Auxiliary Events - Towards an Ontological Account of Events That Affect Other Events

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Abstract

Events may affect the unfolding of other events in several ways. It happens, for instance, when we have an event that consists of a variation of what constitutes the objects that participate in an external, main event - e.g., by replacing parts of some of its participants or by adding/removing portions of the matter of which the participants are made. With that, such side events may result in qualitative changes in the participants of the main event. Sometimes the modified qualities may play a role in the dynamic of the main event. In such cases, any side event that affects these qualities will indeed have an effect on how the main event unfolds. Given this particularity, such a type of side event fill an important position in several domains and an understanding of its ontological nature is in order for a good conceptual modeling of those domains. Thus, in this paper, based on the idea of events as entities delimited by systems, we present an ontological account of *auxiliary events, i.e.,* events that influence the unfolding of other events. We illustrate the proposed idea with a case study from the field of Geology.

Keywords

Ontologies, Events, Processes, Occurrents, Auxiliary Events, Roles, Geology

1. Introduction

In Computer Science, an ontology is the specification of a system of categories accounting for a certain view of the world [1]. Ontologies may include categories for both the things that *are* in time (*e.g.,* a person, a piece of rock, a machine), which are called *continuants*[1], as well as for the things that *happen* in time (*e.g.,* a meeting, the erosion of a mountain, the manufacturing of a good), which are called *events*[2]. Despite their usual focus on continuants, in practical terms, a good model of events can support several ontology-based reasoning activities, such as the inference of pre- and post-condition inference, temporal relations, and missing/implicit events [2]. Accordingly, current ontologies offer rich support to model various aspects of events [3].

Even so, there are certain issues regarding events with which current approaches cannot properly deal. For example, they lack an account of how certain events can affect the unfolding of other events. This issue corresponds to the cases in which the sequence of stages in the

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[1]Sometimes also referred to as *endurants*.

[2]Sometimes also referred to as *processes*, *perdurants*, or *occurrents*.

course of an event is not exclusively determined by the interaction of its participants. Instead, in these cases, some of such stages partially result from the contribution of external elements.

Dealing with such a scenario is important in domains that rely on interference between processes. This is the case, for example, of process industries – such as the chemical or petrochemical industries – in which the unfolding of a main production process is modulated by several secondary processes (*e.g.,* the heating/cooling of chemical reactors in order to control the rate of reaction that is taking place inside it, or the mixing of additives into a fluid in order to ease its flow through pipelines). A good model of how an event can affect another could help both in designing process plants as well as in decision-making during production. An account of how events influence one another is also useful for scenarios in which we are not able to directly observe the happening of a given event – such as geological and other nature processes – but can acquire good information about side events that involve some of the objects that participate in the main event and have an influence on it. Thus, a model of such side events can help in making inferences about the unfolding of the event of interest.

With that, in this paper, we propose an ontological account for what we call *auxiliary events*, *i.e.,* events that affect the unfolding of other events, which is based on a view of events as entities delimited by systems [4]. With that, section 2 recollects some background notions to convey the idea of this paper. In section 3, we elaborate on how an event can affect another event, introducing the notion of *auxiliary event*. Section 4 presents the application of our proposal to a case study in Geology, namely, the turbidity current transport process. Finally, section 5 brings a short discussion and our concluding remarks.

2. Theoretical Background

In this section, we present the basic notions needed to convey the idea we propose in this work. We start by presenting some basic entities (*e.g.,* objects and particularized properties). Then we proceed by describing contextual entities (*e.g.,* situations and systems) that consist of arrangements of the basic ones. Finally, we employ the previous notions to convey the account of events we considered in this work.

2.1. Continuants, Objects, Individualized Properties, and Dispositions

Continuants are things that continue to exist through time while maintaining their identity, being wholly present at any time point they are present [5]. ***Objects*** are continuants that are existentially independent of other entities (*e.g.,* a person, a ball). ***Individualized properties*** are continuants that are existentially dependent on other continuants (*e.g.,* the height of a person, the color of a ball, a contract imposing obligations between two people). We say that an individualized property ***inheres*** in the continuant(s) on which it depends, which is/are the ***bearer(s)*** of the property.

Finally, ***dispositions*** are individualized properties that present characteristic manifestations under some stimulus conditions, corresponding to what we usually refer to as potentialities, propensities, capacities, tendencies, liabilities, and so on [6, 7, 8, 9, 10, 11]. We consider that 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 [12, ch.4.3]. Also, there must be some relationship between x and y so that the matching properties can be exposed to each other [11][12, ch.4.3]. An example is the fragility of a piece of glass, *i.e.,* the disposition to break in response to being struck [7].

2.2. Situations and Systems

In this work, we regard a ***situation*** as an instantaneous, particular configuration of a part of reality that is understood as a whole [13][9]. It is determined by a snapshot at a given instant of a collection of one or more objects, *i.e.,* a set of attributions referring to individualized properties (intrinsic and/or relational) inhering in such objects, and/or about formal relations among them. If a situation s is a snapshot of a collection of objects which includes the object x, we say that x ***is present at*** s and that s ***includes*** x.

