Applying this intuition to our case, we consider that two systems overlap if they share some common object, which may or may not be a component of the considered systems. In other words, it may be an object that is a component of both systems or that is part of components of both systems. Since systems are objects themselves, it may also be the case of one system being a component of the other system or being part of a component of the other system. Thus, for our purposes, we will consider 5 ways in which two systems may overlap[9]

(depicted in figure 4.2, with the overlapping portion of the systems in blue):

(A) The two systems share a common component (fig. 4.2(A));

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[7] <https://dictionary.cambridge.org/dictionary/english/overlap>

[8] <www.britannica.com/dictionary/overlap>

[9] It is important to note that this is not an exhaustive list but rather a list including 5 of the most evident cases of overlapping.

(B) A component of one system shares a common part with a component of the other system (fig. 4.2(B));

(C) A component of one system is part of a component of the other system (fig. 4.2(C));

(D) One system is a component of the other system (fig. 4.2(D));

(E) One system is part of a component of the other system (fig. 4.2(E)).

Given that, we define the *overlap* relation as follows:

Definition 22 ***overlap***$(sys_a,sys_b) =_{def}$ *A binary relation between systems* sys_a *and* sys_b *such that*

(1) There is an object a *such that* component_of(a,sys_a)*;*

(2) There is an object b *such that* component_of(b,sys_b)*;*

(3) At least one of the following conditions holds

  (a) There is an object x *such that* component_of(x,sys_a) *and* component_of(x,sys_b)*;*

  (b) There is an object x *such that* part_of(x,a) *and* part_of(x,b)*;*

  (c) part_of(a,b)*;*

  (d) component_of(sys_b,sys_a)*;*

  (e) part_of(sys_b,a)*.*

A noteworthy consequence of this definition is that overlapping systems necessarily share some amount of basic ontological substrate. The amount of substrate that ultimately constitutes a system at a time instant is the sum of the amounts of substrate that ultimately constitute each of its components at the time. In turn, the amount of substrate that ultimately constitutes each component is the sum of the amounts of substrate that ultimately constitute each of its parts. Hence, given an object x ultimately constituted of sub_x, a system sys_a ultimately constituted of sub_a, and a system sys_b ultimately constituted of sub_b, if x is sys_a itself or a component or part of a component of sys_a, and x is sys_b or a component or part of a component of sys_b, then sub_x is part of both sub_a and sub_b.

4.6 A Basic Account of Events

Following the transition view, we regard events as transitions through situations, which we understand as implying that it is an entity that gathers a given set of situations into a cohesive succession. Moreover, events as transitions through situations consist of changes and/or unchanges on the properties of the participants of the event (*i.e.,* the objects that are present at the gathered situations). Thus, we can characterize an event by the differences and similarities among the situations it gathers.

The transition from a situation s_1 to the successive situation s_2 happens by means of the manifestation of dispositions of the objects that are present in s_1, which brings about s_2. Hence, will call the set of situations that an event gathers as the ***course of the event*** to emphasize the fact that an event is something above the corresponding succession of situations.

Given these considerations, we now present definitions for the terms employed in our initial, basic account of events, building upon the definitions of *situation* and related terms presented in section 2.3 and on elements of the related works discussed in chapter 3.

Definition 23 ***Situation*** $=_{def}$ *A particular configuration of a portion of reality that is bound to single instant in time and that includes at least one object bearing at least one property.*

Definition 24 ***Event*** $=_{def}$ *An entity that*

*(1) gathers a set of temporally successive situations (*i.e., *with no two distinct situations bound to the same time instant);*

(2) is a time-ordered transition through them such that, if a situation s_2 succeeds another situation s_1 within the event, s_1 must be bound to a time instant earlier than that of s_2);

(3) has each of its situations being brought about by the manifestation of dispositions of objects that are present in the immediately preceding situation in the succession.

Definition 25 ***Course of Event*** $=_{def}$ *A set of two or more situations that contains no two situations bound to the same time point and that contains all and only the situations gathered by a given event.*

Definition 26 ***in_the_course_of****(s,e)* $=_{def}$ *A binary relation between a situation s and an event e whose course contains s.*

Definition 27 ***gathers****(e,s_1,...,s_{n-1})* $=_{def}$ *An n-ary relation between an event e and the n-1 situations that compose the course of e.*

Definition 28 ***participates_in****(x,e)* $=_{def}$ *A binary relation between an object x and an event e such that there is a situation s, in_the_course_of(s,e), and includes(s,x).*

Definition 29 ***involves****(e,x)* $=_{def}$ *A binary relation between an event e and an object x such that participates_in(x,e) (*i.e., *the inverse relation of participates_in).*

Definition 30 ***subject_to****(x,e)* $=_{def}$ *A binary relation between an object x and an event e such that*

1. *participates_in(x,e); or*
2. *there is an object y such that participates_in(y,e) and one of the following conditions hold*
   - (a) *part_of(x,y); or*
   - (b) *constitutes(x,y); or*
   - (c) *partially_constitutes(x,y);*

Definition 31 ***initial_situation_of****(s,e)* $=_{def}$ *A binary relation between a situation s and an event e such that in_the_course_of(s,e) and bound_to(s,t), and there is no situation s' such that in_the_course_of(s',e), bound_to(s',t') and earlier_than(t',t).*

Definition 32 ***ending_situation_of****(s,e)* $=_{def}$ *A binary relation between a situation s and an event e such that in_the_course_of(s,e) and bound_to(s,t), and there is no situation s' such that in_the_course_of(s',e), bound_to(s',t') and later_than(t',t).*

Axiom 6 (Mereology of Events) $\forall$*e,e' part_of(e',e)* $\Leftrightarrow$ *temporal_part_of(e',e)* $\vee$ *functional_part_of(e',e).*

Definition 33 ***temporal_part_of****(e',e)* $=_{def}$ *A binary relation between events e' and e such that the course of e' is a subset of successive situations in the course of e.*

Definition 34 ***functional_part_of***(e',e) $=_{def}$ *A binary relation between events* e' *and* e *such that for each situation* s' *such that* in_the_course_of(s',e') *there is a situation* s *such that* in_the_course_of(s,e) *and* part_of(s',s)*.*

Definition 35 ***succeeds***(s_1,s_2) $=_{def}$ *A binary relation between situations* s_1 *and* s_2 *such that there is an event* e, in_the_course_of(s_1,e), in_the_course_of(s_2,e), bound_to(s_1,t_1), bound_to(s_2,t_2) *and* later_than(t_1,t_2)*.*

Definition 36 ***immediately_succeeds***(s_1,s_2) $=_{def}$ *A binary relation between situations* s_1 *and* s_2 *such that there is an event* e, in_the_course_of(s_1,e), in_the_course_of(s_2,e), bound_to(s_1,t_1), bound_to(s_2,t_2) *and* immediately_later_than(t_1,t_2)*.*

Definition 37 ***precedes***(s_1,s_2) $=_{def}$ *A binary relation between situations* s_1 *and* s_2 *such that there is an event* e, in_the_course_of(s_1,e), in_the_course_of(s_2,e), bound_to(s_1,t_1), bound_to(s_2,t_2) *and* earlier_than(t_1,t_2) *(*i.e., *the inverse relation of* succeeds(s_1,s_2)*).*

Definition 38 ***immediately_precedes***(s_1,s_2) $=_{def}$ *A binary relation between situations* s_1 *and* s_2 *such that there is an event* e, in_the_course_of(s_1,e), in_the_course_of(s_2,e), bound_to(s_1,t_1), bound_to(s_2,t_2) *and* immediately_earlier_than(t_1,t_2) *(*i.e., *the inverse relation of* immediately_succeeds(s_1,s_2)*).*

Definition 39 ***earlier_than***(t_1,t_2) $=_{def}$ *A binary relation between time instants* t_1 *and* t_{21} *such that* t_1 *comes before* t_2 *in the temporal line.*

Definition 40 ***later_than***(t_1,t_2) $=_{def}$ *A binary relation between time instants* t_1 *and* t_{21} *such that* t_1 *comes after* t_2 *in the temporal line (*i.e., *the inverse of* earlier_than(t_1,t_2)*).*

Definition 41 ***immediately_earlier_than***(t_1,t_2) $=_{def}$ *A binary relation between time instants* t_1 *and* t_2 *such that* earlier_than(t_1,t_2) *and there is no time* t_x *such that* earlier_than(t_1,t_x) *and* earlier_than(t_x,t_2)*.*

Definition 42 ***immediately_later_than***(s_1,s_2) $=_{def}$ *A binary relation between time instants* t_1 *and* t_2 *such that* later_than(t_1,t_2) *and there is no time* t_x *such that* later_than(t_1,t_x) *and* later_than(t_x,t_2)*.*

5 DELIMITING EVENTS WITH SYSTEMS

In the previous chapter, we presented a basic account of events based on notions that were already proposed in the literature, with some adjustments to better fit our proposal. As exposed in section 2.2, the goal of an ontology can be seen as allowing the description of a set of models as close as possible to the set of models we intend to accept as valid (*i.e.,* including as many intended models as possible and excluding as many unintended ones as possible). Under this perspective, the basic account of events we propose arguably reaches the goal of accounting for a great variety of intended models within the transition view. Still, it does not seem to go so further in offering constraints to rule out unintended models.

In this chapter, we discuss some aspects of this issue and propose the use of the notion of a system as a source of constraints for models of events. On top of that, we explore some implications of this choice for the modeling of events.

5.1 Intended and Unintended Models of Events

We assume that an event is an entity that gathers the elements of a certain set of situations to form its course. However, similarly to the intuition expressed in [BARWISE; PERRY, 1983, p.56], it does not seem to be the case that every set of situations forms the course of an event. In other words, the intended model of an event would be based on a set of situations that we intend to accept as being gathered by the event (*e.g.,* which make sense to be gathered together, each including the right objects, among other things). Correspondingly, an unintended model of an event is likely to be based on a set of situations that we do not intend to accept as forming the course of such an event.

With that, in order to determine what an intended model of an event is, we need to characterize the sets of situations we intend to accept as being gathered by events. The basic account imposes some restrictions on such sets, *e.g.,* establishing that each such a set must be a temporal succession of situations with at most one situation for each instant. However, it does not cover other characteristics that those successions of situations must also present. We can use a couple of scenarios to illustrate the point.

Scenario 1 *Imagine a succession of situations composed of a situation in which someone presses some keys of a piano in a room full of musicians at a given instant succeeded by a* *situation of someone else playing a chord on a guitar in the same room at the next instant, followed by another situation with a musician playing another instrument in the room and so on.*

With the basic account of events presented in the previous chapter, we could easily model an event that is the transition through these situations, with different objects manifesting their dispositions (*e.g.,* people's musical abilities, musical instruments' capacity to resonate). This would be a reasonable modeling decision if the described succession is composed of situations in the course of a blues jam session.[1] On the other hand, it would be an awkward choice if they are just situations obtaining during an ordinary day in a music store, with customers trying some musical instruments before buying them. However, we are mostly on our own to recognize this difference since the basic account does not give any advice on this issue.

Scenario 2 *Imagine the case of a soccer match in a stadium crowded with team fans. There are professional players both on the field and seated on the bench. Sometimes some player on the field is replaced by another from the bench and, in some cases, some player is sent off the match after receiving a red card (usually remaining on the field for a while complaining about such a decision). Occasionally health professionals also enter the field to help injured players.*

The basic account provides well-defined means to model any combination of all those people who are somehow related to the match as participants of the match at any time during the event (*i.e.,* describing a succession of situations involving all of them). Nevertheless, it offers no further guidelines to decide which of these combinations could really picture the participants of the event at each instant.

For example, we regard some of these people as participating during the whole match (in general, most of the players that are on the field at the beginning of the match), which would then be present in each of the situations in the course of the match. Beyond that, we consider those people as participating in the match even when they are not especially active, manifesting their playing abilities (*e.g.,* a goalkeeper when the ball is on the opponent's field). Other people participate during just a part of the match (*e.g.,* players that are expelled or replaced cease to be participants in the match). There are also those that we do not consider as participants in the match at all (*e.g.,* the health professionals,

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[1] A jam session <https://en.wikipedia.org/wiki/Jam_session> is an informal musical event in which musicians gather together to play improvised solos, chord progressions, and songs.

the team supporters). We tend to regard those as natural modeling decisions, but the basic account offers no grounds to justify why we should accept models following those decisions and reject those displaying different arrangements so that the issue completely remains as a matter of individual intuition.

As shown in these two scenarios, once we have *already determined* the succession of situations that characterizes an event along with the objects they will include (*i.e.,* the participants of the event at each time), the basic account provides means to model such an event. Nevertheless, the basic account falls short in offering criteria to assess whether those decisions were adequate and correspond to a faithful picture of the event. In particular, it lacks support to

(1) decide whether or not a succession of situations can constitute the course of an event; and

(2) determine which objects participate in the event at each time.

We believe that this is the case because this basic account leaves aside an important intuition underlying the transition view: when we take a series of situations succeeding one another as the happening of an event we assume that there must be some underlying reason that justifies the *cohesive* development of reality we are witnessing, something grounded on the external world itself rather than on our perception of it or on our will. That is to say, the set of situations that form the course of an event and the collection of objects included in each of them are not just an *ad hoc* selection of entities simply based on arbitrary preferences and cognitively-based criteria of the observer/modeler (*e.g.,* what is possible to observe, the aspect s/he wants to highlight). Rather than that, there must be some *bona fide* ontological ground upon which we base our criteria for unifying a succession of situations as constituting the course of an event and for unifying the sets of objects that are present in each of the successive situations.

For example, scenario 1 suggests that the participants of an event should be in some way related, composing a cohesive whole. On the other hand, scenario 2 indicates that such a whole should be flexible enough to allow variation in the set of participants throughout the event, which can happen either due to the entry or exit of participants (as in the case of the soccer match), or due to creation and destruction of objects (*e.g.,* the product of a manufacturing event is usually regarded as a participant in the event).

Therefore, a solution to the problem rests on emphasizing this cohesive aspect of events both with respect to the succession of situations that compose the course of an event, as well as with respect to what participates in the event at each instant. In other words, cohesion should play a part in devising both a longitudinal unifying criterion for events (*i.e.,* whether or not a succession of situations can be the course of an event or of any event at all), as well as a transversal one (*i.e.,* whether the objects that are present at a situation in the course of an event are indeed the right participants at the time). In the next sections, we discuss some approaches in this direction and propose one of our own.

5.2 Approaches to Devise a Unifying Criterion for Events

As presented in section 3.4, there are different possible approaches to devise unifying criteria for events, including:

(I) **Spatiotemporal Boundaries**: The event is delimited by a given spatiotemporal region and each situation in the course of the event is a temporal slice of this region – *i.e.,* the spatial projection of the region at an instant, encompassing all the objects within this spatial projection, relations among them, and the properties they bear;

(II) **Causal Link**: Each pair of successive situations in the course of the event is linked by a causal (or causal-like) relation, *i.e.,* any given situation causes the following one;

(III) **Non-bounding Content Invariance**: There is an invariant core element that is common to all the situations in the course of the event so that each of the situations includes the core element as well as everything in its neighborhood, *i.e.,* everything within a certain spatial threshold;

(IV) **Bounding Content Invariance**: There is an invariant element that is present in all the situations in the course of the event and that delimits the portion of reality that is subject to the event (*i.e.,* the portion of reality of which each situation is a configuration). Alternatives for such an invariant element include:

   a. a single object;
   b. a set of objects;
   c. a set of focal properties;

(V) **Bounding Structural Invariance**: There is an invariant structural element to which each of the successive configurations of the portion of reality (*i.e.,* situations) in the course of an event conform. Thus, what takes part in an event at each instant is given by what is aggregated by this structural element. Alternatives for such an invariant element include:

a. a variable embodiment;
b. a continuant-like process;
c. a pattern of occurrence.

Even though they provide some sort of cohesion among situations and participants in an event, all of them have drawbacks. A unifying criterion based on a spatiotemporal region – approach (I) – is unable to explain why, in scenario 1, the succession of situations in a jam session corresponds to a genuine event but not the succession comprising snapshots of the customers in a music store. It does not completely explain scenario 2 either. It is true that, if we restrict a soccer match to what happens within the borders of a soccer field during a time interval, we will capture most of the participants involved in the event. Still, it cannot explain why a player that has just received a red card is no longer a participant even before leaving the field (*i.e.,* being outside the boundaries of the event). Moreover, according to this criterion, health professionals that enter the field to help an injured player would become participants in the match.

This criterion is also arbitrary in significant ways. It gives no hint on why it would be weird to consider what happens within the left half of the stadium (including half of the field and half of the bleacher seats) during the time of the match or why individuating an event composed of everything that happens within the field during a week (including a soccer match on Sunday, a rock concert on Friday night, and players practicing in the other days). Finally, it could not account for events simultaneously happening in the same spatial region (*e.g.,* a ball that is rolling on the ground while heating).

The causal link approach – approach (II) – is also unable to help in scenario 1. Both in the jam session and in the music store cases, each situation causes the following one. What the musicians will play next in a jam session is a consequence of what they just played (*e.g.,* with the bassist giving the cue to the guitar player improvising a guitar solo). Likewise, what each of the customers will play next on the musical instruments they are holding is based on what they just played (*e.g.,* having tried the sound on a region of the neck of a guitar, the customer decides to try another region).

Besides that, approach (II) cannot fully account for scenario 2. For sure, the participants in an event at an instant are heavily based on the participants at the previous instant. However, when a player comes to the field to replace another one during a soccer match, the incoming player was not present nor has any ontical connection with anything that was present in the previous situation. Thus, even though the previous situation can partly cause the presence of the incoming player in the current situation (*e.g.,* another player got injured and needed to be replaced), there must be external factors contributing to the player's entry as well. Thus, since part of what causes the current situation to obtain is outside the scope of the previous situation, what unifies the succession of situations cannot be reduced to a causal relation between situations. Besides, it renders the criterion somewhat arbitrary, since it leaves to the modeler to decide which factors external to the event justify the entry of participants.

Unifying the situations in the course of an event by sharing a core invariant content and unifying the participants in each situation as the content within the spatial neighborhood of this core (approach (III)) does not help much to account for either scenario 1 or 2. It does not seem to be the case of there being a fixed core participant or set of participants in a jam session since musicians can enter and exit the event anytime. In a soccer match the ball might be considered as such a core element, but, given that it usually goes off the field many times during a match (clearly not participating in the event at such times), being even replaced by another ball, it cannot be considered an invariant element present in all situations at all.

In addition, the result of this criterion is similar to that of delimiting an event using a spatiotemporal (which, in this case, is determined by the spatial position of the core element at each time). With that, it has similar weaknesses as those of approach (I) (*e.g.,* arbitrariness in determining a suitable extent for the neighborhood of the core element, impossibility of co-located events in this neighborhood). If this neighborhood is defined in terms of certain relationships other than that of proximity (*e.g.,* including everything that is physically attached to the core element), some of those problems may be overcome.

A unifying criterion that constrains an event to what happens to an invariant content with respect to certain properties – approach (IV) – also has shortcomings. Restricting an event to what happens to a single object rules out the events described in scenarios 1 and 2 since they involve multiple participants. If we consider that what participates in the event are the parts of the object rather than the object as whole, it may be possible to account for these events (*e.g.,* the object that delimits a jam session could be a band so that the band members would be the genuine participants). However, this finer granularity analysis does not seem to be the underlying idea when an event is described, for example, as the exemplification of a dynamic property by an object [LOMBARD, 1998].

An account that unifies the situations in the course of an event by encompassing a fixed set of participants would comprehend scenario 1. It accepts the jam session as a genuine event, provided that the same musicians participate throughout the whole event. However, this account cannot rule out the event that is the sum of what happens in a music store during a certain interval (provided that no new customer enters the store).

Regarding scenario 2, with a fixed set of objects we cannot deal with players being replaced or being sent off the match. We would have the same problem with events involving the creation or destruction of objects (*e.g.,* the manufacturing of a product). Relaxing the constraint and delimiting an event using a variable set of objects could solve the issue of variability of participants throughout the event, but then it would introduce the issue of what unifies this variable set of objects to be the invariant element in the course of the event. In the end, the criterion to decide what participates in the event at each time would be completely left to the modeler's intuition.

Anyway, although this criterion establishes that there must be an invariant set of objects that delimits the event, it is still an open issue how to decide which is the suitable set of objects that delimits an event and which ones are not adequate. For example, still regarding scenario 2, there is nothing in this criterion to prevent us from arbitrarily including some of the health professionals that are in a state of readiness on the side of the field as participants of the match.

Constraining an event to what happens to a set of focal properties can help in scenario 1 if we consider that the focal properties that delimit an event are those composing certain necessary relationships among the participants (*e.g.,* the set of commitments and expectations that bond together the members of a band). Hence, this account can accept the jam session as a genuine event while rejecting the case of the music store since there is no further relationship among the customers besides that of being present in the same room. However, if we have two different bands independently carrying out two jam sessions in different practice rooms, this criterion cannot exclude the odd possibility of regarding the sum of the two sessions as a single event. It would just be a matter of considering the sum of the relationships among the members of one band and the relationship among the members of the other band as the set of focal properties that delimits the overall event composed of the two jam sessions.

In addition, delimiting an event by a fixed set of properties prevents this account from dealing with the possible variation of participants in a soccer match (scenario 2) or in the case of the creation and destruction of objects. Since properties are existentially dependent on their bearers, to account for the entry or exit of participants it would be necessary to add or remove properties from the set of focal ones. Even if we consider that the focal properties of an event are the relationships among its participants and that such relationships endure in time and can undergo qualitative changes, the issue persists. Arguably, as suggested in "*a relationship is the particular way a relation holds for a particular set of relata*" [GUARINO; GUIZZARDI, 2015], the identity of a relationship is tied to that of its relata. Thus, the entry/exit of participants would result in the creation/destruction of relationships, altering the set of focal relationships.

Choosing to delimit an event as what happens to a variable set of properties would solve the problem. Nevertheless, as in the case of delimiting an event using a variable set of objects, it would introduce some arbitrariness on how to decide which properties should be focalized at each instant during the event. In the end, similarly to the case of taking a set of objects as the invariant element in an event, it is somewhat arbitrary the decision about which set of focal properties is suitable to delimit an event and which ones are not adequate.

The approach of delimiting an event as the manifestation of a single, complex disposition composed of the dispositions manifested by the participants seems to be very close to that of delimiting an event by a set of focal properties. In other words, it would consist in delimiting the event by the set of dispositions that compose the overall complex disposition whose manifestation constitutes the event. With that, it would also help in scenario 1 by delimiting the jam session as the manifestation of a complex disposition that inheres in the whole band constituted of all the musicians playing in the jam session.

However, this approach would also oddly accept as a single event the sum of two independent jam sessions carried out by distinct bands in distinct places. As exposed in section 2.5.1, for any two dispositions d_1 inhering in b_1 and d_2 inhering in b_2 there is an add-complex disposition d_1+d_2 inhering in b_1+b_2. Thus, the overall dispositions independently manifested by each of the bands would compose a larger, complex disposition manifested by the mereological sum of the two bands. Similarly, this approach would not be able to rule out the case of the music store either. In this case, there would be an overall complex disposition composed of the dispositions inhering in each of the customers that is collectively manifested by the mereological sum of the customers in the store.

Delimiting an event as the manifestation of a single, complex disposition would also face difficulties in accounting for events with varying participants (exemplified in scenario 2). The event would be the manifestation of an overall, complex disposition that inheres in the mereological sum of the participants. Bearing in mind that two dispositions are the same only if their bearers are the same, the overall disposition that unifies the event will remain the same over time only if the mereological sum of the participants of the event preserves its identity in face of the entry and exit of participants. Clearly, this is not the case if we consider that mereological sums have an extensional identity criterion (*i.e.,* two sums are the same iff they have the same components).

Still, it may be the case that the overall disposition remains the same if it inheres in some complex object over and above the varying mereological sum of the participants – which seems to be exemplified in both scenarios 1 and 2. In scenario 1, we could say that the jam session is carried out by the same band, despite possible changes in the band members during the session. In scenario 2, the soccer match involves the same two teams facing each other throughout the match, even though some players may be replaced during the event. These examples seem to point out the existence of an underlying complex object that endures throughout the duration of the event and that bears the overall, complex disposition.

Finally, we have the approach of unifying the situations in the course of an event by conforming to an invariant structural element and unifying the set of objects that are present in each of these situations by being joined according to this structural element (approach (III) In general, following this approach we can account for the events in both scenarios 1 and 2.

Starting with scenario 2, this approach can account for the soccer match and its variation of participants. The match may be seen as a variable embodiment structured as two teams of at most 11 players each plus a soccer field, and some furniture (*e.g.,* a ball, two goals). Additionally, there are some relationships among the members of each team (concerning common goals and tactical procedures), between the teams, and between players of opposed teams (concerning commitments of the players to a set of rules and to a common forum for arbitration of disputes, *i.e.,* the referee), among others, that constitute a framework in respect to which something qualifies as participating in the event. It may also be seen as the repeated manifestation of a pattern of occurrence according to which we have a group of players in possession of a ball trying to take it to the opposite side of the field while another group of players tries to block this advance and take the ball from the other group, with the groups taking turns in playing each of these roles.

Nevertheless, there is no well-established way to determine what the suitable invariant structure is. The principle of variable embodiment could be established simply in terms of a container delimited by the borders of the field, resulting in the involvement of, for example, the health professionals that occasionally enter the field as participants of the match. The match could also be defined, for example, as just the pattern of occurrence characterized by some player with the ball possession being challenged by other players. Then, the match would be the succession of such plays and the participants at each time would be only those players directly involved in the current play.

Analogously, in scenario 1, it can account for the blues jam session. However, the ability to accept the jam session as a genuine event while ruling out the case of a single event composed of the activities of unrelated customers will depend on which invariant structural element is chosen. Both cases can be regarded as concerning a (possibly) variable embodiment of musicians and as being the manifestation of a pattern of occurrence during a time interval. Hence, it remains up to the modeler to decide why one of the cases seems to suitably correspond to an event while the other seems just a discretionary mereological sum of smaller events.

Therefore, the approach of unifying the situations in the course of an event by an invariant structural element seems to reveal a significant aspect of events, which has useful implications. Even so, the treatment of this aspect is given on a very high level of abstraction, with not much guidance regarding its application to concrete cases, leaving a considerable degree of arbitrariness in modeling decisions.

5.2.1 Summary of Weaknesses on Existing Approaches

The spatiotemporal approach (I) restricts the portion of reality that is subject to the event as what is contained in a spatiotemporal region, which provides both a longitudinal unifying criterion for events (*i.e.,* the succession of situations in the course of an event is the temporal slices of the region) and a transversal unifying criterion (*i.e.,* the participants at each time are the contents of each temporal slice). However, besides preventing co-located events, those unifying criteria are based on a discretionary external cut rather than on some account of how reality unfolds in time, so that, in order to account for an ordinary event, one needs to first identify what is the event and, from that, delineate the spatiotemporal borders - which seems to be an a posteriori criterion.

The causal link approach (II) is concerned with internal cohesion for the succession of situations in the course of an event, which provides a longitudinal unifying criterion. It does not provide a transversal unifying criterion though, for it does not establish any cohesion among the participants of the event at each time and seems unable to properly deal with the entry and exit of participants.

The non-bounding content invariance approach (III) relies on tracking a core element and its surroundings through time, which provides a longitudinal unifying criterion based on this master line and a transversal unifying criterion delimited by the surroundings of the core element. The problem here is that the transversal criterion is based on an externally imposed delimitation of a spatial threshold rather than some internal cohesion among the participants of the event that is kept through time.

The bounding content invariance approach (IV) selects the participants of the event beforehand, either directly (*i.e.,* by fixing a single object or set of objects) or indirectly (*i.e.,* by fixing a set of focal properties, consequently selecting their bearers as participants). This provides a longitudinal unifying criterion for the course of the event given by the ontical connection / genidentity relation among the snapshots of the participants over time. It also establishes a transversal unifying criterion for the participants that may reflect some internal cohesion among them (*e.g.,* focusing on the relationships among the participants or on an overall complex disposition they collectively bear), but that leaves room for the selection of non-related participants. Besides that, by fixing the participants throughout the event, this approach is unable to deal with any variation in the set of participants through time.

Finally, the bounding structural invariance approach (V) points to the establishment of some guiding principle for delineating the course of the event, which supplies a longitudinal unifying criterion for events based on the cohesion of its course (*i.e.,* all situations being “stages” of the same structure) as well as a transversal unifying criterion based on the cohesion among the participants (*i.e.,* being components of the same defined structure). Still, although it seems to contemplate a central aspect of the nature of the events, it only yields a high-level guideline (*i.e.,* that there must be an overall structural principle kept throughout the event), not specifying what would be adequate and inadequate structural invariance, leaving a significant discretionary component on the modeling of components.

5.3 System as the Invariant Element Unifying the Situations in the Course of an Event

We can enumerate four major weak points that are present in different degrees on the unifying criterion for events that were discussed in the previous section:

(a) No account for internal cohesion among participants;

(b) No account for internal cohesion among situations;

(c) Inability to account for the possibility of variation of participants throughout an event;

(d) Arbitrariness on application.

If a unifying criterion presents (a), it accepts certain mereological sums of events as composing a single larger event (*e.g.,* all the people having dinner in the same restaurant at the same time could be considered as participating in a single overall dinner). With the flaw described in (b), the criterion accepts a chain of unrelated events as a single one (*e.g.,* the occurrence of a concert in an auditorium shortly followed by the occurrence of another concert could be regarded as the same event). Moreover, (a) and (b) seem to characterize unity criteria that we apply *a posteriori* to rationalize a genuine unity we have already recognized by some other implicit principle (so to speak, to fit the picture we have already delineated by other means).

Unifying criteria that present (c) rule out an arguably important class of events, *e.g.,* parties (with guests constantly coming and leaving), wars (in which countries can enter or leave), or soccer matches. In the case of (d), the criterion is so broad it can incorporate many possible variations and *ad hoc* adjustments that make it accept virtually any model of event. Consequently, it hinders its ability to provide a distinction between intended and unintended models of events.

Each of the discussed criteria presents at least one of those weaknesses. Thus, we have an opportunity to contribute by conceiving a unifying criterion for events that is

(I) Flexible enough to account for the possibility of variation of participants throughout an event;

(II) Based on some internal cohesion of events, related to their nature as such type of entity;

(III) Stricter than the alternatives, mitigating the discretionary component involved in its application so that it can work as a guide to reject unintended models.

In order to do so, we propose to follow the approach of using some bounding structural invariance as the basis for a unifying criterion for events. Particularly, we propose employing the notion of *system* as the invariant element that unifies the situations in the course of an event and unifying the participants in each of such situations, with its components at each instant being the participants of the event at the time.

We believe that this notion qualifies for the task for it tackles the three above-mentioned points. The ability of systems to survive the gaining and losing of components grants the flexibility required in (I). The (causal) connections among the components of a system can reflect the interaction among participants in an event, yielding the transversal aspect of internal cohesion demanded in (II). Complementarily, given the permanence of the same system throughout an event, the ontical connection among the snapshots of the system provides a causal-like link among the situations in the course of the event, filling the longitudinal aspect of (II).

On top of that, the notion of system can be viewed as a particular case of variable embodiment, with a more specific principle of embodiment (based on the arrangement of connections among the components). Consequently, it also conveys a more restrictive criterion of application (*e.g.,* although the mere aggregate of objects in a given spatial region may be considered a variable embodiment, it does not constitute a system). Hence, it reduces the room for broader interpretations that lead to accepting unintended models, as specified in (III).

Therefore, in the remainder of the chapter, we investigate the link between events and systems in the light of the manifestation view of events and discuss how this relationship can be used to delimit events under the transition view. To accomplish that, in the next section we determine a contact point between systems and dispositions. Based on that, in the last section, we establish the link between systems and events that manifest the dispositions associated with such systems.

5.4 Dispositional Connections

Both connections and dispositions are entities that determine the behavior of objects. With that, we can define at least some cases of connections in terms of dispositions.

Connections are relationships that modify the behavior history of objects. This means that, in certain circumstances, *ceteris paribus*, an object standing in a connection would behave in a different way than that it would behave if not standing in the connection.

A disposition determines the behavior of its bearer by enabling its associated realization events to happen to the bearer. Yet, a disposition is only a necessary, but not sufficient condition for its realization [BUNGE, 1977, p.180], since such an event depends not only on the presence of the disposition but also on the presence of the required stimulus conditions. In other words, although a disposition sets the path for some behavior of its bearer under certain circumstances, the effective occurrence of such behavior depends on the presence of those circumstances.

With that, let us suppose we have an object x_1 that bears a disposition d_1, which requires conditions c_1 and c_2 to be manifested in an event e of type E (*i.e.,*e::E) that has x_1 as a participant. Let us also assume that there is a type of relationship R such that if x_1 stands in some relationship r of type R (*i.e.,*r::R) with some object x_2, c_2 is established. Now, we can picture two possible scenarios:

(1) x_1 stands in some r::R with object x_2, *i.e.,*$R(o_1,o_2)$; or

(2) x_1 and x_2 are not related by any R.

Taking scenario (1), if c_1 is established at time t, both c_1 and c_2 will be present, which activates the disposition d_1, leading to the happening of some e::E. On the other hand, taking scenario (2), if c_1 is established at time t, only c_1 will be present, which is not sufficient to activate d_1, so that no e::E happens. In this case, the behavior history of x_1 in scenario (1) is different from that in scenario (1), *i.e.,*x_1 behaves differently upon the establishment of condition c_1 depending on whether it stands in some r::R or not. Given this difference in the behavior history of x_1 in virtue of $R(o_1,o_2)$, a relationship r::R between x_1 and x_2 qualifies as a connection.

This case illustrates the fact that any relationship in which an object stands and that provides some of the stimulus conditions for the activation of a disposition of this object can be considered a connection. With that, we define the notion of ***dispositional connection***:

Definition 43 ***Dispositional Connection*** $=_{def}$ *A relationship that fulfills some (or all) of the stimulus conditions of one or more dispositions of one of its relata.*

If a dispositional connection r fulfills a stimulus condition c of a disposition d, we say that r is *associated with* d. Moreover, if c consists in the bearer of d being connected through r to another object that bears a property p, we also say that r *exposes* d to p and, thus, that d is ***exposed to*** p, which is captured in definition 44. On top of that, we also define the ***mutually exposed*** relation (def. 45) that holds between two dispositions when they are exposed to each other.

Definition 44 ***exposed_to****(d,p)* $=_{def}$ *A binary relation between a disposition* d *and a property* p *of type* P *such that*

(1) d *inheres in an object* x*; and*

(2) p *inheres in an object* y*; and*

(3) there is a dispositional connection c *of type* C *between* x *and* y*; and*

(4) one of the stimulus conditions of d *is having its bearer connected through a connection of type* C *to another object that bears a property of type* P*.*

Definition 45 ***mutually_exposed****(*d_1*,*d_2*)* $=_{def}$ *A binary, symmetrical relation between dispositions* d_1 *and* d_2 *such that* exposed_to(d_1,d_2) *and* exposed_to(d_2,d_1)*.*

Finally, it is an open question whether dispositional connections are just a special case of connection, or they are equivalent to the general notion of connection. Still, for our purposes, it suffices to say that they are full-fledged connections.

5.5 System-Invariant Events

As exposed in the section 2.5, for the class of dispositions considered in this work, in order for a disposition d of an object o_1 to be manifested, a situation gathering stimulus conditions that activate d must exist. Particularly, such a situation must include o_1 bearing d and at least some other object o_2 that is external to o_1, that bears properties that match d (*i.e.,* properties that contribute for the stimulus conditions of d), and that is in some way related to o_1 so that d can be activated.

With that, in light of what was discussed in the previous section, the manifestation of a disposition requires the presence of its bearer and one or more external objects dispositionally connected to it. Given the account of systems in section 2.6, such dispositionally connected objects would form a (concrete) system. Hence, every manifestation of disposition requires the existence of a system for its activation. Therefore, every event that is the manifestation of some disposition requires a system in order to happen, which we will call *activation system*. On top of this, the situation comprising the stimulus conditions for the activation of the disposition is a snapshot of this activation system.

Considering the transition view, we can say that the manifestation of a disposition implies a transition from a situation that gathers the stimulus conditions that activate the disposition to another situation comprising the result of such manifestation. This event is, in fact, a transition between snapshots of the activation system, from a snapshot with its components arranged in a way that activates the disposition to a later snapshot of the same system after the realization of the disposition. Thus, so far, we have that this simple type of event consists of a transition between situations that are snapshots of a single system.

Following that, the resulting situation of such a simple event may also be a snapshot of the activation system arranged in a way that gathers the stimulus conditions to activate some disposition. This would lead to a transition to another snapshot of the system, which may also consist of a state of the system that activates further dispositions, which may again lead to a state that activates further dispositions, and so on, following the dynamics described in [GUIZZARDI et al., 2013, sec. 6]. Particularly, in this case, we would have a series of snapshots of a single system, each bringing about the conditions to activate the dispositions that lead to the following snapshots. This fits the description of the course of a prolonged event which would have a single system as an invariant structural element among the situations. As an account for this type of event, we define the notion of ***system-invariant event*** as follows:

Definition 46 ***System-Invariant Event*** $=_{def}$ *An event whose course is composed of situations that are snapshots of a single system.*

By this definition, a system-invariant event is a transition through situations that are configurations of the components of a system at different time instants. Then, it is an event whose participants maximally compose a system that persists during the happening of the event. That is, at each time t within the duration of a system-invariant event, every participant of the event is a component of the corresponding system and *vice-versa*. Considering that, being a participant in a system-invariant event is a matter of being a component of the corresponding system at some time during the happening of the event.

Besides, the activation system of a system-invariant event works as a context encompassing a set of objects arranged in a way such that their interactions are able to activate some of their dispositions, leading to transitions to further configurations of this set of objects. In other words, this system is responsible[2] for the manifestation of the dispositions that bring about each of the situations in the course of the event.

Given this description, the activation system of a system-invariant event circumscribes all and only the participants of the event. Moreover, it is structured according to the properties that enable the happening of the event (*i.e.,* dispositions and other properties associated with their stimulus conditions). In other words, such a system delimits the portion of reality that is subject to the event. Hence, we can say that a system-invariant event is *delimited by* its activation system, and we define this relationship as follows:

Definition 47 ***delimited_by****(e,sys)* $=_{def}$ *Relationship between a system-invariant event* e *and a system* sys *such that all the situations in the course of* e *are snapshots of* sys*.*

Axiom 7 $\forall$*o,e,t Object(o)* $\wedge$ *System-Invariant-Event(e)* $\wedge$ *Time(t)* $\Rightarrow$ *(participates_in(o,e,t)* $\iff \exists$*s System(s)* $\wedge$ *has_component(s,o,t)* $\wedge$ *delimited_by(e,s)* $\wedge$ *during(e,t)).*

Here we must make a remark. Clearly, given axiom 7, the system that delimits an event must exist during the interval in which the event happens. However, it does not imply that the existence of the system is restricted to such an interval. That is, the interval in which the system exists must include the interval in which the event happens, but we do not claim that those intervals must coincide. For now, we do not promptly exclude cases in which a system already exists before the event it will delimit, with the event starting when the system reaches a state that activates the dispositions whose manifestation gets the event going. Likewise, we do not exclude the possibility of the system remaining in existence after the event, with the event ending when the system reaches a state that activates no further disposition that characterizes the unfolding of the event.

In summary, systems *transversally* delimit events (*i.e.,* establishing the boundaries of any instantaneous cross-section of an event, determining what is involved in or part of an event at a given instant), but do not *longitudinally* delimit them (*i.e.,* determining the temporal boundaries of an event, that is, when it starts and ends). Even so, at least in some cases, we can draw temporal boundaries of an event based on its delimiting system, *e.g.,* if the system that is delimiting an event is dismantled then the event also ends.

On the other hand, the system that delimits an event provides the cohesion that we arguably expect when observing an event. Therefore, we do say that every system-invariant event is both transversally and longitudinally unified by a system, *i.e.,* it is an

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[2] Or, at least, partially responsible, as we will see in the case of open and auxiliary events, in chapter 6.

enduring system that grants the cohesion that gathers the participants of the event at each time and that gathers a succession of situations into the course of the event.

In light of the discussion so far, the next chapter presents further implications of the idea of delimiting events with systems. We investigate the relationships between events whose delimiting systems overlap and combine the notion of system-invariant events with the types of systems defined in section 2.6.3 to derive sub-types of system-invariant events. We also explore interesting consequences of this approach to the conceptual modeling of events.

As a last remark, the recurrent correspondence between the manifestation of dispositions and the transition between snapshots of a system that activated such dispositions suggests the prevalent nature of system-invariant events. Nevertheless, what we have discussed so far does not entail that all events are system-invariant events. Even so, for the sake of easing the flow of the remaining text, from now on we will *assume* all events to be system-invariant events (simply calling them *events*). In chapter 8 we discuss the generality of this account for events, as well as its benefits and limitations.

6 EXPLORING CONSEQUENCES OF DELIMITING EVENTS WITH SYSTEMS

In this chapter, we explore four main consequences of delimiting events with systems. First, by having a way to delimit what is subject to an event, we can identify events that are transformations of portions of reality that have some part in common (*e.g.,* an event that shares some of its participants with another event, such as preparing coffee while listening to music in a smartphone). In other words, we can recognize events that overlap not only in time but also in terms of what is subject to them. Such (partially) *overlapping events* would be events delimited by (partially) overlapping systems (*e.g.,* the system *person* + *coffee machine* overlaps the system *person* + *smartphone*).

