How a Hyper-actor directs Avatars in Virtual Shadow Theater

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ABSTRACT

This paper proposes a method and a set of tools for staging avatar movements that are controlled by a performer during a mixed reality theatrical performance. It refers to the field of Computer Theater as defined by Pinhanez and follows the model of the hyper-actor to control musical and visual expressive instruments in the performance *The Shadow*. The focus is on the construction of the visual instrument designed to direct the simultaneous stage movements of five avatars in a virtual shadow theater. The hypothesis of using only two groups of stage actions, salient and idle, is implemented with two methods in the performance *The Shadow*. We explain the theory and the programming of these methods in the Epic Game videogame engine Unreal Engine 4. The validation of the hypothesis is discussed through the artistic results of the performances. The tools for staging animations during theatrical rehearsals and performances contributes to advancing the expressivity of virtual movements in mixed reality performing arts.

CCS CONCEPTS

• **Human-centered-computing → Interaction design →** Empirical studies in interaction design; • **Computer systems organization → Real-time systems →** Real time system architecture • **Applied computing→ Arts and humanities→** performing arts • **Computing methodologies → Computer graphics → Animation →** Motion capture

KEYWORDS

avatar direction, computer theater, hyper-actor, hyper-instrument, mixed reality, motion capture, performing arts, presence effect

ACM Reference format:

Georges Gagneré, Tom Mays, Anastasiia Ternova. 2020. How a Hyper-actor directs Shadow Avatars in Virtual Shadow Theater. In *7th International Conference on Movement and Computing (MOCO'20). July 15-17, 2020. Jersey City/Virtual, NJ, USA. ACM, New York, NY, USA, 9 pages.* https://doi.org/10.1145/3401956.3404234

MOCO'20, July 15—17, 2020, Jersey City/ Virtual, NJ, USA

ACM 978-1-4503-7505-4/20/07..$15.00
https://doi.org/10.1145/3401956.3404234

1 Introduction

In this paper we discuss an environment composed of five virtual characters acting in a virtual shadow theater in the production of H. C. Andersen*'s The Shadow* [1]. The virtual characters compose a visual instrument dynamically played by an actor performing a story on stage. The theater is therefore confronted with the use of programming to settle movements in interaction with a live performer. Directing an actor on a theatrical stage is a complex artistic practice that is not clearly theorized and that cannot rely on a notation system that would help to write scores with unambiguous rules for the stage direction [16]. Nonetheless, in Fourati and Pelachaud [11], theater is used as a mean to collect a database of emotions that can be clearly recognized by an audience. Bevacqua and colleagues [4] used it to test autonomous virtual actors that improvise with a physical actor. Some systems propose to direct an avatar in immersion on a virtual stage [30]. Theater appears to be a field for computer sciences to achieve complex movement simulation.

Making puppets seem to come alive has always fascinated people [21]. The visual instrument we developed to control five virtual characters is an attempt to explore creating believable animation in the context of live theatre. Section 2 places the constraints of using computers and programming on stage within an historical perspective, underlining how it can be stimulating to employ a computer science approach to studying a theatrical creative process. The definition of the hyper-actor appears as a key concept to delimit the scope of the paper. Section 3 introduces a creative experimental use case, *The Shadow*, through a focus on the musical hyper-instrument played by the performer. Section 4 details the hyper-actor visual instrument composed of five acting avatars in a virtual shadow theater. The movement issues raised by this visual instrument are exposed in section 5 and a movement quality hypothesis is proposed to achieve the desired artistic results.

Implementation and programming of this hypothesis form section 6. Results are discussed in section 7 and some perspectives on the ongoing research are given in the conclusion.

2 Computer Theater perspective

Our methodology is inspired by the pioneering approach of Pinhanez at the end of the 90's about the relationship between theater and computer science, coined in the term *Computer Theater* [31] and developed in the documentation of his staging of the original creation *It/I*.

Computer Theater is an emergent art field putting the computer at the center of traditional theatrical environments where physical actors perform in front of a physical audience. Actions, at the heart of theater practice, are also at the core of computer use in a theatrical context. Following the interactive musical approach of hyper-instruments, as proposed by Machover [23], Pinhanez defined the hyper-actor and the computer-actor entities. Considering that the body is the actor's instrument, he defines the hyper-actor as a computer theater system that enhances the actor's body and his expressive capabilities. On the other side, the computer-actor is a computer program which assumes the role of one of the characters of the play and uses all the necessary devices to make it act on stage.

The interactions between physical actors playing with hyper-actors and autonomous computer-actors establish that action representation, recognition and generation become fundamental issues for computer science. Pinhanez argues that theater provides an excellent laboratory for researchers because it is dedicated to making complex actions seem clear and understandable for an audience. A determinant factor in the success of computer theater is the invaluable process of rehearsal, often time consuming but enabling the actors and the stage director to build rich and surprising dramatic actions. Computer theater must deliver hyper-actors and computer-actors that can be sufficiently rehearsed to achieve results as convincing as with physical actors.

Pinhanez's efforts to combine performing arts and computer science within the idea of Computer Theater are noteworthy. They respect the rules, constraints and richness of the theatrical process and fit the needs of actors and directors. That is not the case of Krueger, interactive art pioneer and computer scientist, when he explained the concept of his artwork VIDEOPLACE, which features one of the first artificially intelligent interactions between a participant and virtual reality [22]. He gave insights about a future « distributed theater » that moved the actors and the audience within the virtual reality and separated theater art from its physical roots.

