IV. Computer Animation

1. Introduction

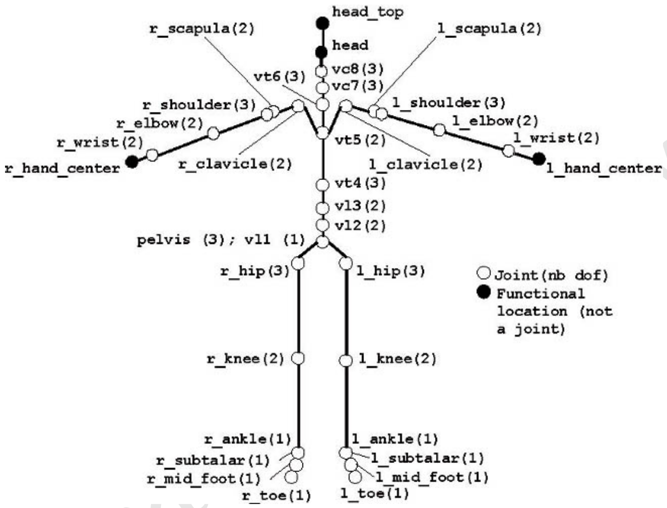
- Computer animation is a technique in which the illusion of movement is created by displaying on a screen, or recording on a recording device, a series of individual states of a dynamic scene.
    - ○ Any computer animation sequence may be defined as a set of objects characterized by state variables evolving over time.
    - ○ It creates the dynamics in virtual worlds.
        - Objects move, rotate, transform themselves;
        - Virtual characters live in inhabited virtual worlds.

- Computer animation sequences can be produced either with a model to create the desired effect or "by hand" to simulate the real-world motion.
    - ○ Typical techniques include key-frame animation and scripted systems.
    - ○ In the next generation of animation systems, motion control tends to be performed automatically.
        - Motion can be planned at a task level and computed using physical laws.
        - More recent progress uses models of behavioral animation and simulation of autonomous creatures.
- Animation Types
    - ○ Real-time computer animation calculates the move-

ments and the transformations sufficiently quickly that the user in front of his or her graphic display can see these movements and transformations at run time.

  - Image-by-image computer animation calculates the images, record them on videotape (or film), and then visualize them or project at a fixed rate, e.g., 25 images/second for video PAL.

- The Skeleton
  - A skeleton has a hierarchically organized set of joints, each having one or more rotational DOF.
    - Each bone has a 4D transformation matrix to represent its length and orientations, together with joint limits in order to avoid unnatural rotations.



- Bone positions and rotations of a global posture are generated as the composition of all previous transformation matrices in the hierarchy, starting from the root.

  - Animation of the skeleton is performed by modifying 4D matrices associated with the bones, either by synthesizing the motion or with the help of inverse kinematics and key-framing.

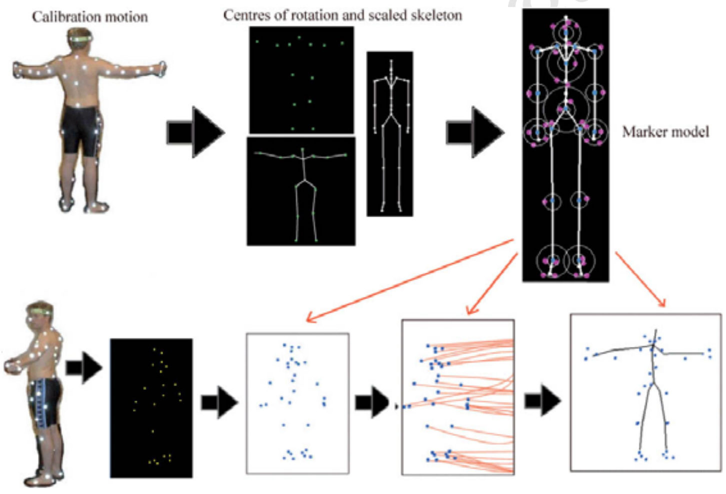
2. Motion Control Methods

- A motion control method specifies how an object or an articulated body is animated and may be characterized according to the type of information to which it is privileged in animating the object or the character.
- Three types of motion control methods:
  - Geometry-based methods define the motion with geometric data provided by motion capture, shape transformation, and parametric key-frame animation.