We also regard a (concrete) ***system*** as a complex object composed of a collection of at least two interrelated material components forming an integrated, unitary whole [14][15, p.4]. The components of a system are linked by what is called ***connections***, *i.e.,* relations through which (at least) one of the relata affects the behavior of the other, changing the way the object will behave given certain circumstances [15, p.6][14], so that its behavior is different from that they would exhibit if they were not in such connection [14, p.55-56] (*e.g.,* exerting pressure). Three main facets characterize a system: a definite *composition* (*i.e.,* the collection of system's components), a definite immediate *environment* (*i.e.,* the collection of entities that are connected to the system or its components, but that are not themselves components of the system), and a definite *structure* (*i.e.,* the connections and other properties among system's components as well as between these and the environment) [15].

In this work, we consider that two systems overlap if they share some common object. It may be the case of two systems that share a common component or whose components share a common part, or that a component of one system is part of a component of the other system, or even that one system is a component or part of a component of the other system. As a last remark, given this description of the notions of situation and system, we can assume the existence of a special type of situation that consists of a snapshot of a system at a given time, corresponding to the configuration of the components of such a system at that point.

2.3. Events

Events are broadly characterized as things that happen in time. An event is usually regarded as a transition among successive states of the world [16][15, p.22] or as a transformation of a portion of reality from a situation to another [9]. Events are also regarded as manifestations of dispositions of objects, such that when we have a situation that gathers all the stimulus conditions needed to activate certain dispositions, an event happens. This event brings about another situation, which may also gather the stimulus conditions required for the manifestation of further dispositions, leading to another situation and so on [9].

2.3.1. System-Invariant Events

If we consider an event as a transformation of a portion of reality, it remains the question of how to delimit such a portion of reality. Regarding this, [4] proposes delimiting events using the notion of systems, restricting an event to a transition through situations that are snapshots of a single, invariant system over time. The idea goes as follows. For a disposition to be manifested, its bearer must stand in a relationship with another object in a way that the stimulus conditions of the disposition are fulfilled. This relation clearly changes the behavior of the disposition bearer since it would behave differently (*i.e.,* not manifesting the disposition) if such a relationship were not present – what characterizes this relationship as a *connection* (sec. 2.2). In fact, any relationship in which an object stands and that provides some of the stimulus conditions for the activation of one of its dispositions consists of a ***dispositional connection***, *i.e.,* a relationship that fulfills some stimulus condition of a disposition of one of its relata.

Given that, whenever a disposition is manifested, we necessarily have a system composed of at least two objects and a dispositional connection between them. Then, every event that is the manifestation of some disposition requires a system in order to happen. Its initial situation is a snapshot of a system with its components arranged in a way that activates certain of their dispositions. The situation the event brings about after that is another configuration of the same system that results from the manifestation of those dispositions. Therefore, for every disposition manifestation, there is a corresponding event consisting of a transition between snapshots of a system. Moreover, the resulting snapshot of the system may consist in an arrangement of its components in order to further activate their dispositions, which keeps the event going on. This recurrent correspondence between the manifestation of dispositions and the transition between snapshots of the system that activates them suggests the pervasive nature of this type of event. With that, we have the notion of ***system-invariant event***, *i.e.,* an event whose course is composed of situations that are snapshots of a single system.

In a system-invariant event, its participants maximally compose a system that persists during the happening of the event and whose connections are responsible for the manifestations of the dispositions that bring about the successive situations in the course of the event. Also, it is said that such a system delimits the event by delimiting the portion of reality that is subject to the event. Thus, being a participant of a system-invariant event at an instant t consists of being, at t, a component of the system that delimits the event and vice versa.

3. How an Event can Affect another Event

In this section, we introduce the notion of *auxiliary events* and the criterion to characterize an event as such. To guide the discussion, we start with an illustrative example to clarify the intuitions underlying the notion of auxiliary events. Then we elaborate on the nature of the effect that such events may have on other events and present the required conditions for attributing such type of effect to an event.

3.1. Illustrative Example: Bacterial Culture and Antibiotic Contamination

Let us consider the process of bacterial culture[3], *i.e.,* the process of multiplying bacteria by letting them reproduce in a culture medium[4]. With some simplification, we will regard it as an