Pinhanez exemplifies Computer Theater in the outstanding documentation of his creation *It/I*, inspired by Samuel Beckett's *Waiting for Godot*. *It/I* features the semi-autonomous computer-actor "It" acting with the physical actor "I" [32]. After describing the story and the theatrical actions, the playwright explains how he programs the computer-actor and directs it along with the actor. Following the script of the story, he details the programming rules that the computer-actor should follow and develops two new software paradigms, *Interval Script* and *ACTSCRIPT*. These helped him to respond to the crucial timing issues involved in maintaining a believable relationship between human actors and computer-actors. Indeed, his evaluation of 6 performances with a total audience of about 500 spectators showed that people accepted the « suspension of disbelief » throughout the 40-minute performance. To our knowledge, this is the only paper to combine artistic and computer science analyses to such an extent in the context of a theatrical production. This underscores the rare double identity of Pinhanez, as a playwright who staged a successful production, and as a computer scientist having to solve complex programming issues.

3 The Hyper-actor in *The Shadow* – musical aspect

In this paper we discuss the building of a hyper-actor used in the *The Shadow* (text by H. C. Andersen) – premiered in Ukraine in September 2019 and then internationally toured [12]. We focus on questions of movement that needed to be solved in order to achieve satisfying artistic results, while introducing programming solutions well suited to our processes as artists and not as computer scientists [34]. We use the term hyper-actor to describe the physical actor who uses a digital audiovisual environment to enhance his acting. Keeping with the paradigm of hyper-instruments, we consider the performer and the software tool producing the enhancement as a single entity. The hyper-actor performs an instrument containing both musical and visual elements. We will now describe the musical component in order to explain the principle.

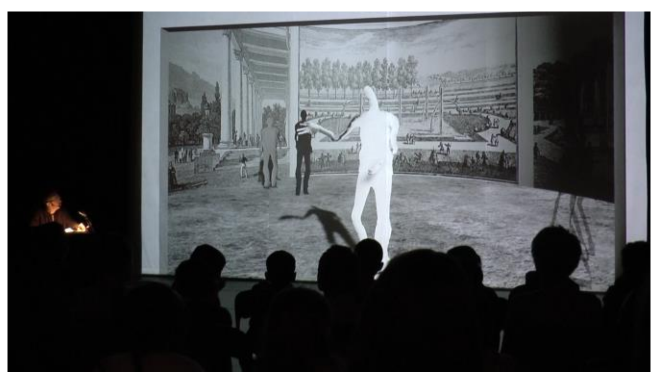

Figure 1. The Narrator (left), The Princess (in white on screen), The Shadow (in black), the Scientist (in grey) in *The Shadow*

In *The Shadow*, a hyper-actor uses his voice to perform an instrument that not only enhances and modifies his voice, but generates the music. He sits stage right at a small table with a desk lamp, near an upstage video projection screen displaying the computer-generated content (fig. 1). He reads the text of the story speaking into a wireless microphone while accessing a midi controller placed in front of him on the table. The composer, Tom Mays, built two families of real time audio processing instruments requiring the hyper-actor to “play” his voice by modifying his prosody. As the rhythmic and intonational aspects of language, prosody is a vocal tool used by an actor to control the expressiveness of his speech. He may use it naturally or artificially to produce desired effects. The first type of real time audio enhancement involves changing the actor’s vocal quality to underscore the different characters of the story: the Narrator with an amplified natural voice, the learned but naive Scholar with a lightened voice, the manipulative Shadow with several deepened voices depending on the mood and the intentions of the character, and the Princess with a processed female voice. The second type of enhancement consists of effects like spectral transformation, harmonizers, reverberation or delays, triggered by the actor himself via the midi controller. These effects are also controlled by the voice directly via envelope, pitch and onset following [26].

To play this instrumental performance, the hyper-actor has to trigger cues at very precise moments between words and phrases or during silences. Voice recognition or text following software could have been a potential solution, but none is yet reliable enough to allow accurate control of the processing instruments. Thus, the hyper-actor had to train himself to manually trigger the cues with the midi controller. This requires the same level of concentration as speaking the words with the understanding that it will produce certain musical effects. This explains why we staged his acting position as a reader sitting at a table with comfortable access to the controller and to the text which serves here as a score. Of course, the hyper-actor does not simply read the text, but he acts it with the added responsibility of creating the musical environment generated in real time with the CRT environment [25] – a challenge that required numerous adjustments during rehearsals with the composer. It is worth noting that the hyper-actor must maintain control of the instruments by triggering the cues himself. It would not be possible to attain the necessary level of synchronization if the cues were triggered by a stage manager following the spoken text from the control booth.

4 Hyper-actor Visual Instrument

The visual instrument used by the hyper-actor to enhance his performance is a troupe of five shadow avatars in a virtual shadow theater [15]. We call these avatars OAVs, according to their French acronym for *Ombre AVatar* (shadow avatar). The visual proposal is that OAVs start listening the story and step by step get involved in it by acting out the situations told by the hyper-actor. They successively take on the role of the Scientist, the Shadow, the Princess, and finally two guards in the epilogue. Sometimes, the OAVs stop acting and go back to listening to the narration of the story. In Pinhanez's Computer Theater perspective, the actor is therefore a hyper-actor who enhances his acting by directing with his words, through programming, digital puppets deprived of autonomy. Following Plessiet’s classification for virtual characters [33], the OAV's movements and decisions are indeed controlled from the outside. If they had been autonomous virtual actors, they would have been seen as computer-actors.

