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Industrial Accident Prevention Training with Time Travel Prevention Games: Adaptive Personalized Story Experiences by Artificial Intelligence

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Abstract

Industrial accident prevention is a problem of societal relevance. It is worth the investment of contemporary education theory and up-to-date information and communication technologies including Artificial Intelligence (AI). Apparent deficiencies of AI that is based on Large Language Models (LLMs) und Generative Pre-trained Transformers (GPTs) bear abundant evidence for the need of going beyond the limits of sub-symbolic AI. Game based training is attractive to practitioners and advantageous over conventional educational methods. There is developed, implemented, and applied the original concept of time travel prevention games. The approach is generic and applies to other domains such as crime prevention and health care as well. The key idea is interactive story engagement that allows, if necessary, for virtual time travel to impact the fate. Trainees experience stories of success. Digital storyboarding is an AI design methodology derived from approaches to dynamic plan generation. Technically, a storyboard is a hierarchically structured family of graphs. Semantically, it determines a potentially infinite space of different stories. Single stories unfold at execution time, i.e. during game play, dynamically in response to human activities and environmental conditions. The game AI analyzes the history of game play represented as a string of actions and events. Operationally, string processing, counting letters in strings, finding properties of strings, and the like is key. The prepared alternatives of unfolding game play represent the interdisciplinary designer team's intelligence based on domain knowledge, education theory, learning psychology, game design principles, VR technology, and the like. The storyboard is the place where AI resides.

Keywords: *industrial accident prevention, prevention training, time travel prevention games, education theory, Artificial Intelligence, sub-symbolic AI, symbolic AI, adaptivity, play state, game state, storyboarding, storyboard interpretation technology.*

1. A Look at Contemporary Education Theory

When pondering variants of a publication of their research into training for the purpose of industrial accident prevention, of their implementations and applications, the authors were puzzled by the term *contemporary education theory*. To them, this is a high-dimensional field in which both contemporary trends of science and technology as well as proven concepts and principles occur and frequently appear somehow amalgamated.

From the perspective of digitization, Mavropoulou and her co-authors discuss an impressively wide spectrum of technologies based on an e-book project [1]. Artificial Intelligence (AI) is playing an important role. The present work is going beyond this valuable work by the deployment of digital games concepts and technology.

The present authors' approach is characterized by its unique selling proposition of deploying time travel prevention games. Interested readers are directed to [2-8] for prior work.

On the one hand, time travel prevention games bring in novel options of and challenges to the deployment of contemporary technologies in educational settings. On the other hand, the opportunity of virtual time travel provokes and enables novel approaches to education theory. The dovetailing of technology and education theory results in unprecedented applications and related player/learner/trainee experiences.

In particular, the role of AI is evolving. There arise novel requirements on the AI as well as a more far reaching impact of the AI. In [6], the authors introduce cascades of increasingly powerful AI support to human trainees. [6] and [7] are devoted to a refinement resp. deepening of human-AI communication by bringing in modalities such as obligations and ought.

Within the authors' framework and applications, training becomes the experience of interactive stories; one might even call it *interactive story engagement* [8]. The authors' present contribution focuses on the role of the AI aiming at exciting experiences of stories of success. Teaching and training with stories of success instead of stories of disaster [9] is a certain educational paradigm that is struggling with the worries that reward may cause detrimental effects [10].

2. Industrial Accident Prevention Training based on Time Travel Prevention Games

This section is intended to provide the audience with some touch and feel of industrial accident prevention training as developed, implemented, and applied by the authors [3,4,5].

Figure 1: A virtual training environment by Fraunhofer IFF.

The virtual reality depicted in Fig. 1 constitutes a framework for playing a training game. Three subsequent player actions are on display in Fig. 2. The task under consideration is to decant some highly inflammable fluid from a container to a given barrel. Related actions are on display in Fig. 2. The first scene shows the placement of the container and the second scene shows that a wall-mounted grounding cable has been attached to the container and both objects are connected by a grounding cable.