The second notable consequence is the possibility of conceiving events that affect the unfolding of other events. For instance, since we can have events that operate over a common portion of reality, it is possible that certain changes that an object x that participates in an event ev undergoes are not consequences of the happening of ev. Instead, it may be the case that those changes are a result of another, *auxiliary event* ev' in which x simultaneously participate. As we will see, we can consider the effect of an *auxiliary event* over a *main event* as an influence of the environment over the system that delimits the affected, main event. Thus, based on the aspects in which a system may be open or closed (presented in 4.3), we can also define sub-types of auxiliary events according to the type of effect that their instances have on other events.

A third point regards the possibility of specializing the category of system-invariant events in terms of the type of system that delimits its instances. Particularly, we can derive sub-types of system-invariant events according to the types of open/close systems described in section 4.3. This allows us to define types of system-invariant events in terms of the possible environmental influences to which their delimiting systems are susceptible (*i.e.,* those related to the aspects to which the delimiting system is open). With that, since an auxiliary event takes place due to the interaction of the delimiting system of the affected main event with the environment of such a system, we can categorize system-invariant events in terms of the types of auxiliary events that can affect them.

Finally, using systems to delimit events leads to other useful consequences for ontological analysis and modeling of events. For example, it allows us to apply the principle of ontological conservation (section 4.4) to the notion of events, and makes it possible to derive further types of events, modeling constraints, and modeling patterns to help modelers.

Each of these points is further discussed in the following sections.

6.1 Overlapping Events

As discussed in section 3.1, in this work we assume that two distinct events can happen to the same objects at the same time. In other words, events can *overlap* with respect to the portion of reality that is subject to them. In the case of a system-invariant event, it is a system that delimits the portion of reality that is subject to it. Therefore, two system-invariant events overlap iff (1) they temporally overlap and (2) their delimiting systems overlap during a time interval in which both events are happening. To capture this idea we define the *subject_overlap* relation as follows:

Definition 48 ***subject_overlap***$(ev_1, ev_2) =_{def}$ *A binary relation between an event* ev_1 *delimited by the system* sys_1 *and another event* ev_2 *delimited by the system* sys_2 *such that*

(1) ev_1 *and* ev_2 *temporally overlap at a time instant* t*; and*

(2) $overlap(sys_1, sys_2)$ *at* t*.*

When we have two overlapping events, we in fact have two distinct events that are transformations of portions of reality that overlap. Consequently, there is always something in each of the overlapping events (*e.g.,* a participant, a part of a participant) that lies within the shared portion of reality and that, ergo, may be affected by the occurrence of both events – which means that neither of the events fully determine the configuration of its respective portion of reality at a given time.

That is to say, when we have two distinct, overlapping events ev_1 and ev_2 there is necessarily something that is subject to ev_1 whose trajectory in the quality space may not be exclusively given by the occurrence of ev_1 but may rather also be affected by the unfolding of the event ev_2. With that, the configuration of the portion of reality that is subject to ev_1 at a given time t may not simply result from the transformation provided by ev_1 over the configuration at $t\text{-}1$. Instead, it may be a result comprising the effects of both ev_1 and ev_2 (or even only ev_2). In other words, in case of event overlapping, an event can affect the portion of reality that is subject to another, external event.

Frequently, such external effects over the portion of reality that is subject to an event are mostly irrelevant to its unfolding. For instance, a change in the color of a car during a race would not affect the race, the same way as a breath that someone takes while having dinner would not considerably influence the dinner). Still, sometimes these external effects can indeed impact the unfolding of an event in a significant way. For example, the fall of rain over the track during a car race may interfere with the performance of the competitors, and the cooling of a reactor may slow down a chemical reaction that is going on inside it. In the next section, we discuss events that lead to effects of the latter sort.

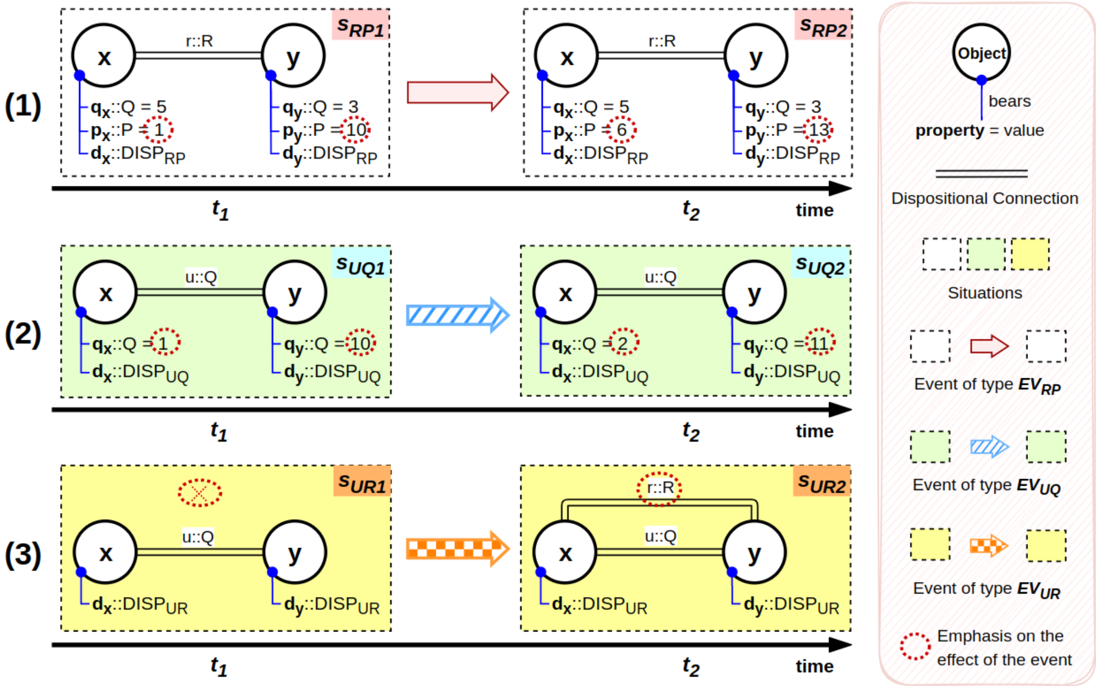
6.2 Auxiliary Events

Recollecting some notions discussed in previous chapters, a prolonged event is a series of transformations of a given portion of reality from one situation to another. Each of such transitions could be viewed as a function mapping the current configuration of this portion of reality, *i.e.,* a situation s, to another configuration of the same portion of reality, *i.e.,* a situation s'. For system-invariant events, it is a system that delimits the portion of reality that undergoes transformation and the succession of situations that compose the course of the event correspond to a sequence of snapshots of this system over time.

Additionally, in section 6.1, we proposed the notion of subject overlapping events as system-invariant events that operate over an overlapping portion of reality and that, in certain circumstances, one of them can have some effect on the unfolding of the other. That is, we may have an event ev_1 that comprises a transition from s to s' such that the configuration in s' is not completely given by ev_1, being rather partially determined by an overlapping event ev_2. Moreover, the contribution of ev_2 to s' may have an impact on which situations will succeed s', making the course of ev_1 distinct from the course of the event that would happen instead of ev_1 if ev_2 had not happened. Here, ev_2 would be what we call *auxiliary events*.

In this section, we elaborate on the nature of such events. We start by presenting some hypothetical scenarios depicting ways in which an event may affect another. Based on that, we propose a definition for auxiliary events as well as a classification of such events according to the type of effect they may have on other events. We end the section with a reflection on the contextual facet of auxiliary events.

Figure 6.1 – Exemplying the types EV_{RP}, EV_{UQ}, and EV_{UR}



Source: the author

6.2.1 Hypothetical Explanatory Scenarios

To construct the referred hypothetical explanatory scenarios, we assume the existence of some hypothetical types of entities. We consider two types of qualities P and Q whose instances have integer values, two types of binary and symmetric relations R and U, and three types of disposition $DISP_{RP}$, $DISP_{UQ}$, and $DISP_{UR}$. On top of that, we consider three types of events EV_{RP}, EV_{UQ}, and EV_{UR}, whose instances comprise the manifestation of, respectively, dispositions of type $DISP_{RP}$, $DISP_{UQ}$, and $DISP_{UR}$.

In what follows, we define each of such types of events. Moreover, figure 6.1 depicts occurrences of each of such types of event, including the relevant properties for their unfolding and emphasizing the effect of each occurrence (*i.e.*, the difference between the entities in the course of the event).

Definition 49 $\boldsymbol{DISP_{RP}} =_{def}$ *A disposition that inheres in an object* x *such that*

(1) *its stimulus conditions are* x *bearing qualities* p::P *and* q::Q*,* x *standing in a relation* $R(x,y)$*, and* y *bearing a disposition* d_y::$DISP_{RP}$*;*

(2) *its manifestation is increasing the value of* p *by the value of* q*.*

Definition 50 $\boldsymbol{DISP_{UQ}} =_{def}$ *A disposition that inheres in an object* x *such that*

(1) its stimulus conditions are x bearing a quality q::Q, x standing in a relation R(x,y), and y bearing a disposition d::$DISP_{UQ}$;

(2) its manifestation is increasing the value of q by 1.

Definition 51 ***$DISP_{UR}$*** $=_{def}$ *A disposition that inheres in an object x such that*

(1) its stimulus condition are x standing in a relation U(x,y) and y bearing a disposition d::$DISP_{UR}$;

(2) its manifestation is the establishment of a relation R(x,y).

Definition 52 ***SYS_{RP}*** $=_{def}$ *A system composed of the objects {x_1, ..., x_n} such that each x_i stands in a relation R(x_i,x_j), bears a disposition d_i::$DISP_{RP}$, and bears qualities p_i::P and q_i::Q.*

Definition 53 ***SYS_{UQ}*** $=_{def}$ *A system composed of the objects {x_1, ..., x_n} such that each x_i stands in a relation U(x_i,x_j), bears a disposition d_i::$DISP_{UQ}$, and bears a quality q_i::Q.*

Definition 54 ***SYS_{UR}*** $=_{def}$ *A system composed of the objects {x_1, ..., x_n} such that each x_i stands in a relation U(x_i,x_j) and bears a disposition d_i::$DISP_{UR}$.*

Definition 55 ***EV_{RP}*** $=_{def}$ *An event that is delimited by a system sys::SYS_{RP} and that consists in the increasing of the value of each quality p_i::P of each participant x_i.*

Definition 56 ***EV_{UQ}*** $=_{def}$ *An event that is delimited by a system sys::SYS_{UQ} and that consists in the increasing of the value of each quality q_i::Q of each participant x_i.*

Definition 57 ***EV_{UR}*** $=_{def}$ *An event that is delimited by a system of type SYS_{UR} and that consists in establishing a relation r::R between each pair of participants that stand in a relation u::U.*

Given that, let us consider a scenario (1) comprising the happening of an event ev_a::EV_{RP}, delimited by a system sys_a::SYS_{RP}, which is composed of the objects a_1 and a_2, and whose structure comprises

- a disposition d_{a1}::$DISP_{RP}$ and the qualities p_{a1}::P and q_{a1}::Q that inhere in a_1;
- a disposition d_{a2}::$DISP_{RP}$ and the qualities p_{a2}::P and q_{a2}::Q that inhere in a_2;

- a relation r::R that holds between a_1 and a_2, which, given definition 49, qualifies as a connection for exposing d_{a1} and d_{a2} to each other.

Such an event takes place during the time interval [t_1,t_3] as a transition through situations corresponding to the snapshots of sys_a at t_1, t_2, and t_3, *i.e.,* the situations sa_1, sa_2, and sa_3, respectively.

Let us also consider two alternative scenarios (2) and (3) in which, instead of ev_a, we have counterpart events ev_a'::EV_{RP} and ev_a''::EV_{RP}, respectively. Both of such events are also delimited by sys_a, also take place during the time interval [t_1,t_3], and also has sa_1 as their initial situation. However, due to the context in which they happen, these events differ in the situations that succeed sa_1 – *i.e.,*sa_2' and sa_3' in the case of ev_a' and sa_2'' and sa_3'' in the case of ev_a''.

Given this description, such scenarios represent three distinct possible worlds comprising alternative behavior histories regarding the components of sys_a. We describe each scenario in the following sections.

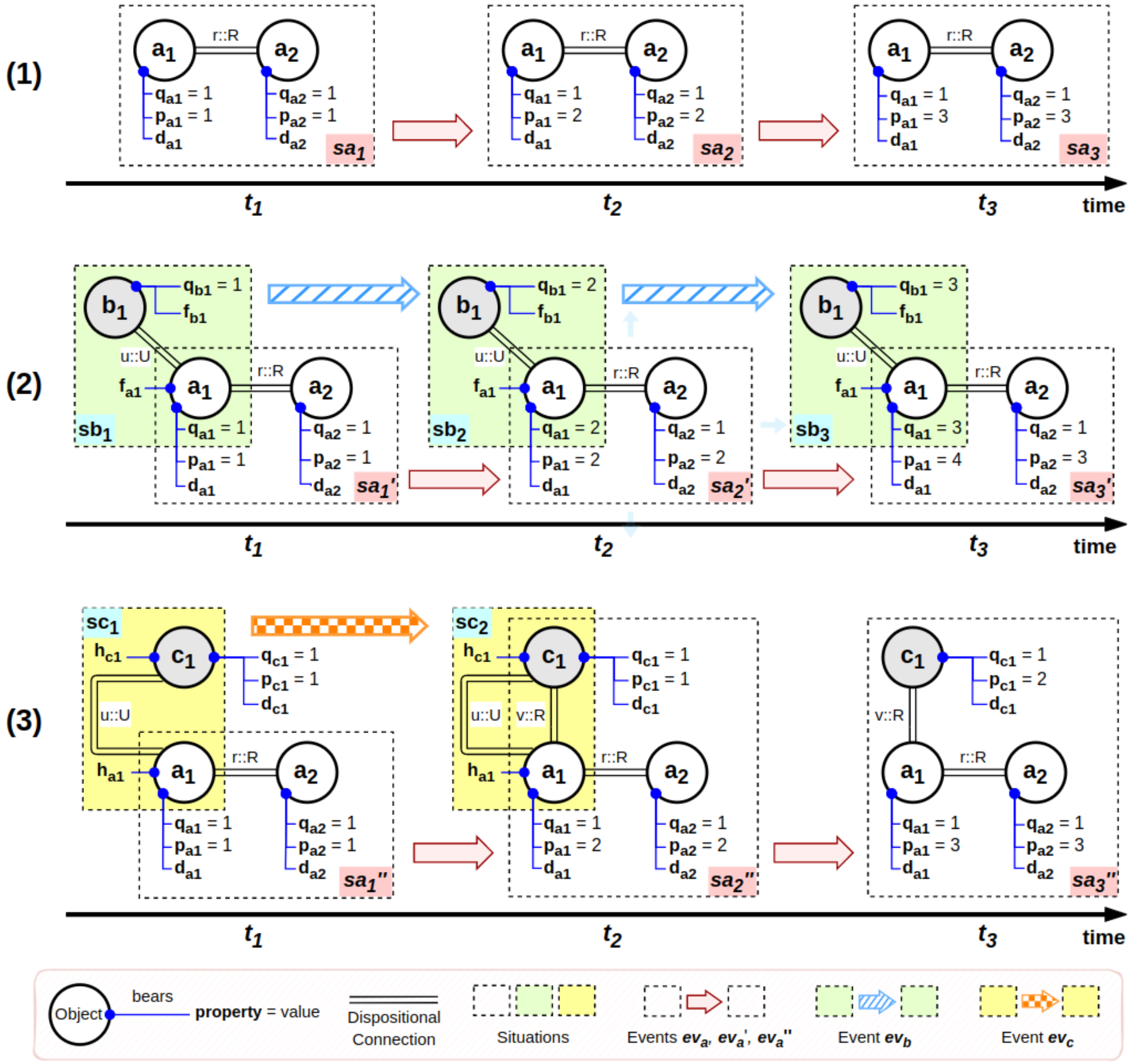
6.2.1.1 Scenario 1

In scenario (1) (fig. 6.2(1)), ev_a is the only event that takes place. At t_1, the values of p_{a1}, p_{a2}, q_{a1}, and q_{a2} are equal to 1. Since ev_a does not affect either q_{a1} or q_{a2}, their values remain 1 during the whole interval [t_1,t_3]. Moreover, since ev_a is the only event happening in this scenario, the situation sa_2 at t_2 would be simply the configuration of sys_a that results from the manifestation of dispositions that were triggered by the conditions provided sa_1 at t_1. The same mechanics applies to sa_3. Therefore, following the definitions of EV_{RP} (def. 55) and $DISP_{RP}$ (def. 49), at t_2 the value of p_{a1} would be the sum of the values of p_{a1} and q_{a1} at t_1, which results in $p_{a1}=2$ at t_2. Similarly, $p_{a2}=2$ at t_2. At t_3, the value of p_{a1} would be 3 (*i.e.,* the sum of $p_{a1}=2$ and $q_{a1}=1$ at t_2). Again, $p_{a2}=3$ at t_3 for analogous reasons.

6.2.1.2 Scenario 2

Now, let us consider scenario (2) (fig. 6.2(2)), in which ev_a' takes place alongside another event ev_b::EV_{UQ} that is delimited by a system sys_b::SYS_{UQ}. ev_b also occurs in the interval [t_1,t_3] and is the transition through the situations sb_1, sb_2 and sb_3, which are the snapshots of sys_b at t_1, t_2 and t_3 respectively. System sys_b is composed of the objects b_1 and a_1. This system is structured by b_1 bearing a disposition f_{b1}::$DISP_{UQ}$ and a quality

Figure 6.2 – Auxiliary Events - Example Scenarios



Source: the author

q_{b1}::Q, by a_1 bearing a disposition f_{a1}::$DISP_{UQ}$ and a quality q_{a1}::Q, and by a relation u::U between b_1 and a_1 – which qualifies as a dispositional connection for exposing f_{b1} and f_{a1}.

Regarding the unfolding of ev_b, at t_1, the values of q_{b1} and q_{a1} are equal to 1. Then, according to the definitions of EV_{UQ} (def. 56) and $DISP_{UQ}$ (def. 50), the values of q_{b1} and q_{a1} increase 1 unit each time their dispositions f_{b1} and f_{a1} are manifested – *i.e.,* being equal to 2 at t_2 and to 3 at t_3.

A particularity of scenario (2) is that a_1 happens to be a component of both the system that delimits ev_a' (*i.e.,*sys_a) and the system that delimits ev_b (*i.e.,*sys_b). Then, considering that ev_a' and ev_b temporally overlap, by definition 48 we have that *subject_overlap*(ev_a',ev_b). With that, since part of the portion of reality subject to ev_a' is also subject to ev_b (namely, the object a_1), the snapshot of sys_a at a time t may not be the exclusive result of manifestations of dispositions activated by the arrangement concretized in the snapshot at t-1. Instead, it may comprise some contribution from the occurrence of ev_b, as exemplified in the situations sa_2' and sa_3'.

In scenario (2), the value of p_{a2} follows the same trajectory as in scenario (1), *i.e.,* being equal to 1 at time t_1, to 2 at t_2 and to 3 at t_3. Likewise, the value of q_{a2} remains 1 during the whole interval [t_1,t_3]. Despite that, at t_3, the value of p_{a1} is equal to 4 rather than 3 as in scenario (1).

The reason for such a difference lies in the distinct contexts in which ev_a' and ev_a happen. The value of q_{a1} is not modified either in ev_a in scenario (1) or in ev_a' in scenario (2). Nevertheless, in scenario (2), it is increased one unit at a time through the happening of ev_b, being equal to 2 at t_2 and to 3 at t_3. Since the value of q_{a1} modulates the activation of d_{a1}, this change affects the degree to which the value of p_{a1} changes in ev_a'. Hence, the happening of ev_b influences how p_{a1} is modified in ev_a', *i.e.,* increasing its value by two units from t_2 to t_3 instead of the increasing only one unit as in ev_a in scenario (1).

6.2.1.3 Scenario 3

Finally, in scenario (3) (fig. 6.2(3)), ev_a" takes place in a context in which another event ev_c::EV_{UR}, delimited by a system sys_c::SYS_{UR}, also happens. The event ev_c occurs in the interval [t_1,t_2] as a transition between the situations sc_1 and sc_2, which are the snapshots of sys_c at t_1 and t_2 respectively. The system sys_c is composed of the objects c_1 and a_1 and its structure comprises c_1 and a_1 bearing the dispositions h_{c1}::$DISP_{UR}$ and h_{a1}::$DISP_{UR}$ respectively, as well as the relation u::U that holds between such objects and that qualifies as a dispositional connection for exposing h_{c1} and h_{a1}.

The unfolding of ev_c is very simple. At t_1, c_1 and a_1 bear dispositions of type $DISP_{UR}$ and stand in a relation of type U. Then, according to the definitions of EV_{UR} (def. 57) and $DISP_{UR}$ (def. 51), this situation fulfills the stimulus conditions for the manifestation of h_{c1} and h_{a1}, which leads to the establishment of the relation $v::R$ between c_1 and a_1 at t_2.

Regarding ev_a'', it happens exactly as ev_a in scenario (1) with respect to the objects a_1 and a_2, *i.e.,* the values of q_{a1} and q_{a2} remain the same throughout the event while the values of p_{a1} and p_{a2} increase one unit at a time. However, the course of ev_a'' is not entirely identical to ev_a. In particular, in scenario (3) ev_a'' is also the event in which the value of the quality $p_{c1}::P$ of object c_1 is modified from 1 at t_1 to 2 at t_2.

This is so because, analogously to scenario (2), ev_a'' and ev_c temporally overlap and operate over a shared portion of reality (*i.e.,* the object a_1), by virtue of which we have that $subject\_overlap(ev_a'',ev_c)$ in scenario (3). With that, once more, the snapshot of sys_a at a time t is not necessarily solely the result of its snapshot at $t\text{-}1$ but may also comprise some contribution of ev_c. In scenario (3) this is exemplified by the appearance of the new participant c_1 in sa_2. This variance of participants happens despite the fact that ev_a'' simply consists in changing the value of the qualities of type P of its participants by manifestation of their dispositions of type $DISP_{RP}$ – not comprising the gathering of new participants.

Still, events of type EV_{RP} (such as ev_a'') are defined as being delimited by systems of type SYS_{RP} (such as sys_a). According to the definition of SYS_{RP} (def. 52), provided that an object x acquires a relation of type R with a current component of a system $sys::SYS_{RP}$, x will become a component of sys. In addition, given the axiom 7 (p. 96), such an x will also become a participant in whatever ongoing event ev that is delimited by sys at the time. Therefore, any event that establishes a relation of type R between such an x and a component of sys will cause the appearance of x as a participant in the course of ev.

This is precisely the case of ev_c, which consists in generating a relation of type R between c_1 and a_1, which happens to create the conditions for c_1 to become a component of sys_a and, consequently, a participant of ev_a''. Hence, the happening of ev_c influences the unfolding of ev_a'' by making it involve three participants (*i.e.,*a_1, a_2 and c_1) at t_2 and t_3 rather than only two (*i.e.,*a_1 and a_2) as in ev_a in scenario (1).

6.2.2 Auxiliary Events as Events that Affect Other Events

Each of the previous scenarios was based on a main event that presents key similarities with its counterparts in the other scenarios, *i.e.,* same type (EV_{RP}), same delimiting system (sys_a), and same initial situation (sa_1). Moreover, to investigate how an event can interfere with the unfolding of another, in scenarios (2) and (3) we also introduced the secondary events ev_b and ev_c alongside the main events ev_a' and ev_a". Each of these secondary events overlaps with the main event in its respective scenario (*i.e.,* object a_1 is a participant of secondary and main events). Still, the secondary event also comprises an additional portion of reality not subject to the main event. In particular, the secondary event involves some object that, at a certain time, is not a participant in the main event (*i.e.,*ev_b involves b_1 and ev_c involves c_1). With that, we exemplify the case of an event that is not part of the main event but that still operates over a fragment of what is subject to such a main event.

As we can see, the courses of ev_a' and ev_a" in scenarios (2) and (3) are different from the course of ev_a in scenario (1), even though they are three events of the same type that start from the same initial conditions. This difference corresponds to the effect of ev_b and ev_c on the unfolding of, respectively, ev_a' and ev_a". Specifically, such an effect consists of a deviation from the default course that an event of type EV_{RP}, with initial situation sa_1, would have in absence of such interference – such as the course of ev_a in scenario (1).

Given the contribution of ev_b and ev_c in delineating the course of their *main events* ev_a' and ev_a", they would be what we will call *auxiliary events* in relation to, respectively, ev_a' and ev_a". In other words, *an **auxiliary event** is an event that overlaps with, but is not part of, another **main event** and has some effect on the unfolding of such a main event.* We gather these characteristics in the *auxiliary_of* relation and use it to define the notions of *auxiliary event* and *main event* as follows.

Definition 58 ***auxiliary_of***(aux,main) $=_{def}$ *A binary relation between system-invariant events aux and main such that delimited_by(aux,sys_{aux}), delimited_by(main,sys_{main}), and*

(1) subject_overlap(aux,main) and ¬part_of(aux,main);

(2) there are three situations s, s'$_{alt}$ and s'$_{default}$ and two time instants t_1 and t_2 such that

(a) earlier_than(t_1,t_2); and

- (b) *the interval during which* aux *and* main *overlap contains* t_1 *and* t_2*; and*
- (c) bound_to(s,t_1), bound_to(s'_{alt},t_2) *and* bound_to($s'_{default}$,t_2)*; and*
- (d) ¬q-equivalent(s'_{alt},$s'_{default}$)*; and*
- (e) s, s'_{alt} *and* $s'_{default}$ *are snapshots of* sys_{main}*; and*
- (f) in_the_course_of(s,main), in_the_course_of(s'_{alt},main), *and*
  ¬ in_the_course_of($s'_{default}$,main)*; and*
- (g) *if* aux *happens, then* succeeds(s'_{alt},s)*; and*
- (h) *if* aux *does not happen, then either* succeeds($s'_{default}$,s) *or* ending_situation_of(s,main)*;*

(3) *the transition from* s *to* s'_{alt} *results from the manifestation of a disposition* d *such that*

- (a) *the stimulus conditions for* d *include being exposed to some property of type* P *and there is a property* p::P *such that* exposed_to(d,p)*;*
- (b) *one of the following conditions hold*
  - (a) *at* t_1, d *is part of the structure of* sys_{aux}*, but not of the structure of* sys_{main}*; or*
  - (b) *at* t_1, p *is part of the structure of* sys_{aux}*, but not of the structure of* sys_{main}*; or*
  - (c) *at* t_1*, both* d *and* p *are part of the structure of* sys_{main} *and there is an object* o *such that*
    - (i) subject_to(o,main) *at* t_1*;*
    - (ii) *the manifestation of* d *results in* ¬subject_to(o,main) *at* t_2.

Definition 59 ***Auxiliary Event*** $=_{def}$ *A system-invariant event* aux *that stands in an* auxiliary_of(aux,main) *relation with another system-invariant event* main.

Definition 60 ***Main Event*** $=_{def}$ *A system-invariant event* main *that stands in an* auxiliary_of(aux,main) *relation with another system-invariant event* aux.

The structure of definition 58 is three-folded. In condition (1) we assert the external character of an auxiliary event in relation to its main event, *i.e.,* it must have some overlap with the main event but must not be part of it. Thus, at least one participant of the auxiliary event must not be subject to the main event at some point, or at least one (intrinsic or relational) property in the structure of the system that delimits the auxiliary event must not be part of the structure of the main system.

Condition (2) defines the general nature of the effect of an auxiliary event over its main event. This effect consists of the contrast between the course of the main event and the course of its counterpart event, delimited by the same system as the main event, that would have taken place in the same time interval if the auxiliary event had not happened. In other words, it is the difference between the course of the main event and the sequence of snapshots of its delimiting system that would obtain at the same time points if the auxiliary event had not happened. Such a contrast comprises at least one of the situations in the course of the main event being qualitatively different from the situation that would obtain at the same time instant if the auxiliary event had not happened. Alternatively, it may also consist of the obtaining of a situation in the course of the main event at a time point in which the counterpart event undisturbed event would have already ended – *i.e.,* with the auxiliary event keeping the main event happening.

Finally, in condition (3) we define the causal link between the auxiliary event and the departure of the course of the main event from the default course of its undisturbed counterpart. That is, it defines the causal contribution of the auxiliary event for the transition from a situation that is in the courses of both the main event and its undisturbed counterpart, to a situation that only composes the course of the main event.

Such a causal link may lie in the fact that such a transition comprises the manifestation of a disposition that only happens due to interaction with some element from the environment of the main system. In other words, the transition relies on the manifestation of a disposition that either inheres in some environment element or inheres in a system component but is activated by stimulus conditions that involve objects and/or properties from the environment. Alternatively, the transition may rely on a disposition in the structure of the main system but whose manifestation consists in ceasing the conditions that qualify some object as subject to the main event, resulting in the removal of the object from the main event.

This description fits events of various sorts. For instance, consider a process of microbial culture, *i.e.,* the process of multiplying microbial organisms by letting them reproduce in a culture medium[1] , as our main event. These events are greatly influenced by laboratory conditions, such as temperature. Thus, if we have an *culture warming*, *i.e.,* the event of placing a heat source near the culture medium in such a way that it

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[1] "*A solid, liquid, or semi-solid designed to support the growth of a population of microorganisms*" <https://en.wikipedia.org/wiki/Growth_medium>.

gets warmer, it will increase the rate of microbial reproduction in such a way that, from this point onwards, the succeeding situations in the course of the microbial culture will include a larger number of microbes in comparison to the situations that would follow if the warming event had not happened.

Similarly, suppose we have an *antibiotic contamination*, *i.e.,* the event of introducing antibiotics in the culture medium. In that case, it will decrease the microbial reproduction rate and, consequently, the following situations will include fewer microbes than the situations that would follow in absence of contamination. Other examples include the introduction of new members into a team while it is carrying on a task, supporters cheering players up during a football match, and the addition of catalysts to a chemical reaction.

There are several relevant types of effects that an auxiliary event can have over its main event. They are related to the aspects in which the course of an undisturbed event may differ from the course of the main event that would happen given the interference of an auxiliary event (*i.e.,* the ways in which the situations that compose the courses of such alternative events may contrast). We can distinguish them into two broader categories:

I. effects on what is subject to the event (*i.e.,* the collection of involved participants or the substrate that ultimately constitutes them); and

II. effects on the dynamics of the event itself (*i.e.,* on the changes or unchanges that the subjects of the event undergo).

To put it another way, an auxiliary event affects *what* is transformed (*i.e.,* I) and/or *how* it is transformed (*i.e.,* II). With this, we can specialize the *auxiliary_of* relation and derive a related type of auxiliary event for each of these types of effects by further specifying the condition (2) of definition 58 – in particular, by specifying the nature of the difference between situations s, $s'_{default}$, and s'_{alt} in each case.

Apart from that, since systems delimit system-invariant events, those categories of effect have some parallels with the different respects in which a system may be open or closed, *i.e.,* the way a system can be affected by virtue of its interaction with its environment (section 2.6.3). In what follows, we will elaborate on these different types of effects and the related types of auxiliary events.

6.2.3 Exchange Events

A band concert attended by a crowd of 100.000 people would feel very differently from a concert of the same band, at the same time and place, but attended by only 100 people. Also, in either case, it will certainly be two sensibly different experiences if the band that is playing is U2 or a garage band of teenagers that have just learned the first chords. Analogously, a fire that takes place in a 100-liters barrel of fuel is much easier to handle and extinguish than another one that burns a tank with 500,000 liters of fuel. The intensity of the fire would also vary very much if the fuel is wood instead of gasoline.

In all those cases the difference between the alternative events comes from the fact that, in one way or another, they differ in the amount of substrate that is subject to them – be it by varying in the number of participants, or in the specific participants that are involved, or in the extent/magnitude of the participants, or yet in what constitutes the participants.

Events that affect other events in such aspects are what we will call ***exchange events***. Hence, an exchange event is such that it contributes to determining what will be the maximal amount of substrate that is subject to another event at a given time. That is, it is by means of an exchange event that an amount of substrate becomes or ceases to be subject to a given system-invariant event (either by exchanging an entire participant or just some amount of substrate that fully or partially constitutes a participant). They correspond to the events that modify *what* is transformed in the main event.

In order to capture these characteristics, we define the ***exchanges substrate with*** and use it to define the notion of ***exchange event***. *Exchanges substrate with* is a sub-type of the *auxiliary of* relation in which the difference between situations s and s'_{alt} (def. 58) is the presence of an amount of substrate in one of the situations but not in the other. With that, an *exchange event* is an event that causes such a difference. The respective definitions go as follows.

Definition 61 (exchanges substrate with) *Given the events aux and main, and the situations s, s'_{alt} and $s'_{default}$ from definition 58, such that bound_to(s,t_1), bound_to(s'_{alt},t_2) and bound_to($s'_{default}$,t_2), then*

***exchanges_substrate_with**(aux,main) $=_{def}$ An auxiliary_of(aux,main) relation such that*

(1) there are two distinct amounts of substrate b and b';

(2) *encompasses(s,b), encompasses(s'$_{alt}$,b') and encompasses(s'$_{default}$,b);*

(3) *there is an amount of substrate b$_{ex}$ such that subject_to(b$_{ex}$,aux) at both t$_1$ and t$_2$, and either*

  (a) *¬part_of(b$_{ex}$,b) and part_of(b$_{ex}$,b'); or*

  (b) *part_of(b$_{ex}$,b) and ¬part_of(b$_{ex}$,b').*

(4) *as consequence of condition (3), either*

  (a) *¬subject_to(b$_{ex}$,main) at t$_1$ and subject_to(b$_{ex}$,main) at t$_2$; or*

  (b) *subject_to(b$_{ex}$,main) at t$_1$ and ¬subject_to(b$_{ex}$,main) at t$_2$.*

Definition 62 ***Exchange Event*** $=_{def}$ *An auxiliary event aux that stands in an exchanges_substrate_with(aux,main) relation with another event main.*

An *exchanges_substrate_with(aux,main)* relation indicates that *aux* is an event of exchange of substrate between *sys*$_{main}$ (*i.e.,* the system that delimits *main*) and its extended environment, which imposes a variation of the substrate that is subject to *main* between situations *s* and *s'*$_{alt}$. However, it does not specify the direction of the transference of substrate operated by *aux*, *i.e.,* whether *aux* is an event by which a given amount of substrate becomes or ceases to be subject to *main* To account for these two possibilities we can define two types of exchange event, *i.e., entry events* and *exit events*.

6.2.3.1 Entry and Exit Events

Entry events are exchange events by means of which some amount of substrate enters the system that delimits an ongoing main event, becoming subject to such an event. We can define it by defining the ***entry_in*** relation as follows:

Definition 63 ***entry_in****(aux,main)* $=_{def}$ *An exchanges_substrate_with(aux,main) relation such that conditions (3)(a) and (4)(a) from definition 61 holds,* i.e.,

(1) *¬part_of(b$_{ex}$,b) and part_of(b$_{ex}$,b'); and*

(2) *¬subject_to(b$_{ex}$,main) at t$_1$ and subject_to(b$_{ex}$,main) at t$_2$.*

Definition 64 ***Entry Event*** $=_{def}$ *An exchange event aux that stands in an entry_in(aux,main) relation with another event main.*

Analogously, ***exit events*** are exchange events by means of which some amount of substrate leaves the system that delimits an ongoing main event, ceasing to be subject to such an event. We can define it by defining the ***exit_from*** relation as follows:

Definition 65 ***exit_from****(aux,main)* $=_{def}$ *An exchanges_substrate_with(aux,main) relation such that conditions (3)(b) and (4)(b) from definition 61 holds,* i.e.,

(1) part_of(b_{ex},b) and ¬part_of(b_{ex},b'); and

(2) subject_to(b_{ex},main) at t_1 and ¬subject_to(b_{ex},main) at t_2.

Definition 66 ***Exit Event*** $=_{def}$ *An exchange event aux that stands in an exit_from(aux,main) relation with another event main.*

Concretely, an exchange of substrate between the system that delimits an event and its extended environment can happen in two ways: by the entry/exit of participants or by the entry/exit of substrate that constitutes the current participants. So, in the following sections, we explore these variants to specialize the category of exchange events.

6.2.4 Participant-Exchange Events

One way substrate can enter or leave an event is by means of an entire object becoming or ceasing to be a component of the system that delimits such an event, carrying along its constituent substrate. With that, such an object becomes or ceases to be a participant in the main event, and its constituent substrate becomes or ceases to be subject to the main event. As an umbrella to account for these possibilities, we define the notion of ***participant-exchange event*** in terms of the ***exchanges participant with*** relation as follows.

Definition 67 ***exchanges_participant_with****(aux,main)* $=_{def}$
An exchanges_substrate_with(aux,main) relation such that engaging_in(aux,main) or disengaging_from(aux,main).

Definition 68 ***Participant-Exchange Event*** $=_{def}$ *An exchange event aux that stands in an exchange_participant_with(aux,main) relation with another event main.*

In the following section, we clarify these definitions by defining the notions of ***engaging*** and ***disengaging*** events based on the relations of ***engaging in*** and ***disengaging from***.

6.2.4.1 Engaging Events

An ***engaging event*** is an event by means of which an object (*i.e.,* a participant of the engaging event) becomes a participant of another event. In particular, it is an entry event in which an amount of substrate enters the main event as the constituent of an object that becomes a component of the system that delimits the main event. We define this type of event in terms of the ***engaging in*** relation as follows.

Definition 69 (engaging in) *Given the events aux and main, and the situations s, s'$_{alt}$ and s'$_{default}$ from definition 58, such that bound_to(s,t_1), bound_to(s'$_{alt}$,t_2) and bound_to(s'$_{default}$,t_2), then*

engaging_in*(aux,main) =$_{def}$ An entry_in(aux,main) relation such that*

(1) there is an object x and an amount of substrate b_x;

(2) participates_in(x,aux) at both t_1 and t_2;

(3) constitutes(b_x,x) at both t_1 and t_2;

(4) ¬includes(s,x), includes(s'$_{alt}$,x) and ¬includes(s'$_{default}$,x);

(5) as a consequence of conditions (3) and (4)

(a) at t_1, ¬participates_in(x,main), by virtue of which ¬subject_to(b_x,main); and

(b) at t_2, participates_in(x,main), by virtue of which subject_to(b_x,main).

Definition 70 ***Engaging Event*** *=$_{def}$ A participant-exchange event aux that stands in an engaging_in(aux,main) relation with another event main.*

We can derive two key roles for the entities involved in an engaging event. First, we have the ***entering participant***, which is the role of the object that becomes a participant of the main event (corresponding to the object *x* in def. 69). Along with that, we have the ***anchoring participant***, which is the role played by some object that is already a participant in the main event and becomes connected to *x* due to the *engaging event*, with such a connection contributing for *x* becoming a component of the system that delimits the main event.

In what follows, we define the *engaging of* and *connecting to* relations and employ them to define the discussed roles. Figure 6.3 presents a modeling pattern integrating the types and relations defined in this section.

Definition 71 ***engaging_of****(aux,x)* $=_{def}$ *A relation between an engaging event aux and an object x such that*

(1) there is an event main such that engaging_in(aux,main);

(2) participates_in(x,aux) and ¬participates_in(x,main) at t_1*, and participates_in(x,aux) and participates_in(x,main) at* t_2*;*

(3) there is an object y such that participates_in(y,aux) and participates_in(y,main) at both t_1 *and* t_2*;*

(4) aux establishes a connection c between y and x at t_2*;*

(5) c qualifies x as a component of the system that delimits main;

(6) as a consequence of condition (5), c qualifies x as a participant of main at t_2*.*

Definition 72 ***Entering Participant*** $=_{def}$ *An object x that stands in a relation engaging_of(aux,x) with an engaging event aux.*

Definition 73 ***connecting_with****(aux,y)* $=_{def}$ *A relation between an engaging event aux and an object y such that*

(1) there is an event main such that engaging_in(aux,main);

(2) y participates in main at both t_1 *and* t_2*;*

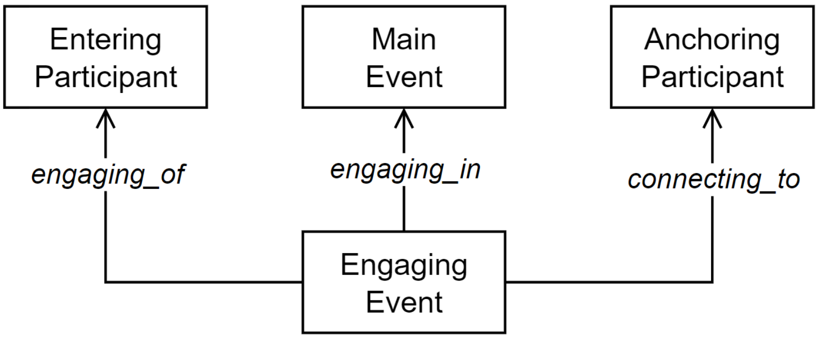
(3) there is an object x such that participates_in(x,aux) and ¬participates_in(x,main) at t_1*, and participates_in(x,aux) and participates_in(x,main) at* t_2*;*

(4) aux establishes a connection c between y and x at t_2*;*

(5) c qualifies x as a component of the system that delimits main;

(6) as a consequence of condition (5), c qualifies x as a participant of main at t_2*.*

Figure 6.3 – Roles derived from an Engaging Event.



