Comenius University, Bratislava

Faculty of Mathematics, Physics and Informatics

Motion Graphs in combination with Blender

Bachelor Thesis

Dominik Kapišinský 2012

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Supervisor: RNDr. Jana Dadová

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Dominik Kapišinský

56333852

Univerzita Komenského v Bratislave
Fakulta matematiky, fyziky a informatiky

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Cieľ: Naštudovanie problematiky analýzy a zápisu pohybu
Naštudovanie štruktúry Motion Graph a možnosti použitia tejto štruktúry
Navrhnutie použitia Motion Graph štruktúry v spojení s Blenderom
Implementácia navrhnutého riešenia
Ukážka použitia skúšobných dát v implementácii

Vedúci: RNDr. Jana Dadová
Katedra: FMFI.KAGDM - Katedra algebry, geometrie a didaktiky matematiky
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garant študijného programu

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študent vedúci práce

I hereby declare I wrote this thesis by myself, only with the help of referenced literature, under the careful supervision of my thesis supervisor.

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Abstract

The aim of a thesis is to implement and show the benefits of a structure Motion Graph and demonstrate its functionality in usage in combination with Blender. The structure Motion Graph is a method for creating realistic and controllable motion. As an input, we obtain an animation and automatically construct a directed graph called a Motion Graph that encapsulates connection within the database. Thanks to the so-called graph walks it is possible to create motion in this structure which was not in original animation. This approach is useful in the film industry and other fields in which the real motion of a human is required. Our solution is implemented in Python's API for modelling and animation tool Blender.

KEYWORDS: Motion Graph, Animation, Blender, Python

Abstrakt

Cieľom práce je implementovať a ukázať výhody štruktúry Motion Graph a demoštrovať jej funkcionalitu a použitie v kombinácii s Blender-om. Štruktúra Motion Graph je metóda na vytváranie realistického a kontrolovateľného pohybu. Ako vstup očakávame animáciu a automaticky skonštruujeme orientovaný graf nazývaný Motion Graph, ktorý zahŕňa prepojenia v databáze póz. V tejto štruktúre, vďaka takzvaným prechádzkam v grafe je možné vytvoriť pohyb, ktorý nebol v povôdnej animácii. Tento prístup je užitočný vo filmovom priemysle a v ďalších oblastiach v ktorých je reálnosť pohybu človeka potrebná. Naše riešenie je implementované v Python API pre modelovací a animačný nástroj Blender.

KĽÚČOVÉ SLOVÁ: Štruktúra Motion Graph, Animácia, Blender, Python

List of Figures

Contents

Introduction

An animation is a main part of the development in a cinema and entertainment industry. In the present the virtual persons, so-called virtual agents in the science of computer animation, occur very often in the film . The virtual agent, human, should have realistic motion.

One of the possible methods how to add realistic motion to the virtual agent is a usage of a Motion Capture method. Motion Capture animation uses the real captured data from real human and allows us to apply these data to the virtual model. One disadvantage is the price of equipments by which it is possible to capture the motion of a human. Second disadvantage is the limited possibilities of animation, because of limitation by human body. Here is the place where our solution can be useful.

Motion Graph structure allows us to create a long varied animation from the small amount of input data consisting of the set of poses. The variety of the animation depends upon the specific features of the key poses in the input data.

Our aim is to implement structure which extract necessary data from existing animation and automatically create own structure. The advantage is that thanks to the so-called graph walks it is possible to create motion in this structure which was not in original animation.

In the first chapter we will define some basic terms necessary to understand given issue. In the next chapter we will mention some related works. The third chapter will be devoted to a proposed solution, description of a given problem will be summarised. The details of implementation will be described in the next chapter, also with some important parts of code. In the last chapter we will present our results.

1
Overview of the problem

1.1 Basic definitions

For reason of clarity and readability we will explain (define) important terms which will be used in following thesis.

• **Animation** - means change of features in computer graphics in time [SK96].

• **Articulated structure** - structure consisting of finite sequence of fixed segments(bones), which are each other connected by joints, in which is possible to rotate with corresponding segments.[WW91]

• **Bones** - basic building unit of skeleton, parameters of bone is its length and rotation in relation to the previous bone in the sequence. [WW91]

• **Skeleton** - tree structure consisting of bones, which are each other connected by joints. For each bone in the tree, except the root, exists the previous, parental bone. In the movement itself the parental bone, the angle between it and the following bone is retained, so by the rotation is in the movement the whole under-tree, in which is this bone a root. [WW91]

• **Mesh** - three dimensional polygonal net, which define a shape of the object. Mesh is defined by the list of its vertices and their coordinates, and also by sequence of vertices which creates either polygons. There is many other types of representation but for our work it is not important [ŽBSF04].

• **Keyframes** - frames, in which animator define key positions and parameters of object. For all other frames of animation are parameters of object computed by interpolation or approximation [Par02].

• **Skeletal animation** - method used for animation of human figure and animals. Body consist of two parts: polygonal mesh and skeleton. There is a relation between the model and skeleton, which in the animation deform the surface of the model. By the movement of bones is possible to define position of the body. Animation is created by definition the position of bones in the keyframes [Par02].

• **XML file** - is a simple text-based format for representing structured information: documents, data, configuration, books, transactions, invoices, and much more. It was derived from an older standard format called SGML (ISO 8879), in order to be more suitable for Web use [w3c12].

• **Blender** - is multiplatform open source 3D software designed for computer modeling and animation. Initially was developed by graphic studio NeoGeo and a company Not a Number Technologies (NaN). From a year 2002 is Blender distributed under open source licence with support of Blender Foundation. In the presence of writing this thesis, the last version is 2.6 [ble12].

• **Python** - is interpreted programming language [pyt12a], which is developed as open source project. Its formation is dated to the begin of 90's. Guido van Rossum was the main engineer. Python is supported over 20 platforms, but at most of its libraries is available only for Linux, BSD, Mac OS X and Windows. An advantage of Python is its easy extensibility. Libraries which can be coded in a languace of C or C++, extend Python in many ways, make available to application interfaces (API) various programs, in which work like scripting language. This is a case of Blender.

Blender consists of two programming interfaces, Blender Python API and Game-Engine Python API. In our work we will use Blender Python API, what is a module collection, which make available a part of internal data and functions of program. This usage allow us big amount diversified options, for example adding new function in to a program. With a help of API is possible to create procedural models, scripts for export and import a many others. Script allow us:

- draw pop up messages, menu, input arrays

- render graphic user interface (GUI)
- edit objects in a scene
- process various events
- perform changes in 3D view - set visible layers, position of camera..
- import scripts to Blender
- usage of external libraries for Python

1.2 Graph Theory

In mathematics and computer science, graph theory is the study of graphs, mathematical structures used to model pairwise relations between objects from a certain collection. A graph in this context refers to a collection of vertices or nodes and a collection of edges or clips that connect pairs of vertices. A graph may be undirected, meaning that there is no distinction between the two vertices associated with each edge, or its edges may be directed from one vertex to another. In this section, we would like to present some definition from Graph Theory [Die06] , because it is close related to Motion Graph.

• **graph** - is a pair G = (V,E) of sets satisfying $E \subset [V]^2$, thus, the elements of E are 2-element subsets of V. The elements of V are the vertices(or nodes, or points) of the graph G, the elements of E are its edges(or lines).

• **adjacent neighbours** - Two vertices x,y of G are adjacent, or neighbours, if xy is an edge of G.

• **path** - is a non-empty graph P = (V,E) of the form

$$\mathrm{V} = x_0, x_1, ..., x_k$$

$$\mathrm{E} = x_0, x_1, x_2, ..., x_{k-1}, x_k$$

where the x_i are all distinct. The vertices x_0 and x_k are linked by P and are called its ends; the vertices $x_1, ..., x_{k-1}$ are the inner vertices of P.

• **length of path** - the number of edges of a path is its length.

