Review Research Paper : Automatic rigging and skinning in Computer Animation

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Introduction:

The standard 3D animation pipeline consists of creating a scene by building the 3D models of the characters, rigging the characters by assigning the joints and creating the skeleton structure, assigning skin weights to deform the character and finally setting keyframes on different poses of the character to create continuous motion at the given frame rate. The rigging process requires an immense amount of time and skill from the animator and is tedious. To overcome the drawbacks of current methods, extensive research has been conducted to make the process of rigging and assigning skin weights automatic. In this paper, I intend to discuss some of the best techniques, their methodologies, accuracy of the results and some limitations which give direction for future work.

Abstract 1:

Baran, I., & Popović, J. (2007). Automatic rigging and animation of 3d characters. *ACM Transactions on graphics (TOG)*, *26*(3), 72.

Problem Statement:

To animate a 3D character, we need to perform manual rigging of the mesh and assign a skeletal structure. This process is tedious, time consuming and requires years to master. This makes rigging and animation difficult. The goal of this paper is to introduce a system that perform automatic rigging with sufficient accuracy in a short amount of time.

Procedures followed:

The ‘Pinocchio’ system introduced here takes as input a static character mesh and a generic skeleton and outputs a mesh with attached skeleton ready for animation. The algorithm used for auto-rigging consists of 2 main steps:

1. skeleton embedding:

It computes the joint positions of the skeleton. A maximum-margin method is used to learn the weights and an A* like heuristic approach is used to search for an optimal skeleton embedding. The given skeleton is resized and positioned to fit inside the character. In the following step, a graph is constructed by packing spheres centered on the medial surface (where spheres are the vertices representing joint positions) and their centers are connected with edges (representing bone segments). The next step is to find the optimal embedding of the skeleton into this graph while considering a penalty function which penalizes short bones, improper orientation between joints, length differences in bones marked symmetric, bone chains sharing vertices,etc.

2. Skin attachment:

It assigns bone weights based on the distance of the bones to the character’s surface. The LBS (Linear Blend Skinning) method is used because of its widespread use. The aim is to find the weight w^i for each vertex to find out how much each bone transform affects each vertex. Independence to mesh resolution, smooth variation across the surface and low artifacts are some of the qualities of good weighting. Heat equilibrium technique is used by considering the characters volume as an insulated heat conducting body. The temperature of bone ‘i’ is forced to be 1 and the rest of the body is at 0. Finally we find the equilibrium temperature at each vertex as the weight of bone ‘i’ at that vertex.

Results and future work:

The system is designed and evaluated based on the 3 criteria of generality (applicability of a single skeleton to a variety of characters), quality (rig quality comparable to that of characters in video games) and performance. The system gives 81% accuracy with 13/16 well rigged meshes and 3 requiring only small tweaking. Pinocchio is unaware of materials and gives a rubbery effect for a dress and knight’s armor.The system performs the rigging in under 1 minute for low poly models on a 1.73 MHz Intel Core 2 Duo with 1GB of RAM.The system can be improved by using ellipsoids instead of spheres for discretization, using a different skinning technique and removing certain assumptions. In the future, the system can be adapted to rig character hands and faces with little human intervention.

Abstract 2:

Borosán, P., Jin, M., DeCarlo, D., Gingold, Y., & Nealen, A. (2012). Rigmesh: automatic rigging for part-based shape modeling and deformation. *ACM Transactions on Graphics (TOG)*, *31*(6), 198.

Problem Statement:

Animators often need to remodel a character after it is first created and rigged. In this case, the model needs to be re-rigged to accomodate for the new changes. This is a long and tedious process and this paper tries to solve the problem by creating algorithms that allow incremental updates, unifies modeling and rigging and updates a rig in real time.

Procedures followed:

The RigMesh system consists of the following components:

1. Initial shape creation:

The user sketches the silhouette of the new shape to be created. From this, the system generates a surface consisting of cylinders, skeleton and skin weights that bind the surface to the skeleton. The closed polygon uses Chordal Axis Transform (CAT) to generate the axis and Constrained Delaunay Triangulation (CDT) to create the junction triangles. The junction triangles form the connecting region and the remainder of the polygon is the cylindrical region which then becomes the generalized cylinders. Finally, the entire mesh is smoothened using Least-squares Meshes technique. The chordal axis is then converted into the skeleton consisting of joints and bones using the Douglas-Peucker algorithm in a greedy manner. Further, the skin weights are calculated using the heat diffusion method from Pinocchio.

2. Modeling Tools:

Cutting (sharp and smooth) and merging are the two operations supported by the system. The deformed surface is computed using dual quaternion skinning. *Snapping merge* joins the two joints, *splitting merge* adds a new joint in the given location and *connecting merge* inserts a new bone in the skeleton. A new *watertight* surface is created when merging takes place. The skin weights are then computed locally as global recomputation takes longer time.