  - Physics-based methods control the motion by using dynamic equations relating the forces, torques, constraints, and the mass distribution of objects as in the physical laws that govern motion in the real world.
  - Behavior-based methods creates motion to simulate the behavior of objects by providing high-level directives indicating a specific behavior without any other stimulus.
- Motion Capture
  - Motion capture, or performance animation, consists of measurement and recording of direct actions of a real person or animal for immediate or delayed analysis and playback.

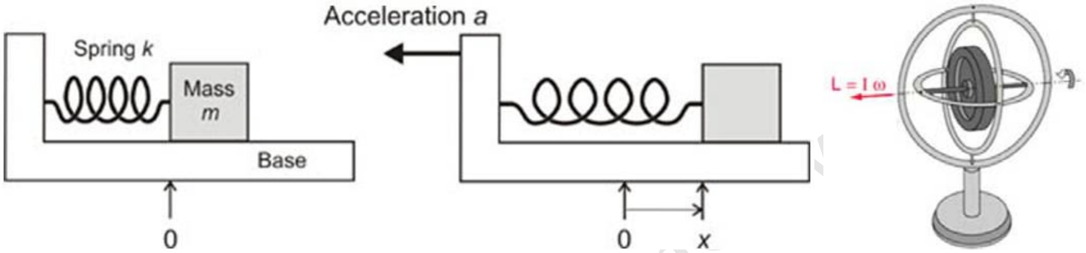
- It provides the computer with important information on the motion of the user: position and orientation of the limbs, postures, and gestures.

○ Optical Motion Capture Systems



- Passive optical systems use markers coated with a retroreflective material to reflect light back that is generated near the cameras lens.
  - Markers are attached to an actor's body and several cameras focused on performance space.
  - Locations corresponding to key points in the animated model can be obtained by tracking the positions of markers.
  - 3D position of each key point can be reconstructed at each time.
  - The main advantage is freedom of movement; but the main problems are occlusion and difficulty in marker distinction.

  - Active optical systems triangulate positions by illuminating one LED at a time very quickly or multiple LEDs at once, but sophisticated software identifies them by their relative positions, somewhat akin to celestial navigation.
- ○ Magnetic Position/Orientation Trackers and Systems
  - Magnetic systems calculate position and orientation by the relative magnetic flux of three orthogonal coils on both the transmitter and each receiver. The relative intensity of the voltage or current of the three coils allows these systems to calculate both range and orientation by meticulously mapping the tracking volume.



- ○ Motion Capture Advantages
  - It works in real time
  - The amount of work does not vary with the complexity or length of the performance
  - Complex movement and realistic physical interactions such as secondary animation, weight, and exchange of forces can be more easily re-created in a physically accurate manner

- Motion capture allows one actor to play multiple roles within a single film.

- ◦ Motion Capture Disadvantages
  - Specific hardware and special programs are required to obtain and process the data
  - Cost of software and equipment and personnel required can be prohibitive

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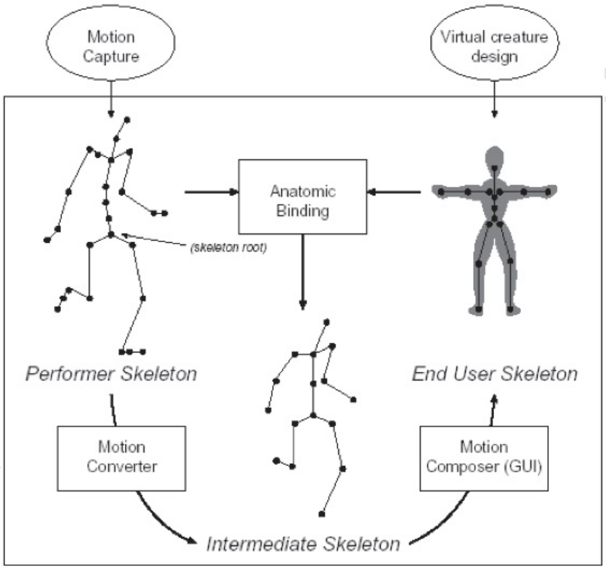
- Motion capture systems may have specific requirements for the space in which they are operated
- Applying motion capture to quadruped characters can be difficult Technology can become obsolete every few years as better software and techniques are invented
- Results are limited to what can be performed within the capture volume without extra editing of the data. Movement that does not follow the laws of physics generally cannot be represented
- If the computer model has different proportions from the capture subject, artifacts may occur.
- Motion capture does not bring any really new con-