4.1 Origin of the Shadow Avatar (OAV)

The idea of creating digital shadow theater that enhances the interpretation of an actor on a physical stage relates to the intemporal fascination that shadows have always had on human beings. The shadow mirrors the human body but can also be imagined as an almost independent entity, sparking people’s imagination since their childhood. This vision has inspired numerous tales and myths throughout history [7]. It is therefore not surprising that shadows are to be found at the core of the first interactive art experiences in a mixed environment linking a physical participant and a computer-generated virtual reality – led by Krueger within the VIDEOPLACE system in the mid 1970’s. With this artistic installation, Krueger built the first virtual theater with digital silhouette shadows allowing the onlooker to interact with an intelligent artificial environment. After these first experiences, capturing the silhouette shadow with video cameras in visible or infrared light remained a widespread way of embodying a participant in an interactive digital installation [19] [27].

Pasquier [29] proposed the concept of a Shadow Agent to make human-machine interactions more natural, especially in a dialogue with artificial agents. Jacquemin [18] listed the various instantiations of digital shadows for a virtual dancer circulating between real and virtual spaces. Batras [3] also used shadows to let a participant play with a virtual actor capable of improvising. Using shadows seems to be a promising way for eliciting audience suspension of disbelief in an acting process.

Figure 2: 3D rendering of the entrance on stage of the five OAVs, from 2D to 3D.

In fig.2, an OAV stands down stage looking back at the translucent screen. It is a flat human silhouette moving in 3D, inspired from *Peter Schlemihl's Miraculous Story* by Chamisso (1814) in which the Devil peels from the floor Peter Schelmihl's shadow cast by the sunlight, and keeps it in exchange for a magic bottomless gold sack. From its existence as a shadow on the wall, the OAV becomes three dimensional after peeling off. This transformation is visible for the two OAVs at each extremity of the translucent screen in fig. 2. By providing the possibility of precisely simulating a realistic shadow effect and then taking it in a magical direction using common 3D visual effects, virtual theater offers a powerful tool to elicit dramatic situations.

4.2 OAV Animation

The OAV movement control is realized through a mixed reality framework called AvatarStaging that we developed for our previous works [13]. In AvatarStaging, a performer, referred to as a mocaptor, an actor wearing a motion capture suit, acts in space C and controls an avatar in virtual space B (fig. 3). He interacts with a physical performer in space A. Space A and space B together form the mixed reality stage in front of the audience E. The setup is currently using Noitom Neuron Motion Capture suit and Axis Neuron software to process the data. The motion retargeting from the Axis Neuron data to the OAV virtual character is done with Autodesk Motion Builder and the Noitom MotionRobot plugin. The retargeted data are sent to Epic Game Unreal Engine 4 (UE4) video game engine through the LiveLink plugin, released in 2018 by Epic Game to facilitate on-set previsualization with third-party software.

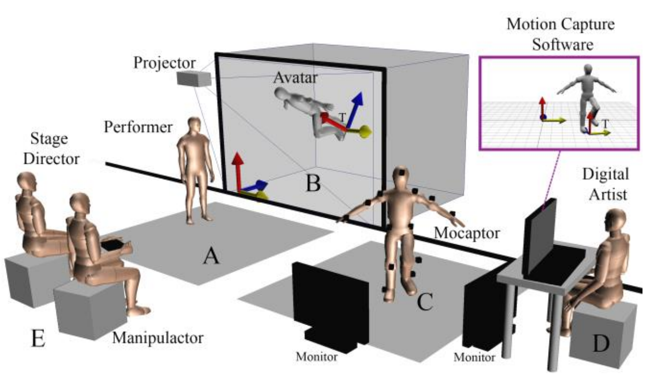

Figure 3: AvatarStaging framework.

Following Wu's real time performance system for virtual theater [36], it would be possible to ask five physical actors hidden from the audience to each control a different OAV character. They could either improvise or act according to a predetermined script established with the hyper-actor. It is worth noticing that real time improvisation does not transform the OAVs into computer-actors. There is no autonomy, only live control using traditional theater techniques performed under stringent technical constraints. Keeping in mind the hyper-actor perspective and the desire to build a low-cost setup usable in different situations[1], we decided to work with pre-recorded animations. We thus wrote and recorded a staging for the five OAVs that the hyper-actor interpreted in the same way as he interpreted the interactive musical score created by the composer.

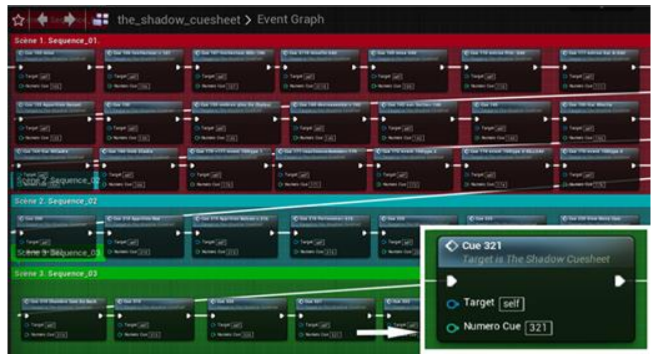

Figure 4: Excerpt of 35 cues from the global AKN-Regie cue sheet. Right down corner: zoom on cue 321.

Recordings were done with the UE4 Sequence Recorder tool and the animations were played back using the AKN-Regie module available in the AvatarStaging framework. The score consists of 147 cues (fig. 4) that blend OAV animations step by step according to the staging scenario. Playing the hyper-actor visual instrument consists of bringing to life virtual characters who perform a theater score and stay synchronized with the hyper-actor's rhythm – leaving him the greatest possible expressive freedom.