Results and future work:

Complex shape creation, on-the-fly modeling and real time re-rigging can be done using this system. The concept of modeling by parts allows re-use and collaboration among multiple users. The system is implemented in C++ with 2.8 GHz Intel i7 in Windows and uses OpenMesh for mesh processing. The system empowers artists who begin modeling without a specific goal in mind. The system is accessible to novices for rapid prototyping and base mesh creation. The implementation supports exporting data into the industry-standard FBX format. The system falls short when for an input sketch without an obvious geometry, it does not generate a desirable shape. The local skin weight computation can lead to incorrect weight assignment in some cases. In the future, instead of using IK, the system can use semantics of the model's parts. The greatest scope is in including animation in the pipeline so that the changes in modeling and rigging are immediately reflected in the animation sequences.

Abstract 3:

Miller, C., Arikan, O., & Fussell, D. (2010, February). Frankenrigs: building character rigs from multiple sources. In *Proceedings of the 2010 ACM SIGGRAPH symposium on Interactive 3D Graphics and Games* (pp. 31-38). ACM.

Problem Statement:

High quality rigging and skinning takes a large amount of time and effort from the animator and painting bone influences is difficult and unintuitive. The solution can be to use a database of pre-existing rigs and apply them to new targets using a correspondence-driven transfer process and reconstructing the skinning information.

Procedures followed:

The system generates a database of partially rigged sources and scans through it to fit the appropriate parts to the target mesh with tags and locations for important joints. The optimal fit is assembled to form a new skeleton for the target mesh. Next, the skinning information is transferred by a correspondence method by solving a velocity matching problem. The remaining skinning information is filled by diffusing the correspondence transfer results over the mesh surface. The steps are as follows:

1. Database construction: It consists entirely of bipeds and the user identifies a set of seam joints to determine how the input rigs are split into body parts. Thus, each source rig has 5 body parts: a torso, two arms and two legs.

2. Part fitting and selection: A multi-step fitting procedure is applied which squashes and stretches the rig to fit the target mesh as closely as possible. This is achieved using Iterative Closest Point (ICP) matching. The user can override and select whichever rig they like but the best ranked fit is chosen by default.

3. Skin transfer: The source rig is attached to the target at the seam joints. If there is conflict between two parts, then an average is taken. The two phase skin transfer begins by setting correspondences between the source and target mesh which lead to a system of equations that try to mimic the behavior of the target to the behavior of the source rig. Solving the equations reconstructs the skinning information and the rest of the region is filled by diffusing the results over the surface. Skinning can be done using automatic, semi-automatic or manual methods.

Results and future work:

The database consists of 70 partial source rigs from 14 character rigs that were rigged by artists. Rig information was removed and the same characters were used for testing, but the original partial rigs were never used for the same character. Database scan takes about 10 seconds for a newly loaded rig and all skinning is done in a fraction of a second on a 2.2 GHz Intel Core 2 Duo laptop. The results obtained match or exceed Maya’s smooth bind feature. If the rig is not good, the data can be exported and used in another editing software. The limitations are that the system is dependent on the quality of the database. Further, skin transfers will be good only as long as the correspondences are good. Undersampling can also take place. Improvement can be achieved by transferring rigging information that contains the skeleton, controls, IK and FK handles, deformers, collision volumes, etc.

Abstract 4:

Dionne, O., & de Lasa, M. (2013, July). Geodesic voxel binding for production character meshes. In *Proceedings of the 12th ACM SIGGRAPH/Eurographics Symposium on Computer Animation* (pp. 173-180). ACM.

Problem Statement:

Painting skin weights in unintuitive and requires the skeleton to be in a rest position (T-stance) when the weights are assigned and the impact is not immediately clear. The research proposes the use of a fully automatic technique for specifying the influence weights for closed-form skinning methods and can overcome artifacts seen in LBS and DQS techniques.

Procedures followed:

The given system first voxelizes the input geometry and calculates the binding weights based on the geodesic distance between each voxel lying on the skeleton bone and the non-exterior voxels. Weights can be modified interactively without additional processing as the weight assignment is decoupled from the distance computation. The steps are as follows:

1. Voxelization: A z-buffer slicing approach classifies a voxel as internal (1) or external (0). First, the bounding box for the geometry is obtained and the near planes are moved at intervals while keeping the far planes fixed. White, red and blue colors are used to represent skeleton, interior and boundary voxels. Finally, the mesh boundary voxels are extracted using an octree from the mesh using Akenine-Moller's separating axis theorem.

2. Distance computation: A modification of Dijkstra's algorithm is used to compute the distance between the voxels lying on the bone and the boundary voxels. This operation is optimized by distributing the calculation of geodesic distances for each bone to multiple cores.

3. Weight computation: The distance value d_j^i is used to compute a weight influence w_j^i of bone 'i' on a vertex 'j' and a parameter α which ranges from [0,1] is used to control the bind smoothness.