• **cycle** - if P = $x_0, ..., x_{k-1}$ is a path and $k \geq 3$ then the graph C := P + $x_{k-1}x_0$ is called cycle.

• **connected graph** - a non empty graph G is called connected if any two of its vertices are linked by a path in G.

• **component of graph** - component of graph G is connected under-graph of graph G, which is not consists in no bigger connected under-graph of graph G (maximal connected under-graph).

• **cost of path** - let G = (V,E) is undirected graph with valued edges, it means for G is given function h : E→R. Path in graph G is sequence of vertices $[v_0, v_1, ..., v_k]$, where (v_{i-1}, v_i)∈E for $i = 1, 2, ..., k$. The cost of path P = $[v_0, v_1, ..., v_k]$ is $\sum_{i=1}^{k} h(v_{i-1,v_i})$. The cost of path we will mark as $|P|$.

1.2.1 Dijstra's algorithm

For a given source vertex in the graph, the algorithm finds the part with lowest cost or the shortest path between that every other vertex. There is no constrain to use this algorithm for finding the shortest path between two single vertices by stopping the algorithm once the shortest path to the destination vertex has been determined. Djistra's algorithm runs in worst case in O($|V|^2$) [Ďu97]. We will mention here the pseudocode [wik12]:

```
function Dijkstra(Graph, source):
    for each vertex v in Graph:
         dist[v] := infinity ;
         previous[v] := undefined ;
    end for ;
    dist[source] := 0 ;
    Q := the set of all nodes in Graph ;
    while Q is not empty:
        u := vertex in Q with smallest distance in dist[] ;
        if dist[u] = infinity:
            break ;
        end if ;
        remove u from Q ;
        for each neighbor v of u:
          alt := dist[u] + dist_between(u, v) ;
          if alt < dist[v]:
              dist[v] := alt ;
           previous[v] := u ;
              decrease-key v in Q;
          end if ;
        end for ;
    end while ;
    return dist[] ;
end Dijkstra.
```

1.3 Structure Motion Graph

In this section, we define the motion graph structure [KGP02] and the procedure for constructing it from a database of clips. A clip of motion is defined as a regular sampling of the character's parameters, which consist of the position of the root joint and quaternions representing the orientations of each joint.

A motion graph is a directed graph where all edges correspond to clips of motion. Nodes serve as choice points connecting these clips, i.e., each outgoing edge is potentially the successor to any incoming edge. A trivial motion graph can be created by placing all the initial clips from the database as nodes in the graph. This creates a disconnected graph with 2n nodes, one at the beginning and end of each clip(expecting n clips). Similarly, an initial clip can be broken into two clips by inserting a node, since the later part of the motion is a valid successor to the earlier part.

A more interesting graph requires greater connectivity. For a node to have multiple outgoing edges, there must be multiple clips that can follow the clip(s) leading into the node. Since it is unlikely that two pieces of original data are sufficiently similar, we need to create edge expressly for this purpose. Transitions are clips designed such that they can seamlessly connect two segments of original data thanks to interpolation. By introducing nodes within the initial clips and inserting transition clips between otherwise disconnected nodes, we can create a wellconnected structure with a wide range of possible graph walks.

Unfortunately, creating transitions is a hard animation problem. Imagine, for example, creating a transition between a run and a backflip. In real life this would require several seconds for an athlete to perform, and the transition motion looks little like the motions it connects. Therefore the problem of automatically creating such a transition is complex. On the other hand, if two motions are "close" to each other then simple blending techniques can reliably generate a transition. How to analyse two motions and compare them, we will describe in next chapters. In light of this, our strategy is to identify positions of the initial clips that are sufficiently similar that straightforward blending is almost certain to produce valid transitions.

How to solve this problem we will describe in the following section.

2 Related works and motivation

2.1 Motivation

This part is devoted to the necessity of the solution of implementation of the Motion Graph structure. We will try to show the advantages in comparison with other animation techniques for creating real human motion. The quoted related papers dealing with the similar aim is listed below, in the next subchapter.

Motivation of implementing of the Motion Graph structure is to render the most real human motion. With this approach, we can create a long varied animation from the small input data consisting of the set of poses. The variety of the animation depends upon the specific features of the key poses in the input data. This method of Motion Graph structure is not very expensive because it depends only upon the input model animation.

Real human motion simulated in the Motion Graph structure is very important from several points of view. Mostly it is exploited in the film and video-gaming industry. In both cases, the most real projection of human motion is desired. Despite the fact that the existing methods in this field are reaching quite a good level of quality, they are demanding resources which are making the final animation more expensive. Another disadvantage of these methods is that the final animation is limited by the ability of the human body movements.

The aim of our thesis is not to improve the existing methods for creating real human motions, but to reveal the new possible approach by which we do not improve the quality of final animation from the point of reality of human motion. However the constraints of the moving apparatus of the human body are removed by our approach and also the requirements upon the resources are quite low.

2.2 Related works

In this subchapter the paper Motion Graphs of the authors Lucas Kovar, Michael Gleicher and Fredéric Pighin is cited. This paper is very interesting and its part dealing with the review of the related works is the most representative in this research field [KGP02].

Much previous work with motion capture has revolved around editing individual clips of motion. Motion warping [WP95] can be used to smoothly add small changes to a motion. Retargeting [Gle98],[LS99] maps the motion of a performer to a character of different proportions while retaining important constraints like footplants. Various signal processing operations [BW95] can be applied to motion data. My work differs from the related works in that it involves creating streams of motion, rather than modifying specific clips.

Another popular approach to motion synthesis is to construct statistical models. Pullen and Bregler [PB00] used kernel-based probability distributions to synthesize new motion based on the statistical properties of example motion. Coherence was added to the model by explicitly accounting for correlations between parameters. Bowden [Bow00], Galata et al. [GJH01], and Brand and Hertzmann [[BH00]] all processed motion capture data by constructing abstract "states" which each represent entire sets of poses. Transition probabilities between states were used to drive motion synthesis. Since these statistical models synthesize motion based on abstractions of data rather than actual data, they risk losing important detail. In our work we have tighter guarantees on the quality of generated motion. Moreover, these systems did not focus on the satisfaction of high-level constraints.

We generate motion by piecing together example motions from a database. Numerous other researchers have pursued similar strategies. Perlin [Per95] and Perlin and Goldberg [PG96] used a rulebased system and simple blends to attach procedurally generated motion into coherent streams. Faloutsos et al. [FvdPT01] used support vector machines to create motion sequences as compositions of actions generated from a set of physically based controllers. Since our system involves motion capture data, rather than procedural or physically based motion, we require different approaches to identifying and generating transitions. Also, these systems were mainly concerned with appropriately generating individual transitions, whereas we address the problem of generating entire motions (with many transitions) that meet user-specified criteria. Lamouret and van de Panne [LdP96] developed a system that used a database to extract motion meeting high-level constraints. However, their system was applied to a simple agent with five degrees of freedom, whereas we generate motion for a far more sophisticated character. Molina-Tanco and Hilton [MTHMH00] used a state-based statistical model similar to those mentioned in the previous paragraph to rearrange segments of original motion data. These segments were attached using linear interpolation. The user could create motion by selecting keyframe poses, which were connected with a highprobability sequence of states. Our work considers more general and sophisticated sets of constraints.

Work similar to ours has been done in the gaming industry to meet the requirements of online motion generation. Many companies use move trees, which (like motion graphs) are graph structures representing connections in a database of motion. However, move trees are created manually—short motion clips are collected in carefully scripted capture sessions and blends are created by hand using interactive tools. Motion graphs are constructed automatically. Also, move trees are typically geared for rudimentary motion planning ("I want to turn left, so I should follow this transition"), as opposed to more complicated objectives. The generation of transitions is an important part of our approach. Early work in this area was done by Perlin [Per95], who presented a simple method for smoothly interpolating between two clips to create a blend. Lee [Lee00] defined orientation filters that allowed these blending operations to be performed on rotational data in a more principled fashion. Rose et al. [RGBC96] presented a more complex method for creating transitions that preserved kinematic constraints and basic dynamic properties.