5 Issues for staging and making OAVs come alive

Achieving this goal supposes tackling two main issues. The first one is to make five virtual characters come alive for the audience during a 50-minute performance. The second one is to keep the acting of the virtual troupe synchronized with the hyper-actor.

5.1 Presence Effect

Working in a mixed reality environment that confronts a physical actor with virtual characters is especially challenging in terms of the presence effect – the audience's acceptance that the virtual bodies share the same space and time as the human actor [10] [5] [6]. This is a requirement for achieving

[1] The technical needs are a computer, a wireless microphone, two NanoKorg2 midi controller, a sound card, a projector, two speakers, a table, a chair and a desk lamp.

"suspension of disbelief" in terms of the nature of the virtual characters displayed on stage. As exposed in 4.2, a solution is given using motion capture [17]. The UE4 Sequence Recorder tool we used was the one that enabled Epic Game to win the *Real-Time Live!* contest in the Siggraph 2016 conference, demonstrating a director shooting a short movie featuring two characters played by the same performer in real time [2].

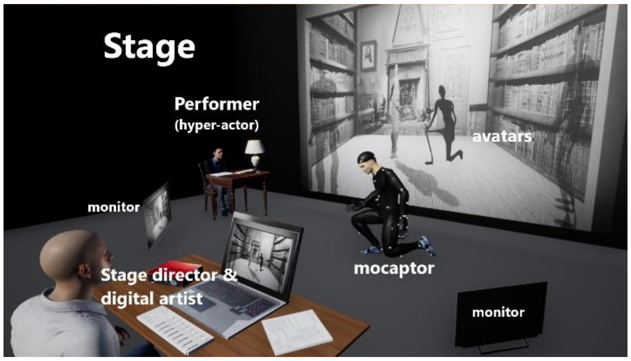

Figure 5: Theatrical environment for motion capture sessions

Combined with an inertial motion capture suit easily usable on a theater stage, the pipeline enables one to record numerous takes in on-set previsualization conditions and to test them in real time in the shadow theater 3D scenography. As understood by Woolford [35] and Norman [27], the motion capture session needs to be performed in the right place to obtain high quality movement matching. Therefore, the physical mocaptor recorded all the animations on a theatrical stage, reproducing the final performance setup. We placed appropriate feedback monitors to let him make immediate adjustments based on the virtual rendering in relationship with the physical setup and the hyper-actor position (fig. 5) [14].

The objective was to guarantee the best conditions for the mocaptor to inhabit the OAVs and respond to the director's intentions. However, the presence effect by itself is not a sufficient criterion for the hyper-actor. It is also necessary to guarantee the synchronization between the animations and the physical acting. It is on this movement quality issue that we will now focus.

5.2 Synchronization Constraint

Within the Computer Theater paradigm, making a fixed video montage with pre-recorded animation sequences is not an acceptable solution. Still, a skilled actor could perform with this temporal constraint, as a ballet dancer dances to a musical recording, and in most cases the audience would likely not question the assumed real time relationship to the audiovisual materials. Nevertheless, for the sake of what is essential to theater, it is invaluable for the actor to be free to improvise with or adapt to the audience – and that was the original motivation for the design of our visual instrument.

This temporal issue is similar to that of musicians playing a traditional instrument in a real time digital sound environment. Synchronization between the instrumentalist and the computer needs a hybridization of the timeline and the time flow paradigms [9]. Formalisms have been developed through software aiming to provide solutions not only for music but for the performing arts in general [9]. Flexible time functionality is not sufficient. Adapting the speed of the animation in relation to the performer would alter the presence effect of the OAVs. The OAVs must in fact "wait" for the reader by suspending their actions and simply "listening" to the physical hyper-actor or their partners on the virtual stage. Time suspension with animation loops, such as idle movement sequences, is one solution. A musical analogy would be to keep chords or clusters in resonance awaiting the execution of a rhythmic sequence. *Live* and *computed* time confront each other and must coexist harmoniously.

5.3 A possible staging for a temporal solution

Even if notation systems are not easily implementable in the performing arts [24], exploring the quality of theatrical movements opens new perspectives on temporal issues and forces one to work on an appropriate staging for the OAVs. Following studies in sign language and co-speech gestures that segment a stream of body movement into phases and identifying different phase types [20], we propose to divide actions into two categories:

- salient: actions with salient gestures are characterized by a starting point and an ending point within a perceivable timeline.
- non-salient: actions which do not contain significant gestures and take on a "listening" or "waiting" position just before or after a salient action.

For an actor on stage, a salient action corresponds to speaking text with or without gesture, while the other actors take on physical positions without salient gestures, as if listening or waiting, so as not to disturb the focus on the speaking character. Sometimes, salient actions can also impact or interrupt each other. But the art of stage direction is to organize these salient actions from the point of view of the spectators' perception and keep the narrative thread.

Non-salient actions are found in video game development under the term idle animation (referred to as an *idle*) – when a virtual character assumes a low-activity position. This indicates presence, but without any significant expressive gestures, and when the animation end point is blended back to its beginning it forms an endless loop. A breath or a position of attentive listening can be an idle. An idle can be played in forward or in reverse. A quick way to build an idle loop from a piece of idle movement is to add the animation to itself in reverse. In this way the loop is continuous. A puppet may maintain an idle loop a long time, waiting to carry out a future salient action. A trained eye will detect the pattern of the loop after a certain time which degrades the puppet presence effect, but idles are often applied to puppets that are not at the center of the stage action. A salient action may be marked by an emotion, while an idle will rather reflect a feeling in terms of emotional dynamics, for example attentive or fearful listening, or an impatient or annoyed expectation.