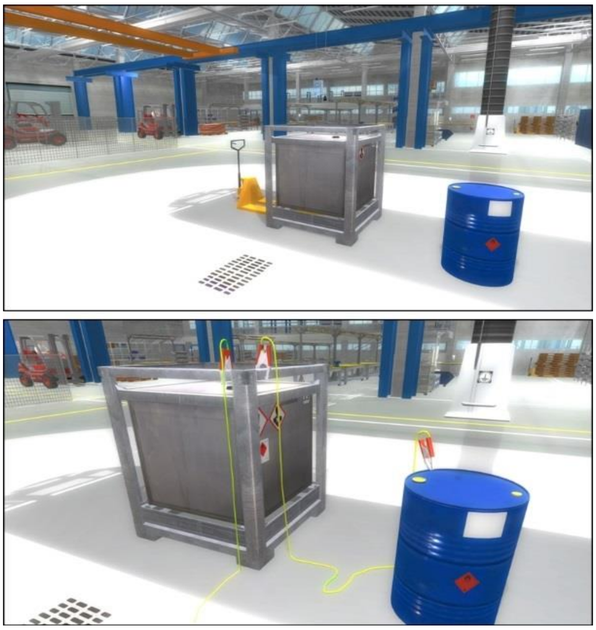

Figure 2: Delivering a container and connecting it to a barrel.

Game play is abstractly represented as a sequence of events such as player actions and actions of the game system.

Throughout a training session, it may happen that undesired events occur such as the explosion with fire shown in Fig. 3.

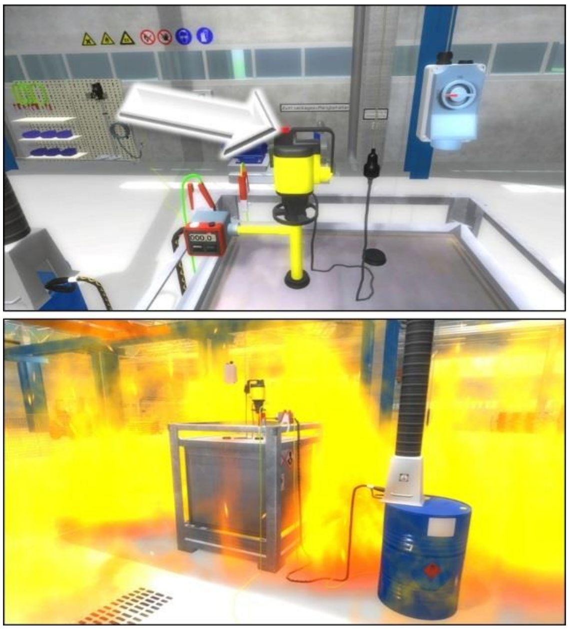

Figure 3: Activation of an inappropriate pump.

A training game ending with an undesired event would mean an experience of a story of disaster. It is the duty of AI to guide human trainees to stories of success.

Virtual time travel allows to impact the fate, in the virtual world, at least. But there occur several difficulties. What to do if a trainee fails repeatedly, goes accordingly on repeated journeys back in time, but does not master the mission? Interested readers may find varying solutions in [2-8]. Within the present paper, the role of AI is in focus including the question to what extent contemporary novelties such as Large Language Models (LLMs) and Generative Pre-trained Transformers (GPTs) might be sufficient.

The authors adapt and adopt ideas, concepts, and methodologies to understand AI very recently published in this journal [11].

Before going into the details of appropriate AI concepts, we need to go into some more detail of accident prevention training. We do so by means of the present case study of decanting a highly inflammable fluid illustrated in the preceding figures.

When during game play an accident happened as on display in the lower screenshot of Fig. 3, human players/trainees get offered an opportunity of time travel. Game play is seen as a sequence of events, be it human game actions or actions of the game system. This extremely simple abstraction allows for far reaching applications such as assessment [13]. Time travel takes place within the framework of such a sequence of game events.

For the purpose of navigation in time, the events are iconically represented (see also [4], section 8) by key objects such as the container of the first event in Fig. 2, the grounding cable of the second event in this figure, and the pump on display in Fig. 3.

