ALTERNATIVE REALITY AND CAUSALITY IN VIRTUAL ENVIRONMENTS

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Abstract

Most of today's Virtual Reality (VR) research and technology pursues realism in order to enhance the user experience. This quest to faithfully replicate our physical world has led to complex simulation engines, and drifted away from the original intentions of VR to experience other realities. In this work, we revisit the “psychedelic” origins of VR and explore an alternative reality VR technology relying on experience-inducing principles. The starting point of this research was to facilitate the description of high-level behaviours for virtual worlds that would form part of interactive VR Art installations, simulating alternative realities. One of the major difficulties in developing such installations is to properly translate the artistic intentions into actual elements of interactivity, which in turn determine the user experience.

The attribution of causes to events, namely Causality, is an essential concept through which we construct our reality. Hence, our overall approach is to modify the causal principles underlying our understanding of reality, by creating non-realistic, yet believable, causal relations from objects’ interactions. Our underlying hypothesis relies on the concept of Event Causality, which stipulates that humans have a compelling tendency to attribute causality to physical events co-occurrences. We therefore posit that event co-occurrences departing from our everyday reality, but eliciting Causal Perception, will induce alternative realities. We term our approach: Alternative Causality, where the fundamental idea is to modify the course of actions to create alternative reality impressions in the user.

To investigate this hypothesis, we developed a VR system in which the normal laws of causality can be altered by substituting default effects of actions with new chain of events. Built on the top of a 3D game engine, our system relies on Artificial Intelligence (AI) techniques to generate alternative consequences of different levels of plausibility. The underlying idea is to use semantic representations for normal physical event co-occurrences, which are then modified by heuristic search using cognitive principles. Different user experimentations and artistic installations have demonstrated the viability and versatility of our approach to design virtual environments (VE) that suggest alternative realities.

This research introduces a new approach to interactivity in VR, oriented towards the elicitation of specific user impressions, based on AI techniques and cognitive principles. At a fundamental level, it indicated a positive correlation between Causal Perception and Presence in VR. At a more practical level, this work illustrated how AI-based VE opens novel perspectives to bridge the gap between design VR designer's intentions and user experience elicitations

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CHAPTER 1: INTRODUCTION

This research was originally driven by the creation of virtual reality (VR) experiences differing from our everyday experience, an approach we have termed alternative reality (Cavazza et al., 2003a). As much VR scientific research and technology concentrates on constructing realistic environments by developing accurate graphical, physical, and audio simulations, we will instead investigate the construction of alternative realities through cognitive aspects. This research has both fundamental and practical aspects, as it will explore the notion and role of realism in VR through the development of a novel kind of technology supporting artistic intentions.

In this chapter, we will first revisit the original intentions of VR, i.e. to experience alternative worlds, and we discuss the notion of "believable" reality instead of "realistic" reality. In a second part, we introduce an approach to create believable alternative worlds through the elicitation of causal impression between unusual events. The PhD thesis is constructed around this hypothesis of "*Alternative Causality*" and its evaluation though user experimentations and artistic applications. The last part of this chapter will expose in further details the thesis structure and methodology.

The "Psychedelic" Origins of Virtual Reality

Virtual Reality (VR) is concerned with the simulation of both immersive and interactive real-time 3D environments (Gutierrez et al., 2006; Sherman & Craig, 2003). In a certain sense, VR is mostly driven by software technology combined with human-machine interfaces both used to present multimodal information, and therefore "sense" the virtual world (Stanney & Zyda, 2002; Coates, 1992). However, beyond technical limitations, the immersive and interactive aspects of a VR application are above all relying on its user's imagination. Burdea and Coiffet (2003) qualified VR as an integrated trio of Interaction-Immersion-Imagination, where Imagination corresponds to the mind's capacity to perceive "non-existent" things, and so to "feel" inside an artificial world. Actually, the use of VR systems typically "transports" a user into an artificial world, by momentarily excluding him from his real physical surrounding and by making him perceive himself as active part of the virtual world (Heim, 2003). This sense of "*Being There*" is emblematic from VR and an essential characteristic of the so-called VR experience (Heeter, 1992; Riva et al., 2003). This notion is referred as "Presence" and it has been considered as a crucial property of VR since its conception (Sadowski & Stanney, 2002). In VR literature, the nature and factors of Presence have been widely debated. Yet researchers agreed to define it as moments during which a user fails to acknowledge the technology mediating the virtual word, and begins to consider the artificial environment as a real physical one.

The immersive aspect of VR has made it an ideal platform for a large range of fundamental and practical applications in domains such as Education & Training, Engineering, Entertaining, Art, Remote Collaboration, Cyber-psychology, Cognitive Science, Architecture and Industrial Design (for a detailed overview see Stone, 2002; Riva et al., 1998; Stanney, 2002). Consequently, VR development, whether scientific, industrial, or commercial, essentially followed the pursuit of realism. Conversely, at its origins VR experience was associated to "psychedelic" experiences emanating from an "imperfect" virtual world that reproduced different realities whose behaviours, appearances, and navigation mode depart from our everyday-life. At this time, VR was perceived as medium for *Reality Evasion,* a novel and powerful form of escape from our physical reality. Timothy Leary (Leary, 1993), a figure of the counter-culture movement, compared Virtual Reality to a psychedelic experience, namely the distortion of reality experienced under psychoactive substances such as LSD[1] (Noel, 2001). As a VR pioneer, Jaron Lanier was a strong opponent of the use of such metaphor (Lanier, 2000). Whatever his real motivations, he put forward a certain number of arguments to refute the psychedelic metaphor that can be summarised as follows:

- Virtual Reality affects the external world rather than the internal world of the subject
- The objectivity of the virtual world can be opposed to the subjectivity of the psychedelic experiment. The virtual world is an objective perception for all its visitors, while psychedelic experiences are in essence individual

Clearly, Lanier was arguing in favour of a strong separation between the subject and the "reality" he is evolving into, which constitutes an objectivist view in which one-reality substitutes for another one[2]. Yet, regardless of this controversy, the essential element, which also constitutes a solution to the virtual reality oxymoron, is that virtual environments do not have to be modelled on reality. Probably this is the true meaning of the psychedelic metaphor: that the emphasis is on distortions or reality, or even experiences that radically depart from our everyday reality. On the other hand, a significant part of the popular success of the concept of virtual reality, at a time where the actual performance of most VR systems was too modest to support a believable alternative to reality, can probably, in retrospect, be attributed to the psychedelic metaphor. Even though this controversy is now outdated, the psychedelic metaphor should still get credit for having first suggested that *"Virtuality needed not model reality*." For instance, there are a number of psychological considerations associated with the design and use of VE systems especially to enhance interaction (Stanney & Zyda, 2002). In that sense, there is a tradition in VR Art to construct alternative

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[1] For whom VR was populated by *delighted acid heads*.

[2] However, if one reintroduces an element of constructivist philosophy and considers the reality built as a product of experience, Lanier's objectivist stance is considerably weakened.

worlds, e.g. in, Davies' *Osmose*^{TM} environment or *Ephémère*^{TM} (Davies, 1995, 1998, 1999, 2003) (Figure 1), Louis Bec's artificial creature (Bec, 1991), or Maurice Benayoun's Quarxs™ (1994), invisible creatures that bend the rules of Physics (Figure 3). Virtual Reality Art is at the forefront of Digital Arts, as it explores at the same time visual aesthetics, the construction of alternative universes and user interactive experiences. To that extent, the notion of alternative reality still owes an intellectual debt to the "vision(s)" of Tim Leary.

Towards Alternative Reality

This research has been originally motivated by the conception of alternative realities in VR in the context of artistic developments through the ALTERNE[3] European project. The starting point of this research was to facilitate the description of high-level behaviours for virtual worlds that would form part of interactive VR Art installations simulating alternative realities. One of the major difficulties in developing such installations is to properly translate the artistic intentions into actual elements of interactivity, which in turn determine the user experience.

Consequently, the main objective of this research is to facilitate the creation of Virtual Worlds, whose behaviour departs from our common sense experience, enabling new kinds of virtual explorations through the development of "alternative realities." The overall context of our research is an "*Art+Science*" approach (Sommerer & Mignonneau, 1998) as VR Art provides an ideal context to revive these early ideas and explore them in the context of state-of-the-art technologies. One of the challenges is to improve the conceptual continuity between the creative stages and their technical implementation. Consequently, our Alternative Reality technology should support the creation of alternative realities from first principles, rather than by the ad hoc scripting of pre-defined effects. At the heart of our research lies the fundamental question of **what is Alternative Reality and subsequently, on what principles shall we simulate it.**

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[3] ALTERNE project (IST-38575-2002-2005) http://www.alterne.info

Figure 1: Forest Stream and Seed, from Ephémère, Char Davies, 1998. Left Image: Char Davies. *Forest Stream*, Ephémère (1998). Digital still captured in real-time through HMD during live performance of immersive virtual reality environment Ephémère. Right Image: Char Davies. *Seeds*, Ephémère (1998). Digital still captured in real-time through HMD during live performance of immersive virtual reality environment Ephémère

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Figure 2: The Spatio Striata quarxs (top picture) and The Spiro Thermophage (bottom picture) © Maurice Benayoun and Z-A Productions 1991-1993

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A Distortion of Reality

From the "Psychedelic" metaphors, Alternative Reality could be defined as the experience of a distorted although believable reality, emerging from virtual environments whose behaviours deviate from our usual experience of the real world. Therefore, the main intention of an Alternative Reality technology would be to create various kinds of experiences whose objectives might not be a deception, but suspension of disbelief. The preservation of the virtual world inner-consistency is essential and represents one challenge to the establishment of alternative behaviour simulation.

The distortion of reality is raising fundamental questions on its human conception, in particular at the philosophical and cognitive level. The ideological and cognitive determinants underlying our construction of reality are numerous and interrelated. However, Causality has been considered as one of the main phenomena through which we perceive our everyday reality. Causality, or the knowledge and recognition of causal relations, is particularly important in our understanding of the laws underlying our world. For instance, understanding causal relations between moving objects is essential for making sense of and interacting with the dynamic physical world.

The recognition of Cause-and-Effect structure from our environment is an essential aspect of our common sense understanding of the physical world and how we experience it. This could also be applied in virtual environments, where an essential part of interactivity in 3D graphics is concerned with the way users perceive the consequences of their actions, and make sense of object behaviours in the environment (O'Sullivan, 2005; O'Sullivan et al., 2003; Reitsma & O'Sullivan, 2008) (Ware et al., 1999). In a certain sense, Causality is filling the gap between interaction and interpretation.

Alternative Causality

This makes Causality an interesting focus of experimentation when designing virtual worlds whose behaviours should depart from our usual experience. Since, we could consider that Causality plays a major role in the user’s interpretation of the virtual world as it does in real world. In matter of what we could hypothesis that atypical causal relation would then suggest alternative reality. In sum, distortion of reality would result from the distortion of Causality. Thus, the elements of Alternative Reality could be identified as being: "*Modifications of the causal principles underpinning our understanding of the world."* In a virtual environment, this modification could reside in the manipulation of event co-occurrence, respectively perceived as cause and effect, in order to produce unexpected consequences. Therefore, the core of this research investigates techniques to program Alternative Causality in VR that would elicit causal impression from event consequences departing from their real-life counterpart.

Research in causality and its relation to realism in VR is of interest from both a basic research and applied perspectives. The questions addressed will be of relevance to cognitive psychologists, perception researchers, developmental psychologists, philosophers, computer scientists, and designers of interactive systems. On the more practical side, the results will have important implications for all VR developers, from immersive environments through to game programming. For these and other domains, it is essential to know the boundary conditions of causality perception, and what role realism and prior experience play in it. All interactive systems in which Causal Perception plays a role, from distributed simulation systems to computer games (including “serious games” and related educational software), could benefit for their design from the output of this research. A unified, synthesized framework of causality will increase our overall understanding of the concept of cause, and may influence work in philosophy, consciousness studies, and perhaps even the social sciences.

Positioning Alternative Causality as a central approach to an alternative reality technology is raising certain number of fundamental and practical questions.

- *On what basis do humans attribute a causal role to an event*?
- *Therefore, on what principles should we deform causality in a virtual environment?*
- *How can we measure the effective perception of causal relation from Alternative Causality?*
- *What kind of alternative reality could emerge from causality manipulation?*

All these questions will be answered in this thesis, in which we will describe the technical approach and experiments behind the creation of Alternative Causality in VE, and its implications at a fundamental level and applied perspectives. The structure of this thesis is presented in the following section.

Thesis Structure

Chapter 1: This introduction succinctly outlines the thesis motivation, objectives, approach, and structure. The first part contains a brief introduction to virtual reality (VR) and its associated alternative reality aspects. The second part describes how alternative causal simulation could support an alternative reality induction and conception.

Chapter 2: In this background chapter, we discuss epistemological aspects of the concept of causality that are relevant to the perception of reality. We begin by introducing a brief history of Causality in philosophy as well as a survey of the causation theory in cognitive science, from which, we isolate a particular cognitive phenomenon, Causal Perception, which could support our Alternative Causality approach. From there, we conclude on the key components of an Alternative Causality-inducing VR system.

Chapter 3: In this chapter, we describe the system developed to create alternative reality by eliciting causal links between abnormal events. We will introduce Artificial Intelligence (AI) techniques, and the visualisation engine, which will support the features of Alternative Causality. In particular, we will focus on AI techniques supporting the representation and manipulation of common sense causal knowledge. We give detailed specifications of the software architecture implementing these techniques within a game engine before finally concluding on the system performances.

Chapter 4: In this section, we expose psychological experimentations validating the capacity of our system to produce "plausible" Alternative Causality and so to induce novel experience. We evaluate the causal impressions experienced by users when facing artificial causal situations generated by the system.

Chapter 5: This chapter illustrates our system’s ability to author and simulate alternative virtual worlds in immersive VR Cave installation. Two VR Art installations represented the first practical applications of this research and technology. Here, we will describe two artistic briefs based on Alternative Causality technology, and relay the artists' impressions of it. They illustrate how controlling causality can underpin sophisticated behaviour generation and convey artistic intentions.

Chapter 6: This chapter describes further experimentations exploring potential correlation between a cognitive phenomenon, Causal Perception, and the well-known psychological state of Presence in virtual environment. The realism and control factors have been considered essential in many Presence theories. Therefore, we used our system to compare causal perception and Presence in environments where realistic physical behaviours have been replaced by alternative behaviours eliciting Causal Perception.

Chapter 7: The last part summarises thesis's findings, publications, and contributions to VR, AI, and Cognitive Sciences fields, while discussing future perspectives. The challenge of making causality one programmable parameter of the Virtual environment, represents an opportunity to explore interactivity and user experience in VR. Hence, we will examine the relevance and perspective of future Causal Perception studies and applications, as well as illustrating the potential of AI-based interactivity for storytelling applications.

CHAPTER 2: VR, ALTERNATIVE REALITY AND CAUSALITY

Introduction

In this chapter, we will first evidence the significant role of causality in Virtual Reality, notably by reviewing its implicit and explicit reference within Presence theories. On the other hand, the concept of causality embraces numerous notions, and the perception of cause has a long history of research in Cognitive Science. Consequently, in the second part, we will introduce a brief history of the concept of Causality in Philosophy, insisting on epistemological aspects that have an impact on the perception of reality.

Following the contemporary philosophical concept of causality, the third part considers the modern theory perception of Causality from a cognitive point of view, and focuses on a particular cognitive phenomenon appearing essential to our causality attribution mechanisms.

Finally, after reviewing related work in interactive systems, we will then conclude this chapter by formalising my central hypothesis supporting the notion of Alternative Causality, and its possible integration in a VR system.

An essential part of interactivity in 3D graphics is about users perceiving the consequences of their actions, as well as making sense of object behaviours in the environment. At the centre of a user's experience is the system’s response to his/her own interaction with virtual world objects (Straaten, 2000), which is mediated not only by the individual objects’ behaviour, but by the integrated response of the environment as a whole. From the user's perspective, such a response is largely interpreted by attributing causal relations between user actions and system responses. To a large extent, interactivity in virtual environments is deeply rooted in the recognition of causal action. There is ample illustration of this at theoretical level, in particular in the literature on Presence in Virtual Environments (see Zahorik & Jenison, 1998).

One simple illustration of this is the extent to which items of Presence questionnaires (such as the Witmer and Singer (1998) questionnaire) explicitly refer to action consequences with several items typically involving Causal Perception. For instance, Item #2 of their original questionnaire reads, “*How responsive was the environment to actions that you initiated?*” (See table below for further example). In the Control Factors proposed by Witmer and Singer (1994) many questions are implicitly referring to Causal Perception such as the immediacy of control understood as the immediacy of environment response to user-initiated action. Furthermore, their use of McGreevy’s argument (McGreevy, 1992) about “*continuities, connectedness, and coherence of the stimulus flow*” is also evocative of Causal Perception.

Although rarely referred to explicitly, there is significant evidence of the use of causality in Presence research, most specifically when considering those aspects of Presence dealing with action, agency, environment control, and the realism of the environment’s responses. From a fundamental perspective, this should not be entirely surprising, as causality is one of the few psychological phenomena bridging the gap between perception and high-level cognitive concepts (Scholl & Tremoulet, 2000).

One of the early works which introduced concepts related to Causal Perception was that of Loomis (1992) on distal attribution, although causality was not considered explicitly. Mantovani and Riva (1999) following Schloerb (1995) introduced the concept of *causal interaction* as an essential aspect of Presence. Finally, Zahorik and

Jenison (1998) in their in-depth discussion of the phenomenological conditions of Presence, advocated that a “lawful response” from the environment to our actions should be a major determinant of Presence.

In conclusion, across existing Presence conceptions and measurements, Causality is implicitly part of many of the factors thought to underlie Presence. Most of the time, it is expressed through Control or Realism Factors, where Control represents the user’s identification of his/her interaction as causal, and Realism is strongly linked to the satisfaction of the user expectation, which in turn is correlated to replication of real world physics.

On the other hand, Causality is a multifaceted concept largely discussed by philosophers, scientists, and engineers. The attribution of an event as the direct consequence of an action characterises the notion of Causality, and its importance in our everyday life. However, ranging from Aristotle to more recent cognitive scientists, Causality and its nature are still actively debated. The next section will briefly review different conceptions of causality in Philosophy and Cognitive Science focusing on relevant concepts for our research.

1. How responsive was the environment to actions that you initiated (or performed)?
2. How much did your experiences in the virtual environment seem consistent with your real-world experiences?
3. Were you able to anticipate what would happen next in response to the actions that you performed?
4. How much delay did you experience between your actions and expected outcomes?
5. How natural did your interactions with the environment seem?
6. How much were you able to control events?

Examples of Witmer & Singer Question referring to Causality

(Complete questionnaire available on http://presence-research.org/Questionnaire.html)

A Brief History of Causality:

Causality is a central concept in our understanding of the world. As such, it traverses physical sciences and philosophy. Causality is part of the apprehension of our everyday world as it is central to both its everyday understanding and its scientific analysis. There exists an abundant literature on causality in cognitive psychology, in Artificial Intelligence (Pearl, 1999, 2000), and is still an active topic in contemporary Philosophy (Galavotti, 2001; Price 2001). This contributes to making causality a complex concept, due to the intertwining of different notions all discussing the causality principles.

In a brief historical introduction, we will present the dominant conceptions of causality, focusing on those that are relevant to our research program. We discuss in particular epistemological aspects of the concept of causality that have an impact on the perception of reality. This should lead us to a characterisation of those philosophical aspects that can assist us in forming a conception of causality supporting Alternative Causality principles.

Causality as Reason

Aristotle (384-322 BC) identified four types of causes, which could explain any kind of change:

(1) The *material cause*: The substances of an entity define its behaviour.

(2) The *formal cause*: The idea preceding an action is the cause.

(3) The *efficient cause*: The physical event that makes changes to occur.

(4) The *final cause*: The final goal towards which the change aims.

Apart from the "efficient" cause, Aristotle mainly approaches causality as a reason for existence and evolution. His classification primarily focuses on "why" events happen, proposing four main categories of reason that emphasise the notion of intentionality to any world or entity transformation. Many centuries later, Galileo (1564 /1642), while introducing algebra as the new language of physics, was the first to withdraw from causal explanations in favour of empirical observations. His maxim "*description first, explanation second*" (in common terms, the "*how*" precedes the *"why*") changed the character of science from speculative to empirical (Pearl, 2000).

Causality as a Universal Principle

Through the middle ages, there has been a move in the conception of causality, which led to retain the *efficient cause* as the only support for intelligibility, whether in Physics or Metaphysics, and to eventually abandon the remaining Aristotelian causes related to essence and existence. This trend will culminate in Descartes' (1596-1650) conception of Causality, which became an axiom of Thought rather than a source of change. Causality as a rational principle can be enounced as two fundamental points:

- Every phenomenon has a cause.
- And to identical conditions, a cause produces an identical effect.

Apart from extending the notion of causes to abstract entities such as ideas, Descartes attempted to unify the notion of cause with that of reason: *causa sive ratio* (*" The reason of the Cause")* (Carraud, 2002).

Causality as Sufficient Explanation

"After Descartes, though, it is the notion of causality that will be subject to rationality, rather than the converse. Nihil est sine ratione ("nothing is without reason") becomes the substitute for nihil est sine causa. ("Nothing happens without a cause") (Carraud, 2002)

This is essentially the contribution of Leibniz (1646-1716), whose **sufficient reason** principle replaces Descartes' causality principle. The following could summarise this principle:

** For every event e, if e occurs, then there is a sufficient explanation why e occurs.*

To a certain extent, this principle implies that any entity behaviour finds its origin in an observable external cause or internal mechanisms. This influence will later resurface in 1772 the Diderot's *Encyclopedie (page 15:635)*: "*Une cause n'est bonne qu'autant qu'elle satisfait au principe de* "*raison suffisante*". (Translation: *"A cause is valid, if it satisfies the principle of Sufficient Reason"*).

The attribution of causality depends on multiple aspects, among which agency plays a central role. However, the spontaneous involvement, as opposed to the analytic observation, is also a relevant aspect. Humans have a compelling tendency to attribute causality to correlated events. This proneness was criticised by the scholastic expression "*Post Hoc, Ergo Propter Hoc" ("after this, therefore because of this"),* which stigmatised the frequent confusion between succession and causality.

Following this trend, David Hume (1711-1776), in his “treatise of human nature,” radicalised even further Galileo’s attitude by stating that causality was a production of the human mind and reality was limited to correlations. In this view, causal relations are inferred from our prior-experiences and knowledge. Causality would rely on high-level cognitive mechanisms capable of recognising regularity between past events and current ones. Therefore, the projection of our memories would allow us to anticipate an event's outcomes, and if the expected effects match the observed effects, then a causal relation is established between events *(i.e. the "changes" observed are interpreted as the direct results of the preceding event and only this event).* At the core of this theory, causal relations are mostly characterised by their "observed" regularities, which are said to reveal necessary event connexions. Causal connexions are then perceived as inevitable sequences of an event, which in turn are interpreted as manifestations of the underlying universal laws of nature. In the light of the above discussion, it can be said that for Hume, causality is the product of the imagination rather than the reason.

In response to Hume, Kant (1724-1804) proposed an approach to the attribution of cause compromising the empiricist and rationalist views. He conceptualised Causality as a "*synthetic a priori principle,"* speculating, in a certain sense, that our mind has a native understanding of what is a causal relation. In his theory, causal impressions would emanate from our brain’s tendency to project causality principles on observed phenomena (event co-occurrences), and retrieve some sort of causal event pattern or schema from them.

However, the extreme empiricism of Hume was an almost fatal blow to the status of causality that needed some two centuries to recover. The defiance towards causality is not restricted to empiricism, however. Bertrand Russell (1872-1970) had little sympathy for the concept of causality in science. He even considered causality as "*a relic of a bygone age, surviving, like the monarchy, only because it is erroneously supposed to do no harm*" (cited by Pearl (2000)). Nowadays, in a move he may have disliked, logicians research formalisms that could account for causal explanations (Pearl, 2000).

Causality as Action and Perception

However, even after Russell's anathema, causality was still discussed within Analytic Philosophy. Analytic philosophers such as Davidson Ramsey, became interested in distinguishing between causes and reasons, and reintroduced the human subject in the study of causality (Petit, 1991). This takes place, not surprisingly, through the reintroduction of intention in actions.

Another aspect, which is central to causality, is the implication of the agent in the world in which these events occur. Implication, which takes place at the origin of events as well as at the level of their interpretation. That causality should be considered from the agent's perspective is a contribution of Price, who claimed that we acquire the notion of causation through our experience as agents (Price, 1992). This view also supports the natural asymmetry of causation.

> *"Causes are potential means, on this view, and effects their potential ends. Causal asymmetry originates in our experience of doing one thing to achieve another; in the fact that in the circumstances in which this is possible, we cannot reverse the order of things, bringing about the second state of affairs in order to achieve the first (Price, 1992 p. 515)".*

Property and Event Causality

In 2001, Galavotti proposes to distinguish *"Property Causality"* from "Event Causality." Property Causality refers to causal relations established between properties, such as "smoking causes diseases" *(see Pearl, 2000; or Cheng, 1997; for authoritative reports on property causality).* While *"Event Causality,"* also named Token Causality, refers to causality between single events. Event causality corresponds to common sense causal interpretation in the physical world. It is best exemplified by work on Causal Perception, from the historical experiments of

Michotte (1963) to the phenomena studied in developmental psychology (Chaput & Cohen, 2001).

> *"Property causality has predictive power, but differs from predictability, since one can usually make predictions based on mere statistical correlations. On the contrary, single events are often unpredictable, and can only be explained after they occur." (Galavotti, 2001)*

Conclusion: from event reason, to anticipation, to perception

Through centuries, Causality has been synonym of universal reasons or natural law principles thus animating numerous philosophical and scientific debates on the determinism or not of our world. Yet, the so-called universal law of Causality, associating every event to a cause, as progressively evolved in recent century to be thought as a "form of a law."

> *"6.32 The law of causality is not a law but the form of a law.*
>
> *6.321 'Law of causality'--that is a general name. And just as in mechanics, for example, there are 'minimum-principles', such as the law of least action, so too in physics there are causal laws, laws of the causal form."*
>
> *(Wittgenstein, 1921, TLP 6.32 and 6.321, p 27)*

Wittgenstein (1889-1951) introduced Causality not as metaphysical concept but rather than a form of description supporting induction, which represents an essential aspect of human construction and understanding of our physical world. Nowadays, despite this troubled history, the concept of causality remains actively discussed in contemporary philosophy, by authors such as Suppes, Price, and Salmon. Sharing view with Wittgenstein's "causal descriptions," these recent philosophical contributions have emphasised the role of agency in causal attributions among events, discussing causality as relative to one's interaction and interpretation. Causality becomes then a reflection of the capacity of human intellect to predict or explain event consequences. Such subjective conception is not well suited to form a fundamental physical concept, although it plays an essential role in our understanding of and ability to manipulate the physical world. Although agency has been associated with both Property Causality and Event *Causality* (Price & Menzies, 1993), it is of particular importance in our context, as we wish elicit causal impression in interactive environment, where events are mostly initiated by the user.

Until recently, the *Humian* empiricist approach was the prominent thesis of Causality nature. For ages, the establishment of causal relation has been thought as causal anticipation emerging from our imagination and experiences. However, modern psychological studies revealed others sources of causal representation, which resuscitated the Causality nature debate. According to the father of Perceptual Causality, Albert Michotte (1963), we perceive causality rather than inferring it from prior-knowledge. From his study of collision events, Michotte highlighted mechanical phenomenon eliciting irresistible and instantaneous causal impression, which are, is a stark contrast with the traditional and popular empiricist view of Causality relying on causal induction. In this rationalist theory, Michotte subsumes that our visual system automatically retrieves causal structure from object interaction and motion. In a similar way, that our visual system recovers physical structure of our world (i.e. recognising object colour, shape, motion, distance, or voices, faces without thinking of it.

Since Michotte's studies in 1963, Causal Perception has been widely studied in cognitive science. The following section will describe in further detail this cognitive phenomenon and especially the psychological studies, which have brought out its determinants. We will also reflect the impact of this theory on contemporary perception and cognition research, as well as related its recent consideration in interactive system design. The final part of this chapter will discuss the relevance of Causal Perception (determinants) regarding our aim of generating of Alternative Causality and so subsequently "distort" reality in plausible and principled ways. In other words, in this section we will answer the question: *Could we exploit this causal impression generated by the human brain to produce alternative causal relation in VR?*

There exists a long history of research on the human perception of physical event. They refer to the ability of the human visual system to distinct events and extract high-level property from them (such as perceiving object physical properties from its motion trajectory after a collision). Humans seem to spontaneously interpret many cues when witnessing physical event co-occurrence such as an object collision (e.g. the cue pool ball hitting another one) and its immediate effects (e.g. projection of the stroke ball and the rebounds of the cue ball). Cognitive studies revealed high involvement of the human visual system in the: **(a) Attribution of physical properties**: automatically extracting inanimate objects physical properties from event observation (Nussek, 2007**) (b) Attribution of *animacy***: perceiving animate or self-moving objects from inert ones. (Scholl & Tremoulet, 2000; Gaur & Scassellati, 2006) **(c) Attribution of causal influences** of one object on another: perceiving causal relations between events (Michotte, 1963; Scholl & Nakayama 2002; Scholl & Tremoulet, 2000; Kadaba, 2007; Chaput, 2001)

In the context of this thesis, we are only interested in the latter one, causal influence attribution, and more specifically in its perceptual nature (i.e. not deriving from *a priori* knowledge). This section reviews recent research on Causal Perception, which began with the classic work of Michotte.

Many cognitive studies showed that in certain mechanical events, as when we see one object colliding with another, we could perceive not only motion, but also higher-level properties such as causal relation (Choi & Scholl, 2006b). Consider, the simple animation pictured by the Figure 3 below , an object A (in red) moves toward a stationary object B(in green) until they collide, at which point A stops and B starts moving along the same path. What is particularly remarkable is that such 'launches' animation are perceived in terms beyond kinematics as we irresistibly see A *causing* B's motion, rather than B autonomously moving" (Scholl, 2007). The importance of such phenomena stems partially from the fact that although it seems to be largely perceptual in nature, it yields impressions such as causality which are typically associated with higher-level cognitive processing. Such phenomena were first studied in the early 1900s by the experimental psychologist Albert Michotte (1881-1965). They later captured the attention of many psychologists since the publication of his book: *The Perception of Causality (1963)*. In this book, he extensively demonstrated and studied causal impressions using, in particular, a famous experiment known as the "*Launching effect*." The Figure 3 below illustrates a collision event, which gives rise to what Michotte called 'phenomenal causality' and what others have termed as Perceptual Causality. In sum, Perceptual Causality describes the direct perception of causal structure (Cause-and-Effect) from object interactions, rather than their inference from statistical observation of similar situation or real-world knowledge.

In the rest of this section, we will introduce and expose the determinants of Causal Perception discovered by Michotte, as well as recent contributions in cognitive science and psychology confirming the perceptual aspect of causal relations.

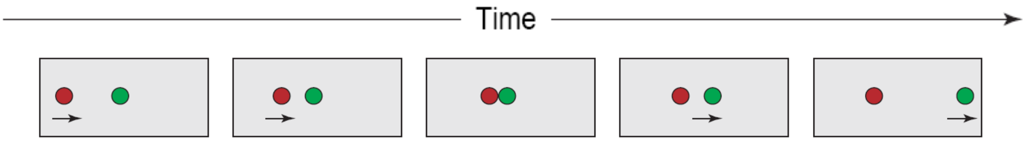


Figure 3: Example of Michotte's demonstration of Perceptual Causality: The "Launching Effect" (note one small object A (Red Sphere) moves until it is adjacent to another item B (Green Sphere), at which point A stops and B starts moving.) (Video: http://research.yale.edu/perception/causality/launching.mov)

After centuries of philosophical enquiry, Causal Perception received its first notable psychological investigation by Michotte (1963). He was the first to note that the apprehension of causality often appears perceptual in nature (i.e. certain physical events give rise to immediate impressions of causality), despite causality being generally considered a high-level property of the world (Scholl & Nakayama, 2002). In Michotte's theory, causality is attributed to co-occurring events from their spatio-temporal contiguity. The canonical example used by Michotte, consists of one pool ball striking another, thus "launching" the latter, which acquires autonomous motion (Figure 4 below).

Michotte presented adults with a scene in which one billiard ball struck another stationary ball, resulting in the launching of the stationary ball, and the halting of the moving ball. The subjects described this scene as a "causal" event reporting that the first ball "caused" the second ball to move. Michotte qualified such collision events rising strong causal impressions: the "*launching"* effect. Launching effect gives rise to what Michotte called 'phenomenal causality' and what others sometimes referred as 'the illusion of causality' (Gordon et al., 1990).

Figure 4: Causal Perception from co-occurring events

In order to analyse the determinant of causal impression, Michotte designed an experimental apparatus: the Disc and Projector methods (Michotte, 1963, p27, p34) replicating 2D animation of the typical pool "launching" effect in which pre/post collision kinematics properties could be manipulated. In these experiments, Michotte explored in particular the spatio-temporal conditions between the two events. (namely: the gap between the two balls and delay between the two motion events). Most Michotte's Causal Perception demonstrations were based on variations of the launching effect. The Figure 5(from Scholl & Tremoulet, 2000) below portrays some of the manipulations explored by Michotte, and the main effects he identified from the impression elicited by the animation on patient.

In conclusion, of his exhaustive experimentations Michotte noticed that by manipulating the collision event along spatial or temporal dimensions, he could affect a subjects' likeliness of perceiving causality. He observed that any deviation from zero gap and zero delay considerably reduce the perception of any causal relation among the subjects. Central to the attribution of a causal relation between the two events is the time interval separating them: Michotte (1963) reported that if the second event was delayed by more than 150 ms, 50% of subjects failed to recognise a causal relation between them. Michotte' s empirical studies evidenced that physical event co-occurrence is immediately perceived as a causal event if spatiotemporal contiguity between collision and motion event is preserved, as well as the overall event kinematics. In particular, "*Michotte (1963) argued that the essence of phenomenal causality is “ampliation” of movement, in which the motion of the first object is perceptually transferred to the second object*" (Kruschke & Fragassi, 1996). Within his theory of "ampliation," Michotte concluded that the perception of causality mostly derives from the property of our visual system to single out individual entity and retrieve continuous motion among them.

In sum, Michotte (1963) argued that the "illusion" of Causality is constructed by our visual system independently of any prior knowledge. His research has shown that the reporting of causal structure is highly sensitive to the spatial and temporal properties of the event co-occurrence. This is one groundbreaking aspect of his theory as it suggests that the recognition of causal relation is independent of learning and experiences as highly stimulus-driven. Such a revolutionary position on our perception of reality has initiated a large amount of research in cognitive science, developmental psychology, and neuroscience. As explained in the next section, most of these extensions to Michotte work consisted of discovering the spatiotemporal and contextual parameters that mediate or prevent causal percept, as well as discussing the inferential and perceptual components involved in causal impression.

Figure 5: Examples of some of Michotte's basic demonstration of perceptual Causality

(Figure reproduced with permission from Scholl & Tremoulet, 2000)

Note: objects A and B as red and green circles.

(a) **The *Launching* Effect**: wherein A is perceived as causing B's motion.
  a. **The *Launching* Effect** is destroyed by adding a temporal gap between A's and B's motions.
  b. **The *Launching* effect** is also destroyed by adding a spatial gap between A's final position and B's initial position.

(b) **The *Entraining* Effect**: wherein A seems to carry B along with it.

(c) **The *Triggering* Effect,** with a small temporal gap wherein B's motion seems autonomous, despite still be causing by A.

(d) **The *Tool* Effect**, where an intermediate item (grey circle) seems merely a tool by which A is perceive as causing the entire motion sequence

Michotte's work continues to inspire current research in perception and cognition. The scope, origins, explanation, and influence of Causal Perception are still on the research agenda in neurological, developmental, comparative research (Wagemans, Lier & Scholl, 2006). Most of these contemporary researches are legacy of Michotte's Causal Perception theory, which specifies that we irresistibly perceive causality between co-occurring mechanical events when they appear spatially and temporally contiguous (Michotte, 1963). The strong perceptual aspect of causal attribution - which appears to be fairly fast, automatic, irresistible and stimulus-driven (Scholl & Tremoulet, 2000) - evidenced the rationalist view of Michotte arguing the existence of strict rules used by the visual system to construct high-level percepts like Causation. Since Michotte, researchers have extended and refined the determinants of Causal Perception. This section briefly reviews these contemporary investigations.

(I) Causal Perception and its Kinematics Determinants: Many experimental studies have clearly confirmed Michotte’s claim that perceptual causality is a stimuli-based phenomenon. Most of the researches focus on temporal contiguity (see Schlottmann et al., 2006 for an overview). All this work essentially agrees that delays exceeding 60 ms between physical events can considerably reduce the causal impression. This is perhaps the most crucial result as Causal Perception seems to be largely stimulus driven, and small manipulations to the displays can cause the causal nature of the events to disappear.

Schlottmann et al. (2006) argued that other relevant kinematic factors have been studied: i) spatial contiguity, ii) object's velocities and direction, iv) and the radius of action. However, these factors have not been clearly confirmed by further studies. Yet, it has been agreed that to elicit Causal Perception, the overall object's motion have to be perceived “natural” in respect of the line of action (Twardy, 2002). In addition, the object motion before the collision has to be less than 110 cm/sec to avoid the "tunnel" Effect (Kawachi & Gyoba, 2006). Moreover, in recent a study reproducing “launching” effect experiments, Fugelsang (2005a) confirmed the strong status of spatiotemporal factors. Movies containing temporal (170 ms) or spatial gaps (1.2 cm) respectively elicited causal impression only on 4.2 % and 10.4 % of the trials (see Figure 6 below). Such temporal and spatial settings successfully eliminated the impression of causality.

Conversely, other movies representing strict “Causal Event” elicited an extremely high rate of causal impression (95.8 %).

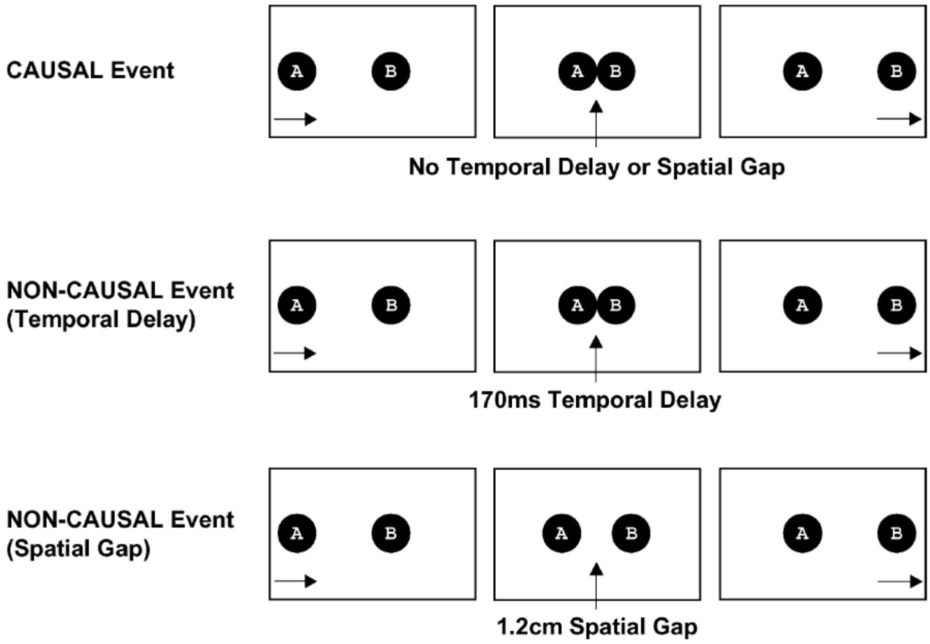


Figure 6: Graphical Illustration of causal, temporal delay and spatial gap *movies*

Notes: Figure reproduced with permission from Fugelsang (2005a) experiments

(II) Causal Perception and Attention: recent contributions argued that the level of attention considerably influences Causal Perception (Choi & Scholl, 2004) (Scholl & Tremoulet, 2000). This work demonstrated that perceptual grouping and attention could both influence the perception of causality in ambiguous displays. They demonstrated that Causal Perception could be strengthened or attenuated based on whether observers are attending or not the event.

(III) Causal Perception and Contextual information: Recent research has also revealed that the nature of the percept arising from a launching stimulus is highly sensitive to subtle variations in the context (Scholl & Nakayama 2002, 2004). They concluded that *"the perception of causality does not proceed completely independently of other visual processes, but can affect the perception of other spatial properties*" (Scholl & Nakayama, 2004). Surprisingly, when a non-Causal Event is surrounded by causal event, it is perceived as Causal in 80% of the case.

In the presence of a distinct nearby launch event an overlapping collisions (one shape remains stationary while another passes over) which are typically seen a completely non-causal are irresistibly perceived as causal event (Scholl & Nakayama, 2002). Choi & Scholl (2006a) presented results demonstrating that postdictive processes can also influence Causal Perception as additional information so obtained can influence the immediate past in our conscious awareness, and so our Causal Perception.

(IV) Scope of Causal Perception: White and Milne (2006, 1997, and 1999) have extended the catalogue of qualitative effects triggering strong causal impressions. Their research suggested that Causal Perception is not restricted to strict "launching" events type. They particularly identified three patterns producing causal impression :

(a) Pulling,
(b) Enforced disintegration and
(c) Busting (see Figure 7 below).

White and Milne explored the effect of several variables on these percepts and demonstrated that they are strictly associated with pre/post-collision velocity pattern.

In addition to physical causality, Schlottmann et al. (2006) also denoted the perception of social causality from minimal motion events. Such observations corroborate the perceived *animacy* from mechanical interactions evidenced by School & Tremoulet (2000). The social interpretation of single causal interaction has also been emphasised by Saxe and Carey (2006) who described the importance of the "agentive" and "receptive" role given by infants in their interpretation of an ambiguous event as causal or not.

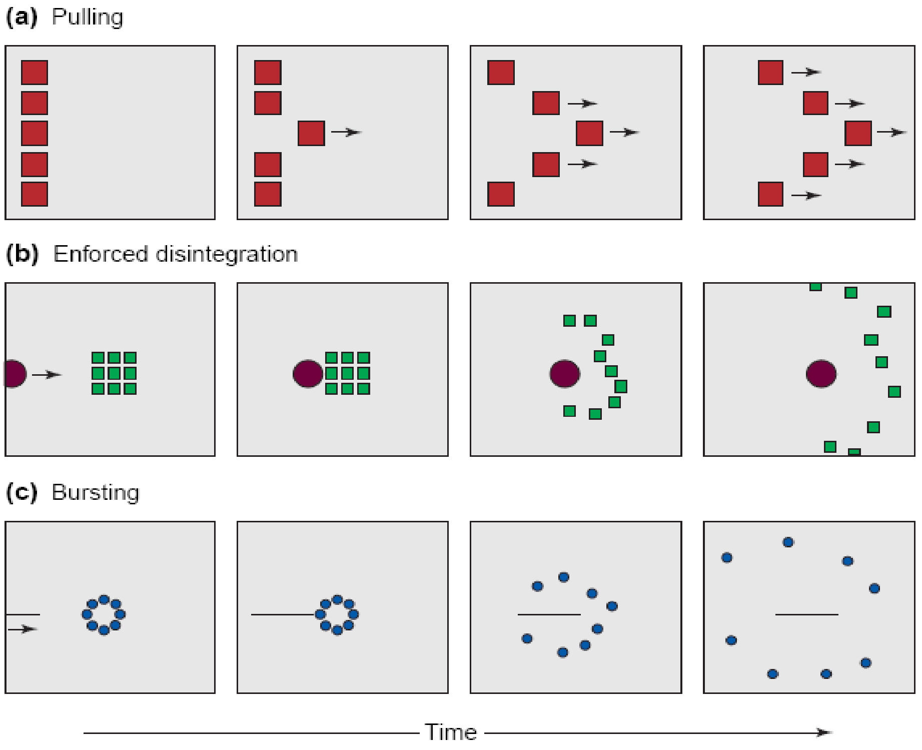


Figure 7: Displays used by White and Milne to extend Michotte’s catalogue of functional Relations

Notes: Figure reproduced with permission from (Scholl & Tremoulet, 2000)

(V) Origin of Causal Perception: At first, a predominant trend of cognitive scientists defined Causal Perception as an innate mechanism part of our genetic endowment. Leslie (1982; Leslie & Keeble, 1987) and Scholttmann (2002) provided evidence that six-month old infants can distinguish causal from non-causal events. However, in a more recent review of infant causal representation, Saxe and Carey (2006) provided evidences that launching and entraining event are interpreted causally by young event: *"Preverbal infants can represent the causal structure of events, including distinguishing the agentive and receptive roles and categorizing entities according to stable causal dispositions"* (Saxe, 2007). However, they failed in evidencing the innateness of these representations. So far, developmental studies failed to solve the innateness debate. Kruschke (2006) suggested that it might be that *ampliation* develops rapidly in response to the visual world. Furthermore, he added that *ampliation* is used as a perceptual cue for subsequent causal interpretation, and so the induction and perception are correlated (Kruschke & Fragassi, 2006).

(VI) Specificity of Causal Perception: In 2000, Scholl and Tremoulet claimed that perceptual causality is modular, in the sense of a mechanism independent of higher cognitive process such as induction. In line with this, Anne Schlottmann and her colleagues have also directly contrasted Causal Perception and causal inference (Schlottmann & Shanks, 1992; Schlottmann, 1999, 2000). Using fMRI, Fugelsang et al (2005a, 2005b) proved that the visual system extracts causality from dynamic visual information using spatial and temporal cues. In other neurological studies, Rosser (2005) demonstrated that understanding causality involves multiple processes in our brain, and provided support for the existence of dissociable perceptual and inferential components. Causal structures determination from rapid dynamic events appeared to be a process localised in the right hemisphere of the brain. Meanwhile, the left hemisphere would infer causality from patterns of co variation between events, which allows the determination of causality in more complex situation. These results imply that the direct perception of causality and the ability to infer causality depend on different hemispheres. Fugelsang's experimentations in 2006 also concluded for *"a multidimensional account of causal knowledge whereby people's representations of causation include, but are not limited to, the "covariation, familiarity, and imageability of cause and effect relationships"* (Fugelsang & Thompson, 2006).