In our storyline, the five OAVs in the background start from a listening posture, like the one held by the physical audience. They move into action by becoming different characters in the story. We therefore stage the animation with a category of idles such as listening to the hyper-actor or to the other OAVs, or another category of salient actions relating directly to Andersen's story. OAVs will alternate between idle and salient movements. We will therefore make the hypothesis that it is possible to stage the animation using only salient and non-salient actions, in order to achieve a presence effect strong enough to keep the attention of the spectators throughout the 50-minute performance.

6 Methods of implementation and programming

6.1 First Method

Before writing the entire scene score for the performance of the five OAVs, it was necessary to validate the implementation of the hypothesis and the programming techniques in virtual shadow theater. Fig. 6 shows why using a prerecorded global animation montage blending salient and idle actions in a fixed way (fig. 6) would not work. The salient part of an action is characterized with an arrow that shows the time direction that links start times to end times. The idle part is characterized with a wavy line that indicates the absence of salient gesture. We have a double wavy line to illustrate the hyper-actor's independent timing making it impossible to fix cues at precise times. Layer 2 (fig. 6) shows that the hyper-actor's timing is flexible and will probably be different for each performance. There is a constant need to synchronize the beginning of each animation with its matching cue: Anim2 with Cue2, Anim3 with Cue3, and so on. One can imagine that stretching animation time to work out this temporal constraint would necessitate precisely knowing the actor's current position within the global timeline – information that we have no reliable means of obtaining. Moreover, modifying animation speed would weaken the presence effect which was a requirement for a successful performance.

A first solution is to record animations composed of the desired salient actions followed by longer idle actions as shown in fig. 6 layer 3, that would give freedom to the hyper-actor to trigger the next salient action. Of course, triggering a new action during a running salient action is a problem that would require writing a different staging. Still, this method underscores several inconvenient side effects. During the recording sessions, asking the mocaptor to maintain long-lasting idle action may degrade the idle quality into an unconscious salient one, or let it drift to an inappropriate posture. From the mocaptor's point of view, it also forces him to unnaturally break his acting stance and may bring him to lose the relationship between salient actions and once again endanger the presence effect. Staging animation with several salient actions interspersed with idles can be implemented at the risk of denaturing the salient action and endangering the OAVs movement qualities.

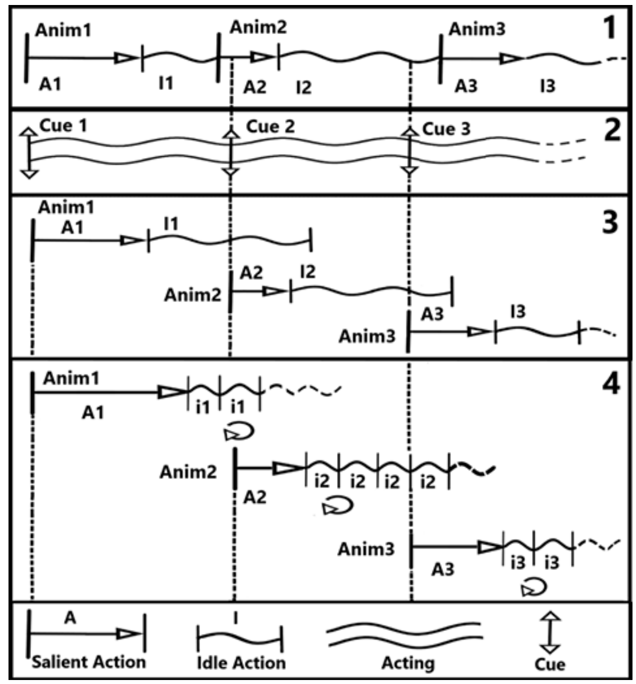

Figure 6: Implementation of the two methods.

6.2 Second Method

This second method of temporal synchronization improves on the former by exploiting the idea that idle actions can be looped. It requires more programming developments but simplifies the idle recording process for the mocaptor by limiting its length. A few seconds of recorded movement are enough to build a much longer animation by looping the sample. Instead of having long I1, I2, or I3 idle actions as in (fig. 6 layer 3), we loop smaller i1, i2 and i3 idle actions (fig. 6 layer 4). The looping process is only necessary until the next cue is triggered (fig. 6 layer 2).

Shortening the recording time of idle gestures affords the possibility of multiple takes and a more flexible selection process to choose the best idle gesture to add to the initial salient action – not possible with the previous method. The mocaptor can either closely follow his acting goals or improvise new idle pauses if not satisfied by what he has done. The director can also ask him to intersperse short pauses into a long salient action. This allows one to subsequently change the staging by dividing it into several shorter sequences, giving more expressive potential to the hyper-actor visual instrument. This method takes greater advantage of the theatrical recording context and uses it in an on-set previsualization pipeline, directly within the rendering video game engine to guarantee optimal results.