Our main application of motion graphs is to control a character's locomotion. This problem is important enough to have received a great deal of prior attention. Because a character's path isn't generally known in advance, synthesis is required. Procedural and physically based synthesis methods have been developed for a few activities such as walking [MD99],[SM01] and running [HWBO95],[BC96]. While techniques such as these can generate flexible motion paths, the current range of movement styles is limited. Also, these methods do not produce the quality of motion attainable by hand animation or motion capture. While Gleicher [Gle01] presented a method for editing the path traversed in a clip of motion capture, it did not address the need for continuous streams of motion, nor could it choose which clip is correct to fit a path (e.g. that a turning motion is better when we have a curved path).

Our basic approach — detecting transitions, constructing a graph, and using graph search techniques to find sequences satisfying user demands —has been applied previously to other problems. Schodl et al. [SSSE00] developed a similar method for synthesizing seamless streams of video from example footage and driving these streams according to high-level user input.

Since writing this thesis, we have learned of similar work done concurrently by a number of research groups. Arikan and Forsythe [AF02] constructed from a motion database a hierarchical graph similar to ours and used a randomized search algorithm to extract motion that meets user constraints. Lee et al. [LCR$^+$02] also constructed a graph and generated motion via three user interfaces: a list of choices, a sketch-based interface similar to what we use for path fitting (Section 5), and a live video feed. Pullen and Bregler [PB02] keyframed a subset of a character's degrees of freedom and matched small segments of this keyframed animation with the lower frequency bands of motion data. This resulted in sequences of short clips forming complete motions. Li et al [LWyS02] generated a two-level statistical model of motion. At the lower level were linear dynamic systems representing characteristic movements called "textons", and the higher level contained transition probabilities among textons. This model was used both to generate new motion based on user keyframes and to edit existing motion.

3 Proposed solution

3.1 Description of the subject

Before we describe the proposed solution or details of its implementation, we will recapitulate what kind of problem is solved and which are the aims and requirements for the final solution. The aim of the work is to study the Motion Graph structure described in several scientific papers and the implementation of the structure into the modelling and animating open source tool Blender.

The 3D model animation or the XML file with required input animation data is supposed as the input data, respectively. The output results in the new animation of the 3D model with the key poses created from the input, however a different animation is created. In more details, a required structure is created from the input data and a new sequence of peaks is created by a graph walk, so the result is a new animation.

The aim of the thesis is as follows:

- to create a tool for the user to create the animations
- to create a realistic animation of articulated model by joining the suitable user settings and algorithmic constraints

On the other side, to transmission among different 3D models is not the aim of our thesis.

3.2 Suggested solution

Adequate solutions mentioned in the previous chapter are financially and algorithmically demanding and are almost unavailable to common users. That is why we decided to implement the Motion Graph structure that can serve as the instrument for creation of the varied animations for the disposal of the widest range of users. From this reason we decided to solve the problem in the form of script for the modelling and animating open source tool Blender, created in programming language Python.

Basic principle

The basic principle of the whole script will be the transmission of the pose of skeleton A to the identical skeleton B, see the figure 3.1. The way how to reach this transmission is to iterate the skeleton A by the individual bones and to assign the matrix of each bone in skeleton A to the bone in skeleton B in the same function from the hierarchy point of view. The basic aim after the pose transmission is to set the pose of skeleton B to the pose of skeleton A, as we can see in figure 3.2. We want to preserve only the pose, not the position in the scene coordinates.

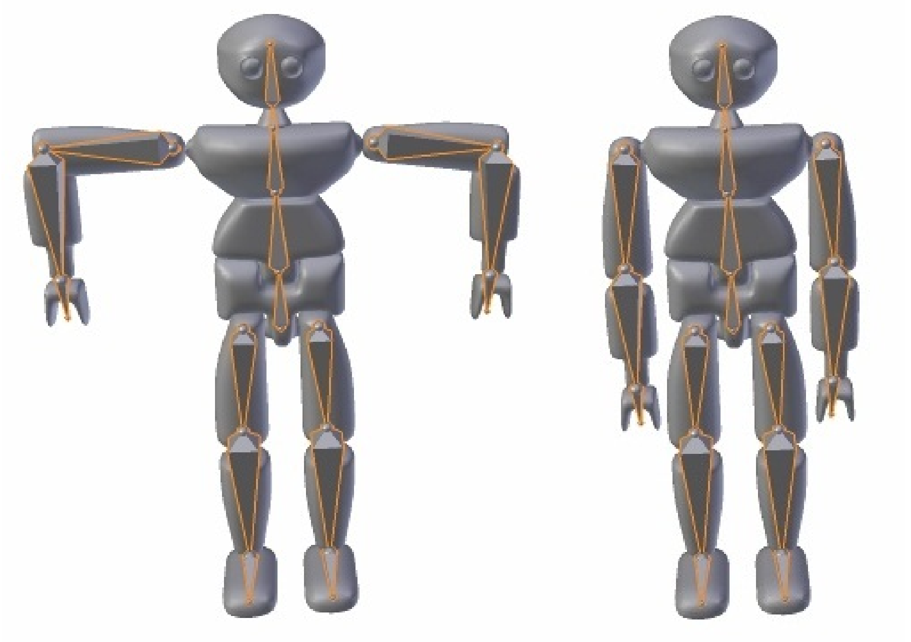


Figure 3.1: The skleton A on the left side, skeleton B in the rest pose on other side.

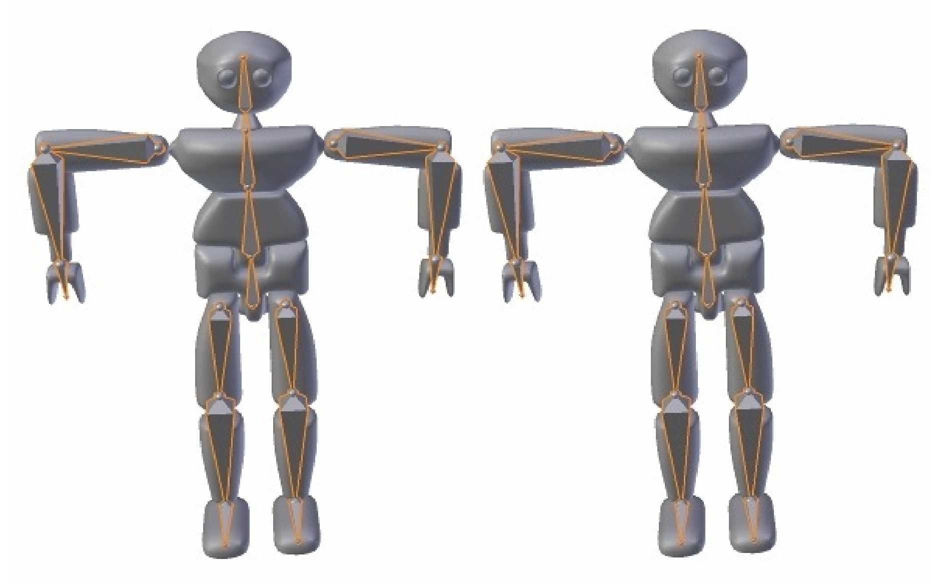


Figure 3.2: The skleton A and the skeleton B in the same pose.

Analysis of the input animation data

The analysis of the input animation data will be realised prior the structure creation itself, in order to extract the key poses of articulated model, which will be the basis in the creation of peaks in graph. Simultaneously with this analysis we will gain further important data on the animation scene as, for example, part of the active animation for the algorithm optimization.

Creation of Motion Graph structure

Owing to complete animation analysis we are able to create a graph represented by the incident matrix. We will consider the non-oriented graph with valued edges. Their value will determined by the difference of the key poses in the input data. The difference between poses will help us to create graph walks. We will keep in other list the pose of skeleton in certain key frame, which will be nothing else as the set of matrices. Every matrix will be assigned to the suitable bone.