[3] https://en.wikipedia.org/wiki/Microbiological_culture

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

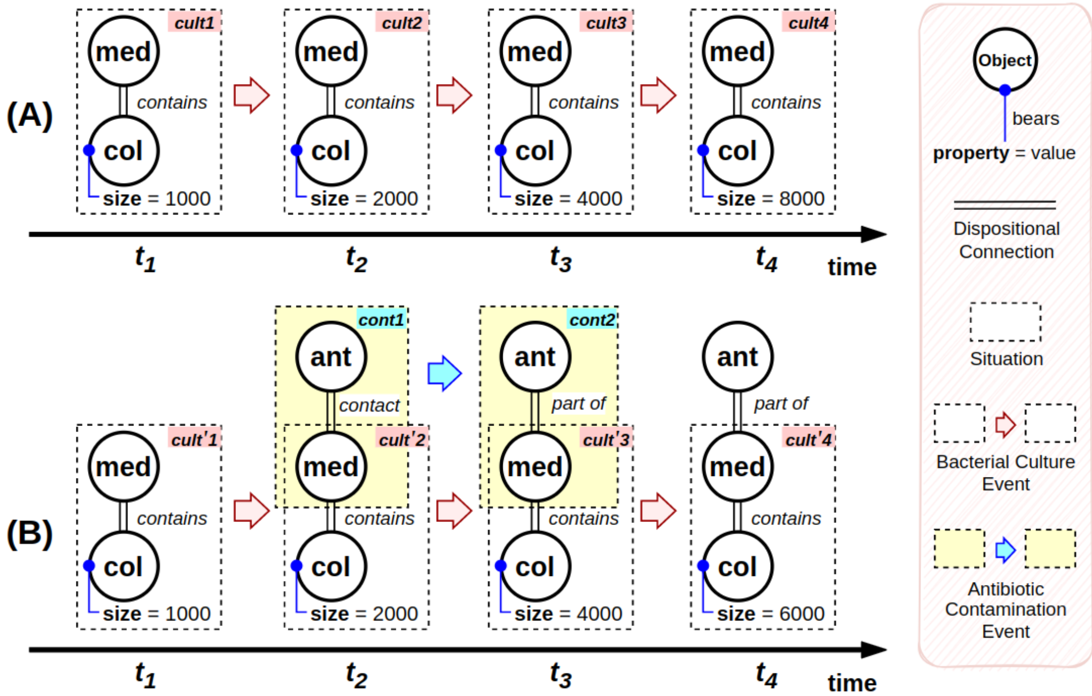

Figure 1: (A) An undisturbed process of bacterial culture; (B) A process of bacterial culture affected by an event of antibiotic contamination. (Source: the authors)

event delimited by a system composed of a microbial colony and a culture medium, which are connected by a relation of containment such that the medium contains the colony. This relation of containment qualifies as a dispositional connection for exposing the nutritive capacity[5] of culture medium to the metabolic capacities of the bacterial colony.

Now, let us consider an ideal scenario *A* (fig. 1(A)) in which a bacterial culture process *cult* happens during 3 hours (from t_1 to t_4), involving a colony *col*, initially composed of 1000 individuals, and a culture medium *med* whose composition allows the colony to double its bacteria count every hour. Therefore, after 3 hours (*i.e.,* at time t_4), the size of *col* reaches 8000 individuals.

Nevertheless, bacterial cultures are processes very sensitive to laboratory conditions, such as temperature or exposition to contaminants, and certain incidents may happen. Hence, let us consider that things actually happened as described in scenario *B* (fig. 1(B)). Here, instead of *cult*, another bacterial culture process *cult'* takes place during the same time interval $[t_1, t_4]$, also involving *col* and *med* as participants, starting in the same conditions (*i.e., col* composed of 1000 individuals and *med* allowing the colony to double its size every hour). However, differently from *cult*, one hour after the start of *cult'* (*i.e.,* at t_2), an event of antibiotic contamination *cont* happens, through which a small portion of antibiotic *ant* becomes part of the medium *med*. With some simplification, we will regard it as an event delimited by a system composed of *ant*

[5]Which we will regard as the ability of the medium to support the growth of bacteria (www.ncbi.nlm.nih.gov/pmc/articles/PMC229120/)

and *med*, which are connected by a relation of contact that exposes the solubility of *ant* to the dissolving ability of *med*.

Due to the presence of *ant* in its composition, from time t_3 onward, *med* only supports a 50% hourly growth of the colony *col*. Hence, at time t_4, *col* only reaches the size of 6000 individuals rather than the 8000 individuals that it would have achieved if *cont* had not happened.

As we can see, the actual bacterial culture *cult'* and its modal counterpart *cult* have many similarities, *i.e.,* they are events of the same type, having the same delimiting system, happening at the same time interval, and starting from the same initial conditions. Despite that, their courses are markedly different. The incorporation of a portion of antibiotic *ant* into the culture medium *med* changes the composition of *med*, which makes it exhibit a weaker nutritive capacity at t_3. In consequence, at the last situation in the course of *cult*, the colony *col* is 1/4 smaller than it would be at the same time point in the course of *cult'*. This divergence in the nutritive capacity of *med* at t_3 and in the size of *col* at t_4 amounts to the effect of the side event of antibiotic contamination *cont* on the unfolding of the actual *cult'* event. Specifically, such an effect consists of a deviation from the default course that an event of bacterial culture, with initial situation *cult'*, would have in the absence of any interference – such as the course of the counterpart event *cult*.

Given its contribution in delineating the course of *cult'*, *cont* would be what we will call an *auxiliary event* in relation to the *main event cult'*. Here, we regard an ***auxiliary event*** as *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.* Thus, an auxiliary event has three main characteristics: (1) it is associated with a counterfactual effect on the main event, (2) it is a transformation of a portion of reality that overlaps with that of the main event, and (3) there is some causal link between the unfolding of the auxiliary event and the main events. We explore each of these characteristics in what follows.

3.2. Counterfactual Effect

Every auxiliary event has a counterfactual effect on its main event. This effect consists of the contrast between the course of the actual main event and the course of its counterpart event, delimited by the same system as the main event, starting from the same initial conditions (*e.g.,* same system composition and structure) and at the same time, that would have taken place 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 that its delimiting system would present at the same time points if the auxiliary event had not happened.

Such a difference basically consists of the course of one of such events containing a situation that is not in the course of the other. That is to say, the courses of both events are equal up to a certain point but diverge after this point. It may be the case that the courses of both events have equivalent situations at a given time, which are succeeded by a distinct situation in the course of each event. For instance, the courses of *cult'* and *cult* are equal up to time t_2 but diverge with respect to the situations that obtain from time t_3 onwards. That is, situations *cult'1* and *cult'2* are, respectively, identical to situations *cult1* and *cult2* (*i.e.,* they obtain at the same time points, include the same colony *col* and medium *med* standing in the same *contains* relationship, with *col* having the same size and *med* having the same nutritive capacity), but situations *cult'3* and *cult'4* are distinct from *cult3* and *cult4* in terms of *med* nutritive capacity and *col* size.