Source: the author

Definition 74 ***Anchoring Participant*** $=_{def}$ *An object y that stands in a relation connecting_with(aux,y) with an engaging event aux.*

As a concrete example, we can imagine the manufacturing of a product, whose participants are workers, tools, a workpiece (*e.g.,* the raw material to which the workers apply the tools), and the created product. In the case of a complex product, this process would require the use of various tools for distinct tasks, in such a way that the involved workers would change the tools they use during the process. With that, the event of *tool employment* would be an engaging event that adds a new participant (*i.e.,* a tool) to the manufacturing process. Moreover, the new tool would be the *entering participant* and the worker who gets hold of it would be the *anchoring participant* since it is its handling by a worker that makes the tool become a participant in the manufacturing process.

6.2.4.2 Disengaging Events

Correspondingly, a ***disengaging event*** is an event by means of which an object that participates in the disengaging event ceases to be a participant of another event. That is, it is an exit event in which an amount of substrate ceases to be subject to the main event for being the constituent of an object that ceases to be a component of the system that delimits the main event. We define this type of event in terms of the ***disengaging from*** relation as follows.

Definition 75 *Given the events aux and main, and the situations s,* s'_{alt} *and* $s'_{default}$ *from definition 58, such that* $bound\_to(s,t_1)$*,* $bound\_to(s'_{alt},t_2)$ *and* $bound\_to(s'_{default},t_2)$*, then*

disengaging_from*(aux,main)* $=_{def}$ *An exit_from(aux,main) relation such that*

(1) there is an object x and an amount of substrate b_x*;*

(2) *participates_in(x,aux) at both t_1 and t_2;*

(3) *constitutes(b_x,x) at both t_1 and t_2;*

(4) *includes(s,x), ¬includes(s'_{alt},x) and includes($s'_{default}$,x).*

(5) *as a consequence of conditions (3) and (4)*

  (a) *at t_1, participates_in(x,main), by virtue of which subject_to(b_x,main); and*

  (b) *at t_2, ¬participates_in(x,main), by virtue of which ¬subject_to(b_x,main).*

Definition 76 ***Disengaging Event*** *$=_{def}$ A participant-exchange event aux that stands in a disengaging_from(aux,main) relation with another event main.*

Again, we can derive two main roles for the entities involved in a disengaging event. First, we have ***exiting participant*** as the role played by the object that ceases to be a participant in the main event (corresponding to the object *x* in def. 75). In addition, we have the ***origin participant***, which is a participant in the main event that is initially connected to *x* in a way that qualifies *x* as a component of that delimits the main event, and that is disconnected from *x* in the disengaging event – which results in *x* leaving the main system.

In what follows, we define the *disengaging of* and *disconnecting from* relations and employ them to define the discussed roles. Figure 6.4 presents a modeling pattern integrating the types and relations defined in this section.

Definition 77 ***disengaging_of****(aux,x) $=_{def}$ A relation between a disengaging event aux and an object x such that*

(1) *there is an event main such that disengaging_from(aux,main);*

(2) *participates_in(x,aux) and participates_in(x,main) at t_1, and participates_in(x,aux) and ¬participates_in(x,main) at t_2;*

(3) *there is an object y such that participates_in(y,aux) and participates_in(y,main) at both t_1 and t_2;*

(4) *there is a connection c between x and y at t_1;*

(5) *aux ceases the connection c, which no longer exists at t_2;*

(6) *c was what qualifies x as a component of the system that delimits main at t_1;*

(7) *as a consequence of condition (6), without c, x no longer qualifies as a participant of main at t_2.*

Definition 78 ***Exiting Participant*** *$=_{def}$ An object x that stands in a relation disengaging_of(aux,x) with a disengaging event aux.*

Definition 79 ***disconnecting_from****(aux,y) $=_{def}$ A relation between a disengaging event aux and an object y such that*

(1) *there is an event main such that disengaging_from(aux,main);*

(2) *participates_in(y,aux) and participates_in(y,main) at both t_1 and t_2;*

(3) *there is an object x such that participates_in(x,aux) and participates_in(x,main) at t_1, and participates_in(x,aux) and ¬participates_in(x,main) at t_2;*

(4) *there is a connection c between x and y at t_1;*

(5) *aux ceases the connection c, which it no longer exists at t_2;*

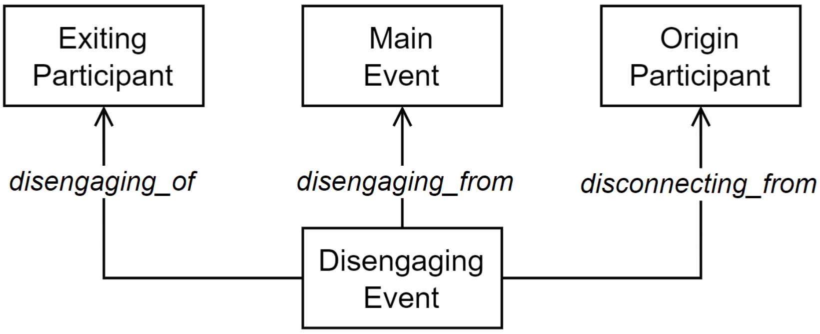
(6) *c was what qualifies x as a component of the system that delimits main at t_1;*

(7) *as a consequence of condition (6), without c, x no longer qualifies as a participant of main at t_2.*

Definition 80 ***Origin Participant*** *$=_{def}$ An object y that stands in a relation disconnecting_from(aux,x) with a disengaging event aux.*

As an illustration, we can revisit the process of manufacturing a product described in the previous section. When a worker is done using a tool, s/he releases it in order to move on to the next task. With that, the event of *tool drop* would be a disengaging event that removes a participant (*i.e.,* a tool) from the manufacturing process by ceasing the ‘handling’ relation between the worker and the tool. In this case, the released tool would be the *exiting participant* and the worker who releases it would be *origin participant*.

Figure 6.4 – Roles derived from a Disengaging Event.



Source: the author

6.2.5 Constituent-Exchange Events

Besides exchanging entire participants, the other way in which substrate can enter or leave an event is by adding or removing some amount of substrate to/from its participants. With that, such participants remain involved in the event while undergoing some change in the substrate that constitutes them (*e.g.,* acquiring or losing some functional part, increasing or decreasing in mass). In this case, the substrate that is added or removed, respectively, becomes or ceases to be subject to the event.

As an umbrella to account for these possibilities, we define the notion of ***constituent-exchange event*** in terms of the ***exchanges constituent with*** relation as follows.

Definition 81 ***exchanges_constituent_with****(aux,main)* $=_{def}$
An exchanges_substrate_with(aux,main) relation such that feeds(aux,main) or drains(aux,main).

Definition 82 ***Constituent-Exchange Event*** $=_{def}$ *An exchange event aux that stands in an exchanges_constituent_with(aux,main) relation with another event main.*

In the following section, we clarify the definitions by defining the notions of ***substrate feeding*** and ***substrate draining*** events, based on the relations of ***feeds_substrate_to*** and ***drains_substrate_from***

6.2.5.1 Substrate Feeding Events

A ***substrate feeding event*** is an entry event in which substrate enters the main event by being added as a partial constituent of an object that is already a participant in the main event. Hence, by means of a substrate feeding event, an amount of substrate can become subject to the main event without any element of the extended environment becoming a participant in such an event. We define this type of event in terms of the ***feeds substrate to*** relation as follows.

Definition 83 (feeds substrate to) Given the events aux and main, and the situations s, s'_{alt} and $s'_{default}$ from definition 58, such that bound_to(s,t_1), bound_to(s'_{alt},t_2) and bound_to($s'_{default}$,t_2), then

feeds_substrate_to(aux,main) $=_{def}$ An entry_in(aux,main) relation such that

(1) there is an amount of substrate b_{fed} such that subject_to(b_{fed},aux) at both t_1 and t_2, and ¬subject_to(b_{fed},main) at t_1;

(2) there is an object x such that

  (a) includes(s,x), includes(s'_{alt},x) and includes($s'_{default}$,x);

  (b) if succeeds(s'_{alt},s) then, at t_2, either partially_constitutes(b_{fed},x) or constitutes(b_{fed},x) and, in consequence, subject_to(b_{fed},main);

  (c) if succeeds($s'_{default}$,s) then ¬subject_to(b_{fed},main) at t_2.

Definition 84 ***Substrate Feeding Event*** $=_{def}$ A constituent-exchange event aux that stands in a feeds_substrate_to(aux,main) relation with another event main.

We can also derive some roles from a substrate-feeding event. Most evidently, we have the ***entering constituent***, which is the role of an amount of substrate that becomes subject to the main event by becoming a total or partial constituent of a participant in the main event. This corresponds to the amount of substrate b_{fed} mentioned in definition 83. We define *entering constituent* in terms of the ***feeding of*** relation as follows.

Definition 85 ***feeding_of***(aux,b_{fed}) $=_{def}$ A relation between a substrate feeding event aux and an amount of substrate b_{fed} such that

(1) there is an event main such that feeds_substrate_to(aux,main);

(2) subject_to(b_{fed},aux) at both t_1 and t_2, and ¬subject_to(b_{fed},main) at t_1;

(3) there is an object x_{rec} such that participates_in(x_{rec},aux) and participates_in(x_{rec},main) at both t_1 and t_2;

(4) *aux establishes the relation constitutes(b_{fed},x_{rec}) or partially_constitutes(b_{fed},x_{rec}) at t_2;*

(5) *as a consequence of condition (4), subject_to(b_{fed},main) at t_2.*

Definition 86 ***Entering Constituent*** *$=_{def}$ An amount substrate $b_{entering}$ that stands in a relation feeding_of(aux,$b_{entering}$ with a substrate feeding event aux.*

Although *entering constituent* is the most evident role, we do not usually trace an amount of substrate directly. Instead, we tend to track the objects that are ultimately constituted of the amount of substrate of interest – which would be the objects that ‘*carry*’ the substrate into or out from the main event. Bearing that in mind, we can derive the role of ***entering constituent carrier***, which is the role played by an object that is constituted of an amount of substrate that a substrate-feeding event feeds to the main event. We define this role in terms of the ***adding of*** relation as follows.

Definition 87 ***adding_of****(aux,carrier) $=_{def}$ A relation between a substrate feeding event aux and an object carrier such that*

(1) *there is an event main such that feeds_substrate_to(aux,main);*

(2) *subject_to(carrier,aux) at both t_1 and t_2, and ¬subject_to(carrier,main) at t_1;*

(3) *there is an amount of substrate b_{fed} such that feeding_of(aux,b_{fed}) and, at both t_1 and t_2, constitutes(b_{fed},carrier);*

(4) *there is an object x such that participates_in(x,aux) and participates_in(x,main) at both t_1 and t_2;*

(5) *aux establishes the relation part_of(carrier,x) at t_2;*

(6) *as a consequence of condition (5), subject_to(carrier,main) at t_2.*

Definition 88 ***Entering Constituent Carrier*** *$=_{def}$ An object carrier that stands in a relation adding_of(aux,carrier) with a substrate feeding event aux.*

Along with that, we can derive the ***receiver participant*** role, which is played by the participant in the main event that receives some *entering constituent* by means of acquiring the respective *entering constituent carrier* as part. It would be the role played by the object *x* in definition 83. We capture the nature of this role in definition 90, which is based on the ***adding into*** relation (definition 89). In addition, figure 6.5 presents a modeling pattern comprising the *entering constituent carrier* and *receiver participant* roles.

Definition 89 ***adding_into*****(aux,receiver)** $=_{def}$ *A relation between a substrate feeding event aux and an object receiver such that*

(1) there is an event main such that feeds_substrate_to(aux,main);

(2) participates_in(receiver,aux) and participates_in(receiver,main) at both t_1 *and* t_2*;*

(3) there is an object carrier such that subject_to(carrier,aux) at both t_1 *and* t_2*, and ¬subject_to(carrier,main) at* t_1*;*

(4) there is an amount of substrate b_{fed} *such that feeding_of(aux,*b_{fed}*) and, at both* t_1 *and* t_2*, constitutes(*b_{fed}*,carrier);*

(5) aux establishes the relation part_of(carrier,receiver) at t_2*;*

(6) as a consequence of condition (5), at t_2*,*

  (a) constitutes(b_{fed}*,receiver) or partially_constitutes(*b_{fed}*,receiver);*

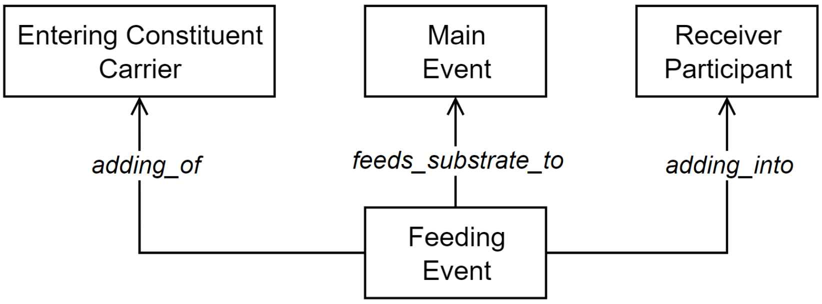
  (b) subject_to(carrier,main);

  (c) subject_to(b_{fed}*,main).*

Definition 90 ***Receiver Participant*** $=_{def}$ *An object receiver that stands in a relation adding_into(aux,receiver) with a substrate feeding event aux.*

As an illustration, imagine an automobile race whose participants are race cars and pilots. During such a race, pilots make pit stops for, among other things, putting on new tires on the car. The mounting of a tire would be an event through which an amount of substrate (*i.e.,* the material that constitutes the tire) is added to a participant in the race (*i.e.,* the car), without any new participant entering the race. Hence, *tire mounting* would be a substrate-feeding event in which the tire is the *entering constituent carrier* and the car is the *receiver participant*.

Figure 6.5 – Roles derived from a Feeding Event.



Source: the author

6.2.5.2 Substrate Draining Events

Complementarily, a ***substrate draining event*** is an entry event in which substrate exits the main event by being removed from the amount of substrate that ultimately constitutes an object that participates in the main event. With that, by means of which a substrate draining event, an amount of substrate can cease to be subject to an event without any participant in such event becoming part of its extended environment. We define this type of event in terms of the ***drains substrate from*** relation as follows.

Definition 91 (drains substrate from) *Given the events aux and main, and the situations s, s'_{alt} and $s'_{default}$ from definition 58, such that bound_to(s,t_1), bound_to(s'_{alt},t_2) and bound_to($s'_{default}$,t_2), then*

drains_substrate_from*(aux,main)* $=_{def}$ *An exit_from(aux,main) relation such that*

(1) there is an amount of substrate $b_{drained}$ such that subject_to($b_{drained}$,aux) at both t_1 and t_2, and subject_to($b_{drained}$,main) at t_1;

(2) there is an object x such that

(a) includes(s,x), includes(s'_{alt},x) and includes($s'_{default}$,x);

(b) at t_1, constitutes($b_{drained}$,x) or partially_constitutes($b_{drained}$,x) and, in consequence, subject_to(b_{fed},main);

(c) if succeeds(s'_{alt},s) then, at t_2, ¬subject_to(b_{fed},main) and, in consequence, ¬constitutes($b_{drained}$,x) and ¬partially_constitutes($b_{drained}$,x);

(d) if succeeds($s'_{default}$,s) then, at t_2, partially_constitutes($b_{drained}$,x) or constitutes($b_{drained}$,x) and, in consequence, subject_to(b_{fed},main);

Definition 92 ***Substrate Draining Event*** $=_{def}$ *A constituent-exchange event aux that stands in a drains_substrate_from(aux,main) relation with another event main.*

Once more, we can derive some roles from a substrate-draining event. Analogously to substrate-feeding events, the most evident role is that of the amount of substrate that is exchanged with the environment. In the case of a substrate-draining event, it is the ***exiting constituent*** role, played by the amount of substrate that ceases to be subject to the main event by ceasing to a totally or partially constitute any participant in the main event (corresponding to the amount of substrate $b_{drained}$ mentioned in definition 91). We define such a role in terms of the ***draining of*** relation as follows.

Definition 93 ***draining_of***(aux,$b_{drained}$) $=_{def}$ *A relation between a substrate feeding event aux and an amount of substrate $b_{drained}$ such that*

(1) there is an event main such that drains_substrate_from(aux,main);

(2) there is an object x_{src} such that participates_in(x_{src},aux) and participates_in(x_{src},main) at both t_1 and t_2;

(3) at t_1, constitutes($b_{drained}$,x_{src}) or partially_constitutes($b_{drained}$,x_{src}), by virtue of which subject_to($b_{drained}$,main);

(4) as a result of aux, at t_2

  (a) ¬constitutes($b_{drained}$,x_{src}) and ¬partially_constitutes($b_{drained}$,x_{src});

  (b) for every object y such that participates_in(y,main)

    (i) ¬constitutes($b_{drained}$,y) and ¬partially_constitutes($b_{drained}$,y);

    (ii) for every amount of substrate $b'_{drained}$ such that part_of($b'_{drained}$,$b_{drained}$), ¬constitutes($b'_{drained}$,y) and ¬partially_constitutes($b'_{drained}$,y);

(5) as a consequence of condition (4), ¬subject_to($b_{drained}$,main) at t_2.

Definition 94 ***Exiting Constituent*** $=_{def}$ *An amount substrate $b_{exiting}$ that stands in a relation draining_of(aux,$b_{exiting}$) with a substrate draining event aux.*

As discussed in section 6.2.5.1, we do not usually track substrate, but rather substrate-carriers (*i.e.,* the objects that are ultimately constituted of an amount of substrate of interest). Thus, analogously to the role of *entering constituent carrier* for substrate-feeding events, we have the ***exiting constituent carrier***, which is the role played by an object that is constituted of an amount of substrate that a substrate-draining event drains from the main event. We define this role in terms of the ***removing of*** relation as follows.

Definition 95 ***removing_of***(aux,carrier) $=_{def}$ *A relation between a substrate feeding event* aux *and an object* carrier *such that*

(1) there is an event main *such that* drains_substrate_to(aux,main);

(2) there is an object x_{src} *such that* participates_in(x_{src},aux) *and* participates_in(x_{src},main) *at both* t_1 *and* t_2*;*

(3) there is an amount of substrate $b_{drained}$ *such that* draining_of(aux,$b_{drained}$) *and* constitutes($b_{drained}$,carrier) *at both* t_1 *and* t_2*;*

(4) at t_1, part_of(carrier,x_{src});

(5) as a result of aux*, at* t_2

  (a) ¬part_of(carrier,x_{src});

  (b) ¬participates_in(carrier,main);

  (c) for every object y *such that* participates_in(y,main), ¬part_of(carrier,y);

(6) as a consequence of condition (5), at t_2, ¬subject_to(carrier,main) *and* ¬subject_to($b_{drained}$,main).

Definition 96 ***Exiting Constituent Carrier*** $=_{def}$ *An object* carrier *that stands in a relation* removing_of(aux,carrier) *with a substrate draining event* aux.

Finally, we have the ***source participant*** role played by the participant in the main event that loses some substrate (*i.e.*, the *exiting constituent*) by means of losing a part that is constituted of such a substrate (*i.e.*, the respective *entering constituent carrier*). This is the role played by the objects x in definition 91 and x_{src} in definitions 93 and 95. We define this role (definition 98) in terms of ***removing from*** relation (definition 97). Figure 6.6 presents a modeling pattern comprising the *exiting constituent carrier* and *source participant* roles.

Definition 97 ***removing_from***(aux,source) $=_{def}$ *A relation between a substrate feeding event* aux *and an object* source *such that*

(1) there is an event main *such that* drains_substrate_from(aux,main);

(2) participates_in(source,aux) and participates_in(source,main) at both t_1 and t_2;

(3) there is an object carrier such that subject_to(carrier,aux) at both t_1 and t_2, and subject_to(carrier,main) at t_1;

(4) there is an amount of substrate b_{fed} such that feeding_of(aux,b_{fed}) and, at both t_1 and t_2, constitutes(b_{fed},carrier);

(5) at t_1, part_of(carrier,source);

(6) as a result of aux, at t_2

  (a) ¬part_of(carrier,source);

  (b) ¬participates_in(carrier,main);

  (c) for every object y such that participates_in(y,main)

    (i) ¬part_of(carrier,y);

    (ii) for every object w such that part_of(w,carrier), ¬part_of(w,y);

(7) as a consequence of condition (6), at t_2, ¬subject_to(carrier,main) and ¬subject_to($b_{drained}$,main).

Definition 98 ***Source Participant*** $=_{def}$ *An object source that stands in a relation removing_from(aux,source) with a substrate draining event aux.*

An illustrative example in manufacturing is the process of equipment *wear*, *i.e.*, the removal of material (such as metal scraps) from a solid surface as a result of mechanical action exerted by another solid, caused by, *e.g.*, friction, abrasion, or stress[2]. Given this description, a process of *wear* is a substrate-draining event in relation to some manufacturing process, with the *metal scraps* as the exiting constituent carriers and some *piece of equipament* as the source participant.

6.2.6 Influence Events

There are also auxiliary events that do not directly result in variation of the substrate that is subject to the main event. They influence *how* the transformation takes place without altering *what* is subject to the transformation (*i.e.*, neither adding to the substrate

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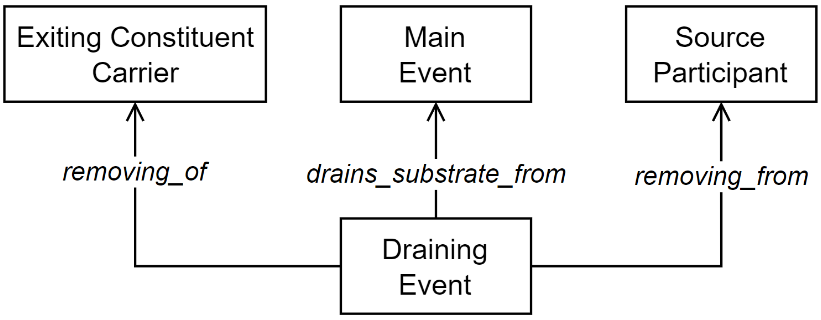
[2] <www.britannica.com/science/wear>

Figure 6.6 – Roles derived from a Draining Event.



Source: the author

that is subject to the main event nor removing any part of it). We call this type of event as ***influence events*** and define it in terms of the ***influences unfolding of*** relation as follows.

Definition 99 *Given the events aux and main, and the situations s, s'_{alt} and $s'_{default}$ from definition 58, such that bound_to(s,t_1), bound_to(s'_{alt},t_2) and bound_to($s'_{default}$,t_2), along with the amount of substrate b_{ex} from definition 61, then*

influences_unfolding_of*(aux,main) $=_{def}$ An auxiliary_of(aux,main) relation such that*

(1) there is an amount of substrate b;

(2) encompasses(s,b), encompasses(s'_{alt},b) and encompasses($s'_{default}$,b);

Definition 100 ***Influence Event*** *$=_{def}$ An auxiliary event aux that stands in an influences_unfolding_of(aux,main) relation with another event main.*

Even though an influence event has no direct contribution to determining what amount of substrate is subject to the main event, it is still an auxiliary event. Thus, it must result in some difference between the course of the main event that actually happens and the course of the counterpart event delimited by the same system that would take place during the same time interval of the main event if the auxiliary event had not happened. In other words, in terms of definition 58 (*auxiliary_of* relation), an influence event must make situations s'_{alt} and $s'_{default}$ different in some respect other them the substrate they encompass. Examples of how an influence event can affect an event *main* include:

(I) Changing the value of an intrinsic property of a participant in *main*. For example, a decrease in the ambient temperature of a pumping system increases the viscosity of the fluid that is being pumped, decreasing the efficiency of the pumping process.

(II) Making a participant in *main* gain or lose an intrinsic property. For instance, the heat exposure of a clock composed of plastic gears causes the plastic material to soften and become sticky, which increases the friction between the gear teeth, thus affecting the process of movement transmission upon which the clock relies.

(III) Establishing or ceasing a relation between participants in *main*. *E.g.,* an electromagnetic interference during a video call that cuts the video communication between the participants but does not affect the audio connection.

(IV) Changing the constituent of a participant of *main* by means of an internal exchange with other participants, without substrate entering in or exiting from *main*. As an example, during the process of formation of sedimentary rocks, the exposure of the sediment deposit and the fluid within its pores to certain ambient temperature-pressure conditions can trigger a cementation sub-process, *i.e.,* the welding of sediments by the precipitation of mineral matter in the pore spaces[3], which consists of a transference of material from the pore aqueous solution to the forming piece of rock.

(V) Changing the collection of participants in *main* by rearranging the substrate that is subject to *main* in a way that creates and/or destroys participants, without substrate entering in or exiting from *main*. The exposure of a microbial culture to a heat source, as described in section 6.2.2, is an example of this type of interference.

To illustrate one type of influence between events, in what follows we define the *qualitative_influence_on* relation and use it to define the notion of ***qualitative influence event***, which corresponds to the influence described in item (I).

Definition 101 ***qualitative_influence_on****(aux,main)* $=_{def}$ *An influences_unfolding_of(aux,main) relation such that*

(1) There is an object x that participates_in(x,main) at t_1 *and* t_2*;*

(2) There is an intrinsic property p that inheres_in(p,x) at both t_1 *and* t_2 *such that*

  a. p = value$_a$ *at* t_1*;*

  b. p = value$_b$ *at* t_2*;*

  c. $value_a \neq value_b$.

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[3] <www.britannica.com/science/cementation-sedimentary-rock>.

Definition 102 ***Qualitative Influence Event*** $=_{def}$ *An auxiliary event aux that stands in an qualitative_influence_on(aux,main) relation with another event main.*

As in the previous cases, we can derive roles from a qualitative influence event. Namely, we have the ***qualitative affected participant***, *i.e.,* the participant in the main event that undergoes a change in the value of one of its intrinsic properties, and the ***qualitative affected aspect***, *i.e.,* the property whose value is modified. They are, respectively, the roles played by object *x* and property *p* in definition 101. In what follows, we define these roles in terms of the ***affecting of*** and ***changing value of*** relations. Besides, figure 6.7 presents a modeling pattern comprising theses roles.

Definition 103 ***affecting_of****(aux,x)* $=_{def}$ *A relation between a qualitative influence event aux and an object x such that*

(1) there is an event main such that qualitative_influence_on(aux,main);

(2) participates_in(x,aux) and participates_in(x,main) at both t_1 *and* t_2*;*

(3) there is an intrinsic property p such that inheres_in(p,x) at both t_1 *and* t_2*;*

(4) the value of p at t_1 *is different from the value of p at* t_2 *due to the happening of aux.*

Definition 104 ***Qualitatively Affected Participant*** $=_{def}$ *An object x that stands in a relation affecting_of(aux,x) with a qualitative influence event aux.*

Definition 105 ***changing_value_of****(aux,p)* $=_{def}$ *A relation between a qualitative influence event aux and an intrinsic property p such that*

(1) there is an event main such that qualitative_influence_on(aux,main);

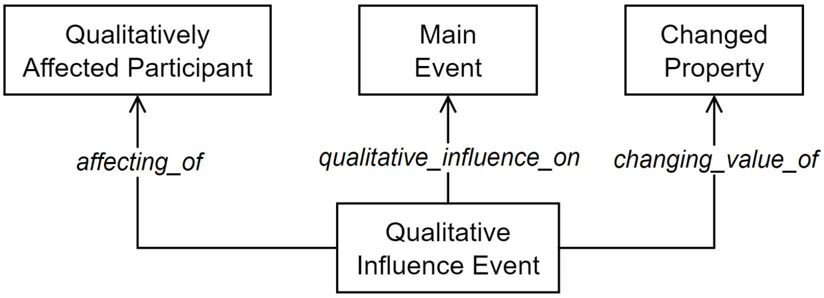
(2) there is an object x such that participates_in(x,aux) and participates_in(x,main) at both t_1 *and* t_2*;*

(3) inheres_in(p,x) at both t_1 *and* t_2*;*

(4) the value of p at t_1 *is different from the value of p at* t_2 *due to the happening of aux.*

Definition 106 ***Qualitatively Affected Aspect*** $=_{def}$ *An instrinsic property p that stands in a relation changing_value_of(aux,x) with a qualitative influence event aux.*

Figure 6.7 – Roles derived from a Qualitative Influence Event.



Source: the author

These roles are present in the pumping process mentioned in item (I). There, the *ambient temperature decrease* would be a qualitative influence event in which the *fluid* would be the qualitatively affected participant and its *viscosity* would be the qualitatively affected aspect.

Wrapping up, figure 6.8 presents a taxonomy of the proposed types of auxiliary events. In the next section, we address the contextual facet of auxiliary events.

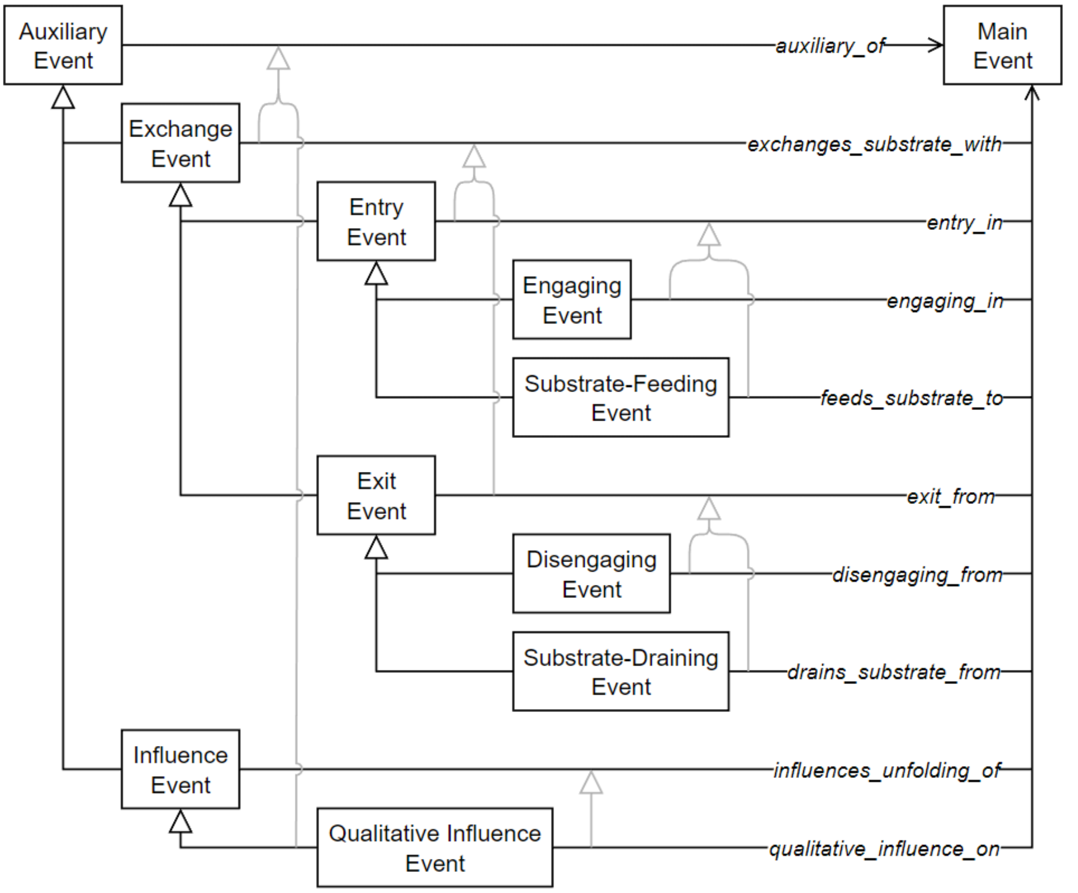
6.2.7 Contextuality of Auxiliary Events

In this section, we will discuss the contextual facet of auxiliary events by considering three levels of abstraction in which they can be understood. Based on this, we argue that, as a general rule, what fundamentally characterizes an auxiliary event as an *event* (*i.e.,* the change/unchange it operates on the involved objects) is distinct from what characterizes it as *auxiliary* (*i.e.,* its relation to other events). As a consequence, in certain conditions, it would be possible to have the same event without being an auxiliary event. We illustrate the discussion with an analysis of an example event (*i.e.,* boarding a train trip) in light of these three levels of abstraction.

6.2.7.1 Three Levels of Abstraction of an Auxiliary Event

We can think about an auxiliary event in three levels of abstraction. The highest one regards the distinctive feature of an auxiliary event, *i.e.,* its relation with a main event. With that, an auxiliary event is one that exerts some effect on the unfolding of another, main event, without being part of it. For instance, a participant-exchange event is an event that operates a variation in the participants (and, consequently, the subject substrate) during the happening of the main event. Also, an influence event may be one that intensifies

Figure 6.8 – Taxonomy of Auxiliary Events



Source: the author

or attenuates, or that speeds up or slows down the transformation carried on in the main event. That is to say, an auxiliary event makes the course of its main event distinct from the course of the counterpart event delimited by the same system and with the same initial conditions as the actual main event, which would have happened if the auxiliary event had not happened.

On the intermediate level, an auxiliary event is an event that modifies a given system in some respect while such a system is delimiting another event. For example, a participant-exchange event would more fundamentally be an event that makes an object become or cease to be a component of a system. Likewise, an influence event could be an event that rearranges the components of a system (*e.g.,* by establishing new relations between them or changing values of their qualities) in a way that their dispositions are more easily and/or more strongly activated, resulting in an earlier and/or intenser manifestation.

Finally, on the lowest level of abstraction, an auxiliary event may be just a local interaction involving certain objects that entails some modification in a system simply by virtue of some of the involved objects being part of such a system. Again, on this level, an engaging event could be simply the establishment of a relationship between two objects. *E.g.,* the subscription to a conference is an event that establishes a contractual relationship between a person and the conference organizers, which makes that person a part of the social system that delimits the conference and, therefore, a participant in the conference.

6.2.7.2 Illustrative Example: Boarding a Train During a Trip[4]

To illustrate the perspective of auxiliary events in three levels of abstraction, we will consider the case of someone boarding a train for a trip. Let us take the following excerpt of an article of *The New York Times* from 6 May 2021:

> *"From a peak of running more than 60 trains a day, Eurostar cut service during the pandemic to one daily round trip between London and Paris, and one on its London-Brussels and Amsterdam routes".*[5]

In this excerpt, the term *trip* – or *train trip* (figure 6.9) – refers to an event in which a train departs from an origin station and travels towards a final destination station, carrying some passengers. Moreover, it is not simply a non-stop origin-to-end trip, with the train stopping by intermediary stations along its route so that people can enter and/or leave the train. Then, we will regard a *train trip* as a transportation event, comprising

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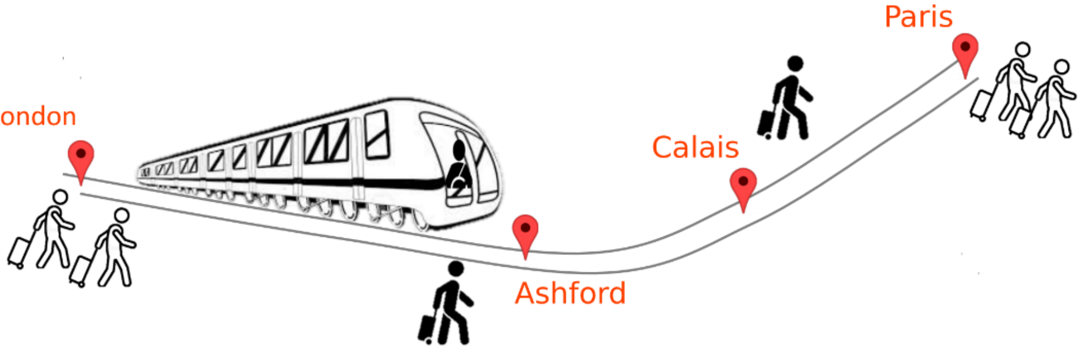
[4] Adapted from [RODRIGUES et al., 2022].

[5] <www.nytimes.com/2021/05/06/business/eurostar-moves-to-double-its-london-paris-service-to-two-trains-a-day.html>

Figure 6.9 – A Train Trip



Source: the author

changes in the spatial position of its participants, which are distributed along a route. With some simplification, we will consider the participants of a train trip to be just a train, a train driver, and some other people (*i.e.,* the passengers). A person participates in a trip during the time s/he is onboard a train that has already departed from the origin station but does not participate in any trip while waiting at and station.

Given this description, we will characterize a *train trip* as a system-invariant event delimited by a system composed of a *train*, a train *driver*, and some *passengers*. The structure of the system includes each passenger's disposition of *transportability*[6] , *i.e.,* the capability of being moved or conveyed from one place to another, which is manifested in the trip. It also includes the driver's *driving ability* and *intention* to reach a destination. The train has the complementary dispositions of *transporting capacity*, *i.e.,* the disposition to carry the objects inside it when in movement, and *guidability*, *i.e.,* the disposition to be driven by a trained person. An *inside* relation connects each passenger to the train by exposing his/her transportability to the transporting capacity of the train. Also, a *guiding* relation connects the driver to the train by exposing his/her driving ability and intention to reach a destination to the guidability of the train. Finally, the environment of this system includes objects that are related to its components in some other way – especially, the *stations* where the train *stops at* along its way.

Complementing the scenario, we will consider the event of *boarding*[7] as the event in which a person that is waiting at a station becomes a passenger on a train trip. It consists of the transition from a situation that includes a person *waiting at* a station and a train *stopped at* this station. Moreover, it is also an *engaging event* in relation to a train trip, as depicted on figure 6.10.

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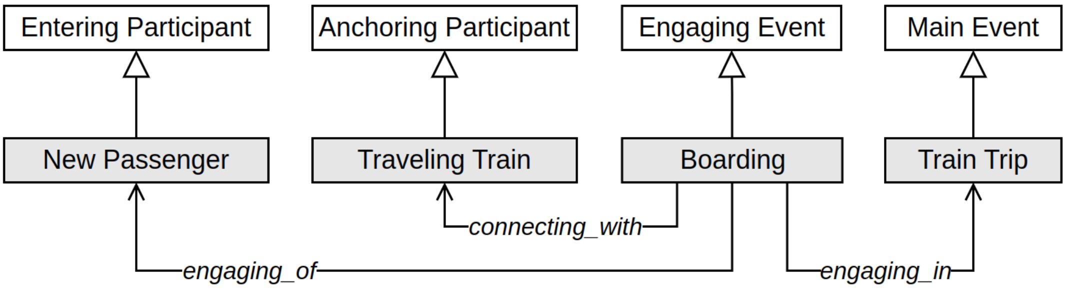
[6] <http://wordnetweb.princeton.edu/perl/webwn?s=transportable>

[7] A person getting on a train to travel somewhere. <www.collinsdictionary.com/dictionary/english/board>

Figure 6.10 – Modeling pattern for *Engaging Events* applied to *Boarding* and *Train Trip*



Source: the author

6.2.7.3 A Boarding Event in Three Levels of Abstraction

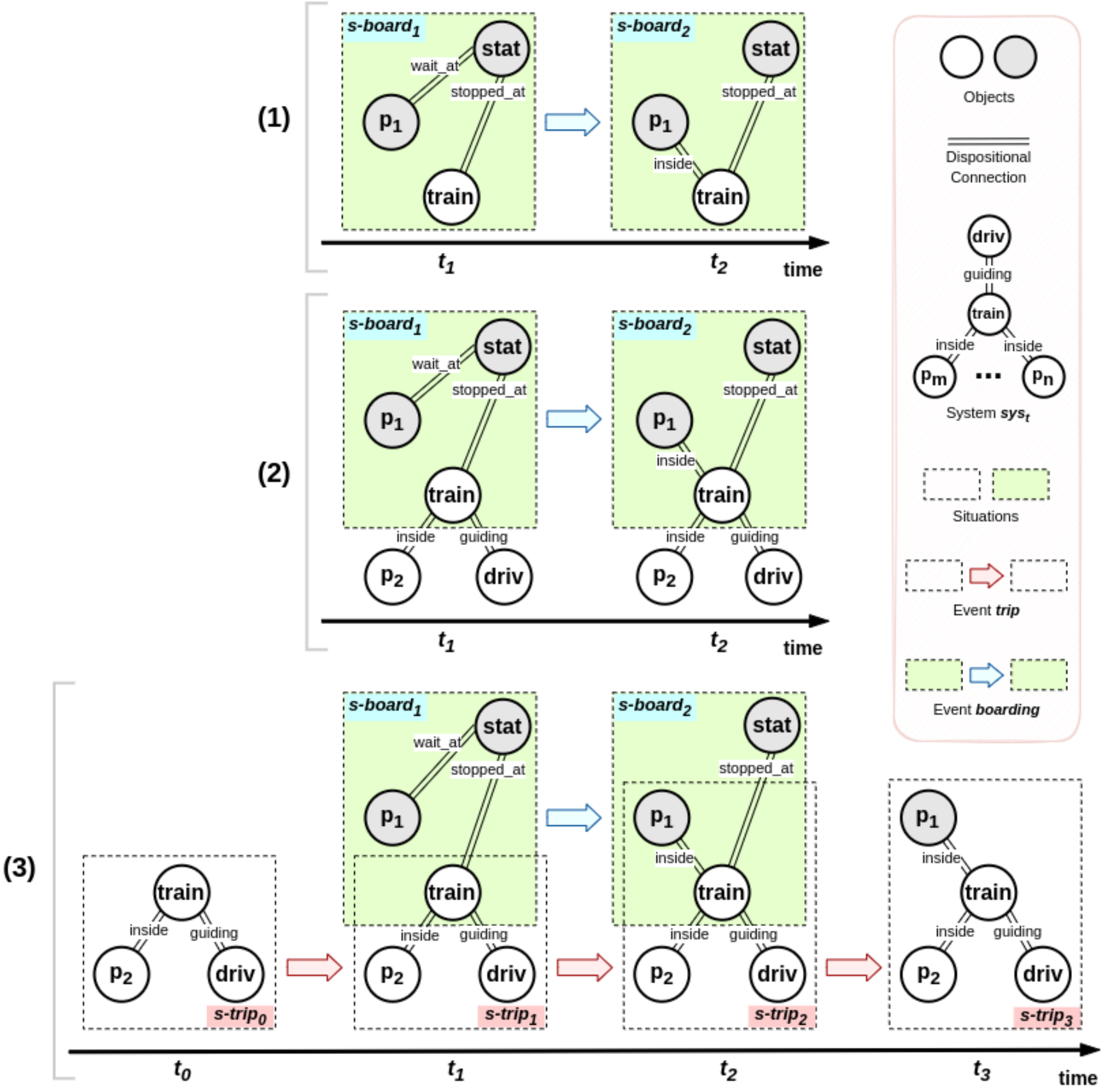
Now, to help in clarifying the view of auxiliary events in different levels of abstraction, figure 6.11 depicts the example of a boarding event *boarding* in each of the three proposed levels. At the lowest level of abstraction (fig. 6.11(1)) we have what most fundamentally happened: the transition between situations $s\text{-}board_1$ and $s\text{-}board_2$, which took place during the time interval $[t_1,t_2]$. In $s\text{-}board_1$, a person p_1 stands in a relation *waits_at* with a station *stat*, which stands in a relation *stopped_at* with a train *train*. With that, $s\text{-}board_1$ fulfilled the stimulus conditions to activate some disposition inhering in p_1 (*e.g.*,p_1's intention to travel), whose manifestation resulted in $s\text{-}board_2$, with p_1 standing in an *inside* relation with *train*.