Saxe & Carey (2007), sharing Michotte's rationalist view, reached a similar conclusion by claiming that our representation of "cause" integrates three sources of evidence:

(a) **Contingency** (i.e. Co-variation-based)
(b) **Causal Perception** (i.e. Direct perception of mechanical Causality)
(c) and **Agency** (i.e. sense of one's own causal effort and efficacy in the world).

(VII) Measuring of Causal Perception: In the vast majority of the studies, the report and rating of Causal Perception has been proven difficult. This is mostly due to the complexity to distinguish percepts and higher-level cognitive inference in post-experience reports (Wolff, 2003; Choi & Scholl, 2006). Consequently, researchers attempted to identified implicit measures of the phenomenon among which we could cite: i) **Representational Momentum** (Hubbard et al., 2001, 2004), (Hubbard & Ruppel, 2002; Hubbard & Favretto, 2003); ii) **Priming** (Kruschke & Fragassi, 1996); iii) **Spatial illusion** (Scholl & Nakayama, 2004); iv)

Neural signature (Fugelsang et al., 2005a, 2005b, 2006). Yet, in spite of evidence of these methods efficiency to detect Causal Perception, there is still a great need for more precise and practical implicit measures. Nowadays, the predominant method to use measure Causal Perception consists in analysing textual descriptions of event in order to recognize causal expressions. Such method has been popularised by Wolff and his colleagues who exposed model and classification of causal verbs and expression (Wolff, 2003, 2007; Wolff & Zettergren, 2002; Wolff & Song, 2003a, 2003b).

(VIII) Explanation of Causal Perception: In Philosophy, Causal Perception is generally referred as Transference Theories of Causation (cf. Dowe, 2000). More specifically, these theories specify that causation imply transfer of some sort of energy or momentum from one object to another. The "Schema Matching" and "Feature transfer" are the main theories derived from Transference theory:

- **The “Schema Matching” Theory:** This theory claims that our visual system is endowed with a schema matching algorithm that matches perceptual experiences with representations of past experiences, which the organism has learnt to identify as causal. As previously explained, White extended the number of kinematic patterns inducing causal impression (White, 2006). According to this account, an abstract stimulus such as a square moving towards a thick line, breaking into smaller pieces upon impact with it, and dispersing away from the line (cf. White & Milne, 1999), would trigger a schema for “smashing.” This suggestion appears to suffer from circularity as to identify an interaction as causal; the system needs to match it with a previously stored causal situation. White’s solution is to propose that the origins of Causal Perception lie in haptic experiences of the organism, which are then extended and widened to create schemas for perceptual experiences outside the haptic domain.

- **“Feature Transfer” Theory:** A non-circular alternative to schema matching has been suggested by Kruschke and Fragassi (1996), who argued that Michotte’s (1946/1963) motion ampliation can be seen as an example of feature transfer. According to this theory, the momentum of

> the causal object is a perceptual feature; at impact with the effect object, this feature is transferred from the causal object to the effect object, which subsequently "acquires" the momentum.

The explanation of Causal Perception is still at the centre of much research in cognitive science. One advantage of feature transfer over schema matching is that it offers a direct perceptual basis for phenomenal causality, which can occur bottom-up, without accessing any previous knowledge. Note that the Transference Theory goes beyond Michotte's original concept of *ampliation*, in that energy can be transferred in ways other than simply transferring momentum. Nevertheless, if feature transfer is the perceptual basis of phenomenal causality, than transfer of features other than motion should likewise result in causal impressions. However, one problem with Transference Theory is that it suggests that our perceptual system "knows" that energy has been transferred, although it is no more equipped to sense energy transfer than it is to causality.

(IX) Causal Perception and Causal Induction: The question of whether human observers perceive or infer causality has a long history (see Scholl & Tremoulet, 2000; Sperber et al., 1995; Premack, 1990; Premack & Premack, 1994). The perception of "Cause" has been debated between Rationalists and Empiricists; this debate mainly lies in the difference between Causal Perception and Causal Induction. Causal Perception is in stark contrast to Causal induction, in that it appears to be spontaneous, irresistible, and not dependent on multiple trials. One of Hume's *(1739/1986)* premises for causal induction is the "constant conjunction" of the events in question; in other words, only if one is exposed to multiple cause-effect sequences will one form a mental causal link between them. Hume's view that causality is not perceived, but is inferred on the basis of spatial and temporal contiguit*y*, has been widely accepted. There are various psychological theories about how such causal *learning* takes place (see Cheng, 1997; or Buehner & Cheng, 2005; for an overview).

However, Michotte (1946/1963) suggested that physical causality is mostly perceived and not inferred. Yet, individual differences in his studies of perceptual causality suggested an inferential aspect, maybe reflecting the individual differences in knowledge of collision. This argument strongly affected the phenomenal aspect of causality (Joynson, 1971) or subsumed it under causal inference (Weir, 1978; White, 1995). However, it is now widely accepted that such data suggested a more complex relationship between process and phenomenology (Schlottman, 2000).

The distinction between perceptual causality and causal judgment or induction has been investigated by Schlottmann and Shanks (1992), who found an interesting dissociation: Judgment and perception can reach opposite conclusions, with participants *expecting* an effect (thus knowing that the cause will produce it), yet reporting that the interaction looked non-causal due to a spatial or temporal gap. This need not mean that causal induction and Causal Perception are two entirely independent processes. Cheng (1995), for instance, provided an inductive analysis of Michotteian perceptual causality. Recent work by Scholl and Nakayama (2002) likewise suggests that the perceptual system, despite its immediate recognition of causal stimuli, incorporates an inductive component.

Synthesis

The survey of Causal Perception confirmed that Human subjects have a strong propensity to perceive causality from co-occurring visual events. Researchers have identified five “key” cues used by humans to determine if an action and an effect are causally related (Fugelsang, 2006):

i) **Co-variation** (Cheng, 1993,1997; Glymour, 2001; Novick & Cheng, 2004; White, 1992; Spellman, 1996);
ii) **Temporal order** (Tversky & Kahneman, 1980; Siegler & Liebert, 1974);
iii) **Mechanism information** (Ahn et al., 1995;; White, 1989,1995) ;
iv) **Similarity between Cause and Effect** (Tversky, 1977; Shultz & Ravinsky, 1977)
v) **Contiguity in time and space** (Michotte, 1963; Fugelsang, 2005a, 2005b).

Among these cues, the last one, spatial and temporal event contiguity, has been extensively studied by Michotte and his successors. The perception of causality from collision events has been qualified by Scholl and Nakayama (2002) as “*phenomenologically instantaneous, automatic and largely irresistible*”. Numerous experimental settings confirmed the impact of spatiotemporal factor on our attribution of causal influence. Most research now agrees that our understanding of causality depends on both perceptual and inferential components. Perceptual causality has been qualified as one of the main source of Human's causal representation (Saxe, 2007), with a large impact on our understanding of world dynamics. There is little doubt that we understand the dynamics of our physical world through the recognition of causal relations from object collisions (Roser et al., 2005).

In addition, it has been agreed that Causal Perception is a cross-cultural phenomenon appearing early in child developmental process (Scholl, 2006; Morris & Peng, 1994 ; Peng & Knowles, 2003; Leslie & Keeble, 1982,1987; Saxe, 2007; Scholl & Nakayama, 2002; Choi et al., 1999). The rationalist and empiricist discussions and debates about its innateness and origins prove irrelevant as much experimentation confirmed its perceptual aspect (Scholl & Tremoulet, 2000) and its importance on our establishment of causal influences.

In conclusion, many psychological and neuroscience contributions demonstrated that Causal Perception plays a major role in the user’s physical interpretation of the world. For all these reasons, Causal Perception is considered as one of the main phenomena through which we perceive our everyday reality. It appears as a central mechanism to our induction of causal relationship, especially from single event observation. This makes Causal Perception an interesting focus of experimentation when designing virtual worlds departing from our everyday life.

Yet, while many psychological phenomena have been studied in their relation to Virtual Reality (VR), very little work has been dedicated specifically to Causal Perception (despite its strong influence on human interaction). Only recently, Causal Perception has become a research topic for a variety of graphic interface systems, as an understanding of Causal Perception has implications to develop better visualisation systems (Ware et al., 1999) and animation systems (O'Sullivan & Dingliana, 2001; O'Sullivan, 2005; O'Sullivan et al., 2003; Reitsma & O'Sullivan, 2008).

In the field of computer graphics, most research examined perceptual thresholds to simulate plausible goal-directed animations while reducing their computational complexity (O'Sullivan & Dingliana, 2001; Barzel et al., 1996; Chenney & Forsyth, 2000; Popovi´c et al., 2000; Twigg & James, 2007). There has been little specific work on users' Causal Perception, with the notable exception of research by O'Sullivan and Dingliana (2001), who have worked on the relation between Causal Perception and collision rendering. O'Sullivan & Dingliana's psychological experiments (2001; 2003) demonstrated that believable real-time physics simulation should imperatively preserve user's causality perception (Figure 8). They argued that such system should therefore implement collision-handling process interruption beyond a 100ms-300ms delay after collision. These data are corroborating those of Michotte's early experimental studies, and evidenced the potential of perceptually-adaptive simulation for interactive system.

In recent research, O'Sullivan (2005) added that the degree of attention (Scholl & Nakayama, 2002) as well as the nature of the dynamic event also play role in its believability. Reitsma & O'Sullivan (2008) compared perceptual sensitivity in physical simulations in realistic and abstract settings. In both type of environment, participants are predominantly affected by spatiotemporal errors in rigid body collisions. Spatial gap and delay considerably reduced the animations perceived plausibility. To a certain extent, their results in 3D realistic environment corroborate Michotte's observation in 2D symbolic display.

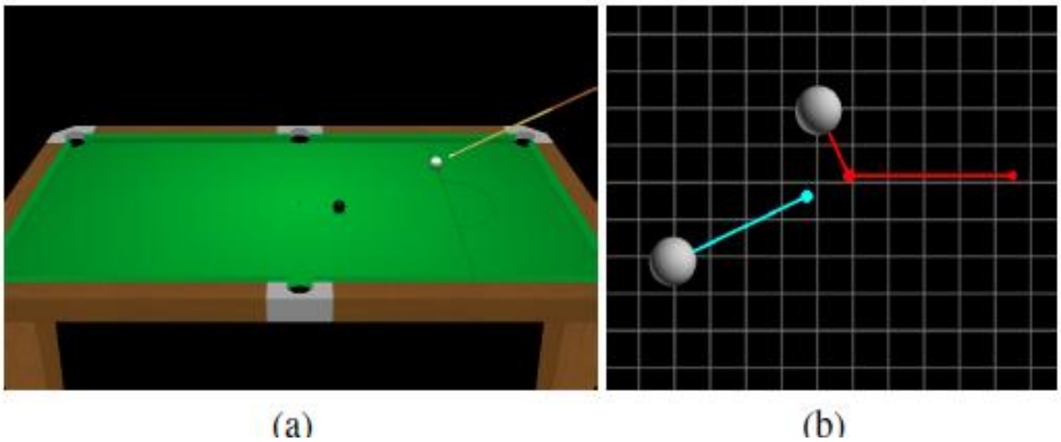


Figure 8: Example of Causal Perception experiments

Notes: Figure reproduced with permission from (O'Sulivan, 2005) (Reitsma & O'Sullivan, 2008)

In the field of cognitive psychology Causal Perception studies have been carried out using simplified and non interactive 2D display (Scholl, 2007) (Fugelsang et al., 2005; Roser et al., 2005; Scholl, 2007; Leslie & Keeble, 1987; Oakes & Cohen, 1990; Choi & Scholl, 2006b). One notable exception has been the research of Wolff, which has made extensive use of 3D animations to elicit Causal Perception in subjects watching them (Wolff & Zettegren, 2002; Wolff, 2003, 2007). Mostly, in order to analyse causal vocabulary. However, these animations were non interactive, which means that their contents had to be entirely scripted in advance, and did not investigate Causal Perception in response to event initiated by the user.

In conclusion, it appears that Causal Perception has never been properly experimented in proper interactive 3D worlds. Yet, previous researches using 3D animation tend to suggest that Causal Perception also depends on spatiotemporal contiguity between events in realistic settings.

One of the principal objectives of this work consists in creating alternative (virtual) reality from first principles. Here, the notion of alternative has to be understood as "distortion" of reality, in which we emphasise the impression of plausible alternative realities rather than inconsistent ones. Causality is a crucial concept from which we understand our reality; therefore, in the introduction of this thesis, we posit that one way of creating alternative realities would be by distorting causality. Producing unexpected causal relations should induce a certain sense of novelty while preserving consistency between events occurring with the virtual world.

The survey of causality conceptions revealed that causal attribution between physical events has both perceptual and higher cognitive aspects. However, for many cognitive scientists, physical causality appears to be automatically attributed by humans on an event co-occurrence basis independently of prior knowledge. This perceptual aspect of causality attribution refers to the irresistible causal impression appearing when a collision and a motion event appear contiguous in time and space, even from single observation. The fact that this phenomenon of Causal Perception does not rely on multiple trials, and mostly depends on kinematic patterns, is extremely relevant to our ambition of maintaining causal impressions from atypical consequences. Furthermore, a considerable amount of cognitive research has finally established the principal determinants of Causal Perception and their limits in 2D or 3D displays settings. Consequently, the generation of abnormal consequences from object collision in VR should theoretically induce causal impressions. Obviously, these alternative event co-occurrences should respect the spatial and temporal determinants of Causal Perception. We can now refine the notion of Alternative Causality to the elicitation of Causal Perception from alternative collision event consequence.

Through our conception of Alternative Causality, a VR user could therefore experience novel physical behaviour that would yet - paradoxically -yield causal impressions just as much as familiar experiences would. This hypothesis is close to the notion of *"Causal illusion"* (Wolff, 2007) referring to kinematic patterns that imply forces that are not really there. This is explicitly referring to the Michotte’s *launching effect* and its capacity to elicit strong causal impression from a simple 2D symbolic display. In the context of this research, which is that of alternative reality, this powerful cognitive mechanism can be used to create various kinds of experiences, whose objective might not be the deception but the suspension of disbelief.

We previously defined Alternative Causality as the generation of artificial physical event co-occurrence. We assumed that such alternative co-occurrences would be perceived as causally related, providing the fact they elicit Causal Perception. In theory, the respect of the Causal Perception’s spatiotemporal determinants in between physical events should induce causal impression to the user.

Consequently, the elicitation of Causal Perception would be a key aspect of Alternative Causality. Another aspect we need to investigate is the notion of "alternative," and more particularly the principles and mechanisms to generate uncommon event consequences. One sensible way of producing abnormal causal behaviour could consist in "distorting" normal ones. In other words, Alternative Causality would derive from ordinary causality, which will be altered according to a certain degree of distortion. Regarding our intentions of alternative reality creation, causality distortion could be based on the "realness" of the causal relations suggested. For instance, the modification mechanisms should provide different causality amplitude disruptions, targeting different level of realness going from realistic to unrealistic causal relation. Consequently, this approach would necessitate, first to represent normal causality, and then to define principles and mechanisms implementing such level of distortion.

From these principles, we can formulate the main requirements of our Alternative Causality-inducing system:

- The system should respond to object interactions by generating effects, which depart from the common sense experience of physical events.

- These modifications should still be determined by cognitive considerations and causality disruption principles, hence ensuring believable, albeit non-standard, co-occurrences (eliciting Causal Perception).

There are fundamental and practical concerns arising from such requirements. The next chapter will present the technical implementation behind our Alternative Causality-inducing system.

Conclusion

In this chapter, we discussed epistemological aspects of the concept of causality that are relevant to the perception of reality. We first introduced a brief history of Causality in philosophy as well as a survey of causation theory in cognitive science. From which, we isolated a particular cognitive phenomenon, Causal Perception, which could support our Alternative Causality approach.

One essential aspect of this phenomenon concerning our objective lies in its highly stimuli-driven aspect, as it seems to be determined by spatial and temporal relations between physical events. In matter of what we hypothesised that any alternative physical event-concurrence respecting spatial and temporal contiguity criteria will elicit Causal Perception and so induce novel experience to the user.

Following our hypothesis, we established the requirements of such Alternative Causality system. Now, considering them, the next chapter will present the technical approach behind the elicitation of causal impression through abnormal event consequences in VR, based on cognitive data and action semantic considerations.

CHAPTER 3: A TECHNICAL APPROACH TO ALTERNATIVE CAUSALITY

Introduction

In chapter 2, we established the principles and features of an alternative-causality inducing VR system. We mentioned two important aspects of such systems: the alteration of real physical causality and the elicitation of Causal Perception from alternative events co-occurrence.

Such Alternative Causality principles fundamentally imply a representation of normal physical causality, and mechanisms to modify it, while preserving Causal Perception determinants. One critical aspect of the system is to formulate generic “rules” for bending causality instead of explicitly specifying novel causal laws. The integration of such rules into a 3D visualisation engine also raises important issues.

In this chapter, we present solutions to simulate such artificial causality in VE. We first discuss design constraints and technical approaches to solve them. Then, we describe the implementation of the system and illustrate its behaviour through examples. The last part will discuss system technical performances regarding our design constraints.

Objectives

The starting point of this research was to facilitate the description of high-level behaviours for virtual worlds that would form part of interactive VR Art installations representing alternative realities. One of the major difficulties in developing such installations is to properly translate the artistic intentions (here: alternative realities) into actual elements of interactivity, which in turn determine the user experience. Our underlying hypothesis has been that alternative (physical) causality, generated from disruption principles, will both suggest alternative realities and provide high-level mechanisms to program interactivity towards different degrees of realism. The fundamental idea is to modify the course of actions to create specific impressions in the user.

Therefore, the overall purpose of the system is to induce alternative realities by producing alternative causal relations of various plausibility levels. In essence, the system should support virtual worlds in which the normal laws of causality can be altered by substituting default effects of actions with new chain of events. In the next section, we will present an approach to modify the course of action in virtual environment based on such requirements. In the following sections, we will first describe the underlying approach behind the systems and overall architecture. In a second part, we will describe related works

Event-based Alternative Causality

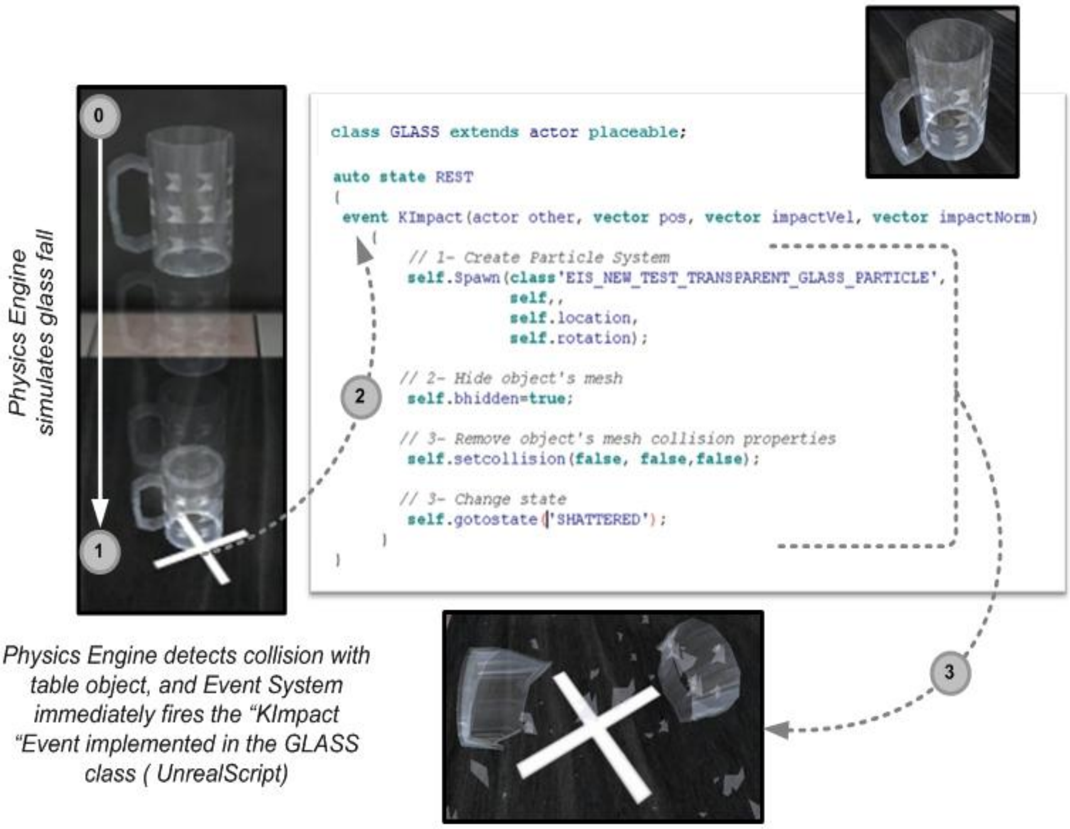
Our overall approach to create Alternative Causality is to exploit the strong tendency of humans to perceive co-occurring events as causally linked. In essence, the system should elicit Causal Perception from event co-occurrence departing from our everyday-life, and generated from an alteration of real world causality. Our overall technical approach to simulate such Alternative Causality is based on VR event systems, high-level representation and AI search techniques.

In few words, the whole approach relies on the recognition of high-level actions from low-level physical events, to generate semantic representations of the virtual world's events as they occur. In other words, from a low-level set of events such as collisions and contacts between objects the system recognises high-level actions affecting world objects, such as “pushing”, “breaking”, “tilting”, etc., which correspond to those actions potentially observed by the user. These actions are represented in the system using a formalism that makes their consequences explicit. A real-time modification of this representation will thus alter an action’s default consequences, thereby affecting the user experience and sense of reality in the virtual environment

The rationale for using an explicit representation for actions is that it supports action modification on a principled basis. Rather than directly associating effects to specific actions, which can be a tedious process and requires a priori definition of that association, the action representation can be modified using high-level operations, for instance substituting the action’s object or modifying its effects. This can support proper experimentations with causality, as it makes possible to explore alternatives in a systematic fashion, and suggest associations to be experimented with.

In other words, AI techniques are used for their ability to represent actions and computing analogical transformation on them in order to elicit user experience. What makes possible to use AI techniques to simulate behaviour in virtual world is to exploit a specific feature of 3D engines, namely the fact that they rely on event-based systems to represent all kinds of interaction (Conway et al., 2000; Jiang et al., 2002).

Event systems originated from the need to discretise physical interaction to simplify physical calculations: while the dynamics of moving objects would be subject to numerical simulation, the consequences of certain physical interactions (e.g. glass shattering following impact from a hard object) could be determined in a discretised system without having to perform complex mechanical simulations in real-time. For instance, the impact of glass on a table does not usually generate a physical simulation of the glass shattering (i.e. fragment generation and projection). Rather, an event is generated (e.g. `Bump(..)` or `Impact(..)`), accepting as input some of the parameters of the dynamic aspects (e.g. impact location vector, direction, momentum, references of the objects involved in the collision), and having as an outcome pre-defined simulations, such as a particle system of a glass shattering. The action-reaction script describing such behaviour is illustrated below by Figure 9. This example is written in Unrealscript, the proprietary java-like language interpreted by the Unreal Game Engine virtual machine. In this example, the fall of the glass is simulated using traditional physical laws applied by the Karma Physics engine embedded in the game engine (Figure 9-0). Once the glass mesh collides with the table mesh, the physics engine detect a collision (Figure 9-1), immediately transmitting the information to the game engine event system, which will be in charge of notifying the event (`Kimpact(...)` to the glass object instance (Figure 9-2). In turn, the event callback function named `Kimpact(...)` defined in the `REST` state of the glass object class will be executed with the event arguments (i.e. impact location, momentum, object colliding reference, etc...). In the body of this function a sequence of graphical function will be in charge of simulating the glass explosion, by triggering a particle system reproducing glass fragments, as well as hiding the object mesh and removing its collision properties to avoid further event notification.



```
class GLASS extends actor placeable;

auto state REST
{
 event KImpact(actor other, vector pos, vector impactVel, vector impactNorm)
   {
       // 1- Create Particle System
       self.Spawn(class'EIS_NEW_TEST_TRANSPARENT_GLASS_PARTICLE',
                 self,,
                 self.location,
                 self.rotation);

      // 2- Hide object's mesh
       self.bhidden=true;

      // 3- Remove object's mesh collision properties
       self.setcollision(false, false,false);

      // 3- Change state
       self.gotostate('SHATTERED');
   }
}
```

Figure 9: Example of event-based physical behaviour programming in unreal script

Note: (here a glass object will shatter upon impact with any object)

As most phenomena in VR systems are controlled by these “event” mechanisms, (we can use these event systems to associate arbitrary outcomes to a given action. This should create event co-occurrences that would be perceived as causally related by human subjects. Consequently, we could rely on native VR event systems to detect physical interactions, modify their outcomes as they occur.

Yet, the implementation of an event’s consequences in traditional interactive systems is entirely procedural and not based on first principles, or on generic concepts or re-usable categories. Our “falling glass” example emphasises the lack of formal description of physical event consequences in traditional interactive systems. The event's effects are spread out in the code, programmed in an ad hoc fashion, and expressed in a procedural way. All of these aspects make any anticipation and modification of physical event consequences extremely difficult. Consequently, the expression of physical causality as such in traditional 3D graphics engine is not well suited as to support any processes modifying it. Therefore, if we want to be able to manipulate events in a rule-based manner so as to create new causality-inducing event co-occurrences, we should provide a proper semantic description for them, so as to base event manipulation on explicit knowledge.

Consequently, our system design is modelled as an Intelligent Virtual Environments system (IVE) (Aylett & Luck 2000; Aylett & Cavazza 2001) where AI techniques and representation underlie our Alternative Causality-inducing system. Figure 10 below illustrates the major components and roles of such an IVE controlling physical causality in VE. The overall architecture is composed of an AI system acting on top of a VR Toolkit, which constantly intercepts collision events, interprets them, and immediately provides alternative effect(s) to them.

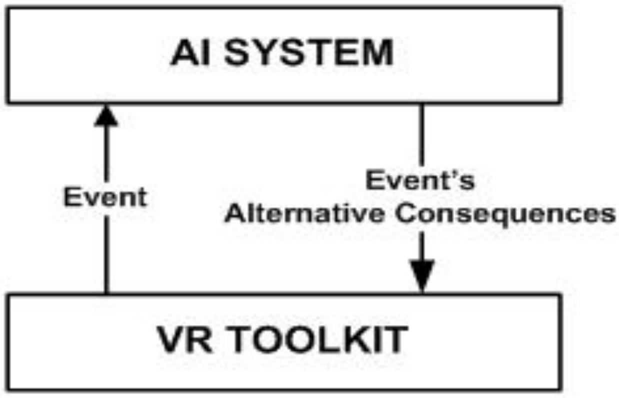


Figure 10: Alternative Causality in VR using AI-based Behaviour approach. (*Overall architecture of an AI module controlling physical causality in a VR Toolkit*)

As previously mentioned our approach to implement Alternative Causality is to intercept normal event consequences as they occur, and replace them by unusual ones based on the context of the event (i.e. object's properties, surrounding objects, and event or effect type).

For instance, we could imagine replacing default effects by substituting, or adding new ones based on causality distortion principles, bearing in mind that these modifications should preserve the perception of causality. Such causality alteration by appending an additional effect to the normal consequence of an action, initiated by a user is illustrated in Figure 11. In this scenario, a user simply drops a glass pint on a table. Upon impact, the falling glass immediately shatters, while a cardboard menu, which is located just beside, is tilting. Whereas, the menu has never been in contact with the falling pint, the double outcome of the object’s collision (i.e. the glass shattering and the menu tilting) would theoretically appear causally related, due to the spatial and temporal contiguity between events. According to this example, the simple addition of an event (i.e. menu tilting) to the expected resulting event (i.e. glass shattering) will create an artificial event co-occurrence while preserving a certain impression of causal relation.

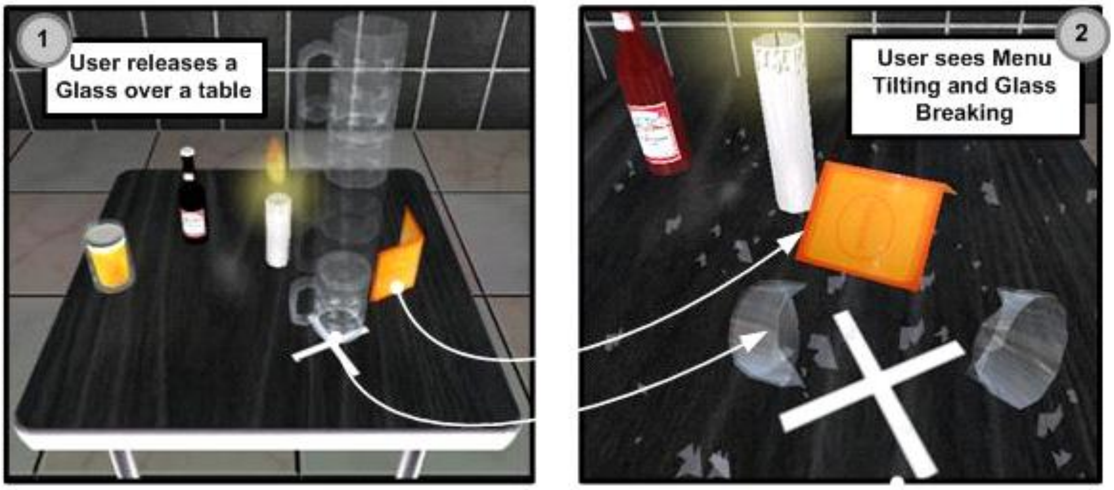


Figure 11: Example of artificial event co-occurrence

(Note: the menu tilting animation has been played with the glass shattering animation; both are perceived as a consequence of the falling pint hitting the table surface).

From the subject’s perspective, their interactions with the world objects will not result in their ordinary consequences. On the contrary, these default consequences will be “intercepted” and substituted with other effects. For instance, while a glass falling on a table would normally shatter (spilling its contents), our system should generate alternative effects, such as the glass landing intact on the table but causing another glass to tumble and spill its contents.

However, our system should operate regardless of the action’s origin (i.e. a user intervention, a simulated process, etc.). In addition, we are also only concerned with effects that could be perceived as directly resulting from the user’s actions, rather than complex causal chains. Even in the case where effects tend to propagate further (as in the case of an impact causing a glass to tilt, and consequently to spill out its contents), only the first consequence (the glass tilting) will be subject to modification by the Causal Engine. Further consequences within the same time sample are not altered. Finally, the overall action modification process would have to respect the critical minimum of 200 ms temporal gap between events and their consequences to preserve Causal Perception (Michotte, 1963; Buehner & May, 2003a; Fugelsang, 2005).

Related Works

A number of researchers has proposed to integrate Artificial Intelligence representations “on top” of virtual worlds, to facilitate a conceptual description of scenes and their evolution, thus introducing the concept of Intelligent Virtual Environments (hence IVE) (Aylett & Luck, 2000; Aylett & Cavazza, 2001). In the following section, we briefly review the uses of high-level representations in VR and possible AI techniques supporting alternative consequence generation. Finally, we conclude by presenting our ontological approach and the requirements of our causality representation.

High-level Representation in Virtual Environments

The development of complex interactive 3D systems raises the need for representations supporting more abstract descriptions of world's dynamics as well as the world's objects and their behaviour (Campos et al., 2003). Therefore, there has been a growing interest in high-level representations of virtual world simulations in recent years, coming from various perspectives, ranging from virtual world design to the implementation of intelligent agents.

Typical applications include:

- World creations from ontological descriptions (Kalogerakis et al., 2006; Vanacken et al., 2007; Kleinermann et al., 2005) or from Natural Language descriptions (Clay & Wilhelms, 1996).
- Multimodal interaction (Latoschik et al., 2005),
- Exploration and Interaction(Müller-Tomfelde et al,. 2004; Kallmann & Thalmann, 2002).
- Behaviour simulation and interpretation (Cavazza & Palmer, 1999; Lugrin & Cavazza, 2006; Bindiganavale et al., 2000; Erignac, 2006; Cavazza et al., 2004; Zhou & Ting, 2006).

Badler's group (Bindiganavale et al., 2000) pioneered the introduction of explicit action representations in virtual environments, initially to support the execution of action variants under the influence of natural language instructions. This was the first time in VR that actions where conceptualised in some form of ontology, which was termed an "actionary." Kallmann and Thalmann (2002) introduced the notion of smart objects in virtual simulations to associate typical behaviours following real-time interactions for instance with virtual agents. Their approach has been a first step towards the introduction of a more generic and abstract behaviour representation associated to the objects (as opposed to all-out scripting), as well as a preoccupation with functional aspects, although not recurring to AI techniques strictly speaking.

Several research groups have recently explored semantic representations for virtual environments: Muller-Tomfelde et al. (2004) used knowledge structures to facilitate the exploration of virtual environments. Latoschik et al. (2005) have developed symbolic representations for virtual environments, initially as part of multimodal interfaces to VR. Kleinermann et al. (2005) have introduced semantic representations for virtual environments to facilitate the design of virtual worlds. Kalogerakis et al. (2006) have proposed the use of ontologies to structure the contents of virtual worlds, using OWL graphs to represent 3D objects and scenes.

From a different perspective, Lieberman et al. (2004) have advocated the introduction of Common Sense (CS) representations in interactive systems. They have given several practical examples of the role of CS in supporting interactive systems (Lieberman & Espinosa, 2006), including an Augmented Reality kitchen (Lee et al., 2006) using a subset of Open Mind (Singh & Barry, 2003).

In the field of AI-based behavioural simulation, Erignac (2006) was the first author to introduce the use of Qualitative Simulation in virtual environments to simulate the behaviour of complex devices with which virtual humans were able to interact. Recent work has explored the use of Qualitative Process Theory (Forbus, 1984,1996) to support Qualitative Simulation in virtual environments, mostly for reasoning with liquids and thermal exchanges (Cavazza et al., 2004a) (Hartley et al., 2004, 2005a ,2005b). Zhou and Ting (2006) have also adopted Qualitative Physics for object behaviour in tactical simulation.

AI and Causality Alteration

While causality has been widely studied in AI (Pearl, 1999, 2000; De kleer & Brown ,1984; Iwasaki & Simon, 1986; Iwasaki, 1994; Iwasaki et al.,1993 , Forbus, 1984; Kuipers, 1984) very little technical work has actually been focusing in experimenting with the alteration of causality. Most of these causation theories rely on probabilistic analysis methods for extracting causality from an analysis of data or equation. The elicitation of causal relations from physical events, neither their modification, are explicitly considered by such theories.

However, the re-ordering of events to establish a new causal chain can be seen as a planning problem. The generation of an appropriate chain of operators based on the transformations they achieve on the world is a classical planning problem. In particular, search-based planning such as HSP (Bonet & Geffner, 2001) or local search methods in planning such as LPG (Gerevini & Serina, 2002 ; Gerevini et al., 2002) can be used to produce a chain of operators corresponding to the events to be sorted at any given time. Considering this approach, the definition of the new rules governing causality can take the form of heuristic(s) governing the search. Consequently, the formulation of the chain of events could be based on planning formalisms-like such as STRIPS (Fykes & Nilsson, 1971) or PDDL (McDermott, 1998). The notion of STRIPS representation in the study of causality has also been advocated by Pearl (2000).

The following section describes our prototype implementation including such AI techniques. We will in particular present our action formalism and modification techniques inspired by heuristic search-based planning. This will be followed by an illustration of their integration into visualisation engine supporting physical behaviour overriding.

Implementation of the Alternative Causality System

System Overview and Architecture

Following event-based Alternative Causality, the system's main operating cycle is divided in three main phases (see Figure 12):

i) Intercepting interaction events at a regular sampling rate,

ii) Recognising the high-level actions they correspond to, and

iii) Modifying their default consequences, so as to create new co-occurrences on a principled basis.

This cycle is integrated by a VR system, composed of three main components (Figure 13):

- A Visualisation System *(Unreal Game Engine)*
- An Event Interception System (EIS)
- A Causal Engine

The Causal Engine operates continuously through sampling cycles that are initiated by the occurrence of actions in the virtual world. The occurrence of events affecting world objects initiates a sampling cycle, during which the system recognises potential actions and stores them while inhibiting their effects (it could be said that it "freezes" them). The Causal Engine then transforms these "frozen" actions, by altering their effects, before re-activating them. This re-activation then initiates a new sampling cycle. The Figure 13 illustrates a set of alternative effects generated by the system following the fall of an empty glass on a table.

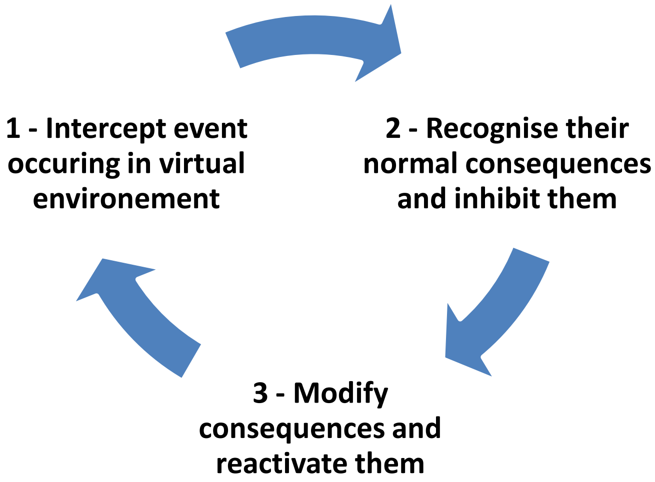


Figure 12: Alternative-Causality System Main Operating Cycles

The Causal Engine is developed on top of the native event system of a (Unreal Engine™), which supports events discretisation in the Physics engine (which in the case of UT 2003 is the Karma™ engine). This means that the default Physics is overridden by the new mechanisms provided by the Causal Engine for any event involving interactions between objects (other aspects, such as kinematics are not altered and remain under the control of the Physics engine). The causal layer communicates with the visualisation engine using UDP messages. It interacts with the engine's behavioural API via our event interception system written in UnrealScript Code. The next section describes in further detail features and roles of these modules before presenting our action formalism.

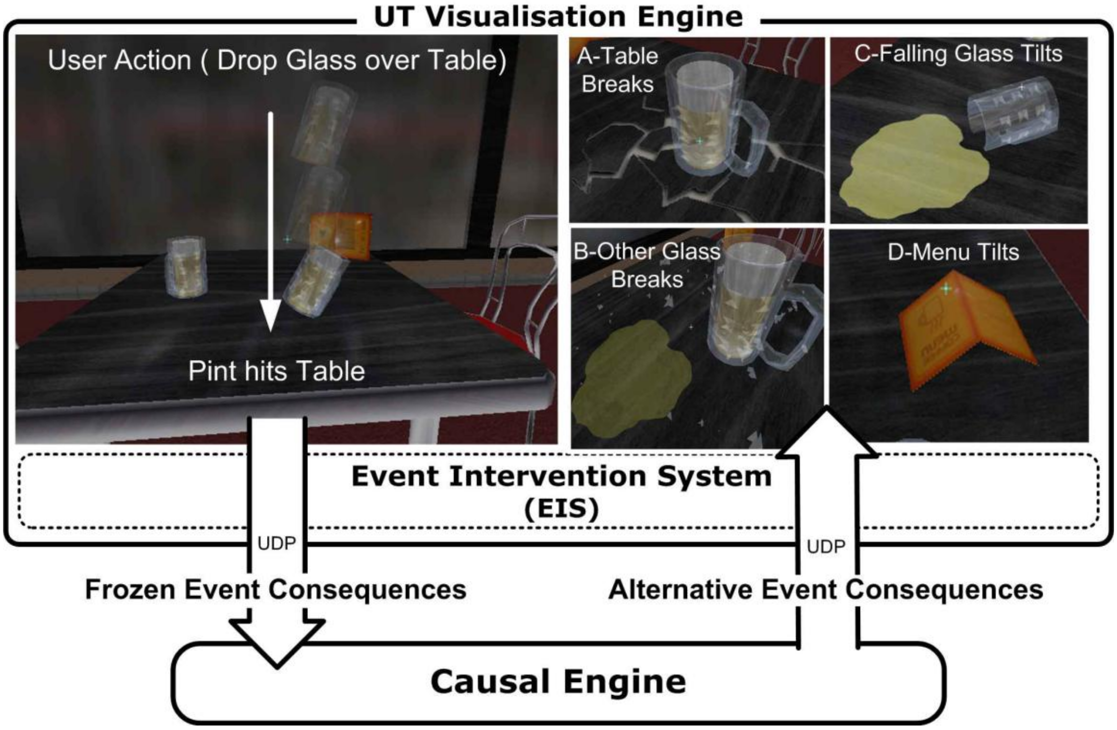


Figure 13: System Overview

A. We substituted the object to be damaged while the glass is slightly bouncing of the table, the table is cracked around the impact point.
B. Another substitution, with the shattering of another glass (than the one falling) situated around the impact point.
C. A substitution and modification of the nature of the effect, this time the menu is tilting upon the impact.
D. As for c) but this time, the other pint (standing on the table before the impact) is tilted after the impact.

The Visualisation Engine (Unreal Game Engine)

Since 2000, most game engines surpass traditional VR Toolkit (such as WorldToolKit[4]) in their visual quality and realism as well as their authoring tools and retail price. Game technologies have been used with success for different types of VR applications, mostly due to their “excellence” for interactive real-time graphics production and displays (Lewis & Jacobson, 2002) (Noh, 2006). Game engine technologies imposed themselves as natural tools in a multitude of activities in the digital domain (Hampshire, 2006). Among them we can cite: Movie making and real-

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[4] . http://www.sense8.com/

time animation making (Machinima), Media Art, Architecture and Construction Simulation, Landscape Architecture, Serious Game, Immersive VR Platform, Interactive Storytelling and much more ,see (Herrlich 2007; Richie et al., 2006) for a detailed overview).

At the time of this research (2003), the most appropriate game technology available was the Unreal Engine 2.0 (freely delivered with any copy of the Unreal Tournament 2003 Game TM [5]). The Unreal technology had a considerable advantage upon any of its rival in terms of graphics and physics simulation quality as well as its authoring tools and large developer community. Its high level scripting language and sophisticated event system made it an ideal platform to integrate our event interception/modification system. As game engines often appear as complex interactive systems, the following section clarifies the Unreal Engine components and its approach for Behaviour programming.