3.3. Subject Overlap

For an auxiliary event to affect the unfolding of an ongoing main event, the effects of the auxiliary event on its subject portion of reality must be in some way 'communicated', so to speak, to the main event. Here we propose that this 'communication' is enabled by both events being transformations of a shared portion of reality. In this way, the effect of the auxiliary event over its subject portion of reality is also an effect over the portion of reality subject to the main event – and, therefore, can act as an input condition for the unfolding of the main event.

This is so because when one event ev_A is a transformation of a portion of reality that overlaps with the portion being transformed in another event ev_B, there is always something in ev_B (*e.g.*, a participant, part of a participant) that can also be affected by the occurrence of ev_A. With that, ev_B may not fully determine the configuration of its respective portion of reality at some time point. In such a case, there will be a situation *s* in the course of ev_B that is not exclusively brought about by the interaction of its participants as they were arranged in the preceding situation. Instead, *s* will have some contribution of external objects, which are participants of ev_A. In other words, there will be a situation *s* in the course of ev_B that would not have been brought about if ev_A had not happened, which corresponds to a counterfactual effect of ev_A over ev_B (as exposed in section 3.2). Given this description, we have the sort of overlap between events – which we will call *subject-overlap* – needed to allow an auxiliary event to affect the unfolding of another, main event.

As discussed in section 2, 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 1. ***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.*

To illustrate, in the example described in section 3.1, we have a subject-overlap relationship between the bacterial culture *cult'* and the antibiotic contamination *cont*. Those events temporally overlap during the interval $[t_2,t_3]$ and, during this interval, their underlying systems overlap by having the culture medium *med* as a common component, and the antibiotic portion *ant* composes the delimiting system of *cont*, but not that of *cult'*.

It is worth noting that even though a subject-overlap between two events *allows* an event to affect the unfolding of the other, it does not *entail* that one event will indeed affect the other. Sometimes, the effect of an event on the portion of reality it shares with another event has no impact on the unfolding of the latter (*e.g.*, a change in the color of a car during a race would not affect the race). In other cases, such an effect does influence how the overlapping event will unfold (*e.g.*, the cooling of a reactor generally slows down a chemical reaction that is going on inside it). That is, although necessary, subject-overlap is not a sufficient condition for an event to affect another.

3.4. Causal Link

Another central characteristic of an auxiliary event is that it is not simply *associated* with a counterfactual effect on its main event; rather, it must *produce* such effect. To put it another way, there must be a causal link between the happening of the auxiliary event and its associated effect on the main event. This feature distinguishes a genuine auxiliary event from an event that also subject-overlaps the main event and that is indeed correlated with a counterfactual effect on it, but that is not the origin of such an effect.

As discussed in section 3.2, if an event *aux* has a counterfactual effect on another event *main*, there will be at least one situation *s* in the course of *main* that would not be established if *aux* had not happened. If *aux* is indeed causally related to such effect on *main*, *aux* must in some way contribute to bringing about *s*. Hence, the causal link between *aux* and its effect on *main* lies in the mechanism that supports this contribution, *i.e.*, the role of *aux* in the disposition manifestations that jointly result in *s*.

In the course of an undisturbed event *u*, every situation is brought about by the manifestation of dispositions of participants of *u*, whose stimulus conditions are all provided by the way in which such participants were arranged in the preceding situation. Stating differently, *u* comprehends all the elements required for the disposition manifestations that bring about each situation in its course. In contrast, in the course of an event *main* affected by an auxiliary event *aux*, at least one situation *s* will result from the manifestation of dispositions whose required activation elements are not all provided in the preceding situation. That is, the bringing about of *s* will comprise the manifestation of a disposition whose activation requires something external to *main*, which is provided by *aux*.

As exposed in section 2.1, the activation of a disposition *d* requires at least 5 elements: (1) the disposition *d*, (2) the bearer of *d*, (3) a property *p* that is complementary to *d*, (4) the bearer of *p*, and (5) a relationship between the bearers of *d* and *p*. With that, for *aux* to contribute to bringing about *s*, *s* must (at least partially) result from the manifestation of a disposition such that one of the elements for its activation is provided by *aux* rather than *main*. Thus, the causal link between *aux* and its effect on *main* lies in the fact that one of the elements for the activation of the referred disposition is, at the time when the disposition is triggered, in the system that delimits *aux* and not in the system that delimits *main*.

To illustrate, in the example from section 3.1, the effect of *cont* on *cult'* consists of the presence of *ant* in the composition of *med* from t_3 onwards, which means a weakening of the nutritive capacity of *med*. Thus, the causal link between *cont* and such effect on *cult'* lies in the fact that the incorporation of *ant* into *med* results from the manifestation of the dissolving ability of *med*, which requires its exposition to the solubility of *ant*, which composes the delimiting system of *cont* but not that of *cult'*.

4. Case Study: Turbidity Currents, Erosion, and Deposition

Turbidity currents (also known as *turbidity flows*) are among the most important processes of transport of sediment [6] from the continental shelf to the deep sea [19, 20]. They are responsible for the creation of sandstone deposits (called *turbidites*) that are one of the most common types of hydrocarbon reservoirs in deep ocean settings [21, 22, 23, 20]. Prediction of the characteristics of turbidites, 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 travel distance [19, 24].