Exporting of the structure Motion Graph into XML file

For application and usability of this solution we will implement the possibility of exporting the animation or structure into the XML file. This file will consist of the most important data for the repeated animation and structure creation. The XML file structure will be described in the following text.

Importing XML file

In this step we will import the initial animation. Parsing the input data is the step before creating structure. We expect XML file in a format which will be described in the next chapter.

Graph walk

After creation of Motion Graph structure, user will set constraints and starting and ending node. We will search for a best fit path between those two nodes. Implementation of search algorithm we will describe in next chapter. Algorithm output will be sequence of nodes.

Creation of the output animation

Animation will be created by the graph walk on the basis of the parameters determined by the user and determined sequence of vertices by graph walk algorithm. It is very important to choose a suitable sequence of peaks to gain the most faithful animation.

4 Solution

4.1 Application possibilities of Blender and Blender Python API

As our solution is implemented in the form of a script and is the part of the modelling and animating open source tool Blender and is created in the applied programme interface Blender Python API, it is reasonable to mention in this chapter which possibilities for the implementation the programme Blender provide us with. We will briefly describe the way how the mentioned elements work and what is the relationship among them like.

Armatures

The skeleton (called armature in Blender) consists of the bones, which are in the rest position. There is an access to the rest position of the skeleton in the Edit Mode of the Blender scene. The bones of armature in the rest position will be called as data bones.

The bones therefore form a hierarchy. The full transform of a child node is the product of its parent transform and its own transform. So moving a thigh bone will move the lower leg too. As the character is animated, the bones change their transformation over time, under the influence of some animation controller. A rig is generally composed of both forward kinematics and inverse kinematics parts that may interact with each other. Skeletal animation is referring to the forward kinematics part of the rig, where a complete set of bones configurations identifies a unique pose.

Pose

The pose defines changes and relationships in the skeleton in the object level. A corresponding pose channel is created for each bone in the skeleton. In the pose channel the translations, rotations and scaling of the bone are recorded with respect to the basic rest position of the skeleton. The pose of the skeleton is accessible via the Pose Mode of the skeleton in the scene. Its bones will be called the pose bones.

Action

The Action stores the Animation Curves (Ipos) for the PoseChannels and its Constraints. You can define an Action as the "Ipo bag", the collection of all animated changes you want to be applied to Poses.

Whether an "Action Channel" works on a specific Pose Channel is defined by the Action Channel name. Therefore an Action doesn't have to be directly derived from an Armature, it can have fewer channels and can potentially work on different Poses as well.

Typical Actions can be walkcycles, jumps, waving, grasping, and so on... and be combined (stacked/strung together) within the NLA editor. The NLA editor actually creates a 'working Pose', applies Actions to it, and blends that Pose with the actual Pose.

There is a possibility to choose one of three basic rotational representations for the rotations of every object, including skeletons and bones in them:

- Quaternions('QUATERNION')
- Euler angles('XYZ','XZY','YXZ','YZX','ZXY','ZYX')
- Rotation with the help of axis and angle(axis-angle representation(AXIS ANGLE))

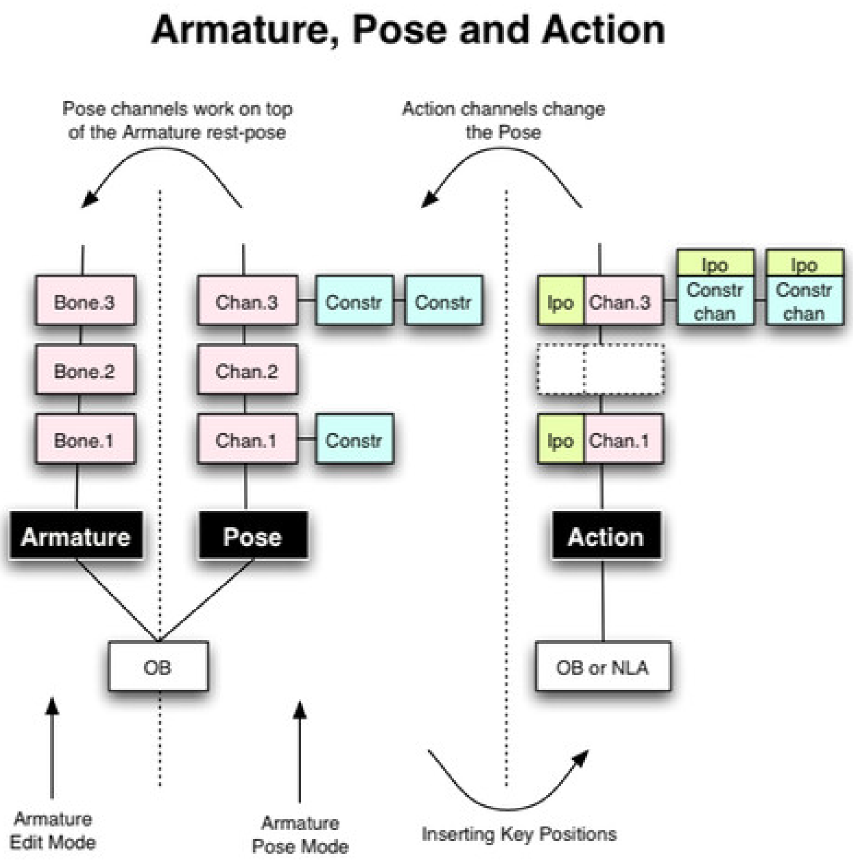


Figure 4.1: The relationship among the animation skeletons, poses and animation actions in Blender [ble12].

4.2 Implementation

The details of the implementation of the solution is described in this chapter. The methods we used and all relevant parts of their codes are mentioned. Several problems arising with the implementation and the decisions we have made to overcome these complications are discussed.

A scene with a mesh object to which an animation skeleton is bounded is the input for the script. The skeleton of the source object has assigned its own animation action with the data of the movement determined for the creation of the Motion Graph structure. To mark the object at first is necessary for the obvious assignment of the source of input data. It is supposed that the animation action will be created by the user itself or he will have a certain action already at the dispose.

4.2.1 Analysis of the input data

The first analysis of the movement source will take place prior the whatever change in the input model with assigned animation action. In the analysis all the key frames of the source animation action will be extracted and for the further run of the programme the following data will be saved:

- list of bones which contains the articulated model with their locations
- list of key frames
- detect active time line of 3D model in the current scene

```
def analyze_animation(source):

    #set of bone name
    bones_names = []
    for bone in source.pose.bones:
        bones_names.append(bone.name)
    print(bones_names)

    #set of bone location
    bones_location = []
    for bone in source.pose.bones:
        bones_location.insert(bones_names.index(bone.name),bone.location)
    print(bones_location)

    #animation frame range
    scn = bpy.context.scene
    frame_range = source.animation_data.action.frame_range
    print(frame_range)
    begin = frame_range[0]
    end = frame_range[1]
    # find key frames
    scn.frame_set(begin - 1)
    global key_frames
    key_frames = []
    key = -1
    before = -2
    while key != before:
           before = key
           bpy.ops.screen.keyframe_jump()
           key = scn.frame_current
           if key != before:
              key_frames.append(key)
    print(key_frames)
    bpy.ops.object.mode_set(mode='OBJECT')
```

4.2.2 Creating structure Motion Graph

The whole work follows from the Motion Graph structure and the createStruct method that creates the variables of the required size. The input parameters "rows" and "cols" are determined by the number of the input key frames. The structure is represented by the global variables with the help of incident matrix and the list, which contains the matrices of bones for each key frame. It is possible to imagine it as many dimensional array of floats.

```
def createStruct(rows,cols):
    global incident_matrix
    global pose_AtKeyFrame
    incident_matrix = [[1 for x in range(rows)] for x in range(rows)]
    print(incident_matrix)
    pose_AtKeyFrame = [[0 for i in range(cols)] for j in range(rows)]
    print (pose_AtKeyFrame)
```

This method is called during the parsing of the input XML file. The structure of required size will be created by the help of createStruct method. In the next step of parsing the structure will be filled in by input data in XML file.