Unreal Engine 2 is a complete game development framework targeting mainstream PC's, and consoles (Microsoft's Xbox game console, and Sony's PlayStation 2). It powered such hit games as Unreal Tournament 2003 TM (Epic TM[6] Games), Splinter Cell TM and Rainbow Six 3 TM (Ubisoft TM) and Lineage II TM (NCsoft TM). The free-licensed version includes a proprietary scripting language, the UnrealScript [7](Figure 15), from which the whole gameplay can be modified without accessing the internal C++ components. The level authoring is assisted by a complete level editor: the UnrealEd[8] (Figure 14). The physical simulation is handled by the Karma physics engine[9] (i.e. a rigid-body physics simulation and collision-detection software package) from which developers can quickly and easily add physical behaviours to their 2D or 3D environment. *(Note: a complete description of the Unreal engine technical feature is available online[10])*

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[5] http://www.unrealtournament2003.com
[6] http://www.epicgames.com
[7] http://udn.epicgames.com/Two/UnrealScriptReference.html
[8] http://udn.epicgames.com/Two/IntroToUnrealEd.html
[9] http://udn.epicgames.com/Two/rsrc/Two/KarmaReference/KarmaUserGuide.pdf
[10] http://www.unrealtechnology.com/features.php?ref=past-versions

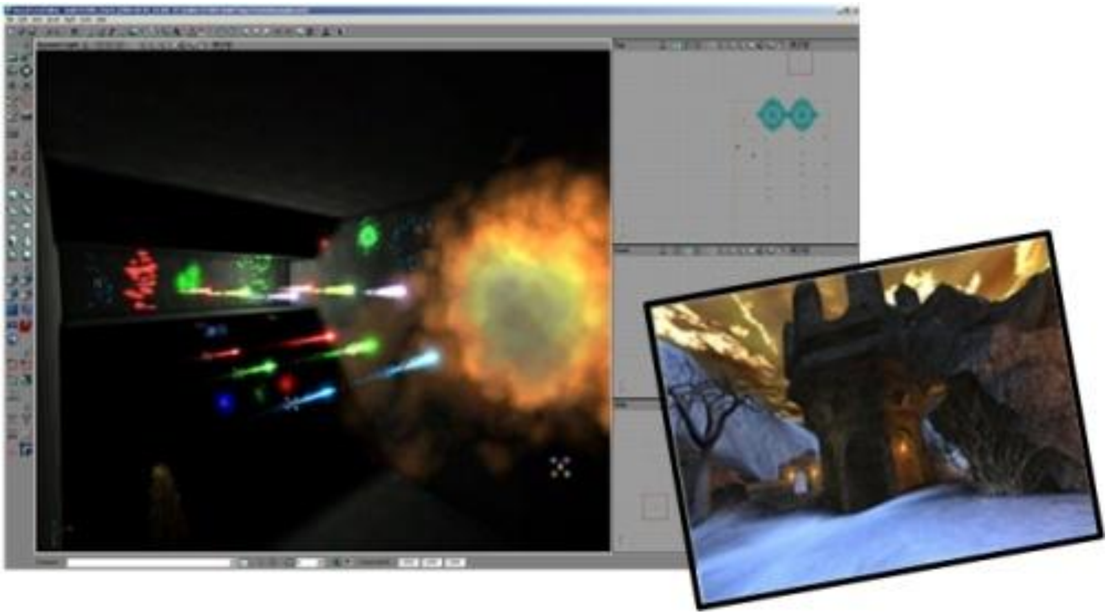
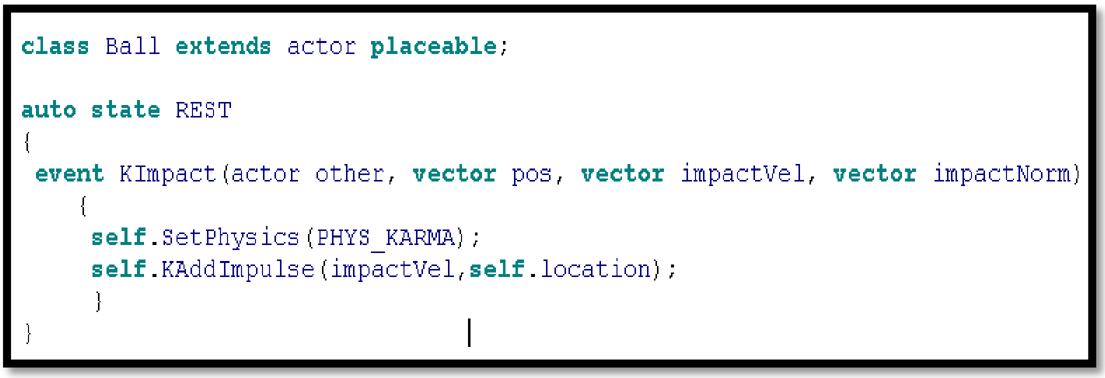


Figure 14: Unreal engine level editor (Unrealed) and example of environment produced

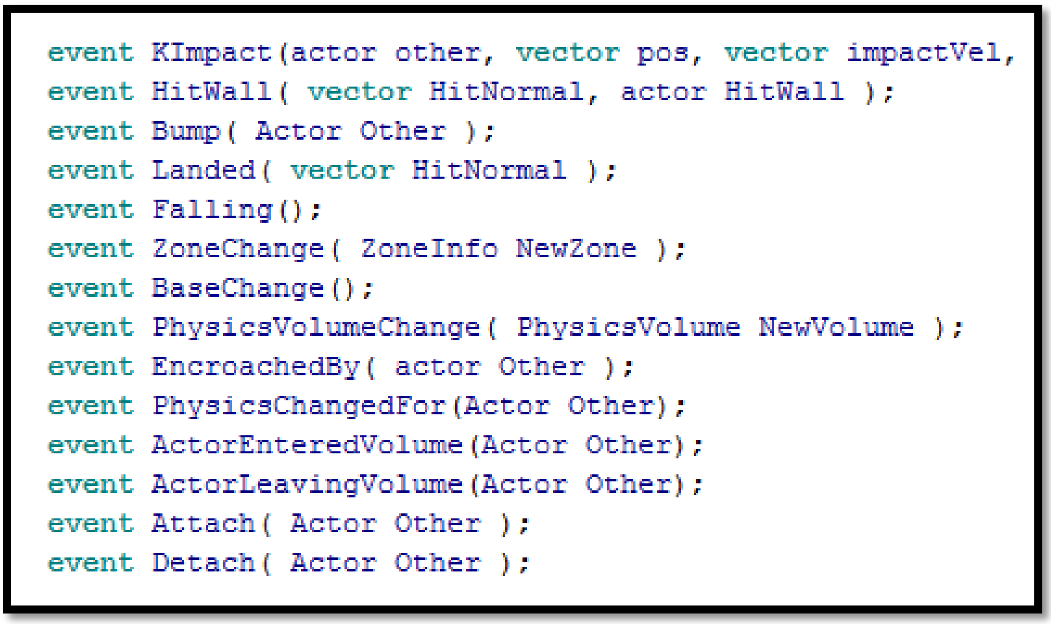


```
class Ball extends actor placeable;

auto state REST
{
 event KImpact(actor other, vector pos, vector impactVel, vector impactNorm)
    {
     self.SetPhysics(PHYS_KARMA);
     self.KAddImpulse(impactVel,self.location);
     }
}
```

Figure 15: Example of Unrealscript (*Here a simple ball object activating karma physics engine simulation when colliding by other moving object (also handled by karma physics engine)*

In addition, the Unreal engine provides a large population of events (around 60) describing different aspects of virtual actor or player interactions. The Unrealscript code snippet below illustrates this diversity of events (Figure 15). One relevant aspect of the Unreal events system regarding our research objective is the fact that it proposes over fifteen different events to denote physical interaction, such as `Bump(...)`, `Landed(...)`, `Hitwall(...)` (Figure 16. The different events categories available and their role in our action recognition process would be discussed later in this chapter.



```
event KImpact(actor other, vector pos, vector impactVel,
event HitWall( vector HitNormal, actor HitWall );
event Bump( Actor Other );
event Landed( vector HitNormal );
event Falling();
event ZoneChange( ZoneInfo NewZone );
event BaseChange();
event PhysicsVolumeChange( PhysicsVolume NewVolume );
event EncroachedBy( actor Other );
event PhysicsChangedFor(Actor Other);
event ActorEnteredVolume(Actor Other);
event ActorLeavingVolume(Actor Other);
event Attach( Actor Other );
event Detach( Actor Other );
```

Figure 16: Example of Unrealscript events *(notifying physical interaction)*

The Event Interception System (EIS)

The Event Interception System (EIS) has been developed on top of the native event system in UT 2003. The EIS derives its name from the fact that it overrides part of the native Physics engine, namely the processing of physical interactions between objects, corresponding to various kinds of contact and collisions. Its role is to act as physical action recognition and inhibition layer, interpreting low-level events in terms of higher-level actions. As previously mentioned our representation for high-level actions is referred as CE (for “Cause-Effect” structure), and constitutes an explicit formalisation of actions and their consequences. This representation is thus organised around the notion of action and consequences, which is the most appropriate to represent event causality. A detailed description of the formalism is given in the following section.

The Causal Engine

The "Causal Engine" could be assimilated to an action modification layer, which produces new event co-occurrences in the virtual world by modifying the effects of actions occurring in the virtual world, and so generating alternative effects. These events co-occurrences will in turn induce causal impressions of the kind discussed previously. In few words, this module receives a set of "frozen" actions from the EIS and outputs a set of modified actions, which are ready to be re-activated, and have their effects triggered in the virtual world. The modification of the CE's effects is the key mechanism for generating such co-occurrences. The detailed behaviour of these modules, as well as the working cycle of the whole system, is discussed in subsequent sections.

Event Co-Occurrence Representation

In this approach of Alternative Causality, knowledge representation is an essential aspect. The alteration of common sense physical causality from principles entails a high-level representation of the virtual world, and more particularly of the possible physical actions within it. After a review of the rational and requirements of our causality representation, we will introduce our causal action formalism in further details.

Representation Rational and Requirements

Our actions description should be supported by an appropriate formalism for change-inducing events, which should clearly identify actions and their consequences. The second step consists in defining a catalogue of such action, i.e. associating high-level events that can be recognised in the virtual environment. This form of representation echoes the proposal of Mantovani and Riva (1999) according to which a virtual environment should be characterised by an ontology, where however we consider an ontology for actions.

Consequently, this system is based on ontological representations for both objects and actions. The ontology for actions will constitute a specification of the main actions taking place in a given virtual world. The expression of an action's effects corresponds to its post-conditions (i.e., change in objects' properties). These effects are also associated with a visualisation of the action itself in the form of a 3D animation of the action so that the action can be properly staged in the virtual world without a detailed simulation of all its phases. This ontology should contain generic actions and specific actions. For instance, all objects can fall, or fly, but only certain object categories can break (depending on their physical properties). In addition, some actions are related to object functionality (i.e. only containers can be filled or emptied).

In conclusion, our ontology should serve different purposes:

i) Action recognition: to determine what should be the normal consequence of an interaction.

ii) Action modification and comparison: To determine in which actions objects can take part into, and how they are affected by them; This would support comparison and analogies between various action, which in turn should enable some sort of modification principles.

In addition, the action ontology should support efficient computations, to be compatible with the real-time requirements of a virtual environment. Finally, following our event-based approach, it should also be able to be incorporated upon a VR event system. The next section will introduce an action and object representation satisfying such requirements.

Related Work in Object Representation

Our working hypothesis is that a successful representation should be able to articulate object representations with the actions they are most likely to take part in, while preserving the possibility of generic inference.

The description of object properties from the perspective of their use constitutes a specific research topic known as Functional Reasoning (Far, 1992). Bicci and Saint-Amant (2003) have provided a valuable classification of the various approaches to functional reasoning by analysing the role assigned to shape, causality, and physics in various approaches. Of particular interest is the fact that, while discussing Winston et al.’s work (1983), they emphasised how shape information can be enriched with semantic properties, for instance the fact that a cup should also be described as “lift-able.” This is important is defining relevant levels of granularity for the object descriptions. Vaina and Jaulent (1989) have introduced a representation scheme to support functional recognition, which they have referred to as a “compatibility model.” They consider that the functional categorisation of objects should make use of criteria, which are specific to actions. This has encouraged us to adopt a representation inspired from the object function, in which for instance physical states could be interpreted in functional terms. This is also in line with much of the contents of the “ontology for liquids” proposed by Hayes (1985), in which much of the basic properties of liquid containers have been described originally.

Our symbolic representation, taking the form of a small semantic network, attempts at relating structure to function, on the basis of actions likely to affect the object (see Figure 17). On the structural side, it describes the part-whole structure of the object and the elementary physical properties of its components. There are not all shown on the Figure 17 as they can be derived from the property of substances of which the object parts are made, etc. On the functional side, it attaches functional states to the object, more specifically object parts such as its external structure, which takes states such as DAMAGED or NORMAL.

An important aspect of this representation is its connection to our action representation, where semantic properties are used to determine objects, which are likely to be affected by events , and are subsequently updated by the post-conditions of actions and processes. Our action representation and its integration of our object symbolic object representation is described in the next section.

Action Formalism: Cause and Effect Representation

In our system, an action is represented in the Causal Engine using our Cause-Effect action formalism (Henceforth CE) inspired from those used in planning and robotics, such as STRIPS (Fikes & Nilsson, 1971), PDDL (McDermott, 1998), or most specifically the operator representation in the SIPE system (Wilkins, 1988). These representations originally describe operators transforming states of affairs in the world. They tend to be organised around pre-conditions, i.e. conditions that should be satisfied for that action to take place and post-conditions, i.e. those world changes induced by their application.

Consequently, our physical action formalism is a Cause-Effect representation (CE), where the “cause” part is a formula containing elementary physical events (such as collisions) plus semantic properties of the objects involved and where the effect is the transformation of these objects. Figure 17 shows the CE: “Break-on-impact,” in which the cause part consists in a collision event between two objects, one of them (Glass#1) is fragile and the other being (Table#1) harder than it is.

Similar to the SIPE representation (Wilkins, 1998), the CE formalism actually comprises three main fields, Triggers, Conditions and Effect, where the Triggers and Conditions represent the "*Cause*." We shall illustrate it on our "Break-on-impact" example, which describes the event by which a fragile object will shatter upon colliding with a hard object (Figure 17).

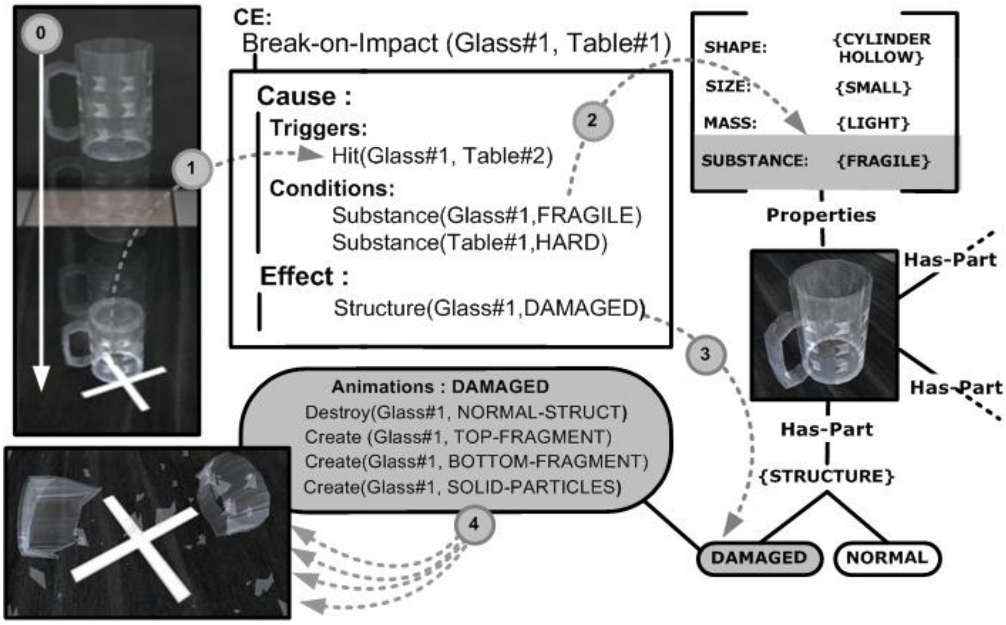


Figure 17: The Cause-and-Effect (CE) Formalism and its use of Objects' Semantic Properties

- The first field, called **triggers**, contains the "*basic*" physical events from which the CE can be recognised, and which prompts instantiation of the corresponding CE representation. In the Break-on-impact CE, this field contains the BE "Hit", derived from the low-level event systems of the UT 2003 engine, such as Touch(…), Bump(…), Kimpact(…) events. Any occurrence of a "Hit" BE can potentially activate the instantiation of a Break-on-impact CE (Figure 17– 1). The notion of "basic" event is defined in detail later on in this section.

- The **conditions** field determines the physical properties that should be satisfied by objects taking part in that specific action, such as being "movable" or "breakable" (these semantic properties being characterised by physical properties). For instance, a moving object hitting another object will break only if its substance is fragile and the object it hits is hard (Figure 17– 2). The condition field is used to filter between candidate CEs primed by similar basic events. For instance, the CE representations for Bouncing and Break-on-impact actions can be activated from the same “Hit” BE. It is the physical properties of the objects involved in the action that will determine which candidate CE describes the situation at hand.

The **triggers** and **conditions** fields govern the CE instantiation: once these fields can be instantiated by the CE recognition mechanism, a corresponding CE representation is created, whose modification will create event co-occurrences.

It can be noted that CE actually represent events rather than intentional actions, as they ignore the course of events preceding the CE. The above CE for breaking-on-impact is recognised in a similar fashion regardless of the origin of the impact, whether the object is falling on a hard surface, has been launched, or is struck by a harder object. This contributes to making this kind of representation more generic and expressive.

- Finally, the **effect** field corresponds to the consequence part of the CE. It contains the default transformations to be applied to the objects affected by the CE (Figure 17– 3). For instance, in case of a glass shattering, the deletion of the glass and the creation of glass fragment (Figure 17– 4).

The CE formalism plays a central role in the creation of event co-occurrences. As it essentially associates actions with their consequences, it can be modified, for instance by substituting alternative consequences to the default ones. In that sense, new event co-occurrences are produced by a cycle composed of three main phases

i) **Inhibiting** the activation of CE’s default effects immediately after their instantiation

ii) **Modifying** the CE’s effects while these are suspended, and

iii) **Re-activating** the CE’s modified effects.

As a result, for any given CE processed by the system, the user perceives the corresponding triggering event followed by an alternative effect. (*The Figure 13 illustrated a set of alternative effects following the fall of an empty glass on a table).* The following section will illustrate in detail the action recognition and modification phases through our "glass falling" example.

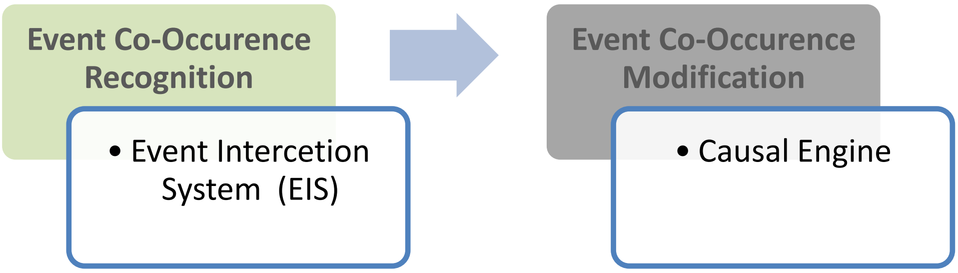


Figure 18: Alternative Causality Main Processes

In our approach, two main sequential processes perform the alteration of physical causality: Event Co-occurrence Recognition (in green) and Modification (in grey), reciprocally operated by the Event Interception System and the Causal Engine (Figure 18). To operate in real-time 3D environments, both operations are divided into concurrent cycles executed by the different components of the EIS and Causal Engine as well as virtual object instances themselves. The overall process is depicted on Figure 18; it includes four main cycles including a total of sixteen phases shared by height main components. Both subsystems components are represented in Figure 19. The EIS is composed of virtual object instances, an Event Controller, CE Generators, a CE Catalogue and a Message controller to communicate with the Causal Engine through network sockets. On the other side, the Causal Engine also includes a Message Controller connected to a Search Engine.

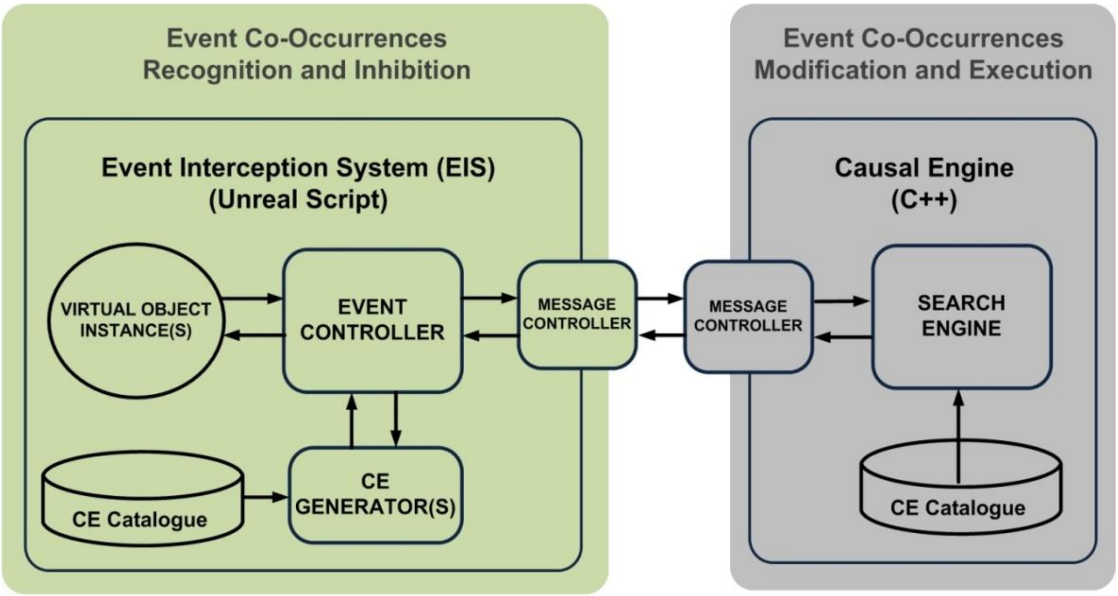


Figure 19: System Main Components

Throughout this section, we will illustrate the behaviour of the EIS and Causal Engine through our "Falling Glass" example, to be part of our subsequent experiments in the next chapter *(This type of event also constitutes a traditional example for causality; see e.g. (Collins et al., 2004)*. In this example, a glass is dropped by a user onto a table surface, which also supports other objects (such as similar glasses, a cardboard menu, a candle, and a beer bottle). In such a scenario, the user would normally expect the glass to shatter upon the impact after a nearly one-meter fall. Yet, the alternative effects produced by our system to such event are presented in Figure 20 below:

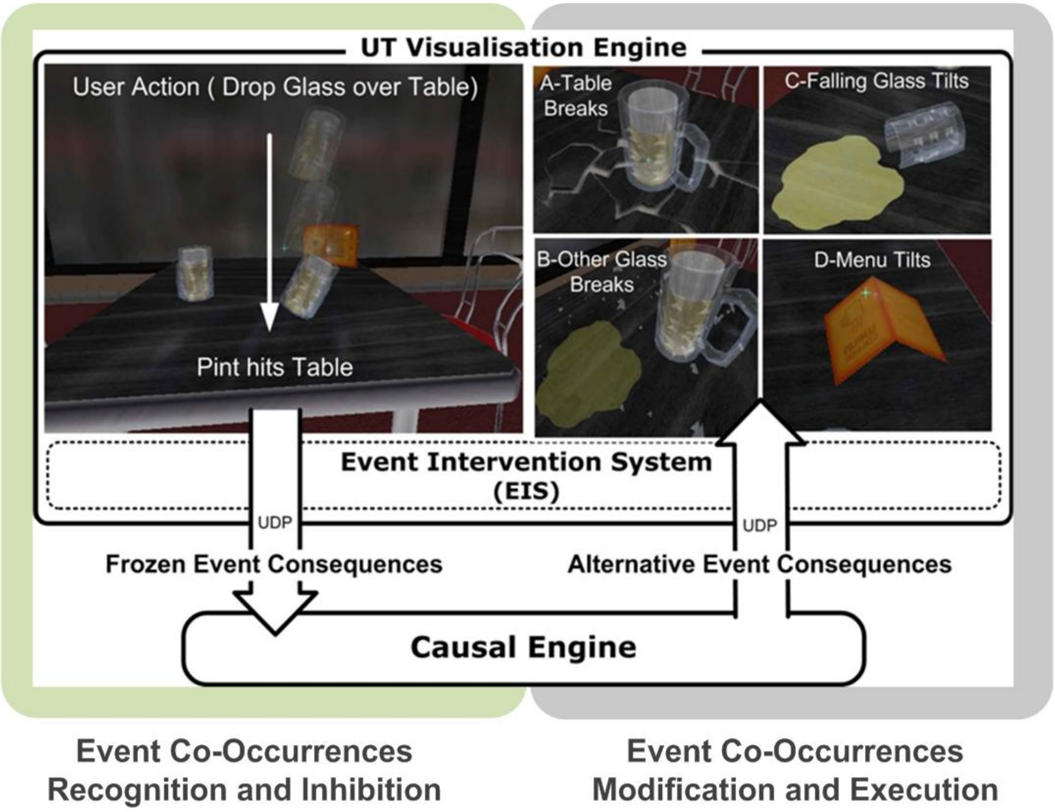


Figure 20: System Overview and Event Co-Occurrences Manipulation Phases

The following parts explain the generation of such alternative event co-occurrences. We will start by illustrating the event recognition and inhibition phase and its implementation, and then demonstrating event modifications and execution phase.

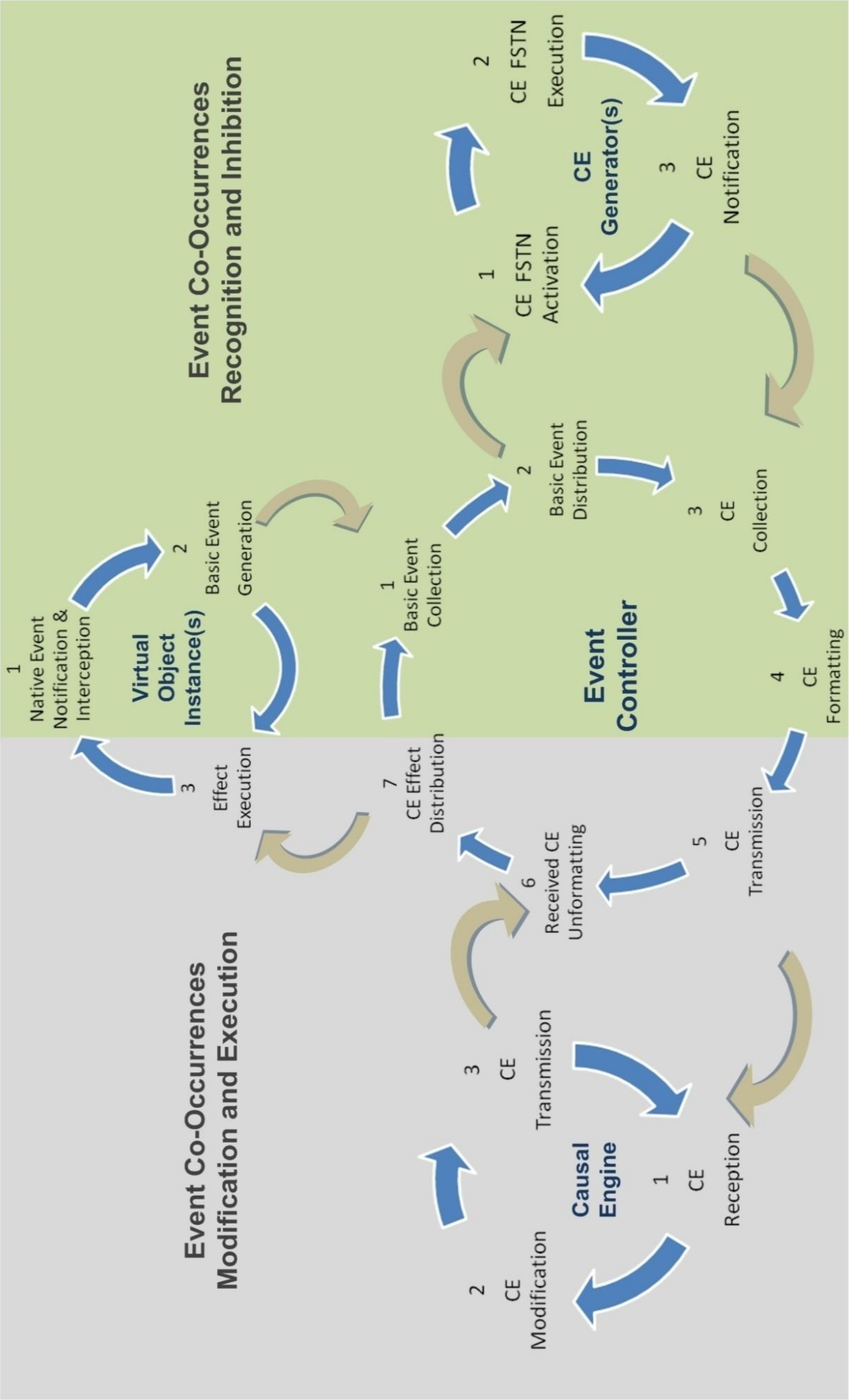


Figure 21: Event co-occurrences recognition and modification main cycles

The action recognition and inhibition process is operated directly at the Unreal Game engine level by the EIS. An external implementation of this process would have considerably overloaded the network with a high flow of native low-level events, as a simple collision between two objects could generate hundreds of contact notifications per second. With the action recognition and inhibition process running on the game engine side, the network bandwidth is efficiently used, as only elicited when a meaningful event succession and context (i.e. an action) is detected. Consequently, an internal implementation considerably simplifies and reduces the overall event processing time.

The overall procedure is shared in nine main operations shared in three concurrent cycles (see Figure 21):

1. Native Event Notification (and interception)
2. Basic Event Generation
3. Basic Event Collection
4. Basic Event Distribution
5. CE FSTN(s) Activation
6. CE FSTN(s) Execution
7. CE Notification (and interception)
8. CE Collection
9. CE Formatting

The first cycle is composed of operation 1 & 2 and run by the virtual object instances. The second one is run by the Event controller and includes five main operations (3 & 4 - 8 & 9), while the third cycle is divided into three main steps (5 & 6 & 7) and executed by independent objects called CE Generators (Figure 22 below). Each CE Generator represents a particular CE and so is dedicated to the recognition of a particular action. Implementation wise, the Event Controller delegates the recognition of high-level event to specific object named CE Generator. Each of them implement a particular CE in the form of a Finite-State-Transition Network (aka FSTN) called CE **Generator** (see Figure 30), the whole CE recognition process is described further detail on the following parts.

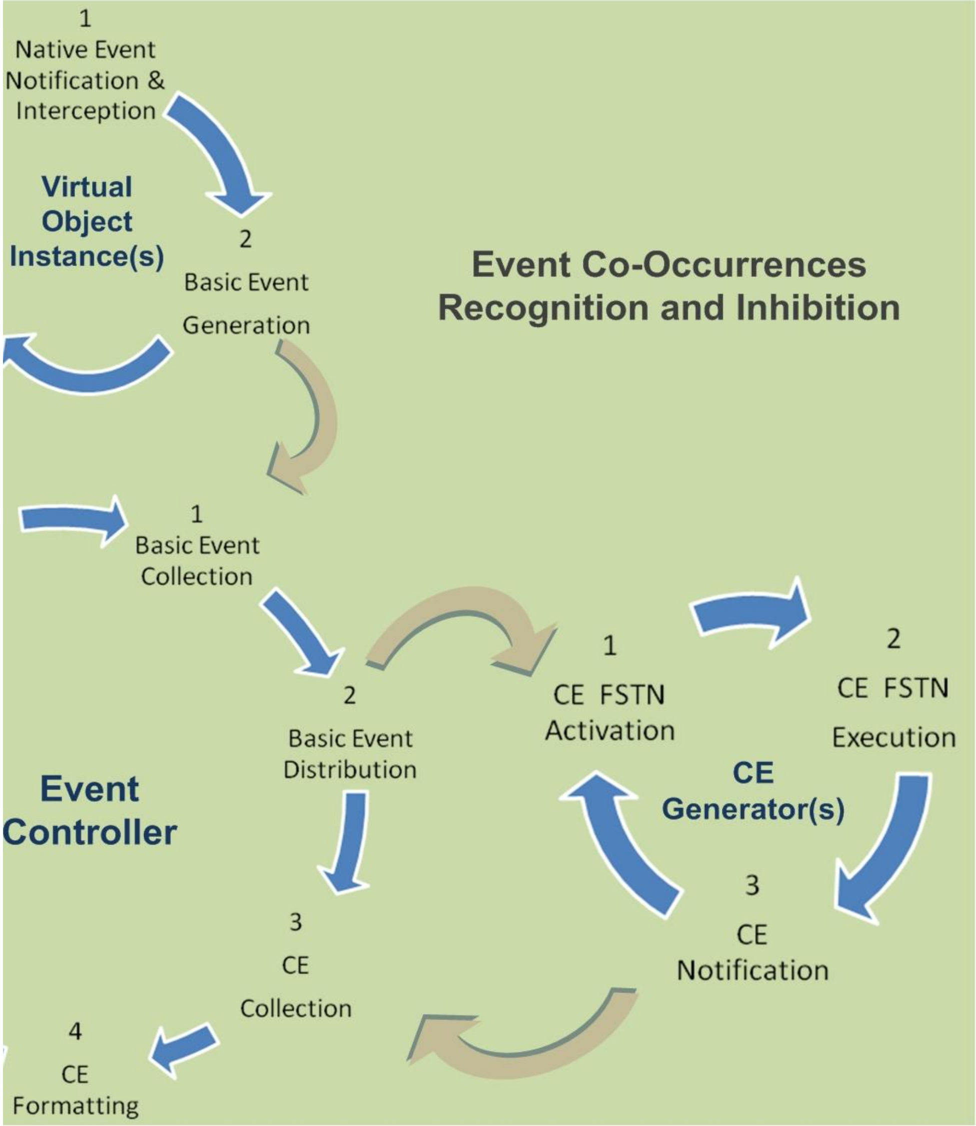


Figure 22: Event co-occurrences recognition and inhibition cycles

In sum, the system operates by first instantiating CE representations for ongoing actions, then modifying the effects of some or all of these representations. As explained in the following section CE instantiation is a bottom-up process performed by the EIS module, which starts with the processing of incoming game engine's native events, to produce a refined set of high-level events co-occurrence representing common sense physical actions.

Native event notification (and Interception)

The type of interaction event generated by the Unreal engine mostly depends on the collision type associated with the object's mesh as well as the physics engine simulating its motions. Object collision properties are divided into two main categories: *Blocking* and *Non-blocking* Collision. Meanwhile their motions can be simulated by the Unreal Physics engine (providing basics physics integration such as "bouncing" effect) or using the realistic rigid-body physics engine: KARMA[11]; capable of advanced rag-doll character animation and vehicles.

A Non-Blocking object triggers collision events such as `Touch(...)` and `UnTouch(...)` signalling the penetration of an object by another. In opposition, *blocking* object, which prevents any possible object penetration, generates other collision events such as `Bump(...), Landed (...), or Hitwall(...).` When controlled by the KARMA physic engine, only *Blocking* object collisions are notified using a single event: `Kimpact(...).` Consequently, our basic event generation overloads both Karma and Unreal Physics events for both types of *Blocking* and *none-blocking* objects.

Based on these object type, the Figure 23 below represents the main physical *event* categories we extracted from the fifteen physical event detected by Unreal game engine. We could distinguish two main types of Physical Events: *Contact* and *Uncontact* events, each of them subdivided into *Blocking/Unblocking* events. A *Contact* Event refers to an object collision, while an *UnContact* Event notifies the separation of two objects, which have previously collided.

In addition to collision and un-collision information, a *blocking* event refers to a collision or separation between solid impenetrable objects, while an *unblocking* event represents a collision with an penetrable object (such as volume delimiting an area in a level, or representing an object activation/deactivation zone known as *Trigger* actor). Obviously the typology and variety of events are naturally biased by the

---

[11] The old Math Engine.

gameplay and architecture targeted by the game middleware developer. However, you can find similar physical event categories in most of the interactive system/game engines currently available. In addition, most of the current game engines propose mechanisms to customise event detection as well as their propagation through scripting language and/or using the Event-based Flow graphs. One of the essential advantages of the Unreal Engine when compared to others lies in its large set of physical events and the capacity to override them. Figure 23 below illustrates the taxonomy of physical events employed within the Unreal engine.

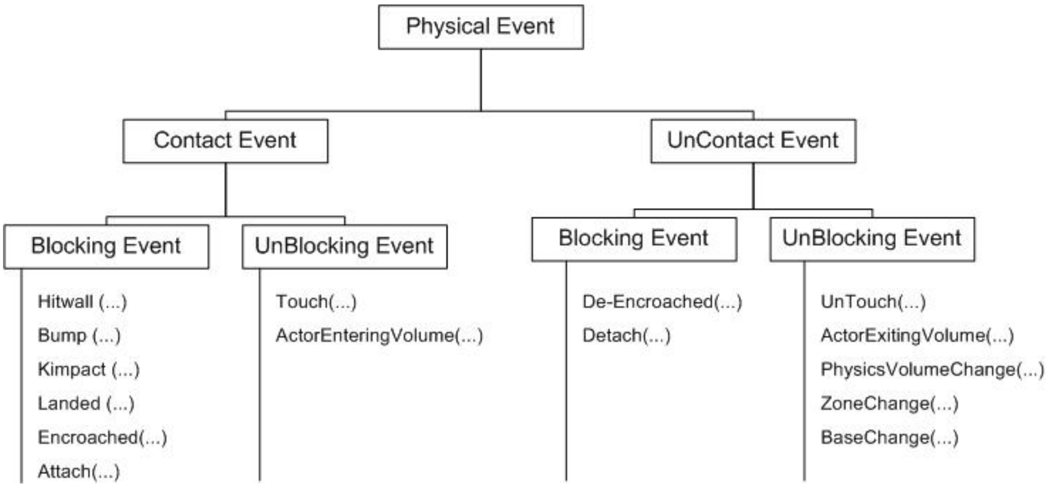


Figure 23: Example of the main physical event categories in the Unreal game engine Basic

Event Generation (and Event Inhibition)

CE instantiation starts with the processing of incoming game engine's native events, to produce a refined set of higher-level events called ***Basic Events*** **(henceforth BE).** A classification of Collision/Separation events has then been defined, and is composed of five main events: BE_HIT, BE_PUSH, BE_TOUCH, BE_IN, BE_OUT. Basic Events represent a refinement of the large population of native UT Events. They are composed of an aggregation of engine events associated with certain conditions. For instance (Figure 24), the magnitude of the object momentum in a colliding event can be used to instantiate a `Hit` Basic Event (`Hit(?obj, ?surface)`) from the set of native events signalling different type of collisions (e.g. `Hitwall, bump, KImpact` and `Landed` events).

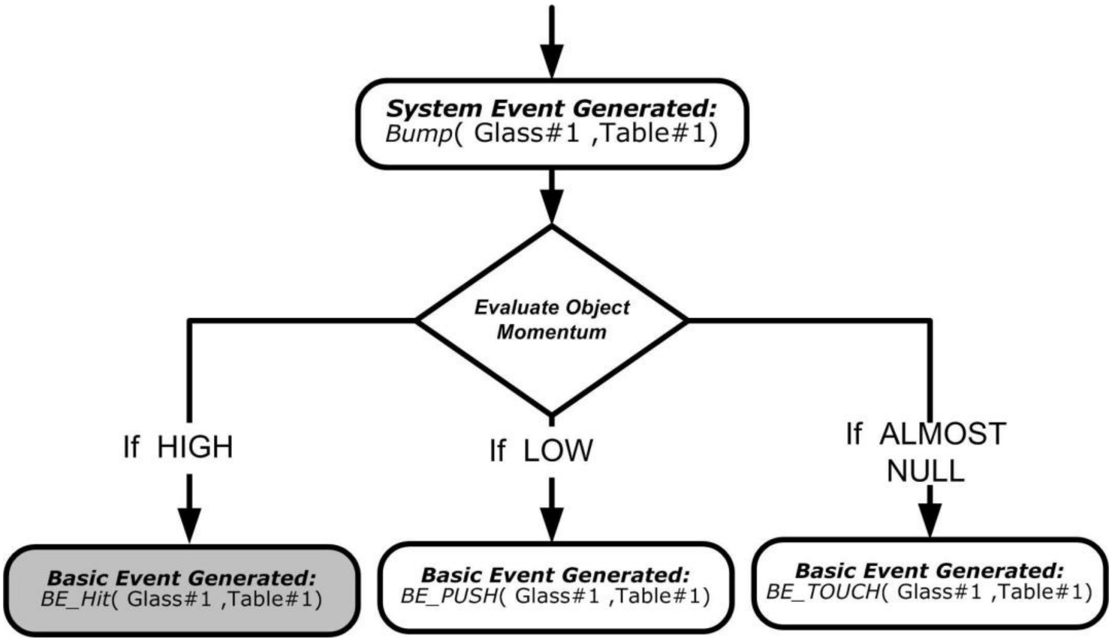


Figure 24: Example of Basic event generation from a system event

As illustrated in the next section, our event controller continuously intercepts BE instances as they are generated by customised virtual object classes. The BE intercepted during a certain sampling time (usually in a range of 3 to 10 ms) are then processed against our physical action description (i.e. CE) to recognise and prevent their possible outcomes.

This first layer of Basic events, generated at the object level, considerably facilitates the recognition of higher-level events such as our CE. Once an instance of a Basic Event has been generated, it is immediately transmitted to the Event controller. At the same time, the objects involved within the event are instantaneously "frozen" (i.e. stopping any physical simulation and low-level event interception). The object will be "unfrozen" only in the case where no particular consequence has been recognised from our catalogue of actions. The sub-section below explains the mechanism behind this inhibition and its role.

Event Inhibition

When an object is frozen, it immediately enters into a "`STANDBY`" state. In this state, the Physics engine action is inhibited and the object appears as immobilised. The pre-freezing object velocity, rotation, state and physics mode are registered before being set to null. During this "`STANDBY`" period, the object is waiting for the event controller to provide a response to the event intercepted, in terms of effect state

(Figure 25). However, after a brief amount of time and in the absence of a specific consequence recognised (i.e. defined by our catalogue of action), the object will automatically recall its kinetics parameters and let the Physics engine simulates its behaviour, until its next collision (i.e. next event generation and interception). This "`STANDBY`" period is usually set between 170-120 ms.

This autonomous-control mechanism, implemented at the object instance level, preserves action fluidity and avoids deadlocks when the consequence of an event has not been planned. This could happen if a certain action has not been encoded in a CE structure. It also represents a handy mechanism to preserve the environment dynamics, and consequently the user experience, in case of an excessive event processing time (over 200 ms).

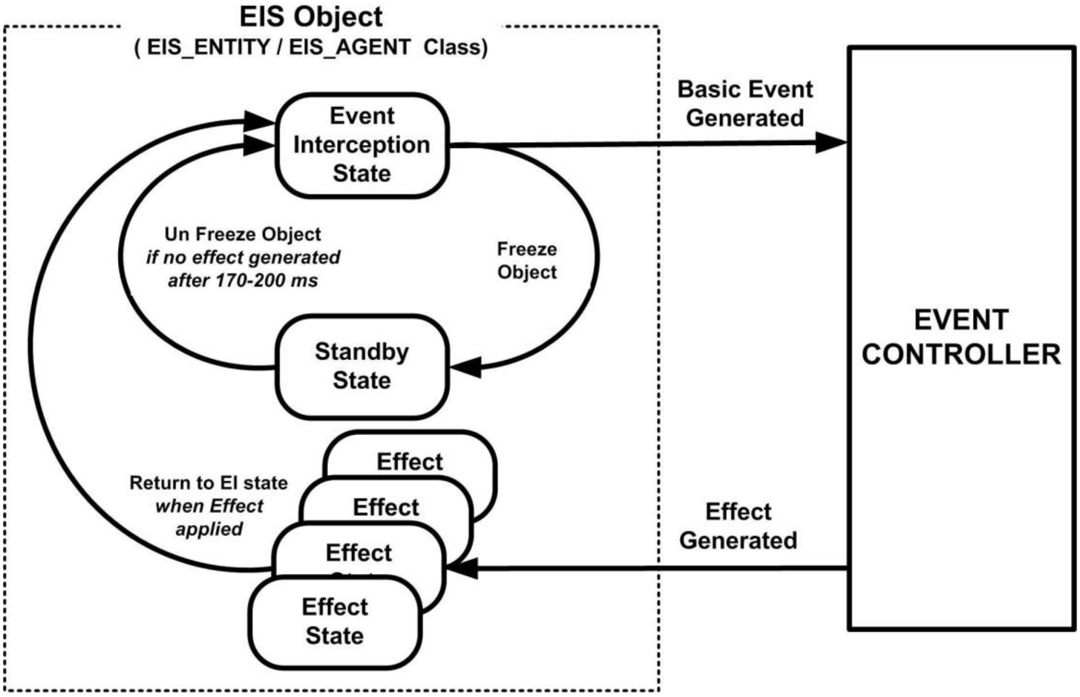


Figure 25: Low-level mechanism handling object inhibition

Basic Event Generation

Similar to the inhibition mechanism, the Basic Event generation is realised directly at the object level. Special functions override native event system calls (see snippet of code below Figure 26) and generate BE instances providing their conditions are satisfied. These instances are immediately notified to the event controller, which records them into specialised FIFO stacks (Figure 27). For each of the five BE types recognised the event controller has a dedicated stack. As explained~~,~~ in the next section, this pre-parsing accelerates the event recognition process. As previously mentioned, once the BE instance has been transmitted the object immediately enters into a “standby” state.

```
simulated  state EVENT_INTERCEPTION_STATE
{
  event HitWall( vector HitNormal, actor HitWall )
  {
     Generate_Collision_BasicEvent  (self, hitwall,100* normal(Hitnormal));
     gotostate('STANDBY');
  }
  event Bump( Actor Other )
  {
     Generate_Collision_BasicEvent  (self, Other);
     gotostate('STANDBY');
  }

  event Landed( vector HitNormal )
  {
    Generate_Collision_BasicEvent   (self,,normal(hitnormal));
    gotostate('STANDBY');
  }

   // Special Karma Physics Engine Collision event
  event KImpact(actor other, vector pos, vector impactVel, vector impactNorm)
  {
      Generate_Collision_BasicEvent  (self,other,normal(impactNorm));
      gotostate('STANDBY');
  }

  event Touch( Actor Other )
  {
      Generate_None_Collision_ENTER_BasicEvent  (self, Other);
      gotostate('STANDBY');
  }

   event UnTouch( Actor Other )
   {
      Generate_None_Collision_EXIT_BasicEvent (self, Other);
      gotostate('STANDBY');
   }
```

Figure 26: Event interception state, native event overriding and basic event generation (Unreal script)

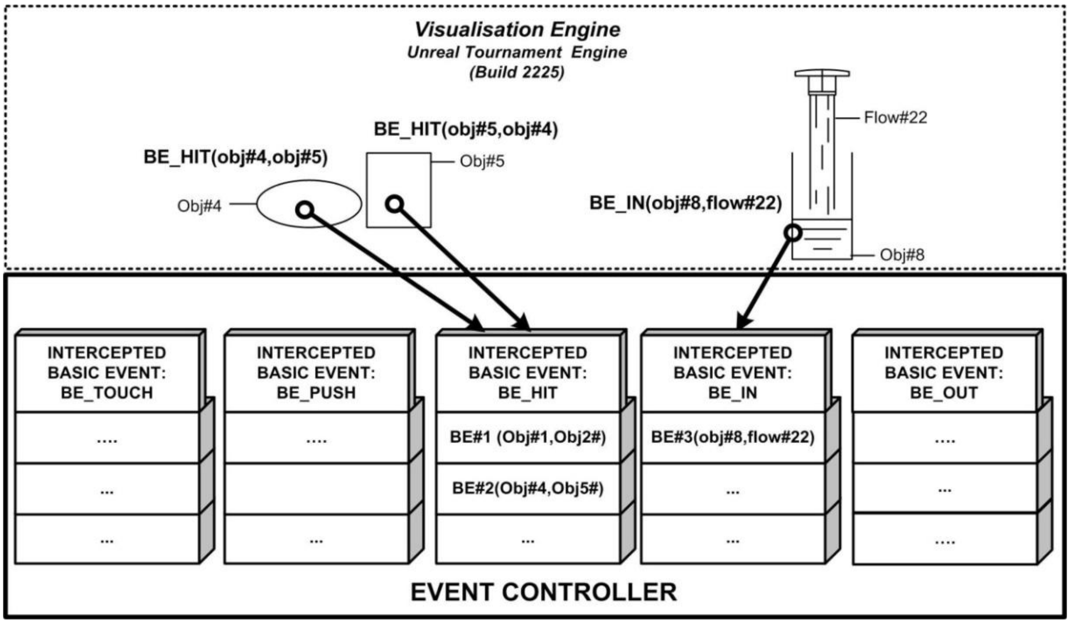
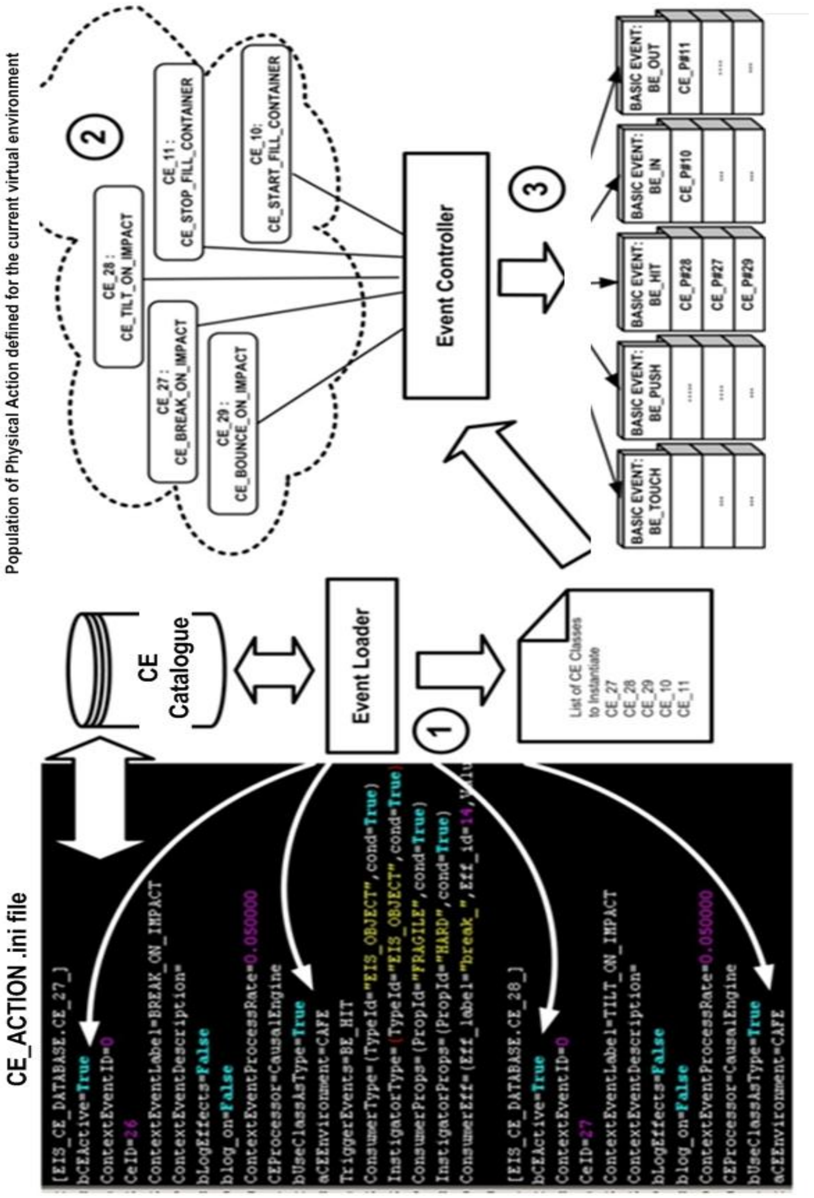


Figure 27: Example of basic event notification

The next step consists in the recognition of potential actions through the identification of CE from the set of intercepted BE. During this operation, the intercepted BE instances are redistributed to relevant CE prototype representations (Figure 28-1), i.e. those CE which have a compatible BE in their trigger field. This process occurs after the BE sampling time has expired (typically 3 to 10 ms).