Physically speaking, a turbidity current is the movement of a mixture of turbulent fluid and suspended sediment (which are habitually called ***interstitial fluid*** and ***suspended sediment load***) down an inclined seabed slope toward the deep marine floor. In a turbidity current, the sediment load is kept in suspension by the interstitial fluid ***turbulence***[7] [26, 27, 20, 28, 29, 24, 30] and the flow is driven by the action of gravity on the suspended sediment, which moves and pulls the interstitial fluid down the seabed slope [22, 27, 31, 28].

Turbidity currents are markedly influenced by some associated processes, especially those of *erosion* and *deposition*. ***Erosion*** is the process by which seabed sediment is incorporated into a flowing fluid-sediment mixture [32, 30]. Thus, erosion increases the suspended load and, consequently, the source of its downslope motive force, which tends to accelerate the moving mixture [33, 20, 24, 32, 34]. Conversely, ***deposition*** is the process by which the part of the suspended sediment load leaves the current and is incorporated into the underlying seabed [33, 31, 35, 30], which tends to slow it down [19, 33, 22, 20].

In this section, we briefly characterize turbidity currents as system-invariant events and erosion as an auxiliary event in relation to a turbidity current.

4.1. Turbidity Current as a System-Invariant Event

Given what was exposed, we can regard a turbidity current as a process of *transport of suspended sediment by a turbulent fluid*. It is a process that 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*'[8] to be transported [22, 20, 31, 36, 29, 30]. 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 [28, p.275].

With that, we propose modeling a turbidity current 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*, connected by *turbulently suspends* relationship that exposes the *suspended-sediment transport capacity* of the flowing fluid [17, 37, 38, 18, 22, 30] to the *transportability* of the sediment load [17, 31, 39].

[6] Sediment can be considered as a collection of unconsolidated grains/particles of minerals, organic matter, or preexisting rocks, which can be transported by water flows or wind and later deposited [17, p.472] [18, p.320].

[7] Turbulence is the irregular, chaotic flow of a fluid [25, p.409], consisting of the local movement of the fluid in various directions, some of them diverging from the main flow direction [18, p.188, 606].

[8] "*something, usually a large quantity or heavy object, which is being carried*" www.collinsdictionary.com/us/dictionary/english/load.

This view is backed up by the literature from the domain, with plenty of descriptions of the fluid-sediment mixtures as entities composed of two components involved in complex interactions [26, 40, 27]. Moreover, Some passages explicitly suggest that a turbidity flow is delimited by a fluid-sediment system, 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.*" [28, p.267-268].

4.2. Erosion as an Auxiliary Event

The fluid-mixture system exists in an environment that includes a ***seabed***, which is connected to the fluid-sediment system by a ***shear contact*** relation. Domain literature reflects this view in various passages that characterize the seabed as an external element that modulates the evolution of the flowing system [26, 19, 22, 27, 20, 31, 41], especially by means of the *exchange* of sediment between the flowing mixture and the seabed via erosion and deposition processes [19, 33, 22, 20, 36, 32, 30].

Hence, we can regard erosion as *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.* Also, erosion can be seen as the manifestation of two reciprocal dispositions, namely, the ***erosivity*** of the flowing mixture, *i.e.,* its ability to cause erosion[9] [42, 26, 19, 43, 31, 35], and the ***erodibility*** of the seabed or of its constituting sediment, *i.e.,* its susceptibility, vulnerability, or proneness to erosion [19, 33, 17, 44, 45].

With that, we have all the elements to characterize erosion as a system-invariant event delimited by a system composed of a flowing fluid-sediment mixture, its suspended sediment load, a seabed, and the amount of sediment that is eroded. The bulk of its structure includes a *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.

Given this description, erosion genuinely qualifies as an auxiliary event in relation to a main turbidity current. First of all, it has a *counterfactual effect* on the turbidity current since, upon the occurrence of erosion, an amount of sediment is added to the suspended load of the turbulent fluid-sediment mixture. This consists of a variation in the volume of the carried load that could not be achieved only by the interaction of the participants of the turbidity current. Such an effect is enabled by the *subject-overlap* between erosion and its main turbidity current, which consists of their underlying systems sharing a common component, *i.e.,* the *suspended load*, and the whole turbulent fluid-sediment mixture system is also a component of the erosion system. Finally, there is a *causal link* between erosion and the variation in the volume of the suspended load. In particular, the variation happens through the manifestation of erosivity of the flowing mixture, which is manifested only when exposed to the complementary disposition of erodibility that inheres in the seabed, which participates in erosion but not in the current.