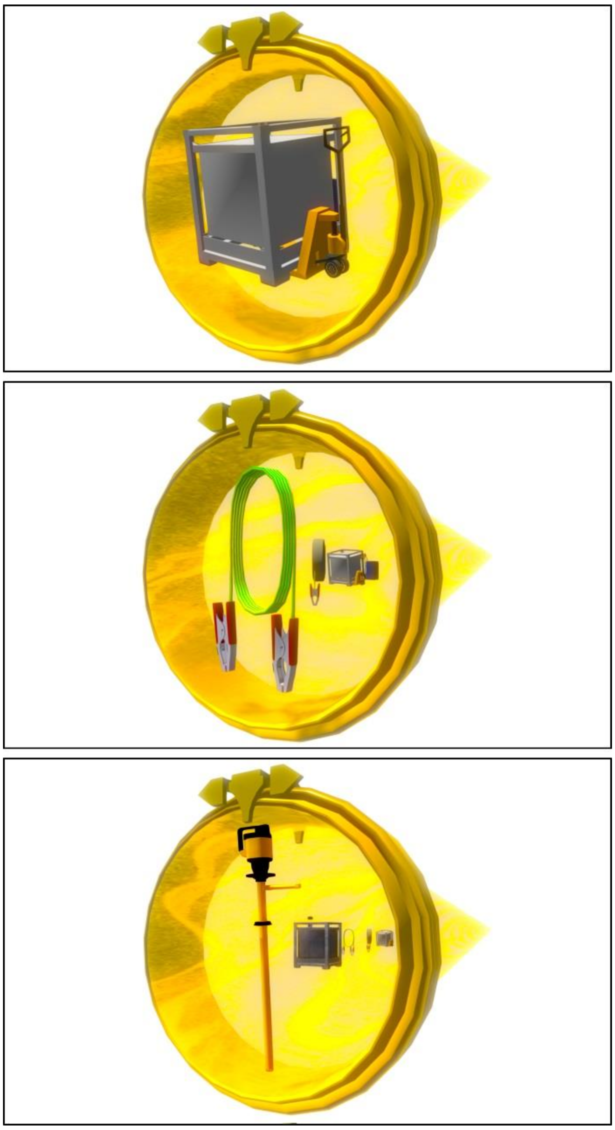

Figure 4: States of a time tunnel by Fraunhofer IFF.

The authors provide a time tunnel as visualized in Fig. 4 that enables the trainee to travel back. In every state, the time tunnel presents an object indicating a destination a trainee may select. Selection is done by clicking the central button on top. The other two buttons enable the trainee to navigate though the time tunnel backwards in time with the left button and forward in time with the right button. The direction of these buttons shall resemble the direction of the arms of a conventional clock.

In the introductory case study under consideration, when clicking the time tunnel as on display in the uppermost picture, the trainee travels back to the early scene of providing the container. Clicking the pump brings her back to the scene of game play before when selecting the pump.

The time travel and its implementation does basically rely on the perspective of a game history as a string. When at some point in play time the opportunity of time travel is offered to impact the fate, a time tunnel may contain the string of objects indicating all the scenes of prior game play. Fig. 4 presents a few illustrations. It is assumed that trainees remember the objects they have been manipulating shortly before. In this way, time travel does not need extra explanations. This is considered advantageous because of reducing cognitive load [13] and mental effort [14]. Both aspects are key to contemporary education theory.

Human trainees aiming at the avoidance of an undesired event may travel back and forth in the time tunnel along the string of icons representing scenes of the game play history. When making a choice and selecting a destination, the time tunnel is left and the trainee arrives at the target scene of the past.

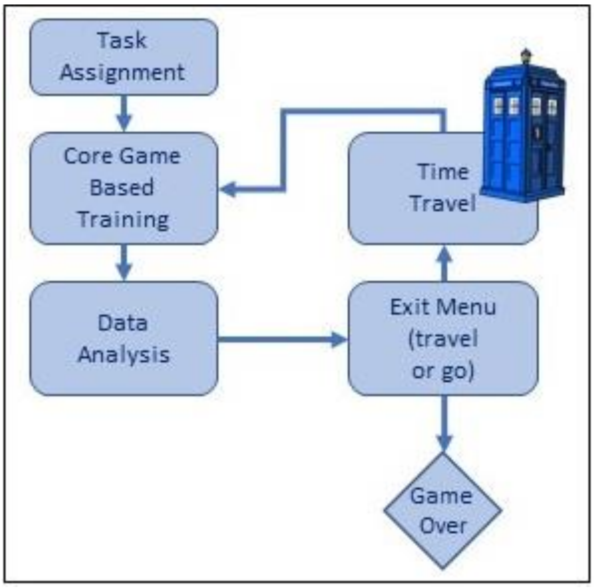

Figure 5: Top-level game design storyboard graph.