4.2.3 Structure of the XML file

In this we will describe proposed structure of the XML file. As the root tag is ”frames” set. This tag has to properties, armature’s count of bones and number of key frames. An example you can see below:

```
<?xml version="1.0"?>
<!--3D model bones-->
<frames count_bones="2" count="3">
<frame id_keyframe="0">
<frame id_keyframe="1">
<frame id_keyframe="2">
</frames>
```

This root tag is consisted from a tag named ”frame”. It has only one property, it is used for identification of given key frame. In this tag we store data of armature in some pose, it mean matrix for every bones of armature. Example of the structure:

```
<frame id_keyframe="0">
<bone id_keyframe="0" id_bone="0">
<bone id_keyframe="0" id_bone="1">
</frame>
```

The last we had to define is named ”bone”. It has two properties, identifier of the key frames and identifier of the bone in armature to which is assigned a matrix stored in this tag. See example:

```
<bone id_keyframe="0" id_bone="1">
0,0,0,0,0,0,0,0,0
</bone>
```

4.2.4 ParseXML - Import XML file

In this part we will describe method which creates structure Motion Graph from XML file. For parsing we use XML dom.minidom library [pyt12b]. It helps as to divide the file in to tags, then by iterating to extract further data and rebuild Motion Graph structure.

```
def parseXML(file_path):
    global pose_AtKeyFrame

    #open the xml file for reading:
    file = open( file_path,'r')
    #convert to string:
    data = file.read()
    #close file because we dont need it anymore:
    file.close()
    #parse the xml you got from the file
    dom = parseString(data)
    element_node_list = dom.getElementsByTagName("frames")
    element_n = element_node_list[0]
    count_keyframes = int(element_n.attributes["count"].value)
    count_bones = int(element_n.attributes["count_bones"].value)
    createStruct(count_keyframes,count_bones)
    element_node_list = dom.getElementsByTagName("bone")
    for i in range(0,element_node_list.length):
         element_n = element_node_list[i]
         id_keyframe = int(element_n.attributes["id_keyframe"].value)
         id_bone = int(element_n.attributes["id_bone"].value)
         data = element_n.firstChild.data
         kf = []
         array = data.rsplit(',')
         for x in array:
            x = float(x)
            kf.append(x)
         newMat = Matrix(((kf[0], kf[1], kf[2], kf[3]),
                 (kf[4],kf[5],kf[6], kf[7]),
                 (kf[8], kf[9], kf[10], kf[11]) ,
                 (kf[12], kf[13], kf[14], kf[15])))
         pose_AtKeyFrame[id_keyframe][id_bone] = newMat
         print("#---BONE---#")
         print (id_keyframe)
         print (id_bone)
         print (newMat)
```

4.2.5 CreateXML - Export structure to XML file

This method provide us opportunity to create some animation using Motion Graph structure and export it to XML file for next work. We fill in the structure of XML file from the structure, in case of only exporting animation, on the back we create a structure for easier implementation.

```
def createXML(path):
    global key_frames
    global pose_AtKeyFrame
    doc = minidom.Document()

    doc.appendChild(doc.createComment("3D model bones"))

    frames = doc.createElement('frames')
    frames.setAttribute("count",str(len(key_frames)))
    frames.setAttribute("count_bones",str(len(bpy.data.objects[0].pose.bones)))

    doc.appendChild(frames)
    for j in range(0,len(key_frames)):
        name = "frame"
        fr = doc.createElement(name)
        fr.setAttribute("id_keyframe", str(j))
        frames.appendChild(fr)
        for i in range(0,len(pose_AtKeyFrame[j])):
           name = "bone"
           obj = doc.createElement(name)
           obj.setAttribute("id_bone", str(i))
           obj.setAttribute("id_keyframe", str(j))
           data = matrixToString(pose_AtKeyFrame[j][i])
           obj.appendChild(doc.createTextNode(data))
           fr.appendChild(obj)

    print (doc.toprettyxml(indent = '   '))
    file = open(path, 'w')
    file.write(doc.toxml())
```

4.2.6 Graph walk - Dijkstra's algorithm

After the creation of structure, we are getting to the core of our thesis. As we have mentioned before, the graph structure is represented by incident matrix. The next step is the evaluation of the edges between the individual peaks. In this step we had to make a decision, how to implement the evaluation function of the edges. The approach we have chosen is straight-lined. The values of edges are in direct dependence upon distinctions of two vertices, it means, difference between the poses stored in each vertex. For example, if two poses are quite similar, the value of the edge is near zero and on the other hand in case of two various poses the edge value is increasing up to number of bones in armature. This is very useful, because we want to find such a path in graph between two vertices, in which there are not great differences(edge values) between individual adjacent vertices. That is the same problem like to find the lowest cost path between two peaks.

Two poses are compared in such a way, that we take bone matrix from one pose, a bone matrix from another pose and we make a difference between every two adequate elements of matrices. If the difference is smaller than a chosen threshold, we continue in computing. Otherwise we return the response, that the given matrices are not similar enough. The edge value consists of value of a count of various matrices between two poses of the adequate bones.

```
def compare_pose(pose1_id, pose2_id, treshold):
    global bones_names
    global pose_AtKeyFrame
    value = 0
    pose1 = pose_AtKeyFrame[pose1_id]
    pose2 = pose_AtKeyFrame[pose2_id]
    for i in range(0,len(pose1)):
          matrix1 = pose1[i].to_3x3()
          matrix2 = pose2[i].to_3x3()
          if not compare_matrices(matrix1, matrix2, treshold):
             value = value + 1
    return value
```

After the edge assessment we can continue with graph walk. The user is asked to determine the starting and the end peak and the required threshold value. It enables to remove the edge that joins two different poses so the edge is of a greater value than the threshold.

With this setting a guaranty will be achieved, that transitions among the poses(vertices) will be chosen with lower difference. This sequence of steps will lead to the smoother animation. For the reason of better implementation we create the representation by the field of neighbours from the adjacent matrix. In this new field there are added edges with lower value than the threshold value. After the graph walk this structure is deleted. Thanks to this copy, we do not have to calculate the deleted edge, which do not fulfil the threshold rule.

At first, we verify if two chosen vertices are in the same component and so it has a sense to compute the lowest cost path between them. For this purpose we use depth-first search. If they are not located in one component, a warning is given to the Toggle Console. In another case, an algorithm for searching of the lowest cost path between these two vertices will be run. For solving of this problem the Dijstra's algorithm is used. It is described in detail in chapter 1. Our implementation follows, as we do not need to compute the distances from the starting node to all in the graph, but only to single given node.

```
def djistra(graph,start,end,visited=[],distances={},predecessors={}):
```

```
global bignum
    if start==end:
        path=[]
        while end != None:
            path.append(end)
            end=predecessors.get(end,None)
        return distances[start], path[::-1]
    if not visited: distances[start]=0
    for neighbor in graph[start]:
        if neighbor not in visited:
            neighbordist = distances.get(neighbor,bignum)
            tentativedist = distances[start] + graph[start][neighbor]
            if tentativedist < neighbordist:
                distances[neighbor] = tentativedist
                predecessors[neighbor]=start
    visited.append(start)
    unvisiteds = dict((k, distances.get(k,bignum))
      for k in graph if k not in visited)
    closestnode = min(unvisiteds, key=unvisiteds.get)
    return djistra(graph,closestnode,end,visited,distances,predecessors)
```

After the gaining of the lowest cost path the sequence of nodes will be stored for further usage in creation of resulting animation described in the following text.

4.2.7 Creating new animation

In this part we describe creating of output, a new animation. As a input parameter we gain a sequence of nodes, computed by Djistra's algorithm. On the user instruction we start computing.