6.3 Programming

Fig. 7 shows how OAVs are directed within a cue. An OAV receives three indications: type of transfer (from the current animation to the next one), salient action animation (A or Action) and idle animation (I or Idle) that need to be played (fig. 8 - frame highlighted in orange). The main transfers are Action-Idle (A-I), Action (A) or Idle (I) that indicates to which combination of movement the OAV blends (fig. 8 - frame highlighted in green). Given that about 150 idles are needed to run the performance, making them on the fly directly inside UE4 was a key factor of success in writing the staging. The videogame engine has a basic editing tool for splitting animations and enabling them to be combined in a game-oriented way. For instance, the UE4 *AnimMontage* feature allows one to combine several prepared animations in real time and trigger similar types of gestures: i.e. taking out a weapon, loading it and then putting it away, while running, walking, crouching, swimming, etc. However, animations are juxtaposed, and the function of *seaming* has to be achieved in pose editing software such as Motion Builder – a time-consuming and fastidious process.

Figure 7: Cue 321 content that launches animations to realize a staging position for the Scientist, the Shadow and the Princess.

To simplify the pipeline of *The Shadow* and maintain its theatrical reactivity, idles are directly computed in UE4. Each idle sample is softly blended to itself playing in reverse (speed -1) at the end of the record (cf. Idle Channel in fig. 8). Therefore, an Action-Idle animation is built in a few clicks directly after a recording session by first isolating Action parts, then a few seconds of Idle parts, and finally by furnishing Action and Idle cue slots with an A-I transfer type.

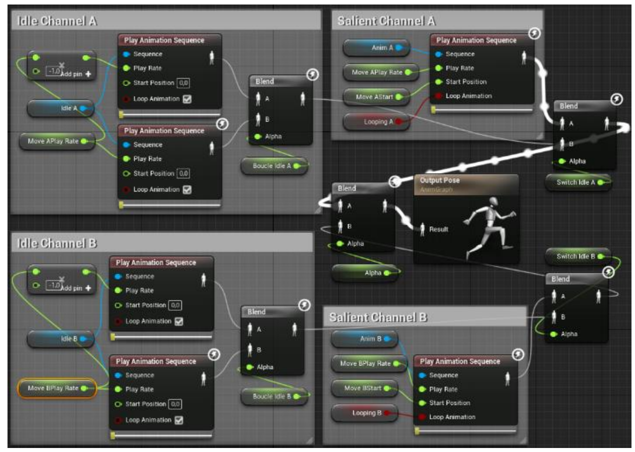

Figure 8: Blending of salient and idle actions

The animation programming is composed of a mix of two mirrored buses, each one mixing a channel for Salient Action (play once), and another for Idle (looping with the reverse technique). The Action-Idle (A-I) transfer consists of blending the current OAV animation (Idle or Action) to the next Action animation automatically followed by the Idle one. The Action transfer (A) is blend from the current to an Action animation (that will stop when finished). The Idle transfer (I) blends towards an Idle.

This global system allows blending from any Action or Idle, to any Action-Idle, Action or Idle combinations. In detail, parameters allow changing the speed of Actions or Idles, while still respecting the presence effect constraint. It is also possible within an A-I transfer to trigger an Idle before an Action animation has finished. Furthermore, we are exploring complex transfers in order to accomplish new directing issues such as Action to Action to Idle.

7 Results and discussion

The first result produced with this system was the theatrical production *The Shadow* – presented in Ukraine and France and over 12 times. In each country, a native actor played the part of the hyper-actor and the musical and visual instruments were adapted for translation to the Ukrainian and French languages and their prosody specificities. Performances were given to adult audiences and to young children from 8 to 12 years old, and they were received as is if it were “traditional” theater with physical actors and puppets. It means that on a theatrical level, the result was successful and that the presence effect of the shadow avatars worked to keep audiences immersed in the story. This result could have been quantified with more precise factors, but the more exigent proof for theater artists is when an audience simply enjoys the performance and maintains their interest. The fact that our audiences suspended their disbelief towards the staging of the avatars was the result we hoped. It validated our hypothesis about the salient and idle categories of gestures and the success of its implementation.

Some children were not even conscious of the real time process and perceived the animation as a feature film. Others believed that hidden actors were playing offstage, directly reacting to the actor's words. The majority were very intrigued by the OAV shape and believed it was of paper or aluminum, not aware of motion capture possibilities.

The recording sessions were very intense for the mocaptor because he had to organize his acting on the physical stage surrounded by feedback monitors in order to create convincing OAV acting presence in the virtual theater. During many of the rehearsals, the director worked simultaneously with the hyper-actor playing the story while the mocaptor controlled the OAV on the same stage used for the public performance (fig. 5). Mutual stimuli between the director's perspective, vocal interpretation and body expression produced OAV acting gestures that succeeded in providing a dynamic expressive framework to be inhabited by the hyper-actor.

Still, subsequent rehearsals were necessary for the hyper-actor to improve the control of the musical and visual parameters stemming from his performance. Some adjustments to the OAV gestures were necessary. The flexibility of the salient/idle decomposition approach and the possibility of suspending motion on the fly within salient animations or adjusting their speed avoided having to rerecord the movements with every change of staging.

We also confirmed that the act of manually triggering the gestures by the actor with a MIDI controller was no more complicated for the actor than knowing that a vocal effect will be applied to specific words or sounds. In other words, an experienced actor can just as easily incorporate the triggering and the vocal transformations into his performance.

8 Conclusion and perspectives

This paper refers to Pinhanez's pioneering description of Computer Theater and its need to place theatrical actions at the heart of the computing process. It focuses on the figure of the hyper-actor in the staging of the theatrical performance *The Shadow* in a mixed reality digital shadow theater. After a description of the digital musical instrument played by the hyper-actor, it exposes his visual one, composed of a troupe of five OAV virtual puppets that either listen to him telling the story or play out its dramatic events. Two main considerations are behind the design of the Computer Theater instruments: achieving a presence effect in the digital acting of the five OAVs and allowing the hyper-actor interpretive freedom within the animation process.