Basic Event Distribution

During the Event sampling time, the BE generated by object instances are collected into different stacks, as previously described. When the BE Sampling time has elapsed, the Event Controller launches the BE *dispatching* process. This process consists in re-distributing the BE collected during the previous phase to the appropriate CE Generator object, the ones mentioning them in their Trigger section. The offline pre-processing operated on the CE prototype hosted by the CE Generators considerably accelerates this dispatching operation. As illustrated by the Figure 28 below, at the initialisation of the system, the Event Controller module accesses the definition of the CE associated to a particular environment (Figure 28-1) and associates each definition to a **CE Generator Object**, each of them representing a particular physical action recognition **(**Figure 28-2). In the meantime, it parses CE generators by Trigger types (i.e. Basic Event) into dedicated stacks (Figure 28-3).



```
[EIS_CE_DATABASE.CE_27_]
bCEActive=True
ContextEventID=0
CeID=26
ContextEventLabel=BREAK_ON_IMPACT
ContextEventDescription=
bLogEffects=False
blog_on=False
ContextEventProcessRate=0.050000
CEProcessor=CausalEngine
bUseClassAsType=True
aCEEnvironment=CAFE
TriggerEvents=BE_HIT
ConsumerType=(TypeId="EIS_OBJECT",cond=True)
InstigatorType=(TypeId="EIS_OBJECT",cond=True)
ConsumerProps=(PropId="FRAGILE",cond=True)
InstigatorProps=(PropId="HARD",cond=True)
ConsumerEff=(Eff_label="break_",Eff_id=14,Valu

[EIS_CE_DATABASE.CE_28_]
bCEActive=True
ContextEventID=0
CeID=27
ContextEventLabel=TILT_ON_IMPACT
ContextEventDescription=
bLogEffects=False
blog_on=False
ContextEventProcessRate=0.050000
CEProcessor=CausalEngine
bUseClassAsType=True
aCEEnvironment=CAFE
```

Figure 28: CE generators initialisation and pre-parsing into categories of basic event.

1 - Event loader extracts from our CE database the CE associated to an VR environment;

2 - The list of CE identified is provided to the event controller that generate their FSTN implementation (CE generator)

3 - to accelerate the recognition process, CE are parsed into stack according to the basic event defined in their trigger.

Therefore, at the beginning of the cycle, the Event Controller accesses stacks of BE collected, and reads the CE generators associated to them (Figure 29). A copy of the BE stack is transmitted to each CE Generator, this list of candidate events is then parsed against the CE definition held by the CE generator during a process called: CE Instantiation process. A successful recognition will lead to the generation of a CE.

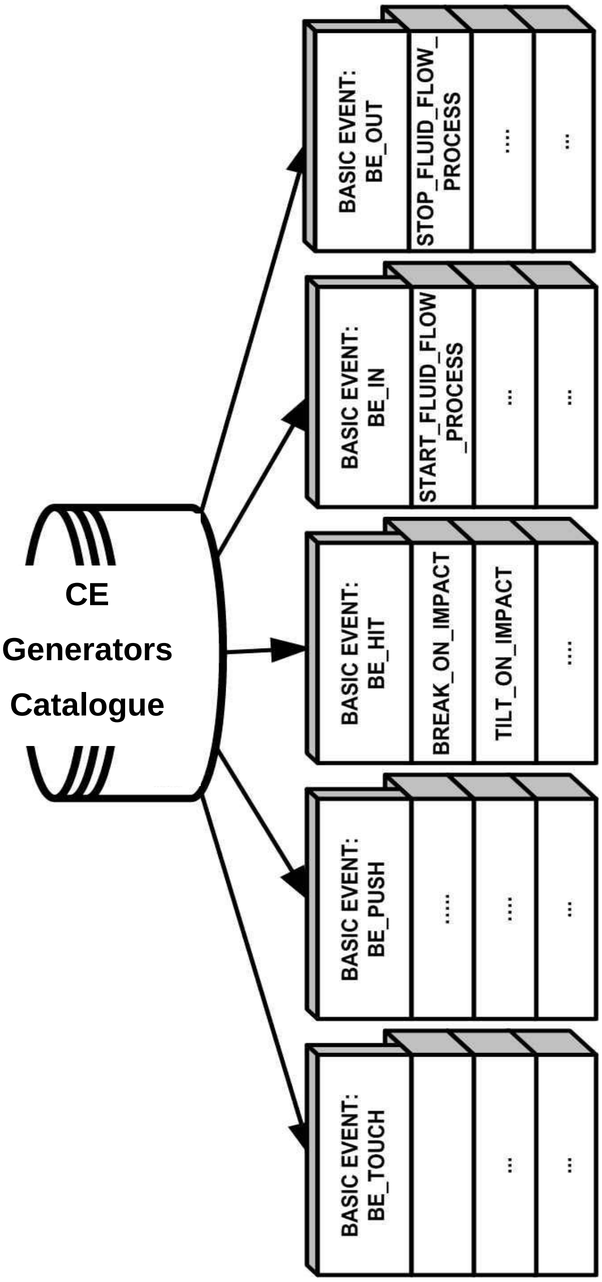


Figure 29: CE generator pre-processing based on basic event type

Our CE Generator models high-level events using underspecified Finite State Transition Network (FSTN) representations (Cavazza & Palmer, 1999). One action is represented by one FSTN, the overall recognition of the action itself is the product of the successful instantiation of the whole FSTN (we said that the CE has been instantiated). As illustrated by the Figure 30 below, each state in the graph is composed of an aggregation of `TYPE`, `STATE`, and `PROPERTIES` predicates. Parsing proceeds bottom up, and every time a new compatible event is received the FSTN instantiation restarts (or continues), until complete action recognition or early termination on failure (Figure 30).

Once activated by the reception of a list of BE, each CE generator acts autonomously (with its own thread) to recognise a particular high-level event. The CE Instantiation algorithm is executed when CE generators are activated and until the whole set of BE dispatched has been processed. This routine applies the CE condition predicates on the objects referenced by the BE. If the candidate object satisfies all of them, a CE is then instantiated. Otherwise, the next candidate is evaluated. The candidate events are handled in a FIFO (First-In-First-Out) fashion. Once instantiated, the CEs are immediately transmitted back to the Event controller.

In our example, the `Hit(glass#1 table#1)` BE activates several CE, among which the `Break-on-impact(glass#1 table#1)`. As previously mentioned, this step is optimised through off-line pre-processing, which indexes CE on their triggering BE categories. CEs, which have recognised compatible BE, are activated and become candidates for instantiation (see Figure 30-1 below).

Activated CE representations immediately execute their Condition predicates on those BE which have activated them. If objects involved in a BE instance satisfy the entire set of predicates, a CE instance is generated. In the falling glass example, `Substance (glass#1, FRAGILE)` is true (Figure 30-2), and so is `Substance (table#1, HARD)` (Figure 30-3). Hence a `Break-on-impact (glass#1, table#1)` CE is instantiated (Figure 30-4). Once a CE is generated, it becomes a target for transformation by the Causal Engine, and therefore it needs to be collected, formatted and transmitted to it through UDP sockets.

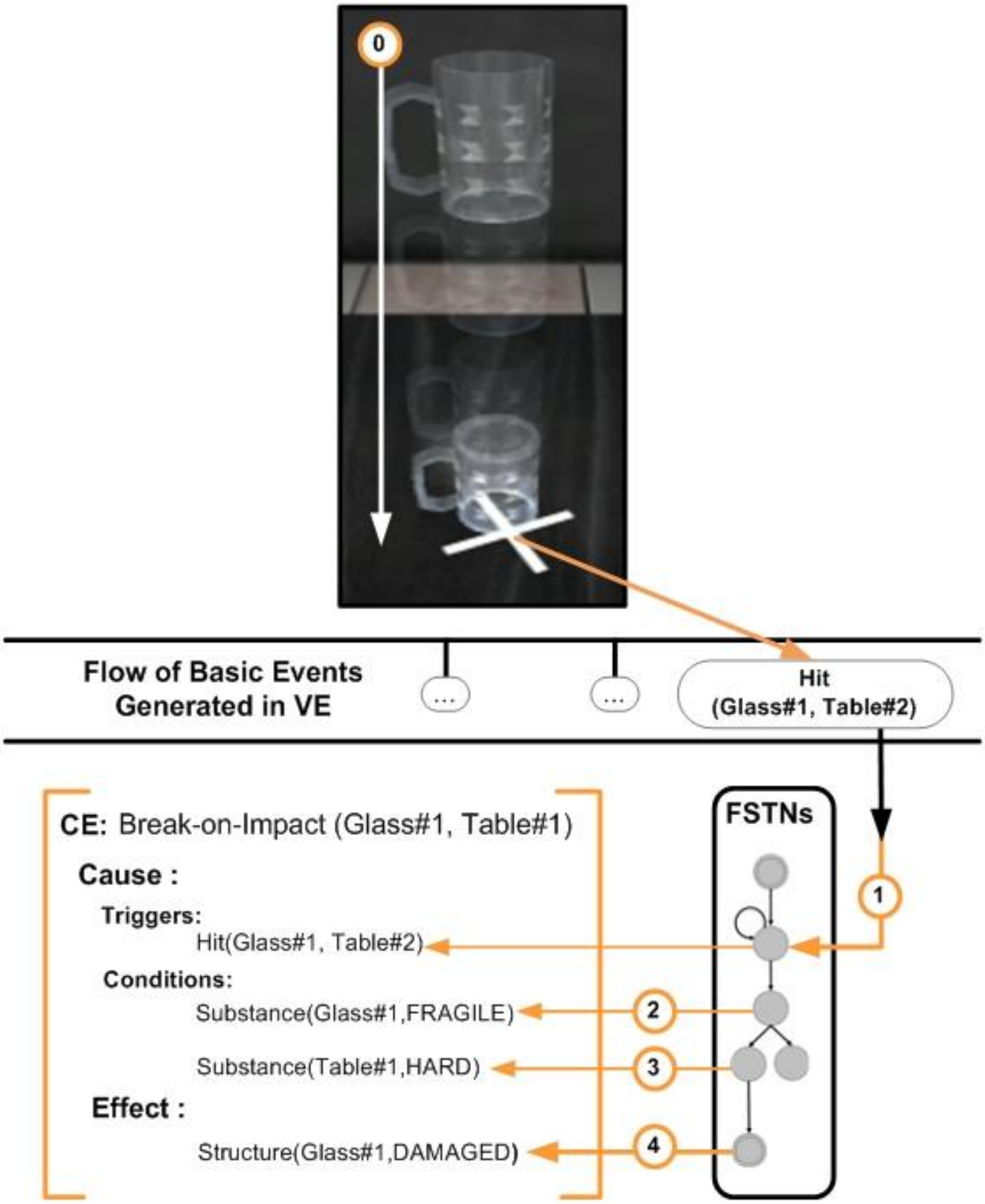


Figure 30: Action Recognition is achieved by parsing primitive collision/separation events into FSTN

In a parallel process, the Event controller continuously collects CE instantiated from the CE Generator into a dedicated stack. After the distribution of the Basic Event (phase 2), it controls the presence or not of event generated, and if one or many events have been received it launches the formatting process. The set of CE generated is then immediately serialised into data packet. The object pointer and effect name are translated to their corresponding ID. The objects' locations are also formatted at this stage. At the end of this process, the Event controller informs the Message controller (UDP interface) that a set of CE is ready to be emitted,

The UDP interface of the EIS is also running as an autonomous thread, which is activated when entering into its Sending state. The UDP interface accesses the set of formatted CE and starts to forward them to Causal Engine. The UDP communication has been previously established and synchronised with the Causal Engine during the initialisation of the system.

Once the last CE generated has been transmitted for further processing, the system enters its second main process named *"Event Co-occurrence Modification and Reactivation."*

Modification of Event Co-occurrences

The action modification process is entirely operated by the Causal Engine, and initialised for each new action intercepted by the EIS. This process relies on a heuristic search algorithm (Bonet & Geffner, 2001) coupled with specific operators, named Macro-Operator (henceforth MOp). Once initialized the Causal Engine enters into a cycle composed of three main processes running concurrently (Figure 31):

1. CE Reception
2. CE Modification
3. CE Transmission

CE Reception and Transmission processes simply represent UDP socket buffers, respectively receiving actions recognised by the EIS and sending back actions modified by to it. This part will mostly focus on the action modification process, which is re-initialised every time a new intercepted action has been received and unformatted into a proper CE structures. In matter of what they are now~~,~~ ready to be manipulated by our event co-occurrence modification procedure. At the end of this operation, the default consequence, previously inhibited in the virtual word, has instead been replaced by one or many alternative effects.

In the first part of this section, we will explain the Macro-Operator intervention on our high-level events structure. Then, we will illustrate their use in our search algorithm, while explaining the heuristics biasing our event modification search. In the second part, we will explain the effect execution system in further details

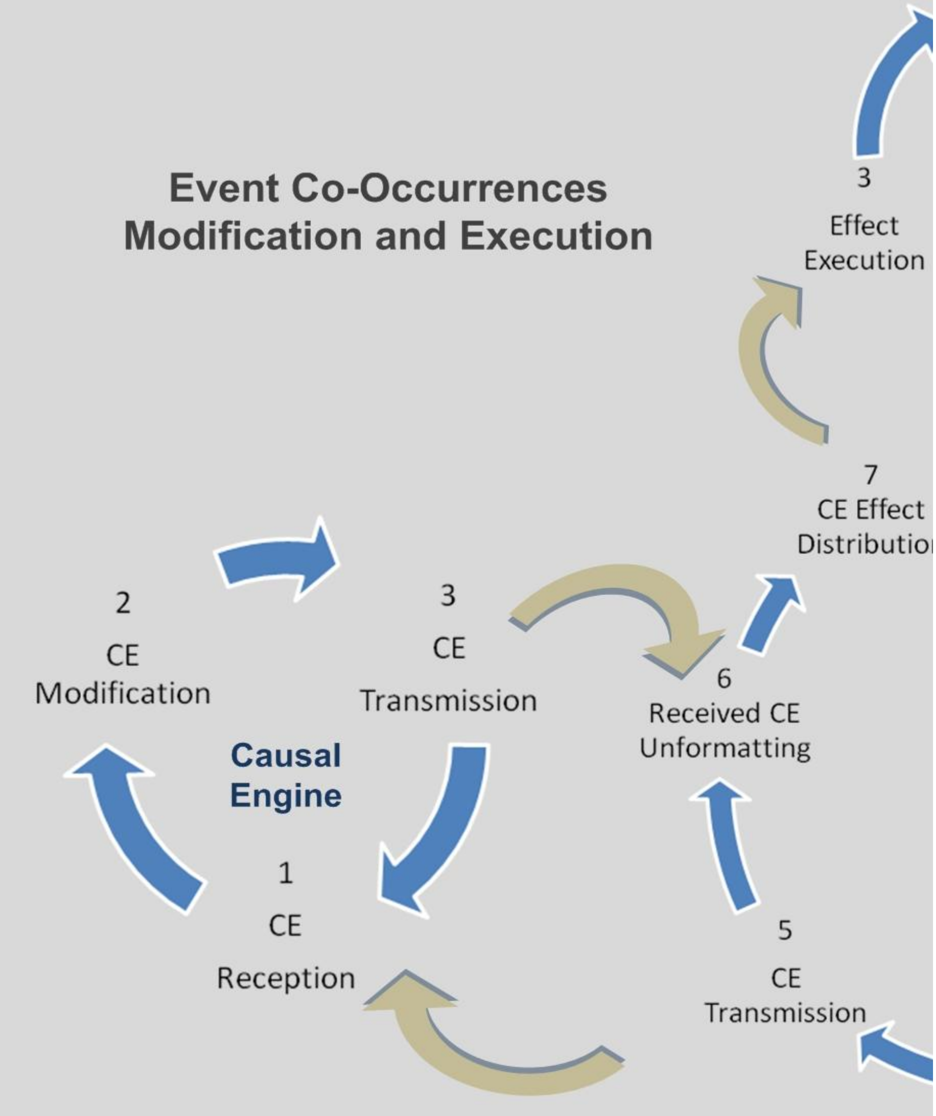


Figure 31: Event Co-occurrences modification main cycles

Once it receives a set of instantiated CE, the Causal Engine modifies the action's outcome by altering the effect field of the CE representation (Figure 32). The effect field contains an action (e.g., shattering) to be applied to the CE's objects (e.g., the falling glass). This is why the Causal Engine can modify either the type of the action, or the objects affected, or both. It does so by applying specific transformation operators (called *Macro-Operators* or *MOp*). The Macro-operators are a Knowledge-based structure, which operates transformations on an intercepted set of CE. The Causal Engine proposes two main Mops:

- The Change-Object MOp
- The Change-Effect MOp

The **Change-Object** MOp replaces the CE's object with another virtual world object. Its consequences are visible on Figure 32. The default object of the Break-on-impact CE is the falling glass, which should shatter on landing. The Causal Engine intercepts that event and substitutes the Break-on-impact object with another one, which is a table surface. As a result, the falling pint lands on the table, "causing" the table surface to shatter.

From the user's perspective, the normal cause-effect sequence is disrupted: the triggering event of a given CE, in this case the glass falling on a table (Figure 32-1), will be followed, not by its default consequence (e.g. the falling glass breaking (Figure 32-2)), but by an alternative effect (e.g. a table surface being shattered instead of the glass (Figure 32-3). This results in the table, rather than the glass, breaking upon impact, even though it is by default the hardest object (Figure 32-4). From an identical initial context, the same Change-Object MOp could have associated the other glass pint rather than the glass to the CE effect. This would have resulted in the nearby glass breaking without being directly hit.

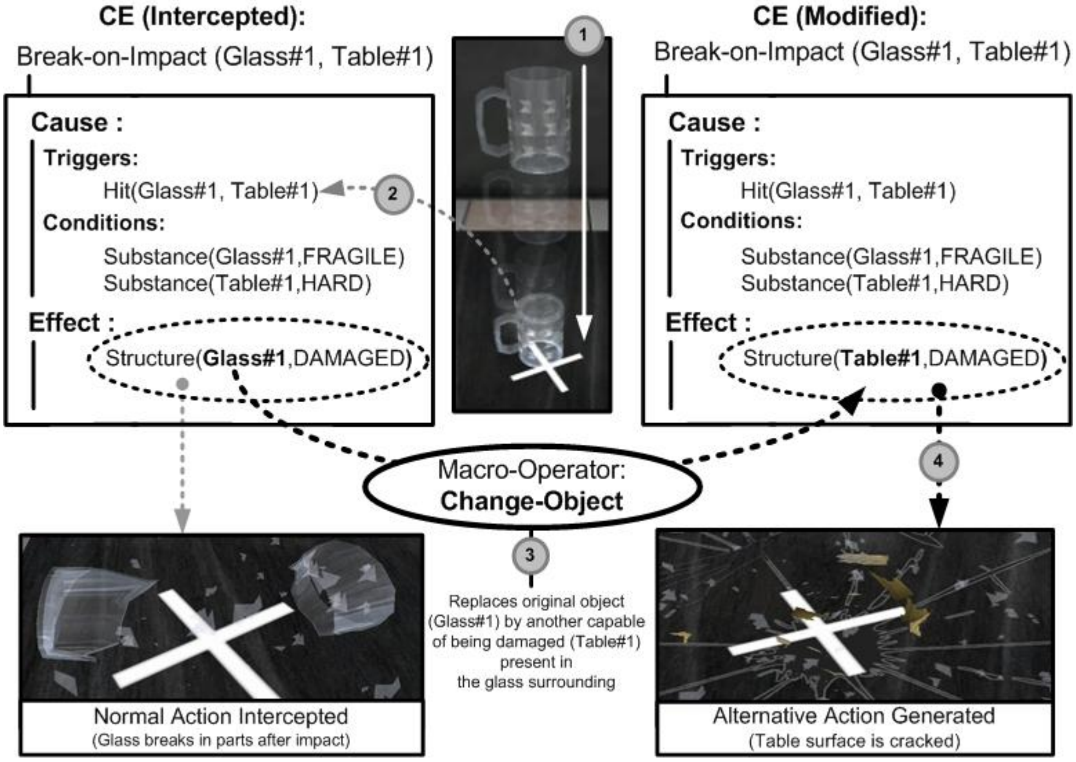


Figure 32: Example of application of the "Change-Object" Macro-Operator (Creation of artificial co-occurrence: here the table shattering instead of the glass breaking)

This also illustrates the use of generic procedures for effects, which depend on generic physical properties, associated with specific animation visualising object transformations. For instance, the generic state DAMAGED is automatically translated into *shattering* when applied to a glass, while, when applied to the table on which an object falls, it corresponds to the *cracking* of the table surface (Figure 32-4). Effect generation will be discussed in detail in the next section.

In a similar way, the **Change-Effect** MOp replaces the CE's effect with another one. In our example, the default effect: Break of the Break-on-impact CE could be replaced by the Tilt effect. As a result, the falling pint lands on the table, is tilting and consequently emptying its content on the surface of the table.

As explained in the following section, transformations involving objects or effect substitutions are based on semantic measures of action and object compatibility.

From the modifications of an intercepted action, the Causal Engine generates alternative consequences and evaluates their plausibility with regard to the normal effects expected. As shown on Figure 33, simple variations of a single parameter, called “*Level of Plausibility*,” supports the generation of different consequences, which vary from normal to plausible, implausible or completely unrealistic effects. We occasionally refer to this heuristic as the "*Level of Causality Disruption*" since, in a certain sense, it can also be considered as an amplitude of causality distortion when compared to realistic simulation.

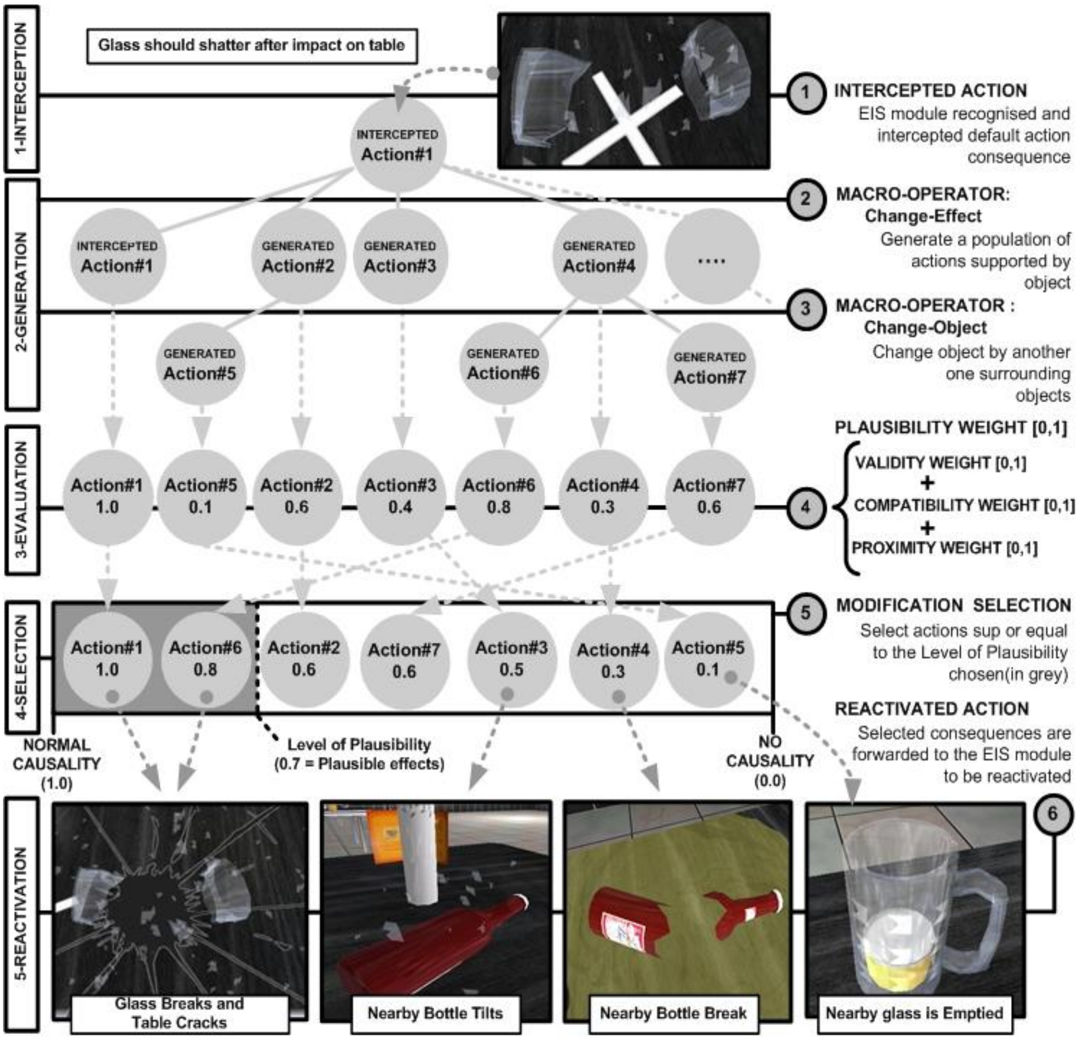


Figure 33: Level of Plausibility and the Action Generation Algorithm

The mechanism allowing such flexibility relies on a heuristic search executed by the Causal Engine, when an action in progress is intercepted by our EIS module (Figure 33-1). The search is based on three successive processes: ***Generation, Evaluation*** and ***Selection.***

- **The *Generation* phase** (Figure 33-2) creates a collection of potential consequences based on the population of objects surrounding the initial action location. The algorithm successively applies a list of Macro-Operators on the intercepted action. For our example, the algorithm is using two different MOPs: `Change-Effect` and `Change-Object`.

  As previously shown (Figure 32), those transformation operators create alternative actions by directly modifying the EFFECT type or the object of the action considered. Here, `Change-Object` replaces the Glass object instance (`Glass#1`) by the Table instance (`Table#1`), its closest object. Hence, if the modified action is reactivated, the table will suffer damages instead of the glass.

  In a similar fashion, the `Change-Effect` operator modifies the effect type of an action, replacing the default effect by another one supported by the object (Figure 33-3). For instance, the effect by which the structure of the glass is damaged (`Structure (Glass#1, DAMAGED))` could be replaced by a simple change in the glass' position (`Position (Glass#1, TILTED`), or `Movement (Glass#1, REBOUNDS))`. The change-effect relies on a small-scale effect classification, pictured by the effect state taxonomy below (Figure 34), which contains the generic state effect applicable in the environment. As previously explained, the 3D animation declared in those states could be customized at the object level. The successive combination of those two operators quickly generates a large set of possible effects around the initial action.

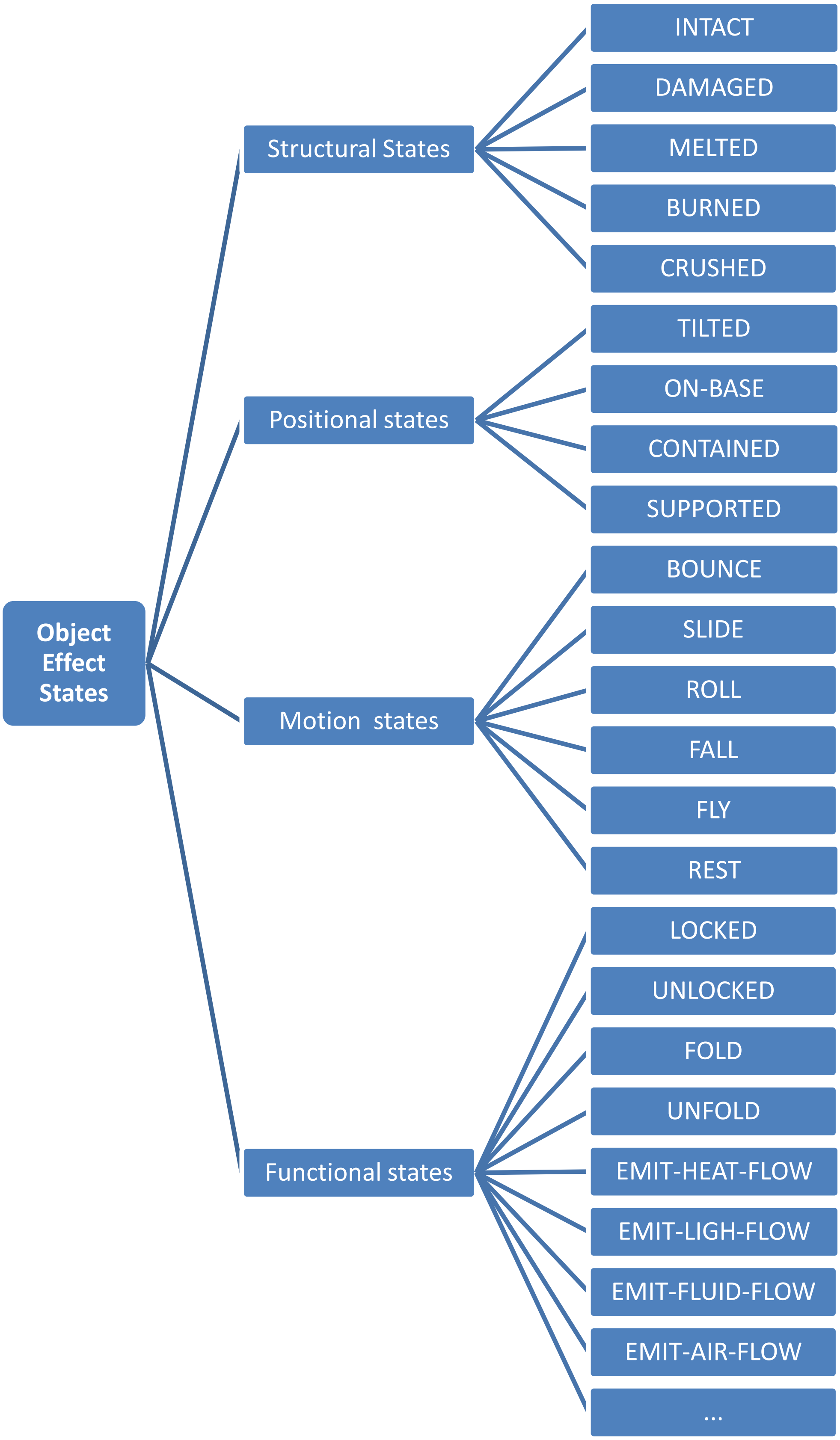


Figure 34: Effect Animation-state taxonomy used by the CHANGE-EFFECT MOp.

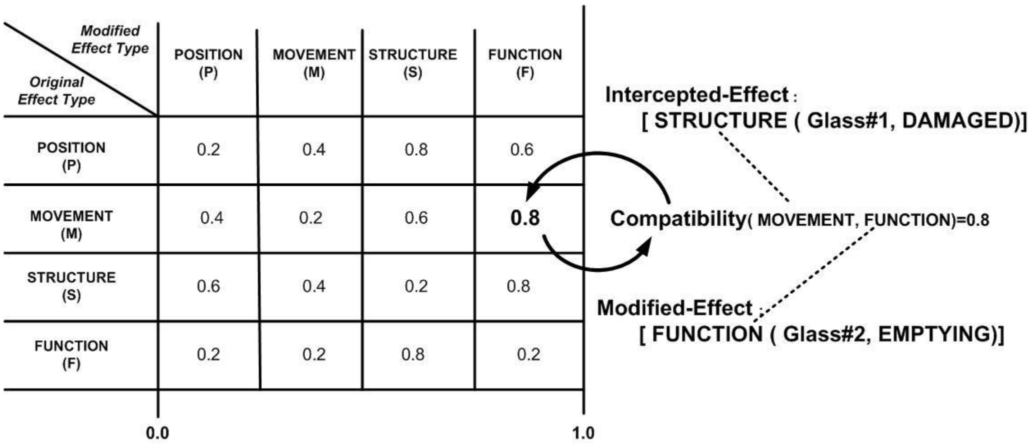
- **The *Evaluation* Phase:** Once the list of MOp has been executed, the collection of actions generated during the previous phase is evaluated in terms of Plausibility. As shown below, our system associates to each action a normalised *Plausibility* weight, which is calculated from three heuristic values named *Validity, Compatibility* and *Proximity* Weight.

Plausibility Weight = Validity Weight + Compatibility Weight + Proximity Weight

  - The *validity weight* simply considers if a generated action is actually applicable on an object by testing if the object, previously substituted by the MOp, satisfies the action's conditions. A validity weight of 1.0 means that the entire set of pre-conditions is satisfied. By contrast, a value of zero means that no object properties can satisfy the preconditions.

  - The *compatibility weight* is computed using a matrix associating a heuristic value to each possible combination of effect type (Figure 35). For instance, changing a MOVEMENT effect like Tilting by another MOVEMENT effect like Sliding, appears a lot less disruptive than replacing Tilting by a FUNCTION-type effect such as Emptying. The Plausibility matrix has been initially established by identifying analogies between potential consequences of a sample set of actions. In a subsequent step, the weights associated to the matrix elements have been readjusted according to feedback from preliminary user experiments discussed in the next chapter.

  - The *Proximity weight* evaluated the spatial proximity of alternative events regarding the original event's location. The plausibility of a modification is also considerably influenced by the spatial contiguity of co-occurring events. Based on the principle that correlation between distant events is less likely to induce Causal Perception, we have reinforced the plausibility weight by spatial considerations using a proximity weight. A spatial weight valued at 0.0 corresponds to the object's original position; a value of 1.0 represents the farthest object.



Modified Effect Type / Original Effect Type	POSITION (P)	MOVEMENT (M)	STRUCTURE (S)	FUNCTION (F)
POSITION (P)	0.2	0.4	0.8	0.6
MOVEMENT (M)	0.4	0.2	0.6	0.8
STRUCTURE (S)	0.6	0.4	0.2	0.8
FUNCTION (F)	0.2	0.2	0.8	0.2

Figure 35: The Compatibility Matrix:

Note: It provides heuristics based on the difference in type between the original effect and the modified one

- **In the *Selection* process** (Figure 33-5) our level of Plausibility is acting as a threshold to guide the search process towards plausible or implausible consequences according to its value. A level of Plausibility of 1.0 corresponds to the default consequence, while a zero value represents a total absence of effect. The possible alternative actions are then classified in decreasing order of their Plausibility weight. As a first step, the process extracts the set of actions with a value equal or superior to the chosen level. Then, for each object involved in this pre-set; it opts for actions closer to the desired plausibility level. Finally, the set of selected actions will be forwarded to the EIS module to be reactivated (Figure 33-6).

Figure 33 shows some co-occurrences generated by the Causal Engine for our "falling glass" example, for different tunings of the "plausibility" heuristic. In all realistic configurations the falling glass will shatter on impact, but the system will generate additional effects, resulting in some of the example associations depicted on Figure 33 (for instance, the falling glass will shatter upon impact on the table, with additional effects affecting one neighbouring object, e.g. the cardboard menu falling). It should thus be noted that realistic effects do not result from the use of the default's Physics engine: they are still artificial effects created by the system, which are simply plausible. Plausibility being defined as the preservation of basic physical mechanisms formulated by our CE Catalogue (the original intercepted CE's effect: the falling glass still shatters) and certain physical compatibility in between effects type. The definition of implausible causality rests on the creation of event co-occurrences for which no straightforward relations exist between events. For instance, upon impact of the falling glass on the table, another glass will start emptying itself without its walls being cracked or the glass tilting at all.

Effect Reactivation

Once the Causal Engine has modified event co-occurrences, the "reactivation" of their new effects is in charge of the EIS module. The whole procedure is divided into four main operations ():

1. CE Reception
2. CE Un-formatting
3. CE Effect Distribution
4. CE Effect Generation

The CE Reception process is an asynchronous process where the EIS Message controller continuously receives and stores datagram coming from the Causal Engine in a FIFO stack. In opposition, the Event Controller will enter the **CE Un-Formatting phase**[12] right after the CE Transmission Phase (described in the Event Recognition and inhibition cycles)**.** During this phase, the list of received CE is copied and un-serialised into proper CE structures. Once the entire set of CE is unformatted, the

---

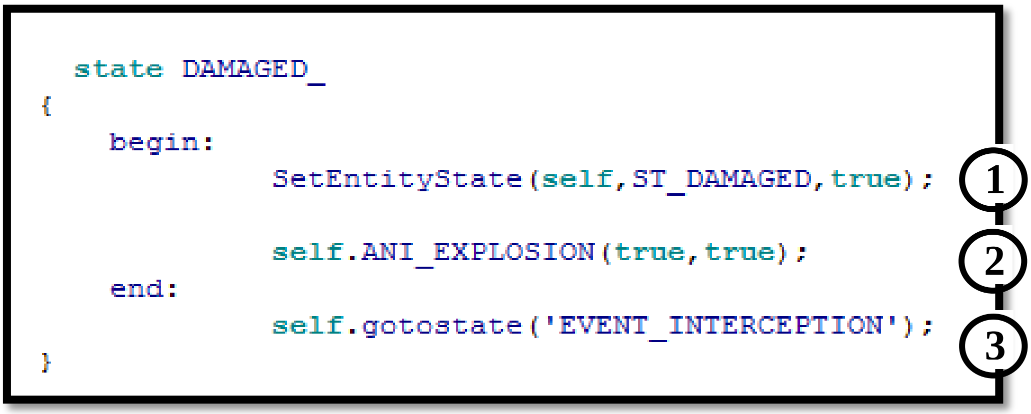
[12] *Notes:*

The CE Un-Formatting and Reactivation Process are dissociated to trigger sets of alternative effects during the exact same cycle. This is relevant when the Causal Engine produced more than one effect for the alternative consequence of one event (such as the glass breaking and the menu beside it tilting after the glass-table impact event). A gap of two cycles between two effects, which are supposed to be simultaneous, could create a noticeable interval between them. This could considerably affect the user's causal impression as the two effects could be perceived as successive, and therefore probably interpreted as another causal chain, the first effect causing the second effect. The separation of the un-formatting and reactivation process and the presence of similar time-stamp on simultaneous effect prevent such side effect.

Event Controller immediately launches **the CE Distribution process**. In this step, the modified effects and their arguments are extracted from the CE structure to be converted into an Unreal script state name, object references and variables. The Event controller requests virtual object instances referenced in the CE Effect field to enter into the corresponding Unreal state, which contains a procedural description of the 3D animation to execute. The **CE effect Generation** is then handled at the virtual object instance level.

In our system, effects are implemented at the class level in terms of object state. This programming approach within an object-oriented scripting language allows an explicit and generic description of a large population of effects while leaves their implementation details at the class level. Moreover, The Unreal script native features facilitate and encourage states programming and overloading. The code snippet demonstrates the implementation of a generic DAMAGED effect as an unreal script state. This state comprises three operations:

1. It updates the semantic representation of the object (Figure 36-1)
2. It executes animation function (Figure 36-2)
3. At the end, it automatically redirects to the object to its EVENT INTERCEPTION state (Figure 36-3)



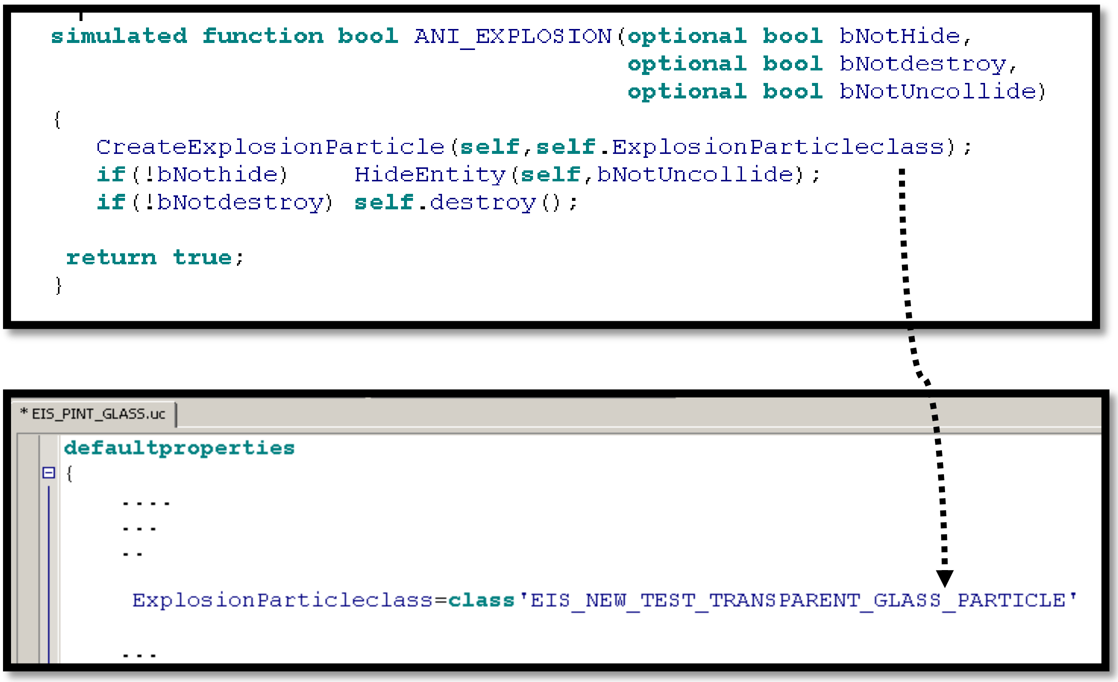
```
  state DAMAGED_
{
    begin:
             SetEntityState(self,ST_DAMAGED,true);

             self.ANI_EXPLOSION(true,true);
    end:
             self.gotostate('EVENT_INTERCEPTION');
}
```

Figure 36: Example of an effect implementation. *Note: the ani_explosion function is overridden in child class*

Our implementation consists of a predefined list of Unreal scrip state declarations (such as the one presented on Figure 36 above) member of the object root class of our EIS Framework. Each effect state is associated with an explicit update of the object's semantic properties (`SetEntityState (self, ST_DAMAGED)`) which update the semantic representation of the object, and therefore supports future recognition or potential application of action with this particular object instance .

An EFFECT state can be rather complex and involves a cycle of multiple type animation procedures. The complexity of the effect depends on its local implementation at the object class level. For instance, a table and a pint breaking do not use the same animation primitives (particle emission versus texture change). The second Figure 37 illustrates for a simple effect how a generic "*Explosion*" animation can be customised at the object class level, by a simple variable initialisation in the default properties of our `PINT_GLASS` Unrealscript class. In this case, the variable is pointing on a particle system responsible of the glass fragment animation (Figure 37). At the end of the **CE Distribution process**, the Event Controller waits for another *Basic Event sampling time* to elapse before re-starting the overall cycle.



```
simulated function bool ANI_EXPLOSION(optional bool bNotHide,
                                      optional bool bNotdestroy,
                                      optional bool bNotUncollide)
{
   CreateExplosionParticle(self,self.ExplosionParticleclass);
   if(!bNothide)     HideEntity(self,bNotUncollide);
   if(!bNotdestroy) self.destroy();

 return true;
}
```

```
defaultproperties
{
    ....
    ...
    ..

     ExplosionParticleclass=class'EIS_NEW_TEST_TRANSPARENT_GLASS_PARTICLE'

    ...
```

Figure 37: Example of generic effect animation procedure

(Notes: The class "EIS_PINT_GLASS" object only provides the particle system to spawn, the "BREAK" state, and ani_explosion function are generic to any object).