[9] www.collinsdictionary.com/dictionary/english/erosivity

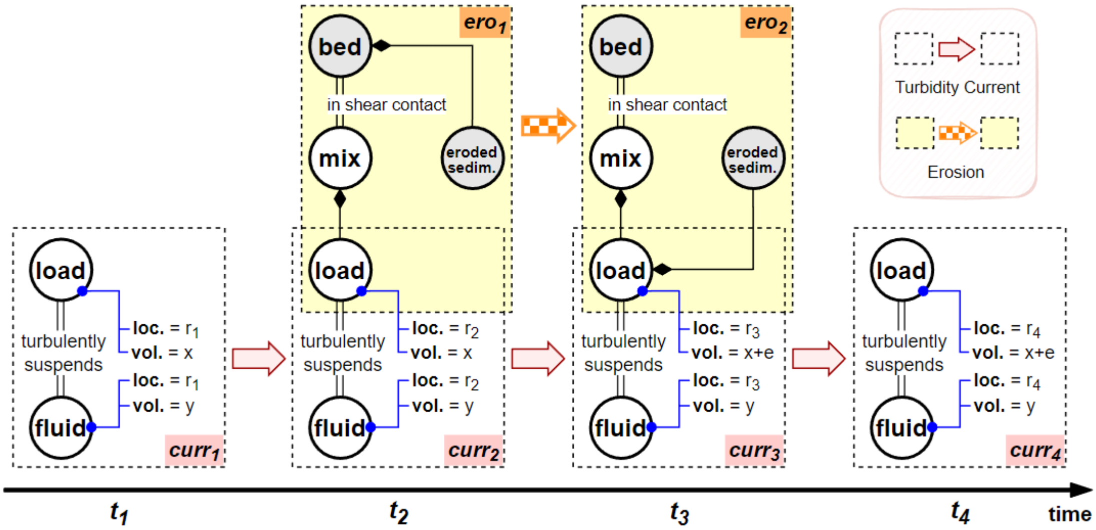

Figure 2: Overlap between Erosion and Turbidity Current (Source: the authors)

This view is also confirmed by domain literature. In the context of turbidity currents, erosion is regarded as an *associated process* through which seafloor topography influences flow behavior [27]. It is also considered equivalent to ***sediment entrainment***, *i.e.*, "*the process by which surface sediment is incorporated into a fluid flow*" [17, p.180]. In other words, erosion is not simply the entry of sediment into a fluid-sediment mixture but rather the *entry of sediment into an event of flow*. Also, erosion is said to *fuel* the current [33] by adding sediment to the suspended load, which increases the density of the flowing mixture and leads to its acceleration, contributing to increasing its erosivity [19, 33, 20, 43, 36, 24, 30], which tends to result in an increase in its travel distance [33].

Figure 2 brings a schematic representation of an erosion event as an auxiliary event of a turbidity current. The erosion is a transition through situations comprising a seabed *bed*, a flowing fluid-sediment mixture *mix*, its suspended sediment load *load*, and the eroded sediment *eroded sedim*, which loses the part-of relation with *bed* and acquires a part-of relation with *load*. The turbidity current involves the interstitial fluid *fluid* and the suspended sediment load *load* and consists of the change in their location *loc* over time (here, from region r_1 to region r_4). The effect of the erosion on the turbidity current consists of the change in the volume *vol* of *load* from its original value *x* to the increased value *x+e* such that *e* is the volume of the eroded sediment *eroded sedim*.

5. Concluding Remarks

This work presented an ontological analysis of how an event can affect the unfolding of another. It was based on the view that an event is a transition among situations that are snapshots of a single system of connected components so that the participants in the event at an instant *t* are the components of such a system at *t*. With that, we proposed the notion of *auxiliary event* as an event *aux* that operates over a portion of reality that overlaps with the one that is subject to another event *main*, and that, by transforming such a shared portion of reality, can affect influence the course of *main*.

A noteworthy point of our work is that it sheds light on a contextual facet of events. The notion of *auxiliary event* allows us to describe an influence network among events that is not possible to account for when relying only on the usual subsumption, mereological, temporal, or successively causal relations. With that, our approach may help in modeling types of events that interfere with another event in various ways, *e.g.,* causing the entry/exit of participants during its occurrence (*e.g.,* manufacturing processes, with different tools being employed in different stages and new components being added to the unfinished product) or qualitatively altering the participants of an event in a way that impacts its dynamic (*e.g.,* heating the oil inside a pipeline in other to increase the flow rate of an oil transport process).

Such an account of how the happening of an event can be molded by its surrounds seems to have a close relation with the ideas of *context* and of *event modifiers* discussed in [46]. In particular, the distinction between the system that delimits an event and the environment of this system may ground a criterion to delineate the border between an event and its external context. Likewise, the distinction between the properties of the components of a system that are part of such a system's structure and the properties that also inhere in such components, but are not in the structure of the system, may be related to the characterization of the internal context of an event delimited by such a system. In addition, our account of events that can affect other events along with the idea of events delimited by systems may provide further grounds for the notions of *countermeasure* and *countermeasure mechanisms* proposed in [47]. We intend to further investigate the links between our proposal and those works. Future work will also focus on specializing auxiliary events according to the type of effect they can have on other events and on deriving roles for the objects that participate in each of such types of events.

Finally, following our reflections in [48], this work is a step towards the development of the notion of roles for events. It is commonplace in applied ontology the idea that an entity may play roles in relation to other entities. Nevertheless, this view is usually constrained to continuants, with just a few works acknowledging the possibility of roles for events [46, 3]. Thus, this work points out that certain types of events 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. For example, an erosion, regarded as "sediment entrainment", essentially is an event in which a portion of sediment *sed* is removed from a seabed *bed* and incorporated into the suspended sediment component *load* of a fluid-sediment mixture *mix*. However, due to happening the special circumstance of *load* participant on an ongoing turbidity current, the erosion is not simply regarded as the addition of sediment to a mixture but rather as a sediment entrainment event through which a portion of sediment becomes subject to a turbidity current process and affects its unfolding from that point onwards.