cept to animation methodology. For any new motion, it is necessary to record the reality again. Moreover, motion capture is not appropriate, especially in real-time simulation activities, where the situation and actions of people cannot be predicted ahead of time, and in dangerous situations, where one cannot involve a human actor.

- Motion Retargeting
  - Motion retargeting refers to the problem of adjusting the violation of spatial constraints when adapting a captured motion to a different character.
    - e.g., the feet going into the ground or a hand unable to reach an object.

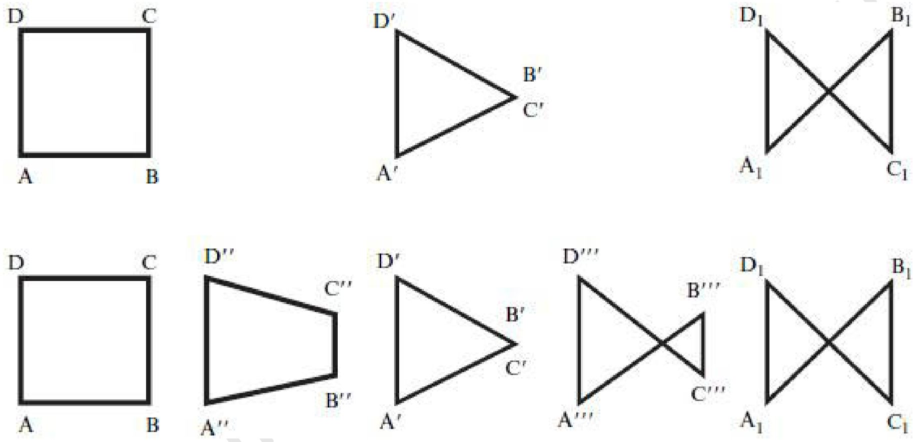
- One of the problem solvers:



(1) Compute the intermediate matrices by orienting the intermediate skeleton bones to reflect the performer skeleton posture (motion converter).

(2) Set the end-user skeleton matrices to the local values of the corresponding intermediate matrices.

- Key-Frame Animation
  - Key-frame animation automatically generates intermediate frames, called in-betweens, based on a set of key-frames supplied by the animator.
  - Shape Interpolation
    - Given v_s and v_e in the starting and ending frames, v_t at intermediate frames is $v_t = (1-t)\,v_s + t\,v_e$; as t ranges from 0 to 1, v_t varies from v_s to v_e.



- In some cases, it is initially necessary to carry out a preprocessing step to equalize the number of vertices in the two drawings.

- Frame is a function of time t, i.e., $F(t)$. Set $t = \frac{F-F_s}{F_e-F_s}$ to ensure $F(0) = F_s$ and $F(1) = F_e$.

- This form of interpolation can be applied to any pair of quantities, whether they be colors, speeds, positions, angles, or coordinates. Problems include discontinuities in time (unlined three key frames) or space (lined key frames).

- ○ Parametric Keyframe Animation
  - Instead of the object itself, parametric keyframe animation interpolates model's parameters, which are normally spatial parameters, physical parameters and visualization parameters that decide the models' behavior.
    - e.g., the transformation of position and velocity from joint space to Cartesian space

