PhD: Groups of humans and animals in natural environments: a multi-scale approach.

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Figure 1: *Natural virtual environments require a high level of interaction with respect to the elements that are part of it (e.g. scene topology or natural elements such as vegetation). The correct modeling of the characters' motion and their integration with the surroundings are key aspects to achieve realistic scenarios in video-games or 3D films.*

Abstract

The design of motion for virtual creatures is a key task for many applications. They can be used to enhance the realism of 3D films or to create reactive characters for video-games. In the research agenda of this PhD thesis, we will consider the challenging application of generating realistic animations of individuals in natural ecosystems in real-time, from a large scale to a more local level, as they interact with the environment and this, in return, provides a response that dynamically impacts the motion of the characters. Our mission is to create new tools to implement such feedback systems, which not only facilitate the creation of animated content for artistic studios, but also propose new possibilities in a more scientific basis, such as the study of pre-human or animal locomotion, as well as their behavior within the environment through prior knowledge, for example from archaeologist's studies.

1. Introduction

This PhD takes place in the context of the Innovative Training Network CLIPE project (http:www.clipe-itn.eu) addressing the challenges of designing new techniques to create and control interactive virtual characters, benefiting from emergent technologies in domains like human digitization and displays, as well as recent progresses of artificial intelligence. The topic conducted during this PhD thesis will specifically address the objective of animating groups of believable characters in dynamic natural environments.

This PhD is supervised by professors Damien Rohmer, Pooran Memari and Marie-Paule Cani, at the Geometric and Visual Computing team at LIX (Laboratoire d'Informatique de l'Ecole Polytechnique), in Palaiseau (Paris). The graduating university is the Institut Polytechnique de Paris (IP Paris). The duration of the thesis is 3 years (October 2020 - October 2023).

2. Motivation

Conveying realism in a virtual scene implies not only enhancing a work on a technical level, but also involving the audience more, capturing their attention to the slightest detail and fading their perception of reality. In a video-game, for example, a character who slips when walking on ice or uses his hands to assist himself when running on a steep slope; a group of herbivores that forage in areas where predators do not stalk them and flee in case of danger; or a jungle, where dense vegetation reduces real-time mobility. All these elements complement the players' perception of the scene, so that they can respond with their actions in a more natural way, as if they were doing it in real life, and therefore achieving a new immersion level.

For this purpose, with this PhD dissertation I seek to define a multi-scale approach to control the locomotion and behavior of groups of bipedal (humanoids) and quadruped creatures, with specific emphasis on tools applicable to generic models of variable morphology in natural environments.

My work will be summarized as follows: In section 2.1, I introduce a large scale scope for this thesis. One should be able to control group behavior, as well as the interaction between different groups and types of characters. In section 2.2, I approach this problem at a smaller scale. The locomotion of the individuals should both be valid with respect to their morphology, as well as automatically adapt to the type of terrain (i.e. walking on a flat ground, in a meadow, in water, versus climbing a steep slope). Finally, section 2.3 introduces the problem of interaction with the terrain and its impact itself to the motion of the character (i.e. slipping in the mud, or walking on stones that may roll under the feet).

2.1. Large scale

At the group scale, we may extend the previous work on animating adaptable crowd patches [JPC*14] to the case of open, natural environments. This extension should take into account terrain-related constraints such as slope, water or vegetation, as well as integrating the notion of group interaction that can be modeled as soft constraints or forces. Refinement and adaptation of the individual trajectory taking into account the constraints and prior knowledge on the group structure can also be integrated [EPMC19]. These trajectories will also need to be segmented and labeled into specific animation-related gaits expressing the type of displacement such as walking, hunting, fleeing, etc. At the end of this step, each gait will be associated with a pre-computed 3D standard animation of a contemporary human or animal.

2.2. Individual scale

At the individual scale, I will tackle the animation transfer from contemporary character animation to match other morphologies, such as a prehistoric counterpart. More specifically, I will need to adapt a standard skeleton animation, described as a set of varying joint angles, to a new morphology taking into account the change of limb dimensions, and possibly a change of mass distribution as well as muscle amount and power. Lastly, the transfer should lead to a valid motion, i.e. free of intersection with the modified morphology. Before handling animation data, a static transfer of the skeleton within a new morphology should be performed. To this end, a mapping between morphological envelope and animation-skeleton will be developed through the use of advanced geometric modeling and analysis methods, for instance using reverse engineering techniques for raw animated models inspired from cage-based models [TTB12]. A fully kinematic approach may be used first to take into account new limbs dimensions [HRE*08] and geometrical morphology while preserving contacts with external elements [BWBM19], or between body parts themselves. The change of dynamic and equilibrium should be handled using a physically-based model based on the new distribution of mass. Finally, an extra layer of adaptation may also be added before handling collision explicitly in considering a simulation triggered by controllers optimized via the use of deep reinforcement learning, optimizing the locomotion from the new muscle distribution.