Results and future work:

The algorithm was tested on meshes with artifacts such as intersecting triangles, multiple disjoint parts, non-watertight meshes and meshes with non-manifold edges/vertices. Skeletons were manually created for each mesh and no post processing or clean-up was performed. Characters were skinned with LBS with α = 0.7. All the characters were animated using a small library of motion clips retargeted using Autodesk Maya HumanIK to account for differences in skeletal proportions to test the skinning quality. Also, limiting number of influences did not have a large impact on the quality of skinning. The algorithm was run on 11 meshes and computations were performed on a MacBook Pro 2.2 GHz Intel Core i7 with 8Gb of RAM and AMD Radeon HD 6750M 1024 MB graphics card. The performance of the method depends on voxelization resolution (256 X 256 X 128 in x, y and z direction) and affects models with A-stance pose. The voxel resolution can be increased to account for additional details. The future work is to generate a sparse voxelization with additional details near the smaller features. The voxelization algorithm can also be used in applications such as collision detection, CSG modeling, fluid simulation, model simplification or skeleton extraction.

Abstract 5:

Feng, A., Casas, D., & Shapiro, A. (2015, November). Avatar reshaping and automatic rigging using a deformable model. In *Proceedings of the 8th ACM SIGGRAPH Conference on Motion in Games* (pp. 57-64). ACM.

Problem Statement:

Photogrammetry methods that use RGB/RGB-D cameras enable the easy generation of 3D meshes of human figures. The research proposes the use of a rig created by a professional 3D rigger to automatically rig these human models to be used in applications such as fitness, body image, plastic surgery, avatar enhancement, etc.

Procedures followed:

The system enables the user to resize and reshape an input body scan according to the required proportions and automatically rig it into skinned virtual characters to be animated in a virtual environment. Automatic rig information transfer and interactive reshaping of the avatar are the two main capabilities of the system. It begins by using SCAPE (Shape Completion and Animation of People) to build a morphable human model from a 3D human model database. The steps consist of:

1. Morphable model fitting:

The template mesh is defined as X = {V, P, B}, where |V| = vertices, |P| = triangles and |B| = joints. The low-dimensional shape space is obtained using Principal Component Analysis (PCA) method and the template is mapped to the target to transfer the rigging correspondences. The system solves a non-linear equation using a Ceres solver to estimate the body shape and pose.

2. 3D Avatar reshaping and automatic rigging:

The new skeleton is computed by transferring mean-value coordinates from the template. Harmonic interpolation provides a better accuracy than barycentric coordinates when performing vertex projection as they avoid non-smooth skin weighting and problematic skin deformations. Skin weights wz_i thus obtained are both smooth and true to the original skin weights. The remaining skin weights are calculated using the Laplace equation (Lh = 0) subject to boundary conditions for all correspondence pairs, where L is the Laplace-Beltrami operator matrix and h is the resulting harmonic fields.

Results and future work:

The rigging quality is highly dependent on the correspondence accuracy and the original rigging quality. SCAPE is used to find good correspondences to the input scan. In one minute, the system processes a 3D scan of approximately 100,000 vertices on an Intel i7 3.3GHz CPU. Compared to the Pinocchio, this system produces superior rigging results with less artifacts and distortions.The human model database is parameterized by measuring the distances between various attributes. Models consisting of excessive clothing may lead to inaccurate model fitting. The system is not suitable for rigging cartoon characters and is limited only to models having shapes similar to the humans. The future work would be to extend the process to accommodate the body shape space of various cartoon characters.

Study of Studies

Common features:

The papers on automatic rigging and skinning focus on reducing the time and effort required in rigging a 3D model while working on the animation pipeline. The seminal work in this field is done by Ilya Baran and Jovan Popovic in their Pinocchio system. The method of skinning and calculating weights using heat transfer techniques is used in several other papers such as RigMesh and Frankenrigs. The auto-rigging technique is referred in both the voxel based and the correspondence method. Papers 1 and 2 are focused on making rigging accessible and easy to use for novices and beginners. The papers also have an option for manual intervention for the cases when the system fails or provides poor results. The Pinocchio system is used as a standard to compare the quality of results from rigging and skin weighting in most of the papers. The discussed papers use several of the machine learning and AI techniques such a maximum-margin method, A* search, support vector machines, supervised learning, PCA analysis, etc. Laplace equation, ICP are some of the algorithms that are encountered often. Real time updation of rigging and skinning information is performed by some systems.

Limitations:

Some systems use databases of source rigs to transfer the skeletal information to the target rigs which leads to some limitations. The system is only as good as the quality of source database. Also, it limits to the variety of characters that can be rigged automatically. Further, the models need to have approximately the same size, shape and pose/orientation to produce accurate results. The auto-rigging techniques are only limited to large models and do not consider detailed body parts such as hands, face and feet. Rigging them accurately stills requires a large amount of time and effort.

Improvements:

The systems can make use of parallel processing and multicore systems to perform the computations faster and in real time. Also, advanced techniques such as neural networks and deep learning can be used to learn newer models that can fit cartoon like characters. Most of the commodity hardware is significantly updated and the computations must consider optimizations provided to maximize the use of resources. Further, most systems use Linear Blend Skinning because of its widespread use, but the accuracy of the system must be tested for skinning techniques like dual quaternion skinning which is explored in only one paper.

Unexplored domains:

Automatic rigging based on live video input can be made possible using computer vision. The system can extract the patterns of body movement and deformations based on object detection and use this information to generate skeletons and weights for uncommon objects. This can generate a large amount of database that can be updated to add more models. Also, this would greatly improve the speed of re-rigging.