Several important methods which we use in the animation creation are described in the following text.

```
def animate(target, key_frames):
    global pose_frame
    global next_frame
    global frame_dist
    global start_frame
    bpy.ops.object.mode_set(mode='POSE')
    for bone in target.bones:
        bone.select = True
    scn = bpy.context.scene
    scn.frame_start = 1
    scn.frame_end = 100
    before = 0
    for f in key_frames:
        print(pose_frame)
        scn.frame_set(start_frame+next_frame)
        ret_source(target,f)
        bpy.ops.anim.keyframe_insert_menu(type='LocRot')
        next_frame = next_frame + frame_dist

    bpy.ops.screen.animation_play()
```

This method gets parameters as target armature and set of the key frames. In software Blender it is very important in which mode the scene is set. From this mode set depends the set of possibilities that we can execute. The choosing of the Pose Mode is also important because in this mode we can work with the skeleton pose, it means to change the position of simple bones. The further logic step is the need to mark each bone of the skeleton in order to determine what we would like to work with in the scene. The cycle in which we will iterate each key frame from the input set consisting of key frames will follow. The pose of skeleton in each key frame will be applied at first on the selected set of bones and then the new key frame will be inserted in the scene. After this operation the created animation will be run in preview, it means, the frames between two key frames will be by linear interpolation software Blender computed.

The next function will be described that directly applies the data from the poses of each bone from a certain peak in the graph to the skeleton in the scene. This function is the base of the script.

```
def ret_source(target,frame):
    bpy.ops.object.mode_set(mode='POSE')
    size = 0
    for bone in target.pose.bones:
        bone.matrix = pose_AtKeyFrame[frame][size]
        size +=1
```

In this function the matrices of each bone are directly assigned to its image in target skeleton. This process will guarantee that the skeleton in the scene will gain the pose that is saved in the given peak. It means, that key pose from the input animation, stored in the certain peak in graph, is applied to given skeleton in the scene.

4.2.8 User interface

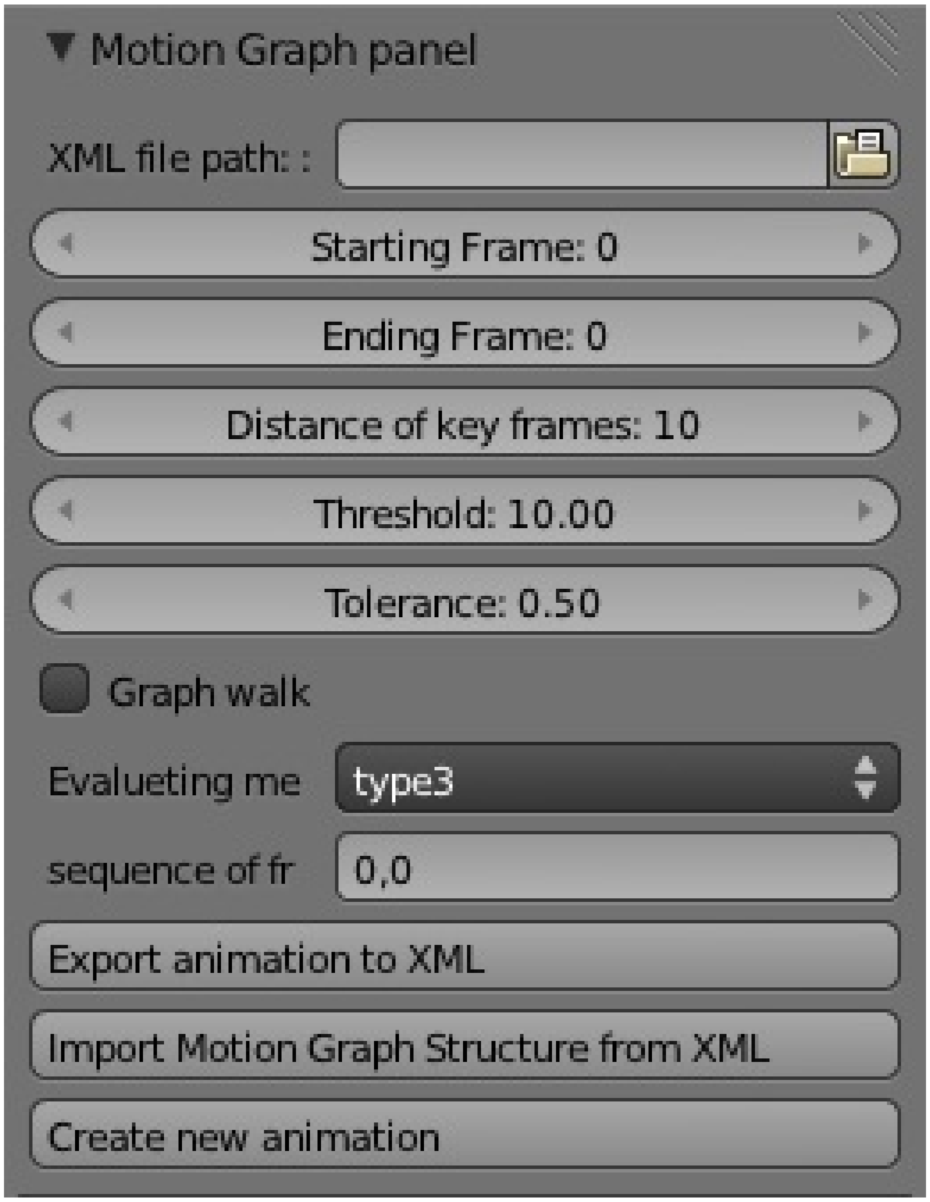
In order to control simply the creation of the animations with the help of the Motion Graph structure we have added a special panel implemented in Blender GUI. The user can choose by marking the target object, the path to XML file for loading of the structure in case of need and a lot of further settings. After setting of the required parameters in dependence upon the situation the user has a possibility to push the buttons according to the given situation and to export the structure to XML file, to import the structure from XML file or to run the creation of a new animation in dependence of the given parameters and sequence of key frames.

The example how the defined button and its method execute will be performed after the pushing of the button is as follows:

```
class OBJECT_OT_Input_Button(bpy.types.Operator):
    bl_idname = "input.animation"
    bl_label = "Export animation to XML"

    def execute(self, context):
      global key_frames
```

```
scn = context.scene
bpy.ops.wm.console_toggle()
bpy.ops.object.mode_set(mode='OBJECT')
# choose selected object in the scene
name_of_selected_object = bpy.context.active_object.name
armature = bpy.data.objects[name_of_selected_object]
analyze_animation(armature)
createStructure(armature)
createXML()
return{'FINISHED'}
```


▼ Motion Graph panel

XML file path: :

Starting Frame: 0

Ending Frame: 0

Distance of key frames: 10

Threshold: 10.00

Tolerance: 0.50

Graph walk

Evalueting me type3

sequence of fr 0,0

Export animation to XML

Import Motion Graph Structure from XML

Create new animation

Figure 4.2: Control panel in Blender

5 Results

These chapter is dedicated to the results of our solving of the implementation structure Motion Graph into the modelling and animating tool Blender. We will describe the usage and controlling of the script and also we will present the samples of generated animations from the structure.

5.1 Controlling

As first, is needed to do some changes on 3D model settings. The thing we have to change is the settings of bones. Change your mode to edit mode. For each bone, select it, in right panel in Blender, choose the bookmark "Bone" and deselect the box Inherit Rotation and select Connected(in case this bone should be connected to the parent bone).

After the script is installed or run a possibility to work with the structure Motion graph is gained from the text editor integrated in the Blender.