2.3. Interaction between the character and the environment

In the last step, I will develop the local adaptation of the character motion to the terrain. Indeed, walking in mud, on a river or within dense vegetation impacts the way each character moves. The terrain or vegetation may also deform under the action of the human or animal [SOH99], which should itself respond accordingly to preserve its stability. We aim at tackling this problem using an efficient, hierarchical approach. A global animated model used as a proxy may be set at a high level. Then sub-parts of this model will be refined to locally tackle the interaction with the deformable elements. Each response on the character motion may be locally adapted using efficient and adapted models, possibly based on simple physically-based simulation and taking into account the overall character equilibrium [YLV07].

3. Our research

In the early stages of this thesis, I have started by tackling the challenge of elaborating general methods for synthesizing novel motion from kinematic animations with respect to the environment (as described in section 2.3). To do this, I search for ways that can comprise procedural techniques, and inclusively, physically-based simulations. In combination with generic descriptive animations and the character's interaction with its surroundings, I am looking for new ideas for the creation of tools that facilitate the work of animators in their respective animation pipelines.

3.1. Current research situation

During these three years, we want to conduct research in a growing sense in terms of the scale of the problem, as described in section 2. First, I would like to develop methods to integrate two-way interactions between descriptive animations and the environment, while keeping them compatible with future additions at a mayor scale. Walking on loose terrains composed of different materials or containing elements like vegetation should induce a respective modification of the surroundings. In turn, this deformation might produce a corresponding alteration in the character's gait.

In my first work, I helped build a real-time multi-layer method to model this two-ways interaction. First, we make use of controllers to correct the angular position and velocity of a moving character and improve its oscillations while walking on terrains of varying slope and materials. Secondly, feet consequently deform the ground based on its material properties, and accordingly, the character responds to such deformations by adapting its gait using the implemented controller and applying a torque to correct dynamically its pose.

With respect to vegetation, I built a procedural system to adapt the character's movement while walking on high grass. One may observe on footage of natural gaits that humans tend to raise their knees higher and land more abruptly when reaching a short and dense vegetation layer. Indeed, walkers cannot accurately perceive the actual distance from their feet to the ground, but only roughly estimate it. They thus typically target higher positions, while the vegetation will suddenly crush under their feet. I captured this effect using virtual platforms placed under the feet, and modeling the perceived ground. These platforms, serving as targets for the IK system, were procedurally controlled depending on the height of the vegetation layer. In addition, I implemented such natural elements using 2D intersecting meshes and shader-graphs, which were vertex-wise deformed in real-time based on the distance between each plant element and the body position (figure 2).

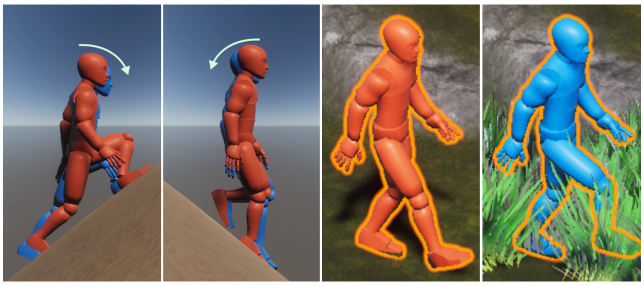

Figure 2: *The blue character (middle-left) uses a torque-based controller unlike its corresponding red version, in order to tilt its position dynamically forwards or backwards, depending on the slope. Additionally, I procedurally animate its gait by lifting the legs based on the presence and height of vegetation (middle-right).*

3.2. Short-term Work. Constraints and Challenges.

Currently, there is an important involvement on the research of motion synthesis for physically-based models, for example, using exploration techniques [HSK16], template-based approaches [AV16] or Machine Learning techniques (such as Deep Supervised Learning [ZSKS18] [SZKS19] or Deep Reinforcement Learning [XLKvdP20] [HTS*17]). However, the large amount of data that some of these methods would require to simulate such complexity of scenarios, especially those that involve a high level of diversity such as natural environments, would be extremely costly to obtain and out of the reach of many typical virtual applications. With this in mind, we want our methods not to rely entirely on data-driven approaches, but to use procedural tools that, in combination with other techniques such as descriptive animations, motion capture or learning-based techniques, would allow us to synthesize novel motion with fewer data requirements while maintaining its functionality in real-time.

These constraints are important to us. We are looking for methods that are robust and efficient enough for daily game applications, yet interactive and general to serve as a reference tool for content creation, while maintaining certain flexibility such that the artist can still have a degree of creativity (figure 3).