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References

[1] N. Guarino, Formal Ontology and Information Systems, in: International Conference on Formal Ontology and Information Systems (FOIS'98), 1998, pp. 3–15.
[2] S. Borgo, L. Bozzato, A. P. Aprosio, M. Rospocher, L. Serafini, On coreferring text-extracted event descriptions with the aid of ontological reasoning, arXiv preprint arXiv:1612.00227 (2016).
[3] F. H. Rodrigues, M. Abel, What to consider about events: A survey on the ontology of occurrents, Applied Ontology 14 (2019) 343–378.
[4] F. H. Rodrigues, J. L. Carbonera, L. V. Vieira, L. F. Garcia, M. Abel, What delimits an event: systems as invariant elements along events, in: Proceedings of the XIV Seminar on Ontology Research in Brazil (ONTOBRAS 2021), CEUR-RS, 2021, pp. 218–230.
[5] R. Arp, B. Smith, A. D. Spear, Building Ontologies with Basic Formal Ontology, The MIT Press, 2015.
[6] S. Choi, M. Fara, Dispositions, in: The Stanford Encyclopedia of Philosophy, fall 2018 ed., Metaphysics Research Lab, Stanford University, 2018.
[7] A. Barton, L. Jansen, J.-F. Ethier, A taxonomy of disposition-parthood, in: Proceedings of the Joint Ontology Workshops 2017 Episode 3: The Tyrolean Autumn of Ontology (JOWO 2017), volume 2050, CEUR-WS, 2017.
[8] N. Guarino, G. Guizzardi, Relationships and events: Towards a general theory of reification and truthmaking, in: Conference of the Italian Association for Artificial Intelligence (AI*IA 2016), number 10037 in Advances in Artificial Intelligence, Springer International Publishing, Genova, Italy, 2016, pp. 237–249.
[9] G. Guizzardi, G. Wagner, R. de Almeida Falbo, R. Guizzardi, J. Almeida, Towards ontological foundations for the conceptual modeling of events, in: International Conf. on Conceptual Modeling (ER 2013), Springer, 2013, pp. 327–341.
[10] G. Guizzardi, G. Wagner, Dispositions and causal laws as the ontological foundation of transition rules in simulation models, in: 2013 Winter Simulations Conference (WSC), IEEE, Washington, DC, USA, 2013, pp. 1335–1346.
[11] J. Röhl, L. Jansen, Representing dispositions, Journal of Biomedical Semantics 2 (2011).
[12] M. A. Bunge, Treatise on Basic Philosophy: Ontology I: The Furniture of the World, volume 1, D. Reidel Publishing Company, Dordrecht, Holland, 1977.
[13] H. Herre, General Formal Ontology (GFO): A foundational ontology for conceptual modelling, Springer, Dordrecht, Netherlands, 2010, pp. 297–345.
[14] L. von Bertalanffy, General Systems Theory Foundations, Development, Applications (Revised Edition), George Braziller, New York, NY, 1968.
[15] M. A. Bunge, Treatise on Basic Philosophy: Ontology II: A World of Systems, volume 4, Reidel Publishing Company, Boston, MA, 1979.
[16] A. Botti Benevides, C. Masolo, States, events, and truth-makers, in: Proceedings of the 8th International Conference of Formal Ontology in Information Systems (FOIS 2014), IOS Press, Amsterdam, 2014, pp. 93–102.
[17] D. S. G. Thomas, The dictionary of physical geography, 4 ed., John Wiley & Sons Ltd, 2016.
[18] M. Allaby, A Dictionary of Geology and Earth Sciences (Oxford Quick Reference), 4 ed., Oxford University Press, 2013.

[19] C. J. Heerema, P. J. Talling, M. J. Cartigny, C. K. Paull, L. Bailey, S. M. Simmons, D. R. Parsons, M. A. Clare, R. Gwiazda, E. Lundsten, et al., What determines the downstream evolution of turbidity currents?, Earth and Planetary Science Letters 532 (2020) 1–11.

[20] E. Meiburg, B. Kneller, Turbidity currents and their deposits, Annual Review of Fluid Mechanics 42 (2010) 135–156. doi:10.1146/annurev-fluid-121108-145618.

[21] L. V. Lucchese, L. R. Monteiro, E. B. C. Schettini, J. H. Silvestrini, Direct numerical simulations of turbidity currents with evolutive deposit method, considering topography updates during the simulation, Computers & Geosciences 133 (2019) 1–9.

[22] R. Manica, Sediment Gravity Flows: Study Based on Experimental Simulations, IntechOpen, Rijeka, 2012. doi:10.5772/28794.

[23] T. McHargue, M. J. Pyrcz, M. D. Sullivan, J. Clark, A. Fildani, B. Romans, J. Covault, M. Levy, H. Posamentier, N. Drinkwater, Architecture of turbidite channel systems on the continental slope: patterns and predictions, Marine and petroleum geology 28 (2011) 728–743.

[24] B. Kneller, C. Buckee, The structure and fluid mechanics of turbidity currents: a review of some recent studies and their geological implications, Sedimentology 47 (2000) 62–94. doi:10.1046/j.1365-3091.2000.047s1062.x.

[25] H. D. Young, R. A. Freedman, University physics with modern physics, 14 ed., Pearson Education, London, England, 2015.