Thus, at the lowest level of abstraction, *boarding* is plainly the event of ceasing the relation $waits\_at(p_1,stat)$ and establishing the relation $inside(p_1,train)$. That is, at this level of abstraction, the event is seen purely as the interaction between the objects that are involved in it, regardless of any context, *i.e.*, any entity in its surroundings.

Figure 6.11(2) pictures *boarding* at the intermediary level of abstraction. Here we observe that, while *boarding* is happening (*i.e.*, during the interval $[t_1,t_2]$), *train* was a component of a system sys_t, whose composition was given by the object *train*, a train driver *driv* and whatever persons connected to it by an *inside* relation – in such a way that for a person to be a component of sys_t it is a matter of standing in *inside* relation with *train*. At time t_1, sys_t was composed of *train*, the driver *driv*, and the person p_2. However, *boarding* established the relation $inside(p_1,train)$ at t_2 (in situation $s\text{-}board_2$), which made p_1 meet the requirements to be a component of sys_t from this time onwards, implicating in a change in the composition of sys_t.

Therefore, at the intermediary level of abstraction, *boarding* is the event by virtue of which the new component p_1 was added to sys_t. In other words, at this level, the

Figure 6.11 – The three levels of an Auxiliary Event of Boarding



Source: the author

event is already regarded in relation to some context – namely, the incidental connections linking *train* to *drive* and p_2, which are in the environment of the system that delimits *boarding*. Moreover, here *boarding* is also considered w.r.t. its effects over entities that are not involved in the event – *i.e.,* being the event that not only changed the status of *train* but also modified the composition of the whole sys_t.

Finally, figure 6.11(3) represents *boarding* at the highest abstraction level. It reveals that sys_t delimited a train trip *trip*, which was the transition through the snapshots of sys_t at times t_0, t_1, t_2 and t_3 – *i.e.,* respectively, the situations $s\text{-}trip_0$, $s\text{-}trip_1$, $s\text{-}trip_2$ and $s\text{-}trip_3$. Considering that *trip* happened during the interval [t_0,t_3], we have that sys_t was delimiting *trip* while *boarding* was happening (*i.e.,* during the interval [t_1,t_2]). Consequently, by being a component of sys_t at t_2, p_1 was present at $s\text{-}trip_2$ and successive situations, which qualifies it as a participant in *trip* from this time on. Hence, since it was due to *boarding* that p_1 entered into sys_t, at the highest abstraction level we can regard *boarding* as the event by virtue of which p_1 entered in the event *trip*.

With that, at this level, the event is predominantly regarded in relation to its context – namely, in relation to an event that was happening in parallel to *boarding* and that involved elements from its environment. That is to say, although *boarding* is still the event of a person entering a train, the emphasis is redirected to the fact that this entry translates into the engaging of such a person in a trip.

Summing up, the event *boarding* established a connection *inside* between p_1 and *train*, in virtue of which p_1 became a component of sys_t and, as a consequence, p_1 became a participant of *trip*. That is, above all, *boarding* is the event in which p_1 ceased to stand in a *waits_at* relation with *stat* and acquired an *inside* relation with *train*. However, it also happened to modify sys_t because *train* was a component of such a system. Additionally, *boarding* ended up affecting the external event *trip* by adding a participant to it, but only because sys_t happened to be delimiting *trip*.

With that, although it is true that *boarding* is the event by which p_1 joined in the *trip*, it seems to be so just incidentally, whereas *boarding* is the entering of p_1 into *train* independently of the circumstances. In other words, *boarding* is indeed an auxiliary event of *trip* – more specifically, *engaging_in(boarding,trip)* –, but merely due to external factors, not in virtue of its intrinsic nature.

6.2.7.4 Boarding Exemplifying the Contextuality of Auxiliary Events

The previous description of *boarding* presents an independent, self-contained event that, given the circumstances in which it happens, ends up affecting a parallel system-invariant event. To put it another way, instead of being essentially subordinated or supplementary to another event, it is just a plain system-invariant event that contextually plays this auxiliary role in relation to some other event. Therefore, we have an event that happens exclusively by virtue of the connections and associated dispositions of its participants, independently of the status of some of them as components of the system that delimits the main event. With that, it would happen in the same way even though none of its participants were also participants of the main event.

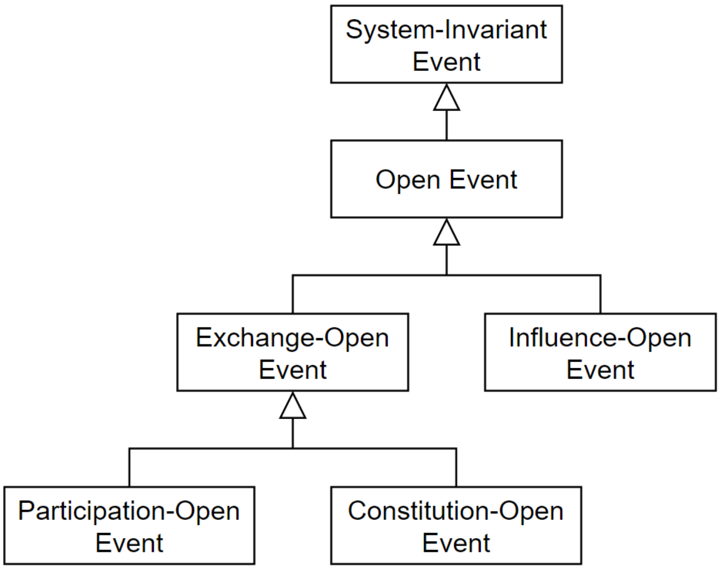
All of this suggests that there are types of events that are not instantiated in virtue of what an event is on its own but just in relation to its context – in particular, in relation to other events. In the case of boarding, it is essentially the simple event of a person p_1 entering a train *train* that is stopped at a station *stat*, which, however, happens in special circumstances – namely, with *train* being guided by *driv* towards a destination station (and, therefore, while *train* was taking part on an ongoing trip). Now, let us suppose that during the same time interval $[t_1,t_2]$, but in an alternative possible world, the same train *train* was on display in an exposition of trains at the same station *stat* and the same person p_1 visited the exposition and entered *train* to take a look inside. It would still be exactly the same event of someone entering a train, but it would no longer be a boarding event.

By revealing this contextual facet of events, the idea of auxiliary events seems to shed some light on the notion of *roles* for events, with *auxiliary event* being a role played by an event that affects another. The idea that an entity may play roles in relation to other entities is well accepted and widely employed in applied ontology (*e.g.,* in ontologies such as UFO [GUIZZARDI, 2005] and BFO [ARP; SMITH; SPEAR, 2015]), although usually restricted to roles for continuants, with just a few works considering the possibility of event roles (*e.g.,* [GUARINO; BARATELLA; GUIZZARDI, 2022; RODRIGUES; ABEL, 2019]). Hence, this work may contribute to expanding this notion.

6.3 Open Events

As discussed in the previous section, the effect of an auxiliary event *aux* on its main event *main* is given by a change in the system *sys* that delimits such an event. Thus,

Figure 6.12 – Types of Open Event



Source: the author

aux can only happen if *sys* is able to undergo the type of change operated by *aux*, *i.e.,* if *sys* is *open* w.r.t. the aspect that is affected by *aux*. Consequently, a system-invariant event can only be affected by an auxiliary event if it is delimited by an open system. We will call this category of events as ***open events***, which we define as follows.

Definition 107 ***Open Event*** $=_{def}$ *A system-invariant event e such that delimited_by(e,sys) ∧ Open_System(sys).*

Analogously to systems, an event may be open in some respects and closed in others – namely, the respects in which its delimiting system is open or closed. Moreover, similarly to the taxonomy of systems presented in section 4.3.5, we can specialize the category of open events based on the type of system that delimits its instances (which results in the taxonomy depicted in figure 6.12). We will present such sub-types in the following sections.

6.3.1 Exchange-Open Events

An ***exchange-open event*** (def. 108) is an event that is delimited by an *exchange-open system* (def. 16). Therefore, events of this type may be affected by *exchange events* (sec. 6.2.3). With that, the amount of substrate that is subject to an *exchange-open event* may vary throughout its occurrence, *i.e.,* the situations in the course of the event may encompass distinct amounts of substrate.

Definition 108 ***Exchange-Open Event*** $=_{def}$ *An open event e such that delimited_by(e,sys) ∧ Exchange-Open_System(sys).*

Exchange-open systems are *composition-open* (def. 12) and/or *constitution-open* (def. 14). Analogously, an event is exchange-open iff it is *participation-open* (*i.e.,* if it may gain/lose participants from/to the extended environment during its occurrence) and/or *constitution-open* (*i.e.,* if its participants may gain/lose substrate from/to the extended environment during its occurrence). We discuss *participation-open* and *constitution-open* in what follows.

6.3.1.1 Participation-Open Events

A ***participation-open event*** (def. 109) is an event that is delimited by a *composition-open system*. Hence, events of this type may be affected by *participant-exchange events* (sec. 6.2.4), resulting in a variation of participants throughout its occurrence, *i.e.,* the situations in the course of the event may include distinct objects. That is to say, an event of this type is not necessarily the interaction of a fixed collection of objects but may rather comprise, upon the happening of *participation-open events*, the interaction of diverse groups of objects at different times.

Definition 109 ***Participation-Open Event*** $=_{def}$ *An open event e* i.e., *such that delimited_by(e,sys) ∧ Composition-Open_System(sys).*

A *train trip*, as described in section 6.2.7.2, is an example of a participation-open event. Another example is a *civil lawsuit*[8] (*i.e.,* a legal process by which a person can hold another person liable for some wrong, injury, or damage). This event may be affected by a *joinder of parties*, *i.e.,* the process by which one or more parties are added to an ongoing lawsuit[9] – an *engaging event* in relation to the lawsuit. Also, participants may leave a lawsuit by a *disengaging event* of *settlement*, *i.e.,* an agreement between parties that ends a dispute and results in the voluntary dismissal of the litigation between them[10][11].

Other examples include a *football match*, during which the *participant-exchange events* of *player replacement* and/or *player expelling* may happen, and the *manufacturing* of a complex good, in which different professionals and tools take part in the event at different stages.

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[8] <https://legaldictionary.net/civil-lawsuit/>

[9] <https://web.archive.org/web/20210616003245/https://lawshelf.com/coursewarecontentview/adding-parties-and-claims/>

[10] <www.law.cornell.edu/wex/settlement>

[11] <www.britannica.com/topic/settlement-law>

6.3.1.2 Constitution-Open Events

A ***constitution-open event*** (def. 110) is an event that is delimited by a *constitution-open system*. Thus, events of this type may be affected by *constituent-exchange events* (sec. 6.2.5). Examples include an *automobile race* (as described in section 6.2.5.2) and a process of equipment *wear* (as described in section 6.2.5.1).

Definition 110 ***Constitution-Open Event*** $=_{def}$ *An open event e such that delimited_by(e,sys) ∧ Constitution-Open_System(sys).*

6.3.2 Influence-Open Events

An ***influence-open event*** (def. 111) is an event that is delimited by an *influence-open system*. Then, events of this type may be affected by *influence events* (sec. 6.2.6).

Definition 111 ***Influence-Open Event*** $=_{def}$ *An open event e such that delimited_by(e,sys) ∧ Influence-Open_System(sys).*

A process of *microbial culture* (mentioned in section 6.2.2) is an example of an influence-open event. Another example is a *chemical reaction* whose reaction rate is sensitive to the ambient temperature and that takes place inside a closed reactor equipped with a cooling system, such that it may be affected by a *cooling* event. The *carrying* of objects by a solar-powered vehicle would also be an influenced-open event, affected by the event of *solar irradiation*, whose intensity determines the velocity of the vehicle, thus influencing which would be the positions of the participants in the following situation.

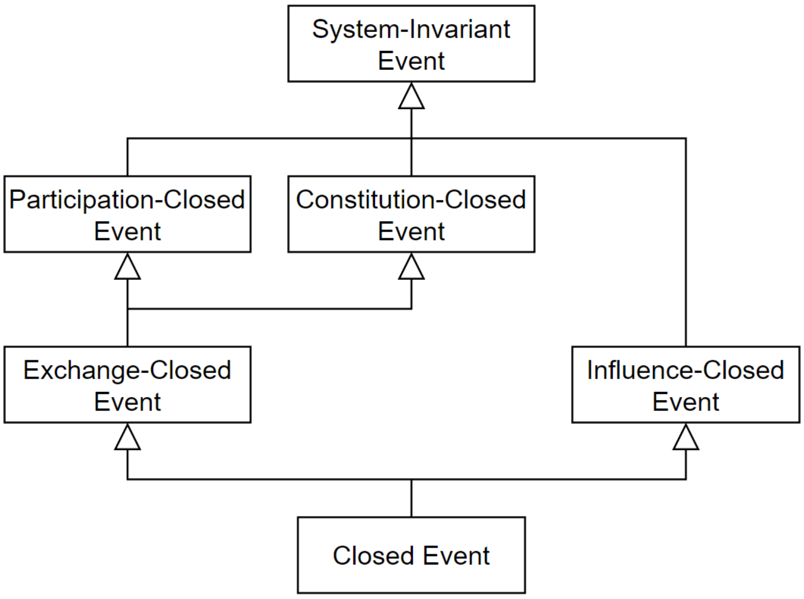
6.4 Closed Events

hklsjdfjhskdjf ashjdfkjsadf Complementing the notion of open events, we have the notion of ***closed events*** whose definition is straightforward:

Definition 112 ***Closed Event*** $=_{def}$ *A system-invariant event e such that delimited_by(e,sys) ∧ Closed_System(sys).*

Given the definition of closed systems (def. 21), a closed event is delimited by a system that is both exchange-closed and influence-closed. In other words, just as a closed

Figure 6.13 – Super-Types of Closed Event



Source: the author

system is a system that is closed in every respect, a closed event is an event closed in every respect so that it cannot be affected by any auxiliary event of any type. This renders a very specific type of event consisting of the conjunction of the super-types that correspond to each of the respects in which an event can be closed (fig. 6.13).

Thus, in a like manner to closed systems, there is hardly any example of a completely closed event, making this type of event too narrow to be relevant in practice. Still, we can take advantage of the specificities of each of its super-types, which will present in the following sections.

6.4.1 Exchange-Closed Events

An ***exchange-closed event*** (def. 113) is an event that is delimited by an *exchange-closed system*. With that, the amount of substrate that is subject to this event is the same throughout its occurrence, *i.e.,* all the situations in the course of the event encompass the same amount of substrate. Thus, an event of this type consists exclusively of rearranging a fixed amount of substrate.

Definition 113 ***Exchange-Closed Event*** $=_{def}$ *A system-invariant event e such that delimited_by(e,sys)* $\wedge$ *Exchange-Closed_System(sys).*

Given the definition 17, the category of exchange-closed systems is the conjunction of the categories of *composition-closed* and *constitution-closed systems*. Analogously, the category of exchange-closed events is a conjunction of the categories of *participation-closed* and *constitution-closed* events, which are presented in what follows.

6.4.1.1 Participation-Closed Events

A ***participation-closed event*** (def. 114) is an event delimited by a *composition-closed system*, that is, by a system unable to exchange components with its extended environment. Thus, events of this type cannot be affected by *participant-exchange events* (sec. 6.2.4), such that no external object can take part in and no participant can cease participating in an ongoing participation-closed event. Consequently, a participation-closed event is limited to the interaction between its initial participants and/or those that may possibly be created in the event, as well as the consequent changes and/or unchanges such participants may undergo.

Definition 114 ***Participation-Closed Event*** $=_{def}$ *A system-invariant event e such that delimited_by(e,sys)* $\wedge$ *Composition-Closed_System(sys).*

A *judo* match is, by definition, an example of a participation-closed event. It is an event involving exactly two *judokas* (*i.e.,* judo athletes), with the referees as elements of the environment. There is no possibility of engagement of an additional judoka, disengagement of an involved judoka, or exchanging of judokas.

6.4.1.2 Constitution-Closed Events

A ***constitution-closed event*** (def. 115) is an event that is delimited by a *constitution-closed system*. Hence, events of this type cannot be affected by *constituent-exchange events* (sec. 6.2.5). Then, participants cannot receive/lose substrate from/to the extended environment while participating in the event. In other words, given two immediately successive situations s_1 (bound to t_1) and s_2 (bound to t_2) in the course of a constitution-closed event e, if an object x is present at both s_1 and s_2, then the substrate that constitutes x at t_2 must be part of the substrate encompassed by s_1. A chemical reaction that happens inside a sealed reactor is an example of a constitution-closed event.

Definition 115 ***Constitution-Closed Event*** $=_{def}$ *A system-invariant event e such that delimited_by(e,sys)* $\wedge$ *Constitution-Closed_System(sys).*

6.4.2 Influence-Closed Events

An ***influence-closed event*** (def. 116) is an event that is delimited by an *influence-closed system*, such that it cannot be affected by *influence events* (sec. 6.2.6). With that, all the changes and/or unchanges that the participants undergo in the event (*i.e.,* changes/unchanges in the focal properties of the event) must result from manifestations of dispositions that inhere in participants of the event at the time they are activated and manifested. In addition, the stimulus conditions for such dispositions must comprise only objects that are components of the system that underlies the event and properties/relations that are part of the structure of this system.

Definition 116 ***Influence-Closed Event*** $=_{def}$ *A system-invariant event* e *such that delimited_by(e,sys)* $\wedge$ *Influence-Closed_System(sys).*

Arguably, there is a great variety of dispositions that an object may bear, with diverse possible combinations of conditions for their activation, along with numerous ways in which their manifestations can influence the activation of other dispositions inhering in the same object. Given that, probably every event will involve some object that bears a disposition that can be activated by conditions external to the event and whose manifestation would interfere with the dispositions whose manifestations characterize the event.

Even so, analogously to *closed events*, this type of event could also be defined as the conjunction of diverse less restrictive categories of events, each gathering events that are closed to a certain type of influence. For instance, we have *eletromagnetic-closed events*, whose delimiting systems are closed to electromagnetic interaction between its components and elements of the environment, *e.g.,* any event happening inside a *Faraday cage*[12]. Another example is that of *adiabatic processes*[13] , *i.e.,* processes delimited by systems that are closed to heat transference with the environment, such as a chemical reaction that takes place inside an adiabatic isolated reactor. We also *information-closed events*, which are delimited by systems that are closed to the exchange of information between its components and the environment, *e.g.,* the interrogation of a suspect within a communication-proof room, illustrated in traditional descriptions of the *prisioner's dilemma*[14].

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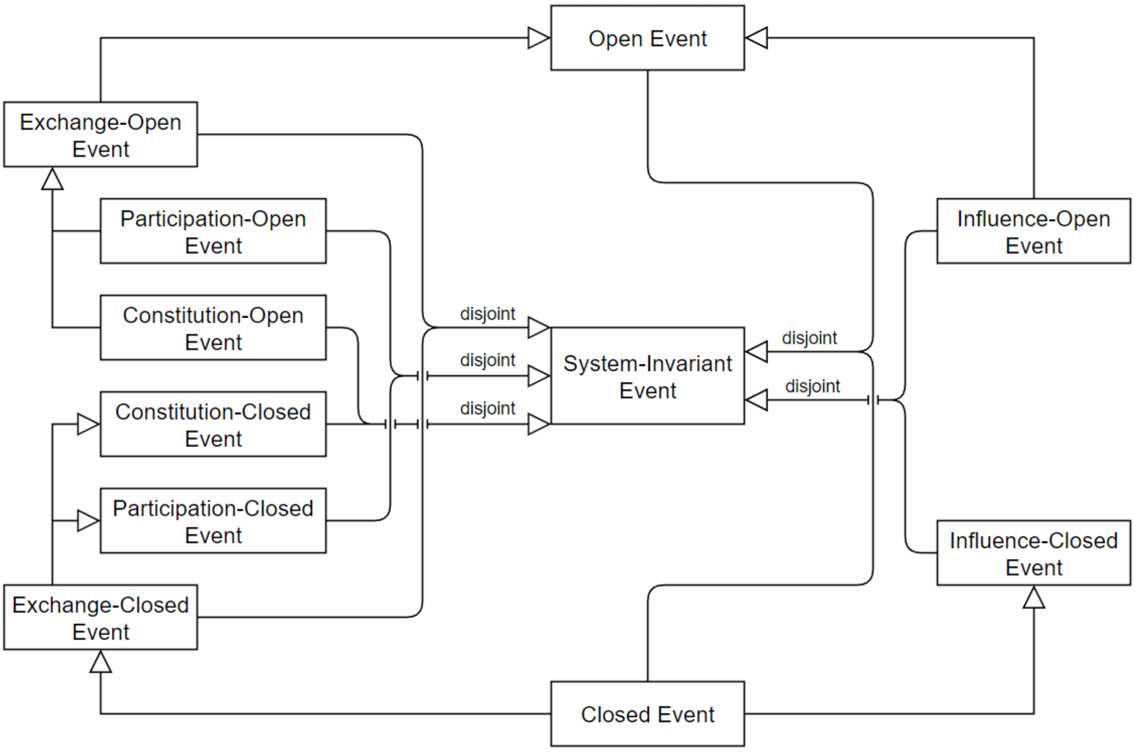
[12] An earthed screen made of metal wire that surrounds an electric device in order to shield it from external electrical fields [RENNIE; LAW, 2019a].

[13] <www.britannica.com/science/adiabatic-process>

[14] <www.britannica.com/topic/prisoners-dilemma>

Figure 6.14 – Types of System-Invariant Event



Source: the author

Combining the types of events defined in this section and in section 6.3, we arrive at a taxonomy of system-invariant events (fig. 6.14) that resembles the taxonomy of systems presented in figure 4.1.

6.5 Useful Consequences for Conceptual Modeling

This section briefly discusses some ways in which the proposed theory can be used to inform the modeler's choices, as well as to provide guidance for consistency verification and for fixing problematic models. We present possible inferences based on the application of the principle of ontological conservation (sec. 4.4) and on the transversal unifying criterion provided by the approach of delimiting events using systems (sec. 5.5).

6.5.1 Application of the Principle of Ontological Substrate

In natural sciences, conservation laws are valuable for their abstraction power, making it possible to predict the macroscopic behavior of a system without having to consider the microscopic details of the course of particular physical processes or chemical reactions [BRITANNICA, 2018]. Ecology is one example. Most ecosystems enclose so many chemical reactions that it is impossible to take all of them into account individually. Still, the law of conservation of mass applies to each of these reactions, as well as to the ecosystem as a whole. Therefore, by conducting a mass balance study that considers the inputs and outputs of mass, ecologists can have a grasp of the internal functioning of an ecosystem [STERNER; SMALL; HOOD, 2011].

For example, early successional forests gain biomass as trees grow, capturing larger amounts of carbon from the atmosphere via photosynthesis than the amounts of carbon released via respiration, which results in carbon being stored in the forest. In mature forests, the amounts of carbon that are captured and released are roughly equivalent, so there is no significant change in the quantity of stored carbon over time. When a forest is harvested, this stored carbon reenters the atmosphere as CO_2. Thus, by considering the carbon inputs and outputs in a region of forest, ecologists can determine at which stage the forest is without having to consider the metabolic processes of any particular tree.

In Formal Ontology, the principle of ontological conservation (section 4.4) may play a similar role. According to this principle, situations that are snapshots of the same exchange-closed system must encompass the same maximal amount of substrate. Each of such situations would be an arrangement of the same underlying amount of substrate to constitute the components of the system at the time. With that, an exchange-closed event necessarily consists of a transition through arrangements of an invariant amount of substrate. Then, as pointed out in section 6.4.1, any change in the participants during the event is ultimately a rearrangement of this invariant amount of substrate, given in terms of changes in (intrinsic or relational) properties of the components of the system.

As a consequence, for every object that is present in a situation in the course of an exchange-closed event, there must be some correspondence with entities in each of the other situations that precede or succeed it. That is, given an object x that is constituted of some substrate b, and that is present in a situation s in the course of an exchange-closed event e, each situation in the course of e must include

(1) the object x itself still constituted of b; or

(2) another object x' totally or partially constituted of b; or

(3) objects $[x'_1,...,x'_n]$ constituted of the amounts of substrate $[b'_1,...,b'_n]$ whose mereological sum is b.

In other words, for every object in a situation in the course of an exchange-closed event, there will be a relation of identity or *genidentity*[15] with one or more entities in each of the other situations. Then, no matter what happens to an object in the event, there will be some trace of it in every other situation in the course of the event.

Without invariance of substrate, the situations in the course of an exchange-open event do not necessarily follow the same genidentity restrictions imposed over the objects that are present in the situations in an exchange-closed event. Still, applying the principle of ontological conservation over exchange-open events has another useful implication. Given some variation of substrate among the situations in the course of an exchange-open event, if such a variation is not reflected in genidentity relations among the objects present in different situations in the course of the event, it must be the result of substrate entering or leaving the system that delimits the event. That is, given an exchange-open event e, two situations s and s' in the course of e that respectively encompass the amounts of substrate b and b', and an amount of substrate b_{ex} that is part of b but not part of b', there must have happened an *exchange event* such that

(1) if *precedes(b’,b)*, there must have happened an *entry event* through which b_{ex} entered the system that delimits e; or

(2) if *precedes(b,b’)*, there must have happened an *exit event* through which b_{ex} left the system that delimits e.

From this application of the principle of ontological conservation, we can derive some constraints and paths of inference that may help in the conceptual modeling of events. We will discuss some of them in the following section.

6.5.2 Modeling Constraints and Useful Inferences

The application of the principle of ontological conservation in the ontological analysis of both exchange-closed events and exchange-open events reveals some constraints on how events can be. Given such restrictions, we have means to spot inconsistencies in models of events, such as the misclassification of entities, the presence of

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[15] The relation of *being-such-as-to-have-come-forth-from*, *e.g.*, the relation between a chunk of wood w and the sum of the two smaller chunks of wood w_1 and w_2 created by cutting w in two pieces [SMITH; MULLIGAN, 1982]. The relation of genidentity may be either *simple* or *complete* [SMITH; MULLIGAN, 1982, p.70]. For example, the relation between w and the sum w_1 and w_2 is that of complete genidentity, whereas the relation between w and w_1 is that of simple genidentity (or, as we would call, *partial* genidentity).

spurious entities, or the absence of expected ones. Based on that, we can derive some approaches to fix such inconsistent models. In the following sections, we briefly discuss some implications for the cases of substrate variation in the course of exchange-closed and exchange-open events.

6.5.2.1 Substrate Variation in Exchange-Closed Events

An exchange-closed event consists of rearranging a fixed amount of substrate. For this reason, if we have a model of an exchange-closed event such that the situations in its course differ with respect to the substrate they encompass, we necessarily have an inconsistent model. There are three distinct reasons for this type of inconsistency. Namely, it may arise from the fact that the substrate that appears in some situations but not in others

(1) is spurious and should not have been represented in the model;

(2) is genuinely subject to the event and should be represented as part of the substrate that is encompassed by each situation in the course of the event;

(3) should indeed appear in some situations and not in others, which implies that the event was misclassified, being, in fact, an exchange-open event.

For example, given a model m_A of an exchange-closed event e that involves a participant p, it must be possible to determine identity or genidentity relations between p and entities in every situation in the course of e. If some situation s in the course of e does not include any entity corresponding to p, it indicates that

(A1) p is not a genuine participant in e, but rather an extraneous object that has been added to m_A by mistake and that must be removed from m_A in order to faithfully depict e; or

(A2) p is really a participant in e that came into or went out of existence in the course of e, which implies that there is some entity or collection of entities in s that is genidentical to p, but that was (or were) neglected in m_A, and hence must be added to the model to faithfully depict e; or

(A3) e is, in fact, an exchange-open event that was misclassified as an exchanged-closed one in m_A, so its classification must be adjusted and it must comply with the constraints for exchange-open events (described in section 6.5.2.2).

Complementarily, we can think about a model m_B of an exchange-closed event e such that all the situations include the same objects, but do not encompass the same amount of substrate. That is to say, m_B depicts two situations s and s' in the course of e such that they encompass, respectively, the amounts of substrate b and b', but there is an amount of substrate b_{ex} that is part of b and not part of b'. This scenario indicates that

(B1) there was a mistake in the representation of s in m_B and b_{ex} is not really part of b, which must be reflected in m_B to faithfully depict e; or

(B2) there was a mistake in the representation of s' in m_B and b_{ex} is indeed part of b', which must be reflected in m_B to faithfully depict e; or

(B3) e is, in fact, an exchange-open event that was misclassified as an exchanged-closed one in m_B, so its classification must be adjusted and it must comply with the constraints for exchange-open events (described in section 6.5.2.2).

6.5.2.2 Substrate Variation in Exchange-Open Events

In the case of an exchange-open event, it is possible that the situations in its course truly differ with respect to the substrate they encompass. Therefore, a model that depicts this scenario is not necessarily inconsistent. Instead, it may just be the case that the variation of substrate along the course of the event is simply the effect of some exchange event. If such an exchange event is not represented in the model and cannot be identified, it may indeed indicate some inconsistency in the model, similar to the ones presented in items (1) and (2) in the previous section. Then, in summary, if a model depicts some substrate variation in an exchange-open event, it means that the substrate that appears in some situations but not in others

(1) is spurious and should not have been represented in the model; or

(2) is indeed subject to the event during its whole occurrence and should be represented as part of the substrate that is encompassed by each situation in the course of the event; or

(3) should indeed appear in some situations and not others, implying that some exchange event must have happened.

For example, given a model m_C of an exchange-open event e whose course contains situations s and s' that respectively encompass the amounts of substrate b and b', and an amount of substrate b_{ex} that is part of b but not part of b', it indicates that

(C1) there was a mistake in the representation of s' in m_C and b_{ex} is indeed part of b', which must be reflected in m_C to faithfully depict e; or

(C2) there was a mistake in the representation of s in m_C and b_{ex} is not really part of b, which must be reflected in m_C to faithfully depict e; or

(C3) m_C is correct and thus the difference between the amounts of substrate encompassed by s and s' is evidence that there must have happened an exit event through which b_{ex} ceased to be subjected to e.

With that, applying the principle of ontological conservation to the modeling events not only helps us to spot flaws in the model but also supports predicting the existence of entities that were overlooked during the modeling process – *i.e.,* missing participants in the case of exchange-closed events or relevant auxiliary events in the case of exchange-open events.

It is noteworthy that, although we can identify inconsistencies and make inferences by inspecting any section of the course of an event, we do not need such detailed knowledge to take advantage of an ontological conservation analysis. In fact, even comparing the initial and ending situations of an event may suffice for recognizing a substrate variation during the event, allowing us to make inferences about the details of its unfolding and make adjustments in its model. That is, analogously to the case of physical conservation laws, we can have an understanding of the general characteristics of an event without the need to inspect its specific features.

Still, in line with the idea of grasping the general characteristics of an event without diving into its particularities, the principle of ontological conservation can also be used to identify regularities in the unfolding of events. In particular, since an exchange-closed event boils down to the rearrangement of a fixed amount of substrate, we can pinpoint patterns of occurrence by comparing how this fixed substrate is arranged in distinct situations in the course of an event.

For example, the variation of participants during an exchange-closed event exclusively results from the unfolding of such an event. Hence, the presence of a participant in the ending situation of the event that was not present in its initial situation reveals that this participant was created in the event. To put it another way, this event comprises the rearrangement of some amount of substrate in a way to constitute a new object.[16]

6.5.2.3 Qualitative Variation in Influence-Open and Influence-Closed Events

Similarly to the case of variation of substrate, we can also follow the qualitative variation of participants along the course of an event in order to identify overlooked auxiliary events. The course of an influence-closed event ev consists of a succession of snapshots of an influence-closed system sys. Thus, each situation in the course of ev must exclusively result from the interaction between components of sys with respect to properties that are part of the structure of sys, without any interference from external elements. That is to say, both the dispositions whose manifestation brings about a situation in the course of ev and the stimulus conditions that trigger such dispositions must be part of the structure of sys.

This means that each situation in the course of ev exclusively results from the interaction of the participants as they were arranged in preceding situations in the course of ev. In other words, both the dispositions and the stimulus conditions involved in bringing about a situation in the course of an influence-closed event must be part of the preceding situations in the course of such an event.

With that, if we have a model of an influence-closed event such that some qualitative variation in its course cannot be explained exclusively by the interaction of its participants in preceding situations, then we must be facing one of two types of inconsistency:

(1) the course of the event was erroneously described; or

(2) the event in question was misclassified as an influence-closed event and is actually open in some respect.

To fix the first case, we could review the information we have about the event and check how the unfolding should actually have been described. In the second case, the classification of the event must be adjusted and we can look for the evidence of influence events that can explain the qualitative variation we observed in the course of the main event under analysis. In the case of models of influence-open events, we can draw similar

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[16] In [RODRIGUES; CARBONERA; ABEL, 2020] we propose a handful of such patterns, covering events of *stasis*, the qualitative event of *simple change*, and the existential events of *transformation* (or *identity change*), *creation*, and *destruction*, each of which would correspond to a sub-type of exchange-closed event.

inferences, with the difference that we would only have inconsistencies of the second type.

To illustrate, consider the thermally-closed (*i.e.,* adiabatic) event of a chemical reaction that, in principle, occurs inside an adiabatic isolated reactor initially containing two reactants in a given proportion. Also, consider that the evolution of the reaction is recorded by a sensor that measures the volume of the reactants and the product inside the reactor at fixed intervals. If the record does not reflect the expected chemical kinetics – *e.g.,* the reaction rate is too high, with more product being generated than expected for the given proportion of reactants –, we may have that either (1) the record is not accurate (*e.g.,* the initial proportion of reactants was not the registered one or there is some problem with the sensor readings) or (2) the chemical reaction is not in fact an adiabatic process (*e.g.,* the reactor is not properly insulated and the room temperature outside the reactor is affecting the reaction).

7 CASE STUDY: TURBIDITY CURRENTS

In this chapter, we apply the proposed framework to a case study in the Geology domain: the case of *turbidity currents* (also known as *turbidity flows*).[1] Turbidity currents are among the most important processes of transport of sediment from the continental shelf to the deep sea [HEEREMA et al., 2020; MEIBURG; KNELLER, 2010]. These are processes of large economic significance since they are responsible for the creation of sandstone deposits (called *turbidites*) that are one of the most common types of hydrocarbon reservoirs found in deep ocean settings [LUCCHESE et al., 2019; MANICA, 2012; MCHARGUE et al., 2011; MEIBURG; KNELLER, 2010]. Prediction of the characteristics of turbidite deposits such as their distribution, extent, thickness, shape, and grain size, requires an understanding of how turbidity currents operate, especially concerning what controls the changes in flow velocity with distance and what determines their final runout (or travel) distance [HEEREMA et al., 2020; KNELLER; BUCKEE, 2000].

In light of the proposed framework, our hypothesis is that a turbidity current event is delimited by a continuant entity that can be characterized as a system. We further hypothesize that, by reflecting an aspect of reality, the proposed framework can help in distinguishing the event from its underlying system as well as in modeling these and other related entities in the domain. Hence, our goal here is two-fold:

(1) Demonstrating that the proposed framework is suitable to model a relevant and complex event;

(2) Bringing evidence that our ontological theory reflects the way in which authors from the domain independently describe and deal with turbidity currents and related entities.

With that, we will present the application of our framework for

- Identifying the underlying delimiting system of a turbidity current event;
- Determining the participants of the event by determining the components of the system;
- Identifying the elements of the environment;

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[1] The terms flow and current are often employed interchangeably in the geological domain (*e.g.,* “*We define suspension current as ‘flow induced by [...]*” [KNELLER; BUCKEE, 2000, p.63], “*Hyperpycnal flows are currents that [...]*” [WELLS; DORRELL, 2021, p.60])). We will adopt the same approach throughout the text.

- Identifying auxiliary events involving these elements of the environment;
- Determining the relation between such events and turbidity currents.

We based this demonstration on an analysis of the discourse of a set of texts from the geological domain. As a general approach, we conduct the case study by, iteratively, identifying entities presented in the texts from the domain, applying the framework to draw conclusions about such entities (*e.g.,* identifying additional entities), and analyzing the texts to verify whether there is evidence that supports the conclusions (*e.g.,* mentions to the predicted entities).

In the next section, we describe the process of knowledge acquisition about the domain, which provided the basis for our case study. The following sections bring a description of turbidity currents and related processes, as well as the ontological analysis and modeling of the entities from the domain according to our framework. The chapter ends with some considerations about the results of the case study.

7.1 Knowledge Acquisition and Analysis Process

In order to get acquainted with the domain, we started by reading research articles (*e.g.,* [MCHARGUE et al., 2011; KNOBLAUCH, 1999]) and encyclopedia entries ([CENEDESE, 2012; BRITANNICA, 2015]) about the turbidity currents and related processes.

Given the input from initial readings, we conducted a series of interviews (in a total of about 10 hours) with a geologist experienced in sedimentary processes in order to adjust and validate our initial understanding of turbidity currents. Our first focus was clarifying the terminology of the domain. During the interviews, we also identified the main entities involved in our case from a geological point of view (*e.g.,* turbidity current, erosion, deposition, sediment, fluid, bed, density, concentration, velocity) and made an initial sketch on how they are related.

From the interviews, we moved to a second round of readings to further detail the description of the identified entities. In order to get a better picture of the interaction among the identified entities, we focused on research papers describing the dynamics of turbidity currents (*e.g.,* [WELLS; DORRELL, 2021; MEIBURG; KNELLER, 2010; PARSONS et al., 2007]). Besides that, we also privileged papers based on experimental works (*e.g.,* [MANICA, 2012; SEQUEIROS et al., 2009; OEHY; SCHLEISS, 2007]) and simulations (*e.g.,* [LUCCHESE et al., 2019]) since in this type of study the authors tend to have a better-structured presentation of how different properties influence one another and how they affect the evolution of the process. Moreover, their choice of which entities to consider and which of their attributes to observe or simulate tend to reveal what are key entities to make sense of the studied processes.

The knowledge acquired from the first interviews guided the second round of readings to identify the entities to be modeled and which parts of the text refer to them (sometimes implicitly). Then, we employed our ontological framework for classifying the identified entities based on their textual descriptions. This process resulted in an initial model of turbidity current as a system-invariant event, including its connection to auxiliary events such as erosion and deposition.

Next, we interviewed (for about 3h) an engineer with a Ph.D. in hydraulics, who is an expert in modeling of sediment gravity flows and has authored some of the papers we are using. In this interview, we presented our initial model, validated our modeling decisions, and got positive feedback on the adequacy of the system-oriented approach to deal with the case. We corrected misunderstandings regarding some entities and identified additional elements to include in the model.

After this interview, we proceeded to a third round of readings in order to consolidate the model. Our focus was characterizing the additional elements we identified with the expert, searching for crispier evidence of the adequacy of the system view to the case, and enlarging our repertory in order to assure that we are indeed dealing with a *shared conceptualization* of the domain. In this round, we included seminal work suggested by the expert (*e.g.,* [PARKER; FUKUSHIMA; PANTIN, 1986]), articles that were cited in the previously read papers (*e.g.,* [MULDER; SYVITSKI, 1995] and [COVAULT, 2011], which are cited in [WELLS; DORRELL, 2021]; [KNELLER; BUCKEE, 2000] cited in [MEIBURG; KNELLER, 2010]), and relevant work from other authors who were not previously included (*e.g.,* [HEEREMA et al., 2020; DASGUPTA, 2003]). We also inspect again papers already read in light of the improved understanding acquired at this point.