Game design relies of the storyboarding technology according to [15] which is an adaptation of the early AI dynamic plan generation technology [16]. Interested readers find a more comprehensive discussion [17,18] and – tailored toward the needs of time travel prevention games – in [4].

The top-level storyboard graph on display in Fig. 5 illustrates a few essentials. To mention just a single aspect, the smaller boxes such as the first one are called scenes. A scene may have varying implementations. By way of illustration, the scene of Task Assignment may be implemented by a text on the screen, by an audio file, by a video file, by a PDF for download or anything like that. But it has no internal structure in the sense that is not decomposable into sub-events. In contrast, larger boxes denote episodes. Such an episode may be implemented by varying scenes or – even more complex – by another graph of scenes and episodes. The storyboard is a hierarchically structured family of graphs [15]. Substitution yields dynamics.

Obviously, the opportunity to travel back in time for trying once more to master a task brings in cycles into an experienced story.

3. Artificial Intelligence for Adaptivity in Story Engagement and Experience

Whereas the preceding section is a bit more oriented toward the audience's intuition, the present section needs more precision. For the sake of illustration, the authors present screenshots from training with a time travel prevention game for the paint and coatings industry,

Figure 6: Virtual installation of the paint and coatings industry

On display in the upper screenshot of Fig. 6, there are dispensers of chemicals. The lower screenshot shows a workplace that is equipped with basket mills.

It belongs to a trainee's task to get the right amount of the right chemicals from the dispenser and to fill this material into some selected basket mill.

In the paint and coatings industry application case, undesired events are mostly more subtle than just and explosion with fire as reported in Fig. 3. Consequently, it seems appropriate to describe the history of game play not only by a string, i.e. some sequence of letters, but as a string of letters that may carry annotations. Formally, if a letter a occurs that denotes an action, this action has some annotations or attributes $\alpha(a)$. Such an approach is already discussed in some detail in the source [15]. But all this is just syntax that possibly establishes a target human experience.

When education is in focus, there is an urgent need to consider the experiences of game play – notably a quite intriguing issue. But how to relate syntax and semantics [19] …?

Speaking in very formal terms, the duty of AI is to control the syntax such that the emergence of the intended semantics becomes very likely. AI guides the trainee to success.

Let us briefly come back to the formalities. There are varying versions that are mutually equivalent. For instance, one may make every action a with its annotation $\alpha(a)$ a pair [a, $\alpha(a)$]. Based on this assumption, a game history is a string of pairs. But nested expressions sometimes bring with it certain difficulties. It is not the intention of the authors to outwit the AI. Therefore, we confine ourselves to string in which every letter describing an action is followed by its annotation $\alpha(a)$. As a result, we deal with plain strings exclusively. One may think of $\alpha(a)$ as a link or a pointer to a possibly more complex data structure. This will become clear in the sequel.