[26] M. G. Wells, R. M. Dorrell, Turbulence processes within turbidity currents, Annual Review of Fluid Mechanics 53 (2021) 59–83. doi:10.1146/annurev-fluid-010719-060309.

[27] J. A. Covault, Submarine fans and canyon-channel systems: A review of processes, products, and models, Nature Education Knowledge 3 (2011).

[28] P. Dasgupta, Sediment gravity flow—the conceptual problems, Earth-Science Reviews 62 (2003) 265–281. URL: www.sciencedirect.com/science/article/pii/S0012825202001605. doi:10.1016/S0012-8252(02)00160-5.

[29] G. Shanmugam, 50 years of the turbidite paradigm (1950s—1990s): deep-water processes and facies models—a critical perspective, Marine and petroleum Geology 17 (2000) 285–342.

[30] G. Parker, Y. Fukushima, H. M. Pantin, Self-accelerating turbidity currents, Journal of Fluid Mechanics 171 (1986) 145–181. doi:10.1017/S0022112086001404.

[31] J. D. Parsons, C. T. Friedrichs, P. A. Traykovski, D. Mohrig, J. Imran, J. P. Syvitski, G. Parker, P. Puig, J. L. Buttles, M. H. García, et al., The mechanics of marine sediment gravity flows, Continental margin sedimentation: from sediment transport to sequence stratigraphy 37 (2007) 275–334.

[32] H. Knoblauch, Overview of density flows and turbidity currents, Water Resources Research Laboratory, US Bureau of Reclamation: Denver, CO, USA (1999) 1–27.

[33] J. H. Baas, R. Manica, E. Puhl, A. L. de Oliveira Borges, Thresholds of intrabed flow and other interactions of turbidity currents with soft muddy substrates, Sedimentology 63 (2016) 2002–2036. doi:10.1111/sed.12292.

[34] Y. Fukushima, G. Parker, H. Pantin, Prediction of ignitive turbidity currents in scripps submarine canyon, Marine Geology 67 (1985) 55–81. doi:10.1016/0025-3227(85)90148-3.

[35] B. Kneller, The influence of flow parameters on turbidite slope channel architecture, Marine and Petroleum Geology 20 (2003) 901–910.

[36] C. D. Oehy, A. J. Schleiss, Control of turbidity currents in reservoirs by solid and permeable

obstacles, Journal of Hydraulic Engineering 133 (2007) 637–648.

[37] L. Strelich, Sediment transport capacity carries many meanings, Eos (Washington DC) 97 (2016). URL: https://eos.org/research-spotlights/sediment-transport-capacity-carries-many-meanings.

[38] J. Wainwright, A. J. Parsons, J. R. Cooper, P. Gao, J. A. Gillies, L. Mao, J. D. Orford, P. G. Knight, The concept of transport capacity in geomorphology, Reviews of Geophysics 53 (2015) 1155–1202. doi:10.1002/2014RG000474.

[39] T. Mulder, J. P. Syvitski, Turbidity currents generated at river mouths during exceptional discharges to the world oceans, The Journal of Geology 103 (1995) 285–299.

[40] S. Nomura, J. Hitomi, G. De Cesare, Y. Takeda, Y. Yamamoto, H. Sakaguchi, Sediment mass movement of a particle-laden turbidity current based on ultrasound velocity profiling and the distribution of sediment concentration, Geol. Soc. Spec. Publ. 477 (2019) 427–437.

[41] G. V. Middleton, Sediment deposition from turbidity currents, Annual Review of Earth and Planetary Sciences 21 (1993) 89–114. doi:10.1146/annurev.ea.21.050193.000513.

[42] J. H. Baas, R. Manica, E. Puhl, I. Verhagen, A. L. d. O. Borges, Processes and products of turbidity currents entering soft muddy substrates, Geology 42 (2014) 371–374. doi:10.1130/G35296.1.

[43] O. E. Sequeiros, H. Naruse, N. Endo, M. H. Garcia, G. Parker, Experimental study on self-accelerating turbidity currents, J. Geophys. Res. 114 (2009).

[44] D. Thomas, Aeolian paleoenvironments of desert landscapes, in: Treatise on Geomorphology, Academic Press, San Diego, 2013, pp. 356–374. doi:10.1016/B978-0-12-374739-6.00311-0.

[45] D. Hillel, Soil-water cycle, in: D. Hillel (Ed.), Soil in the Environment, Academic Press, San Diego, 2008, pp. 103–120. doi:10.1016/B978-0-12-348536-6.50013-7.

[46] N. Guarino, R. Baratella, G. Guizzardi, Events, their names, and their synchronic structure, Applied Ontology (preprint) (2022) 1–35.

[47] R. Baratella, M. Fumagalli, Í. Oliveira, G. Guizzardi, Understanding and modeling prevention, in: R. Guizzardi, J. Ralyté, X. Franch (Eds.), Research Challenges in Information Science, Springer International Publishing, Cham, 2022, pp. 389–405.

[48] F. H. Rodrigues, J. L. Carbonera, L. V. Vieira, M. Abel, "All the Things That Come and Go, Stop and Say Hello": Towards an ontological account of how participants enter and exit events, in: Conceptual Modeling: 41st International Conference, ER 2022, Hyderabad, India, October 17–20, 2022, Proceedings, Springer-Verlag, Berlin, Heidelberg, 2022, p. 102–112. doi:10.1007/978-3-031-17995-2_8.