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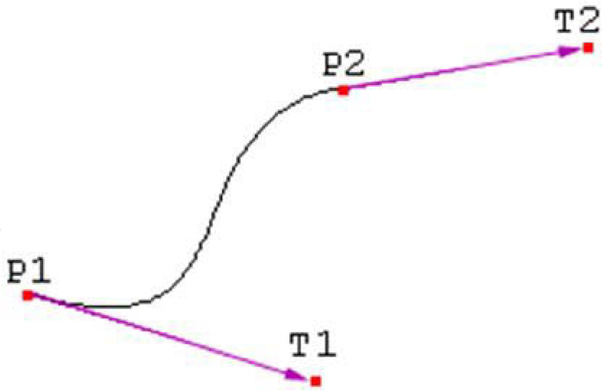
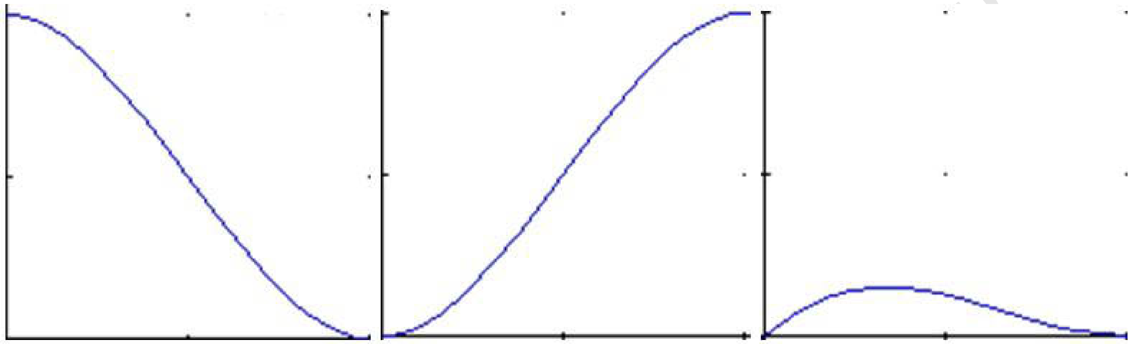
- Parametric key-frame animation is considered a direct kinematics method in motion control when the interpolated parameters are defined in the joint space of the articulated figure.

- ○ Kochanek-Bartels Spline Interpolation
  - Hermite curve:



$$\begin{aligned}\mathbf{Q}(t) &= \mathbf{THC}^T \\ &= [t^3\ t^2\ t\ 1]\begin{bmatrix} 2 & -2 & 1 & 1 \\ -3 & 3 & -2 & -1 \\ 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}\begin{bmatrix} \mathbf{P}_i \\ \mathbf{P}_{i+1} \\ \mathbf{T}_i \\ \mathbf{T}_{i+1} \end{bmatrix}\end{aligned}$$

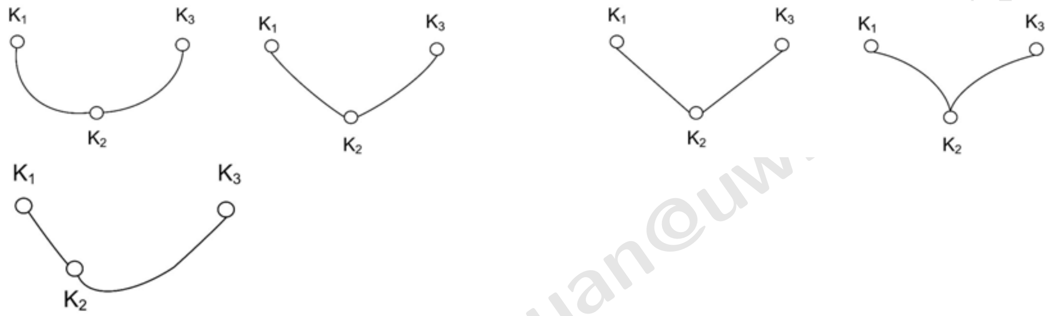
- Spline interpolation
  - e.g., the 1st starts at 1 and goes slowly to 0.
  - e.g., the 2nd starts at 0 and goes slowly to 1.
- Source derivative (tangent vector) $\mathbf{D}_{i_S}$ and destination derivative (tangent vector) $\mathbf{D}_{i_D}$



$$\mathbf{D}_{i_S} = 0.5[(1-t)(1+c)(1-b)(\mathbf{P}_{i+1}-\mathbf{P}_i) + (1-t)(1-c)(1+b)(\mathbf{P}_i-\mathbf{P}_{i-1})]$$