In the end, we based this case study on an analysis of the discourse of a set of 32 main texts from the geological domain covering the topic of turbidity currents and similar processes (*i.e.,* [WELLS; DORRELL, 2021; HEEREMA et al., 2020; LUCCHESE et al., 2019; NOMURA et al., 2019; SHANMUGAM, 2018; FICK; MANICA; TOLDO, 2017; BAAS et al., 2016; THOMAS, 2016; BRITANNICA, 2015; BAAS et al., 2014; ALLABY, 2013; MANICA, 2012; CENEDESE, 2012; COVAULT, 2011;

MCHARGUE et al., 2011; MEIBURG; KNELLER, 2010; SEQUEIROS et al., 2009; OEHY; SCHLEISS, 2007; PARSONS et al., 2007; THOMPSON et al., 2006; DASGUPTA, 2003; KNELLER, 2003; KNELLER; BUCKEE, 2000; SHANMUGAM, 2000; KNOBLAUCH, 1999; KNELLER; BENNETT; MCCAFFREY, 1999; HüRZELER; IMBERGER; IVEY, 1996; MULDER; SYVITSKI, 1995; MOSSA; SERIO, 2016; MIDDLETON, 1993; PARKER; FUKUSHIMA; PANTIN, 1986; FUKUSHIMA; PARKER; PANTIN, 1985]).

7.2 Turbidity Currents and Other Sedimentary Processes

This section presents turbidity currents and related entities. It begins with basic notions that are used to describe the dynamics of sedimentary processes, followed by a description of general types of flow (*i.e.,* mass movements, density flows, and sediment gravity flows). After that, we present turbidity currents and other related processes (*e.g.,* erosion and deposition).

7.2.1 Shear Force and Shear Stress

Shear force is a force that acts in a direction that is parallel to a surface (either external or an internal cross-section) of a material object [RENNIE; LAW, 2019b, p.534] [SCHASCHKE, 2014c, p.343] [ESCUDIER; ATKINS, 2019e, p.322] [KENT, 2007b]. It is what is called a *contact force*, *i.e.,* a force that requires the contact between the object that exerts the force and the object that experiences the force [YOUNG; FREEDMAN, 2015, p.126, 141, 166] [HALLIDAY; RESNICK; WALKER, 2010, p.111] [KENT, 2007a]. This force tends to cause a ***shear*** deformation on the object, in which one portion of the object slides with respect to another adjacent portion of the same object [ESCUDIER; ATKINS, 2019d, p.322] [KENT, 2007b; LAW; MCFERRAN, 2021; MAYHEW, 2015b].

A notion closely related to *shear force* is that of *shear stress*. Similar to *pressure*, ***shear stress*** is a force per unit area, but that acts parallel to a surface rather than perpendicular to it as in the case of pressure [JAFFE; TAYLOR, 2019, p.557] [RENNIE; LAW, 2019c, p.568] [YOUNG; FREEDMAN, 2015, p.376] [HALLIDAY; RESNICK; WALKER, 2010, p.374] [ESCUDIER; ATKINS, 2019g]. Thus, it is regarded as the intensity of the shear force applied to the body [THOMAS, 2016, p.479, 505] [ALLABY, 2013, p.528, 563].[2]

7.2.2 Sediment, Fluid, Flow, Current, and Stream

Sedimentary processes basically concern the movement of sediment by means of interacting with some moving fluid. Thus, we start by defining some of such basic entities.

Sediment[3] can be considered as a collection of unconsolidated grains/particles of minerals, organic matter or preexisting rocks, that can be transported by water flows or wind and later deposited [THOMAS, 2016, p.472] [ALLABY, 2013, p.320]. Sediment is usually characterized by properties such as ***volume*** (*i.e.,* dimensional measure of three-dimensional geometric objects, the size of the object [BRITANNICA, 2009]), ***density*** (*i.e.,* mass of a unit volume of a material substance [BRITANNICA, 2021a]), ***grain/particle size*** (*i.e.,* mean diameter or volume of the grains/particles in a sediment [ALLABY, 2013, p.428]), and ***grain/particle shape*** (*i.e.,* mean shape of the particles that compose a sediment defined as a measure of the relation between the three axial dimensions of an object [ALLABY, 2013, p.428] [THOMAS, 2016, p.391]).

When accumulated in deposits, sediment exhibits additional properties such as ***shear strength*** (*i.e.,* the ability of a material to resist shear stress [THOMAS, 2016, p.479] [ALLABY, 2013, p.528]) and ***sediment cohesion*** (*i.e.,* ability of particles to stick together without dependence of interparticle friction [ALLABY, 2013, p.120] [THOMAS, 2016, p.104]). In our context, a particularly important type of deposit is *seabed*. ***Seabed*** can be described as a broadly horizontal layer of deposited sediment or sedimentary rock that is located at the bottom of a sea or ocean (thus composing the surface of the seafloor), that is internally consistent and distinguishable from adjacent layers [PARK; ALLABY, 2017b; PARK, 2007; ENCYCLOPEDIA, 2004]. It is considered the smallest formally recognized division in a sediment or rock formation within a defined stratigraphic series [DARVILL, 2009].

Fluid[4] is a continuous material that is able to flow, *i.e.,* that undergoes a continuous

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[2] The notions of shear force and shear stress are closely related that occasionally we have some confusion between them such as in "*Shear stress is a force that deforms a mass of material by one part sliding over another*" [THOMAS, 2016, p.505], "*shear stress, force tending to cause deformation of a material by slippage along a plane or planes parallel to the imposed stress.*" [BRITANNICA, 2022c], or "*A material such as a solid or fluid is deformed by the application of a shear force over a surface, known as the shear stress.*" [SCHASCHKE, 2014c, p.343].

[3] <www.glossary.slb.com/en/terms/s/sediment>

[4] <www.collinsdictionary.com/dictionary/english/fluid>

and irreversible change in shape when subject to an applied shear stress/force [BRITANNICA, 2021b; ESCUDIER; ATKINS, 2019b] [SHANMUGAM, 2018, p.229] (in contrast to solids, which can maintain its shape [BRITANNICA, 2021b] [YOUNG; FREEDMAN, 2015, p.393]). Fluids include both liquids and gases [FALKOVICH, 2018, p.1] [YOUNG; FREEDMAN, 2015, p.393] [SCHASCHKE, 2014b] [HALLIDAY; RESNICK; WALKER, 2010, p.459]. Solid particles may also be made to behave as fluids when they are dispersed in liquids or gases [SCHASCHKE, 2014b]. Thus, ***fluidal mixtures*** of water and sediment involved in turbidity currents (which will be discussed in the following sections) are also considered to be fluids. Properties that are commonly attributed to fluids include ***density***, ***volume***, and ***viscosity*** (*i.e.,* internal resistance of a fluid to flow or to change in shape when a shear force is applied to it [BRITANNICA, 2022d; RENNIE; LAW, 2019d] [JAFFE; TAYLOR, 2019, p.564, 565] [ALLABY, 2013, p.621] [HALLIDAY; RESNICK; WALKER, 2010, p.469] [DASGUPTA, 2003, p.270]). Fluidal mixtures are also characterized by further properties, *e.g.,* ***volumetric sediment concentration*** (*i.e.,* ratio of the volume of sediment by the volume of water in the mixture [THOMPSON et al., 2006, p.6]).

Flow[5][6][7][8] is regarded as the steady and continuous movement of a fluid in a given direction by the "*change of position of one part of the material relative to another part in response to shear stress*" [BRITANNICA, 2021b; ESCUDIER; ATKINS, 2019a; PARK; ALLABY, 2017a; SCHASCHKE, 2014a]. ***Current***[9][10] has a similar definition [MAYHEW, 2009] and can be considered as synonymous of ***flow*** in our context.[11]

7.2.3 Mass Movements, Density Flows, and Sediment Gravity Flows

Turbidity currents are processes included in the broader category of mass movements [COVAULT, 2011]. ***Mass movements*** are movements of Earth material down an inclined ground surface (called *slope*) in response to the action of gravity [ALLABY, 2013; BRITANNICA, 2015]. A special type of mass movement is ***density current*** (also

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[5] <www.collinsdictionary.com/dictionary/english/flow>

[6] <www.dictionary.cambridge.org/dictionary/english/flow>

[7] <www.merriam-webster.com/dictionary/flow>

[8] <www.britannica.com/dictionary/flow>

[9] <www.collinsdictionary.com/dictionary/english/current>

[10] <www.merriam-webster.com/dictionary/current>

[11] This equivalence is sometimes made explicit, *e.g.,* when defining *flow* as a "*stream or current*" <www.collinsdictionary.com/dictionary/english/flow>, *current* as "*a flowing*" or "*a steady usually natural flow*" <www.collinsdictionary.com/dictionary/english/current>.

referred to as ***density flow***, ***gravity current***, or ***gravity flow***), which is a flow that takes place due to density differences between two fluids so that the denser fluid moves into the other [ALLABY, 2013; CENEDESE, 2012; MANICA, 2012; PARSONS et al., 2007; KNELLER; BUCKEE, 2000; KNOBLAUCH, 1999].

Among density currents, ***sediment gravity flows*** are those in which the density difference is due to sediment that is suspended in the fluid (which are habitually called ***suspended sediment load*** and ***interstitial fluid***[12]) [COVAULT, 2011; PARSONS et al., 2007; KNELLER; BUCKEE, 2000]. These flows are driven by the action of gravity on the suspended sediment, which moves and pulls the interstitial fluid down the seabed slope [MANICA, 2012; COVAULT, 2011; PARSONS et al., 2007; DASGUPTA, 2003]. The steeper the slope, the faster the fluid-sediment mixture flows. Given those characteristics, sediment gravity flows are responsible for the transport of large amounts of sediment toward the deep seafloor [WELLS; DORRELL, 2021; HEEREMA et al., 2020; PARSONS et al., 2007; SHANMUGAM, 2000; KNELLER; BUCKEE, 2000; MULDER; SYVITSKI, 1995].

7.2.4 Turbidity Currents

Turbidity currents (also referred to as ***turbidity flows***) are one of the most regularly studied types of sediment gravity flows [MANICA, 2012], sometimes regarded as "*the dominant global mechanism for transporting sediment from the continental shelf to the deep sea*" [HEEREMA et al., 2020]. Such processes consist of sediment gravity flows in which the sediment load is kept in suspension by interstitial fluid ***turbulence*** [WELLS; DORRELL, 2021] [HEEREMA et al., 2020, p.8] [LUCCHESE et al., 2019; ALLABY, 2013; MANICA, 2012; COVAULT, 2011; MEIBURG; KNELLER, 2010; PARSONS et al., 2007] [BAGCHI; BALACHANDAR, 2003, p.3496] [DASGUPTA, 2003; KNELLER; BUCKEE, 2000; SHANMUGAM, 2000; PARKER; FUKUSHIMA; PANTIN, 1986] [KNOBLAUCH, 1999, p.5]. Turbulence is the irregular, chaotic flow of a fluid [YOUNG; FREEDMAN, 2015, p.409], consisting of the local movement of the fluid in various directions, some of them diverging from the main flow direction in the case of currents (with such diverging movements being called *eddies*) [ALLABY, 2013, p.188, 606].

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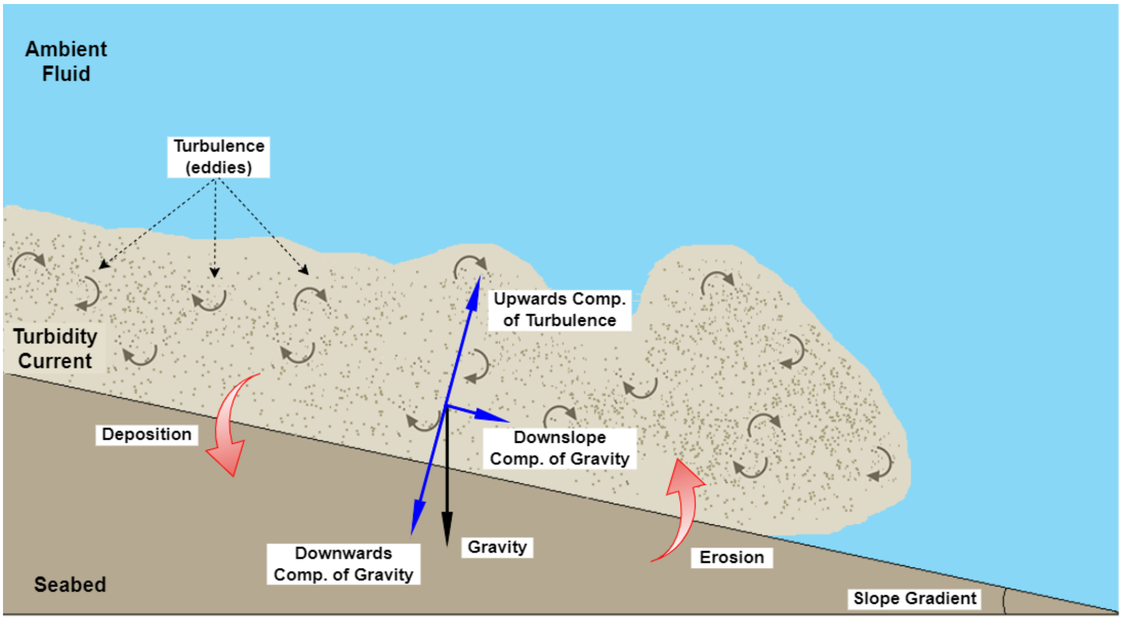
[12] With *interstitial* meaning "*Pertaining to the spaces (interstices) between sedimentary particles.*" [ALLABY, 2013, p.307].

Figure 7.1 – Turbidity Current Schema



Source: the author

Figure 7.1 presents a schematic view of a turbidity current running over an inclined seabed surface, with a given slope gradient, and under a mass of ambient fluid. The darker brown dots represent the sediment particles that are dispersed in the interstitial fluid. Interstitial fluid turbulence is represented by the spinning arrows distributed along the current. Thicker arrows represent the main forces operating in a turbidity current.

As earlier discussed, a turbidity current takes place by virtue of the action of gravity on its suspended load. Since the current typically propagates on an inclined rather than horizontal surface, the direction of gravity force is not perpendicular to this surface, but rather oblique. Hence, we have two components of gravity force acting on the sediment, affecting the current in distinct ways [PARKER; FUKUSHIMA; PANTIN, 1986, p.150].

One of them is the downslope component of gravity, which is parallel to the seabed surface and drives the current forward. It provides forward momentum to the suspended sediment, which makes it move and drag the interstitial fluid downslope. The other is the downwards component of gravity, which is perpendicular to the seabed surface and acts to pull the sediment load down towards the seabed, contributing to removing it from the mixture.

Since suspended sediment is what provides the motive force of a turbidity current, the downward component of gravity works to abbreviate the current. The upward component of turbulence counteracts it, preventing the sediment from falling out of suspension and then keeping a turbidity current going on [MANICA, 2012, p.266] [COVAULT, 2011]

[MEIBURG; KNELLER, 2010, p.136, 142] [DASGUPTA, 2003, p.266, 268] [PARKER; FUKUSHIMA; PANTIN, 1986, p.150, 175, 176]. For this reason, the turbulence of interstitial fluid is regarded as the main *sediment-support mechanism*[13] in turbidity currents.

7.2.5 Turbulence Generation

In turbidity currents, turbulence is generated by the forward motion of the fluid-sediment mixture due to shear stress at its upper and lower interfaces [WELLS; DORRELL, 2021, p.64] [HEEREMA et al., 2020, p.8] [MEIBURG; KNELLER, 2010, p.136, 142] [KNELLER; BUCKEE, 2000, p.76] [KNOBLAUCH, 1999, p.15, 18].

With that, the unfolding of a turbidity current relies on a feedback mechanism (sometimes called *autosuspension*): turbulence maintains the sediment suspended in the fluid, the sediment provides the excess density to the mixture, the excess density makes the mixture move downslope, and this movement generates the fluid turbulence that keeps the sediment in suspension [WELLS; DORRELL, 2021, p.68] [ALLABY, 2013] [MEIBURG; KNELLER, 2010, p.136]. This feedback loop is kept as long as the bed slope inclination can generate enough movement to produce the turbulence needed to suspend the sediment.

In other words, the kinetic energy of a turbidity current comes from the action of the downslope component of gravity on the suspended sediment [PARKER; FUKUSHIMA; PANTIN, 1986, p.145-146]. Then, this energy must be expended in generating turbulent kinetic energy, which is expended to overcome the downwards component of gravity on the sediment load in order to hold it in suspension [PARKER; FUKUSHIMA; PANTIN, 1986, p.150].

7.2.6 Erosion (Sediment Entrainment)

A turbidity current may also expend turbulent energy in picking sediment up from the seabed and incorporating it in the fluid-sediment mixture in a process called ***erosion*** (*i.e.,* the breakdown and removal of rock material by flowing water, wind, or moving ice)[14] [KNOBLAUCH, 1999, p.5] [PARKER; FUKUSHIMA; PANTIN, 1986, p.148]. In the context of sediment gravity flows, *erosion* is regarded as equivalent to ***sediment en-***

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[13] Mechanism that keeps sediment particles in suspension.

[14] <www.geolsoc.org.uk/ks3/gsl/education/resources/rockcycle/page3451.html>

trainment, *i.e., "the process by which surface sediment is incorporated into a fluid flow"* [THOMAS, 2016, p.180], resulting in the entrained sediment being carried in suspension within the flow.[15] Thus, erosion is said to *fuel* the flow by increasing its load and, consequently, the density of the mixture – the source of its downslope motive force –, accelerating the current [BAAS et al., 2016, p.2003-2004] [MEIBURG; KNELLER, 2010, p.136] [KNELLER; BUCKEE, 2000, p.66] [KNOBLAUCH, 1999, p.5] [FUKUSHIMA; PARKER; PANTIN, 1985, p.56].

Erosion occurs – or, in other words, bed sediment is entrained into the flow – when the forces acting to move seabed sediment overcome the forces resisting such a movement [THOMAS, 2016, p.180] [PARSONS et al., 2007]. In special, it happens when the *shear stress* that the flowing mixture exerts on the seabed is greater than the *shear strength* of its constituting sediment [BAAS et al., 2016, p.2025, 2034] [BAAS et al., 2014]. That is to say, erosion happens by virtue of the ability of a turbidity current to produce enough bed shear to increase its load [PARSONS et al., 2007, p.277].

The exerted shear stress is sometimes expressed in terms of the shear velocity of the flowing mixture [KNELLER, 2003, p.902, 903]. Complementarily, as presented in section 7.2.2, ***shear strength*** is the ability of a material to resist shear stress, corresponding to the maximum shear stress that the material can resist before a portion of it is detached from the rest [THOMAS, 2016, p.479] [ALLABY, 2013, p.212, 528]. This is customarily expressed in terms of *critical erosion velocity* (*i.e.,* the flow velocity required to initiate the entrainment of sediment particles [THOMAS, 2016, p.180]) and *critical shear stress* or *yield stress* (*i.e.,* the maximum shear stress that material can withstand without being eroded [ESCUDIER; ATKINS, 2019f] [SHANMUGAM, 2018, p.231] [MAYHEW, 2015a]) [BAAS et al., 2016, p.2003, 2004, 2017, 2025, 2034] [BAAS et al., 2014, p.373] [PARSONS et al., 2007, p.319].

Several properties of the flowing mixture contribute to the shear stress it applies on the seabed, including *density*, *velocity*, and the *turbulence level*[16] of its interstitial fluid [BAAS et al., 2016, p.2003, 2030] [BAAS et al., 2014] [THOMPSON et al., 2006, p.2] [KNELLER; BUCKEE, 2000, p.75] [SHANMUGAM, 2000] [PARKER; FUKUSHIMA;

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[15] In general, *erosion* is understood as the process of removing sediment or rock material from Earth's surface *and* transporting it to other locations [THOMAS, 2016; BRITANNICA, 2022a]. Even so, in some contexts, erosion and the following transport of the removed material are regarded as separated processes [BRITANNICA, 2022a]. This is the case with turbidity currents, as indicated in, *e.g.,* "*downflow transport of the eroded sediment*" [BAAS et al., 2016, p.2020], "*resuspension and the subsequent movement of the resuspended material due to gravity*" [PARSONS et al., 2007, p.323], "*Sediments, which have already settled down, can thus be eroded again and transported*" [OEHY; SCHLEISS, 2007, p.637].

[16] Mean turbulent kinetic energy per unit mass [KNOBLAUCH, 1999, p.19].

PANTIN, 1986, p.145, 156, 173]. Likewise, several properties of the seabed or sediment contribute to its shear strength, including sediment *grain size*, and *grain shape*, *sediment density*, and *sediment cohesion* (*i.e.,* existence of cohesive bonds among sediment particles, especially due to presence of clay in the sediment) [BAAS et al., 2016, p.2003, 2030] [THOMAS, 2016, p.121, 122, 180] [BAAS et al., 2014, p.370, 372] [KNELLER, 2003, 903] [ANDERSEN; HOUWING; PEJRUP, 2002].

7.2.7 Deposition

When a turbidity current cannot produce enough turbulence to keep its sediment load in suspension, it loses part of the load to the seabed in a process called ***deposition*** (or ***sedimentation***) [BAAS et al., 2016, p.2003] [PARSONS et al., 2007, p.328] [KNELLER, 2003, 903] [PARKER; FUKUSHIMA; PANTIN, 1986, p.148].

Occurrence of deposition decreases the density of the mixture [BAAS et al., 2016, p.2003, 2026] [MANICA, 2012, p.273], which translates into a loss of momentum, making the current slow down [HEEREMA et al., 2020, p.1] [MEIBURG; KNELLER, 2010, p.145]. This decrease in downslope velocity tends to decrease the turbulence production, which, in certain cases, leads to more sediment deposition, further decelerating the current, with this negative feedback loop going on until the current eventually completely dissipates and stops [WELLS; DORRELL, 2021, p.68] [HEEREMA et al., 2020, p.1, 2, 7] [MANICA, 2012, p.279-280] [MEIBURG; KNELLER, 2010, p.136, 145].

7.2.8 Fluid Entrainment and Detrainment

Besides that, turbidity currents can also exchange fluid with its surroundings by means of the processes of ***fluid entrainment*** (*i.e.,* mixing of ambient fluid into the mixture) and ***fluid detrainment*** (*i.e.,* loss of interstitial fluid to the ambient) [MANICA, 2012, p.265, 279-280] [MEIBURG; KNELLER, 2010, p.135, 136] [PARSONS et al., 2007, p.289] [KNELLER; BUCKEE, 2000, p.71] [KNOBLAUCH, 1999, p.15]. They happen mainly at the upper interface between the flowing mixture and the ambient fluid [MANICA, 2012, p.280] [KNELLER; BUCKEE, 2000, p.72] [KNOBLAUCH, 1999, p.15] [MIDDLETON, 1993, p.94].

Similarly to sediment entrainment, these hydrodynamic processes are also associated with the interfacial shear stress, but, in this case, between the flowing mixture and the ambient fluid [MANICA, 2012, p.265, 266, 283-284] [PARSONS et al., 2007, p.283-284, 308, 330] [KNELLER; BUCKEE, 2000, p.74, 75] [MIDDLETON, 1993, p.94, 104, 107]. Besides that, such processes also affect the inner properties of the flow, *e.g.,* the entrainment of ambient fluid reduces the density and momentum of the mixture [HEEREMA et al., 2020, p.8] [MANICA, 2012, p.279-280] [PARSONS et al., 2007, p.289].

7.3 Ontological Analysis of Turbidity Currents

In this section, we conduct an analysis of the ontological nature of turbidity currents. We discuss the intention underlying the notion of turbidity current, considering it as the flowing of a fluid-sediment mixture. Contextually, the flow of the mixture happens over a seabed and is surrounded by a mass of ambient fluid, with possible interaction between these entities and the flowing mixture.

7.3.1 Turbidity Current as Sediment Transport

As discussed in sections 7.2.3 and 7.2.4, much of what is said about sediment gravity flows in general, and especially about turbidity currents, emphasizes their nature as processes of transport of sediment. This sort of transport process takes place due to a complex interaction between the solid and fluid phases of the mixture, which are treated as first-order participants with specific roles in the process. Namely, the sediment in suspension is regarded as the suspended '*load*'[17] to be transported [MANICA, 2012, p.264] [MEIBURG; KNELLER, 2010, p.142] [PARSONS et al., 2007, p.277, 309] [OEHY; SCHLEISS, 2007, p.642] [SHANMUGAM, 2000, p.299, 301] [PARKER; FUKUSHIMA; PANTIN, 1986, p.148]. Conversely, the interstitial fluid is regarded as the means of suspending and transporting the sediment – in other words, the '*host*' and '*transporting medium*' for the sediment [DASGUPTA, 2003, p.275].

It seems clear that the fluid-sediment mixture is the core of a sediment gravity flow, which we will consider as a process of *transport of suspended sediment by a fluid*. Moreover, regarding turbidity currents, its distinctive feature is precisely the movement of sediment in suspension due to the turbulent state of the fluid [DASGUPTA, 2003, p.275].

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[17] "*something, usually a large quantity or heavy object, which is being carried*" <www.collinsdictionary.com/us/dictionary/english/load>.

Therefore, we will consider a turbidity current as a process of *transport of suspended sediment by a turbulent fluid.*

This view seems to be corroborated by a particularity regarding the use of the terms *flow* and *current* in the geological domain. The standard view of flows and currents regards them as events or processes, as evidenced in section 7.2.2 and reinforced by numerous direct references to that in the literature (*e.g.,* "*This flow was also the only event to occur in summer*" [HEEREMA et al., 2020, p.6], "*Turbidity currents are powerful processes*" [FICK; MANICA; TOLDO, 2017, p.346]). Despite that, the terms *flow* and *current* may also be used to refer to the continuant entity that is moving instead of the event of motion – *e.g.,* when defined as the "*material that is flowing*"[18][19] or "*the part of a fluid body (such as air or water) moving continuously in a certain direction*"[20]. In fact, authors from the geological domain seem to consistently commit to this conflicting continuant nature of these entities in their discourse.

One way in which this commitment is manifested is the attribution of arguably continuant properties to flows and currents such as ***volume***, ***viscosity*** and ***thickness***. An emblematic example is ***density***, which is frequently attributed both to flows and currents as well as to fluids and sediments – sometimes even in the same paragraph or sentence (*e.g.,* "*density difference between flow and ambient fluid*" [WELLS; DORRELL, 2021, p.71], "*density of the turbidity current is larger than the density of the muddy substrate*" [BAAS et al., 2016, p.2019]).

Authors also implicitly recognize flows and currents as continuants when characterizing them as participating in events. Notably, flows and currents are commonly said to ***move***, to ***travel***, or even to ***flow*** [WELLS; DORRELL, 2021, p.59] [HEEREMA et al., 2020, p.8] [BAAS et al., 2016, p.2030] [BAAS et al., 2014, p.372] [MANICA, 2012, p.263, 274, 280] [CENEDESE, 2012] [MEIBURG; KNELLER, 2010, p.136, 140] [PARSONS et al., 2007, p.276, 278, 285, 321, 322, 326] [KNELLER, 2003, p.902, 903] [KNELLER; BUCKEE, 2000, p.66, 75] [KNOBLAUCH, 1999, p.8] [MULDER; SYVITSKI, 1995, p.285].

In addition, flows/currents are treated as being able to ***enter*** and ***leave*** places or objects (*e.g.,* a lake or ocean), to undergo ***qualitative changes*** (*e.g.,* in density and sediment concentration), and to ***mix*** with the ambient fluid [WELLS; DORRELL, 2021, p.59] [HEEREMA et al., 2020, p.2] [FICK; MANICA; TOLDO, 2017, p.348] [BAAS et

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[18] <www.britannica.com/dictionary/flow>

[19] <www.dictionary.cambridge.org/dictionary/english/flow>

[20] <www.merriam-webster.com/dictionary/current>

al., 2016, p.2034] [BAAS et al., 2014, p.371, 372, 373] [MANICA, 2012, p.274, 280] [CENEDESE, 2012] [COVAULT, 2011] [PARSONS et al., 2007, p.277, 283, 289, 290, 291, 292] [OEHY; SCHLEISS, 2007, p.637, 640, 642] [KNELLER; BUCKEE, 2000, p.71] [KNOBLAUCH, 1999, p.8, 18].

This dual treatment of flows/currents as both events and continuants suggests that the usual discourse in the domain collapses two distinct entities under the same term. In other words, we have the sort of *systematic polysemy*[21] reported in [GUIZZARDI; GUARINO; ALMEIDA, 2016, p.10-11], *i.e.,* "*whenever we refer to something that is on going, that can qualitatively change and still maintain its identity, we are not referring to an event but to the endurant underlying that event*".

Given that, we would have distinct, yet related, entities: the *flow/current* that flows (a continuant), and the *flow* of the flow/current (an event). Indeed, this is explicitly stated in some passages, *e.g.,*

- "*the turbulent flow of the turbidity current*" [LUCCHESE et al., 2019, p.2];
- "*turbidity current [...] density difference that drives its flow.*" [CENEDESE, 2012];
- "*the flow of turbidity currents*" [MEIBURG; KNELLER, 2010, p.142].

It leaves the question of what is the entity corresponding to the flow/current *qua* continuant – that is, the underlying continuant entity that *flows* in a flow/current *qua* event. Considering the literature from the domain, we can conclude that this entity is a *fluid-sediment mixture*. Mixtures of this sort are frequently considered as bearers of continuant properties such as *density*, being used in comparisons (*e.g.,* "*relative density between the flowing sediment–water mixture and the ambient water"* [DASGUPTA, 2003, p.266]). They are also said to enter the ocean, flow within an ambient fluid body, move downslope, mix with ambient water, and other events. In fact, several passages indicate this correspondence, such as

- "*Flow [...] Continuous, irreversible deformation of sediment-water mixture that occurs in response to applied stress*" [SHANMUGAM, 2018, p.229];
- "*a solid mass of mixture flowing downstream*" [MANICA, 2012, p.280];
- "*A sediment gravity flow is a general term for a mixture of sediment and water in which the sediment component pulls interstitial water*" [COVAULT, 2011];

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[21] The phenomenon in which "*a noun has several distinct but related meanings whereby the same relation holds between the meanings for a series of nouns*" [DöLLING, 2020].

- "*Turbidity current is characterized by the flow of sediment-fluid mixture*" [DASGUPTA, 2003, p.266];
- "*suspension current as flow induced by the action of gravity upon a (fluidal) turbid mixture of fluid and (suspended) sediment*" [KNELLER; BUCKEE, 2000, p.63];
- "*flow velocity of the mixture*" [PARKER; FUKUSHIMA; PANTIN, 1986, p.174].

7.3.2 Turbidity Current as Downslope Underwater Movement

Sediment gravity flows are also depicted as a *downslope movement of a fluid-sediment mixture over the seabed intruding a stagnant body of fluid*. Following this view, at a first glance, the seabed over which the mixture flows and the surrounding fluid into which the mixture advances should also be considered participants of the event. However, authors seem to deal with the underlain seabed and the surrounding fluid as entities external to the flow. This external character is especially evident in the choice of terms used to characterize these entities.

One of such terms is *ambient* (*i.e.,* a synonymous of *environment*[22][23][24] or an adjective for what surrounds a phenomenon [THOMAS, 2016, p.21]). For example, the fluid that surrounds the mixture is almost unanimously referred to as '*ambient* fluid/water' [WELLS; DORRELL, 2021; LUCCHESE et al., 2019; SHANMUGAM, 2018; FICK; MANICA; TOLDO, 2017; BAAS et al., 2016; CENEDESE, 2012; MANICA, 2012; COVAULT, 2011; MEIBURG; KNELLER, 2010; PARSONS et al., 2007; OEHY; SCHLEISS, 2007; KNELLER, 2003; DASGUPTA, 2003; KNELLER; BUCKEE, 2000; SHANMUGAM, 2000; KNOBLAUCH, 1999; HüRZELER; IMBERGER; IVEY, 1996; MULDER; SYVITSKI, 1995].

Separation of flow/current and ambient fluid is also explicit in the references to an *interface* between them [PARSONS et al., 2007, p.289, 291] [KNOBLAUCH, 1999, p.15] [HüRZELER; IMBERGER; IVEY, 1996, p.232, 235] or to a *surface* of the current through which the ambient water can enter [MANICA, 2012, p.279-280]. Likewise, authors refer to *boundaries* dividing both current and ambient fluid as well as current and seabed [HEEREMA et al., 2020, p.8] [MANICA, 2012, p.265] [MEIBURG; KNELLER, 2010, p.136, 145] [PARSONS et al., 2007, p.278] [KNELLER; BUCKEE, 2000, p.68,

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[22] <www.dictionary.cambridge.org/us/dictionary/english/ambient>

[23] <www.merriam-webster.com/dictionary/ambient>

[24] <www.collinsdictionary.com/dictionary/english/ambient>

72, 75, 76]. Sometimes seabed itself is considered to be one of the boundaries of the (*e.g.,* "*Turbidity currents [...] may exchange particles with a loose lower boundary (*i.e.,* a sediment bed)*" [MEIBURG; KNELLER, 2010, p.136]).

Recurrently, seabed and ambient fluids are treated as external objects with which the turbidity current interacts. In the case of seabed, authors literally refer to *interactions* between flow/current and bed [WELLS; DORRELL, 2021, p.60] [BAAS et al., 2016, p.2004] [BAAS et al., 2014, p.371] [MANICA, 2012, p.265] [MEIBURG; KNELLER, 2010, p.147] [SEQUEIROS et al., 2009, p.2-3] [PARSONS et al., 2007, p.294]) [KNELLER; BUCKEE, 2000, p.63], which include erosion and deposition [BAAS et al., 2016, p.2025, 2034] [MANICA, 2012, p.265]. There are also many references to the *exchange* of sediment with the seabed and of fluid with the ambient, *e.g.,* [HEEREMA et al., 2020, p.2] [MEIBURG; KNELLER, 2010, p.136, 149] [OEHY; SCHLEISS, 2007, p.638] [KNOBLAUCH, 1999, p.5] [PARKER; FUKUSHIMA; PANTIN, 1986, p.145].

All these indications suggest that an event of a sediment gravity flow, such as a turbidity current, is regarded as the flowing of the mixture, which may be affected by the seabed and ambient fluid (*e.g.,* facilitating or hindering the unfolding of the process), without this influence qualifying them as participants in the flow.

7.3.3 Turbidity Current as Turbulent Fluid Carrying Suspended Sediment in a Deep-Marine Environment

The discussion so far highlighted four main points:

(1) The prevalence of the view of sediment gravity flows (including turbidity currents) as events of transport of sediment;

(2) The recurrent confusion between the notions of flow/current and the underlying flowing mixture;

(3) The systematic breaking down of the involved mixture into its fluid and sediment components to emphasize their interaction (*i.e.,* the carrying of suspended sediment by a transporting medium), which also reveals the distinctive feature of turbidity currents in relation to other sediment gravity flows (*i.e.,* the turbulent suspension of the sediment);

(4) The external character of seabed and ambient fluid in relation to the current.

These considerations convey a strong intuition about what a sediment gravity flow ultimately is: an event in which an interstitial fluid carries a given sediment load in suspension along the deep seafloor. In other words, it is a transition through a series of situations in which the interstitial fluid stands in a *suspends* relation with the sediment load and, as time passes, both are located in farther regions of the seafloor. Accordingly, we define sediment gravity flows as follows:

Definition 117 (Sediment Gravity Flow) *Given a set of situations successive* {s_1, ..., s_n}, *a set of regions on the seafloor* {r_1, ..., r_n}, *an interstitial fluid* inter_fluid, *and a suspended sediment load* sed_load:

Sediment Gravity Flow $=_{def}$ *An event that is a transition through situations* {s_1, ..., s_n} *such that, for each* s_i,

(1) includes(s_i,$fluid_{inter}$) *and* includes(s_i,$load_{susp}$);

(2) suspends($fluid_{inter}$,$load_{susp}$);

(3) located_in($fluid_{inter}$,r_i) *and* located_in($load_{susp}$,r_i); *and*

(4) r_{i+1} *is farther into the seafloor than* r_i.

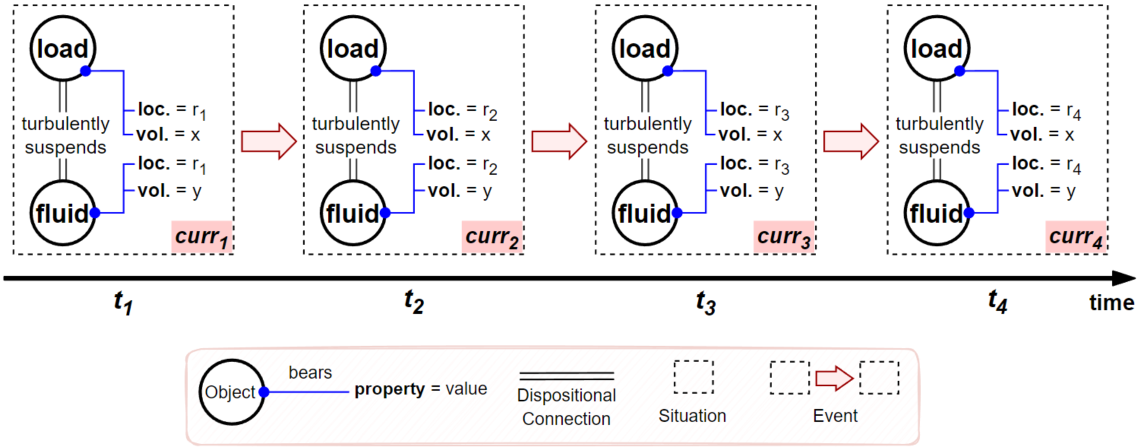
Correspondingly, turbulent currents are a particular type of sediment gravity flow in which the sediment load is suspended due to the turbulence in the fluid, as following defined:

Definition 118 ***Turbidity Current*** $=_{def}$ *A sediment gravity flow that involves an interstitial fluid* inter_fluid *and a suspended sediment load* sed_load *(as described in def. 117) such that* inter_fluid *is turbulent and* turbulently_suspends($fluid_{inter}$,$load_{susp}$).

Figure 7.2 brings a schematic representation of a turbidity current as a transition through situations comprising an interstitial fluid *fluid* that turbulently suspends a suspended sediment load *load*. Those entities are also characterized by their volumes of such entities (‘*vol.*’) – which remain the same throughout the current – and their locations (‘*loc.*) – which change over time as the fluid-sediment mixture flows deeper into the sea.

Despite the proposed definitions, to have a faithful account of turbidity currents, we cannot neglect the fact that these events happen in a deep-marine context. With that, the model should somehow include seabed and ambient fluid as additional elements that influence the occurrence of the flow. Even so, we should also do justice to the intuition that such elements do not take part in the event.

Figure 7.2 – Turbidity Current as a Transition through Situations (schematic representation)



Source: the author

Therefore, in order to provide ontological grounds for the choice of the participants of a turbidity current and their differentiation from the additional elements, we propose to delimit turbidity currents as system-invariant events, as detailed in the next section.

7.4 Turbidity Currents as System-Invariant Events

In this section, we propose modeling turbidity currents as system-invariant events. We take a flowing fluid-sediment mixture to be the system that delimits any event of this type. Thus, we briefly present this type of system in terms of its components, its connections, and its immediate environment. Then we argue for the adequacy of this picture based on evidence from domain literature.

Following, we describe such a system in further detail. We discuss the nature of the flowing fluid-sediment mixture and its components (*i.e.,* interstitial fluid and suspended sediment load) as variable embodiments rather than fixed material portions. After that, we characterize the *turbulently suspends* relation as a dispositional connection between the components of the system.

Then, concluding the section, we present turbidity currents as open-system events, preparing for the discussion in the next section about environment elements and auxiliary events.

Lastly, a brief remark about the notion of *gravity*. Despite its central role in describing turbidity currents as happening due to the action of gravity on the suspended sediment (sec. 7.2.3), in practice, gravity is only employed indirectly via notions such as *weight*, *density*, *potential energy*, or *slope*. Therefore, instead of explicitly accounting for this notion in our model, *e.g.,* via dispositions inhering in two mutually attracting bodies [BARTON; ROVETTO; MIZOGUCHI, 2014], we will simply deal with it as a boundary condition in our analysis, underlying certain contact forces between the objects in the domain.

7.4.1 Fluid-Sediment Mixture as the System Delimiting a Turbidity Current

Initially, we propose modeling a sediment gravity flow as an event delimited by a flowing *fluid-sediment mixture*, which we regard as a system with two components, *i.e.,* an *interstitial fluid* and a *suspended sediment load*. Moreover, these components are connected by a *suspends* relation, *i.e.,* "*the 'holding up' of grains above the bed*" [KNELLER; BUCKEE, 2000, p.63].[25] Besides, such a system exists in an environment consisting of some *seabed* (and its constituting *sediment substrate*) and a surrounding body of *ambient fluid*, which are connected to the turbidity current system by a *in_contact* relation.

Given that, as a special case of sediment gravity flow, a turbidity current would also be an event delimited by a fluid-sediment system, but with the particularity of its components being connected by the more specific relation of *turbulently suspends* relation. Figure 7.3 brings a schematic representation of this view.

With that, we contemplate all the elements that are considered to play a role in our scenario of interest, while conveying their relative importance. Specifically, we take interstitial fluid and suspended load to be first-order participants, which allows us to account for their interaction mechanisms (*i.e.,* for sediment support and transportation), whose operation sets the current in motion and keeps it going. Alongside, we preserve seabed and ambient fluid as additional elements that provide necessary conditions for the occurrence of the flow without taking part in it – just as the life of a breathing organism depends on the presence of oxygen without oxygen being a part of the organism.