Causal Perception Determinant: System Response time

A first evaluation of the system performance consisted in comparing its response time with data from psychological literature. According to psychological literature, there exists a minimum delay between two consecutive events for these to elicit Causal Perception. In the original experiments from Michotte (1963), events delayed by more than 150 ms progressively ceased to be perceived as causally linked. Buehner and May (2003b) contrasted “immediate” and “delayed” action-outcome sequences. The average response time on immediate pairings was “less than 0.25 s” and participants assessed action-outcomes contingencies under such a schedule accurately. When interpreting Michotte-style launching events, Kruschke and Fragassi (1996) considered that motion *ampliation* (considered to account for causal impressions in Michotte’s theory) took place within a critical 200 ms interval. Recent research led by Fugelsang et al. (2005a, 2005b) also confirmed the strong status of these spatiotemporal factors. This research demonstrated that “launching effect” movies containing temporal gap over 330 ms, or spatial gap superior to 1.2 cm, respectively elicited causal impression only on 4.2 % and 10.4 % of the trials. Such extreme temporal and spatial setting successfully eliminated the impression of causality. Conversely, other movies that represented a strict “launching Event” have elicited an extremely high rate of causal impression (95.8 %). In overall, the system performance is in line with its initial design constraints, which imposed a response time below a threshold of 150 ms. With a population of 100 objects and 30 actions, the action recognition and reactivation process is achieved between 40 ms and 60 ms. Meanwhile, the action modification process is executed in a range of time of 20-60 ms. Our tests have shown the overall response time to be on average 90-100 ms.

This data suggests that the system’s response time is compatible with results from the psychological literature: consequently, the co-occurrences generated should be perceived by the vast majority of subjects as sufficiently close to induce Causal Perception. There is no indication as to how the system should scale-up to more complex environments. However, Causal Perception can only take place within the focus of attention of the user, which somehow suggests an upper bound on the environment’s complexity.

Alternative Event Generation: Level of Causality Disruption

The combination of Common sense physical causality representation, event interception and heuristic search provides an original approach that allows a systematic exploration of an event co-occurrence transformation space**.** The innovative aspect of our system lies in the possibility of adjusting dynamically the plausibility of an action's output using single variable without specifying manually the consequences of a given action in a given context. The actual generation of co-occurrences is thus dynamic and context-dependant leading to the production of variable effects (in both nature and order) for each user. The level of Plausibility is one essential aspect of the system as it allows exploring different amplitudes of causality disruption, and so to "program" alternative realities based on a high-level concept (i.e. our level of plausibility).

Conclusion

In conclusion, the system performances satisfied Causal Perception determinants, and its design allows to control the amplitude of the physical causality modification based on generic principles (*i.e. Level of Plausibility*). However, the capacity of the system to elicit Causal Perception from alternative physical causality needs now to be properly experimented with user studies. Consequently, the following chapter describes different user experimentations within the system. Our first experimentations will study causal impressions left on users while facing such alternative physical causality. Our main intention with these experiments is to evaluate the role of pure realistic event co-occurrence against causality-inducing ones.

CHAPTER 4: EXPERIMENTING ALTERNATIVE CAUSALITY

Introduction

In this Chapter, we describe a set of user experimentations, through which we evaluated the central hypothesis of the thesis: *The capacity to elicit Causal Perception from alternative physical co-occurrence*. The system described in Chapter 3 has been used to create a realistic virtual world, a “Pub-like” environment, where causal laws differ from our everyday reality. Two main experiments have been realised within this environment, and the aim of the chapter is to discuss their protocols and results.

Hypothesis and Methodology

Previous research in the psychology of Causal Perception has shown that temporal and spatial contiguity plays a pivotal role in human causal induction. We have constructed our “Causal illusion” hypothesis and generation principles around this assumption. The experiments described here, aimed at an empiric proof that contiguity-bias may over-ride high-level considerations of causal mechanism, and consequently sustain the illusion of Causality.

Therefore, in the following experimentations, we investigated the creation of causal impressions from artificially generated co-occurrences. We posit that alternative physical event-concurrences generated by our system, based on cognitive data and action analogy, will elicit Causal Perception on the user. Both experimental environments rely on our heuristic search to create alternative consequences to user-initiated actions. These experiments attempted to measure the causal relation attributed or not by subject by analysing their textual descriptions of virtual scenes displaying Alternative Causality. The difficulty to extract evidence of causal attribution from textual description is also discussed in this section.

Prior to the description of our experimentations, we review previous work on Causal Perception in the field of interactive systems. Following this, we explain our experimentation settings and results; both experiments propose different types of user interactions and environments. The second experiment completes the results obtained from the first one, and includes an improved experimental protocol and result analysis

The study of Causal Perception constitutes an important topic not only for cognitive psychology, but for a variety of Human-Computer Interface systems, as a better understanding of Causal Perception has implications for user interfaces (Ware et al., 1999; Besnard et al., 2004),or even knowledge-based systems as event structure plays an important role in knowledge representation (Zacks & Tversky, 2001). Yet, while a number of psychological phenomena have been studied in relation to Virtual Reality (VR), very little work has been specifically dedicated to Causal Perception (despite its strong influence on human interaction). The only specific studies of techniques for enforcing causality have taken place in distributed virtual environments (see e.g. (Roberts & Sharkey, 1997)), and have investigated the correct propagation of consequences, rather than the fundamental determinants of Causal Perception. Only recently, Causal Perception has become a popular research topic for a variety of graphic interface systems, as the understanding of Causal Perception has potential to develop better visualisation systems (Ware et al., 1999) and animation systems (O'Sullivan & Dingliana, 2001; O'Sullivan, 2005; O'Sullivan et al., 2003; Reitsma & O'Sullivan, 2008).

Dingliana's psychological experiments (2001, 2003) demonstrated that believable real-time physics simulation should imperatively preserve a user's causality perception (Figure 38). They argued that such system should therefore implement a collision-handling process automatically interrupted beyond a 100ms-300ms delay after collision. This data is corroborating Michotte's early experimental studies, and evidences the potential of perceptually-adaptive simulation for interactive systems. In more recent research, O'Sullivan (2005) added that the degree of attention (Scholl & Nakayama, 2002), as well as the nature of the dynamic event, also play a role in its believability. Reitsma & O'Sullivan (2008) compared perceptual sensitivity in physical simulations in both realistic and abstract settings. In both types of environment, participants are predominantly affected by spatiotemporal errors in rigid body collisions. Spatial gap and delay considerably reduced the animation’s perceived plausibility. To a certain extent, their results in 3D realistic environment corroborate Michotte's observation in 2D symbolic display. O’Sullivan & Lee (2004) also worked on the user prediction of collision trajectories, using computer graphics models of pool tables. The only specific work on the visualisation of causal relations is that of

Ware et al. (1999), which however only addresses two-dimensional, non-interactive visualisation.

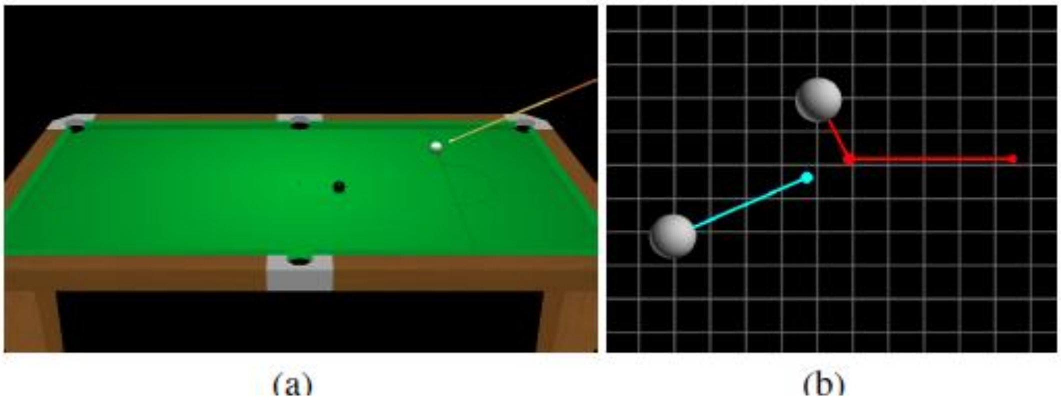


Figure 38: Example of Causal Perception Experiments

Notes: Screenshots of causal event and with path of the object shows in red (striking) and blue (struck).Figures reproduced with permission from O'Sulivan studies (O'Sulivan, 2005; Reitsma & O'Sullivan, 2008)

In the field of cognitive psychology, Causal Perception studies have been carried out using simplified and non-interactive 2D display (Scholl, 2007; Fugelsang et al., 2005a; Roser et al., 2005; Scholl, 2007; Leslie, 1982, 1984, 1988; Leslie & Keeble, 1987; Oakes & Cohen, 1990; Oakes, 1994; Choi & Scholl, 2006b). One notable exception has been the research of Wolff and his collaborators (Wolff & Zettegren, 2002; Wolff, 2003, 2007) which has made extensive use of 3D animations to elicit Causal Perception in subjects watching them (Figure 39), mostly, in order to analyse causal vocabulary. However, these animations were non-interactive, which means that their content had to be entirely scripted in advance, and did not investigate Causal Perception in response to events initiated by the user.

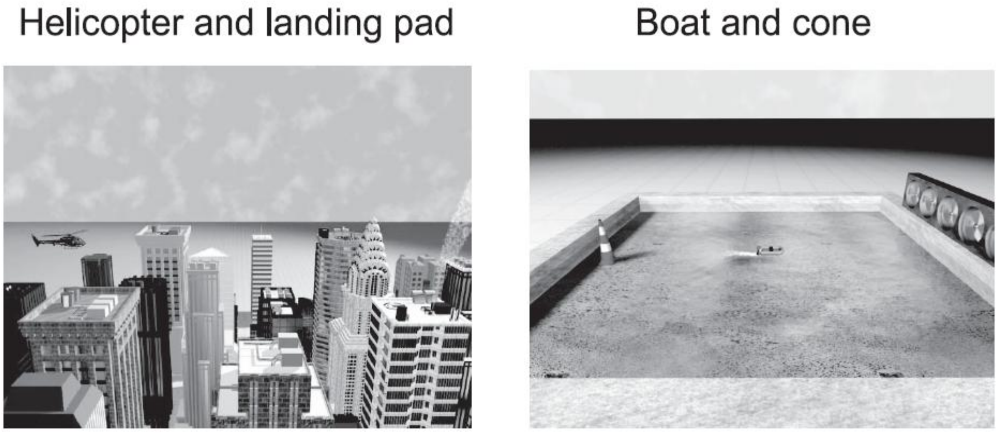


Figure 39: 3D animations used in Causal judgment studies (Figures reproduced with permission from Wolff (2002, 2007)

PRELIMINARY EXPERIMENTATION – *“The Falling Glass”*

In this experiment, the setting consisted of a table supporting several objects, which were two glasses and a cardboard menu (see figure below). The users were instructed to grasp one of the glasses, lift it above the table, and then drop it so it would fall vertically on the table. The default effect, the one that would be obtained through a realistic physical simulation, consists for the glass to shatter on impact.

However, in this experiment, the Causal Engine was parameterised so as to create an alternative plausible consequence to the glass shattering, involving the other objects standing on the table (and the table itself). More specifically, upon impact of the dropped glass on the table this can result in the following effects taking place, instead of the shattering of the glass: the cardboard menu falls; the nearby glass tilts over, spilling its contents; the tables surface cracks; the nearby glass shatters (see Figure 40).

Generation of Object Behaviour

The whole experimentation is backboned by our Artificial Causality VR system, which will create the different consequences to our falling glass action according to the event location and surrounding context. As previously described, the system is composed of three main components (please refer to the implementation chapter (Chapter 3) for further details).

- A Game Engine (Unreal Game Engine) for visualization, interaction and physical simulation.
- An Event Interception System for the recognition of default consequence, and their inhibition.
- A Causal Engine, responsible of the alternative consequence generation using a heuristic search process inspired from search-based planning.

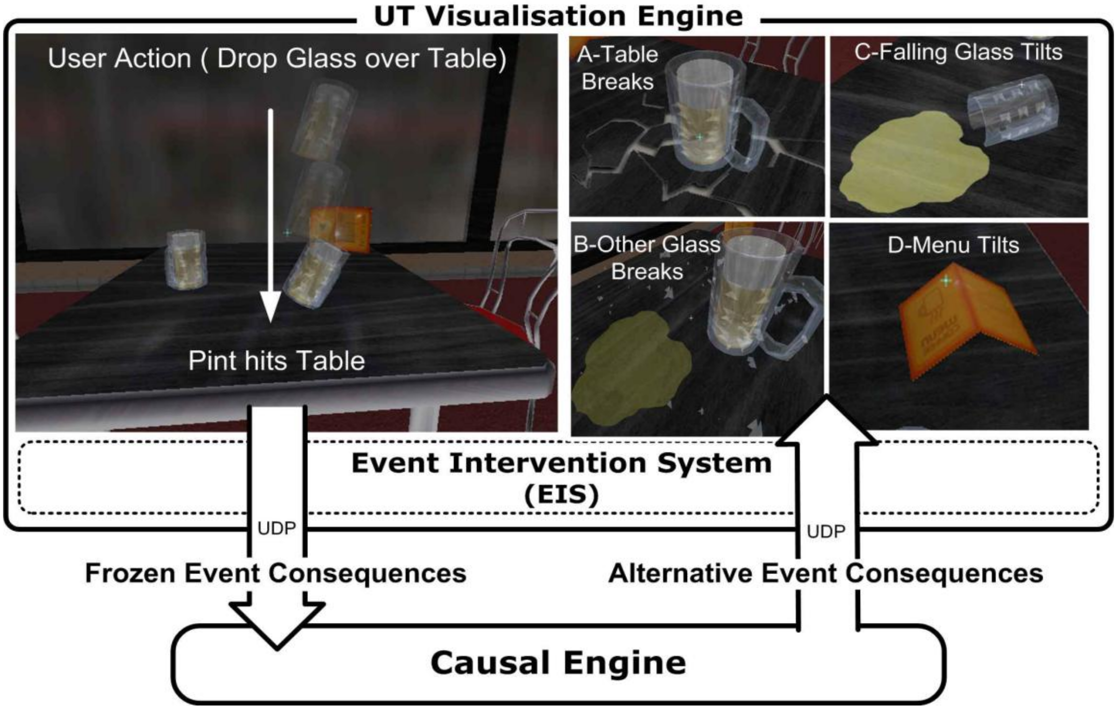


Figure 40: Possible alternative effects generated for "Falling Pint"

Note: The user would normally expect glass to shatter upon the impact after a nearly one-meter fall. However, our system produced alternative to this default behaviour:

A) We substituted the object to be damaged while the glass is slightly bouncing of the table, the table is cracked around the impact point.

B) Another substitution, with the shattering of another glass (than the one falling) situated around the impact point.

C) A substitution and modification of the nature of the effect, this time the menu is tilting upon the impact.

D) As for c) but this time, the other pint (standing on the table before the impact) is tilted after the impact.

Experimental Protocol and Settings

Thirty-three subjects took part in this experiment. Subjects were facing an 18-inch screen from a distance of 30-45 cm. The corresponding field of vision in the virtual environment was approximately 80 degrees.

After being explained the basic interaction mechanisms for grasping, lifting, and dropping objects in a similar environment, subjects were given instructions for the task they had to carry out. Subjects were instructed to repeat the task four times on four different tables and to give a short textual explanation of what they observed after each repetition of the task. In addition, at the end of the experiment they were asked to identify the topic, which best described the subject of the experiment in a multiple-choice question between:

a. Physics
b. Causes and effects
c. Interacting with objects

Results and Discussion

As an outcome of this first experiment, 80% of subjects identified causes and effects as the main topic of the experiment. When we analysed the textual descriptions provided, we encountered explicit causal descriptions of the phenomena observed, such as "*seems to have caused the other pint to fall down*", "*as a consequence, the menu fell off the table*", "*caused glass nearby to tip over and spill its contents*", etc. Several subjects perceived a causal link between co-occurring events, but provided in addition mechanistic explanations, such as the fact that vibrations accounted for the perceived causality. This was in particular the case for two cases of action-outcome: the fall of the cardboard menu from the table ("the menu fell on the ground because of the vibrations of the table") and the tilting of the second glass following the impact of the falling glass on the table ("the vibrations of the table induced the falling over of the second glass present on the table"). This is consistent with reports linking Causal Perceptions to mechanistic explanations (Scholltman, 1999). These results confirm the existence of Causal Perception in these experiments. However, in this experiment it proved difficult to derive quantitative measures from the textual descriptions given, as a significant proportion of subjects failed to give explanations at all, limiting themselves to a mere description of events.

ADDITIONAL EXPERIMENTATIONS – “*The Pool Table*”

In this experiment, the virtual environment consisted in a set of pool tables *(an implicit tribute to Michotte)* each supporting several objects on the front edge of the pool table. These were a lightened candle, a glass and a bottle. A pool stick was also positioned vertically against one of the sides of the pool table (see Figure 42).

The subjects were presented with the following task, which consisted in trying to strike the red ball with the cue ball, taking one rebound on the front cushion. For each pool table, the impact of the cue ball on the cushion creates a bouncing event that is the main target for our alternative causal simulation. This event has an action part, which is the impact and an effect part, which is the new motion of the ball. In this experiment, alternative effects were propagated to the nearby objects by the Causal Engine, creating artificial co-occurrences

Generation of Object Behaviour

Al previously described; our Alternative Causality system (Figure 41) is composed of three main components (please refer to the implementation chapter for further details)

- A Game Engine (Unreal Game Engine) for visualization, interaction and physical simulation.
- An Event Interception System for the recognition of default consequence, and their inhibition.
- A Causal Engine: responsible of the alternative consequence generation using a technique inspired from search-based planning relying on specific action alteration operator, named Macro-operator.

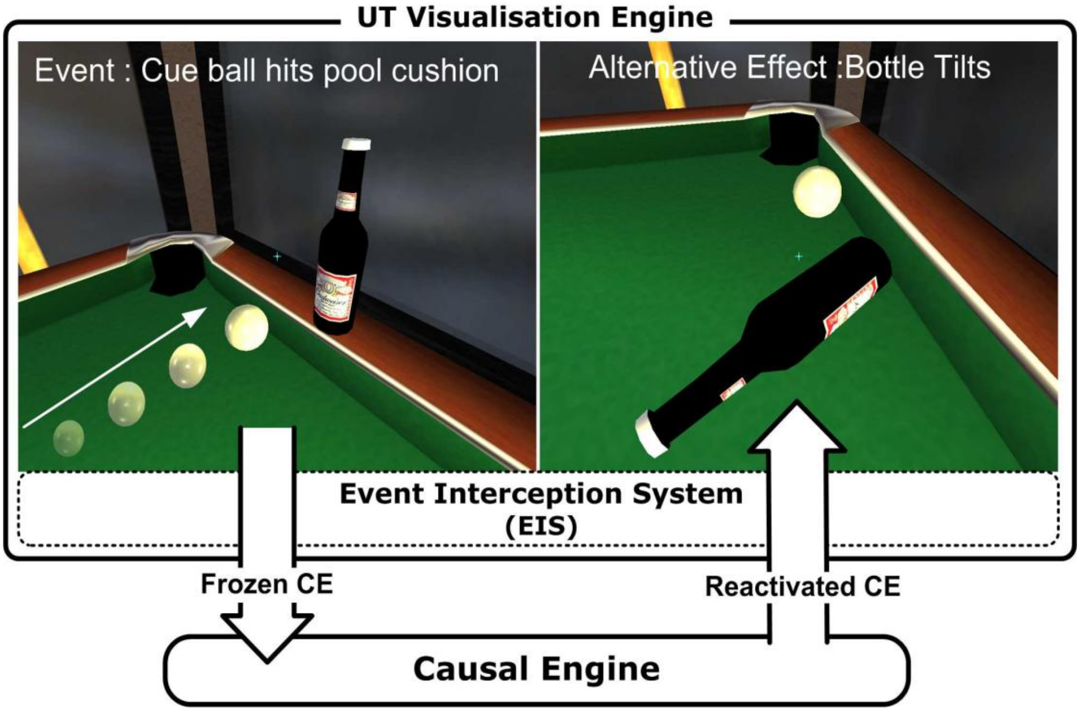


Figure 41: System Architecture and Event Interception

In this experiment, these effects are chosen by the Causal Engine according to the event context, and in order to maximize the elicitation of Causal Perception between the ball's impact and the additional physical effects generated. In example of alternative effects that have been triggered to the various objects is illustrated by the Figure 40 below: the candle can either fall or be blown off, and the glass (and bottle) can either fall or shatter. In addition, the pool stick leaning against the border can fall to the ground.

Figure 42: Experiment B - Alternative Effects for the “Bouncing Cue Ball

We carried the experiment with twenty-three subjects who were facing an 18-inch screen from a distance of 30-45 cm. The corresponding field of vision in the virtual environment was approximately 80 degrees. There was virtually no overlap with the subject population of the previous experiment.

For each experiment, the subjects where this time instructed to give a free text explanation of the events immediately after each try. Once again, the instructions did not contain any mention of cause, causality, etc. or what the experiment was about. Each subject has to repeat this task four times, on four different pool tables, each with its own disposition of the red ball and cue ball, but an identical line-up of objects standing on the border. The position from which they could shoot was also constrained so that their viewpoint on events would be largely identical across experiments. The respective positions of the two balls was modified in the four pool tables so as to force the rebound to take place next to different objects on the cushion, assuming the right aiming angle was taken. Aiming was taking place, like in most computer pool games, by pointing at the cue ball with the mouse pointer. Subjects were allowed to practice this skill on a dedicated table prior to the experiment so as to familiarise themselves with the interface. The force with which the cue ball could be struck was left constant and not controllable by the user, as distances from the balls to the front edge did not vary from table to table.

At the end of the experiment, they were asked again to identify what in their view had been the topic of the experiment using the same multiple-choice question as above.

In addition, each subject was asked, after completion of the four trials, to identify the subject of the experiment amongst:

a) Causality (“causes and effects”)
b) Physics, and
c) Interaction with objects.

Analysis of Causal Descriptions

"The white ball impact to the top cushion causes the lite candle to fall on the table."
"The ball was hit, missing the red ball, this caused a pool cue to fall over"
"This is caused by the impact of the white ball"
"The bottle fell off because the cue ball is hitting the cushion hard"
"The force brought by the white ball made the empty glass fall down"

Example of Textual descriptions given by participants

The interpretation of free text descriptions is faced with several difficulties. The method we decided to use consisted in counting for each explanation the occurrences of causal vocabulary. The method we decided to use consists in analysing each individual explanation for causal expressions corresponding to linguistic descriptions identified by Wolff (2003). We considered each explanation that included such expressions as a causal explanation, regardless of the number of occurrences of causal expressions in the explanation.

We have applied this method in a rather conservative way, preferring to underestimate Causal Perception rather than over-estimate it. For instance, we discarded statements such as "*the ball hit the border, the beer bottle tilted*," which is actually a description of the co-occurrence itself that may or may not intend to convey a causal content.

We have retained the following expressions as causal:

- **Use of explicit causal vocabulary** ("causes", "causing", "caused by"), as in "this caused a pool cue to fall over", "[…] causing the glass to fall onto the pool" , "the glass fell and smashed causing the bottle to fall over", "glass shattered causing candle to fall over".
- **Expressions introduced by "because"** provided they included an action description (such as *"hit," "stroke", "bounced"*). In that sense "*the bottle fell off because the cue ball is hitting the cushion hard*" will be considered as causal, but not "*the glass broke because I aimed at it*".

- **Any expression such as “make N V”,** where N refers to an experiment’s object and V stands for a verb indicating motion transfer or change of state (the effect), such as *“fall”, “move”, “tilt”* or *“break”, “shatter”,* etc. For instance, “*the force brought by the white ball made the empty glass fall down*”.
- **Action verbs** relating an agent object to a patient one, as in “the movement created extinguished the flame,” “the force of the cue ball knocked an object off the side of the table,” etc.
- **Lexical causatives** (verbs that allow speakers to describe a causal situation in a single clause, as listed in (Wolff, 2003), e.g. *“when dropping the glass it moved the other glass along the table”*
- **Two-argument activity verbs** (also listed in (Wolff, 2003)) whenever their effects are also mentioned (to overcome one of Wolff’s objections), as in the following *“glass shattered also knocking card over”* or *“when dropping the glass, it broke and the pieces hit the candle which in turn fell over”*.

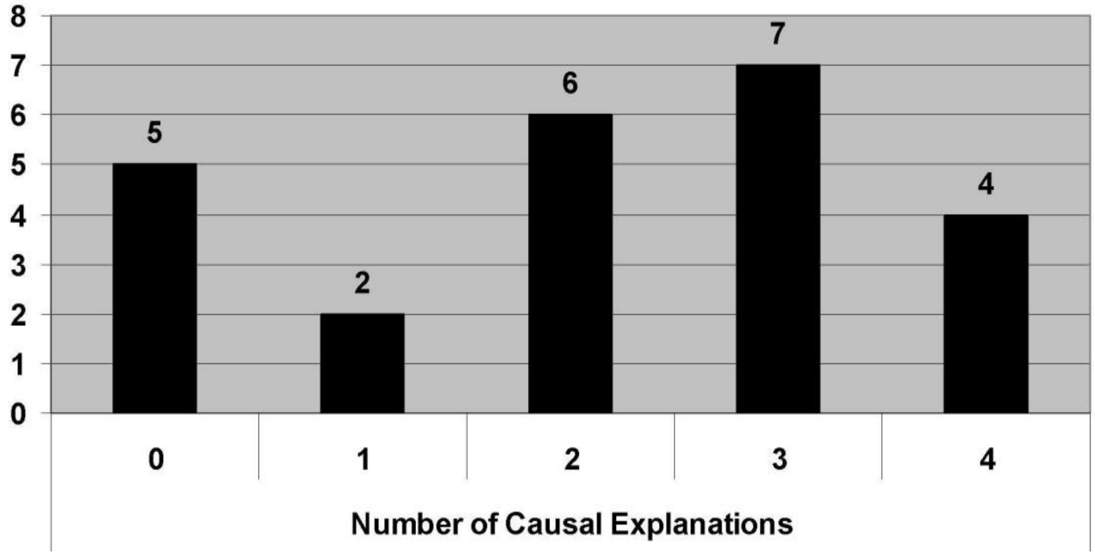


Figure 43: Frequency of causal explanation by subject.

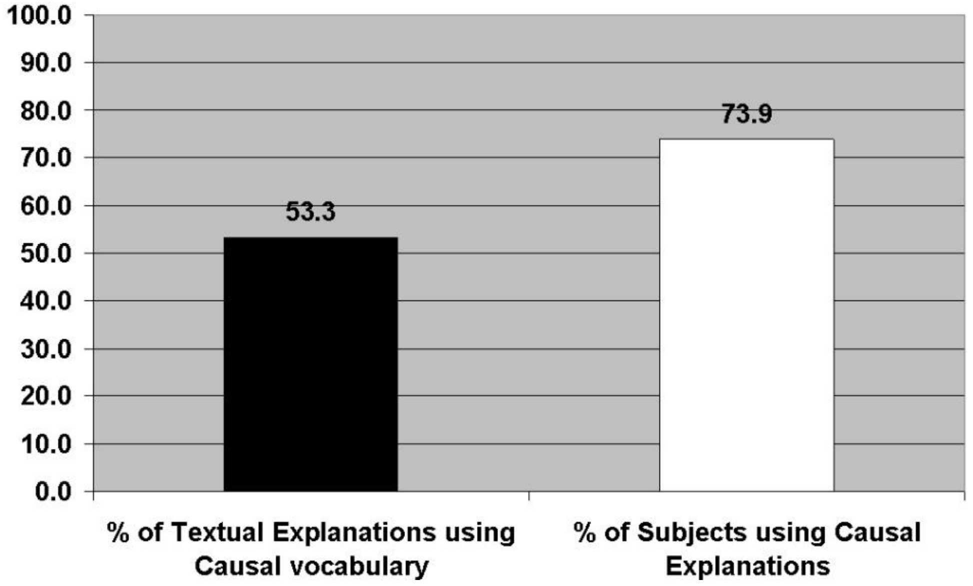


Figure 44: Occurrences of causal descriptions in textual explanations.

We used a concordance software (“Simple Concordance Program” v. 4.07 by A. Reed) to analyse the textual descriptions. This program provides a list of vocabulary and supports “keyword in context” analysis. Using the program, we confirmed the occurrence of causal vocabulary as described above, and verified using a keyword in context analysis that these occurrences were indeed part of causal explanations. When counting occurrences of the causal expressions identified above, we obtained a total of 49 occurrences over the corpus (of which 24 occurrences of “*cause*” and “to *cause*”). This suggests that, on average, 53% of those short textual explanations make use of causal vocabulary (Figure 44). Overall, 73.9% of subjects used a causal explanation at least once.

Results are presented on Figure 43 and Figure 44. The former (i.e. Figure 43) plots the distribution of subjects as a function of the number of causal explanations produced in the course of the experiment. Overall, 71% of subjects have produced two or more causal explanations for the four trials. This has to be interpreted considering that, we have taken a conservative approach to textual interpretation, preferring to under-estimate the number of causal explanations. In terms of identification of the experiment subject, 85% of subjects recognise “causes and effects” as the main subject of this experiment (Figure 45). These results suggest that the generation of co-occurrences by the Causal Engine actually induces a high level of Causal Perception in the test subjects.

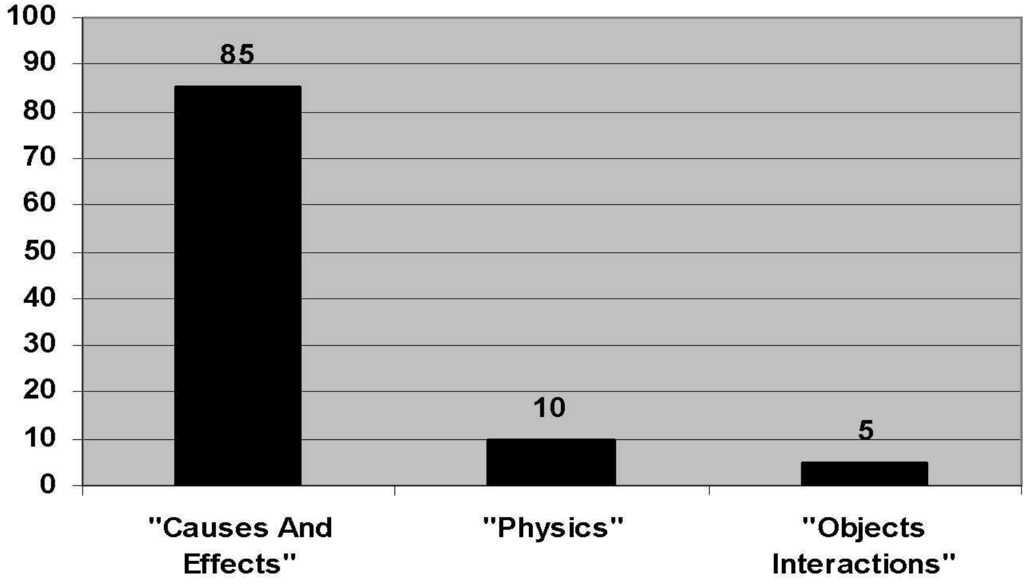


Figure 45: Subject identification of experiment topic.

Conclusions

In this section, we described the user experiments we have carried out in order to evaluate the ability of our system to elicit causal impression from alternative event co-occurrences. The system responds to user interactions by generating effects that depart from the common sense experience of physical events, while preserving a certain “illusion of Causality.” Nearly 70 % of the participants perceived causal relation between the action they initiated and the alternative consequences they observed later on. To a certain extent, the results presented here corroborate recent proposals for a bottom-up contiguity basis for causal relation identification. When two events co-occurred, the sequence had strong causal appeal, even in those cases where there was no plausible causal mechanism linking the events. This confirmed our Alternative Causality hypothesis and generation principles. The next chapter will demonstrate the practical applications of our “Alternative Causality” technology, regarding the conception of alternative reality environments. We will discuss this novel approach for VR behaviour conception and simulation, as well as its potential to support fundamental cognitive studies.

CHAPTER 5: ALTERNATIVE CAUSALITY AND VIRTUAL REALITY ART

Introduction

In this chapter, we illustrate how a cognitive concept, causality, can be used for the conceptual underpinning of Virtual Reality Art installations. Causality plays an important role in our construction of reality (see Chapter 2), and, as such, it makes sense to use it as a principle to define VR experiences. Thus, as one of the essential concepts of our experience, Causality can be a direct part of the artistic reflection (Sato, 2001). Causality can also be the mode of description of dynamic behaviours that are meant to elicit a certain kind of spectator's experience. In both cases, we want to demonstrate that causality can be directly manipulated as part of VR systems and as such, it could constitute a knowledge-level formalism to express artistic intentions, while at the same time providing a direct route for their implementations.

In this thesis, we presented a VR system using cognitive data on Causal Perception to create artificial event co-occurrences, which can be perceived as possible outcomes for user actions or object interactions. Based on this system, this chapter introduces a novel approach to the creation of Virtual Reality, which supports the design of alternative worlds, where laws of causality can be redefined (i.e. distorted) in real-time to induce new user experiences. After preliminary validations of this technology by user experiments, our Alternative Causality system has been further utilised to implement prototypes of artistic VR installations developed in VR-cave. In the first section of this chapter, we review previous VR Arts and their relation to causality to create experiences that produce immersion into alternative reality. Following this, we present both artistic installations developed, as well the authoring tools that have supported their development. We will also discuss the artists' impressions before concluding on the perspective of such cognitive-based AI approach to create VR experiences.

Virtual Reality Art offers many possibilities to create experiences that produce an illusion of realism or from a different perspective, an immersion into fantasy worlds and alternative realities (Grau, 2003). In that sense, there is a tradition in VR Art to construct alternative worlds, e.g. in Char Davies' *Osmose*TM environment (Davies, 1995) or *Ephémère*TM (Davies, 1995, 1998, 1999, 2003) (Figure 46), Louis Bec's artificial creature (Bec, 1991), or Maurice Benayoun's Quarxs™(1994). Virtual Reality Art is at the forefront of Digital Arts, as it explores visual aesthetics, the construction of alternative universes as well as user interactive experiences. To that extent, the notion of alternative reality still owes an intellectual debt to the "vision(s)" of Tim Leary (i.e. "VR as Reality distortion").

Figure 46: Char Davies, Forest Stream and Seed, from Ephémère, 1998 Left-Image: Char Davies. *Forest Stream*, Ephémère (1998). Digital still captured in real-time through HMD during live performance of immersive virtual reality environment Ephémère. Right Image: Char Davies. *Seeds*, Ephémère (1998). Digital still captured in real-time through HMD during live performance of immersive virtual reality environment Ephémère

Figures reproduced with permission

It is worth investigating the extent to which the Alternative Reality concept has been addressed in Digital Arts. In particular, we are looking for explicit references, both in the Art Works and their authors' statements, to twists in the laws of Physics underlying reality as we know it, and/or the use of causality explicitly mentioned in Digital Art.

We were actually able to identify in recent work such explicit notions. In the following sections, we shall discuss:

- The Quarxs™ by Maurice Benayoun, explicitly addressing common sense physics (and alternative physics).
- The "Amplitude of Chance", a collective exhibition of Digital Art in Kawasaki (2001), explicitly addressing causality.

Physics as an Inspiration in Digital Arts: The Quarxs™

The animation series The Quarxs™, by Maurice Benayoun, is perhaps to date the best, if the only, example of digital creation featuring alternative reality in the sense we use it in this project. Although the Quarxs™ are 3D animations their study gives a clear indication of what can be pursued in this direction.

The Quarxs™ are creatures whose definition is precisely based on the laws of reality/physics they are bending or violating! And to some extent, "real-time" Quarxs™ would be a good test case for the implementation of the techniques supporting alternative reality.

The original brief ("*In the beginning, God made a mistake*…") introduces Quarxs™ as invisible entities embodied as living forms, whose existence explains the multiple odd phenomena encountered in our everyday life. This is the reason why Quarxs are featured in everyday environments, such as kitchen sinks, etc., archives and laboratories. Each Quarx explains a particular phenomenon: why we cannot find everyday utensils where we last left them, why is water from the tap cold when we would expect it warm, etc. In any case, the definition of a Quarx, its very nature, is the physical law it is bending, in mechanics or thermodynamics. The fact that these laws are not expressed formally but rather as everyday physics is not relevant at this stage (and even more compatible with qualitative physics approaches). More than 10 Quarxs™ have been described and the phenomena they trigger concern various different areas of physics, which in its own way constitutes a precursor work in alternative physics. A simple description of some of the Quarxs™, with their characteristic behaviour will summarise better than any other analysis their conceptual connection to alternative physics[13].

- The **Spatio Striata** (Figure 47) appears as a discontinous entity, which is absent of certain regions of space/time. From the Quarxs'™ brief: "*Let's take a closer look at this phenomenon. For the spatio striata, the world is traversed by spatial slices or portions, within which it simply doesn't exist.*"

Figure 47: Spatio Striata quarxs © Maurice Benayoun and Z-A Productions 1991-1993 (Figure reproduced with permission)

- The **Reverso Chronocycli** (Figure 48) causes time to flow "backwards" in the environment it evolves.

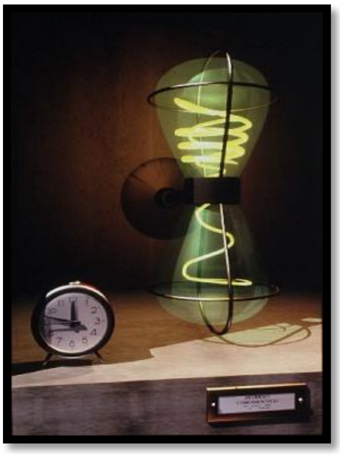


Figure 48: The Reverso Chronocycli quarxs© Maurice Benayoun and Z-A Productions1991-1993 (Figure reproduced with permission)

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[13] We have retained the names and spelling of the English brief for the series, courtesy of Maurice Benayoun.

- The **Spiro Thermophage** (Figure 49) inhabits pipes and is the explanation for sudden variations in the temperature of tap water: “*My nerves were completely shattered. Four different plumbers had already been in, but they were too stupid to understand what was going on. Yet the clues were building up steadily. Today I have tangible, irrefutable proof. The pipes are inhabited. Look at this unique document. Breathtaking.*”

Figure 49: The Spiro Thermophage quarxs© Maurice Benayoun and Z-A Productions 1991-1993 (Figure reproduced with permission)

- The **Albertus Morphoconfusans** alters the phase of any matter it comes in contact with, causing him to walk (crawl) on water as much as it swims through marble …

Causality in Digital Arts: The Amplitude of Chance

The collective exhibition *Amplitude of Chance: the Horizon of Occurrence*, held in Kawasaki, Japan, in 2001 is one illustration of the reflection on causality in our experience of the world. The exhibition as a whole was based on a brief asking various artists to explore the notions of chance and randomness (Sato & Makiura, 2001).

In the critical introduction to the exhibition volume, they introduce the relationship between experience and the attribution of causality:

> *Our experience and perception looks for the consistency of a cause and effect relationship, namely causality. In the case where that consistency fits in well with our actual experience, the concept of causality remains valid. For example, let us look at material or physical aspects […]. To put it another way, doubts have arisen regarding whether cause and effect are so firmly connected – the aspect that has most vigorously explained the world in terms of causality. […] But in recent years, it is very interesting indeed that this doubt has come out in the world of physics, where occurrences have always been described in the most definite and* qualitative[14] *way* (Sato & Makiura, 2001).

Later we find the following arguments on the formation of causal chains from contiguity relations, as a support for experience:

> *One more necessary element of causality is continuity of things across time and space, what we call "causal chain" […] Alternatively, we can say that, at a certain time or position, the contiguity relationship (as the previous and following/the before and after relationship) is joined by a causal chain because it is continuous. […] However, we can perhaps call this an experiential concept. In other words, we can be the frame, which maintains continuity through our experiences in a given range* (Sato & Makiura, 2001).

One of the artists taking part in the exhibition, Kenichiro Kawamura, elaborates on the notion of contingency (a weaker relation than causality, which often tends to support causal interpretation in humans), defined as:

> *In "Guzensei no Mondai" (The Problem of Contingency), Shuzo Kuki describes this (contingency) appropriately as "the meeting by chance of heterogeneous cause and effect relations."*

For the emergence of our experiences:

---

[14] Emphasis ours.

> *To question contingency is to question our bodies, which are at the centre of our experiences. […] the contingency of the experience is the same as its reality.*

In conclusion, what in these statements remains at the level of critical analysis or ad hoc development (when artistic installations are concerned), we could try to render operative for the production of artistic content through the development of alternative reality technologies relying on Alternative Causality.

Causality in VR Art Installations

In an artistic context, causal impressions can be an important aspect of a user's experience. The difficulty lies in being able to "program" causality on the basis of the artistic intentions: this requires mechanisms for the explicit handling of causality, such as those provided by our Causal Engine. In this section, we describe how our system was used in the development of two artistic installations: "Ego.Geo.Graphies" (artist: Alok Nandi) and "Gyre and Gimble" (artist: Marc Palmer). The two artistic environments exploited the Causal Engine features to modify causality in real-time. In the first part of this section, we briefly describe the immersive VR installation chosen and its integration within our Alternative Causality Engine. Then, we illustrate the system behaviour and authoring with the two VR Artistic briefs developed.

The VR Platform and Alternative Causality Engine

The VR platform should support immersive visualisation as required by VR Art installations. CAVE™-like systems offer several advantages in terms of visualisation quality, user interaction, user and audience participation. For all these reasons, we selected a CAVE™-like PC-based system, the SAS Cube™, which is a 4-wall, 3 x 3 metre immersive display powered by a PC cluster and supporting stereoscopic images through the use of shutter glasses (Figure 50).

The Unreal game engine upon which our Alternative Causality engine has been integrated, has been previously ported to the SAS Cube™ using the CaveUT™ system (Cruz-Neira et al., 1993; Jacobson 2002, 2003; Jacobson & Hwang, 2002). We have extended their original system to support stereoscopic displays, interaction and animation synchronisation (Cavazza et al., 2004b).

Figure 50: The SAS-Cube installation in France running one of our artistic installations (Ego.Geo.Graphies)

The software architecture (Figure 51) also integrates our additional software layer, the Causal Engine, on top of the visualisation system. As explained in previous chapters, the Causal Engine overrides part of the native Physics engine to support the definition of new world behaviours, namely the principled generation of event co-occurrences. As described in Chapter 3, it intercepts frozen event consequences and reactive alternative consequences, using our specific event interception system (EIS), which is directly embedded within the visualisation engine (UT Engine).

In a planning search-like process, the Causal Engine generates possible sets of transformations of one intercepted event, by using a special operator, called Macro-operator or MOPs. At the end of the search, the sets of possible alterations are classified from the “most plausible” to the “less plausible,” using a multi-components heuristics normalised between zero and one. The heuristic search is based on cognitive factors of Causal Perception, reinforced by similarity considerations between expected and alternative effect types considered. Among these alternatives, the Causal Engine will select the ones below a certain range of "Plausibility". In matter of clarity, we sometime refer to the level of Plausibility as level of Causality Disruption, as it can also be considered as the amplitude of the causality distortion. We have developed interfaces to allow the artists to visualise and control the Causal Engines search process. These interfaces as well as the authoring process are described in the following section.

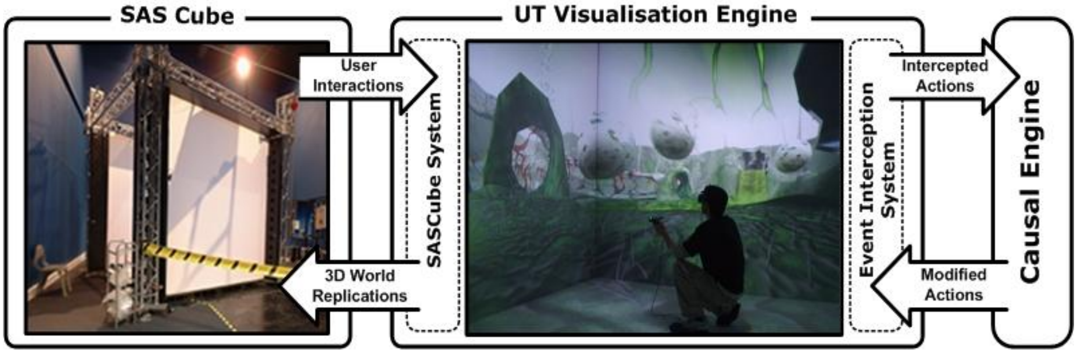


Figure 51: System architecture together with a view from one of our artistic installation.

Authoring of Alternative Causality

As explained in previous chapters, the Causal Engine coupled with the EIS dynamically redefines the behaviours of virtual actors. We have developed interfaces to allow the artists to author and control Alternative Causality in a seamless way. As illustrated in Figure 52 below, the whole authoring process is constituted of three main phases: i) Causality definition, ii) implementation and iii) alteration settings.

The EIS proposed a graphical interface to program Cause-Effect Action that defines the causality of the environment as well as the associating semantic properties to the object. In its side, the Causal Engine interface provides tools to set up the level of causality disruption and the list of Macro-operators to use.