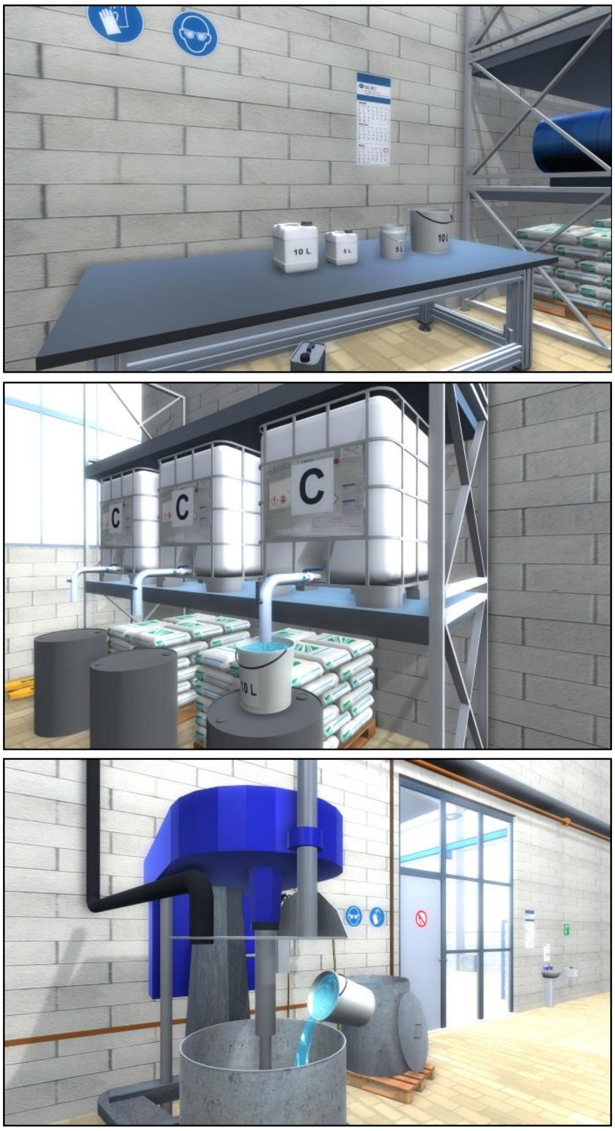

Figure 7: Subsequent actions of taking a bucket, filling the bucket with chemical C, and pouring this into the basket mill.

Let us denote the three actions of Fig. 7 by the "letters" tb, fb, and pb, resp. Then, $\alpha(tb) = 10$ (the volume of the bucket in liter), $\alpha(fb) = C$, and possibly $\alpha(pb) = 3$ denoting the mill's number. This is the string written down explicitly: tb 10 fb C pb 3.

Assume that the "letter" tj means the action of taking a jerrycan. Given as history of game play, one may ask whether or not the string contains tb or tj. This is algorithmically extremely simple.

The screenshots of Fig. 8 are, perhaps, more interesting. The uppermost one is showing a chart that is presented to the trainee in the Data Analysis episode (see Fig. 5). There is measured a high pollution above the threshold (red line).

The letter indicating the action of presenting the data analysis is da and the annotation $\alpha(da)$ is some link to the data of the chart. The episode may contain further scenes such as explaining the data to the trainee or a human-system dialogue about the data.

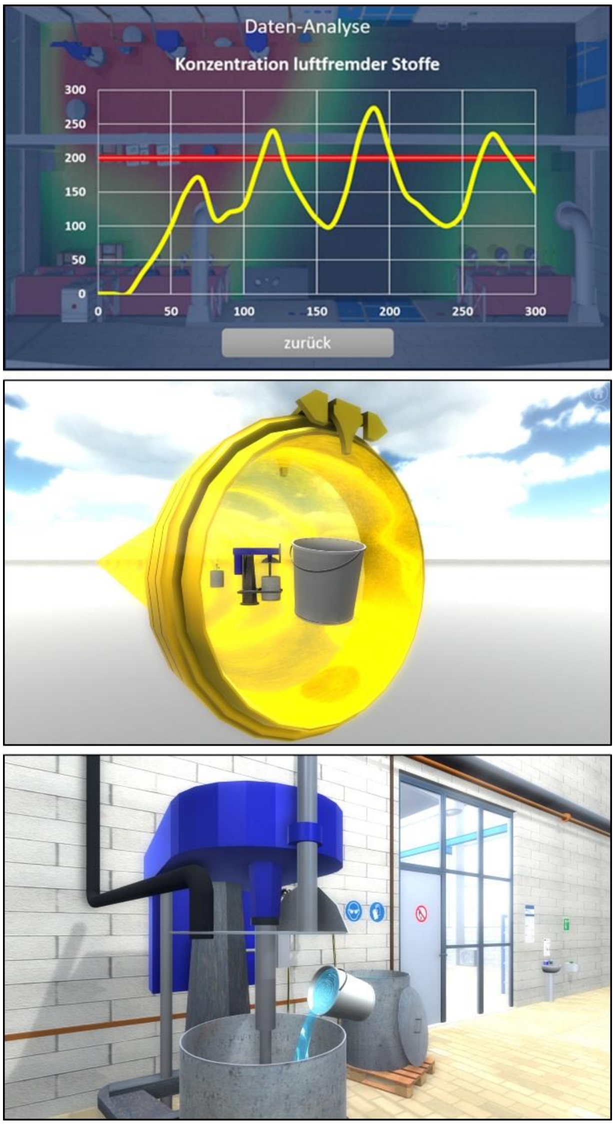

Figure 8: Data analysis giving reason to some time travel.