This second consideration leads to proposing a staging approach using a linguistically inspired division between salient and idle gestures in the mocaptor's acting. It is implemented in the AvatarStaging AKN-Regie cueing system and requires a programming solution to produce idle animations on the fly in a UE4 real-time rendering pipeline. The creative approach was positively welcomed by international audiences through performances of *The Shadow*.

The research now heads toward three directions concerning movement computing. Developing more complex and adjustable transfer combinations between Action and Idle animations would help to provide richer direction options after the recording sessions. Finding a way to constitute a catalogue of varied expressive gestural postures for idle animations to be blended to the contextual recordings would give a second possibility to enhance the staging. And finally, the experience given by the construction of the virtual shadow theater opens the way to exploring the semi-autonomous behavior of virtual golems [33] and enables a richer interaction between the hyper-actor and his expressive digital instruments.

ACKNOWLEDGMENTS

We would like to thank didascalie.net which supports the development of the AvatarStaging framework and produces the theatrical performance *The Shadow* (http://didascalie.net).

REFERENCES

[1] Hans Christian Andersen. 1847. *The Shadow*

[2] Tameem Antoniades. 2016. Creating a live real-time performance-captured digital human. In *ACM SIGGRAPH 2016 Real-Time Live! (SIGGRAPH '16)*. Association for Computing Machinery, New York, NY, USA, Article 36, 21. DOI: https://doi.org/10.1145/2933540.2933551

[3] Dimitrios Batras, Judith Guez, Jean-François Jégo, and Marie-Hélène Tramus. 2016. A virtual reality agent-based platform for improvisation between real and virtual actors using gestures. In *Proceedings of the 2016 Virtual Reality International Conference (VRIC '16)*. Association for Computing Machinery, New York, USA, Article 34, 1–4. DOI:https://doi.org/10.1145/2927929.2927947

[4] Elisabetta Bevacqua, Romain Richard, Julien Soler, and Pierre De Loor. 2016. INGREDIBLE : A platform for full body interaction between human and virtual agent that improves co-presence. In *Proceedings of the 3rd International Symposium on Movement and Computing (MOCO '16)*. Association for Computing Machinery, New York, NY, USA, Article 22, 1–8. DOI: https://doi.org/10.1145/2948910.2948943

[5] Renée Bourassa et Louise Poissant (sous la dir. de). 2013. *Avatars, personnages et acteurs virtuels*. Sainte-Foy. Presse de l'Université du Québec

[6] Renée Bourassa et Louise Poissant. 2013. *Personnage virtuel et corps performatif: effets de présence*. Québec, Presses de l'Université du Québec

[7] Roberto Casati. and Patrick Cavanagh. 2019. *The Visual World of Shadows*, MIT Press. DOI: https://doi.org/10.7551/mitpress/11007.001.0001

[8] Jean-Michaël Celerier, Myriam Desainte-Catherine, Jean-Michel Couturier. 2016. Graphical Temporal Structured Programming for Interactive Music. *International Computer Music Conference*. Utrecht, Netherlands. (hal-01364702)

[9] Myriam Desainte-Catherine, Antoine Allombert, and Gérard Assayag. 2013. Towards a hybrid temporal paradigm for musical composition and performance: The case of musical interpretation. Comput. *Music J*. 37, 2 (June 2013), 61–72. DOI: https://doi.org/10.1162/COMJ_a_00179

[10] Josette Féral et Edwige Perrot. 2013. Le réel à l'épreuve des technologies : les arts de la scène et les arts médiatiques. Rennes. Presses Universitaires de Rennes

[11] Nesrine Fourati and Catherine Pelachaud. 2018. Perception of Emotions and Body Movement in the Emilya Database. In IEEE *Transactions on Affective Computing*, vol. 9, no. 1, p. 90-101, Jan.-March 2018. https://doi.org/10.1109/TAFFC.2016.2591039

[12] Georges Gagneré. 2019. *The Shadow*, by H. C. Andersen. Director, set designer and programmer. Featuring Eric Jakobiak (France) and Pavlo Chirva (Ukraine) (performers), Tom Mays (composer), Anastasiia Ternova (programming and set design assistant), Remy Gorski (mocaptor). Produced by didascalie.net.

[13] Georges Gagneré and Cédric Plessiet. 2018. Experiencing avatar direction in low cost theatrical mixed reality setup. In *Proceedings of the 5th International Conference on Movement and Computing (MOCO '18)*. Association for Computing Machinery, New York, NY, USA, Article 55, 1–6. DOI: https://doi.org/10.1145/3212721.3212892

[14] Georges Gagneré, Andy Lavender, Cédric Plessiet, and Tim White. 2018. Challenges of movement quality using motion capture in theatre. In *Proceedings of the 5th International Conference on Movement and Computing (MOCO '18)*. Association for Computing Machinery, New York, NY, USA, Article 44, 1–6. DOI: https://doi.org/10.1145/3212721.3212883

[15] Georges Gagneré and Anastasiia Ternova. 2020. A CAstelet in Virtual reality for shadOw AVatar (CAVOAV). In *ConVRgence (VRIC) Virtual Reality International Conference Proceedings*. Simon Richir (dir.). International Journal of Virtual Reality. DOI: https://doi.org/10.20870/IJVR.2020...3316