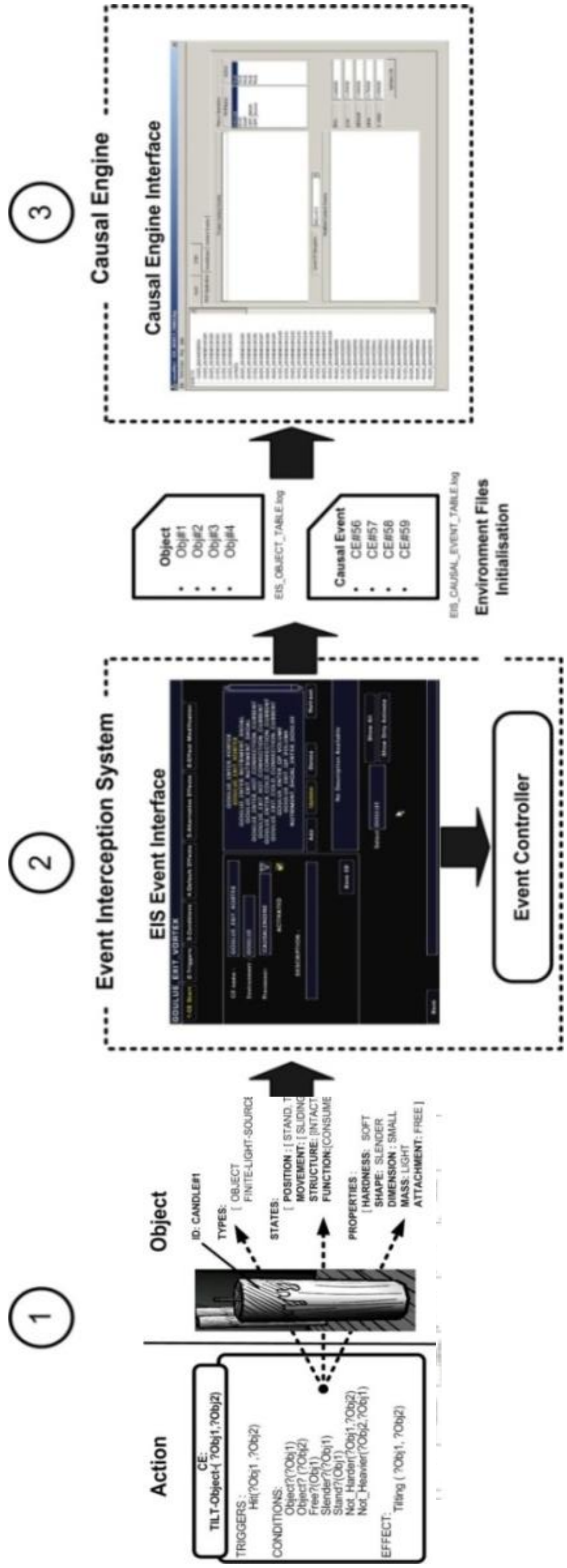


Figure 52: Alternative Causality authoring processes and tools.

In our system, event causality is expressed in a declarative form, with formalism that is accessible to a non-VR Expert. However, this unusual approach requests a particular authoring process and tools. The first phase consists of defining the "normal" causality in the world that consisting in declaring event-co-occurrence following our formalism, and associating semantic properties to object to enable their instantiations. We use the term *Normal Causality* to refer to the "baseline" causality, usually representing our common sense physics apprehension. In other words, it represents the everyday physics principles that we use to plan and predict object interactions.

As previously presented, in our formalism, these naïve causal co-occurrences are symbolically expressed with aggregation of predicates into an explicit Causes-and-Effect structure, referencing abstract categories of object types, physical and functional states and attributes. Objects semantic properties are described using three main categories of attributes: `TYPE`, `STATES` and `PROPERTIES`.

- **`TYPE`**: identifies the generic categories of an entity (e.g. `OBJECT, AGENT`) reinforced with sub-type (e.g. *`ARTIFACT, DEVICE, SOURCE, FLOW, SURFACE`*). Here, we will not discuss the veracity of these types, as their primary function is to refine and accelerate the action recognition process.
- **`STATES`**: represents formal, structural, material, kinematics or functional states, subdivided in `MOTION, STRUCTURE, FUNCTION, POSITION` categories.
- **`PROPERTIES`**: represents formal, structural, material, kinematics or functional properties: refined into many attribute qualities such as `HARDNESS, SHAPE, DIMENSION, MASS` type.

The system presents more than two hundred semantic attributes and our test-bed environments included between 30-60 actions (i.e. physical event co-occurrences)). This constitutes a significant library of "standard" Causal laws, which cover generic actions, or objects that could be instantly re-used in future environments. Obviously, the establishment of causal co-occurrence is the most demanding task and requires certain knowledge of AI representations. However, our system benefits from a library of pre-existing co-occurrences, and its explicit declarative form makes it understanding straightforward.

Once a set of co-occurrences is defined, their integration in a VR environment is assisted by the EIS graphical user interface. As the EIS is embedded into the Unreal Game engine, its interface is directly accessible from the visualisation engine interface (see Figure 53).

CE name : GOULUE_EXIT_VORTEX
Environment : GOULUE
Processor: CAUSALENGINE
ACTIVATED ☑
DESCRIPTION :

GOULUE_ENTER_VORTEX
GOULUE_EXIT_VORTEX
GOULUE_ENTER_NUTRIMENT_SHOAL
GOULUE_EXIT_NUTRIMENT_SHOAL
GOULUE_ENTER_HOT_CONVECTION_CURRENT
GOULUE_EXIT_HOT_CONVECTION_CURRENT
GOULUE_ENTER_COLD_CONVECTION_CURRENT
GOULUE_EXIT_COLD_CONVECTION_CURRENT
GOULUE_ENTER_QP_VOLUME
GOULUE_EXIT_QP_VOLUME
NUTRIMENT_SHOAL_ENTER_GOULUE

No Description Available

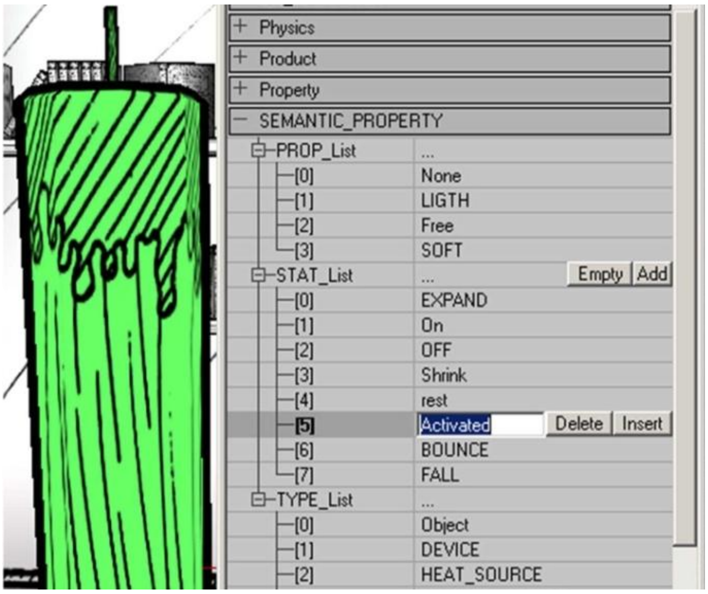
Select GOULUE

Figure 53: EIS authoring interface (Unreal Engine)

This interface enables non-VR-developers to easily edit CE actions and directly associate them to a UT virtual environment. As depicted in the snapshot below (Figure 54), the integration of semantic properties to an object, is done through a custom object edition directly accessible from the Unreal Level Editor.

The co-occurrences created and the object properties will be saved in a database, in the form of a text file, which would be used to instantiate and activate action recognition when loading the environment. These files will also provide the Causal Engine with a description of the environment's actions and object availability.

Once the Causality has been defined and integrated into an environment, the degree of causality disruption could be set through the Causal Engine interface (see Figure 55). The principal aim of this interface is to provide a limited set of sophisticated control to bias the causal search, and experiment different heuristic values. The customisation of the search is realised at high-level, by controlling the level of disruption/plausibility wished, and by re-organising the list of alteration operators (i.e. MOp).



PROP_List ...
[0] None
[1] LIGTH
[2] Free
[3] SOFT
STAT_List ...
[0] EXPAND
[1] On
[2] OFF
[3] Shrink
[4] rest
[5] Activated
[6] BOUNCE
[7] FALL
TYPE_List ...
[0] Object
[1] DEVICE
[2] HEAT_SOURCE

Figure 54: Example of object semantic properties setting via Unreal level editor

Our engine search is targeting alternative consequences to an action that presents an amplitude of causality disruptions below or equal to a certain threshold, named: level of Plausibility (or Disruptions). We discretised this threshold into five levels `NULL, LOW, MEDIUM, HIGH, VERY HIGH` defining ranges of values on a zero-to-one scale. In a certain sense, these levels could be interpreted as `REALISTIC, PLAUSIBLE, HARDLY PLAUSIBLE, IMPLAUSIBLE` or `UNREALISTIC` causality. From the interface, the user can attribute a maximum value for each level of disruption, and force the level of causality distortion to apply during the runtime.

Another way to affect the causal search is to modify the list of Macro-operators used to generate possible transformations. In its primer version, the Causal Engine proposed a large population of specific macro-operators `CHANGE_EFFECT, CHANGE_OBJECT, PROPAGATE_EFFECT, LINK_EFFECT, LINK_OBJECT,` which on later version has been reduced to two main generic ones: `CHANGE_OBJECT` and `CHANGE_EFFECT`[15]

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[15] *(The integration of specific MOp will be the subject of future investigation)*

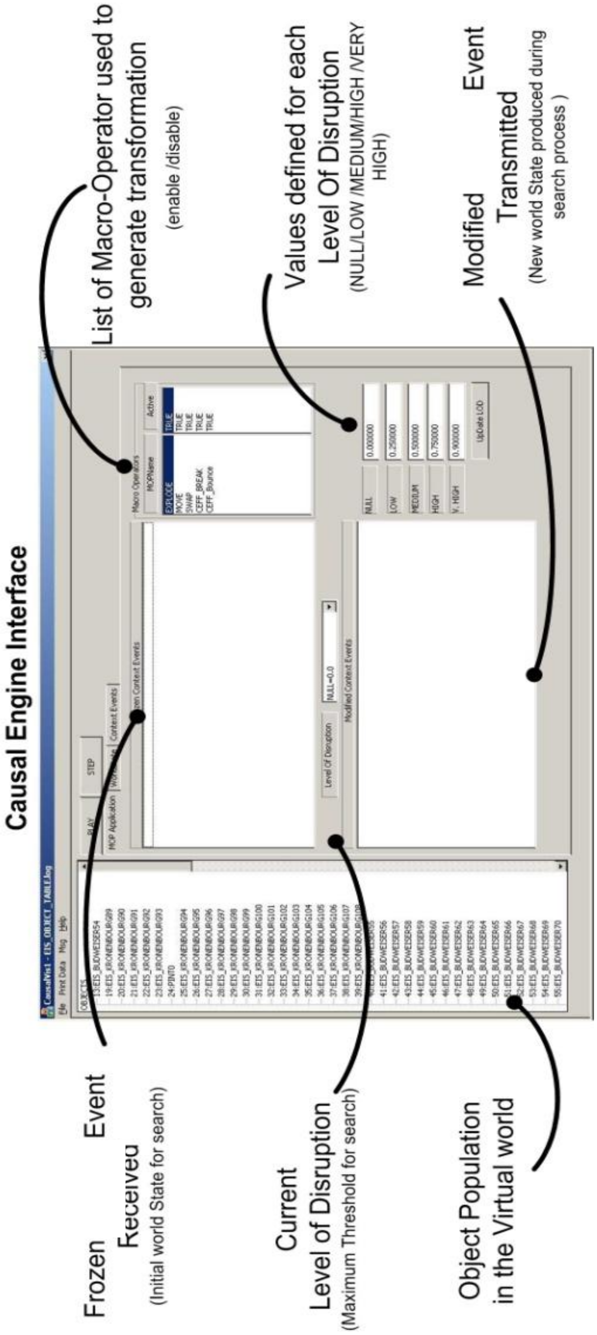

Figure 55 : Modification of the Causal Engine Search parameters: *(Note; Possibility of Adjusting of the different values for each level of disruption)*

The authoring tools described here have been developed during the conception of the psychological experiments, and used to create alternative reality worlds. The following part of this chapter illustrates alternative reality virtual worlds designed on artistic intentions and implemented with our Alternative Causality technology

Gyre and Gimble is a VR artistic project based upon Carroll’s Alice stories. Although *Gyre and Gimble* draws upon the Alice stories, the intention was never to reproduce their narratives, but to explore the disruption to perception offered within them. In fact, Carroll’s stories provide a natural starting point for anybody interested in the consequences of logic and the creation of alternative realities. The way that we often encounter this in his stories is through the mixing, collision and invention of games as well as the transformation of their rules. A playfulness that he also directs towards language presenting us with paradoxes[16] arising out of the situations and conversation that Alice finds herself. This is why his books are always far more than just the presentation of a plot; they are events that unfold involving the reader in their own logic. Reacting to this interaction becomes the primary driver of *Gyre and Gimble* deliberately distancing itself from narrative. Rather than becoming a vehicle for retelling portions of the Alice story, like the stories themselves it becomes an ‘event’ and the occasion that involves users in this disruptive process.

Here the challenge was to make a technology based upon gaming as effective as Carroll’s creative subversion of games. The joint decision to draw from the scene in *Through the Looking Glass,* where Alice discovers that, try as she might to look at things in a shop they evade her gaze, was to provide the opportunity to use spectacle itself as a means of interaction. Using a combination of a viewer’s distance and centre of focus it became possible to employ attention as a means of interaction. The collision of objects that then occurred as a result of an object’s desire to escape constitute, from the system perspective, the starting point for the computation of chain of events (and consequences).

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[16] “When we were little,” the Mock Turtle went on at last, more calmly, though still sobbing now and then, “We went to school in the sea. The master was an old Turtle – we used to call him Tortoise-”“Why did you call him Tortoise, if he wasn’t one?” Alice asked. “We called him Tortoise because he taught us”, said the Mock Turtle angrily. “Really you are very dull!” p.83 *Alice’s Adventures in Wonderland and Through the Looking Glass*, Penguin Books, London 1998.

Artistic Intentions

Mark Palmer’s artistic work has been exploring user interaction with complex systems, in which the determinism of local interaction does not entail the predictability of the system’s response. In other words, the fact that user experience can derive from interaction does not imply any kind of control over the system he is interacting with. In addition to simple and direct causality, the system should be able to generate unpredictable events.

This approach draws reference from Spinoza’s philosophy, in rejecting transcendental explanations, as well as the notion of final cause. In that sense, the very term of “user” is misleading in its utilitarianism and in that, it suggests a simple causality as a means to an end. Interaction should never resonate with the notion of a final cause; rather, experience should derive from adjustments of efficient causes only.

In the context of this research, his “Gyre and Gimble” brief revisits Alice in Wonderland, through an interactive VR installation. In the original novel, as in this installation, Alice is certainly confronting an environment, which exhibits behaviour of its own. Objects have a life of their own, generating all sorts of (inter)actions. In addition, the world itself is hardly predictable, the outcome of such interactions depending on changing conditions.

The “Gyre and Gimble” Environment

The brief environment is a 3D world reflecting the aesthetics of the original Tenniel's’ illustration (using 3D objects with non-photorealistic rendering, Figure 56). The user, evolving in the environment as Alice, in first person mode is a witness to various objects behaviour, which she can also affect by her presence.

Let us consider the situation where Alice faces a cupboard containing several animated object on its shelves. Objects will try to escape from the approaching Alice, but in doing so can only move on the shelves supporting them. This is bound to generate all kinds of collisions between events, yet the consequences of these collisions can vary to reflect the global mood of the situation or the identity of objects.

The environment is composed of one room surrounded by several cabinets and a table represents the Gyre and Gimble world. The place is composed of ten different types of objects, a total of 90 interactive objects such as candles, holder, clock, and book, dispersed on shelves, cabinet and table (see screenshot below on Figure 56).

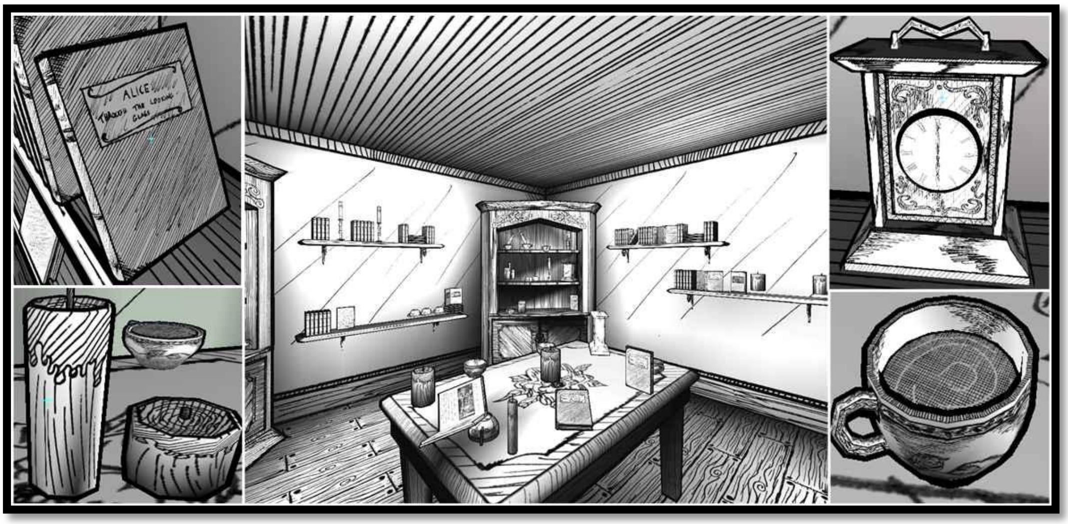

Figure 56: The "Gyre and Gimble" Environment[17] and Example of Interactive Objects.

Notes: Non-photorealistic rendering has been preferred, inspired from the original Tenniel's illustrations.

User Interaction and Object Behaviour

The User interacts with the VR Art installation through navigation and interaction with objects, as with any virtual environment. However, as part of the technical implementation of the artistic brief described above, world objects are associated a "native" behaviour, by which they will evade the user's gaze, and escape towards other objects, depending on the object categories.

The user triggers objects' spontaneous movement by the simple means of her gaze[18], whose direction is calculated using an approximation from head tracking data (see Figure 57 below). As a result, the user witnesses a stream of object behaviours, prompted by his/her interaction but whose precise logic is not directly accessible to

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[17] The visual content presented here represents a first version of the environment.

[18] Actually measured from the head vector, with fair approximation considering the average distance from the screens.

her. Another interaction mechanism, which is more specific of this type of installation, actually consists in the integration of user trajectories and navigation patterns to determine the user attitude towards specific parts of the environments and the objects they contain. Ultimately, the user's attitude will be reflected by the behaviour of those objects through global mechanisms involving degrees of "perturbation" and "surprise", as detailed in the following sections.

The spontaneous motion of objects provokes collisions between them, which are the starting point for the generation of an event chain by the AI module. This chain of events will induce various forms of Causal Perception by the user, and constitutes a central aspect of her interactive experience. The amplitude of the alteration to causal event chains is based on semantic properties and analogies between effects, as well as depending on how the user engages with the environment. This type of computation can provide a principled measure of concepts directly related to the user experience such as "surprise" (Macedo & Cardoso, 2001).

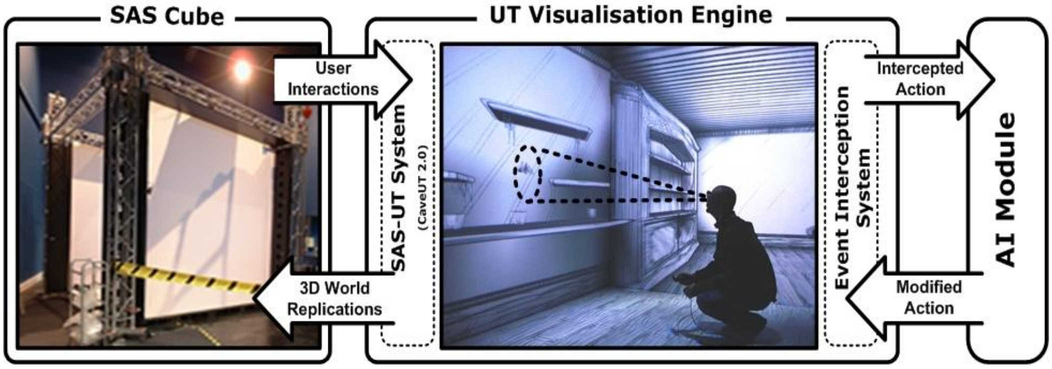

Figure 57: System Architecture

(Gyre and Gimble Environment and user indirect interaction (with head tracking))

As previously explained, the Level of Disruption corresponds to a threshold for the use of heuristic values. According to the value of this threshold, the transformation produced goes from the more natural (0) to the more artificial (1). Our system discretises this value into five disruption levels: NULL / LOW / MEDIUM / HIGH / VERY HIGH

One innovative aspect in the *Gyre and Gymble* world is the fact that the Level of Plausibility is dynamically updated to represent the environment's response to the perceived attitude of the user towards it. Two parameters are regularly updated that represent the user's attitude: one (User-Objects-Proximity) integrates the amount of time spent by the user in proximity with certain world objects and the other (User-Activity) is a reflection of the world exploration by the user.

More specifically:

- **User-Object-Proximity** is weighted between [0-1] and corresponds to the average distance of the user to objects present in this field of view. This metric reflects a level of engagement of the users with the objects, which, depending on the artistic brief, can be interpreted as interest or threat.
- **User-Activity** represents an appreciation of the user’s frequency movement, expressed by a weight between [0-1] (a value of zero meaning that the user is immobile).

The level of disruption is then frequently updated using a simple matrix (see Figure 58). Increasing or decreasing it in response to the user’s behaviour creates different user experiences in terms of emotions reflected in, and by, the world itself. The user thus indirectly influences the transformation amplitude through values for his/her behaviour. This constitutes to another example of the generation of more sophisticated user experiences through AI technologies.

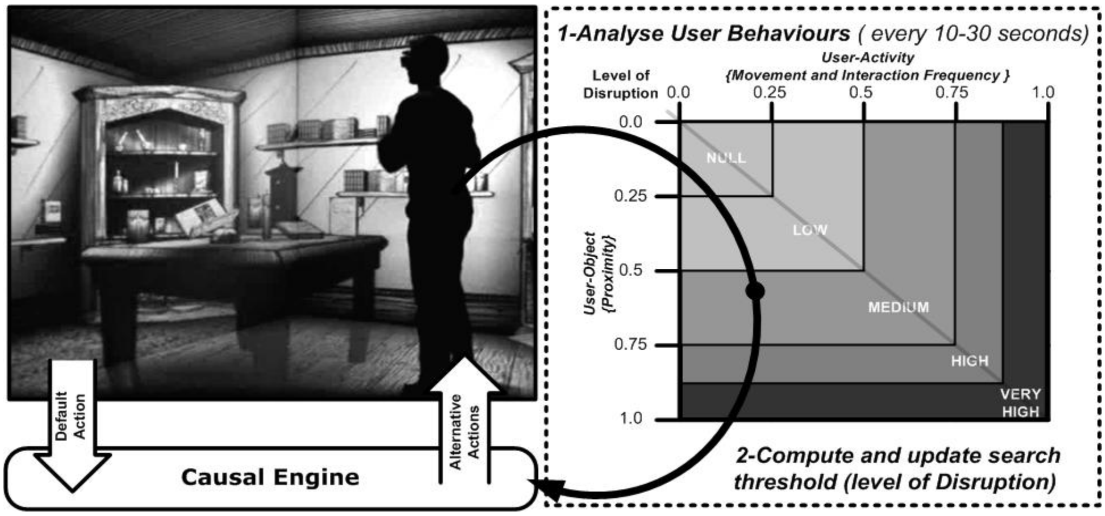

Figure 58: User Behaviour and Current Level of Disruption

A low value for the level of disruption parameter (close to 0.25) tends to result in minor changes. Indeed, they are often related to the propagation of a normal consequence to spatially close and/or same-type objects. For instance, the book-candle collision will also project one of the closest similar candles (Figure 59-1).

However, a medium level of disruption (around 0.5) usually extends or substitutes default consequences to different objects, as when the book is projected with the candles around, instead of the original candle (Figure 59-2).

Higher levels of disruption (close to 1.0) affect the type of effects generated and the entire population of objects situated in the user’s field of view. At this level, the consequence of an interaction becomes hardly predictable, as it depends of the local context of the environment (i.e.: the type, state, and distance of objects surrounding the initial event). Here, such a level triggers the opening of the book while some candles start burning or tilting (Figure 59-3).

The essential advantages of this approach consist in being able to control the consequences of user interaction, at different levels, using concepts that can be related to artistic intentions. Most importantly, these principles also support generative aspects, where the system enriches the creative process.

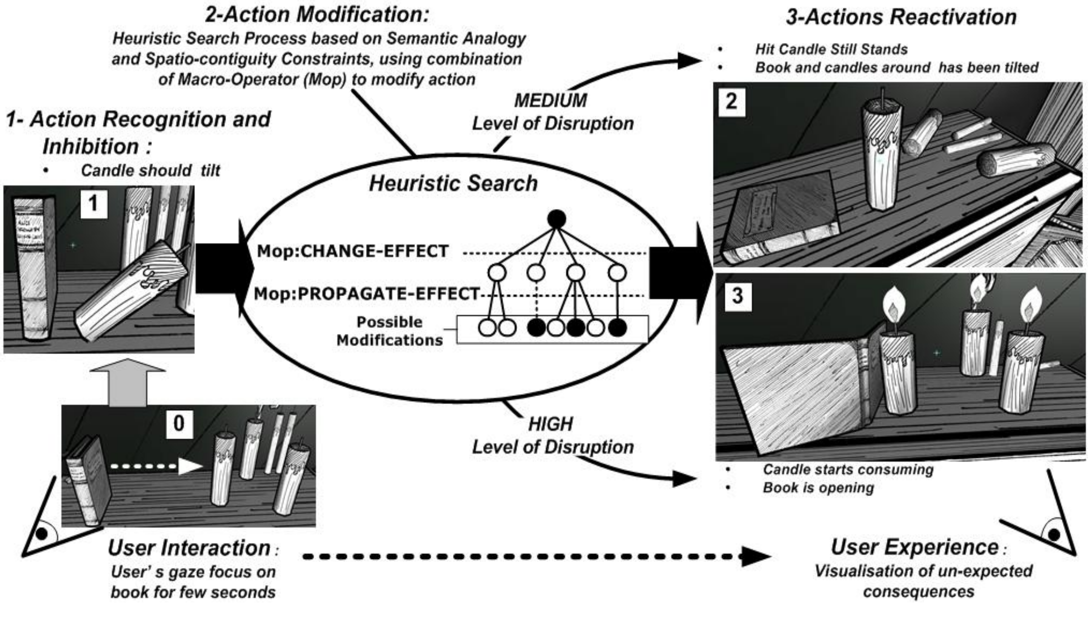

Figure 59: Level of Disruption and User Experience

Mark Palmer Comments:

"… The workshop days provided an opportunity to come to terms with the 'middleware'/'authoring' environment being developed by the UoT (University of Teesside) team. Whereas previous discussions had tended to focus upon issues to do with Gyre and Gimble, this was the first exposure I had to the proposed system and the ways in which it might be used. This provided me with a far greater (and welcome) opportunity to come to terms with the aims of the project from the UoT perspective. The system looks to be a welcome, robust and inexpensive way to author work away from the assumed expectation of imitating reality often associated with virtual systems. I am sure that it will provide a very productive and useful way to introduce students working within art and design to developing interactive immersive/environmental work…".

“*Ego.Geo.Graphies*,” by Alok Nandi was also developed as part of the ALTERNE project. This artistic brief is exploring interaction and navigation in a non-anthropomorphic world, blurring the boundaries between organic and inorganic.

Artistic Intentions

The title of this brief “*Ego.Geo.Graphies*” reveals the core concept illustrated by this artistic installation, Geo means "earth" in ancient Greek, here in general the place in which we human live and Ego ("me" in Latin), in other words the visitor-spectator-player in the interactive installation. In this installation, the user navigates in an organic world populated by spheres, which originate in determinate areas of the environment. The spheres’ behaviour depends on the perceived “empathy” of the user, which is a function of the user’s navigation patterns, unknown to user.

Through the staging of the Ego.Geo.Graphies installation, Alok Nandi is interested in exploring aspects related to predictability, non-predictability and hence some kind of narrative accessibility, from the perspective of user interaction. This also implies that we explore how the user can be affected by causality. The spontaneous movements of the spheres focus the user’s attention, within the constraints of his/her visual and physical exploration of the landscape.

The user expects a dialogue to emerge from this situation: user exploration will affect world behaviour through levels of perceived empathy, and in return the kind of observed causality will influence user exploration and navigation. The next section describes how a user's attitude and interactions influence the whole world's causality.

An overview of the virtual representation of the “Ego.Geo.Graphies” world is presented in Figure 60. This environment represents a closed world surrounded by hills within which a single user can freely explore in a walking-like fashion. This environment experiments an original type of implicit interaction, where user's behaviour influence the world landscape and creature's agitation. The user’s behaviour is interpreted in terms of empathy, while the world's agitation corresponds to the notion of Causality disruption. Here, the main intention is to blur the boundaries between organic and non-organic (between inert and animated substance). In this world, two sorts of interaction take place: those involving elements of the world (spheres and landscape) and those involving the user. The first type of interaction is essentially mediated by creature's collisions (spheres and landscape) and will be perceived in terms of causality. The second is based on navigation and position and will be sensed by the world in terms of “empathy,” as a high-level, emotional translation of the user’s exploration.

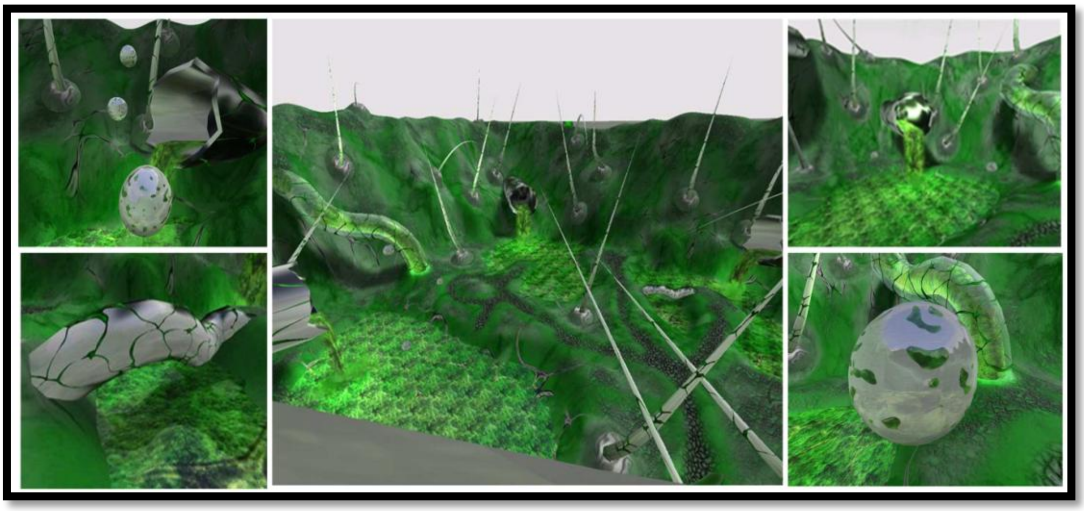

Figure 60 : The "Ego.Geo.Graphies" World Overview

The world’s behaviour manifests itself essentially through the effects that follow collision between spheres, which range from soft sphere merging to explosions propagating to the environment (Figure 61). These effects are under the control of the Causal Engine, which intercepts collision events and computes alternative forms of causality.

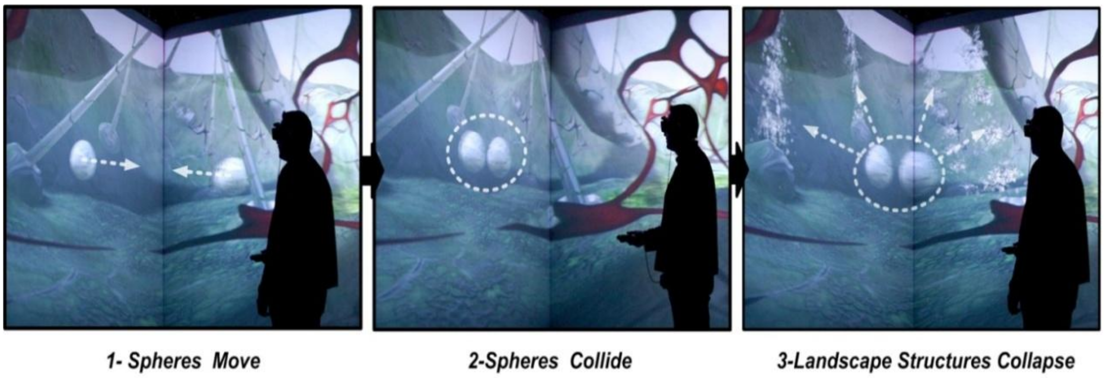
1- Spheres Move
2-Spheres Collide
3-Landscape Structures Collapse

Figure 61: Example of artificial co-occurrence in SAS-Cube^{Tm}

(Here the creature's (sphere) collision triggered environment destructions)

This brief makes use of most of the features supported by CaveUT, from tracking and object interaction to stereoscopic visualization (Figure 62). User navigation brings her in close vicinity to geometrical structures which acquire their full dimension as real stereo 3D objects, prompting the user to adopt appropriate navigation patterns around or under such objects. The spheres themselves can traverse the SAS Cube™ volume as floating 3D objects, conferring a high level of realism to the user interaction. In addition, the ultrasonic tracking implemented in CaveUT supports direct physical interaction with the spheres through the SAS Cube™ gamepad, which can be attracted or pushed back by the user.

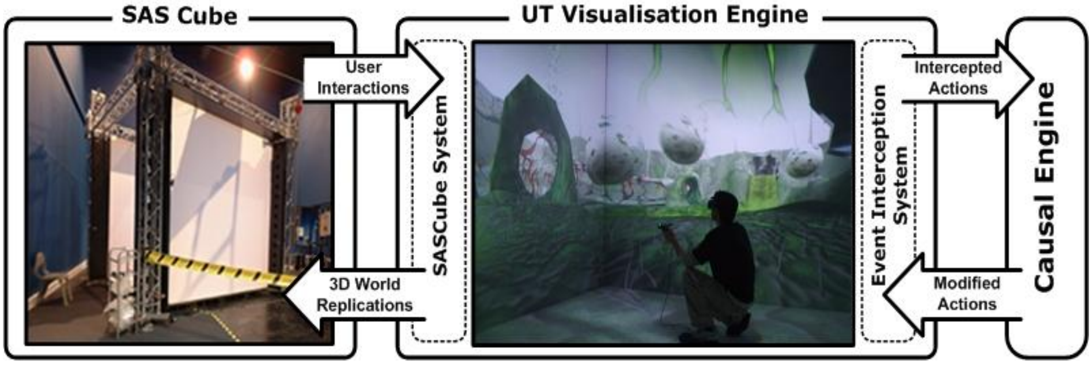

Figure 62: System Architecture together with a view from the Ego.Geo.Graphies

The presence of explicit paths inside the world helps user's navigation and localisation (see Figure 63 below). They also direct the user to potential “action zones,” like creature emission/collision zones (around for instance a puddle). The user navigation is not limited to paths; the user can also freely explore the whole terrain, including a puddle zone. At a human scale, the surface of the map is equivalent to 17000 square meters (approximately 130 by 130 meters).

Within this world, there exist two types of interactions: Direct and Indirect interactions;

- **Indirect interaction**: When a user is not frequently moving, he attracts floating creatures. In sum, creatures approach the user when he is stationary or slowly moving. If the user continuously move the creature are repulsed or ignore him.

- **Direct interaction:** The user is also able to push creatures in a close radius around him against each other. The user “pulls” or “pushes” spheres using the SAS Cube wand tracker. The Creatures are then projected in the direction pointed by the user.

In a first time, the user can appreciate the direct effect of his movement / interaction in term of Creature movement (attraction/repulsion). Consequently, the user can directly influence creatures' movements and so their potential collision within each other. In second time, the user behaviour is interpreted in term of “empathy.” As explained in the next section, the degree of user's empathy is associated with different level of Causality disruption, which in turn determines the world's agitation. To a certain extent, different effect types (e.g. bouncing, exploding ...) generated for a similar events (as sphere colliding) could be interpreted as different creature emotional/agitation states.

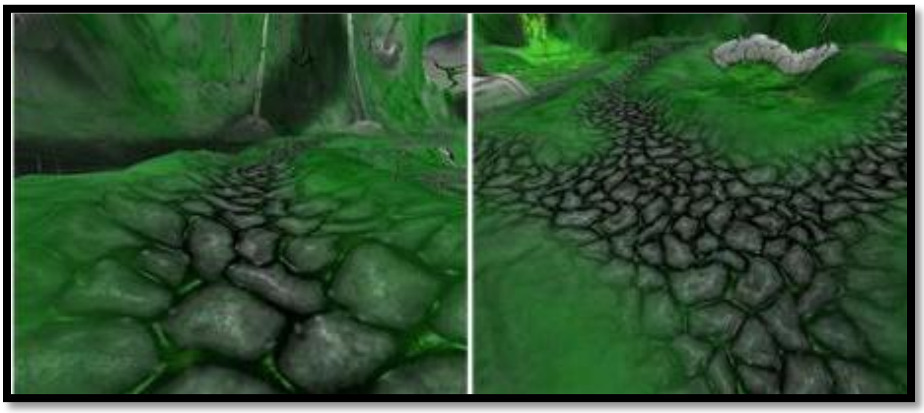

Figure 63: Paths guiding user explorations

Empathy and Causality Manipulation:

In the Ego.Geo.Graphies world, the level of Causality disruption is dynamically updated in relation to the user's degree of empathy, itself measured in term of User-Creature proximity and User-Agitation amplitude.

- The **User-Creature proximity** is weighted between [0 -1] that corresponds to the average distance of the user to creatures present in a specific radius around him. A weight close to zero signifies that the user is very close to creatures (could virtually touch them). A weight of one means that user is far away from any creature.
- The **User-Agitation** represents an appreciation of the user movement, expressed by a weight between [0-1]. A Value of zero means that the user is immobile or moving very slowly; a value close to one denotes a user is quickly moving (or rotating).

The amplitude of causality disruption is then computed from those variables using a simple matrix (Figure 64) (every 5-30 seconds).

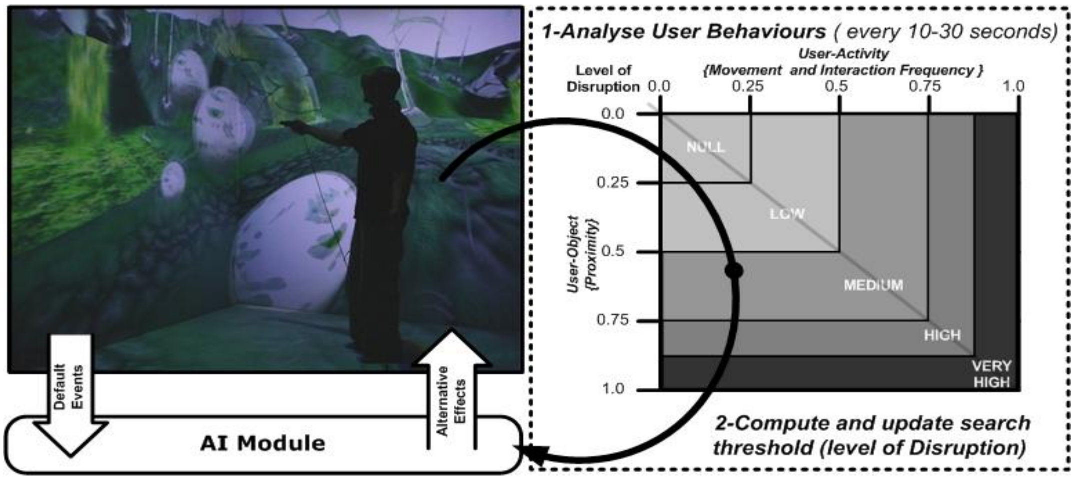

Figure 64: User Empathy Measurement and Causality Modification.

Note: User is repulsing/attracting creatures (floating sphere) using wand tracker

In the world of Ego.Geo.Graphies, sphere-shaped object-actors may collide with one another or with elements of the landscape. The effects of a collision between spheres is normally expected to be felt on the spheres themselves and the nature of the effect will depend on visual cues as to their physical properties (i.e. soft/hard, deformable, etc.), which can be conveyed to some extent by their textures and animations. Because the spheres are all part of the same organism, when they collide, the basic effect should be that they coalesce into a bigger sphere. This is represented as the baseline action for sphere-sphere collision (Figure 65-D).

However, the Causal Engine can apply various transformations to this baseline action. It can for instance replace the merging effect with the explosion of one (Figure 65-E), or both spheres (by applying a “change effect” macro-operator). As an alternative, both spheres can also bounce back from each other (Figure 65-A). In addition, another way of inducing Causal Perception is to propagate effects to elements of the landscape itself. In that instance, the collision between two spheres will result in the explosion of landscape elements (Figure 65-B). These alternative effects correspond to various levels of causality disruption, which in turn are related to the perceived levels of empathy.

As we previously explained in this thesis, the Level of Causality Disruption directly influences the Causal Engine search. In few words, the Causal Engine generates a population of possible transformation from which it computes their degree of plausibility, in term of action's semantic property and other spatial-temporal proximity constraints. Thus, the system can choose one or multiple transformations according to a single variable: the level of disruption chosen. Consequently, the sphere's collision consequences vary with the value of the level of disruption. Figure 65 below illustrates the different behaviours obtained with different Level of Disruption after a similar event (Floating sphere colliding). Within a high level, the collision consequences involved more object and more "violent" effects. In a certain sense, the less plausible is the Causality, the more agitated the environment appears.

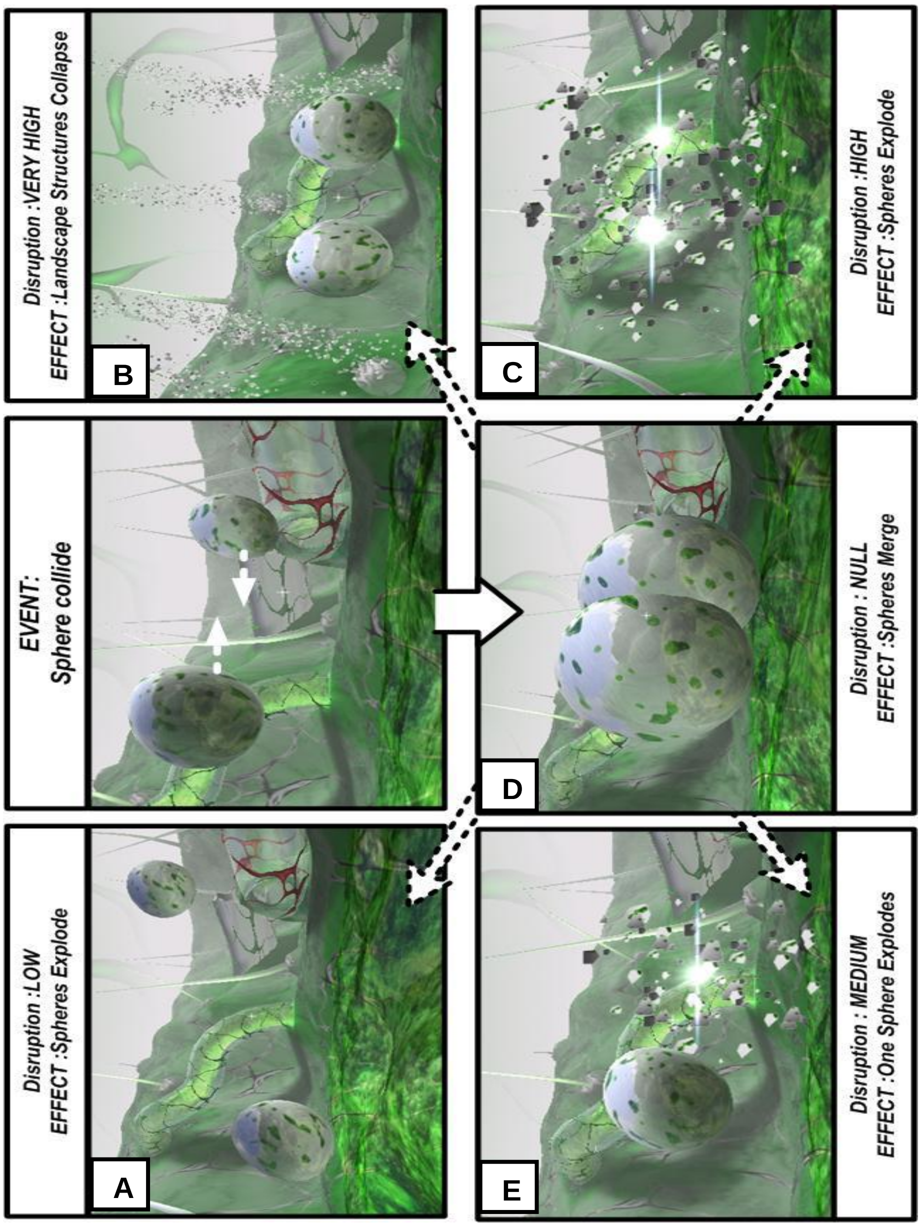

Figure 65: Level of Disruption and World Behaviours

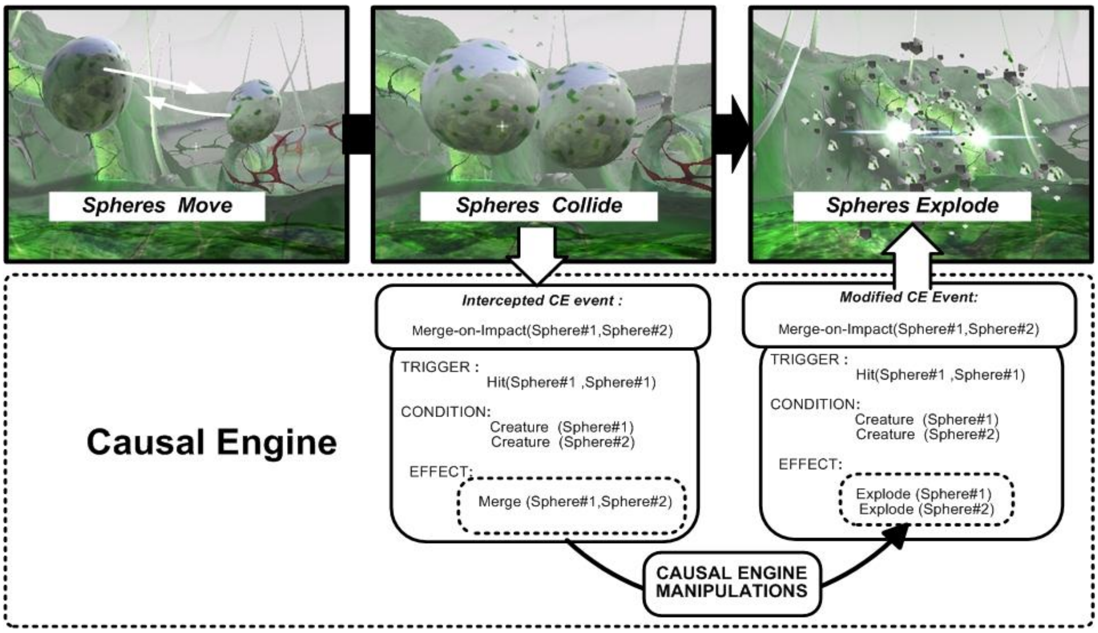

Figure 66: Example of a Causal Engine manipulation on an intercepted action (i.e. it changes the effect type (from merge to explode) and propagates it to its surrounding actors)

Figure 66 details the operation of the Causal Engine on the collision event between two spheres. First, the Causal Engine recognises the collision event and instantiates the default action representation for merging spheres, while at the same time it freezes its execution. This representation can thus be modified to create alternative outcomes for that collision: the nature of this modification derives from some parameters of the user's interactions history, thus implementing the implicit “dialogue” between empathy and causality wished by the artist.