After the data analysis, the trainee is moved to an episode named Exit Menu. There is offered the opportunity of a journey back in time (second screenshot of Fig. 8). It may happen that a trainee selects the bucket destination, selects a bucket again, and proceeds as before (third screenshot of Fig. 8).

There arises the danger of repeatedly performing erroneous actions of game play. This is easily detectable in playing history. What do we expect of an AI analyzing game play and guiding human trainees to the ultimate success? First, very general, not yet fine-grained, but highly important from the perspective of education theory: The AI must be able to guide every trainee to the experience of a personalized story of success. In contrast, second, very fine-grained and somehow nitpicking, the AI must be able to search strings for the occurrence of substrings with particular properties. In particular, third, the AI must be able to count the number of occurrences of a single letter in a string.

The formalization of game play as a sequence of letters that represent actions resp. events is extremely expressive [20-22]. To a few interested readers, the report [22] might be of interest. Variations of string properties are introduced ([22], section 4.4, see esp. figure 4.2) that characterize a player's loss of initiative.

The present string perspective is appropriate even for purposes of dramaturgical design [23-25] and for the study of phenomena that appear abnormal at a first glance. By way of illustration, think of non-monotonicity [25]. In the condition of interactive story experience, non-monotonicity means that an event may disappear from a story. A classical digital game that draws benefit from non-monotonicity is Shadow of Destiny by Konami, 2001.

Non-monotonicity is a key dramaturgical concept underlying time travel prevention games. The goal of journeys back in time is to wipe out particular undesired events. By way of illustration, players may remember an explosion with fire as visualized in Fig. 3. but there is no impact left at the workplace, when a player returns.

During time travel prevention training, it may happen that a trainee fails repeatedly. This leads to a number of time journeys. There are many points where AI comes into play toward an ultimately successful story experience. Let us briefly discuss two essential approaches to adaptivity.

First, the more frequently a player failed, the more stringent should be the support for finding the appropriate destination of time travel. In dependence on the number of preceding journeys, the AI may reduce the selectable destinations in the time tunnel. After too many returns, the time tunnel directs the player to a uniquely determined scene of the past where the player has a chance to turn the tide (see [4], especially figures 8 and 9).

This first approach may be dovetailed with the second one briefly described subsequently.

Second, the training system's AI may change the game world such that, so to speak, the past is no longer what is used to be. Fig. 9 is intended to provide an illustration of modifications of a scene. The authors put a bit more emphasis on the discussion of this education principle controlled by AI and implemented by contemporary information and communication technology.

The AI is counting the number of Data Analysis scenes that have been traversed followed by a journey in time back to the past. Within the interdisciplinary team of designers – domain experts, learning psychologists, game designers, VR technicians, … – takes place a negotiation how to respond to repeated mistakes.

With a larger number of erroneous trainee actions of game play, changes of the past are implemented that are more likely to guide a trainee/player to success. Usually, when a scene of the past is visited again for the first time, it appears unchanged.

Figure 9: Varying manifestations of the past.

Modifications of the past vary from application to application based on combinations of domain knowledge and pedagogical principles taking technological conditions into account. This is a form of multidisciplinary reasoning performed by game AI.
A sensitive class of modifications of the past does not explicitly tell a trainee what to do. Instead, the trainee's attention is directed to problems, provokes thinking about solutions, and enables trainees to find solutions by themselves.

The first screenshot of Fig. 9 shows a case where the past is different from earlier visits. This time, the evaporation that results from filling a bucket with a chemical becomes visible. There is a large spectrum of visualizations including heat maps.

It is a bit less sensitive, if an AI arranges play states in which players are directly addressed. By way of illustration, the authors' approach presented in [7] illustrated such a case in Fig. 7 on page 12 by a non-player character (NPC) who talks to the player. Somehow similar, the second screenshot of Fig. 9 shows an NPC who appears to directly offer a jerrycan as a substitute for a bucket. A strong version of modification of the past consist in changing the physical structure of the virtual world. By way of illustration, the AI may take away all buckets such that the trainee has no alternative to using a jerrycan.

To some up, adaptivity to a human trainee's needs and desires toward the experience of successful stories of game play requires string processing. Particular tasks are checking the occurrence of a letter in a string, the occurrence of particular substrings, and the counting of occurrences of a letter in a string.