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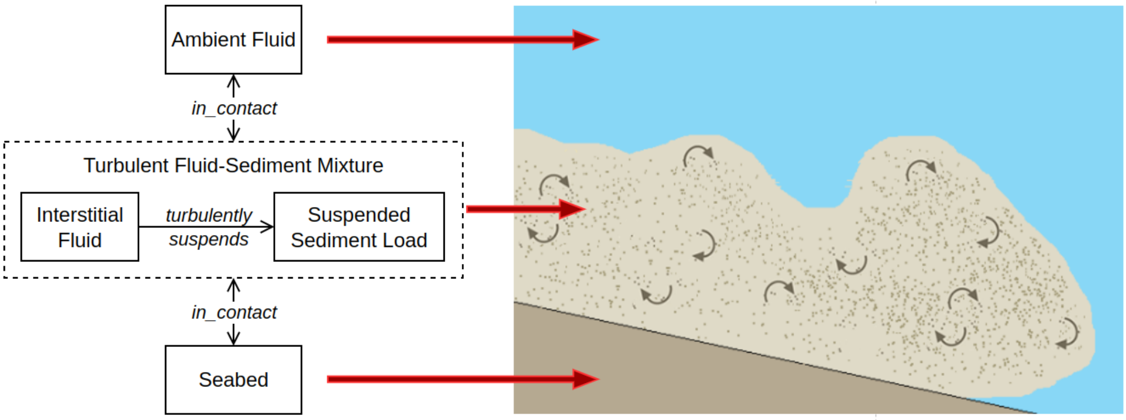
[25] The term *suspend* is also defined as "*to keep from falling or sinking by some invisible support*" <www.merriam-webster.com/dictionary/suspend> or "*to cause to remain floating or hanging; to cause (particles) to be held in suspension in a fluid*" <www.collinsdictionary.com/dictionary/english/suspend>.

Figure 7.3 – Turbulent Fluid-Sediment Mixture System (schematic representation)



Source: the author

The view that a mixture of fluid and suspended sediment forms a system is compatible with common sense. Such mixtures are sometimes referred to as *suspensions* or *dispersions*, which are defined as a system consisting of small, solid particles kept dispersed in a surrounding medium (*e.g.,* liquid).[26][27][28][29]

More importantly, the literature from the domain also reflects this view. On the one hand, there are plenty of indications of the commitment to the system nature of fluid-sediment mixtures. Sometimes it is implicit in the usual characterization of mixtures as entities composed of two components involved in complex interactions (*e.g.,* "*particle–fluid interactions causing sediment and mass transport, energy production, or dissipation.*" [NOMURA et al., 2019, p.436]; "*In energetic high-concentration flows [...] there is non-negligible energy exchange between particle and fluid phases*" [WELLS; DORRELL, 2021, p.63], "*mixture of sediment and water in which the sediment component pulls interstitial water down slope*" [COVAULT, 2011]). In other passages, this commitment is made explicit, such as in

> "*In turbidity current, the particles constitute relatively minor [...] fraction of the flowing mass and remain in dispersed state within the turbulent fluid. [...] in this flowing system, the fluid component [...] control the movement of the grains within the flow.*" [DASGUPTA, 2003, p.267-268].

Moreover, this passage suggests that a turbidity flow is delimited by a fluid-sediment system (the "*flowing system*"), which is reinforced in other aspects of the domain

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[26] "*a system consisting of small particles kept dispersed [...] in the surrounding medium*" <www.collinsdictionary.com/dictionary/english/suspension>.

[27] "*a system consisting of a solid dispersed in a solid, liquid, or gas usually in particles of larger than colloidal size*" <www.merriam-webster.com/dictionary/suspension>.

[28] "*a system of dispersed particles suspended in a solid, liquid, or gas*" <www.collinsdictionary.com/dictionary/english/dispersion>.

[29] "*a system consisting of a dispersed substance and the medium in which it is dispersed*" <www.merriam-webster.com/dictionary/dispersion>.

discourse. One of such aspects is the coincidence between the initiation of the event with the setting up of the system, such as in

- “*The initiation of turbidity currents depends on the formation of a sediment suspension*” [MEIBURG; KNELLER, 2010, p.145];
- “*[...] mixes the material entrained into the water column. This material quickly initiates a turbidity current*” [PARSONS et al., 2007, p.320]);
- “*Remobilization of subaqueous sediments caused by instability may lead to generation of debris flow or turbidity current.*” [DASGUPTA, 2003, p.274];
- “*Addition of particles in pure fluid flow [...] within ambient water body as density currents or underflows, turbidity current is generated.*” [DASGUPTA, 2003, p.276].

Along with that, the end of the event is strongly related to the dissolution of the system, habitually called “*dissipation*” of the current. It happens by the ceasing of the suspension relation between fluid and sediment, with sediment particles leaving the mixture (*i.e.*, “*falling out from suspension*” [MANICA, 2012, p.274], “*suspended sediment will settle out*” [HEEREMA et al., 2020, p.7]) through “*deposition*” or “*sedimentation*”[30], which results from the loss of transport capacity of the current due to the reduction of turbulence. For instance,

- “*loss of density by sedimentation leads to a sudden termination of flow as the buoyancy that drives the flow decreases, reducing any turbulence that might keep sediment is suspension.*” [WELLS; DORRELL, 2021, p.76]
- “*Dissipation is caused by sediment deposition, which leads to spatial decreases in flow density, and thus velocity. This negative feedback causes the flow to eventually die out.*” [HEEREMA et al., 2020, p.2]
- “*the dissipation of turbulence caused the loss of sediment-transport capacity of the flow [...] the current become more diluted due to deceleration of the flow [...] (grains settled down) and then, tend to stop.*” [MANICA, 2012, p.274, 279-280]
- “*Turbidity currents [...] Such flows dissipate mainly through deposition of the particles*” [MEIBURG; KNELLER, 2010, p.136];

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[30] “*sedimentation, in the geological sciences, process of deposition of a solid material from a state of suspension or solution in a fluid (usually air or water).*” [BRITANNICA, 2022b].

- "*turbidity currents slow down on low slopes, which causes the {sediments* to settle and the current to die out" [OEHY; SCHLEISS, 2007, p.637];
- "*turbulent energy consumed [...] exceeds the supply of energy to the turbulence, so that the turbulence, and thus the turbidity current, must die.*" [PARKER; FUKUSHIMA; PANTIN, 1986, p.145]

On the other hand, in addition to the plausible adequacy of fluid-sediment mixture as the system delimiting a turbidity current, domain literature also support the view of seabed and ambient fluid as composing the setting or context in which a current happens. In our terms, domain discourse suggests the view of seabed and ambient fluid as elements composing the *environment* of the flowing system.

In section 7.3.2 we already present some indications that ambient fluid and seabed are treated as entities external to the flowing system. On top of that, despite the strong interaction between these elements and the mixture, they are consistently considered to interact with the mixture itself instead of individually interacting with its components (*e.g.,* seabed acting as path or conduit over which the mixture flows [SHANMUGAM, 2018, p.246] [MCHARGUE et al., 2011, p.732] and ambient fluid imposing resistance to its advance [MANICA, 2012, p.265]). Moreover, the nature of these interactions seems to be that of a modulation of the turbidity flow process by modulating the evolution of the flowing system. This can be observed in passages such as

- "*Turbulence in a gravity, or turbidity, current is generated by shear instabilities in the upper interface, or from drag at the lower boundary.*" [WELLS; DORRELL, 2021, p.64];
- "*Turbidity current evolution is therefore highly sensitive to both initial velocities and seabed character*" [HEEREMA et al., 2020, p.1];
- "*erosion and deposition during the movement, modifies the mechanisms of transport and deposition of particles within the flow*" [MANICA, 2012, p.269]

  "*Seafloor topography can influence flow behavior*" [COVAULT, 2011]
- "*the evolution of the current is strongly affected by the loss of particles and interstitial fluid at its lower boundary*" [MEIBURG; KNELLER, 2010, p.145];
- "*[...] it is the near-bed region that is most crucial to the evolution of a turbidity current. Near-bed shear regulates resuspension and deposition of sediment, which is*

the primary mechanism responsible for growth in a turbidity current.” [PARSONS et al., 2007, p.295].

- “*The entrainment of ambient fluid into the flow, and its downslope evolution (including erosion or deposition of sediment) [...]*” [MIDDLETON, 1993, p.108]

Complementarily, the turbidity current also seems to regulate the evolution of the environment elements, *e.g.,*

- “*The downstream evolution of velocities and runout lengths controls how sediment is dispersed, the resulting deposit character and shape [...]*” [HEEREMA et al., 2020, p.1];
- “*The great disparity presented by [...] fans in terms of morphology and depositional evolution suggests that [...] turbidity currents had decisive influence on the different morphologies*” [FICK; MANICA; TOLDO, 2017, p.363]
- “*The coupling between the evolution of the turbidity current and that of the underlying substrate*” [MEIBURG; KNELLER, 2010, p.150];
- “*As turbidity currents propagate over the seafloor, they can trigger the evolution of a host of topographical features through the processes of deposition and erosion [...]*” [MEIBURG; KNELLER, 2010, p.135];
- “temporal variation of the bottom topography in response to erosion and deposition.” [MEIBURG; KNELLER, 2010, p.143]
- “*evolution and development of an erodible bed due to sediment entrainment and deposition*” [OEHY; SCHLEISS, 2007, p.638];
- “*both aggradational and erosional channels evolve in response to changes in flow size, density and/or grain-size*” [KNELLER, 2003, p.908].

7.4.2 Flowing Mixture, Interstitial Fluid, and Suspended Load as Variable Embodiments

Provided that a turbulent fluid-sediment mixture is the system that delimits a turbidity current, we should be able to identify the elements that characterize the system as such. The components of the system are an interstitial fluid and a suspended sediment load, which are constituted of fluid and sediment, respectively. So, we start by defining *fluid* and *sediment*.

Definition 119 ***Fluid*** $=_{def}$ *A portion of continuous material that is able to undergo a continuous, irreversible change in shape (*i.e., *able to flow) when subject to an applied shear force.*

Definition 120 ***Sediment*** $=_{def}$ *A collection of solid grains/particles of minerals, organic matter or preexisting rocks, that is unconsolidated (*i.e., *not solidified into a rock), so that it can be transported by some fluid and later deposited.*

We assume that a turbidity current is an event delimited by a single, enduring fluid-sediment mixture that flows downslope for a given runout distance (*i.e.,* the distance over which the currents travels [PARSONS et al., 2007, p.278]). Moreover, this flowing mixture may undergo changes during the event, such as in density, volume, and velocity [HEEREMA et al., 2020, p.8] [MANICA, 2012, p.280] [MIDDLETON, 1993, p.104, 107].

Besides, the fluid-sediment mixture is not simply the fixed amount of material that was initially set in motion. Instead, it is individuated by its density contrast with the ambient fluid due to the high concentration of sediments within the mixture [MIDDLETON, 1993, p.107] [DASGUPTA, 2003, p.266] [PARSONS et al., 2007, p.278]. With that, the composition of the flowing mixture may vary over time due to the incorporation/loss of water into/from the interstitial fluid and sediment into/from the suspended load, so that the mixture may be composed of distinct amounts of fluid and sediment at different stages of the event. Given those features, the flowing fluid-sediment mixture qualifies as a *variable embodiment* [FINE, 1999; MOLTMANN, 2020].

As discussed in section 3.2, a variable embodiment is an entity that allows for the replacement of its constituting material and, thus, that may have different material manifestations at different times, being associated with a principle that determines which is the material manifestation in every instant in which the entity exists [FINE, 1999; MOLTMANN, 2020]. Besides organisms and artifacts, another prototypical example from [FINE, 1999, p.68-69] is that of "*the water in the river*", conceived as a variable portion of water whose material manifestation at a given time instant is whatever water that is running inside the river channel at the time. Interestingly, literature from the geological domain often poses rivers and turbidity currents as similar entities that fall into the class of sediment flows [SHANMUGAM, 2018, p.230] [DASGUPTA, 2003, p.269] [SHANMUGAM, 2000, p.296, 300] [PARKER; FUKUSHIMA; PANTIN, 1986, p.152] – which suggests the applicability of the notion of variable embodiment to our case.

The material manifestation of the fluid-sediment mixture flowing in a turbidity current is, initially, the amount of turbulent fluid and suspended sediment that exhibits a density contrast with ambient fluid and starts moving downslope.[31] From this point onwards, the material manifestation of the flowing mixture at time *t* is given by the amount of turbulent fluid and suspended sediment that exhibits a sharp density contrast with the ambient fluid and presents a spatiotemporal continuity with the material manifestation of the mixture at time *t-1*.

Likewise, interstitial fluid and suspended sediment load also qualify as variable embodiments. They are treated as the fluid and sediment phases or components of the mixture, whatever their contents are (*e.g.,* "*Turbidity currents are gravity currents, where the denser phase contains settling granular material.*" [KNOBLAUCH, 1999, p.4]; "*gravity does no work on the fluid phase.*" [PARKER; FUKUSHIMA; PANTIN, 1986, p.150]). This is reinforced by references to changes that their constituents undergo (*e.g.,* "*When a turbidity current enters the self-accelerative mode, it continually increases its velocity and suspended load*" [SEQUEIROS et al., 2009, p.2]; "*ability of a turbidity current [...] to increase its load*" [PARSONS et al., 2007, p.277]).

Although domain discourse evidently deals with both interstitial fluid and suspended sediment load as variable embodiments, it is not completely clear what would be their variable embodiment principle. A first approach would be indirectly relying on the principle for the whole flowing mixture. With that, the manifestation of the interstitial fluid of the flowing mixture at a given time instant would be whatever amount of fluid that is suspending the sediment phase of the mixture at the time. Analogously, the manifestation of suspended sediment load would be whatever amount of sediment that is suspended in the fluid phase of the mixture at the time.

Nevertheless, the fluid and sediment phases of the mixture are not just beneficiaries of the individuation criterion provided by the mixture but also contribute to it. In particular, the interstitial fluid is distinguished from the ambient fluid by some physical discontinuity, such as a difference in temperature, density, momentum, or kinetic energy. Accordingly, we define interstitial fluid as follows:

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[31] To illustrate such a density contrast, experimental simulations of gravity flows work with density values of around 1000 kg m^{-3} for ambient fluid and 1030 kg m^{-3} for the flowing fluid (*e.g.*,, 1000 kg m^{-3} and 1032 kg m^{-3} in [NOMURA et al., 2019, p.428-430]).

Definition 121 ***Interstitial Fluid*** $=_{def}$ *A variable embodiment of fluid that is individuated by some physical discontinuity with its surroundings and that is constituted at each time by a portion of fluid that stands in a* suspends *relation with an amount of sediment.*

In the case of turbidity currents, turbulence is a key aspect of their occurrence. Then, the interstitial fluid of the mixture always shows a contrast with the ambient fluid in terms of turbulence level, which is much higher in the former. With that, the manifestation of the interstitial fluid would be an amount of fluid that suspends some amount of sediment and has a turbulence contrast with the environment fluid at the time. We capture this characterization by defining the notion of *turbulent interstitial fluid* as follows:

Definition 122 ***Turbulent Interstitial Fluid*** $=_{def}$ *An interstitial fluid that is individuated by presenting a turbulence level higher than that of the ambient fluid.*

Regarding suspended load, its variable embodiment principle could be based on the interstitial fluid, *i.e.,* the manifestation of the suspended load would be whatever amount of sediment that is suspended in an interstitial fluid at the time. Still, it also has some discontinuities of its own, *e.g.,* it is more concentrated within the flowing mixture than the eventual sediment that is dispersed in the ambient fluid. Thus, the manifestation of a suspended sediment load would be an amount of sediment that is suspended by an amount of turbulent fluid and that has a concentration contrast with the sediment dispersed in the ambient fluid.

Definition 123 ***Suspended Sediment Load*** $=_{def}$ *A variable embodiment of sediment that is constituted at each time by an amount of sediment that stands in a* suspends *relation with a given interstitial fluid and that has a concentration contrast with the sediment on its surrounds.*

Finally, since flowing mixture, interstitial fluid and suspended sediment load are variable embodiments, they have several properties derivatively, based on their material manifestation at the time, including *density*, *velocity*, and *level of turbulent energy*.

7.4.3 '*Turbulently Suspends*' as a Dispositional Connection

As mentioned before, the components of the system that delimits a sediment gravity flow are mainly linked by a ***suspends*** relation. Such a relation builds upon the ***in contact*** and ***contains*** relations. We define these relations as follows:

Definition 124 ***in_contact****(x,y)* $=_{def}$ *A binary, symmetric relation between material objects x and y such that there is no spatial region in between some part of x and some part of y.*

Definition 125 ***contains****(x,y)* $=_{def}$ *A binary, asymmetric relationbetween material objects x and y such that the spatial region occupied by y is part of the spatial region occupied by x.*

Definition 126 (suspends) *Given a portion of fluid or a variable embodiment of fluid fluid and an amount of sediment or a variable embodiment of sediment sediment:*

suspends*(fluid,sediment)* $=_{def}$ *A binary, asymmetric relation between fluid and sediment such that*

(1) contains(fluid,sediment);

(2) in_contact(fluid,sediment);

(3) fluid exerts an upward force on sediment that keeps it afloat.

The *suspends* relation intuitively qualifies as a connection for allowing an interstitial fluid and a suspended sediment load to affect each other's behavior. Nevertheless, in order to characterize the fluid-sediment mixture as the system that delimits a sediment gravity flow event, we need to characterize *suspends* as a dispositional connection (sec. 5.4) with respect to the dispositions whose manifestations correspond to the unfolding of the event.

We assumed the view that a sediment gravity flow is an event of transporting a sediment load while suspended in some interstitial fluid. Given that, we should find evidence of dispositions related to two following components of the event:

(1) The maintenance of sediment in suspension within the interstitial fluid;

(2) The down-slope movement of the fluid-sediment mixture.

As we discussed in section 7.2.3, sediment gravity flows happen by virtue of the action of gravity. Such action has a downward component due to which suspended sediment tends to move toward the seabed. Thus, considering (1), maintaining sediment in suspension is a matter of counteracting this tendency, *i.e.,* applying an upwards force on the sediment to balance the downward component of gravity.

Any object in relative movement through a fluid (*i.e.,* either moving through the fluid or having the fluid moving past around it) experiences a resistance force in the opposite direction of the movement usually called *drag*, which arises in virtue of the *viscosity* of the fluid [JAFFE; TAYLOR, 2019, p.556, 567, 570, 742] [FALKOVICH, 2018, p.35, 37] [HALLIDAY; RESNICK; WALKER, 2010, p.163]. As presented in section 7.2.2, ***viscosity*** is defined as the resistance of a fluid to flow or to change in shape when a shear force is applied to it.

Therefore, in other words, viscosity is the ability of a fluid to exert a drag force (which is also a contact force [YOUNG; FREEDMAN, 2015, p.179]) on the material entity that is applying the shear force on the fluid. This drag force is applied in the opposite direction of the shear force that the fluid experiences, counteracting its effects. Given that, we can define viscosity as follows:

Definition 127 ***Viscosity*** $=_{def}$ *Disposition of a fluid* f *to, when a material entity* m *applies a shear force onto* f*, exert a drag force onto* m *on the opposite direction of applied shear force.*

One way to trigger the manifestation of the viscosity of a fluid is by the relative movement of a material entity through a fluid, *i.e.,* either the object moving through the fluid or the fluid moving around the object. When a material object exerts a force on the fluid to push it out of the way (even when the effective movement of the object does not happen), the fluid pushes back with an opposite drag force [YOUNG; FREEDMAN, 2015, p.171]. Given that, we could say that material entities have the disposition to experience a (resistance) drag force when exerting a shear force on a fluid. Although there seems to be no explicit name for such a disposition, resources from physics and fluid mechanics fields indeed mention the resistance of a body to move through a fluid, which is related to body's shape, size (diameter), density, and surface area and is commonly expressed in terms of the *drag coefficient* of the body [RIAZI; TüRKER, 2019, p.428, 433, 435] [JAFFE; TAYLOR, 2019, p.21, 40] [FALKOVICH, 2018, p.5] [DOROODCHI et al., 2008, p.130] [HOTTOVY; SYLVESTER, 1979, p.433]. We will refer to this disposition as *draggability*, defined as follows.

Definition 128 ***Draggability*** $=_{def}$ *Disposition of a material object* m *to experience a drag force when exerting a shear force on fluid* f*, whose categorical bases include the shape and size of* m.

The manifestation of both viscosity and draggability requires a material object to exert a contact force on another. Thus, both dispositions require as a stimulus condition the contact between the two objects. The *suspends* relation provides the required contact, fulfilling this condition, which qualifies this relation as a disposition connection that exposes the viscosity of the interstitial fluid to the draggability of the suspended sediment in a sediment gravity flow.

Regarding (2), the fluid-sediment mixture moves forward in virtue of the action of the down-slope component of gravity on the suspended sediment[32] so that the sediment pulls the fluid downslope [COVAULT, 2011; PARSONS et al., 2007; DASGUPTA, 2003; PARKER; FUKUSHIMA; PANTIN, 1986]. Given that, the mechanics of the downslope movement of the mixture is similar to that of the maintenance of the suspension. There is a movement of an object immersed in a fluid, exerting some force on the fluid, which responds with a drag force. The difference is that, in this case, the force that the sediment exerts overcomes the fluid drag in such a way that the sediment moves forward, making the interstitial fluid advance as well.

Here, instead of viscosity, the fluid manifests the inverse disposition, that is, its ***fluidity***, *i.e.,* tendency of a fluid to flow [ESCUDIER; ATKINS, 2019c; BRITANNICA, 2022d][33], which we define as follows:

Definition 129 ***Fluidity*** $=_{def}$ *Disposition of a material f to flow when a material object m exerts a shear force on f.*

Concerning the suspended sediment, the manifested disposition is its ability to exert a shear force on the fluid when in contact with it (*e.g.,* when moving through it), which we will call ***shear capacity*** and define as follows:

Definition 130 ***Shear Capacity*** $=_{def}$ *Disposition of a material object x to exert a shear force on another material object y when in_contact(x,y).*

Analogously to the case of viscosity and draggability, the manifestations of both fluidity and shear capacity require that a material object exerts a contact force on another.

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[32] It is understood that, in turbidity currents, gravity does not work on the fluid phase of the mixture [PARKER; FUKUSHIMA; PANTIN, 1986, p.150].

[33] Notably, for certain sediment gravity flows other than turbidity currents (*e.g.,* debris flows), deposition of sediment occurs due to a decrease in fluidity, so that the effect of the downslope component of gravity over the suspended sediment can no longer overcome the resistance of the interstitial fluid (*e.g.,* "*The whole mass keeps on moving until the shear force exerted by the downslope component of gravitational pull falls below the yield strength of the material and it freezes en masse.*" [DASGUPTA, 2003, p.271]; "*fluid shear stress is lower than yield strength of the mixture, generating an instantaneously mass deposit (cohesive freezing)*" [MANICA, 2012, p.276]).

With that, the contact between the two objects is a stimulus condition for both dispositions. Hence, the *suspends* relation also qualifies as a disposition connection that exposes the fluidity of the fluid to the shear capacity of the sediment it suspends.

Given the discussion so far, we are characterizing the interstitial fluid involved in a sediment gravity flow as having the ability to allow the downslope movement of the suspended load while keeping it in suspension. This corresponds to the ***suspended-sediment transport capacity*** of the fluid, which is described as the ability of a flowing fluid to transport sediment, customarily expressed in terms of the maximum load that the fluid can carry in suspension [THOMAS, 2016, p.78] [STRELICH, 2016] [WAINWRIGHT et al., 2015, p.1155, 1157, 1160, 1165] [ALLABY, 2013, p.90] [MANICA, 2012, p.266]. Here we regard it as a disposition defined as follows:

Definition 131 ***Suspended-Sediment Transport Capacity*** $=_{def}$ *Disposition of a flowing fluid* f *to carry an amount of sediment* s *when* s *is suspended by* f*.*

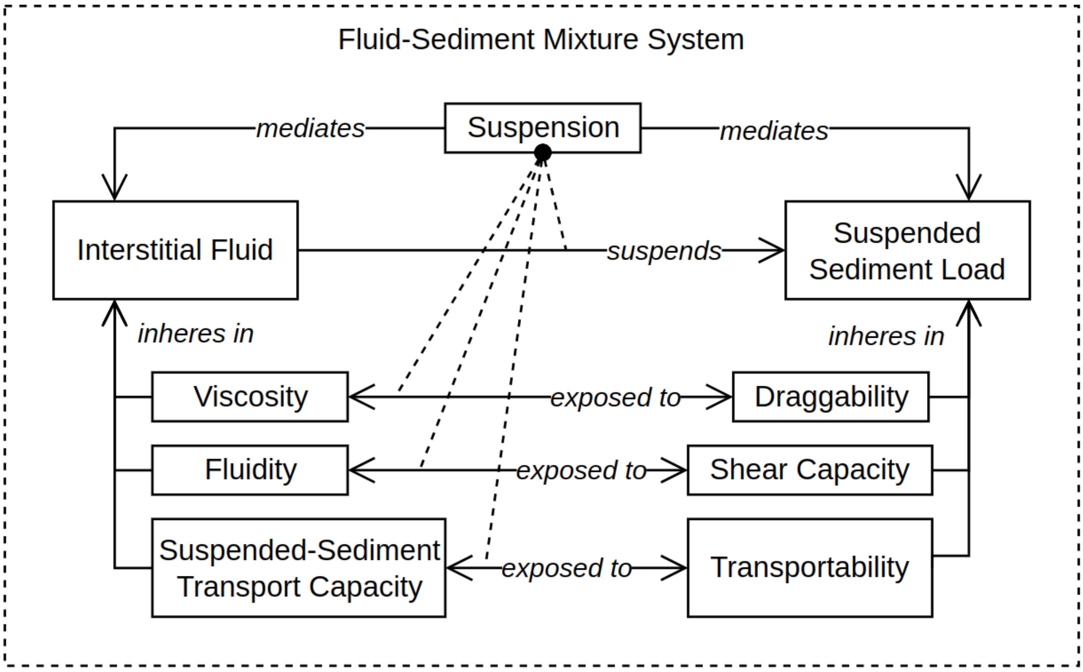
Complementarily, sediment is often said to be *transportable* [MULDER; SYVITSKI, 1995, p.288] [THOMAS, 2016, p.19, 78, 106] [PARSONS et al., 2007, p.320]. This implies the existence of a ***transportability*** disposition, which we define as follows:

Definition 132 ***Transportability*** $=_{def}$ *Disposition of a sediment* s *to be carried by a flowing fluid* f*.*

So far we have defined the types of the entities that are responsible for the unfolding of a sediment gravity flow – *i.e.,* its participants, the relevant dispositions, and the relationship that allows their manifestation. Consequently, we have the core characterization of the type of the system that delimits a sediment gravity flow (depicted in figure 7.4), which we will call ***fluid-sediment mixture system***.

Namely, we have defined the composition of the system, *i.e.,* interstitial fluid and suspended sediment, as well as the bulk of its structure, *i.e.,* a suspends relation that exposes the *viscosity*, *fluidity*, and *transport capacity* of the fluid to, respectively, the *draggability*, shear *capacity*, and *transportability* of the sediment. The structure of the system is complemented by other properties that are relevant to the dynamics of a sediment gravity flow, such as the location of the components of the system, and the volume and composition of the suspended sediment – omitted from figure 7.4 for the sake of visual clarity. We also reified *suspension* as an entity akin to a *relational moment* or *relator* [GUIZZARDI, 2005, Ch. 6] from which the relations of *suspends* between fluid and sediment, and *exposed to* between their dispositions are derived. Then, we have that

Figure 7.4 – Delimiting System of a Sediment Gravity Flow (Core Characterization)



Source: the author

Axiom 8 (Sediment Gravity Flow Delimiting System) *∀f Sediment_Gravity_Flow(f) ⇒ ∃m Fluid-Sediment_Mixture_System(m) ∧ delimits(m,f).*

This is also largely the type of system that delimits turbidity currents as well, except for some particularities. In section 7.2.4, we presented turbulence as the main sediment-support mechanism in turbidity currents, with the upward component of interstitial fluid turbulence balancing the downward component of gravity on the suspended sediment. To capture this particular type of suspension, we specialize the *suspends* relation by defining the ***turbulently suspends*** relation as follows:

Definition 133 ***turbulently_suspends****(fluid,sediment)* $=_{def}$ *A suspends(fluid,sediment) relation such that*

(1) fluid is in a turbulent state;

(2) the force that keeps sediment afloat is the upward component of fluid turbulence.

Therefore, in the case of turbidity currents, the interstitial fluid and the suspended sediment are connected by a *turbulently_suspends* relation. Just as *suspends*, *turbulently_suspends* also exposes the viscosity, fluidity, and transport capacity of the interstitial fluid to, respectively, the draggability, shear capacity, and transportability of the sediment. Still, turbidity currents differ from general sediment gravity flows with respect to the nature of the *viscosity* that the interstitial fluid manifests.

For fluids that are still or in a laminar flow, drag force comes from *molecular viscosity* (due to molecular motion in the fluid), being called *viscous drag* [FALKOVICH, 2018, p.37, 77]. However, for fluids in a turbulent state (as in the case of turbidity currents), molecular viscosity is negligible and ***turbulent viscosity*** (or ***eddy viscosity***) comes into play, giving rise to *turbulent drag* [FALKOVICH, 2018, p.37, 76, 77] [PARKER; FUKUSHIMA; PANTIN, 1986, p.175]. Then, we define *turbidity viscosity* as follows:

Definition 134 ***Turbulent Viscosity*** $=_{def}$ *Viscosity of a fluid f whose categorical bases includes the density and turbulence level of f.*

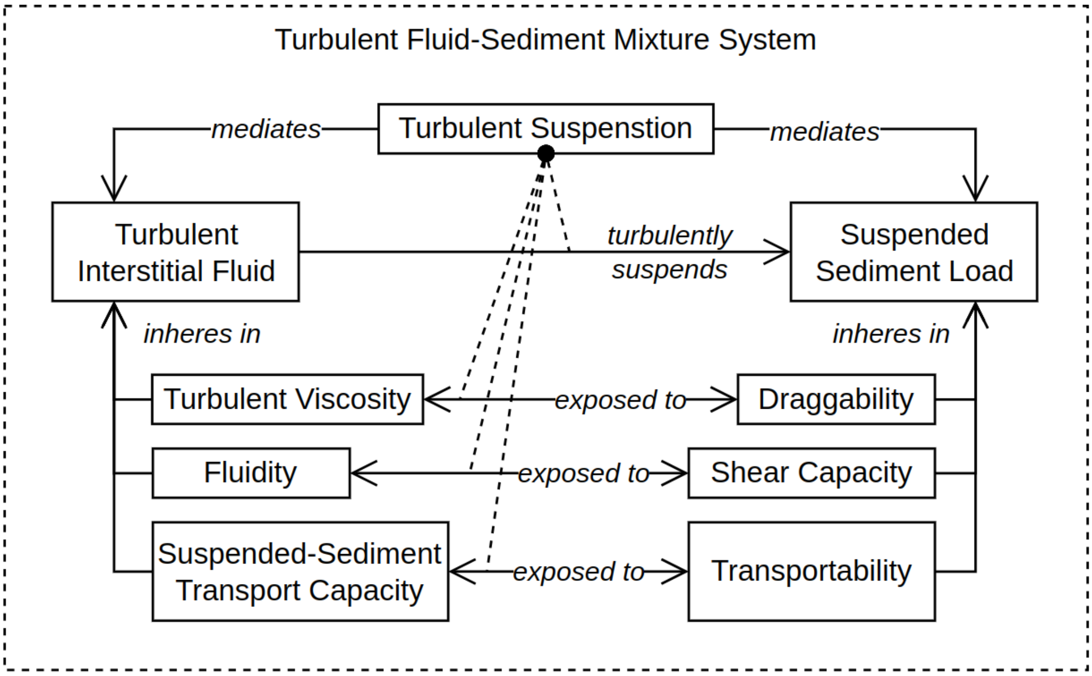
Then, replacing *suspends* by *turbulently_suspends* and *viscosity* by *turbulent viscosity* we have the type of system that delimits turbidity currents, which we will call ***turbulent fluid-sediment mixture system*** (figure 7.5). The structure of the system is complemented by other properties that are relevant to the dynamics of a turbidity current, such as the turbulence level of its interstitial fluid – again, not included in the figure for visual clarity. Then, we have that

Axiom 9 (Turbidity Current Delimiting System) $\forall$*c Turbidity_Current(c)* $\Rightarrow$ $\exists$*m Turbulent_Fluid-Sediment_Mixture_System(m)* $\wedge$ *delimits(m,c).*

7.4.4 Turbidity Currents as Open Events

Turbidity currents are highly complex events by themselves due to the feedback between fluid turbulence and sediment downslope pull [KNELLER; BUCKEE, 2000]. Still, this complexity is further increased by interactions between the flowing mixture and its environment, which influences its density and turbulence difference in relation to the ambient fluid and, consequently, its flowing dynamics [WELLS; DORRELL, 2021; HEEREMA et al., 2020; BAAS et al., 2016; MANICA, 2012; MEIBURG; KNELLER, 2010; PARSONS et al., 2007; KNELLER; BUCKEE, 2000]. These interactions indicate that turbidity currents are open in some important respects, which will discuss in what follows.

Figure 7.5 – Delimiting System of a Turbidity Current (Core Characterization)



Source: the author

7.4.4.1 Turbidity Currents as Exchange-Open Events

In section 7.4.2 we characterized flowing a fluid-sediment mixture, as well as the interstitial fluid and the suspended sediment load that compose it, as a variable embodiment. We adopted this approach to handle the fact that the amounts of fluid and sediment that constitute the flowing mixture may vary throughout the occurrence of a sediment gravity flow, such as a turbidity current. In light of our proposed theory, this possibility of variation of constituent suggests that such a flowing fluid-sediment mixture is an *exchange-open system* (def. 16), which makes sediment gravity flows in general – and turbidity currents in particular – *exchange-open events* (def. 108).

This hypothesis is supported by the domain literature, specifically when stating that a gravity current can be open or closed with respect to the source of its driving force, *i.e.,* the source of its excess density. In their terms, gravity currents can be *conservative* or *non-conservative* [MANICA, 2012, p.265] [PARSONS et al., 2007, p.279].

A conservative gravity current is a current that does not interact with its boundary (*i.e.,* environment, in our terms), so that the source of its excess density does not vary throughout the event [MANICA, 2012, p.265] [PARSONS et al., 2007, p.278]. Examples of conservative gravity currents include those in which the density excess is provided by a difference in temperature or by the presence of dissolved substances in the fluid (*e.g.,* saline gravity currents) [PARSONS et al., 2007, p.285] [KNOBLAUCH, 1999, p.4].

In contrast, a non-conservative gravity current is a current that can interact with its boundary in a way that its source of density difference may vary during the event [MANICA, 2012, p.265] [KNOBLAUCH, 1999, p.4, 5]. Sediment gravity flows, including turbidity currents, are considered non-conservative gravity currents since they can interact with their environment both by exchanging sediment with seabed (through erosion and deposition) and by exchanging fluid with the ambient fluid (through fluid entrainment and detrainment) [MANICA, 2012, p.269] [MEIBURG; KNELLER, 2010, p.136] [KNELLER; BUCKEE, 2000, p.68] [KNOBLAUCH, 1999, p.5]. Thus, the density difference is not conserved along the event, possibly leading to several changes in the system (*e.g.,* density and velocity of the mixture, suspended load volume, interstitial fluid turbulence level). Such changes translate into distinct dynamics in later stages of the current (*e.g.,* acceleration or deceleration of the flowing mixture) [MANICA, 2012, p.269] [KNELLER; BUCKEE, 2000, p.68] [KNOBLAUCH, 1999, p.4, 5].

7.4.4.2 Turbidity Currents as Influence-Open Events

Aside from the exchange of fluid and sediment, the environment affects the behavior of turbidity currents in other ways. Notably, as discussed in section 7.2.5, the fluid turbulence that keeps a turbidity current going on is produced in the interaction between the flowing fluid-sediment mixture and the seabed and ambient fluid (*e.g.,* "*Turbulence [...] is generated by shear instabilities in the upper interface, or from drag at the lower boundary*" [WELLS; DORRELL, 2021, p.64]; "*turbulence production occurred due to shearing near the lower boundary*" [KNELLER; BUCKEE, 2000, p.76]). In addition to the maintenance of the flow, turbulence generation affects the internal functioning of turbidity currents in various ways (*e.g.,* "*Turbulence generated by bottom roughness entrains reservoir water into the underflow.*" [KNOBLAUCH, 1999, p.15]). Given such dynamics, turbidity currents are also *influence-open events*.

7.5 Turbidity Currents Environment and Auxiliary Events

In this section, we characterize the environment of the turbulent fluid-sediment system that delimits a turbidity current as well as the associated auxiliary events. According to 7.4, a turbidity current system exists in an environment consisting of some *seabed* and the *ambient fluid*. Thus, we start by defining these entities.

Definition 135 ***Ambient Fluid*** $=_{def}$ *A variable embodiment of fluid* f *that surrounds a given material object* m*, so that* in_contact(f,m)*.*

Definition 136 ***Seabed*** $=_{def}$ *A variable embodiment of deposited sediment or sedimentary rock located on the surface of the seafloor that is internally consistent and that has a discontinuity that distinguishes it from adjacent layers (*e.g., *a difference in sediment composition or granularity).*

As prescribed in section 2.6.2, for those entities to be characterized as elements in the environment of a turbidity current system, there must be a connection between them and such a system or some component of it. In section 7.4, we proposed the *in_contact* relation (definition 124) to be such a connection. It is this relation that enables the interaction between the system and the elements of the environment through contact forces, in special the shear stress at the bottom and upper interfaces of the flowing mixture [BAAS et al., 2016, p.2030] [MANICA, 2012, p.266] [PARSONS et al., 2007, p.277, 308, 330] [THOMPSON et al., 2006, p.2] [MIDDLETON, 1993, p.97].

Recollecting sections 7.2.5, 7.2.6 and 7.2.8, shear stresses play a part in turbulence generation, erosion, fluid entrainment, and in the shear resistance of both the seabed and the ambient fluid to the advance of the flowing mixture [NOMURA et al., 2019, p.431] [MANICA, 2012, p.273]fl [KNELLER; BUCKEE, 2000, p.71]. Shear stresses are also responsible for the characteristic shape of the flowing mass (fig. 7.1) – with a 'body' and a thicker 'head' with a pronounced 'nose' [MANICA, 2012, p.265][34]. As we can see, being exposed to shear stress is clearly a factor that affects the behavior history of the fluid-sediment mixture as well as both the seabed and the ambient fluid. Therefore, the *in_contact* relation qualifies as a connection for allowing this exposition and, consequently, the ambient fluid and seabed in contact with the fluid-sediment mixture qualify as elements of its environment.

Based on that, in the following sections, we characterize the main auxiliary events associated with turbidity currents. In particular, we will analyze the events of sediment and fluid exchange (*i.e.,* erosion, deposition, fluid entrainment, and fluid detrainment), and

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[34] "*The head or front of the current is roughly shaped as a semielipse. In most cases, the head is thicker than the body and tail, because of the resistance imposed by the ambient fluid (fluid resistance) to its advance. [...] The most advanced point of the front is called nose and it is located slightly above the bottom surface, as a result of the no-slip condition at the bottom as well as the resistance (shear) at upper surface*" [MANICA, 2012, p.265])

the event of turbulence generation. For each of such types of events, we first characterize it as a transition between situations and as a manifestation of dispositions in order to capture the essence of what is happening. Then, we analyze the event in relation to the main event of turbidity current to characterize it as an auxiliary event, describing what overlaps with the main event, what does not overlap (the exclusive portion of the auxiliary event), and how it influences the main event.

As a last remark, the referred processes can take place in various circumstances (*e.g.,* erosion of rocky mountains by wind or glaciers, industrial processes of sedimentation to separate solid particles floating in liquids, entrainment of air in a preexisting organized air current) and are of interest in various domains (*e.g.,* meteorology, environment and conservation, engineering). Even so, in order to keep a manageable scope for our case study, we will constrain such processes to those happening in the context of underwater sediment gravity flows. Hence, for example, we will use '*erosion*' as referring to '*erosion by a sediment gravity flow*', '*fluid entrainment*' as '*fluid entrainment by a sediment gravity flow*', and so on.

7.5.1 Erosion (Sediment Entrainment)

In this section, we make an ontological analysis of *erosion* or *sediment entrainment.*

7.5.1.1 Erosion as Transition between Situations

Basically, *erosion* or *sediment entrainment* is the event of transferring an amount of sediment from a seabed to a fluid-sediment mixture flowing over it. With that, it would certainly have the following three participants: the seabed that undergoes erosion, the flowing mixture that performs the erosion, and the transferred amount of sediment, *i.e.,* the eroded sediment. However, there are some specificities in the way the transferred sediment is incorporated by the flowing mixture.