In this moment there is a possibility to choose (select) one from three actions:

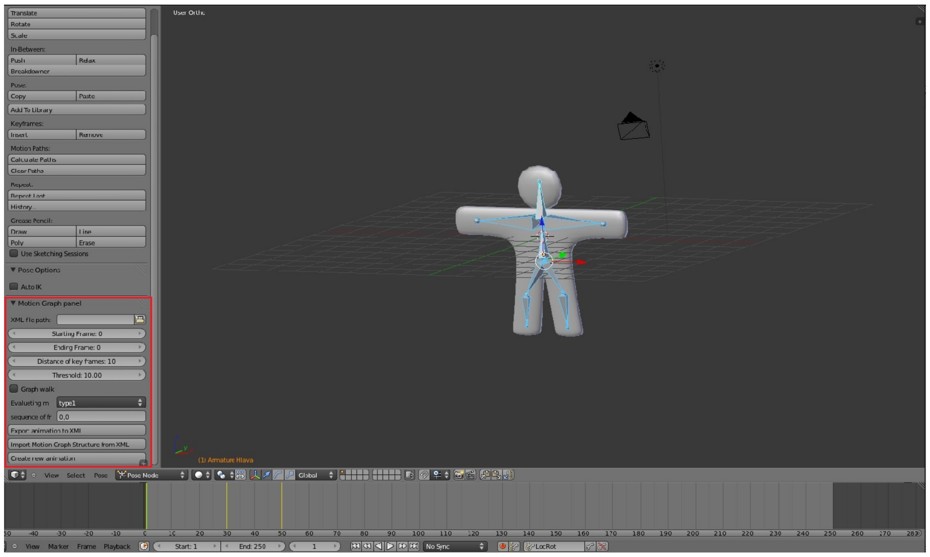
1 – a structure from the XML file can be imported

2 – an animation into XML file can be exported

3 – a new animation with the help of the structure Motion Graph can be created.

When using it the blender console is required to be open. This can be found in the item Help –Toggle Console. In this window the relevant (potential) warnings occur during the work with our script.

When the Motion Graph structure is already created, there are two possible ways how to create a new animation. The first way is to mark a Boolean Graph walk. With this option (set-up, setting, positioning) it is obligatory to set the Starting Key Frame and Ending Key Frame. A number of the Key Frame is its index and the numbering starts from 0. In the lower part of the scene there is a timeline, where the user can easily find out (recognize, determine) from which key frame he would like to start the walk and in which key frame to finish it. With this selection the setting of the Threshold value is very important. This value will remove (eliminate) the edges with higher value in comparison with the given value. After stroking Create new animation a lowest cost path between two given vertices will be found in the graph by our script. In case the Graph walk is not stroked (marked), the user has a possibility to simply insert id of the individual (separate) key frames into the field sequence of frames. In this case the lowest cost path will not be found, but the interpolation between the given peaks is used. For each of these two possibilities it is possible to choose an additional setting of a key frame distance in the resulting animation.



Starting Frame: 0
Ending Frame: 0
Distance of key frames: 10
Threshold: 10.00
Evaluating m: type1
sequence of fr: 0,0

Figure 5.1: Part of the Blender scene using our script.

5.2 Review of chosen results

When testing our solution a 3D model of humanoid armature was used. Naturally our solution is implemented in such a way, that it could be for any 3D model with a bound armature. In the figure 5.2 the poses extracted from the initial animation are presented. They are numbered in order to make it more transparent. The results of our graph walk algorithm between two peaks selected by the user are demonstrated. In some cases the animation is the same in both cases (examples, situations) because the selected two poses were similar and so the lowest cost path was directed via the edges between them. For these two approaches(graph walk and basic interpolation) we tried to select the examples with two non-identical animations. Perhaps the results would be more attractive if the armature animation with a really great number of the key frames had been at the disposal. However, our animation is satisfying (suitable, convenient) to demonstrate the functionality of the solution, too.

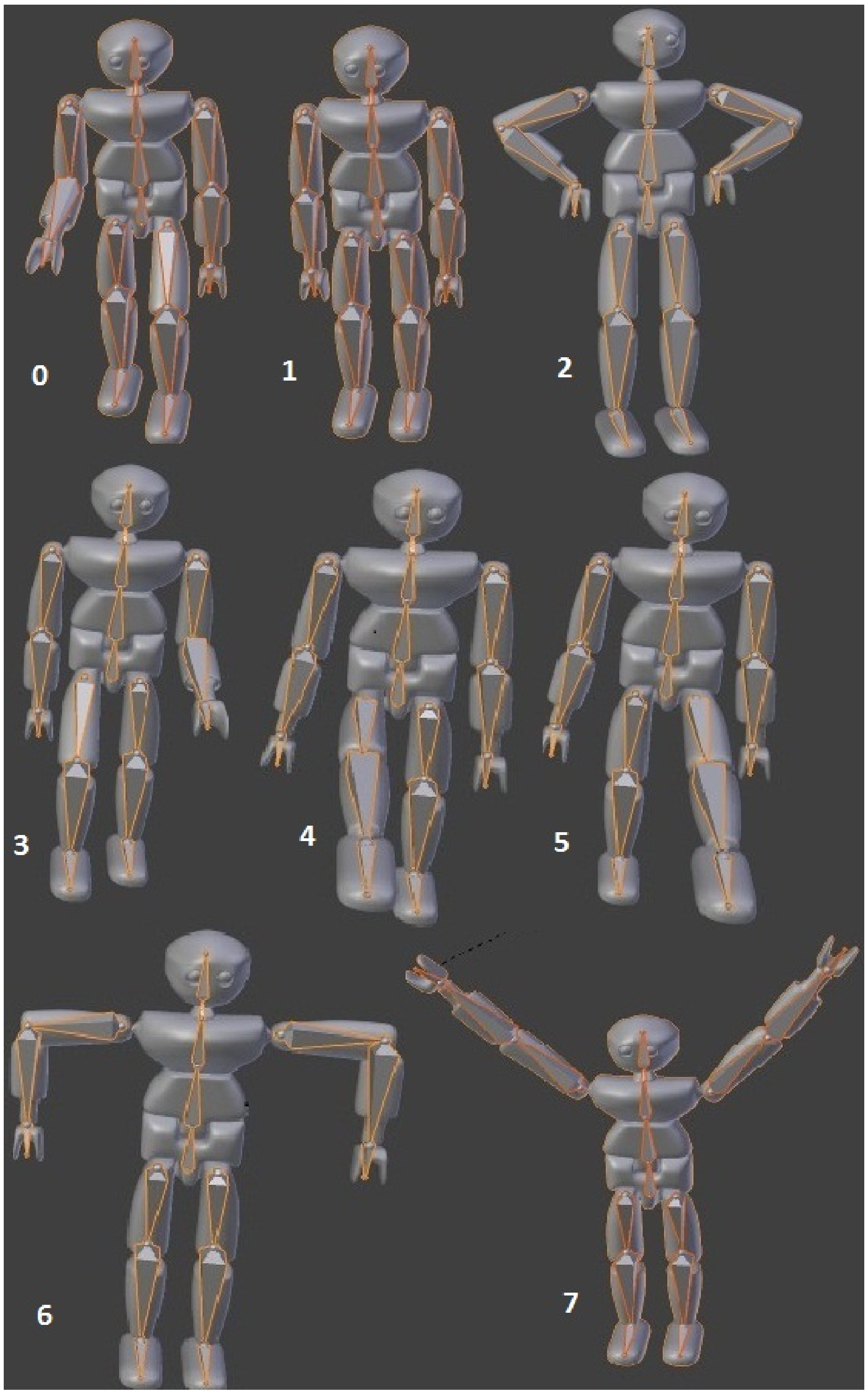


Figure 5.2: Extracted key poses from input animation.