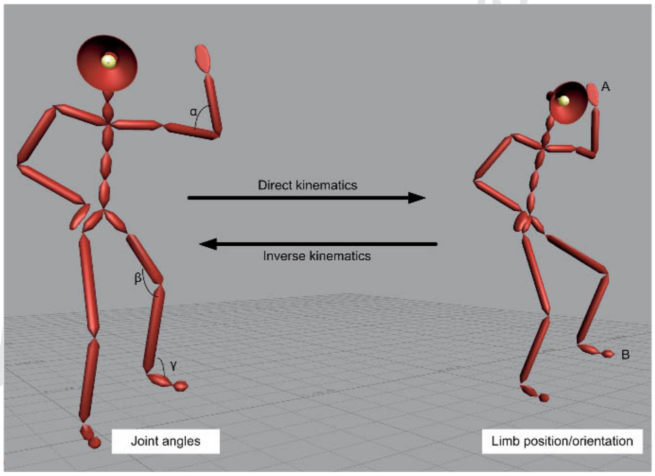
$$\mathbf{D}_{i_D} = 0.5[(1-t)(1-c)(1-b)(\mathbf{P}_{i+1}-\mathbf{P}_i) + (1-t)(1+c)(1+b)(\mathbf{P}_i-\mathbf{P}_{i-1})]$$

- three parameters for local control: tension (t), continuity (c), and bias (b)



- Inverse Kinematics
  - Direct and inverse kinematics
    - Direct kinematics finds the position of endpoint positions (e.g., hand, foot) with respect to a fixed-reference coordinate system as a function of time without regard to the forces or moments that cause the motion.

- Inverse kinematics determines the joint variables given the position and the orientation of the end of the manipulator, or end effector, with respect to the reference coordinate system.



- General solution in discrete form:
  - Let *m* be the dimension of the end effector in Cartesian space, and *n* be the dimension of the joint space. is usually six: three rotations and three translations). The dimension *m* of the main task is usually less than or equal to the dimension *n* of the joint space.

$$\Delta q = \mathbf{J}_{+}\Delta x + (\mathbf{I} - \mathbf{J}\mathbf{J}_{+})\Delta z$$

  - Δq is the unknown vector in the joint variation space of dimension *n*.
  - Δx describes the main task as a variation of the end effector position/orientation in Cartesian space.

  - $\mathbf{J}$ is the Jacobian matrix of the linear transformation, representing the differential behavior of the controlled system over the dimensions specified by the main task.
  - $\mathbf{J}_{+}$ is the unique pseudo-inverse of J providing the minimum norm solution to realize the main task.
  - $\mathbf{I}$ is the identity matrix of the joint variation space.
  - Δz describes a secondary task in the joint variation space, i.e., the $(n - m)$ vector in Cartesian space.

- Procedural Animation
  - Procedural animation corresponds to the creation of a motion by a procedure describing specifically the motion.

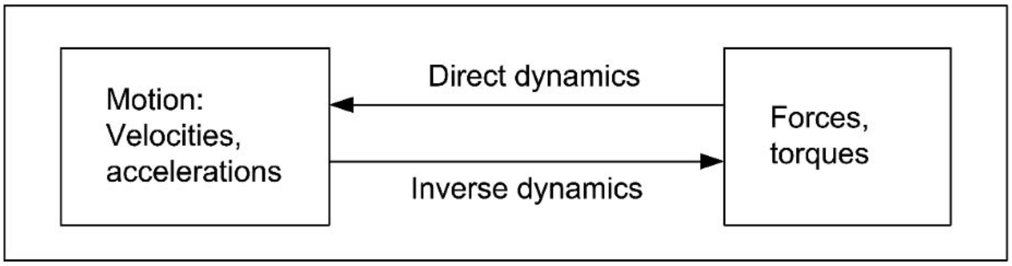
- Two important ways of motion expression use laws of physics or behavior.

○ In physics-based animation, the motion of an articulated body was computed according to the laws of rigid body dynamics.

- Mathematically, forward dynamics translates into differential equations, which are typically posed as an initial-value problem; the user has little control other than setting up the initial configuration.
- In practice, it is more common for an animator to specify a desired active behavior and to use inverse dynamics to generate the corresponding coordinate sequence of force/torque activation.