The notions of erosion (or sediment entrainment) carry the idea that the eroded (or entrained) sediment becomes suspended in the flow. For example, several passages refer to the *entrainment of sediment <u>into suspension</u>*, *e.g.,* [WELLS; DORRELL, 2021, p.70] [SEQUEIROS et al., 2009, p.1] [PARSONS et al., 2007, p.302, 322] [THOMPSON et al., 2006, p.1] [MIDDLETON, 1993, p.107] [PARKER; FUKUSHIMA; PANTIN, 1986, p.150, 178] or to the "*introduction of additional suspended sediments into a turbidity current*" [OEHY; SCHLEISS, 2007, p.637]. Sometimes the expression *entrained sediment* is even employed simply in the sense of *suspended sediment* (*e.g.,* "*turbidity currents cannot operate without their entrained sediment*" [SHANMUGAM, 2018, p.230]).

Besides that, erosion and entrainment of sediment are associated with the idea that the sediment that is displaced from the bed will become part of the load that the flowing mixture is carrying (*e.g.,* "*Turbidity currents [...] are driven by the weight of sediment they carry, and this sediment can be entrained*" [HEEREMA et al., 2020, p.2]; "*a turbidity current [...] to increase its load [...] causing more entrainment"* [PARSONS et al., 2007, p.277]). This view is reinforced by the common association of erosion to a following transport of the eroded material (*e.g.,* "*downflow transport of the eroded sediment*" [BAAS et al., 2016, p.2020]; "*resuspension and the subsequent movement of the resuspended material due to gravity*" [PARSONS et al., 2007, p.323]; "*Sediments, which have already settled down, can thus be eroded again and transported*" [OEHY; SCHLEISS, 2007, p.637]).

Therefore, a full account of the event should contemplate the entering of the sediment in suspension within the mixture, more specifically, by being incorporated into its suspended-sediment load. In other words, erosion or sediment entrainment would be *the event by which an amount of sediment ceases to be part of the sediment that constitutes the seabed and enters in suspension in the flowing mixture, becoming part of its sediment load*. With that, we define erosion in terms of a transition between situations as follows:

Definition 137 (Erosion) *Given two time instants* t_1 *and* t_2 *such that* $precedes(t_1,t_2)$, *a flowing fluid-sediment mixture* mix, *a suspended-sediment load* $load$, *a seabed* b, *and an amount of sediment* sed_{transf}*:*

Erosion $=_{def}$ *An event that is a transition from a situation* s_1 *bound to* t_1 *to a situation* s_2 *bound to* t_2 *such that,*

(1) $includes(s_1,mix)$, $includes(s_1,load)$, $includes(s_1,b)$ *and* $includes(s_1,sed_{transf})$;

(2) $includes(s_2,mix)$, $includes(s_2,load)$, $includes(s_2,b)$ *and* $includes(s_2,sed_{transf})$;

(3) *at both* t_1 *and* t_2, $part\_of(load,mix)$;

(4) *at* t_1, $partially\_constituted\_of(b,sed_{transf})$ *and* $\neg partially\_constituted\_of(load,sed_{transf})$;

(5) *at* t_2, $\neg partially\_constituted\_of(b,sed_{transf})$ *and* $partially\_constituted\_of(load,sed_{transf})$.

7.5.1.2 Erosion as Manifestation of Dispositions

As discussed in section 7.2.6, erosion occurs when the flowing mixture exerts a shear force that overcomes the shear strength of the bed sediment. Consonant with this view, erosion is also described as the manifestation of two reciprocal dispositions, namely, the ***erosivity*** (also called *erosiveness* or *erosive power*) of the flowing mixture and the ***erodibility*** of the seabed or of its constituting sediment [THOMAS, 2016, p.193].

Erosivity is defined as the ability to cause erosion[35] . It is explicitly mentioned (*e.g.,* [BAAS et al., 2014, p.373]) or implied in references to the ability or capacity to erode or to entrain bed sediment [WELLS; DORRELL, 2021, p.70] [HEEREMA et al., 2020, p.2] [SEQUEIROS et al., 2009, p.6] [PARSONS et al., 2007, p.277] [KNELLER, 2003, p.905].

Conversely, ***erodibility*** is defined as the susceptibility, vulnerability, or proneness to erosion [THOMAS, 2016, p.192, 193] [THOMAS, 2013; HILLEL, 2008]). It is both explicitly mentioned (*e.g.,* [HEEREMA et al., 2020, p.2, 10] [BAAS et al., 2016, p.2]) or implicitly present in references to *erodible* bed, substrate, sediment or material (*e.g.,* [HEEREMA et al., 2020, p.7, 10] [MEIBURG; KNELLER, 2010, p.148] [SEQUEIROS et al., 2009, p.2, 3] [OEHY; SCHLEISS, 2007, p.638] [KNELLER; BENNETT; MCCAFFREY, 1999, p.5390]). Sometimes, erodibility is also implied in references to the inverse property of *erosion resistance*[36] (*e.g.,* [THOMAS, 2016, p.180] [PARSONS et al., 2007, p.300] [PARKER; FUKUSHIMA; PANTIN, 1986, p.173]).

Such dispositions are closely related to shear force and shear strength. If erosivity is the ability to erode and erosion happens when the flowing mass exerts enough shear force on the sediment bed, the manifestation of erosivity requires the flowing mass to exert shear stress on the bed. Similarly, if erodibility is the vulnerability to erosion and erosion happens when the shear strength of the bed sediment is overcome, the manifestation of erodibility requires the shear strength of the bed sediment to be smaller than the experienced shear force. Finally, the application of a shear force is only possible if the involved bodies are in contact with each other. With that, we have the stimulus conditions for the referred dispositions, which are defined as follows:

Definition 138 ***Erosivity*** $=_{def}$ *Ability of a flowing material* f *to erode a bed* b *when* in_contact(f,b) *and* f *is exerting a shear force on* b *that overcomes the shear strength*

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[35] <www.collinsdictionary.com/dictionary/english/erosivity>

[36] "*The erodibility, or erosion resistance of Earth materials*" [THOMAS, 2016, p.193], "*relative erosion resistance, or erodibility, of bedrock channel beds*" [THOMAS, 2016, p.163].

of b.

Definition 139 ***Erodibility*** *=$_{def}$ Ability of a bed* b *to be eroded by a flowing material* f *when* in_contact(f,b) *and* f *is exerting a shear force on* b *that overcomes the shear strength of* b.

In order to capture the relation between objects that are in contact *and* such that one exerts some shear force on the other, we define the *in shear contact* relation as follows

Definition 140 ***in_shear_contact(a,b)*** *=$_{def}$ A binary relation between two material objects* a *and* b *such that* in_contact(a,b) *and* a *exerts a shear force on* b.

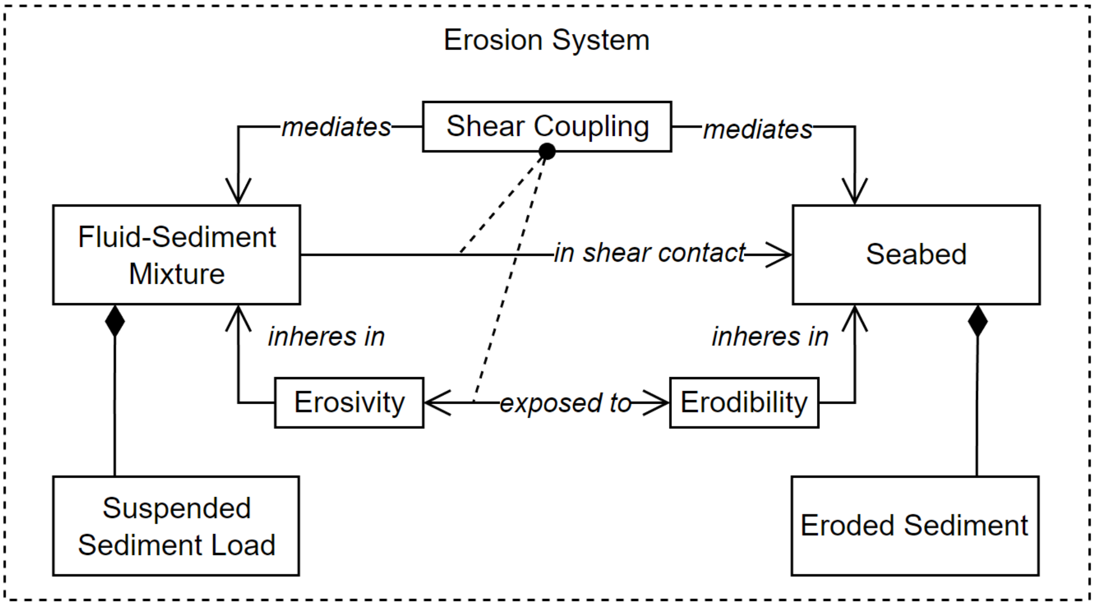
It is worth noting that, although related, erosivity and shear capacity are distinct dispositions. It is possible for the flowing mass to exert some shear force over the bed which does not overcome the shear strength of the bed, so that shear capacity is manifested, but erosivity does not. Analogously, whenever the bed experiences a shear force, it will manifest its shear strength, but it will only manifest its erodibility when the shear strength is overcome.

7.5.1.3 Erosion as Auxiliary Event

The definition of erosion or sediment entrainment in the previous sections describes what it fundamentally is: the detaching of an amount of sediment from a seabed and its entry in suspension in a fluid-sediment mixture flowing above the bed by means of the flowing mixture applying enough shear force on the bed to overcome its shear strength.

Moreover, we have all the elements to make the core characterization of the type of system that delimits events of erosion (depicted in figure 7.6). It is composed of a flowing fluid-sediment mixture, its suspended sediment load, a seabed, and an amount of sediment that is transferred from the seabed to the flowing mixture. The bulk of its structure includes the *in shear contact* relation between the flowing mixture and the seabed, which exposes the erosivity of the former to the erodibility of the latter. It also includes the part-of relation between the load and the flowing mixture and between the eroded sediment and either the seabed or the flowing mixture depending on the stage of the erosion (figure 7.6 depicts system configuration at the beginning of the event). Based on the mentions in the literature, we reified the *shear coupling* between the flowing mixture and

Figure 7.6 – Delimiting System of an Erosion Event (Core Characterization)



Source: the author

the seabed[37] as an entity as mediating entity (akin to a *relational moment* [GUIZZARDI, 2005, Ch. 6]) from which the relations of *in shear contact* between the flowing mixture and the seabed, and *exposed to* between their dispositions are derived.

Even so, it does not fully capture the intention behind the references to this type of event in the domain literature, which points to its relational dependence on a main event of flow. In other words, erosion and sediment entrainment are not regarded as simply the entry of sediment in any suspension, but as its entry in a process of transport, *i.e.,* the *flow* process by which the sediment will move forward. The association of erosion of sediment to its subsequent transport that was discussed in section 7.5.1.1 is an indication of that. Various definitions of *entrainment* also carry this idea, *e.g.*, "*the process by which surface sediment is incorporated into a fluid flow*" [THOMAS, 2016, p.180], "*to draw in and transport (something, such as solid particles or gas) by the flow of a fluid*"[38], "*the process of making something part of a liquid or flow of something and carrying it along*"[39], "*Entrainment is when a fluid picks up and drags another fluid or a solid.*"[40].

Moreover, erosion and deposition are regarded as "*associated processes*" through which seafloor topography influences flow behavior [COVAULT, 2011]. Indeed, men-

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[37] "*Remobilization and erosion of a substrate by a debris flow are governed by the ability of this flow to overcome resisting stresses of the substrate. [...] to reduce the shear coupling between a flow and its substrate, thereby reducing the degree of substrate remobilization*" [PARSONS et al., 2007, p.300].

[38] <www.merriam-webster.com/dictionary/entrain>

[39] <www.dictionary.cambridge.org/dictionary/english/entrainment>

[40] <www.collinsdictionary.com/dictionary/english/entrainment>

tions of erosion or sediment entrainment are customarily accompanied by an emphasis on their relationship with the main flow event, especially regarding their effects on the latter (*e.g.,* "*The dynamics of turbidity currents is complex due to the processes of erosion and deposition.*" [BAAS et al., 2014]; "*Seafloor topography can influence flow behavior and transformations with associated processes of erosion and deposition*" [COVAULT, 2011]; "*effects of entrainment of bed sediment into an auto-suspending current*" [MEIBURG; KNELLER, 2010]).

Such effects are summarized by saying that an erosion *fuels* the sediment gravity flow to which it is associated [BAAS et al., 2016, p.2003]. In other words, it increases the density and sediment concentration of the flowing mixture, which leads to an increase in its velocity (an acceleration) in the downstream direction and contributes to increasing its erosivity [HEEREMA et al., 2020, p.2, 8] [BAAS et al., 2016, p.2003-2004] [MEIBURG; KNELLER, 2010, p.136] [SEQUEIROS et al., 2009, p.2, 6, 23] [OEHY; SCHLEISS, 2007, p.637] [KNELLER; BUCKEE, 2000, 68] [PARKER; FUKUSHIMA; PANTIN, 1986, p.145, 146, 149]. This tends to result in an increase in its travel distance [BAAS et al., 2016, p.2003-2004] (that is, affecting the very aspect that defines a turbidity current, *i.e.,* the change in location of its participants). In view of that, we can say that erosion is genuinely seen as a type of *auxiliary event* in relation to turbidity currents.

Still, in order to properly characterize erosion as an auxiliary event, we have to identify how it fulfills the requirements put forward in section 6.2.2. Particularly, it has to meet the three main conditions that compose the definition of the *auxiliary_of* relation (def. 58), *i.e.,*

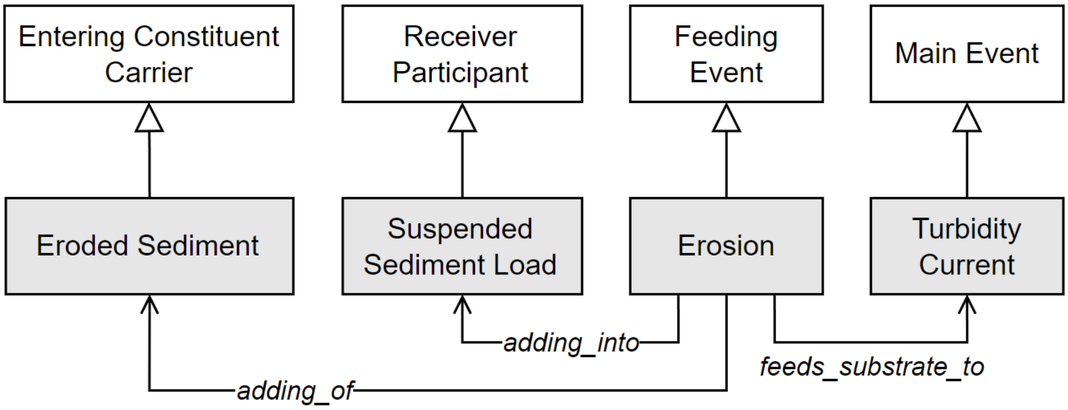
(1) the auxiliary event having an overlap with a given main event, but not being part of it;

(2) the auxiliary event being associated to some effect on the unfolding of the main event;

(3) such effect being causally linked to the auxiliary event.

Regarding (1), an erosion that happens in the context of a turbidity current clearly has an overlap with such a main event. Namely, it shares a participant with the main event, *i.e.,* the *suspended load* of the current, besides involving as a participant the whole turbulent fluid-sediment mixture system that delimits the main event. Additionally, erosion also involves an exclusive participant, *i.e.,* the *seabed.* Concerning (2), upon the occurrence of erosion, an amount of sediment is added to the suspended load of the turbulent

Figure 7.7 – Modeling pattern for *Substrate-Feeding Events* applied to *Erosion* and *Turbidity Current*



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fluid-sediment mixture. This represents a variation in the amount of sediment that constitutes the load from one time to another that could not be achieved only by the interaction of the participants of the turbidity current. Finally, with respect to (3), such variation effect is caused by the joint manifestation of the dispositions of *erosivity* and *erodibility*, which inhere in the participants of the erosion. Meeting these three conditions, erosion qualifies as an auxiliary event.

Furthermore, the addition of sediment into the suspended load of a turbidity current consists of a change in the amount of ontological substrate that ultimately constitutes one of the participants of such a current. Given that, erosion is an event that changes the ontological substrate that is subject to an ongoing turbidity current event. Therefore, erosion qualifies as a *substrate-feeding event* (def. 84) in relation to the current.[41] Figure 7.7 presents the application of the modeling pattern for substrate-draining events to the process of deposition, highlighting its related entities (*i.e.,* turbidity current, suspended sediment load, and eroded sediment) and the roles they play in this context (*i.e.,* main event, receiver participant, and entering constituent carrier, respectively).

Finally, figure 7.8 brings a schematic representation of an erosion event as a transition through situations comprising a seabed *bed*, a flowing fluid-sediment mixture *mix*, its suspended sediment load *load* component, and the amount of transferred sediment *eroded sedim*. The situations in the course of the erosion event show the mereological change that takes place, *i.e., eroded sedim* loses the part-of relation with *bed* and acquires a part-

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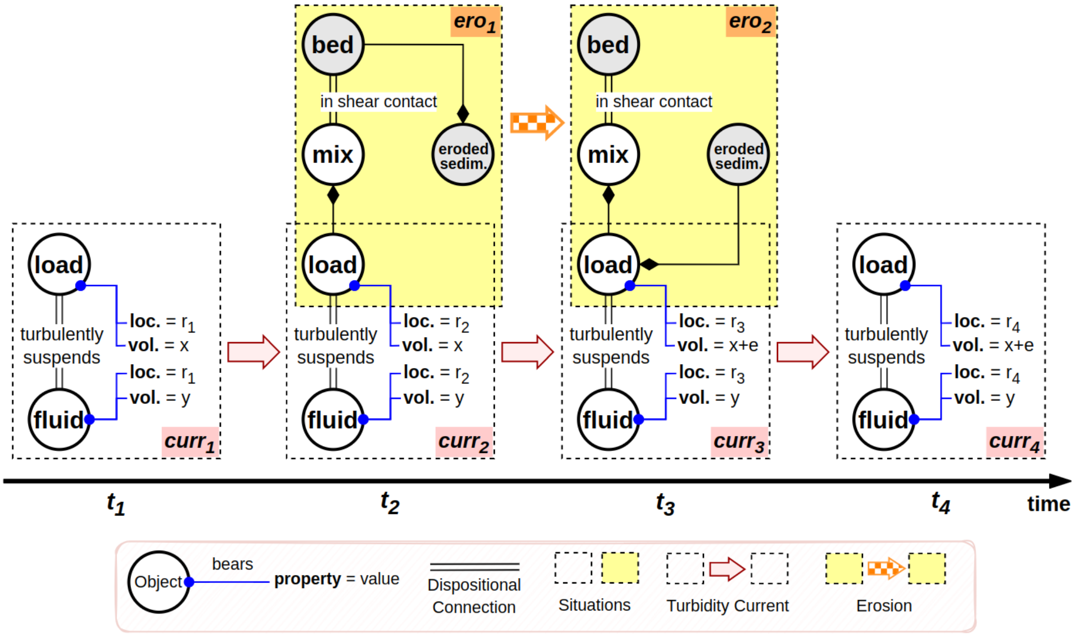
[41] Some passages in the domain literature reflect this view, *e.g.,* "*The bulk of the particles fed to most streams come from soil erosion*" [THOMAS, 2016, p.78], "*turbidity-current strength was sufficient to entrain large amounts of material [...] These currents were fed from surf-zone resuspension*" [PARSONS et al., 2007, p.322], "*Bed erosion fuels the sediment gravity flow with sediment*" [BAAS et al., 2016, p.2003].

Figure 7.8 – Overlap between Erosion and Turbidity Current (schematic representation)



Source: the author

of relation with *load*. The figure also depicts the overlap between the erosion event and its main turbidity current, which is delimited by the fluid-sediment mixture *mix*. Therefore, situations $curr_1$ to $curr_4$ are snapshots of *mix*, which, for clarity, were further detailed to show the interstitial fluid *fluid* and the suspended sediment load *load* that compose *mix*, as well as their volume (‘*vol.*’) and location (‘*loc.*’). As in any turbidity current, the location of *fluid* and *load* change over time (here, from region r_1 to region r_4). Moreover, the effect of the erosion on the turbidity current is represented in the change in the volume of *load* from its original value *x* to the increased value *x+e* such that *e* is the volume of the transferred sediment *eroded sedim.*

7.5.2 Deposition

In this section, we make an ontological analysis of *deposition*.

7.5.2.1 Deposition as a Transition between Situations

Complementing erosion, *deposition* is the event of transferring an amount of sediment from a fluid-sediment mixture to the seabed over which the mixture is flowing. It is associated with the removal of suspended sediment [DASGUPTA, 2003, p.275] or with its loss by the current [MEIBURG; KNELLER, 2010, p.145] [PARKER; FUKUSHIMA;

PANTIN, 1986, p.148, 178] or, more specifically, with the loss of a part of the load it is carrying (*e.g.,* "*deposition of excess load*" [THOMAS, 2016, p.190]). Moreover, the notion of deposition carries the idea that the deposited sediment ceases to be suspended in the flow, *e.g.,* with sediment being said to *settle/fall out of suspension* [HEEREMA et al., 2020, p.7] [SHANMUGAM, 2018, p.244] [MANICA, 2012, p.273, 274] [COVAULT, 2011] [SEQUEIROS et al., 2009, p.1] [SHANMUGAM, 2000, p.297, 306, 327] [PARKER; FUKUSHIMA; PANTIN, 1986, p.148].

Given that, a deposition would be *the event by which an amount of sediment ceases to be part of the suspended load of a flowing mixture and becomes part of the sediment that constitutes the seabed over which the mixture is flowing*. Thus, we define deposition as the following transition between situations:

Definition 141 (Deposition) *Given two time instants t_1 and t_2 such that precedes(t_1,t_2), a flowing fluid-sediment mixture mix, a suspended-sediment load load, a seabed b, and an amount of sediment sed_{transf}:*

Deposition $=_{def}$ *An event that is a transition from a situation s_1 bound to t_1 to a situation s_2 bound to t_2 such that,*

(1) includes(s_1,mix), includes(s_1,load), includes(s_1,b) and includes(s_1,sed_{transf});

(2) includes(s_2,mix), includes(s_2,load), includes(s_2,b) and includes(s_2,sed_{transf});

(3) at both t_1 and t_2, part_of(load,mix);

(4) at t_1, $\neg$partially_constituted_of(b,sed_{transf}) and partially_constituted_of(load,sed_{transf});

(5) at t_2, partially_constituted_of(b,sed_{transf}) and $\neg$partially_constituted_of(load,sed_{transf}).

7.5.2.2 Deposition as Manifestation of Dispositions

Differently from erosion, which is associated with erosivity and erodibility, there are no evidently recognizable dispositions associated with the process of deposition. Even so, we can find some evidence of their existence in passages attributing to turbidity currents some species of 'mode of operation' related to erosion or deposition, *e.g.,* "*Turbidity currents can be erosive or depositional.*" [KNOBLAUCH, 1999, p.5] and "*The periphery of the flow will therefore become depositionally dominated, while the core can remain erosional.*" [PARSONS et al., 2007, p.287].

From the seafloor point of view, mentions to *equilibrium profile* (*i.e.,* "*the theoretical elevation along the path of the channel at which there is no net erosion or deposition*" [MCHARGUE et al., 2011, p.732]) and *accommodation* (*i.e.,* "*The gap between the equilibrium profile and the actual sediment surface*" [KNELLER, 2003, p.901] also suggest that, according to the shape of the seafloor surface, it may have the potential to be eroded or to aggrade (*i.e.,* to grow due to sediment deposition) [KNELLER, 2003, p.901, 903].

Despite that, we can find properties associated with the ability of a flowing fluid-sediment mixture to deposit sediment. In summary, the mixture becomes depositional when it no longer presents the needed sediment transport capacity so that part of its load settles out of suspension [THOMAS, 2016, p.190] [MANICA, 2012, p.274]. This loss of transport capacity results from a deceleration of the flowing mixture, a decrease in its turbulent energy, and a reduction in the shear stress that the flowin mixture apply on the bed [HEEREMA et al., 2020, p.1, 7] [BAAS et al., 2016, p.2003, 2004, 2026, 2034] [BAAS et al., 2014, p.373] [MANICA, 2012, p.273, 274] [PARSONS et al., 2007, p.285] [KNELLER, 2003, 903] [PARKER; FUKUSHIMA; PANTIN, 1986, p.148].

7.5.2.3 Deposition as Auxiliary Event

Analogously to erosion, the definition of deposition we have so far depicts what fundamentally happens in a deposition event, but it does not completely grasp the idea of this type of event in the domain literature. In our context, a deposition is not simply the migration of an amount of sediment from a fluid-sediment mixture onto a seabed. Instead, it is sediment leaving a flow.

As erosion, deposition is also regarded as a process associated with a main flow whose behavior is affected by the loss of sediment [COVAULT, 2011]. References to this type of event commonly come together with a complementary reference to its effects on the main flow (*e.g.,* "*As the flow propagates downstream [...] depositional processes [...] take place, transforming the inner properties of the flow.*" [MANICA, 2012, p.279-280]; "*the current entrains more sediment than it loses through deposition*" [PARKER; FUKUSHIMA; PANTIN, 1986, p.148]). These effects include the reduction in the density and sediment concentration of the flowing mixture, decreasing its density difference with the ambient fluid, which leads to a deceleration of the mixture [HEEREMA et al., 2020, p.2] [BAAS et al., 2016, p.2003] [MEIBURG; KNELLER, 2010, p.145]. Also, deposition also leads to a decrease in the turbulence and the transport capacity of the flowing mixture [MANICA, 2012, p.274, 279-280], which tend to result in a reduction in the travel distance of the mixture [BAAS et al., 2016, p.2003].

Along with that, deposition is often described as the *settling* of the sediment, which conveys the idea of leaving a process of movement (with the term *settle*[42] being defined as "*stop moving and stay in one place*" and "*to come to rest or a halt*"). This is also reflected in passages such as "*removal of suspended sediment by deposition during downslope movement*" [DASGUPTA, 2003, p.275].

In view of this relational character of deposition events, we can intuitively recognize them as *auxiliary events* in relation to turbidity currents. Now, in a similar fashion to what we have done in section 7.5.1.3, we have to consider the conditions for an event to be an auxiliary event.

With respect to (1), the overlap and the difference between a deposition and its main turbidity current are the same as those of erosion. Concerning the overlap, the suspended load participates in both deposition and turbidity current, and the flowing fluid-sediment mixture as a whole is a participant in the deposition. With respect to the difference, the seabed participates only in the deposition process. Regarding (2), the influence of deposition over the turbidity current is roughly the inverse of that of erosion. In other words, upon the occurrence of erosion, the suspended load of the turbidity current loses an amount of sediment. Once more, this represents a variation in the suspended load constituent that could not be achieved exclusively by the interaction of the participants of the turbidity current. Then, concerning (3), such variation is attributed to a *depositional* character of the flowing mixture, which is a participant of the deposition event, but not of the turbidity current. With that, deposition qualifies as an auxiliary event.

Moreover, similarly to erosion, deposition changes the amount of ontological substrate that ultimately constitutes the suspended load of a turbidity current by removing sediment from such a load. Hence, it is an event of exit of a part of the ontological substrate that is subject to the turbidity current, *i.e.,* a *substrate-draining event* (def. 92).[43] Figure 7.9 presents the application of the modeling pattern for substrate-draining events to the process of deposition, highlighting the roles played by related entities.

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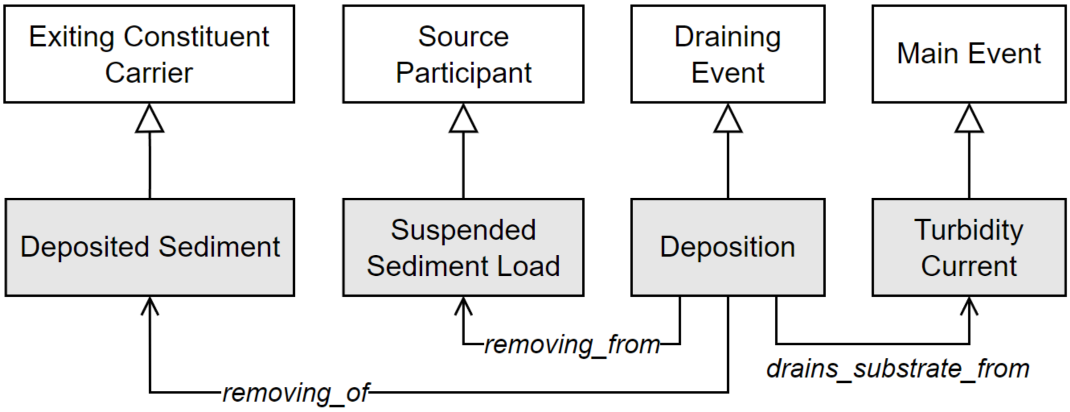
[42] <www.collinsdictionary.com/dictionary/english/settle>

[43] The nature of deposition as an exit event seems to be present in the already mentioned domain literature references to the *loss* of sediment by the current, the *settling/falling* of sediment *out of* or *from* the current

Figure 7.9 – Modeling pattern for *Substrate-Draining Events* applied to *Deposition* and *Turbidity Current*



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7.5.3 Fluid Entrainment and Detrainment

In this section, we make an ontological analysis of the events of *fluid entrainment* and *fluid detrainment*l

7.5.3.1 Fluid Entrainment and Detrainment as Transitions between Situations

Fluid entrainment and *fluid detrainment* are analogous, respectively, to erosion (or sediment entrainment) and deposition, but involving interstitial and ambient fluids instead of suspended-sediment load and seabed. With that, we can regard fluid entrainment as *the event by which an amount of fluid ceases to be part of the ambient fluid and becomes part of the interstitial fluid of the flowing mixture*. Likewise, fluid detrainment is *the event by which an amount of fluid ceases to be part of the interstitial fluid of a flowing mixture and becomes part of the ambient fluid*. We define these events in what follows.

Definition 142 (Fluid Entrainment) *Given two time instants* t_1 *and* t_2 *such that* precedes(t_1,t_2), *a flowing fluid-sediment mixture* mix*, an interstitial fluid* inter*, an ambient fluid* amb*, and an amount of fluid* f_{transf}*:*

Fluid Entrainment $=_{def}$ *An event that is a transition from a situation* s_1 *bound to* t_1 *to a situation* s_2 *bound to* t_2 *such that,*

- *includes(s_1,mix), includes(s_1,inter), includes(s_1,amb) and includes(s_1,f_{transf});*
- *includes(s_2,mix), includes(s_2,inter), includes(s_2,amb) and includes(s_2,f_{transf});*
- *at t_1, partially_constituted_of(amb,f_{transf}) and ¬partially_constituted_of(inter,f_{transf});*

- *at* t_2*,* ¬partially_constituted_of(amb,f_{transf}) *and* partially_constituted_of(inter,f_{transf})*.*

Definition 143 (Fluid Detrainment) *Given two time instants* t_1 *and* t_2 *such that* precedes(t_1,t_2)*, a flowing fluid-sediment mixture* mix*, an interstitial fluid* inter*, an ambient fluid* amb*, and an amount of fluid* f_{transf}*:*

Fluid Detrainment $=_{def}$ *An event that is a transition from a situation* s_1 *bound to* t_1 *to a situation* s_2 *bound to* t_2 *such that,*

- includes(s_1,mix), includes(s_1,inter), includes(s_1,amb) *and* includes(s_1,f_{transf})*;*

- includes(s_2,mix), includes(s_2,inter), includes(s_2,amb) *and* includes(s_2,f_{transf})*;*

- *at both* t_1 *and* t_2*,* part_of(inter,mix)*;*

- *at* t_1*,* ¬partially_constituted_of(amb,f_{transf}) *and* partially_constituted_of(inter,f_{transf})*;*

- *at* t_2*,* partially_constituted_of(amb,f_{transf}) *and* ¬partially_constituted_of(inter,f_{transf})*.*

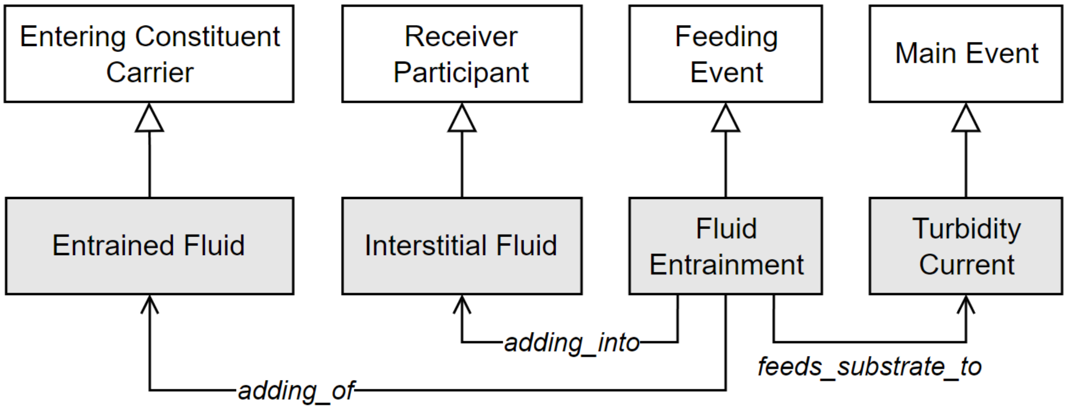
7.5.3.2 Fluid Entrainment and Detrainment as Manifestations of Dispositions

As in the case of deposition, there is no evident named disposition associated with fluid entrainment and detrainment. Still, there are references to properties that are associated with these processes. Both fluid entrainment and detrainment happen due to the shear stress at the interface between the mixture and the ambient fluid, with entrainment happening on the upper and frontal surfaces, while detrainment happens mainly at the back of the head of the flowing mixture [WELLS; DORRELL, 2021, p.70] [MANICA, 2012, p.265, 279-280] [PARSONS et al., 2007, p.290, 291] [KNELLER; BUCKEE, 2000, p.71, 72] [SHANMUGAM, 2018, p.244] [TURNER, 1973, p.117] [NOMURA et al., 2019, p.431] [MIDDLETON, 1993, p.97].

7.5.3.3 Fluid Entrainment and Detrainment as Auxiliary Events

Further in the analogy with erosion and deposition, fluid entrainment and detrainment can be intuitively characterized as auxiliary events in relation to turbidity currents. As discussed in section 7.5.1.3, the very definition of entrainment carries the idea that it is not simply something entering into a fluid, but rather entering into a flow. Complementarily, the definition of detrainment, *i.e.*, "*the process by which fluid is expelled from a*

Figure 7.10 – Modeling pattern for *Substrate-Feeding Events* applied to *Fluid Entrainment* and *Turbidity Current*



Source: the author

turbulent flow" [MOSSA; SERIO, 2016, p.2], conveys the opposite idea that something leaves a flow.[44]

On top of that, both events meet the requirements to qualify as auxiliary events. Their overlap with their associated turbidity currents consists of having the *interstitial fluid* as a common participant. They also have the *ambient fluid* and the *transferred fluid* as exclusive participants. Upon the occurrence of fluid entrainment/detrainment, an amount of fluid is added/removed to/from the interstitial fluid of the turbidity current. Finally, the exchange of fluid with the necessary contribution of an exclusive participant of the fluid entrainment/detrainment event, *i.e.,* the ambient fluid that promotes the shear stress on the upper boundary of the flowing mixture. Therefore, both fluid entrainment and detrainment events qualify as auxiliary events. Moreover, they are, respectively, a *substrate-feeding events* and a *substrate-draining events*, as depicted in figures 7.10 and 7.11.

7.5.4 Turbulence Generation

This section presents an ontological analysis of the event of *turbulence generation*.

7.5.4.1 Turbulence Generation as Transition between Situations

As exposed in section 7.2.5, the interstitial fluid turbulence that keeps sediment suspended in a turbidity current comes from shear stresses at its interface with the seabed

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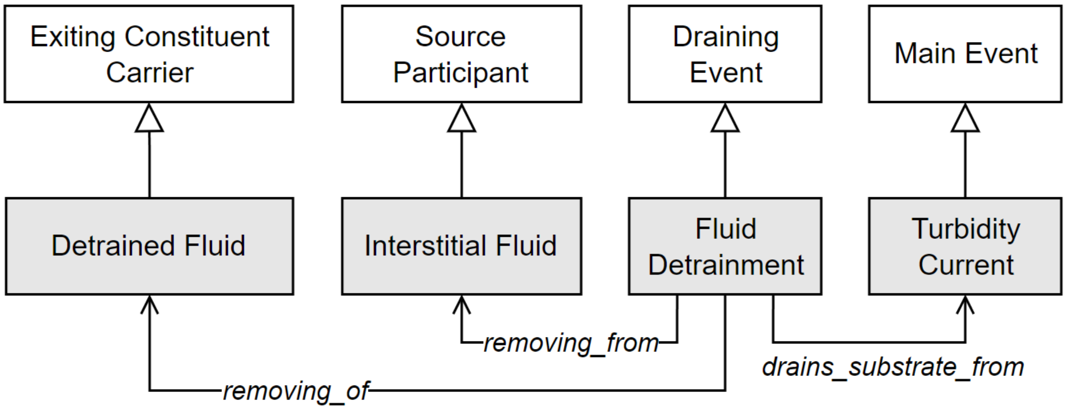
[44] Sometimes entrainment and detrainment are explicitly described as opposite processes, *e.g.,* <https://glossary.ametsoc.org/wiki/Detrainment> and <https://glossary.ametsoc.org/wiki/Entrainment>.

Figure 7.11 – Modeling pattern for *Substrate-Draining Events* applied to *Fluid Detrainment* and *Turbidity Current*



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and the ambient fluid. We will call this process ***turbulence generation***, whose participants are the interstitial fluid and the seabed or the ambient fluid. So, disregarding the expenditure of turbulent kinetic energy to keep the sediment load in suspension, *turbulence generation* would be *the process of increasing the turbulence level of the interstitial fluid of a turbidity current.*

Definition 144 (Turbulence Generation) *Given two time instants t_1 and t_2 such that precedes(t_1,t_2), and an interstitial-fluid $fluid_{inter}$ that bears a turbulence level $turb_{level}$:*

Turbulence Generation $=_{def}$ *An event that is a transition from a situation s_1 bound to t_1 to a situation s_2 bound to t_2 such that*

(1) *there is an object stress-inducer which is either the seabed or a body of ambient fluid;*

(2) *in_contact($fluid_{inter}$,stress-inducer) at both t_1 and t_2;*

(3) *includes(s_1,$fluid_{inter}$) and includes(s_1,stress-inducer);*

(4) *includes(s_2,$fluid_{inter}$) and includes(s_2,stress-inducer);*

(5) *at t_1, has_value($turb_{level}$,v_1);*

(6) *at t_2, has_value($turb_{level}$,v_2);*

(7) $v_1 > v_2$.

7.5.4.2 Turbulence Generation as Manifestation of Dispositions

As in the cases of *deposition* and *fluid entrainment/detrainment*, there is no evident named disposition specifically related to *turbulence generation* – such as *erosivity* and *erodibility* in the case of *erosion*. Even so, literature refers to some properties associated with this type of process, such as the *roughness* of the seabed [BAAS et al., 2016, p.2003] [KNOBLAUCH, 1999, p.15]. Besides that, *turbulence generation* comprises the manifestation of the *shear capacity* disposition (def. 130) of both the interstitial fluid and the stress-inducer, which are triggered by the contact between these two objects.

7.5.4.3 Turbulence Generation as Auxiliary Event

The previous sections describe what *turbulence generation* fundamentally is: the increase in the turbulence of a variable embodiment of fluid due to its interaction with a seabed or a body of surrounding fluid over/through which it flows. Based on that, we can model this process as a system-invariant event whose delimiting system is composed of the flowing fluid and some seabed or surrounding body of fluid, which are connected by a *shear contact* relation that exposes their *shear capacity* dispositions to each other.

Even so, as in the previous cases (erosion, deposition, fluid entrainment, and fluid detrainment), this model still does not fully capture the relational dependence of turbulence generation on a turbidity current. That is to say, *turbulence generation* is not regarded as simply the increase in the turbulence of just any fluid. Rather, it is the increase in the turbulence of the carrier of a process of sediment transport – *i.e.,* the increase in the turbulence level of the *interstitial fluid* of a *turbidity current*. More than that, the process of turbulence generation provides a crucial factor for the continuity of the current (*e.g.,* "*When turbulence is not strong enough to [...] keep sediment in suspension [...] loss of density by sedimentation leads to a sudden termination of flow*" [WELLS; DORRELL, 2021, p.59, 75-76]; "*dissipation of turbulence caused the lost of sediment-transport capacity of the flow*" [MANICA, 2012, p.274]).

Additionally, turbulence generation is usually described as a process associated with the main flow (*e.g.,* "*The sediment-laden flow must generate enough turbulence to hold the sediment in suspension.*" [KNOBLAUCH, 1999, p.4]), which also involves elements of its environment (*e.g.,* "*Turbidity currents [...] turbulence is typically generated by the forward motion of the current along the lower boundary of the domain [...]*" [MEIBURG; KNELLER, 2010, p.136]; "*Turbulence generated by bottom roughness*""

[KNOBLAUCH, 1999, p.15]; "*turbulence production occurred due to shearing near the lower boundary*" [KNELLER; BUCKEE, 2000, p.76]). Thus, turbulence generation can be intuitively regarded as an *auxiliary event* in relation to turbidity currents.