Feedback from the Artist

Alok' Nandi Comments *:*

"…The SAS3 (i.e. SAS-Cube installation in France) on-site session was fundamental in getting a comprehensive view of the potentialities of the tool and its authoring interface put in place by the scientific / tech team. For perspective, being active in new media for 10 years, I was able to compare the features of a system, both in terms of functionalityi, user-friendliness and usability (see Figure 66).

The comparison took place with applications designed with collaborative teams in different sectors:

- *Web applications, from 1993 to now: one can see the evolution of the authoring tools and hence the efficiency but the lost of a certain flexibility, for specific usage*
- *Mixed-reality applications: from 1998 to 2004, I co-initiated a software platform architecture for mixed-realities Transfiction, i.e. in the framework of the EU IST project art.live: one of the frustration as a media artist/designer was to see that for each visual effect, it was needed to involve the tech team for a couple of days to get the desired effect.*

Not only there was a lack of flexibility in playing with variables in the universe designed but also, the tech team was need for each manipulation. These concrete examples allow to understand that in the SAS3 authoring platform the tech team has succeeded in providing a tool where variables can be manipulated easily in order to "get a feel for" the user experience in the SAS3, without waiting for two days of coding.

This day was also important to confirm a working hypothesis: in interactive installations, the only way to get the right feeling is to be in the real set-up; and in order to provide this right feeling, as a director (like in film editing), one needs to play, to fine-tune with very narrow variable fields; This was provided by the editing tool in the ALTERNE Platform (i.e. Causal Simulation interface and CAVEUT Interaction interface.

Figure 67: Alok Nandi experimenting different user's empathy settings

This research has been funded in part by the European Commission through the ALTERNE project (IST-38575-2002-2005). The aim of this project was to introduce a novel approach to the creation of Virtual Reality, which supports the design of alternative worlds, in which laws of Physics can be redefined to induce new user experiences. The conception of Alternative Reality VR technologies and its utilisation in immersive digital artistic installation were at the core of this project.

During my participation to the ALTERNE project, I have been collaborating with digital artists, 3D modellers, engineers and research colleagues. This section purposely clarifies my involvement concerning the development of this novel VR platform, and of the artistic briefs described in this chapter.

My essential participation to the project was to develop an alternative reality technology capable of supporting high-level artistic intentions. I therefore developed and experimented an Alternative Causality system, which acted as a behavioural engine for the artistic briefs described above. In addition, I worked in collaboration with the commissioned artists: Alok Nandi and Mark Palmer, and 2D/3D modellers to design the environment’s layout. More particularly, I have designed and implemented the environment layouts, placed and configured objects within them, and programmed all animations, user interfaces, and autonomous entity behaviours.

Concerning my work on the VR-Cave system, I upgraded the first version of the Cave-UT system (Jacobson, 2002; Jacobson & Hwang, 2002) in collaboration with a French engineer: Marc LeRenard (Member of the CLARTE VR centre[19]). I integrated an animation replication/ synchronisation system, which is essential to support a high-quality active stereoscopic, while displaying complex animation. I have also optimised the Cave-UT algorithms to improve the frame rate (up to 60fps), as well as produced a generic interface to plug VR tracker devices directly within the game engine's input system (*Note: these upgrades are discussed in detail in Cavazza et al. (2004b) and Jacobson et al. (2005).*

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[19] http://www.clarte.asso.fr/uk/   ALTERNE project's partner

So far, the creation of virtual worlds has been essentially based on visual rendering and pre-defined modes of interaction, in a context where many technical problems are given design-based solutions. Traditional interactive systems rely on direct associations between interaction events and their scripted consequences. This presents a number of limitations, forcing the specification of all low-level events when implementing. Such an approach has also limited flexibility when it comes to eliciting more complex user experiences, such as reacting to the user's global behaviour. The novelty of our AI approach, lies in the possibility to aim at a more sophisticated world making, by re-incorporating high-level concepts and describing the dynamic behaviour of the virtual world into the design process.

An AI perspective has offered two major advantages:

- The first one consists in an explicit representation layer for high-level actions, which supports principled modifications of actions' consequences, where these principles derived from artistic intentions.

- Another advantage is the use of the generative properties of the AI approach to enrich the user experience, while the generic aspect of AI symbolic representation simplifying the authoring process and collaboration amongst non-programmers.

As VR develops, the requirements of advanced interactivity will become more demanding, and mediating interaction through AI representations seems a promising research direction. Creating a common symbolic level facilitates the collaboration for projects with a strong epistemological stance. This has the potential to shift the implementation phase of VR Artworks, from pure software engineering to knowledge engineering, which in turn would not only facilitate development but also potentially improve the creation of abstract building blocks and their re-use within certain classes of applications.

Conclusion

In this chapter, we introduced a novel approach to the use of AI technologies based on cognitive concepts to support user experience in Virtual Reality Art installations. The system is based on a game engine ported to a CAVE-like immersive display. It uses the engine's event system to integrate AI-based simulations into the user's real-time interaction loop. The combination of a set of action transformation operators within heuristic search, based on cognitive factors, provides a powerful mechanism to generate a causality-inducing chain of events. The underlying idea was to use semantic representations for interaction events, so as to modify the course of actions to create specific impressions to the user.

The viability of our approach has been demonstrated by the development of two actual VR Art installations, which illustrated the system performance and flexibility, over traditional All-scripted approaches. We have developed a new kind of tool for VR Art, which supports the definition of behaviours at a conceptual level, facilitating the development of VR Art (Cavazza et al., 2003a, 2003b, 2004a, 2004b, 2004c, 2004d, 2004e, 2005; Lugrin et al., 2005, 2006b). We have illustrated this approach, using causality as a test case. As a psychological concept, it can relate elements of the artistic brief to the user experience (the details of which are still open to inter-personal variability, so the process in not restrictively deterministic). In that sense, there is a faithful transposition of the artistic intention to the user experience. At the same time, we have developed technical tools, which can work directly at the level of causal phenomena. This in turn, facilitates the technical implementation of VR installations.

This work is an example of the use of cognitive concepts to support the creation of VR Artworks. Fundamental knowledge of cognitive mechanisms is a determinant of the elicitation of experience, which can be made to serve artistic intentions, by bridging the gap between user experience and the VR implementation produces it.

In line with the relation cognition/VR simulation, the next chapter is investigating the correlations between the cognitive phenomenon of Causal Perception, and the well-known psychological state of Presence in virtual world.

CHAPTER 6: CAUSAL PERCEPTION AND PRESENCE

Introduction

In VR theory, the effectiveness[20] of a VR design is commonly estimated in terms of the “sense of presence inside the virtual world” felt by the user. This concept, referred to as Presence, is defined as the subjective experience of being in one place, even when one is physically situated in another (Witmer & Singer, 1998). In VR literature, the nature of this phenomenon and the factors contributing to it has been and are still widely debated (Schuemie et al., 2001). Nevertheless, many authors have assumed a strong relation between Presence and the level of interactivity (Schuemie & van der Mast, 1999*).*In the same time, the roles of the variables of interactivity, such as the ones proposed by Steurer (1992) *(i.e. Speed, Range and Mapping),* are still difficult to evaluate and compare regarding their impact on Presence.

In this chapter, we propose to relate a well-observed cognitive phenomenon, Causal Perception, to these action-based conceptions of Presence (see e.g. Zahorik & Jenison, 1998; Held & Durlach, 1992; Sheridan, 1992). Therefore, in this experiment, we evaluate the correlation between the elicitations of Causal Perception and Presence. In the first part of this section, we briefly introduce the different conceptions of Presence discussed in VR literature, and relate them to our experimentation. We will then describe our experience protocols and implementations, before finally concluding on the analysis of our results and methods.

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[20] The capacity to product a desired effect

Virtual Reality is a unique technology that immerses the user’s senses in an electronically simulated environment. Most of the research in this subject is related to the concept of **Presence**: the sense of “*being there*” in a virtual environment. In its essence, the concept of Presence defines Virtual Reality in terms of human experience, rather that technological hardware capacity. The nature and factors of the sense of presence in VR have been widely discussed since 1992 in VR literature. Numerous contemporary researches continues to actively prospect the elements of Presence in the intention of enhancing the user’s virtual experience (Bracken et al. 2008; Tamborini & Skalski, 2006; Ermi & Mayra, 2005; Pinchbeck, 2005; Bracken, 2005; Tamborini et al., 2004; Schneider et al., 2004; Skalski, 2004; Ravaja et al., 2004; Bartfield, 1995; Nicovish et al., 2005; Dillon et al., 2000).

However, the definition of Presence has yet to be agreed upon by researchers. Among the existing definitions, the most discussed ones in VR literature could be divided in three main views (see below):

- **Immersion-based views:** Presence happens when the individual feels as “*being in*” the virtual environment ,Sheridan, 1992; Zeltzer, 1992;Witmer & Singer, 1998).
- **Non-Mediation-based views:** Presence happens when the individual *“forgets”* the technological interface. It is the “*perceptual illusion of non mediation*” evoked by Lombard and Ditton (1997). It typically happens when the user confounds real stimuli and stimuli mediated by the VR Technology.
- **Ecological & Social-based views:** Presence happens when the individual *“"perceives”* the virtual environment as an extension of their physical or social reality, in which he can evolve and interact (Zahorik &Jenison 1998; Pinchbeck & Stevens, 2005, 2005b; Loomis, 1992). As discussed in the following sections, the “**Action-based**” theories of Presence, deriving from this view, has become a predominant conception. They consider the ecological and social validity of virtual environments as essential criteria to elicit a strong sense of presence. According to these theories, our sense of Presence mostly derives from the perception of our action’s consequences and satisfaction of our expectations (see quote below).

> *"Presence is instead tied to one's successfully supported action in the environment, this environment being either virtual or real. The coupling between perception and action is crucial for determining the extent to which actions are successfully supported" (Zahorik & Jenison, 1998).*

In all these conceptions, the notion of immersion, involvement, interactivity and believability are present, with obvious nuances on the contributing factors of the elicitation of Presence. The subjective feeling of 'being there' has been conceived as deriving from immersion, interaction, social and narrative involvement with suitable technology (Carassa et al., 2004). Despite numerous discussions on the concept of Presence, a theory encompassing the full set of characteristics contributing to the experience of presence has yet to be defined. Nevertheless, previous research on Presence has demonstrated that the feeling of presence arises from a certain combination of factors. Seven main factors have been identified; they represent "rules" of which the non-respect considerably impoverish or prevent the experience of Presence. Most of these factors are interrelated to environment attributes, individual ability and state-of-mind, tasks related and VR platform equipment. The list below summarises the seven main factors believed to underlie presence, which are now used as guidelines for maximising virtual experiences.

- **The "ease" of Interaction :** The "naturalness" of interaction and navigation mode offer by the VE (Billinhurst &Weghorst, 1995).

- **Image Realism:** The degree of realism of an image in terms of the level of detail and unambiguous signification (i.e. allowing a fast recognition of the artefact)(Witmer & Singer, 1998; Welch et al., 1996; Wilson et al., 1997; Snow & Williges, 1998).

- **Duration of Exposure:** Minimum duration is necessary for the users to familiarise themselves with the task (and controls) and in order to achieve a better sensory adaptation. It should also be noted that prolonged session could result in cyber-sickness that is negatively affecting presence (Stanney, 2000; Witmer &Singer, 1998; Stanney et al., 1998).

- **Social Interaction:** Presence of other individuals (avatar or human), offering evidence that the user "exists" in the VE (Lombard, 2000; Mantovani & Riva, 1999).

- **Individual Cognitive Tendency :** individuals with a tendency to favour Visual over Auditory and Kinaesthetic representational systems are easily subject to presence (or as source of information) (Slater & Usoh, 1993) We should also highlight that individual characteristics that would promote presence, and their taxonomy are still considered controversial and require further study. Individuals perceive environment stimulus differently, as suggested by the theory of Affordance (1979). In this Gisbonian view, our Perceptual systems are guiding the way we interpret and react to the virtual world. Affordance theory suggests that we see our environment and its content as function, rather than as structure. Allocation of attentional resources is also essential to induce presence. Fontaine in 1992 added that broad focus is also necessary for a high-level of Presence in VE. According to these views, the user's facility to focus on a meaningful set of stimuli in the VE would conduct to the exclusion of unrelated stimuli in the real physical location. The notion of "*Suspension of Disbelief* "is also necessary to this immersion as identification with story characters Slater & Usoh (1993c). In other words, certain individuals are predisposed to accept reduced sets of stimuli as significantly real, provided that the reduction is managed and maintained effectively (PinchBeck, 2007; Whitton, 2003).

- **VR Platform Interfaces vividness and isolation:** This view considers the degree of isolation provided by a VR system as primarily responsible for the induction of the state of Presence. VR systems should include input-output devices stimulating a large range of senses with a quality close to the real world. This could be achieved with Multimodal Interaction, Stereoscopic vision and Haptic feedback (Slater & Usoh, 1993). Any distractions from the real world have the potential to impair a user's sense of immersion, as their focus and attention is drawn away from the current activity or scenario (McCall, O'Neill & Carroll, 2004). Sadowski and Stanney (2002) demonstrated that external distraction considerably interfered with the user

VR experience. For many researchers, the user immersion depends on its physical isolation from its surrounding environment (Slater & Wilbur, 1997; Bystrom et al., 1999; Draper et al., 1997). Slater et al. (1994) points out that a high sense of presence in a VE, requires a simultaneous low level of presence in the real world, and vice versa. Witmer & Singer (1998) state that presence in a virtual environment depends on one's attention shifting from the physical environment to the virtual environment, but does not require the total displacement of attention from the physical locale. In 2002, Sadowski and Stanney (2002) demonstrated that external distraction considerably interfered with a user's VR experience. As a result, despite the numerous debates on user's immersion nature, most researchers agree on the necessity to maintain a certain degree of user isolation, in order to develop a feeling of presence (Biocca, 1997; Lombard, 2000; Slater et al., 1994; Slater & Steed, 2000; Witmer & Singer, 1998). Consequently, a technologically-based Immersion has been qualified as an important factor that contributes to the apparition of the sense of presence.

- **User's sense of control:** In **t**his view, the increase of the amount of interactivity subsequently increases the feeling of immersion (McCall, O'Neil & Carroll, 2004). The degree of interactivity corresponds to a user's ability to control his/her sensors (point of view) and modify virtual environments (Sheridan, 1992; Welch et al., 1996). Mantovani and Riva (1999) have equally emphasized the importance of freedom of movement and actions of actors in the virtual environments. This speculation has been reinforced by recent studies of interactivity in education (Richards, 2006). Witmer and Singer (1994) added that the immediacy of environment response to user initiated action is an essential factor to induce this sense of control.

In this research, we are only investigating the "User's sense of control" factors of Presence. Considering that Causality is deeply rooted to the notion of interaction in VE, which in turn determines the user's sense of control, we thus propose investigate the significance of causal impression on the sense of Presence. The next sections review the role given to causality in the main conceptions of Presence and their respective measurement questionnaires.

Van and Martijn (2001) have proposed an ontology of Presence, retracing its prominent views in current research and literature of presence. This ontology exposes the different conceptions into four main trends: Traditional views, Ecological views, Estimation Theory and Embodied Presence Model. From the Traditional view to the more contemporary Ecological views, the factors of Presence shifted from **quality of image** to **freedom of movement**, and then from **replication** of reality to the **perception of "lawful" actions** of actors in the environment. In this section, we will briefly review the reference to causality, and more especially to Causal Perception in the main conceptions of Presence and associated measurement questionnaires.

One of the early works, which introduced concepts related to Causal Perception, was that of Loomis (1992) on distal attribution, although causality was not considered explicitly. Following traditional views, Steuer (1992) proposes to evaluate interaction quality based on three factors: *Speed*, *Range* and *Mapping*, where the *Speed* is considered as the delay between the user action triggering and the observation of its consequences in the world. Consequently, the notion of Speed, which is sometimes referred to as system response-time, is closely related to the temporal determinant of Causal Perception.

For Lombard and Ditton, Presence is '*the perceptual illusion of non-mediation*.' In other words, Presence happens when the user forgets the medium's existence, or fails to acknowledge the role of technology (Lombard & Ditton, 1997). One major aspect of non-mediation is the necessity of the technology to exactly replicate real world sensory (i.e. *it feels-like, looks like, acts-like something I know in the real world*). Lombard and his collaborators divided presence into different types of "illusions" from which a particular one: the **"Social Realism"** illusion, appears to implicitly refer to causality. At the base, this illusion relies on the fact that virtual object, event and agent could also exist in real world.

The ecological views gained interest from many researchers as they represent a promising theoretical foundation for understanding and measuring the reality of the virtual experience, and therefore the determinant of presence (Flach & Holden, 1998). In these views, inspired by Gibson's ecological approach to visual perception (Gibson, 1979) and Heidegger's phenomenal existentialism, the sense of Presence depends on possible actions foreseen and their realisation. According to these view, a user perceives a VR environment in terms of “*what can be done*”, and if his/her interaction with a virtual object produces the expected result, the user will then perceive it as “existing”. In a similar vein, Zahorik and Jenison (1998) in their in-depth discussion of the phenomenological conditions of Presence, advocate that a “lawful response” from the environment to our actions should be a major determinant of Presence. More importantly, their strong Gibsonian perspective is somehow close, in terms of its philosophy of perception, to that of Michotte, the father of Causal Perception (Michotte, 1963). They also suggest that presence is experienced when the environment’s responses to the action initiated by the user, are *equivalent* to real world responses, which our perceptual system evolves. In other words, the consequence of an action has to conform to the one predicted by the user, and in respect of real world physical laws. The notion of Lawful action evokes the principles of causality, and position causal interaction as important factors contributing to Presence.

Mantovani and Riva (1999) following Schloerb (1995) introduced the concept of *causal interaction* as an essential aspect of Presence. Mantovani and Riva (1999) also suggested that a user’s action has to satisfy physical and social/cultural expectation: ‘*Presence is always mediated by both physical and conceptual tools that belong to a given culture.’*

According to the “Embodied Presence” theory (Schubert, 1999), individuals unconsciously construct internal representations of a “space of action” from a virtual environment, by mentally projecting their own body in to it. Presence is experienced when those perceived actions are possible. Following his experimentations with game-based environments, Schubert recognised that the “realness” of the world has also a large impact on Presence. In adequacy with the ecological validity view, O’Brien et al. (1998) suggested that Presence emerges from our understanding of the sequence of event-effect. In a certain sense, they recognised that the understanding of causal relation contributes to Presence elicitation.

In his Estimation theory, inspired from the Ecological and traditional rationalistic theories, Sheridan (1999) suggests that we constantly refine our model of reality, based on experience, and of the affordances in the environment. Sheridan (1999) suggested that humans are continuously making and refining a mental model, which estimates reality, based on their senses and interaction with that reality. Consequently, in order to achieve a high degree of presence he suggested that we need to replicate the experiences and affordances present in our real world. However, he failed to combine an ecological perspective with a rationalistic tradition. As we can never truly know objective reality, our perception of a “lawful” action appears relative to the inner coherence of the world. From there, ecological theory also considered the concept of a perception-action loop, which signifies that not only perception affects our actions, but also in return actions can have an effect on our perception. In other words, our representation of reality is constantly (re)constructed from our interaction, where our notion of realness is not only based on the satisfaction of our expectation (i.e. on our real-world knowledge). Nunez (2004), similarly suggests that realism should be replaced with expectation as a variable. In his view, the user establishes a methodology for perceiving and exploring the environment, rather than comparing with its real physical environment. Suspension of disbelief allows cinema audience to be emotionally and empathetically connected with the media content (the movie), even with the full knowledge of the unreality of the stimuli. He concluded that only the inner-coherence of the mediated stimuli affects the sense of co-location, and, to a certain extent, even unrealistic environment would induce presence.

Although rarely referred to explicitly, there is significant evidence of the use of causality in Presence research, most specifically when considering those aspects of Presence dealing with action, agency, environment control, and the realism of an environment’s responses. From a fundamental perspective, this should not be entirely surprising, as causality is one of the few psychological phenomena bridging the gap between perception and high-level cognitive concepts (Scholl & Tremoulet, 2000).

The next section will review the Causality and Causal Perception reference in the questionnaire measuring the degree of Presence elicited by a virtual environment.

There exist twenty[21] different questionnaires quantifying Presence in VR literature, each varying according to their author's conceptualisation of presence and their context of application (see list below). There have been several generic questionnaires developed over the past years, as well as specific ones for atypical environments or experimentations. In the context of our research, we will review in this section the implicit or explicit references to causality, found in those questionnaires.

The Witmer and Singer's Presence questionnaire (PQ) is one of most popular questionnaires in VR research. Witmer and Singer advocated that valid measure of presence should address factors influencing the levels of involvement and immersion in VR Thus a high level of involvement will increase immersion and vice-versa (knowing that they are both interdependent to subjective experience). Witmer and Singer tried to answer the following questions: "*What are the factors influencing Presence in VR*?" and "*What role does Immersion and involvement play in experiencing Presence*?" They proposed a 32-item questionnaire considering four main factors thought to influence presences, which are Control, Sensory, Distraction and Realism Factors. In turn, each of these factors have been decomposed into sub-factors (as illustrated by the table below - For further details the reader is referred to the original article of Witmer and Singer,1998). In their questionnaire, the notion of causality appears under the control factors, where the *immediacy of control*, the *anticipation of events* and *physical environment modifiability* refer in particular to physical causality (Figure 68).

One simple illustration of this is the extent to which items of the Presence questionnaires explicitly refer to action consequences with several items typically involving Causal Perception. For instance, Item #2 of their original questionnaire reads, "*How responsive was the environment to actions that you initiated?*" (See table below for further example).Further on, their use of McGreevy's argument

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[21]

(McGreevy, 1992) about “*continuities, connectedness and coherence of the stimulus flow*” is also evocative of Causal Perception.

- How responsive was the environment to actions that you initiated (or performed)?
- How much did your experiences in the virtual environment seem consistent with your real-world experiences
- Were you able to anticipate what would happen next in response to the actions that you performed
- How much delay did you experience between your actions and expected outcomes?
- How natural did your interactions with the environment seem?
- How much were you able to control events?

Example of Witmer & Singer Questions referring to Causality

(Complete questionnaire available on http://presence-research.org/Questionnaire.html)

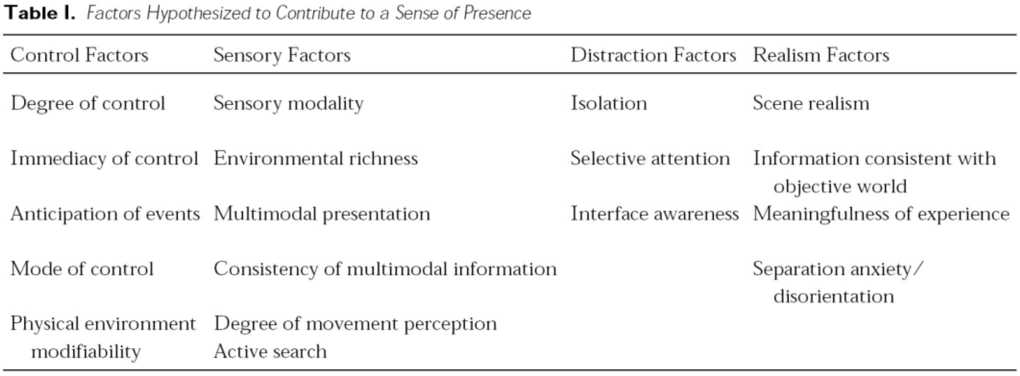

Table I. *Factors Hypothesized to Contribute to a Sense of Presence*

Control Factors	Sensory Factors	Distraction Factors	Realism Factors
Degree of control	Sensory modality	Isolation	Scene realism
Immediacy of control	Environmental richness	Selective attention	Information consistent with objective world
Anticipation of events	Multimodal presentation	Interface awareness	Meaningfulness of experience
Mode of control	Consistency of multimodal information		Separation anxiety/ disorientation
Physical environment modifiability	Degree of movement perception		
	Active search		

Figure 68: Factor Hypothesised to Contribute to a sense of Presence *(Figure reproduced from Witmer & Singer, 1998)*.

These questionnaires have been criticised by Slater (1999) in his reply to Witmer and Singer, he qualified the PQ as evaluating the user’s own perception of the entire VR system properties (e.g. graphical and physical simulations quality) rather than the psychological experiences elicited by it. Slater and Colleagues (1999) proposed a questionnaire (the SUS Questionnaire) based on the variation of three themes:

a) Sense of being in the VE
b) The extend to which the VE become the dominant reality
c) The extend to which the VE is remembered as a place (feeling of "visiting" a place rather than "viewing" a place)

The Slater-USOH-STEED Questionnaire does not consider causal interactions as a critical Presence factor. However, another popular questionnaire, the ITC-SOPI implicitly refers to the need of causal consistency through their "Ecological Validity" factors. The whole questionnaire contains 44 items, divided into four main factors: *Sense of Physical Space, Engagement, Ecological Validity and Negative Effects*. It consists of questions rated on a 5-points likert-scale (i.e. 1- I strongly disagree, 5- I strongly agree) The ITC-Sense of presence inventory (ITC-SOPI) has been designed to be relevant across media and content and tests on a variety of settings (IMAX, 3D Movies, videos, video games consoles). The Igroup Presence Questionnaire (IPQ) (Schubert et al., 1999) has been constructed by combining previously published questionnaires, among which those of Witmer and Singer (1998) , Slater and colleagues (Usoh et al., 2000), and Regenbrecht et al. (1998), with some newly developed questions on technological and context variables. The resulting 75-item questionnaire targets eight factors, which are divided into three factors for overall user VR experience, and five for Immersions (see below). In their questionnaire, the predictability factor also implicitly refers to the causal interactions in the environment and their perception by the user.

- **Spatial presence (SP),** the relation between the VE as a space and our own body.
- **Involvement (INV),** the awareness devoted to the VE.
- **Realness (REAL),** the sense of reality attributed to the VE.

The immersion factors, which the authors describe as the factors concerned with descriptions of the interaction of the user with the VE, or with descriptions of the technological side of the VE, were:

- **Quality of immersion (QI),** the sensory quality for richness and consistency of the multimodal presentation.
- **Drama (DRAMA),** the perception of the dramatic content and structures.
- **Interface awareness (IA),** the awareness of interfaces that distract from the VE experience.

- **Exploration of VE (EXPL),** the possibility to explore and actively search the VE.
- **Predictability (PRED),** the ability to predict and anticipate what will happen next.

In conclusion, most of the Presence questionnaires consider causal interactions recognition as contributing factors to the elicitation of presence. To summarise, it is clear that across existing Presence conceptions and measurements, Causality is implicitly part of many of the factors thought to underlie Presence. Most of the time, it is expressed trough Control or Realism Factors, where Control represents the user's recognition of his/her interaction as causal, and Realism is strongly linked to the satisfaction of the user's expectation, which in turn is correlated to replication of real world physics.

Hypothesis and Methodology: *Causal Perception as a Presence Factor*?

Our survey of the Presence conception's measurements demonstrated that its determinants appear to be strongly related to the notion of attention, as well as the perception of coherent (i.e. lawful) actions in a virtual world, even though they might be conflicting with our real world experiences.

Therefore, in this experiment, we propose to evaluate the role of realism regarding a user's sense of presence within a VE. We want to compare causal impressions and Presence scores in environments where realistic physical behaviours have been replaced by alternative behaviours eliciting Causal Perception. Our experiments aimed at evaluating the possible association between Causal Perception and some previously described factors of Presence (Witmer & Singer, 1988), mostly described as *Control* factors. In that sense, the variable we controlled was the elicitation of Causal Perception, while measuring Presence factors by using a 10-item subset of the original Presence Questionnaire of Witmer and Singer (1998). Fundamentally, we are investigating if there is correlation between the elicitation of Causal Perception and the elicitation of Presence. We are thus questioning if Causal Perception should be considered as a determinant factor of Presence rather than pure realism.

In order to evaluate possible correlation we then created three versions of the same environment; one is showing "realistic causality", the other one displaying "unrealistic causality, while the last one, used as control group, is simply "preventing" any object behaviour, cancelling any Causal Perception elicitation. We relied on our Cause-Inducing VR system to automatically create such behaviours. More specifically, we focused on its faculty to generate different physical events co-occurrences with different level of plausibility from a single event. This environment is represented on Figure 69 and comprises of five tables each supporting two glasses (one empty, one full), a beer bottle, a lit candle and a cardboard menu. Subjects were interacting and viewing the VR though a typical PC-desktop configuration with a traditional keyboard/mouse interaction.

In line with our preceding experimentations, we extracted causal impressions left through the user's textual explanations of the behaviour observed. Following this, we compared the percentages of the causal explanation to the presence scores, computed from our post-test presence questionnaire. In the following sections, we will shortly summarise the principles of our cause-Inducting VR system and its implementation. We will then describe our questionnaire and experimental protocol. In the last section we will conclude with discussing the results of the experiment.

Generation of Object Behaviour

As previously mentioned, we have developed an Alternative Causality VR system, which operates by modifying virtual world events as they take place, so as to create alternative event co-occurrences, which will induce causal impressions to the user. The system operates by intercepting ongoing events and altering them, while their effects are temporarily "frozen."

What we exploited is the strong penchant of humans to perceive co-occurring events as causally linked, especially when they initiate the first event through their own actions. From the subject's perspective, their interactions with the world objects will not result in their ordinary consequences. Rather, these default consequences will be "intercepted" and substituted with other effects. For instance, while a glass falling on a table would normally shatter (spilling its contents), our system can generate alternative effects, such as the glass landing intact on the table, but causing another glass to tumble and spill its contents.

Our causal system has been developed as an additional layer on top of a visualisation engine, the Unreal Tournament 2003 Game Engine^{TM} (Lewis & Jacobson, 2002). Its architecture is composed of an Event Interception System (or EIS) and a Causal Engine (see Figure 69). The EIS, integrated to the game engine, is responsible for the recognition of physical actions, such as breaking, emptying, filling, pushing, and tilting an object. By default, the expected consequence of the action is "*frozen*" and immediately modified by our Causal Engine, which can change, add or remove objects and/or effects *(in Figure 69, the Causal Engine added the Tilting action to the breaking action)*. From an intercepted action, this causal module computes a range of alternative effects, classified from the most plausible (i.e. Realistic Causality) to the most unbelievable consequences (i.e. Unrealistic Causality). In our view, a plausible event co-occurrence should strongly elicit Causal Perception. In other words, our system is aiming at inducing "unconscious" sentiment of (mechanical) causal relation from artificial physical events. (In this context, the term 'Artificial' is employed in the sense of not deriving from Physics principles).

Note: for further information, the detailed behaviour of these modules, as well as the working cycle of the whole system, are discussed in Chapter 3.

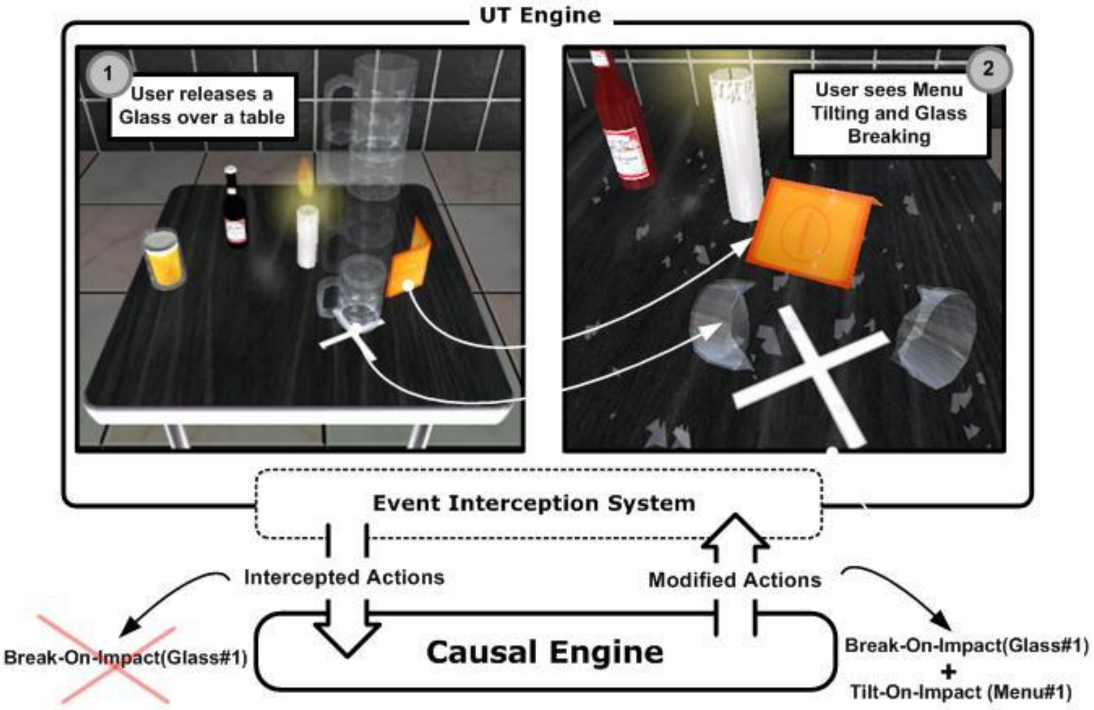

Figure 69: Cause-inducing VR system architecture and artificial causality examples (Here the tilting of the menu (i.e. The ADDED EFFECT) is triggered simultaneously with the breaking of the glass (i.e. the expected effect).

Experiment groups

The Alternative Causality system has been employed to create different versions of an environment, where one will exhibit “realistic” causality, while the other one will display “unrealistic” one.

As presented in the table below, in the first group, subjects will be presented with plausible event co-occurrences, which should induce Causal Perceptions (Figure 71). A third group of subjects (Figure 72) will be presented with deliberately “unrealistic” effects, i.e. behaviours not semantically or physically related to the initial action (for instance, upon the impact of a glass on the table, the contents of a nearby glass will evaporate). The Presence score for these two groups will be compared to the control group, while simultaneously assessing the actual level of Causal Perception in each group, through the analysis of the participant’s textual explanations of what they have experienced.

	Group 1 **“Realistic Causality”**	**Group 2:** **“No Causality”**	**Group3** **“Unrealistic Causality”**
Alternative Effects Generated	Nearby Bottle tilts	Glass Floating and slowly landing on table	Nearby Glass beer evaporates
	Nearby Menu tilts		Nearby Glass breaks
	Nearby Candle tilts		Nearby Bottle breaks
	Table surface cracks		Nearby candle is projected.

Table 1 : Experiments Groups and their different level of Causality realisms

Our last group represents the control group thus corresponds to an environment where no physical co-occurrences are created. Namely, when a subject drops a glass, the latter floats in mid-air before eventually landing on the table after a few seconds, without that landing being followed by any specific consequence. This behaviour introduces temporal gaps (which are known to impair Causal Perceptions), while also possibly decreasing perceived motion transfer (through slow or irregular motion of the falling object). For this control group, the Causal Engine was not activated; instead, scripted behaviours were randomly selected, each corresponding to the selected object returning to its original place unaltered (Figure 70).

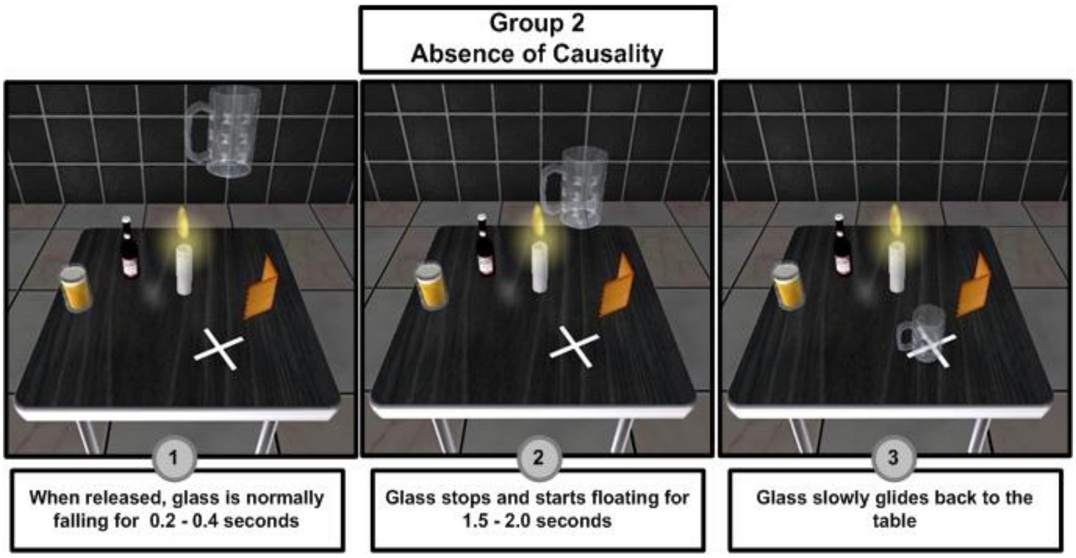

Figure 70: Example of an “absence of causality” scenario (Control Group)

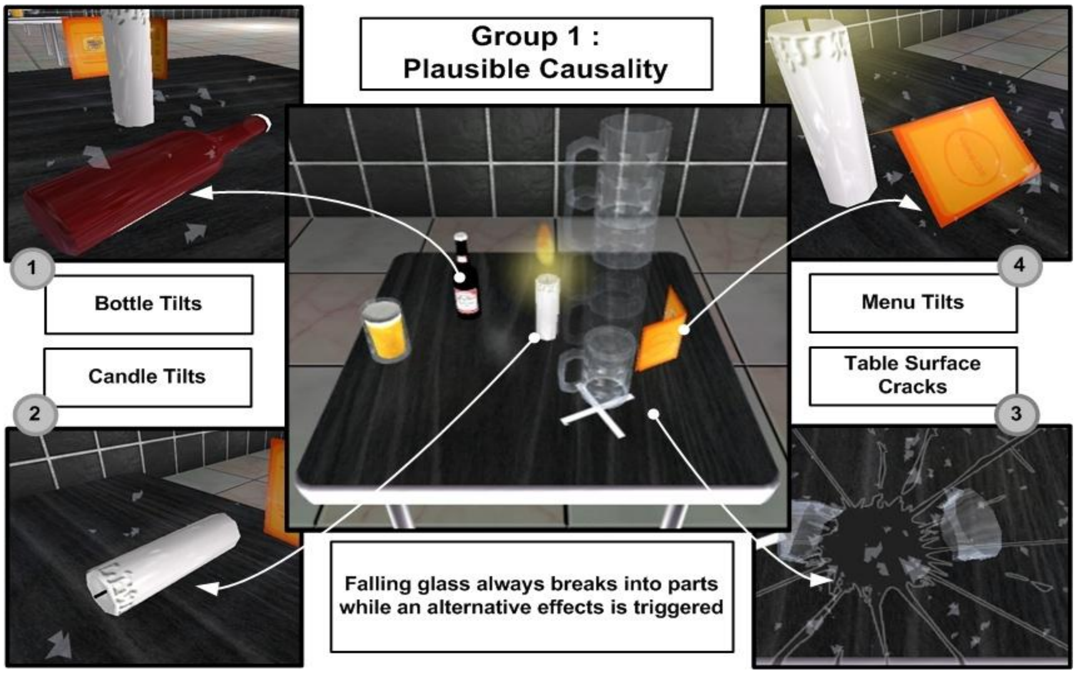

Figure 71: Example of co-occurrence generated by the system with a high level of plausibility

(Experiment group 1 – realistic (i.e. "plausible”) causality)

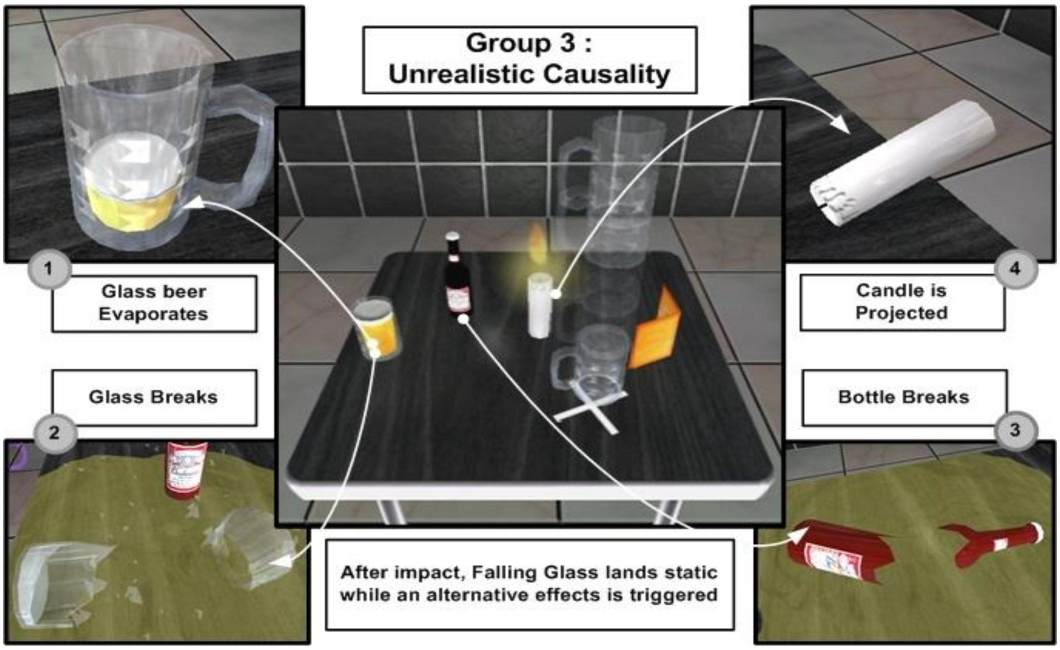

Figure 72: Example of Co-occurrence generated by the System with a low level of plausibility

(Experiment group 3 – unrealistic causality)

Questionnaire

We have selected 10 questions from the original Presence Questionnaire of Witmer and Singer (1998), considering them from the perspective of how they could relate to simulated causality (*see complete questionnaire in Appendix A at the end of this thesis).*

This questionnaire comprises of 9 of the 12 questions of the Presence Questionnaire categorised as questions exploring the Control factor. We have not included more questions in the Realism cluster, as most of these referred to multimodal sensory perception and/or included sound, which was not used in our experiments.

Furthermore, it can also be noted that 9 of these 10 questions exhibit a strong correlation between their individual score and the total PQ score (actually among the highest correlations for all questions in the PQ) Our emphasis in this experiment is however on Presence *factors*, in particular those dealing with control and predictability.

After completing their participation in the experiments, subjects were asked to fill in a questionnaire (complete question is attached below). The questionnaire was presented in a paper form and subjects had to respond by putting a cross on the continuous 7-grade scale (Figure 73). The complete questionnaire used is available in the appendix section.

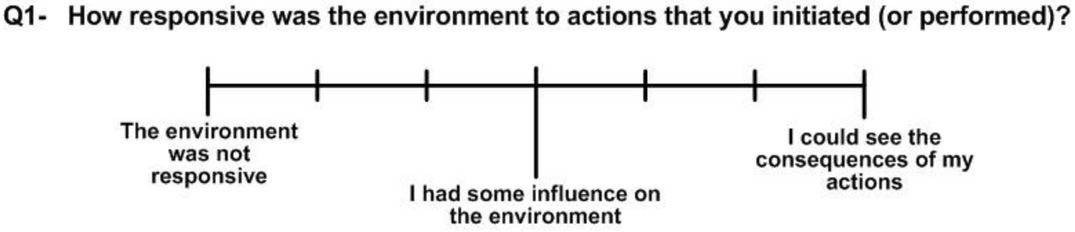

Figure 73: Example Question and its associated response grade scale.

Each of these ten questions were presented to the subjects as a continuous seven-point scale (from 0 to 6), where extremities, as well as the middle point were associated with textual descriptions (as originally described in (Witmer and Singer, 1998)). Consideration was taken, at all times, not to mention the words "cause" or "causality" in the experiments' instructions, the questionnaire elements, or in the textual descriptions underlying the grading scale.

Experimental Protocol and Settings

A total of 53 subjects were recruited and allocated to the three groups above.

- Group 1 -"Realistic Causality"- comprised 16 subjects (average age 22.6; 8 male, 8 female),
- Group 2- "No Causality" comprised 20 subjects (average age 27.8; 9 female and 11 male)
- Group 3 – "Unrealistic Causality" comprised 17 subjects (average age 26.9; 6 female and 11 male).

Subjects were introduced to a desktop 3D virtual environment supporting interactions with the virtual world's objects. The environment is represented in Figure 69 and comprises five tables each supporting two glasses (one empty, one full), a beer bottle, a lit candle and a cardboard menu.