Unfortunately, any AI that consists of Large Language Models (LLMs) and Generative Pre-trained Transformers (GPTs) is unable to do all this. There is a discussion in [26] reporting that ridiculously ChatGPT is unable to count letters in strings – a flaw that is determined by the nature of the technology. Interested readers will find on the internet numerous discussions of this issue.

Arnold [27] discusses in some detail what it means to have a calculus for reasoning and she sketches the key properties of correctness and completeness. Going back to Gödel, she argues that there is no hope to get a complete calculus. What remains is correctness. One may consider the way in which ChatGPT processes strings of tokens a calculus. But as Arnold put it, such a calculus is not even correct. This fundamental flaw of the technology is reflected by [28]'s title that ends with the sarcastic words "intelligence without reasoning". Some other authors are a bit more explicit like [29,30] who simply call ChatGPT bullshit or ask whether GPTs are on LSD.

The present authors prefer a slightly more constructive approach agreeing with [31] "that the benefits of ChatGPT can only be fully realized if the challenges identified are effectively addressed". Because the authors understand the necessity of string processing as discussed above, they agree with an approach such as [11] very recently published in this journal.

An AI that has the duty to guide a human trainee to success must intervene at particular play states. Notice that a play state is represented as a string as discussed before. Different play states may lead to what is conventionally called a game state.

Because play states are strings, there is a need to consider the letters of a string, the relations of letters occurring in a string, and substring relations. For a letter a and a string π, "a in π" denotes that a occurs in π. For two string π_1 and π_2, "$\pi_1 \leq \pi_2$" means that the first string is an initial part of the second one.
This allows for the expression of properties such the following:
$\exists a \, \forall \pi' \, (\pi \neq \pi' \wedge \pi \leq \pi' \rightarrow \pi a \leq \pi')$

This logical property of π expresses an immediate zugzwang.

There is abundant evidence for the need to go beyond the limits of sub-symbolic AI. As a consequence, the final section is dedicated to symbolic AI. Where does it sit in the game system? How does it come in? How does it appear at work?

4. AI in Time Travel Prevention Games

The behavior of the time travel prevention game is determined in its storyboard. This is the place where the AI is sitting. There are sufficiently many of the authors' publications such as [3-8] and [17,18] about storyboarding outgoing from [15] and firmly grounded in [16] such that this section may be kept short. Formalisms such as the zugzwang property exemplified above are suppressed. There are far too many properties, too many variations, and too long formulas [20].

A digital storyboard emerges from the negotiation among designers – possible distributed in space and asynchronously – reflecting knowledge from largely different disciplines such as the application domain, learning psychology, VR technology, game design, and so on. With the emergence of the storyboard emerges its inherent intelligence which reflects the intelligence of the designers as a team.

As said before, a storyboard is a hierarchically structure family of graphs [15] based on elaborated technologies of graph rewriting [16]. Nodes of graphs may be subject to substitution. A substitution of a scene specifies how the scene is experienced during game play (reading a text, hearing a voice, …) and a substitution of an episode is an expansion that specifies in more detail what happens. Substitution is taking place at execution time, a concept introduced in [16] that determines the dynamics of the approach. Substitutions depend on logical conditions and these conditions depend on some parameters that change during game play. By way of illustration, whether or not a zugzwang occurs does depend on the actual play state.

There is sufficient knowledge in a storyboard to run it like a computer program. This leads to a novel methodology named storyboard interpretation technology [32].

Game play, i.e. training with a time travel prevention game, means – unobservable by the player/trainee – to travers the storyboard. As soon as the next scene or episode is reached, substitution takes place in dependence on the property of the current play state. By way of illustration, the number of time travel events that occur in the play state is counted and the scene's appearance (occurrence of an NPC, …) is generated accordingly.

The storyboard implicitly specifies a whole space of stories [8]. Which story unfolds and, thus, which is experienced depends on the system's adaptive response to the trainee's game play so far. Digital storyboarding is an AI technology. The behavior of AI depends dynamically on the evolving play states.

Ethical Statement

This contribution does not contain any studies with human or animal subjects performed by any of the authors.

Conflicts of Interest

The authors have no conflicts of interest to this work.

Data Availability Statement

does not apply

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