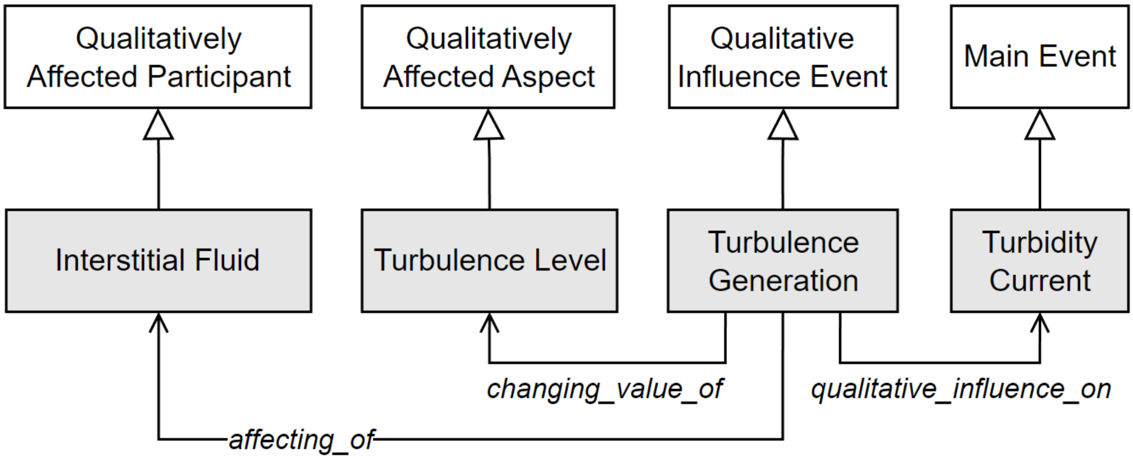
In consonance with this intuition, the process of turbulence generation meets the requirements to qualify as an auxiliary event. First, a turbulence generation process overlaps with its turbidity current by involving a common participant, *i.e.,* the *interstitial fluid*, but is not part of the current for involving an exclusive participant, *i.e.,* the *ambient fluid* or the *seabed*. Second, it has clear effects on the turbidity current. For example, by keeping the interstitial fluid in a turbulent state, the process of turbulence generation allows the fluid-sediment mixture to flow much longer than it would if only relying on its initial turbulent kinetic energy budget provided at the onset of the current. Lastly, turbulence generation comprises the manifestation of dispositions that inhere in its exclusive participants, such as the *shear capacity* of the ambient fluid or seabed that is in contact with the interstitial fluid.

Given all that, turbulence generation qualifies as an *auxiliary event* in relation to a turbidity current. More specifically, by affecting a turbidity current without altering the amount of substrate that is subject to it, turbulence generation also qualifies as an *influence event* (def. 100) in relation to a turbidity current. Finally, since it consists of a change in the value of an intrinsic property of a participant of a turbidity current (*i.e.,* the turbulence level of the interstitial fluid), turbulence generation is a *qualitative influence event* (def. 102). Figure 7.12 presents the characterization of turbulence level as a qualitative influence over a turbidity current, also illustrating the roles played by the interstitial fluid and its turbulence level.

7.6 Considerations about the Case Study

The results of the ontological analysis and modeling of turbidity currents indicate the adherence of our theory to this particular domain. In most cases, we were able to find concrete exemplifications for all the elements in our theory (*e.g.,* the type of system that delimits turbidity currents, its components and elements of the environment, the dispositional connections and related dispositions, the auxiliary events). Although we had to infer the existence of some of such elements based on indirect references, a great part of them were well-known named entities in the domain (*e.g.,* the named components *interstitial fluid* and *suspended load*; the dispositions of *erosivity*, *erodibility*, *transport capacity*,

Figure 7.12 – Modeling pattern for *Qualitative Influence Events* applied to *Turbulence Generation* and *Turbidity Current*



Source: the author

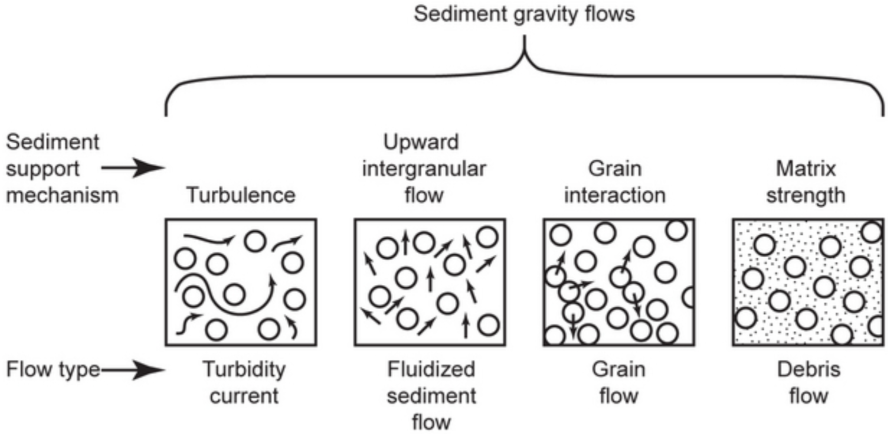
and *viscosity*; the relations of *suspension* and *shear contact*; and so on).

On top of that, parts of the typical discourse of the domain seem to reflect the structure of our theory (*e.g.,* the explicit reference to the flowing fluid-sediment mixture as a *system*, the use of the term *ambient* fluid to refer to an actual element of the environment, the categorization of gravity currents as *conservative* and *non-conservative*). With that, the finds suggest that, over the years, the practice of the domain led to the emergence of a systematic way to describe the entities of the domain that resembles some of the structure of our theory. Then, we have evidence that, to some extent, the proposed theory indeed reveals some underlying ontological aspects of events.

There are other auxiliary events related to turbidity currents that could be modeled in a similar fashion to our case study. For example, the processes of ***flow stripping*** and ***overspill*** [PARSONS et al., 2007, p.289-292] seem to be good examples of substrate-draining events associated with turbidity currents that flow confined by submarine channels. *Flow stripping* is the process by which an upper portion of the turbidity current is detached (*stripped*) from the main body of the flow and begins to propagate away from the confining channel. Similarly, *overspill* is also a process by which the flowing mixture spills to areas outside the confining channel, but that happens in a more continuous and gradual way.

Additionally, we have the processes of ***acceleration*** and ***deceleration*** of the flow due to the interaction with the environment, which seem to characterize them as *qualitative influence events*. In particular, they correspond to the influence of seabed slope gradient and frictional surface, as suggested in several passages, *e.g.,*

Figure 7.13 – Types of Sediment Support Mechanisms for Different Types of Sediment Gravity Flows



Source: [COVAULT, 2011]

(1) “*frontal velocity [...] as a function of [...] seafloor gradient*” [HEEREMA et al., 2020, p.7];

(2) “*increase frictional drag and thus reduce flow velocities*” [HEEREMA et al., 2020, p.2];

(3) “*the force of turbidity flows [...] is proportional to the steepness of the gradient*” [MCHARGUE et al., 2011, p.731];

(4) “*effects of gradient changes on flow behavior*” [MEIBURG; KNELLER, 2010, p.142];

(5) “*turbidity currents slow down on low slopes*” [OEHY; SCHLEISS, 2007, p.637];

(6) “*if the slope is steeper [...] flows will accelerate*” [KNELLER, 2003, p.903]

We can also use the same framework to model other types of underwater mass movements, *e.g.*, ***slides*** and ***slumps***, including other types of sediment gravity flows, such as ***debris flows***. Many of these cases comprise a delimiting system also composed of fluid and solid Earth material, as well as a seabed and a body of ambient fluid as the elements of the environment. The difference will reside in the interactions between those elements, such as the mechanism by which the fluid transports the solid material and, in the case of sediment gravity flows, the sediment support mechanism (figure... illustrates the mechanisms for sediment suspension in different types of sediment gravity flows).

For example, in *debris flows*, the flowing mixture will present a much more cohesive character due to a high concentration of clay in its suspended load, with the flow exhibiting a more laminar rather than turbulent character. With that, instead of turbulence, the sediment support mechanism is that of *matrix strength*, with the clay particles holding the coarser sediment in suspension [DASGUPTA, 2003, p.271].

Moreover, the possibility of modeling the various types of underwater sediment transport processes may also help to account for the phenomenon of ***flow transformation***, which is sometimes regarded as "*the most important and the least understood phenomenon in process sedimentology.*" [SHANMUGAM, 2000, p.301]. Roughly speaking, *flow transformation* is the event in which a given load that was being transported in a type of transport process proceeds forward in a different mode of transportation. For example, in a debris flow, the acceleration of the flowing fluid-sediment mixture may lead to its progressively diluted due to fluid entrainment and to the onset of turbulence, in such a way that the debris flow eventually ends and a turbidity current, transporting the same suspended load, begins [COVAULT, 2011][PARSONS et al., 2007, p.301][DASGUPTA, 2003, p.274,275][SHANMUGAM, 2000, p.302].

Through the lens of our theory, this phenomenon would be a matter of a transformation of the underlying system that delimits the initial event. In other words, we have a flow transformation when the initial system is dismantled, *e.g.,* by the termination of the connections among its components, and a new system is assembled with the same components, but a distinct structure. The transformation of a debris flow into a turbidity current is an illustrative case, which happens by the breaking of the characteristic connection between the participants in a debris flow (*i.e.,* the ceasing of the matrix strength mechanism due to the dilution of the mixture) and the establishment of a connection that characterizes the system that delimits a turbidity current (*i.e.,* a turbulent suspension).

An account of flow transformation is important for identifying and interpreting sediment gravity-flow deposits because knowing the type of flow that took place in different regions of the seafloor is critical in developing good geologic models [MCHARGUE et al., 2011; PARSONS et al., 2007; SHANMUGAM, 2000]. For example, "*turbidity currents are more likely to spread laterally than debris flows, and deposition of sediment by settling from turbidity currents vs by freezing from debris flows will make a difference in sandbody geometry*" [SHANMUGAM, 2000, p.302].

As a matter of fact, it is widely understood that the development of geological models that make effective predictions about the characteristics of sedimentary deposits heavily relies on the understanding of the various processes involved in the transport of sediment into the deep seafloor. Beyond that, creating such predictive models depends on our ability to develop an integrated model of such processes that accounts for their interactions [PARSONS et al., 2007, p.320, 325][KNELLER; BUCKEE, 2000, p.67][HEEREMA et al., 2020, p.1. 2]. Our work may contribute to that with an ontological account for such a network of processes.

8 DISCUSSION

In this work, we adhere to the view that an event is a transformation of a portion of reality from one situation to another – in other words, a reconfiguration of a portion of reality – by means of the manifestation of dispositions of its participants. Based on this view, our general goal was to determine *bona fide* aspects of reality that delimit the portion of reality that is subject to such a transformation and that can reveal the structure of what is happening. With that, we intend to provide modeling constructs and establish a set of consequences for modeling decisions regarding events which may give rise to guidelines for the analysis and modeling of events, as well as for conceptual verification of models.

Upon that, we postulated 3 main hypotheses that guided the work:

(I) There are ontological constraints for an object to participate in an event;

(II) There are ontological constraints for a succession of situations to constitute an event;

(III) There are types of events derived from those constraints that can reveal distinct general structures of events along with distinct consequences for the analysis and modeling of events.

Those hypotheses were translated into 3 main objectives:

(1) Determining a unifying criterion for events based on the constraints mentioned in hypotheses (I) and (II);

(2) From the unifying criterion referred to in (1) and other related ontological constraints, deriving types of events and relations between events;

(3) Outlining general rules on how to employ the findings from (1) and (2) to guide the analysis and modeling of events, as well as the conceptual verification of these models.

From the investigation of the postulated hypotheses, we achieved the following results, which amount to the main contributions of this work:

(A) A unifying criterion for events based on the notion of *system*;

(B) An enriched account for the notion of participation in an event;

(C) The notion of *auxiliary event* and an account for the types of interference an event can have on another;

(D) A taxonomy of events based on the type of system that delimits the event, reflecting the ways in which it can be affected by other events;

(E) An initial set of modeling guidelines and useful inferences.

Concerning (A) (presented in sec. 5.5), regarding an event as a transition through snapshots of a single system provides a transversal unifying criterion for events, *i.e.,* a criterion to unify the participants at an instant during the happening of an event. Such a criterion also contributes to drawing the boundaries of an event since we have means to determine which objects participate in an event at a given instant (*i.e.,* those that are components of the system at the time) and which ones do not. This finding corroborates the hypothesis (I) and contributes to object (1).

Also, using systems to delimit events provides a longitudinal unifying criterion for events, *i.e.,* a criterion to unify the successive situations in the course of an event. It can also contribute to drawing the temporal boundaries of events in certain cases, *i.e.,* with the starting instant of the event coinciding with the establishment of its delimiting system and/or its ending coinciding with the instant in which its delimiting system is dismantled (*e.g.,* a chemical reaction, a sale, a turbidity current). This seems to corroborate the hypothesis (II). Furthermore, considering both criteria, we have a partial criterion of individuation for events, in the sense of defining the conditions under which a segment of reality is an individual event distinct from its environment [SAVELLOS, 1992, p.808-809].

Regarding (B), restricting the participants of an event to the components of its delimiting system, we could also derive an informative account of participation. Given the notion of dispositional connection, we impose that an object participates in an event either if it contributes to the manifestation of a disposition of another participant (*i.e.,* if it provides stimulus conditions for that) or if its relations with other participants provide stimulus conditions for the manifestation of its own dispositions. This is another finding that seems to corroborate the hypothesis (I).

It is arguably an advance in comparison to the usual account of participation as a primitive relation between events and continuants [ARP; SMITH; SPEAR, 2015, p.135], which is left unexplained (*e.g.,* "*The relation between a material entity and a process that obtains in virtue of the fact that the former participates in the latter.*" [ARP; SMITH; SPEAR, 2015, p.182]). We also believe that it adds to the account of participation as a relation between an object and an event in virtue of the event being (wholly or in part) a manifestation of a disposition of the object [ALMEIDA; FALBO; GUIZZARDI, 2019, p.5].

On one side, this enriched account of participation allows continued participation of objects while they are (at least apparently) not manifesting dispositions that are characteristic of the event. For instance, when a train stops at an intermediary station during a trip, the passengers inside the train keep participating in the trip due to their status as components of the system that delimits the trip event, even though they are not manifesting any trip-related disposition. Additionally, it imposes the requirement that the manifestations of dispositions of a participant must be in some way connected to those of the other participants, preventing the inclusion of extraneous participants in our models. On top of that, this derived account of participation unlocks the notion of entry and exit of participants into/from an event as events of their own (which forms part of contribution (C)).

Contribution (C) mainly comes from realizing that, having a criterion to delimit the portion of reality that is subject to an event, we also have means to identify events that overlap, *i.e.,* that are transformations of an overlapping portion of reality. Moreover, by operating over a shared portion of reality, some events may have an effect on other events with which they overlap. Based on that we proposed the notion of *auxiliary event* (def. 59, sec. 6.2) as an event that overlaps with another event (*i.e.,* its *main event*) and interferes with its unfolding. This interference may come in various ways, affecting *what* is transformed by the main event and/or *how* such a transformation happens. Such types of interference were captured in a set of relations between events (described in section 6.2), from which we derived a taxonomy of auxiliary (presented in figure 6.8) and modeling patterns for the entities involved in each type of auxiliary event.

With that, our theory offers an account of additional phenomena. It describes what it means for an object to become or cease to be a participant in an event and how it happens (*i.e., engaging* and *disengaging* events, sec. 6.2.4). It also gives an account for the entry/exit of amorphous substrate into/from an event (*i.e., feeding* and *draining* events, sec. 6.2.5). Additionally, it covers events that influence the dynamics of other events (*i.e., influence* events, sec. 6.2.6). These findings can contribute to discerning side events that may have a great influence on an event of interest, even though not being part of it (*e.g.,* the ingestion of food is not part of the event of digestion, the replacement of a soccer player during a soccer match is not part of the match, adding fuel to a fire is not part of the burning event). This corroborates hypothesis (III) and contributes to objective (2).

It is also noteworthy that auxiliary events seem not to have any dependency on their corresponding main event. In other words, an auxiliary event is not fundamentally an auxiliary event, but just an event that contingently happens to affect another event due to the circumstances in which they occur (*i.e.,* operating over an overlapping portion of reality). With that, this finding seems to reveal a complementary, orthogonal classification of events, with respect to its relation to other events rather than to its happening nature (*i.e.,* the changes and unchanges it consists in), which could be seen as some sort of *role* that events can play.

Regarding (D), the type of the system that delimits a system-invariant event determines the types of interference to which the event is open or closed – that is, the types of auxiliary event that may affect its unfolding. Therefore, by specializing the category of system-invariant events according to the type of system that delimits its instances we got a taxonomy of events such that each type is associated with the types of auxiliary events that may interfere with its instances (presented in fig. 6.14). Once more, it corroborates hypothesis (III) and contributes to objective (2).

Finally, combining this taxonomy with that of auxiliary events and with the principle of ontological conservation (sec. 4.4) we gain the ability to predict missing events as well as to recognize problems in our models and identify approaches to fix them (as discussed in section 6.5). This corresponds to contribution (E), which corroborates hypothesis (III) and fulfills to objective (3)l

8.1 Interface with Related Work

Our proposal is consistent with some previous works and, to some extent, refines them. The notion of system specializes that of variable embodiment proposed in [GUARINO, 2017]. The idea that each situation in the course of an event is a configuration of the components of a system that results from their arrangement an instant earlier is consonant with the view of a world that 'ticks' in [GUIZZARDI et al., 2013] and evidences the causal link between situations in the course of an event referred in [HERRE, 2010]. Moreover, it may provide a possible account for the means by which a stage of a process leads to the following one as described in [GALTON; MIZOGUCHI, 2009] [GALTON, 2016] [GALTON, 2018].

Besides that, even though our approach diverges from some other works, it can still dialogue with them and may suggest a complementary view. Considering an event as "*whatever happens to a suitably selected set of individual qualities in a particular spatiotemporal region*" [GUARINO; GUIZZARDI, 2016], our approach can be seen as a particular way of selecting such focal properties (*i.e.,* the properties that structure the system that delimits the event). With that, we intend to contribute with a selection criterion that is flexible enough to allow variation of participants (including the case of existential events), while still ensuring cohesion among them to avoid integrating the behavior history of non-interacting, unrelated objects into a single event (as discussed in chapter 5).

Likewise, the system that delimits an event can be seen, in a loose sense, as the single concrete object to which the event happens (as prescribed in several approaches presented in chapter 3 and discussed in chapter 5). The difference in our case is that, whereas those views imply that such an object is the only participant of the event, our approach describes the event as involving the components of the system rather than the system itself, which is employed only to delimit and give structure to the event.

In this sense, our approach resembles the view in [GALTON; MIZOGUCHI, 2009, p.22-24], according to which "*A process is enacted by exactly one object at any one time [...] If a process appears to be being enacted by several different individuals, in reality, it is being enacted by a composite which has those individuals as parts*". Moreover, such a process arises from the coordinated interactions among the parts of the composite, which are themselves participants of the process. Thus, in our approach, a system fills the role of the single composite that enacts the process.

The notion of system would fill a similar role regarding the view that an event is the manifestation of an overall, complex disposition composed of dispositions of its participants (as discussed in chapter 5). In our approach, a system works as an object that can survive the variation of participants during an event. With that, it can be the single bearer of the overall disposition manifested in the event, allowing the possibility of an event being the manifestation of the same complex disposition throughout its occurrence.

Finally, some works suggest the value of exploring the interplay of the notions of system and events. For instance, in [MIZOGUCHI; BORGO, 2021] we have a discussion about applying a systemic view to foundational ontologies, emphasizing the benefits of using the notion of system to capture the dynamism of the real world. The authors adopt a functional account of systems, such that a system has a function, a characteristic behavior (*i.e.,* an event) that realizes this function, and a network of interacting components that collaboratively manifest such a behavior. With that, they argue that the sistemic view can highlight the causal connections among the participants of an event, besides helping in integrating apparently unrelated events as collaborative and coherent changes of reality. In [LUKYANENKO; STOREY; PASTOR, 2021], authors argue for employing the notion of systems to support the modeling of biological processes. Also, the work in [CAMERON et al., 2022] evidences the association between systems and processes in industrial contexts.

From the philosophy of science domain, we have Cartwright's notion of *nomological machine* as what underlies the regularities that are usually associated with laws of nature (*i.e.,* "*laws of nature obtain . . . on account of the repeated operation of a system of components with stable capacities in particularly fortunate circumstances. . . . what I call a nomological machine*" [CARTWRIGHT, 1999, p.49]). Thus, she defines a nomological machine as

> "*a fixed (enough) arrangement of components, or factors, with stable (enough) capacities that in the right sort of stable (enough) environment will, with repeated operation, give rise to the kind of regular behaviour that we represent in our scientific laws*" [CARTWRIGHT, 1999, p. 50].

Although not directly related to the characterization of events, it articulates the same main elements that we employ in our approach, *i.e.,* a system of arranged components with certain capacities (dispositions), in a given environment, that gives rise to some behavior (an event). We believe that this correspondence of elements with a theory on such a fundamental level points to the suitability of our approach and can be a source of guidance for future work.

We have a similar case in the context of biomedical ontology, with the notion of *mechanism* being used to causally explain certain stable behaviors of biological systems. In [RöHL, 2012], a mechanism is defined as "*(1) a complex continuant . . . that has (2) a specified biological function that is essential for it, and that (3) necessarily has a substructure of functional parts with functions that contribute to the function of the* *whole*".

8.2 Limitations

This work establishes additional constraints over the notion of events as transitions through situations. Hence, the two main sorts of limitations it faces are related to the generality of the approach, *i.e.,* the extent to which it can cover the intended models of events (*e.g.,* whether it is applicable for all events, or to a broad category of events, or to just some particular cases), and to the clarity of the constraints, *i.e.,* how well the constraints are specified in order to allow their application on the analysis and modeling of events.

Regarding the generality of the approach, it focuses on events that are manifestations of dispositions and presupposes the idea that dispositions require external stimuli to happen. Thus, it becomes unable to cover certain classes of events, in particular

(1) Events with a single participant;

(2) Events involving aggregates of causally unrelated objects;

(3) Events that are manifestations of properties/entities other than dispositions.

Concerning (1), we have the problem of spontaneous manifestation of a disposition, *i.e.,* an event that is the manifestation of some disposition of an object without any stimulus conditions. Thus, such an object could undergo a change without the need for any interaction with external objects. That is to say, we would have a full-fledged event without an activation system to delimit it. An example is the ripening of a fruit (*i.e.,* the process that causes fruit to become more palatable, sweeter, less green, and softer[1]) independently of external factors (*e.g.,* being no longer connected to the tree, without exposition to external agents that accelerate ripening, such as acetylene). Then, we would have an event involving a single object (*i.e.,* a fruit) that undergoes changes in certain properties (*e.g.,* color, softness, sweetness) by manifesting a disposition (*i.e.,* of becoming ripe).

Here we may have an issue with the level of resolution in which we consider the portion of reality that is being transformed. In a higher level of detail, what happens is the interaction of several components of the fruit (*e.g.,* cells, hormones, degrading

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[1] en.wikipedia.org/wiki/Ripening

enzymes) that leads to several changes in certain components (*e.g.,* destruction of cell walls, breaking down of complex carbohydrates into simpler ones such as glucose and fructose, degradation of chlorophyll and production of other pigments) and whose overall result, from a lower level of resolution, characterizes a fruit being ripe. In other words, the fruit as composed of several smaller objects would be the system that delimits this complex underlying event that, in a lower level of resolution, presents itself as the ripening of a single fruit. In fact, it seems to agree with Bunge's remark that "*in every system there is spontaneous activity,* i.e., *not elicited by any inputs*" [BUNGE, 1979, p.25].

Of course, it is not to say that the ripening of the fruit and the corresponding underlying complex process would be the same event since they involve distinct participants (*i.e.,* the whole fruit in the former, the components of the fruit in the latter). However, it seems to reveal an interesting organization of levels of events based on the notion of systems that can be further explored to extend our account to cover those cases. Here, the idea of internal processes supporting the external processes that an object enacts (as found in [GALTON; MIZOGUCHI, 2009]) may be useful. Also, the idea of mereology of dispositions [BARTON; JANSEN; ETHIER, 2017] may be handy to characterize such a single-participant event as the manifestation of a complex disposition by the participant (*e.g.,* the fruit) composed of interacting dispositions inhering in distinct parts of such an object (*e.g.,* cells, hormones, enzymes).

Another, more problematic example, is that of the inertial movement of a single atomic object, which can be seen as the constant manifestation of dispositions corresponding to inertia and instant velocity of the object [BARTON; ETHIER, 2016]. With that, it is also an event that prescinds any additional participant to happen. Additionally, differently from the previous case, since the object is atomic it cannot have components and, thus, it cannot be a system on its own whose components are interacting to manifest their dispositions resulting in the spontaneous manifestation of an overall disposition of the object. Therefore, it seems to be indeed a case where our theory fundamentally falls short in explaining.

In (2) we have the case of any event with non-connected participants, *i.e.,* whose participants compose a mere aggregate of objects rather than a system. One example is the event of approximation of an object x towards an object y by the moving of x while y remains at rest. Assuming that x is not actively seeking y in any way, nor being attracted by y (*e.g.,* gravitationally or magnetically), x and y do not compose a system to delimit such an event.

Here it remains the question of whether an approximation is a genuine event or it is simply an arbitrary sum of the states of x and y over time, with the movement of x being the only event taking place. While x is indeed undergoing a change in its spatial position, y is not undergoing any change in such respect, nor contribution in anyways to the change that x is undergoing. Following [HACKER, 1982, p.12], in the case of changes involving spatial relations like the approximation of x towards y, the reality underlying the event wholly consists of the moving of x, not in any non-relational change to y. Indeed, it exemplifies a *Cambridge Change*, *i.e.,* the case in which a proposition is true of an entity at one time and false of the same entity at a later time, but merely as a consequence of some other event (the 'real' event) [HACKER, 1982]. Cambridge changes are acknowledged problematic cases [LOMBARD, 1998, note 46], sometimes not even considered real changes [GEACH, 1969, p.72][2].

Thus, if events involving a mere aggregate of objects fall under the case of Cambridge changes (which seems to be the case), we believe that not covering them makes no great harm to our approach. Considering them as events seems to be as adequate as regarding the ten tallest buildings in the world as a single object any more than a mere, arbitrary mereological sum. With that, we are not saying that accounting for differences is not useful at all, just that they could be conveyed by other means.

Regarding (3), we have the problem of events that can be considered as manifestations of properties other than dispositions, such as roles in BFO (which are realizable entities an object bears due to some external circumstances, in contrast to dispositions that are internally grounded realizable entities [ARP; SMITH; SPEAR, 2015]) or modes in UFO [GUIZZARDI et al., 2021]. We believe that events comprising realizations of such entities are, in the end, realizations of dispositions.

To illustrate, an example of role in BFO is given by "*the role of a doctor is realized when he examines or treats patients*" [ARP; SMITH; SPEAR, 2015, p.99]. Although the act of a doctor examining a patient may be associated with her/his role as a doctor, it seems clear that it indeed consists of manifestations of the doctor's abilities and capacities. Consonant with this view, the work in [BARTON; TOYOSHIMA; ETHIER, 2020] brings an account of some causal roles in terms of sums of reciprocal dispositions – more specifically, sums of affordances and effectivities. Besides that, the view adopted in UFO seems to support ours, *e.g.,* with manifestations of modes being considered as manifestations of the dispositions that compose such modes [GUIZZARDI et al., 2021].

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[2] "*I am here naturally considering only 'real' changes, not mere 'Cambridge' changes that are not 'real'*" [GEACH, 1969, p.72]

Still concerning the generality of the approach, it conceives a system-invariant event as being delimited by a single system throughout its happening. Although this idea seems powerful and brings interesting consequences when applied, it is still not clear how comprehensive it is. We have made an argument showing the suitability of this constraint for instantaneous events (at least for those involving multiple interacting participants). Also, we have made a case for the existence of prolonged events that do follow the system-invariance constraint, with some of them being indeed primarily structured around a system of participants even priorly to any particular outcome (*e.g.,* a war, a soccer match).

Even so, we still cannot undoubtedly assert that this constraint applies to all multi-participant prolonged events. That is to say, even if every instantaneous event is delimited by a system and every prolonged event is composed of a chain of system-delimited instantaneous events, we do not have definitive grounds to affirm that all the system-delimited instantaneous events composing the prolonged event are delimited by the very same system. Indeed, there are examples of events that seem to challenge this idea, apparently being delimited by different systems over time.

A case in point is a trip composed of various stages involving different means of transportation. Let us take a solo trip from Brazil to the North Pole by first taking a plane to Russia and then taking an icebreaker ship to the North Pole. This would be an event composed of two smaller events, *i.e.,* a flight followed by a ship journey, each of which can be delimited by a system, *i.e.,* with some simplification, the system composed of the traveler and the plane, and the system composed of the traveler and the ship, respectively. For such a trip to be delimited by a single system throughout its happening the traveler-plane and traveler-ship systems would have to be the same system in distinct configurations. For example, it could be a single system composed of a traveler and a transport medium, with the ship replacing the plane in the latter role. However, it still may be the case that this North Pole trip is simply an event delimited by two different systems that have a main component in common (*i.e.,* the traveler).

Concerning the clarity of the constraints employed in our approach, we have the issue of the identity criterion for systems. In fact, this issue is closely related to the previous one. In order to determine whether an event is delimited by the same system throughout its happening we first need to determine what it is for a system to be the same. Despite that, *system* seems to be a dispersive universal[3] and then we would not have a

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[3] A universal whose instances may follow distinct criteria of identity [GUIZZARDI, 2005, p.128].

general criterion of identity that is applicable to all its instances, which must be provided by lower-level types specializing that of systems.

Still, the system category is informative about certain necessary conditions for the persistence of its instances. A determinant characteristic of systems is that the behavior trajectory of a whole system differs from the union of the histories of its isolated components [BUNGE, 1979, p.4]. Moreover, a system is said to be a whole that is associated with one or more defining, essential properties and functions (here understood as certain potential behaviors and capacities of the whole) that emerge from the interaction of such parts and that are not shared by any of them (*e.g.,* a person walks, but the person's legs do not) [ACKOFF, 1999, p.5-8]. This seems to point out that, regardless of the criterion of identity that is applicable to a given individual system, its persistence can be determined by, *e.g.,* the permanence of certain functions and certain characteristic parts that exhibit a joint behavior.

Given those limitations on employing the notion of system, it is worth questioning whether we are not simply shifting the burden of individualizing a relatively ill-defined type of entity, *i.e.,* events, to the task of individualizing another equally ill-defined type of entity, *i.e.,* systems. We believe that even though it might be the case, resorting to the notion of systems is still a worthy approach. Although we do not have clear guidelines on how to delimit the entities of either type and mostly rely on our best intuitions, using the notion of systems to delimit events has useful implications, *e.g.,* additional modeling constructs and constraints, that would not be directly available otherwise.

Indeed, this situation resembles the case of determining whether or not a given type provides an identity criterion for its instances, as prescribed by OntoClean [GUARINO; WELTY, 2002; GUARINO; WELTY, 2009]. Recognizing an identity criterion associated with a type of entity is an acknowledgedly hard task even for experienced conceptual modelers [GUARINO; WELTY, 2009, p.205][GUARINO; WELTY, 2002, p.62]. Despite that, as exemplified in [GUARINO; WELTY, 2009, p.208], the mere assumption that a given type supplies an identity criterion for its instances, without a precise account of such criterion, already allows us to explore the logical consequences of our modeling choices and identify problems in our model. Drawing a parallel to our situation, the simple recognition that an event is delimited by a system of a certain type can enable us to make valuable inferences about the event, even if we do not have a complete characterization of that particular system.

9 CONCLUDING REMARKS

We rooted this work on the hypotheses that there are ontological constraints for unifying and delimiting events, that there are types of events based on these constraints, and that such constraints and types are useful for the modeling of events. As a positive indication towards those hypotheses, we found some promising constraints applicable to the notion of event (in particular, the idea of system-invariance and the principle of ontological conservation). Upon these constraints, we managed to articulate them into a framework that provides several types of events, relations between events, roles that their participants can play, and general modeling guidelines, which we believe to be valuable tools for modeling scenarios comprising the interaction of multiple events.

It is noteworthy that those constraints are grounded in *bona fide* aspects of reality, such as the nature of events as manifestations of dispositions, the nature of dispositions as realizable properties activated due to some external stimulus, and the relation between the notion of constitution and the existence of objects. Delimiting an event with a system of dispositionally connected objects we are unifying its participants in terms of the interactions that are needed for the activation of the dispositions manifested in the event. Moreover, we are also stating that it is the maintenance of a cohesive, characteristic interaction among objects that unifies a succession of situations as the course of an event, describing a transition through configurations of a specified portion of reality. With that, we propose a way of delimiting events based on what they are, independently of what is significant from the cognitive standpoint.

Of course, the core definition of any specific type of event is naturally at the discretion of the person that argues for the existence of such a type of event. That is, determining the dispositions whose manifestations characterize a type of event is a matter of stipulation by who proposes the type and is completely out of our reach. The distinguishing feature of our approach is that although the modeler is free to choose the focal points of the event (*i.e.,* the dispositions whose manifestation will build the event up), s/he is a prisoner of the consequences of this choice. Although the core of the event is still necessarily arbitrarily chosen, we propose that the remaining elements are, to a great extent, determined by following certain rules and the very course of the event must exhibit certain characteristics to assure a cohesive continuity.

In other words, there is a limited set of systems from which the event may arise, *i.e.,* those whose structure is able to activate the dispositions chosen as characterizing the event. Each of such systems includes a distinct set of additional elements (*e.g.,* complementary components, additional relationships), ascribing distinct, further aspects to the event. Then, our approach focuses on establishing a constrained set of choices and a way to derive the consequences of each choice, allowing us to verify which one best fits the modeler's intention.

With that, we intend to provide a prescriptive framework upon which we can build guidelines for the analysis and modeling of events. Then, we would have a reference model for assessment of the quality of the models that can also guide the fixing of problematic models. In fact, much of the novelty and contribution of our work relies on its prescriptive aspects, *e.g.,* the ability to point out what is missing in the model, such as overlooked participants or side events.

Moreover, we try to give a full description of what fundamentally happens. Hence, we consider all the interactions and connections among objects that unify the manifestations of the focal dispositions as an integrated whole of tied behavior histories of some objects, discarding mere mereological sums of unrelated manifestations of independent dispositions. That is to say, our framework is intended to reveal a fuller description of what happens and give a rationale for the structure of the event, allowing the modeler to analyze the case, uncover the elements that the event comprises, and evaluate the modeling decisions. Yet, it is still up to the modeler to decide which of such elements to include in a particular implementation of the model according to its intended use.

Finally, at the current state, the proposed theory still lacks a complete logical formalization. Still, we believe that it can already guide conceptual modeling tasks in several domains, providing the basis for practical applications. Therefore, further directions for our research include:

- Formalizing the theory;
- Applying it to case studies in other areas (*e.g.,* industrial processes, law) to assess the extent of the category of system-invariant events and the practical impact of our theory;
- Investigating criteria of identity and persistence for systems;
- Further specializing the category of influence events;
- Integrating with the types of events proposed in [RODRIGUES; CARBONERA; ABEL, 2020].

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APPENDIX A — RESUMO EXPANDIDO

Em Informática, uma *ontologia* é a especificação de um sistema de categorias que representa determinada visão do mundo. Normalmente, uma ontologia inclui categorias para as coisas que *existem* no tempo, comumente chamadas de *continuantes*, tais como como uma pessoa, um pedaço de rocha ou uma máquina. Uma ontologia também pode incluir categorias para as coisas que *acontecem* no tempo na forma de uma transição através de situações sucessivas – ou seja, uma transição através de uma série de configurações instantâneas de uma porção da realidade. Essas entidades geralmente são chamadas de *eventos* ou *processos* e incluem, por exemplo, uma reunião, a erosão de uma montanha ou a fabricação de um produto. Apesar da prioridade usualmente dada aos continuantes, em termos práticos, um bom modelo de eventos pode apoiar várias atividades de raciocínio baseadas em ontologia, tais como a inferência de condições pré e pós-evento ou a inferência de relações temporais.

Nesse sentido, as ontologias atualmente disponíveis oferecem construtos de modelagem poderosos, que nos permitem representar uma grande variedade de tipos de eventos. Em contraste, tais ontologias fornecem muito menos restrições sobre os possíveis modelos que podem ser construídos.Em especial, existem deficiências nos critérios atuais para determinar que sequência de situações caracteriza adequadamente o desenrolar de determinado evento e quais continuantes participam do evento em cada uma dessas situações. Essa falta de restrições claras sobre como modelar eventos compromete a capacidade dessas ontologias em orientar o processo de modelagem e permite um grau maior de ambiguidade nos modelos resultantes. Portanto, restrições mais rígidas sobre a noção de eventos podem ser úteis para capacitar os modeladores a transmitir a intenção por trás de seus modelos de forma mais eficaz. Além disso, restrições adicionais também podem ajudar a descobrir novas relações entre eventos e novos tipos de eventos que permitam representar cenários de modelagem relevantes que não são adequadamente tratáveis com os recursos atuais.

Diante disso, este trabalho apresenta uma teoria para a análise ontológica e modelagem de eventos baseada na noção de *sistema* como o elemento invariante que delimita um evento. Para os fins deste trabalho, um *sistema* consiste em um objeto formado por dois ou mais componentes conectados, com uma *conexão* sendo uma relação que afete a forma como um ou mais dos objetos por ela relacionados irá se comportar em certas circunstâncias. Sob essa perspectiva, um evento seria uma transição através de diferentes configurações instantâneos de um mesmo sistema. Tal restrição permite captar a coesão que se observa entre as situações que compõem o curso de um evento. Além disso, ela proporciona um critério mais claro para decidir quais objetos podem ser considerados participantes de um evento em cada instante, bem como qual sucessão de situações pode traçar adequadamente o desenrolar de um evento.

Assim, este trabalho introduz a noção de *evento de sistema invariante* como um evento delimitado por um sistema – ou seja, um evento de sistema invariante seria transformação de uma porção da realidade delimitada por um sistema. Com isso, os participantes desse evento em um dado instante são os objetos que compõem o referido sistema em tal instante.

Dada essa delimitação, o trabalho propõe a noção de *evento auxiliar* como um evento que afeta a ocorrência de outro evento, referido como *evento principal*. Um característica importante de um evento auxiliar é que ele tem uma sobreposição temporal com o evento principal (*i.e.,* há um intervalo de tempo em que ambos eventos estão ocorrendo em simultâneo). Além disso, durante o intervalo em que ambos eventos estão ocorrendo em simultâneo, o sistema que delimita o evento auxiliar deve ter alguma sobreposição com o sistema que delimita o evento principal (*e.g.,* ambos tem um componente em comum, ou um componente de um dos sistemas é parte de um componente do outro sistema). Dada essa sobreposição de sistemas, temos que, durante algum intervalo, os eventos auxiliar e principal operam sobre uma porção compartilhada da realidade. Desse modo, o evento auxiliar consegue ter influência sobre a configuração da porção de realidade transformada pelo evento principal, o que corresponde ao efeito do evento auxiliar sobre o evento principal.

No trabalho são explorados 3 tipos principais de efeito que um evento auxiliar pode ter sobre um evento principal, sendo derivados alguns tipos de evento auxiliar para cada efeito.

- **Alteração dos Participantes.** Um evento auxiliar pode ser um *evento de engajamento*, que consiste na entrada de novos participantes no evento principal (*e.g.,* o embarque de um novo passageiro em uma viagem de trem). De maneira análoga, um evento auxiliar pode ser um *evento de desengajamento*, que consiste na saída de participantes do evento principal (*e.g.,* a expulsão de um jogador em uma partida de futebol).

- **Alteração da Constituição dos Participantes.** Alguns eventos auxiliares correspondem à modificação da constituição dos participantes do evento principal, *e.g.,* com algum participante ganhando ou perdendo partes. Eventos que consistem na adição de constituinte a algum participante são chamados *eventos de fornecimento de substrato*, ao passo que eventos de remoção de constituinte de algum participante são chamados *eventos de drenagem de substrato*. Um evento de troca de pneus durante uma corrida de Fórmula 1 exemplifica ambos tipos de evento.

- **Alteração da Dinâmica.** Há também eventos auxiliares que afetam a dinâmica do evento principal de formas que não envolvam mudanças no inventário de participantes do evento principal ou na constituição desses participantes. Esse é o caso de *eventos de influência qualitativa*, *i.e.,* eventos que alteram o valor de alguma propriedade de um participante do evento principal de forma que essa alteração afete a forma como o evento principal se desenvolve (*e.g.,* reduzir a temperatura dos reagentes tende a desacelerar uma reação química).

O trabalho também propõe uma taxonomia de eventos de sistema invariante de acordo com o tipo de sistema que delimita o evento. Concretamente, essa taxonomia contempla tipos de evento conforme o tipo de evento auxiliar a que estão sujeitos. Por fim, a partir das taxonomias propostas e do *princípio de conservação ontológica* (também introduzido neste trabalho), são propostas algumas diretrizes gerais para guiar a tarefa de modelagem conceitual de eventos.

A aplicação da teoria proposta é demonstrada em um caso de estudo no domínio de Geologia. Mais especificamente, o caso consiste na modelagem do processo de corrente turbidítica como um evento de sistema invariante e de seus processos associados como eventos auxiliares, *e.g.,* o processo de erosão como um evento de fornecimento de substrato para a corrente (na forma de sedimento) e deposição como um evento de drenagem de substrado da corrente (também na forma de sedimento).