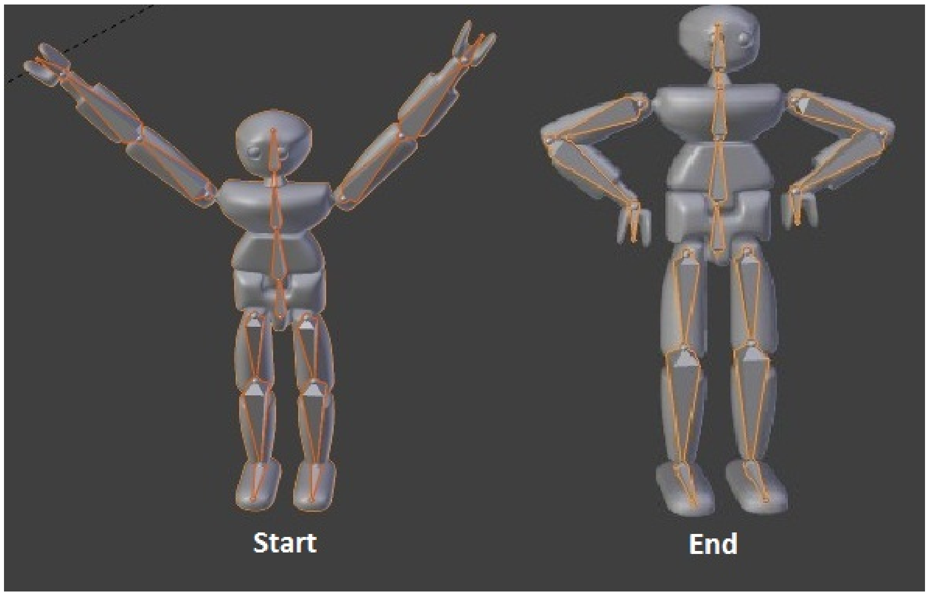


Figure 5.3: Example 1- we set starting and ending pose.

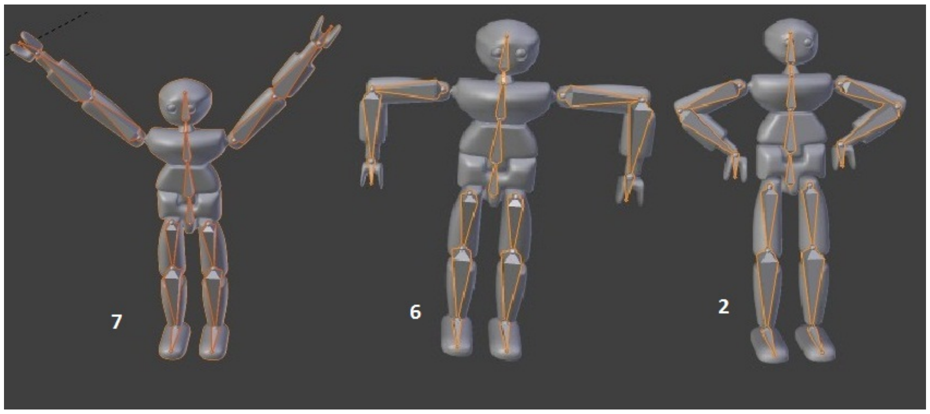


Figure 5.4: Example 1- generated path by graph walk.

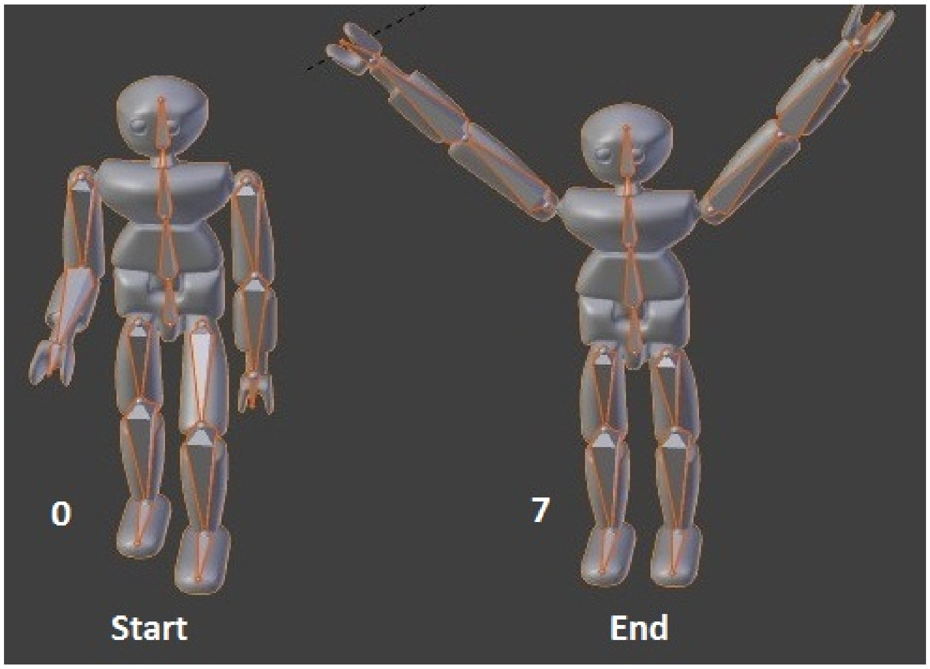


Figure 5.5: Example 2- we set starting and ending pose.

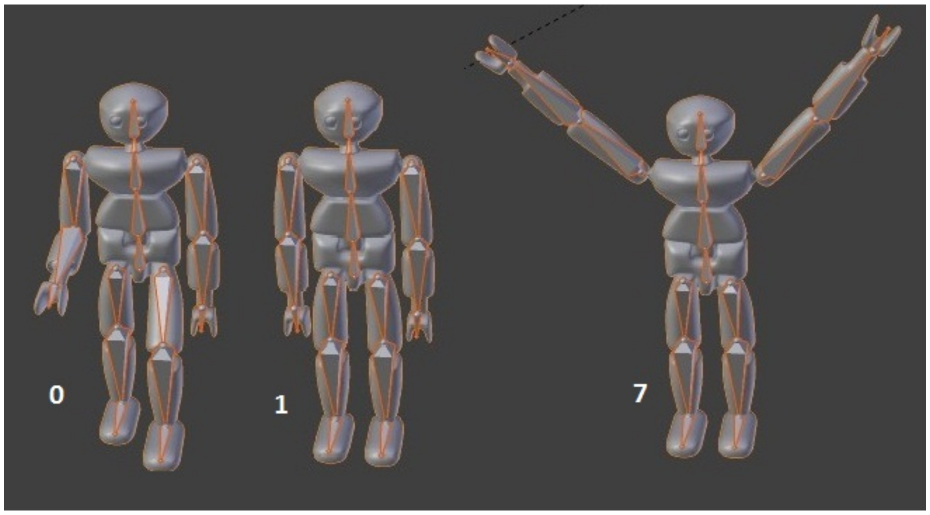


Figure 5.6: Example 2- generated path by graph walk.

Conclusion

In our thesis we were dealing with the implementation of the structure motion graph that serves as a tool for generating the new original animations. To study a given structure and to implement it later into the modeling and animating tool Blender was the main aim of this thesis.

In Chapter 1 several basic terms were introduced, the knowledge of which is necessary to understand this thesis. First of all we tried to understand the graph theory. In Chapter 2 we were discussing the motivation of this work and why is it so interesting to solve a given issue. The already published related works have been mentioned, too. In the next chapter the issue that is discussed was resumed and a suggested solution was described. In Chapter 4 a precise implementation of solution was described, especially the usage of the algorithm on the graph structure.

Solution in the form of a script in the modelling and animating tool Blender was implemented. It is assumed that a wide range of the users could exploit (use) it.

Now it is suitable to summarize the results of our thesis and its possible benefits. With our solution the implementation of the extracted key frames from the animation was successful. The next step was the creation of the motion graph structure. A decision followed on how to compare the individual key poses and the evaluation function was implemented. Finally the algorithm proposal for finding the most suitable path between two chosen vertices was realized.

These results are satisfying, but it will be very interesting to deal with the following issues in the future. It would be suitable to deal with the task how to compare two poses in a more effective way, how to decide whether two poses are similar enough, i. e. to create a satisfactory animation by the interpolation of their data. Second interesting task for improving results is the optimalization of the graph walk algorithm to get smoother animations .

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