Subjects were facing an 18-inch screen from a distance of 30-45 cm. The corresponding field of vision in the virtual environment was approximately 80 degrees. In addition, they operated in a quiet and silent room. The average duration of a session was 30 minutes and each subject was rewarded for its participation with a £15 voucher.

After being explained the basic interaction mechanisms for grasping, lifting, and dropping objects in a similar but different environment (including a short training session to familiarise themselves with the system controls), subjects were given instructions for the “task” they had to carry.

The task consisted of the user having to select the empty glass from each table in the virtual world, lift it above the table, then drop it and let it fall on the table aiming at a specific virtual marker drawn on the table (Note: this was instructed in order to avoid unwanted or different situations from one user to another, such as a subject dropping the glass on other objects on the table).

They would then witness the virtual world reaction to their actions, in other words the consequences of the falling pint hitting the table. The subjects would interact with the virtual objects using the controls provided by the native game engine: through a combination of mouse buttons and mouse movements they are able to select and move objects in the 3D world. Visual feedback was provided for object selection as well as object position above the table (through a virtual shadow, disappearing when a sufficient height had been reached signalling the object could be dropped).

After each interaction, the subjects were asked to give a short textual explanation of the observed events, which they entered directly on the computer used for the experiments. The rationale is that explanations, rather than simple descriptions, would force the expression of causal concepts relating their actions to the observed system response. These explanations were to be used in analysing whether subjects actually attributed causality between the events they observed.

We thus collected four short textual explanations for each subject taking part in these experiments (i.e. a total of 64 for Group 1, 80 for Group 2 and 68 for Group 3). The average length of one textual explanation was 20 words for Group 1, and 30 words for both Group 2 and Group 3 (as summarised in the table below).

	Number of Textual explanations	*Average length per textual explanation (in number of words)*
Group 1 – “Realistic Causality”	64	20
Group 2 – “Absence of Causality”	80	30
Group 3 – Unrealistic Causality”	68	30

Table 2: Textual Explanations collected for each group

The goal was to analyse these answers for the occurrence of causal explanations, hence validating the existence of Causal Perception in any given experiment. The analysis of free text explanations was also a way to determine how implausible events were perceived or judged and whether mechanistic explanations were invented for them.

Note: Videos demonstrating the experiment for each group are available online at (http://ive.scm.tees.ac.uk/?pID=5&aID=7) or on the DVD attached to this document (see Annexes page 200)

Presence Score Analysis

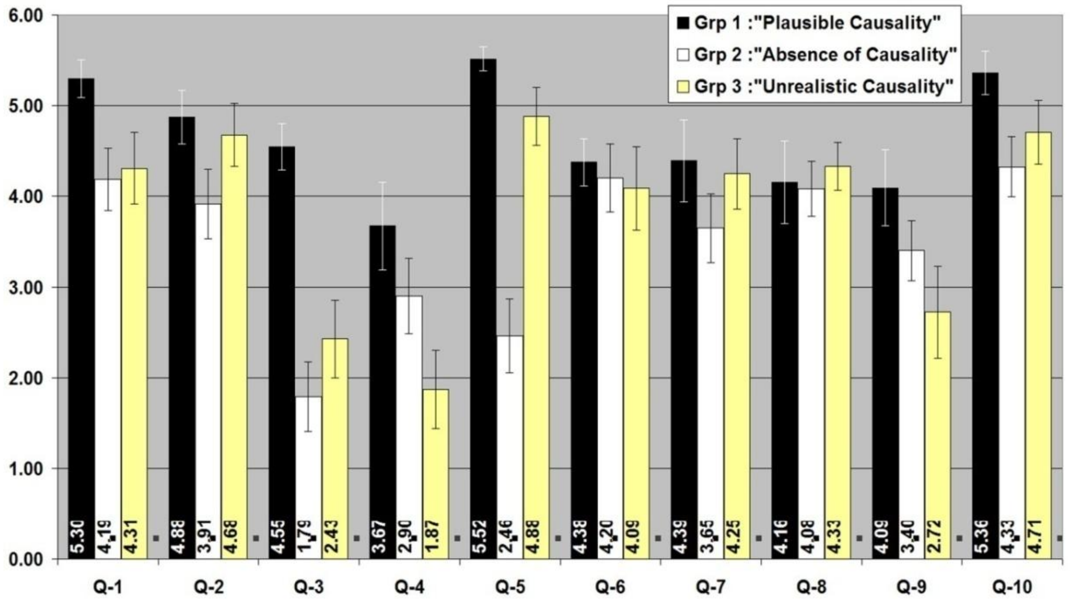

Figure 74: Scores obtained per question / per group (1-2-3)

The Presence scores for each group were calculated by adding the responses to all 10 selected questions (Figure 73) on their 0-6 scales. Figure 74 represents the Presence scores for each of the three groups with their error margins. For Group 1 (the group with realistic causal effects) the average Presence score was 46.28; for Group 3 (the group with unrealistic causal effects) it was 33.92 and for the reference group, Group 2 (absence of causality) it was 30.82.

An ANOVA computed over the Presence scores revealed a significant effect of Group, $F(2,50) = 20.17$, $p < 0.001$. Tukey HSD post-hoc tests confirmed that Presence Scores for the *Realistic Causality* group were higher than those in the *Absence of Causality* and *Unrealistic Causality* Groups (*p*s <.001), and that these latter two groups did not differ.

In each group, subjects were asked to enter on-screen a brief explanation of the phenomena observed after each trial. They were specifically instructed to explain what happened rather than just to describe the events they had witnessed. The set of explanations (five for each subject) was pooled over individual groups and was subsequently analysed for causal explanations. Some of the causal explanations provided by the subjects are shown in Figure 75.

Group 1 "Realistic Causality"

Glass shattered causing candle to fall over.
When dropping the glass it moved the other glass along the table.
Glass shattered also knocking card over.
The glass broke and it moved the other glass to the corner of table.
The pint smashed which knocked the menu over.
The fractured glass pieces caused the menu to fall over.
When dropping the glass it broke and the pieces hit the candle which in turn fell over.
It smashed into lots of pieces and knocked over the beer bottle.
The glass smashed and knocked over the bottle.
The glass fell and smashed causing the bottle to fall over.

Group 3 "Unrealistic Causality"

The glass fell and broke the beer bottle next to it.
The pint full of beer broke. It happened because it was very close of the point of impact of the pint.
The glass fell and appeared to knock a candle off the table even though the candle did not seem to be in the path of the glass.
The bottle of wine broke. I think it happened because it was the only closed recipient on the table and the vibrations, due to the fall of the pint, have broken the bottle.

Comments expressing surprise in Group 3:

The beer in the pint disappeared like if somebody was drinking it. I have no explications for that because it could not happen in real life.
Now the cross is on the left and when I released the glass the bottle broke I did not expect it. It surprised me because I was trying to put the glass on the cross.
I was very surprised this time, the glass which contains beer did not get empty but it exploded when I released the glass. I expected that something happened but not a explosion.
When the glass was dropped the bottle in the background split. The top half of the bottle landed on the table next to the bottom half of the bottle and the liquid from bottle spilt on the table.

Figure 75: Example of causal explanation provided by subject for groups 1 and 3

One problem with the interpretation of these textual explanations is of course the use of language. Although sometimes a simple juxtaposition of descriptions can constitute an implicit causal statement (see, e.g. (Oestermeier & Hesse, 2001)), we could only interpret descriptions by making explicit use of causal vocabulary.

In adequacy with our preceding experimentation, we analysed each individual explanation for causal expressions corresponding to linguistic descriptions identified by Wolff, 2003).

Here is an example of what we have retained as causal expression:

- **Explicit causal vocabulary** ("causes," "causing," "caused by"), as in "the glass fell and smashed causing the bottle to fall over", "glass shattered causing candle to fall over."
- **Lexical causatives** (verbs that allow speakers to describe a causal situation in a single clause, as listed in (Wolff, 2003), e.g. *"when dropping the glass it moved the other glass along the table"*.
- **Two-argument activity verbs** (also listed in (Wolff, 2003)) whenever their effects are also mentioned to overcome one of Wolff's objections), as in the following *"glass shattered also knocking card over"* or *"when dropping the glass, it broke and the pieces hit the candle which in turn fell over"*.

It can be noted that such vocabulary encompasses both the reporting of Causal Perception and the production of more sophisticated mechanistic explanations.

For each individual explanation, we considered it as a causal explanation if it contains one or more of the above causal expressions. We then compute the ratio of causal explanations for the whole group of subjects. Figure 76 shows the results of that analysis. For the reference group (Group 2), there were no detectable causal explanations (0% score). The few occurrences of causal (or mechanistic) vocabulary (e.g. *"because"*) were not referring to the events observed but rather to the subject's own analysis of performance (e.g. *"[...] which missed the mark because I had moved the mouse after the glass began to drop."*). For Group 1 (plausible causality), the level of causal explanations was approximately 50%. For Group 3 (unrealistic causality) it was 22%.

Overall, a significant number of subjects simply neglected to give the explanations they were asked for, and merely gave descriptions of the events without any further explanation. This obviously affected the absolute number of causal explanations, although in a uniform fashion across groups.

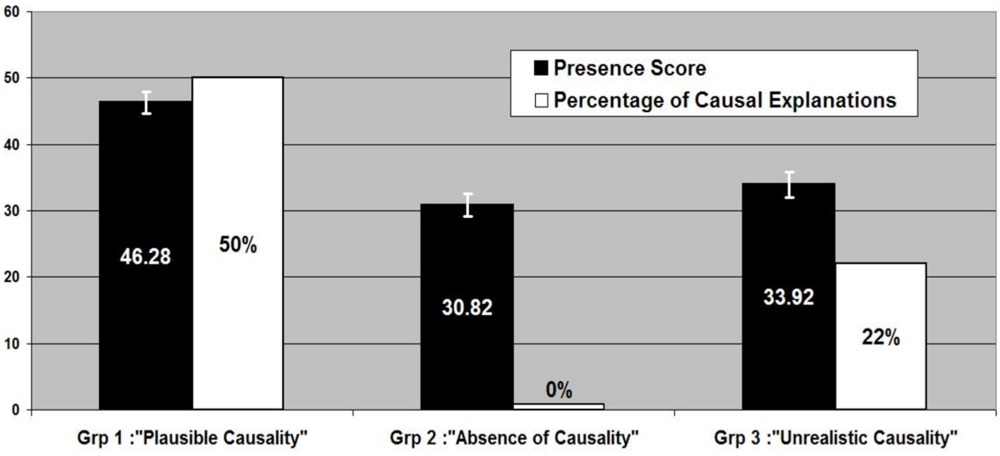

Figure 76: Presence Score and percentage of Causal Explanation per group

The detailed proportion of causal explanations provided by participants were 32/64 for the Realistic Causality group, 0/80 for the Non-Causal group, and 15/68 for the Unrealistic Causality Group. A Chi-Square test revealed that the frequencies of causal explanations were distributed differently between the three groups, $\chi^2(2) = 51.52$, $p<.001$. Because the proportion of Causal explanations was 0 in Group 2 (“absence of causality”), we also performed another Chi-Square test on the Realistic and Unrealistic Causality groups only. This test also revealed a significant difference in distribution of causal explanations between those groups, $\chi^2 (1) = 11.23$, $p<.001$

Discussion

Several subjects perceived a causal link between co-occurring events, but provided in addition mechanistic explanations, such as the fact that “vibrations” accounted for the perceived causality (as in *“the vibrations due to the fall of the pint have broken the bottle”*). This is consistent with reports linking Causal Perceptions to mechanistic explanations (Schlottmann, 1999), although with this analysis, we were not able to observe any instance of dissociation between Causal Perception and causality judgment (Schlottmann & Shanks, 1992).

The Presence score was significantly higher for Group 1 (plausible causality) than for the control (Group 2), with a difference in total score of approximately 50% with respect to the control group. Confirmation of Causal Perception in Group 1 comes from the level of causal explanations in this group, while confirmation that Group 2 indeed behaved as a reference group can be derived from the absence of causal descriptions.

Secondly, no major difference in the Presence Score was observed between Group 3 and 2. In Group 3, the system produced highly unrealistic associations and Group 2, the reference group, where effects were selected not to elicit Causal Perception (even though the difference observed was found to be statistically significant)There are several possible explanations to this observation. The first one would consider that "realism" contributes most significantly to the Presence score, even with our specific selection of *control* questions (some of which are categorised by Witmer and Singer (1998) as involving both aspects, and some also occur in the "Reality questionnaire" (Bob & Micheal, 1998) under a slightly rephrased form)[22]. In that sense, the unrealistic behaviour observed in Group 3 would be less likely to produce high Presence scores with the use of PQ. On the other hand, the *control* factor of Presence, being also defined in terms of anticipation (Witmer & Singer, 1998), would naturally be affected by the occurrence of unrealistic effects.

However, the simultaneous analysis of the verbal explanations suggests another explanation, due to the low level of Causal Perception in Group 3, at 22%, which is that some effects in Group 3 actually failed to induce Causal Perception. This is further confirmed by the occurrence, in the textual explanations of Group 3, of explicit statements of surprise or incomprehension (e.g. *"I have no explications for that"*, *"it surprised me because [...]"*). The mixed results observed for Group 3 could be explained by the fact that some "unrealistic events" appear more unrealistic than others.

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[22] The importance given to realism could constitute a limitation of the Presence Questionnaire, as it would rule out Presence in some purposefully unrealistic environments (artistic installations or fantasy/narrative worlds).

The specific and novel contribution of this work consisted in attempting to relate one well-observed psychological phenomenon, Causal Perception, to some fundamental ideas of Presence, namely the action-based conception of Presence (see e.g. Zahorik & Jenison, 1998; Held & Durlach, 1992; Sheridan, 1992). Overall, these results suggest a positive influence of Causal Perception on some Presence factors, which cannot be entirely accounted for by physical realism, as many of the plausible causal associations generated in the experiment involving Group 1 actually depart from accurate physical simulation (this is why they have been termed 'plausible' rather than 'realistic'). In addition, the criteria for eliciting Causal Perception may be more accessible to experimentation than those for complex concept such as realism.

Throughout this chapter, we have referred to "conceptual" determinants of Presence as originally introduced by Witmer and Singer (1998), although they lack the validation of factor analysis (Schubert et al., 2001). It is interesting to note, however, that in their paper on the analysis of the respective contribution of Presence factors, Schubert et al. (2001) have only attributed a minor role to "control and predictability" (stating that it would account for only 2.9% of variance in Presence scores), making it one of the least significant determinants of Presence. Our results would suggest that, at least in specific circumstances, the effect of control and predictability on Presence could actually be more important.

One question that we could not answer completely concerns the exact impact of unrealistic cause-effects associations on Presence. In Group 3 , subjects produced a lower proportion of causal explanations and sometimes clearly stated their disbelief at some observed effects. It could indeed be the case that some "implausible" generated effects could actually violate certain principles of Causal Perception, such as feature transfer or motion *ampliation*. This should probably be revisited after gaining a better understanding of Causal Perception in realistic environments, which will include knowledge of relevant perceptual features inducing Causal Perception.

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CHAPTER 7: CONCLUSIONS AND PERSPECTIVES

Introduction

In this chapter, we will first reflect on the achieved objectives and results, before concluding on further research perspectives. This chapter begins with a synthesis of the thesis's findings, in which we also briefly revisit the original aims, hypothesis, methodology and the results of the research. This is concluded by the presentation of the different scientific publications originated from this research work.

In the second part, we introduce future work and potential improvement by discussing the extensions require to manipulate causality in larger scale environment.

The third part discusses and illustrates the potential applications of this research to open novel perspectives in programming and understanding interactivity in VR. We begin by considering future experimentations on the role and determinants of Causal Perception in interactive systems. We then turn to an illustration of the potential of AI-based world behaviour for interactive and emergent storytelling.

In the final part, we conclude this thesis by making a couple of remarks on the theoretical, technical and personal achievements realised.

Summary of Findings

This research was originally motivated by the creation of alternative reality from high-level principles and its exploration at an artistic and scientific level. The starting point of this research was to facilitate the description of high-level behaviours for virtual worlds that would form part of interactive VR Art installations simulating alternative realities. One of the major difficulties in developing such installations, is to properly translate the artistic intentions into actual elements of interactivity, which in turn determine the user’s experience. Additionally, in such a context the notion of alternative reality itself and its definition in term of "alternative" interactions also represents a delicate challenge.

In this thesis, we proposed a novel approach to the creation of such virtual reality experiences, stemming from our everyday experiences, based on the notion of Alternative Causality (Chapter 1). Our underlying hypothesis relied on the concept of Event Causality, which stipulates that humans have a compelling tendency to attribute causality to physical event co-occurrences. As Causality is an essential concept through which we understand our reality, we have therefore posited that the elicitation of Causal Perception from alternative action's consequences would persuade users of a different reality. An alternative reality where causal principles underlying object behaviour would appear different to our everyday reality. In essence, we assumed that Alternative Causality is one essential key to a coherent alternative reality, as it should induce a sense of novelty while giving a (causal) meaning to unusual events succession (Chapter 2). Accordingly, the core of this research consisted in producing alternative event co-occurrences and proving that they would nevertheless appear as causally related.

Our underlying idea to induce causal relation from abnormal event successions was funded from the predominant theory of Causal Perception elaborated by Michotte (1963). He demonstrated that event co-occurrence appearing spatially and temporally contiguous, automatically elicits a strong sense of causality. We then refined our Alternative Causality concept to rely on the elicitation of Causal Perception from alternative collision event's consequences.

In order to experiment our hypothesis, we used AI techniques and symbolic representations to explicitly manipulate event co-occurrences in a virtual environment. Consequently, an AI system has been built on top of a 3D game engine's event system. The overall system supports virtual worlds in which the normal laws of causality can be altered, by substituting the default effects of actions with new chain of events. The system generates Alternative Causality by constantly intercepting, interpreting, and modifying event's consequences, as they occur in the virtual world. The range of the alternative effects produced, varies from "plausible" to "unrealistic", according to the settings chosen.

In order to recognise and modify the normal consequences of an action in real-time, the system represents action and object at a symbolic level. Both action and object have semantic descriptions that support fast recognition, comparison and modification. The action representation has been termed CE (standing for Cause & Effect). Once recognised and intercepted, the ordinary outcomes of the event are modified by a heuristic search evaluating the "*Plausibility*" of each possible alternative chain of events. This *Level of Plausibility* corresponds to a multi-component heuristic based on cognitive data and action analogy. This heuristic represents a convenient mechanism to generate and explore a large range of alternative going from "plausible" to "unrealistic" Alternative Causality. This mechanism represents an important aspect of this research, as it allows artists to guide interactivity (i.e. an object’s interactions) towards different user's impressions using one simple variable. We occasionally referred to this heuristic as the "*Level of Causality Disruption*" since, in a certain sense, it can also be considered as an amplitude of causality distortion when compared to realistic simulations (Chapter 3).

User experiments validated the ability of our approach, principles, and heuristics to induce Alternative Causality from real-world causality disruption. Our experimental results corroborated the system's capacity to produce a large range of alternative causal effects going from "plausible" to "unrealistic" causality (Chapter 4). Additionally, the two VR Art installations exploiting our Alternative Causality system have demonstrated its ability to create artificial reality from high-level principles, while faithfully transcribing artistic intentions into actual elements of interactivity (Chapter 5). Furthermore, in additional user experiments we evaluated the role of Causal Perception regarding a user's sense of presence within a VE. We compared causal impressions and Presence scores in environments, where realistic physical behaviours have been replaced by alternative behaviours eliciting Causal Perception.

Our results evidenced a positive correlation between the elicitation of Causal Perception and Presence. To a certain extent, these results question the importance of the realistic factors regarding user immersion (Chapter 6). In overall, our results demonstrated that the creation of alternative reality from high-level principles is possible through the concept of Alternative Causality. We evidenced this approach by proving that a singular alternative event co-occurrence can indeed induce causal impressions. We have also demonstrated that such Alternative Causality can be generated from principles and so controlled by high-level concepts (*i.e.* our *level of Plausibility).*

In conclusion, this thesis has presented an original approach to create alternative reality in virtual environments based on high-level principles. This research introduces a new method to control interactivity in VR, towards specific user's impressions, based cognitive principles and on AI techniques. Different user experimentations and artistic applications have demonstrated the viability and versatility of our approach to design virtual environments that suggest alternative realities. The overall approach was based on the concept of Alternative Causality, where the fundamental idea was to modify the course of actions to create alternative reality impressions to the user. One of the essential aspects of this approach is its ability to program and control causality in VR, at a symbolic level towards different levels of plausibility.

At a fundamental level, experimental results indicated a positive correlation between Causal Perception and Presence in VR. At a more practical level, this work illustrated how AI-based VE opens novel perspectives to bridge the gap between design intentions and user experience elicitations. The thesis's approach, experimentations, and applications have been published in a wide range of international conferences and journals. The next section briefly lists those publications.

Note: Publications and related video are available for download at

http://ive.scm.tees.ac.uk/?pID=5&aID=7 or on the DVD attached to this document (Appendix B)

This research has originated eleven publications in leading conferences and journals (e.g. IEEE Intelligent Systems, VRST, ACE, PRESENCE, ACM Multimedia, and IUI). The complete list of publications is presented below:

- **Lugrin, J-L**., Libardi, P., Barnes, M., Le Bras, M., & Cavazza, M. (2004). Event-based Causality in Virtual Environment. *IEEE International Conference on Systems, Man and Cybernetics*, The Hague, The Netherlands, vol.1, 156-163

- Cavazza, M., Hartley, S., **Lugrin, J-L**., Libardi, P., & Le Bras, M. (2004d). New Behavioural Approaches for Virtual Environment. *Second International Conference on Entertainment Computing (ICEC), Lecture Notes in Computer Science ,Springer Berlin / The Netherlands*, *Volume 3166/2004*, 29-48

- Cavazza, M., Hartley, S., **Lugrin, J.-L**., & Le Bras, M. (2003a). Alternative Reality: a New Platform for Digital Arts. *ACM Virtual Reality Software and Technology Conference*, Osaka, Japan, 100 - 107.

The user experiments on the elicitation on Causal Perception have supported an international publication at SMART GRAPHICS 2006 conference. This conference brings together Computer Graphics, Artificial intelligence and Cognitive Sciences, focusing on graphics environments and their role in supporting a deeper understanding of human perception, cognition and action.

- **Lugrin, J-L**., Cavazza M., & Buehner, M. (2006). Causal Perception in Virtual Environments. *In the Proc. of 6th International Symposium on Smart Graphics, Lecture Notes in Computer Science, Springer Berlin / Heidelberg, Volume 4073/2006*, 50-61.

The research on Presence and its relation to Causal Perception has been published in the PRESENCE Journal, a leading journal in the study of Presence since 1992.

- Cavazza, M., **Lugrin, J-L**., & Buehner, M. (2007). Causal Perception in virtual reality and its implications for presence factors. *Presence: Teleoper. Virtual Environ, 16*, 6 (Dec. 2007), 623-642.

The overall research on VR Art, Alternative Reality, Causality and AI-based World Behaviour has elicited five publications in international conferences and journals related to Intelligent Entertaining Systems, Creativity and Cognition.

- **Lugrin, J-L**., Cavazza, M.,Palmer, M., & Crooks, S. (2006). AI-Mediated Interactions in Virtual Reality Art, *IEEE Intelligent Systems Journal, Special Issue on Intelligent Technologies for Interactive Entertainment,* Vol. 21, No. 5, 54-62.

- **Lugrin, J-L**., Cavazza, M.,Palmer, M., & Crooks, S. (2005). AI-Mediated Interactions in Virtual Reality Art. *In Proc. Of. Intelligent Technologies for Interactive Entertainment (INTETAIN 2005), Lecture Notes in Computer Science, Springer Berlin / Heidelber, Volume 3814/2005*, 74-83.

- Cavazza, M. **Lugrin, J-L**. Crooks, S. Nandi, A. Palmer, M., &Le Renard, M. (2005). Causality and Virtual Reality Art. *Fifth International Conference on Creativity and Cognition, Goldsmiths College, London,* ACM Press, 4-12.

- Cavazza, M., **Lugrin, J-L**., Hartly, S., Libardi, P., Barnes, M. J., LeBras, M., Le Renard, M., Bec, L., & Nandi, A. (2004b). New Ways of Worldmaking: the Alterne Platform for VR Art. *In Proc. Of. ACM Multimedia 2004,* New York, USA, 80-87.

- Cavazza, M., **Lugrin, J.-L**., Hartley, S., Libardi, P., Barnes, M.J, & Le Bras, M. (2004c). ALTERNE: Intelligent Virtual Environments for Virtual Reality Arts. *Smart Graphics 2004 Symposium, Banff, Canada, Lecture Notes in Computer Science, Springer Verlag, vol. 303,1* 21-30.

The research on immersive VR platforms and its relation to VR Arts has been published in the ACM Conference on Advances in Computing Entertainment (ACE)

- Jacobson, J., Le Renard, M., **Lugrin, J-L**., & Cavazza M. (2005). The CaveUT System: Immersive Entertainment Based on a Game Engine. *In Proc. Of. the second ACM Conference on Advances in Computing Entertainment (ACE),* 184-187.

For the purpose of this research, we only considered and manipulated Causality in small-scale virtual environments and only in term of event co-occurrences. In order to extend our work to larger environments and interpret long-term causal relationships, the whole system will need to be revisited. The (re)insertion of Causality above Physics in VE will indeed request an approach which will consider physical, functional and structural properties of virtual objects in further depth. The recognition of causal actions, going beyond simple action/reaction, implies then the need for representations supporting more complete descriptions of world's dynamics and objects. Yet, the inclusion of Artificial Intelligence representations and their use within 3D graphic worlds face both fundamental and technical issues due to the difference in representational logic between computer graphics and knowledge-based systems (as discussed in Chapter 4).

In a recent paper (Lugrin & Cavazza, 2007) we introduced such a framework integrating causal interpretations above both physical and graphical simulations. This paper introduced an innovative framework for an efficient integration of semantic representations in VR, supporting the interleaving of simulation and interpretation (Figure 77). We articulated object and action representations into the cycle of transformations affecting the virtual world, and investigated the specific representational problems faced when relating the virtual world dynamics to knowledge structures. In our prototype, we have integrated work from several areas of Artificial Intelligence supporting Common Sense reasoning (mostly Qualitative Reasoning and Knowledge Representation), and have proposed an architecture for their real-time integration into VR. (*Please refer to the original publication for further details, available on the DVD or at http://ive.scm.tees.ac.uk/?pID=5&aID=7*)

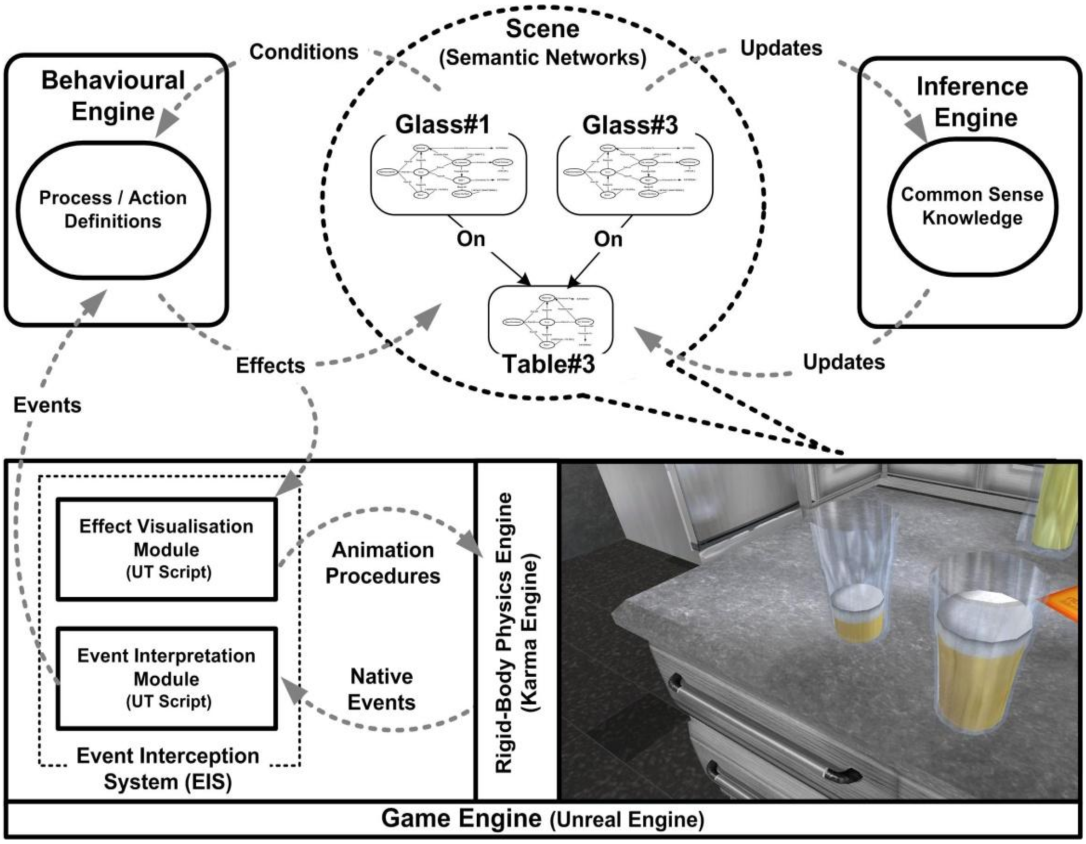

Figure 77: System Architecture for the Integration of a Knowledge Layer in an Interactive 3D Environment

This paper represents a first step towards future large-scale experimentations on causal perception as well as the integration of semantic information in VR. As virtual worlds are mainly governed by physical simulations, it appears relatively important to impose semantic representation to those procedural physical/graphical representations. As highlighted in Chapter 3, the research on Semantic-based virtual is constantly gaining more interest. As the integration of semantic data represents an essential step towards the analysis of simulations' outcomes, the understanding of the user's behaviour, the interactions in natural language, and the reasoning on scene's configuration or state. One perspective of this work is thus to continue to participate to the establishment of such a Semantic VR and its application to different domains. In that sense, the next section discusses and illustrates the potential applications and perspectives of this research regarding fundamental research in cognitive science, and more practical research in interactive storytelling.

Potential Applications

This thesis opens novel perspectives, both in terms of improving and studying interactivity in virtual environments. Therefore, we begin by discussing future explorations of causal inferences in VR, where we briefly describe directions for future psychological experimentations in VR. The second part then illustrates the perspective of an AI-based Causality approach in the field of emergent narrative.

Experimentations on Causal Perception in VR

As previously mentioned, further experiments on Causal Perception could improve our overall comprehension of causal attribution, and have an impact on VR conception and implementation. For this reason, the following section will discuss a number of further experimentations with Causal Perception in VR, which will continue our evaluation of the role and determinants of causal inferences in VE.

The work presented in this thesis has the potential to support various kinds of scientific experiments on Causal Perception, within a fully immersive and interactive setting, and as such, could provide new tools for cognitive research. As previously described, most research on Causal Perception has been based on experiments that used simple animations and artificial tasks (Wolff, 2003, 2007). In addition, most of the fundamental experimentations of Causal Perception involved primitive animations of symbolic shapes (circle, square). Consequently, the absence of background and the simplified nature of shapes may make certain features more salient. Furthermore, current experimental paradigms based on animation, could be limited by the poor engagement of the participant. If the participants only engage superficially, rather than being absorbed in the task, they may not be able to sustain enough attention to keep track, for instance, of long-term relations. On the other hand, a realistic virtual world, in contrast, suggests that what happens is the result of a complex set of interacting rules and constraints, and should have better ecological validity. In this context, a realistic environment does not refer to a “photorealistic” mirroring reality, but contrasts with the symbolic environment. Therefore, the lack of realism and engagement of the traditional experimental apparatus raises the question of whether some aspects of real-world situated Causal Perception are accessible to current experimental approaches.

Therefore, in future work, we should re-address traditional Causal Perception experimentations using non-symbolic interactive virtual environments, and so re-evaluate the strong stimuli-based aspect of Causal Perception. Another advantage of the use of unrealistic virtual environments for cognitive experimentations is that they will also allow to further experiment other determinants of Causal Perception, such as the necessity of prior experience, as proposed by White (2006). VR system could indeed provide an ideal platform to experiment other causation. For instance, our system has relied on the Michotte's theory of Causal Perception, but certain causation theories deriving of Transferences theory propose more elaborated models of causal attribution, which have not been extensively experimented yet. Thus, we could also imagine constructing and experimenting with VR system based on other causation theories, such as the Features Transfers theory (Kruschke & Fragassi 1996).

Emergent Narrative & Alternative Causality

Research in Interactive Narrative has developed new approaches to the behaviour of virtual actors, but has dedicated little attention to the physical behaviour of the environment in which the action takes place. The work presented in this thesis represents a first steps towards the inclusion of narrative elements at the objects' physical behaviour level. In a recent this paper, we illustrated the potential of AI-based world behaviour for emergent narratives (Lugrin & Cavazza, 2006). In line with the work presented in this thesis, we applied the concept of Alternative Causality to the generation of interactive storytelling, where narrative aspects influence object's behaviours. The paper described a method supporting the AI-based simulation of object behaviour, so that interactive narrative can feature the physical environment inhabited by the player character as an “actor.”

As previously explained in this thesis, the generation of alternative causal relations was only guided towards the level of Plausibility wished. This mechanism has been convenient to explore our Alternative Causality hypothesis and provide a single and elegant variable to distort the whole world causality. However, the main limitations deriving from such approach is the difficulty to control and to suggest long-term alternative causal laws, as the search results may differ according to the context.

In our paper (Lugrin & Cavazza, 2006), we proposed to add a novel level of control to the generation of alternative event-co-occurrences, through the introduction of an additional heuristic. A complete prototype has been developed on top of the Unreal Tournament game engine; it relies on our "Causal Engine," which essentially bypasses the native Physics engine to generate alternative consequences to player interventions. On this version, the Causal Engine has been modified and operates now using a small depth-bound planning system, which it is used to determine the most appropriate object behaviours following player interaction. The prototype is illustrated through a test application called "Death Kitchen," freely inspired from various thriller and horror films, in which the kitchen is plotting against the player character to generate domestic accidents (see Figure 78 below; *note: Please refer to the original publication for further details, available on the DVD or at http://ive.scm.tees.ac.uk/?pID=5&aID=7).* The thesis's outcomes completed by our current research, demonstrate the potential of Perception-based/AI-based world behaviour in VR. A natural evolution of this research would be to re-incorporate it within an Interactive Storytelling system that would provide high-level control over the plot and the role of virtual actors.

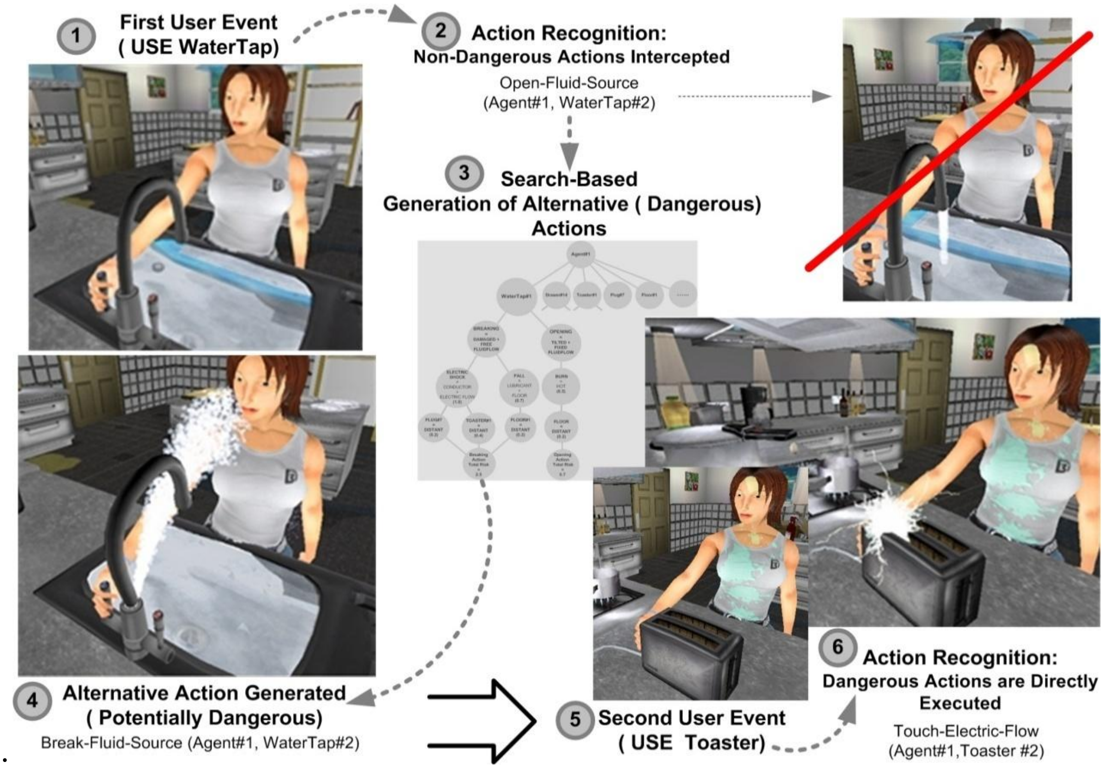

Figure 78: An Example of Hazardous Action Generation based on Alternative Causality principles

Concluding Remarks

This thesis has raised a considerable amount of theoretical, technical and experimental issues, and proposed original solutions to each of these challenges. The topic discussed, Alternative Reality within VR Art, transported us into a journey across ancient philosophy, modern cognitive theories, state of the art VR technology, AI techniques, and "psychedelic" artistic intentions, to finally reach a user's experience-inducing technology. Fundamentally, this research explored the notion and boundaries of realism in VR through scientific and artistic experimentations. That is this "*Art+ Science*" context, which gave its original approach, where artistic concepts echoed scientific enquiries and conversely, new technical approaches supported new forms of experience in artistic installations

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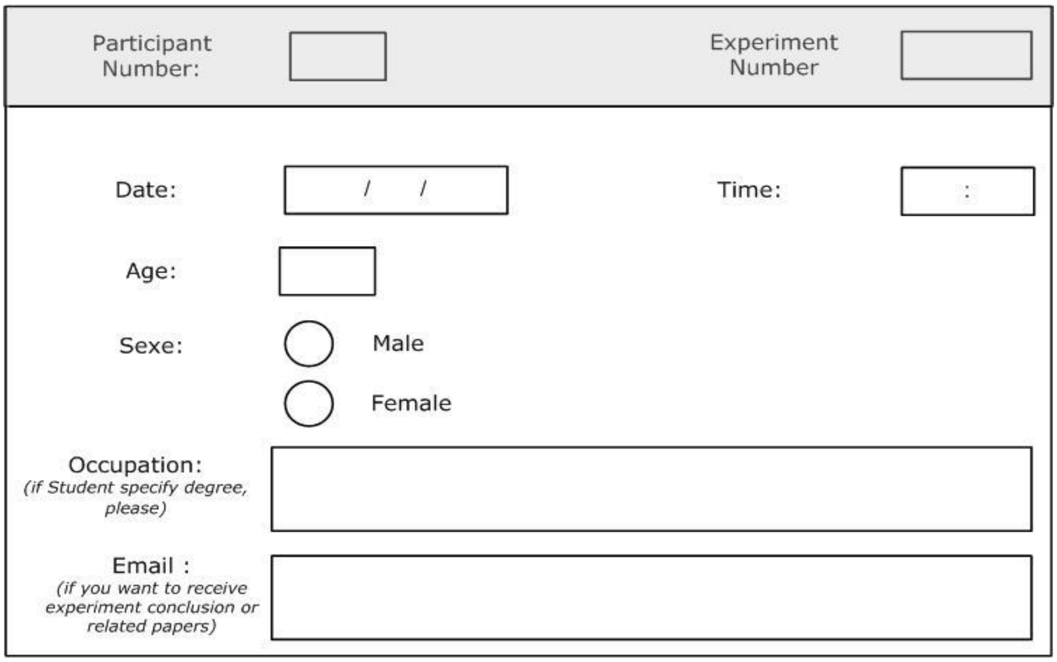
APPENDIX A: EXPERIMENT'S QUESTIONNAIRE



Participant Number: ☐

Experiment Number ☐

Date: / /

Time: :

Age: ☐

Sexe:
○ Male
○ Female

Occupation: *(if Student specify degree, please)*

Email : *(if you want to receive experiment conclusion or related papers)*

Table One :

Describe and Explain what happened:

Table Two :

Describe and Explain what happened:

Table Three:

Describe and Explain what happened:

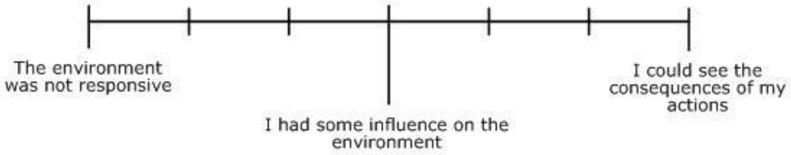
Table Four:

Describe and Explain what happened:

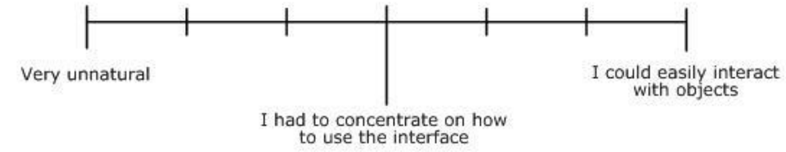
Table Five:

Describe and Explain what happened:

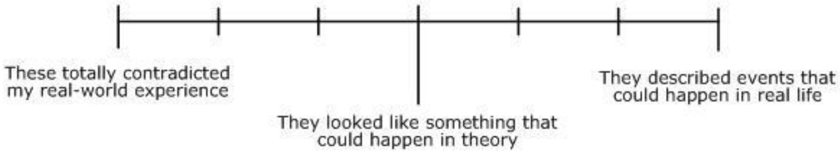
1- How responsive was the environment to actions that you initiated (or performed)?



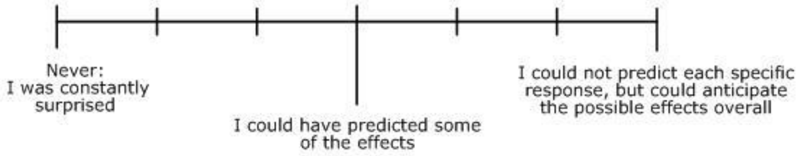
2- How natural did your interactions with the environment seem?



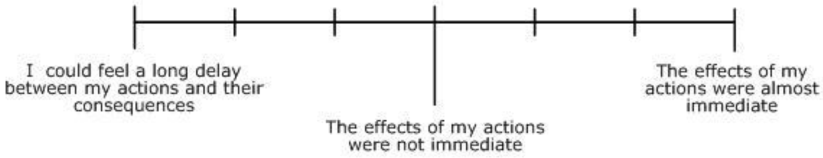
3-How much did your experiences in the virtual environment seem consistent with your real-world experiences?



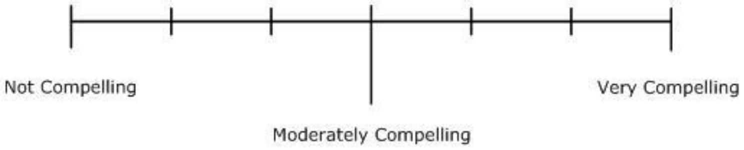
4-Were you able to anticipate what would happen next in response to the actions that you performed?



5-How much delay did you experience between your actions and expected outcomes?



6-How well could you move or manipulate objects in the virtual environment?



7-How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?

Not at all

Interfered somewhat

Prevented Task Performance

8-How much did the control devices interfere with the performance of assigned tasks or with other activities?

Not at all

Interfered somewhat

Prevented Task Performance

9-How well could you concentrate on the assigned tasks or required activities rather than on the mechanisms used to perform those tasks or activities?

Not Concentrated

Some

Greatly Concentrated

10-Did you learn new techniques that enabled you to improve your performance?

Nothing new

Some

Completely new

11- How much were you able to control events?

Not at all

somewhat

Completely

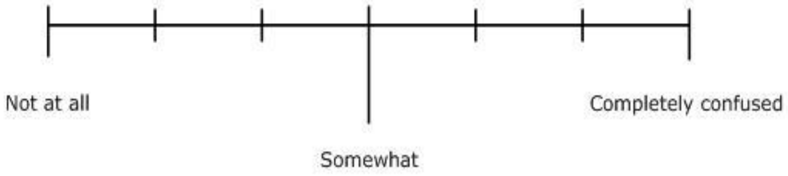
13- How natural was the mechanism which controlled movement through the environment?

Extremely Artificial

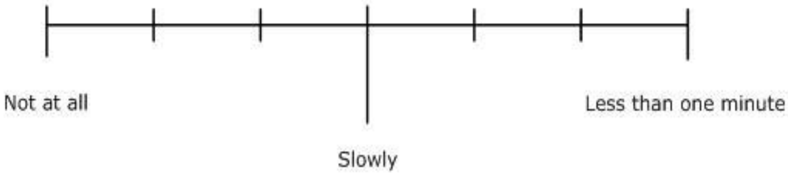
Borderline

Completely natural

14- To what degree did you feel confused or disoriented at the beginning of breaks or at the end of the experimental session?



15- How quickly did you adjust to the virtual environment experience?



16- Do you play computer games ? (ONE ANSWER ONLY)

- ☐ Never
- ☐ Sometimes, I'm familiar with some of them
- ☐ Very often, I learn how to play new titles very quickly

17-In your view, what characterises *best* the experiment you took part in ?(ONE ANSWER ONLY)

- ☐ It's about Physics
- ☐ It's about causes and effects (actions and their consequences)
- ☐ It's about interacting with objects

Overall Comments

APPENDIX B: DVD CONTENT (PUBLICATIONS &VIDEOS)

The DVD attached to this document contains:

- *An electronic version of this thesis (.pdf/.docx)*

- *The publications realised and their associated videos, classified per Venue (Conference/Journal) and per chapter.*

- *The media player and codecs necessary to run the videos (for Windows and Mac)*

Note: papers and videos are also available online at

http://ive.scm.tees.ac.uk/?pID=5&aID=7