[16] Nelson Goodman, Languages of Art: An Approach to a Theory of Symbols, Bobbs-Merril, 1968

[17] Marco Grosoli et Jean-Baptiste Massuet (sous la dir.). 2014. *La capture de mouvement : Ou le modelage de l'invisible*. Rennes. Presses universitaires de Rennes. DOI: 10.4000/books.pur.75521

[18] Christian Jacquemin, Rami Ajaj and Bertrand Planes. 2011. Alice on both sides of the looking glass: Performance, installations, and the real/virtual continuity. *Computer in Entertainment*. Vol. 9 N°3, Article 12 (November 2011), 23 pages. DOI: https://doi.org/10.1145/2027456.2027458

[19] Christian Jacquemin, Georges Gagneré and Benoît Lahoz. 2011. Shedding Light On Shadow: Real-time interactive artworks based on cast shadows or silhouettes. In *Proceedings of the 19th International Conference on Multimedia (MM '11)*. Association for Computing Machinery, New York, NY, USA, 173–182. DOI: https://doi.org/10.1145/2072298.2072322

[20] Sotaro Kita, Ingeborg van Gijn and Harry van der Hulst. 1998. Movement Phases en Signs and Co-speech Gestures, and Their Transcription by Human Coders. In *Proceedings Lecture notes in computer science*. (Volume 1371, pp. 23-35). Berlin. Springer. DOI: http://dx.doi.org/10.1007/BFb0052986

[21] Heinrich von Kleist. 1810. *Über das Marionettentheater*

[22] Myron W. Krueger. 1991. *Artificial Reality II*. Addison-Wesley

[23] Tod Machover. 1992. *Hyperinstruments – A Progress Report 1987-1991*. MIT Media Laboratory

[24] Monique Martinez Thomas et Sophie Proust (dir.).2016. *La notation du travail théâtral: du manuscrit au numérique*. Edition Lansman

[25] Tom Mays. 2015. CRT – Composition in Real Time *:* Environnement de composition temps réel dans Max. https://forum.ircam.fr/projects/detail/crt-composition-in-real-time/

[26] Tom Mays. 2015. L'harmonisateur augmenté : le dispositif d'écriture mixte dans l'œuvre Le Patch bien tempéré III. In *Actes des Journées d'Informatique Musicale (JIM 2015)*. Montréal, Canada

[27] Sally-Jane Norman. 2014. Grappling With Movement Models: Performing Arts And Slippery Contexts. In *Proceedings of the 2014 International Workshop on Movement and Computing (MOCO '14)*. Association for Computing Machinery, New York, NY, USA, 136–141. DOI: https://doi.org/10.1145/2617995.2618019

[28] Noriyasu Obushi and Makoto Koshino. 2018. Temari and Shadow: an interactive installation combining virtual handicraft and real shadow. In *Proceedings of the Virtual Reality International Conference - Laval Virtual (VRIC '18)*. Association for Computing Machinery, New York, NY, USA, Article 31, 1–4. DOI: https://doi.org/10.1145/3234253.3234321

[29] Philippe Pasquier, Eunjung Han, Kirak Kim and Keechul Jung. 2008. Shadow agent: a new type of virtual agent. In *Proceedings of the 2008 International Conference on Advances in Computer Entertainment Technology (ACE '08)*. Association for Computing Machinery, New York, NY, USA, 71–74. DOI: https://doi.org/10.1145/1501750.1501766

[30] Pietroszek K., Eckhardt C., & Tahai L. (2018). Hamlet: directing virtual actors in computational live theater. In Proceedings of the 24th ACM Symposium on Virtual Reality Software and Technology (VRST '18). Association for Computing Machinery, New York, NY, USA, Article 93, 1–2. DOI: https://doi.org/10.1145/3281505.3281600

[31] Claudio S. Pinhanez and Aaron F. Bobick. 1996. Computer Theater : Stage for Action Understanding. In *Proceedings of the AAAI 96 Workshop on Entertainment and AI/A-Live*, 28-33

[32] Claudio S. Pinhanez and Aaron F. Bobick. 2002. "It/I": a theater play featuring an autonomous computer character. Presence: *Teleoper. Virtual Environ*. 11, 5 (October 2002), 536–548. DOI: https://doi.org/10.1162/105474602320935865

[33] Cédric Plessiet, Georges Gagneré and Rémy Sohier. 2019. A Proposal for the Classification of Virtual Character. In Proceedings of the 14th International Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications. Volume 1: HUCAPP, Prague, Czech Republic, 168-174. DOI: https://doi.org/10.5220/0007569401680174

[34] Izabella Pluta. 2019. When Theater Director Collaborates with Computer Engineer. In *Emerging Affinities - Possible Futures of Performative Arts*, dir. Borowski, M.; Chaberski, M.; Sugiera, M. Theater, V.127; Transcipt Verlag: Bielefeld, p. 49-70

[35] Kirk Woolford. 2014. Capturing Human Movement in the Wild. In *Proceedings of the 2014 International Workshop on Movement and Computing (MOCO '14)*. Association for Computing Machinery, New York, NY, USA, 19–24. DOI: https://doi.org/10.1145/2617995.2617999

[36] Qiong Wu, Pierre Boulanger, Maryia Kazakevich and Robyn Taylor. 2010. A real-time performance system for virtual theater. In *Proceedings of the 2010 ACM workshop on Surreal media and virtual cloning (SMVC '10)*. Association for Computing Machinery, New York, NY, USA, 3–8. DOI: https://doi.org/10.1145/1878083.1878087