○ Behavioral animation can use scripts to describe behavior for step-by-step description of interactions.

- This approach provides full control and flexibility, but is not practical for larger systems if used alone



as it requires programming of every possible outcome of an interaction.

- A solution is to use scripting in a complementary role to other methods of specifying behavior.
  - e.g., the lower-level details (usually related to animation since behavior and animation cannot be fully separated) can be scripted, whereas a higher-level module can carry out reasoning.

- In behavioral animation, behaviors can also be specified based on rules, each of which corresponds to a if-then statement.
  - A combination of scripting and rule-based behavior can be achieved with an animation engine for generating motion and a behavior engine for describing the decision-making process through rules.
  - A distributed behavioral model is useful to simulate flocks of birds, herds of land animals and fish schools.
  - In a production-based approach, a user may create any realistic or abstract shape, play with fascinating tree structures, and generate any concept of growth

and life development in the resulting animation.

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3. Mixed Reality Software

- Mixed realities refers to either *augmented reality* or *augmented virtuality*, since both of them combine elements from real and virtual worlds.
  - ○ In addition to algorithms and devices for interaction, mixed realities also need a tracking mechanism to "attach" computer-generated images to real objects or portions of the scene.
    - Tracking is usually done applying computer-vision and image-processing techniques.
    - It detects relevant objects in the real-world to acquire their position, orientation, contour, and other visual features.

- It is important for the effective operation of MR systems to know what is presented in the real world and where.
  - All the MR processes must be able to keep pace with the captured image frame rate when superimposing computer-generated graphics on live images of the surrounding world in real time.
  - The information of real-world objects can be used to aid virtual object placement, occlusion culling, collision detection, or many other visual or simulated effects.
- The main challenge of MR systems is to build up and reconstruct this real-world description in real time.

- Tracking algorithms and techniques for real-time reconstruction of real-world description
  - Computer vision has the potential to yield noninvasive, accurate, and low cost solutions. In addition, other techniques can be used to achieve 3D tracking.
    - Mechanical trackers are accurate enough, although they constrain the user to a limited working space.
    - Magnetic trackers are vulnerable to distortions by metallic structures in the environment, and limit the range of displacements.
    - Ultrasonic trackers suffer from noise and tend to be inaccurate at long ranges because of variations in the ambient temperature.

- ○ Markers-Based Tracking
  - The use fiducials, also called landmarks or markers, greatly helps to extract information from the image and to estimate the pose of the tracked objects.
  - Two types of fiducials
    - Point fiducials are commonly circular markers because they are easier to detect. The markers can also be arranged in a distinctive geometric pattern to help their identification.
    - Planar rectangular fiducials have gained popularity as a single planar fiducial provides all six spatial constraints needed to define a coordinate frame (position and orientation).

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  0.98  -0.01  -0.47  0.0
A -0.17  -0.06  -0.99  0.0
A -0.01  0.99  -0.06  0.0
A 163.02  26.33  932.36  1.0
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  - Drawbacks
    - This method assumes that one or more fiducials are visible at all times. Otherwise, the registration cannot be done.
    - It is also not always possible to place fiducials.

- ○ Marker-Less Tracking
  - – In some applications, it is either undesirable or very difficult to add markers to the scene, for example, outdoor environments or unknown environments.
  - – Two types of approaches
    - . Edge-based methods match edge projections of the target object to an area of high image gradient.
    - . Optical flow is the apparent motion of the image projection of a physical point in an image sequence, where the velocity at each pixel location is computed under the assumption that projection's intensity remains constant.

- – Difficulty
  - . Finding and following feature points or edges can be difficult because they are hard to detect, and in many cases there are not enough of them on typical objects.

    - 3D knowledge is often used to ease the task of marker-less tracking algorithms. The 3D knowledge can come in the form of a CAD model, a set of planar parts, or even a rough 3D model such as an ellipsoid.

- (Free) Tool Kits
  - The most popular solution for rapid development of augmented reality applications is the ARToolkit.
  - An alternative to ARToolkit is the Mixed Reality Toolkit, or MRT, which can be rapidly applied over live video streams or still images to reconstruct and register 3D shapes.