One open question is how to expand such idea at different levels and still meeting our requirements. Therefore, I am looking to adapt the descriptive motion to the environment or the character's self-inertia using more complex physically-based techniques and

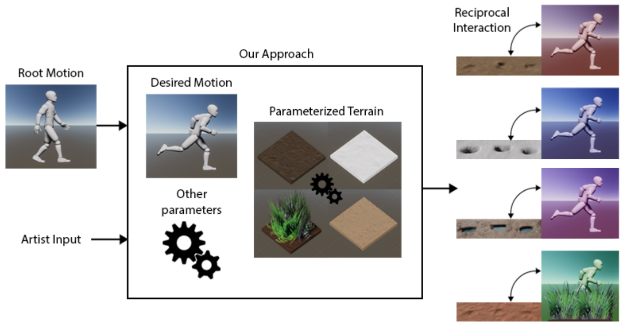

Figure 3: *We want to create efficient tools that provide flexibility in the synthesis of novel animations. Ideally, an artist could take a given animation as a reference and, by setting an intuitive set of dynamic parameters, define the scene (e.g., terrain properties or the maximum energy of the character). The system would adapt the character's movement to this configuration by synthesizing multiple versions of the initial animation.*

more accurate limb representations. One of my first research directions is to decouple the overall movement of a character into two main parts (lower- and upper-body) to help tackle the problem by splitting it into two smaller sub-tasks. While I have encountered related methods in the context of "on-the-spot" animations, for example applied to conversations [LKN09] (where the animation is divided into a body position and a gesture, with the arms as the main agents to convey realism), I wanted to use these ideas to address the complex challenge of adapting the character's gait during dynamic animations, such as walking or running, and at the same time maintaining a high interaction with the environment.

One known way to deal with this problem is by using the so-called active ragdolls models. This concept integrates two complete skeletons for one character: one is animated using forward kinematics (used as a reference) and the other is physically-based. The system transfers the positions and rotations from the kinematic system to the physical one. Although this method provides to the character a greater sensitivity to perturbations, these can become too excessive, with the cost of appearing less realistic. This is why its implementation is not standardized except for applications where such a magnified effect is sought, e.g. during collisions.

Instead, our method seeks to find the correct trade-off. I would like to raise the possibility of dividing the model into two parts: a lower-body component (hips and both legs) using forwards kinematics assisted by IK to adapt the feet on the ground, and an upper-body component (head, torso and arms defined by rigid bodies and joints) would be subject to the effect of the physics system. While the lower component remains stable, it might be possible to feed the upper part with information from its animated version which uses forward kinematics, to interpolate a model and achieving an in-between term that could be considered as a more relaxed version of the purely descriptive one. A similar objective was already introduced to model energy muscle optimization [NF02], using antagonistic controllers based on stiffness/relaxed actuators for fully physically-based arms. Other papers, which introduces gesture augmentation given motion capture data for body positions [LKN09] [LN12], discuss about the influence of lower-body key positions and performs a correlation study with respect to the upper-body to address this aspect, something that I would also like to do to shed some light on the problem.

However, the method still raises many open questions, as it is still in its initial phase, so I would like to continue searching for the right solution. In addition, I believe that it would be very beneficial to assist the consortium in this regard, in order to receive feedback on our work, while I am open to other techniques, such as learning-based or exploration approaches.

3.3. Long-term Work and Expected Contributions

During the first year, I expect to contribute with versatile ways to model character-environment interaction in natural environments. While we already developed methods to alter the terrain and the character's motion, I want to optimize our approaches to make such alterations more realistic and purposeful for the character's behavior. The dynamic changes produced to the character can still be improved, by adding more complexity to the model, e.g. allowing it to adapt its posture along all possible directions, as our model only adapts now forward and backwards (as shown in figure 2), or adapting new animation methods, as we commended in section 2.

Vegetation should play a crucial part for the gait alteration in natural environments too. I want to model realistic natural elements such as plants, grass or rocks that act as additional sources of instability/change on the character's gait, while reciprocally, it alters these elements in return (e.g. rocks falling or compressed grass that deteriorates over time).

We also believe in the potential of procedural animation along with inverse kinematics for arm control. One case scenario would be walking though vegetation. Real humans tend raise their arms higher when moving through high grass, for example, or try to break through the vegetation with their hands to make their way forward. I would like to exploit the ability of procedural motion to cover these kind of actions for any type of humanoid morphology, and additionally, to look for ways to carry out such purposes with quadrupeds, through the study of the behavior of different animals under the same circumstances.

Once we have reliable methods for the definition of the character and its interaction with the environment, I will proceed to study new methodologies of motion transfer based on the prehistoric morphology data, and subsequently extending our work to group-based behavior systems in natural environments.

4. Conclusion

During this thesis, I would like to address several aspects related to the virtualization of natural environments and the interaction with the individuals moving in them, with the aim of using these tools to aid artists during the creation of creative content or the study of alternative morphologies using prior knowledge. I would like to divide this problem into three levels: a large scale layer for groups behavior, an individual scale layer for the morphology and one level for the interaction with the environment. Finally, a full integration of the whole ecosystem should be made.

I believe that this consortium would be the ideal way to present my first results and to receive valuable feedback from the community in the search for solutions, methodologies and experiments, particularly now that I find myself in the initial phase stage of the PhD dissertation.

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