V. VIRTUAL CHARACTERS

1. Virtual Human

- Virtual humans should behave like real humans, having capabilities such as perception, language understanding, and generation, emotions, goal-driven behavior, reactivity to the environment with other virtual humans, memory, inference, appearance of thought and personalities, interpersonal interactions, and social skills.
- To be believable an actor has to be affected his/her surroundings and needs to engage in social behaviors.
  - The behavioral model of an actor needs to be versatile enough to allow a change of behavior.

  - The emotional state of the actor must be reflected and must affect its behavior.
  - The interpersonal relationships with the other actors must be taken into account and possibly bring the actor to engage in social interactions.
  - These actors should be able to act freely and emotionally. Ideally, they should be conscious and unpredictable. But we are far from such an ideal situation.

2. Character Skinning

- Skeleton-Based Deformations
  - Joint-dependent local deformation first assigns a set of joints with weights to each vertex, and compute its deformation by a weighted combination.

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- The multiweighting approach assigns each vertex one weight for each coefficient of each influencing joints transformation matrix instead of a single weight per influencing joint.
  - The multiweights can be derived from a set of example poses.

- Each bone is assigned with an influence map, which defines its influence over the surface vertices.
- The user defines the influence maps and provide a scaling parameter to control the smoothness of the deformation solution and avoid overfitting, when large weights deform skin badly on a new pose.
- Training poses are then used as examples to estimate the multiweight vectors using a statistical analysis (principal component analysis) and a modified least square optimization method.
- The weights computed from the set of training poses generalize to other postures.

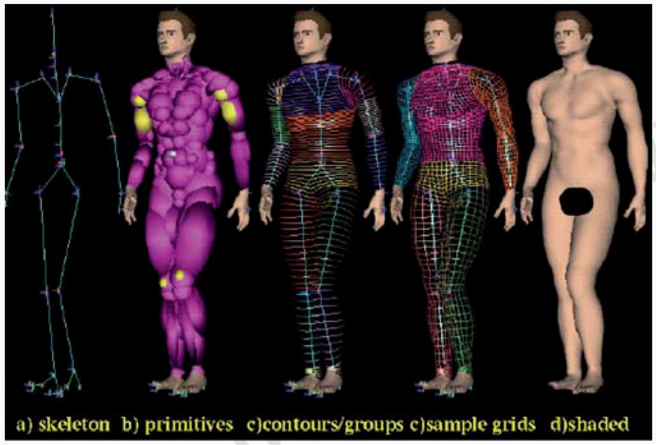
- As it would be almost impossible to define the multiweight values interactively, an automated process automatically estimates the set of values.

◦ More complex models include intermediate layers to improve and refine the control of the skin.

- An intermediate structure is attached to the skeleton in forms of free-form deformation control boxes, which are parameterized with the joint angles.
  - The first controls the bending of the mesh around the joint.
  - The second mimics the muscle behavior by inflating the skin along the bones to replicate the muscle contraction effect.

- Another approach combines implicit surfaces and B-spline patches.
  - The implicit surfaces are ellipsoidal metaballs that represent the shape of bone, muscle, and tissue.
  - The motion/deformation of each primitive is specified via a graphical interface.
  - A skin of fixed topology is extracted by casting rays from skeleton segments whose intersection points become control points of B-spline patches.

◦ Approaches based upon anatomy assume that the skin surface changes may be accurately represented as the result of the behavior of the underlying anatomical structures such as muscles, fat, and tissues.



- Passive muscles
  - Geometric or physics-based deformations are used to adjust the shape of the muscle to the current posture of the skeleton.
- Active muscles

  - Biomechanical physics-based deformation models simulate the dynamic behavior of muscles[1].

$$r = (1 - t)r_n + ktr_n = (1 - t + kt)r_n$$

- abstract muscles
  - An action line represents the force produced by the muscle on the bones, and a surface mesh is deformed by an equivalent masss-pring mesh.

• Data-Driven Methods
  - They use examples of varying postures and blending them during animation.

[1] k is a tension-control parameter, t a tension parameter, r the ratio of the width and height of the muscle, and r_n this ratio in a fully relaxed state

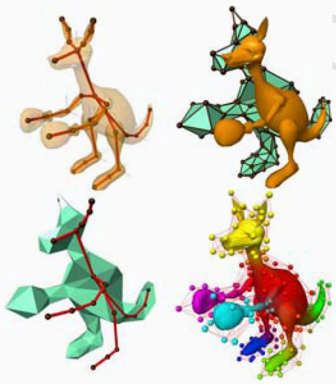
   - They try to leverage realistic shapes from captured skin shape of real people, physically based simulation results, or sculpted by skilled designers.

- The basic idea is to train a deformable model with real shape data from variation of characters.
   - Acquisition devices, such as 3D scanners, provide reliable and accurate data from complex shapes like the human body.
   - This family of methods initially started by modeling static shape variations (morphology) such as the human face, and has been further applied to address dynamic shape variations (poses) such as deformable human bodies.

- Skinning Mesh Animations (SMAs)
   - Rather than requiring a predefined skeleton, this method takes as inputs a set of deformed meshes representing the pseudo-articulated deformable shape in different poses.
      - Bones are estimated statistically based on the hypothesis that clustering triangles with analogous rotation sequences indicates the near rigid structure of the mesh animation.
      - It determines bone transformations, bone-vertex influence sets, and vertex weight values for producing skinned animations that approximate the original deformable animation.

– The skinning approximation is particularly suited for shapes with a sufficient near-rigid structure and does not apply well for highly deformable shapes.

- Physics-Based Approaches
  - They use dynamic-based deformations for realism.
  - Finite element method based animation



– A character is embedded in a coarse volumetric control lattice.

– This method uses continuum elasticity and FEM to compute the dynamics of the object being deformed.

. Bones of the control skeleton are restricted to lying along the edges of the control lattice, so that the skeleton can be considered a constraint in the dynamic system.

3. Locomotion[2]

- Locomotion Generation

[2] Locomotion refers to the movement of an organism from one place to another, often by the action of appendages such as flagella, limbs, or wings. In some animals, such as fish, locomotion results from a wavelike series of muscle contractions.

- Walking has global and specific characteristics.
  - Characteristics of walking
    - At any time, at least one foot is in contact with the floor, the single support duration.
    - There exists a short instant during the walk cycle, where both feet are in contact with the floor, the double support duration.
    - It is a periodic motion that has to be normalized in order to adapt to different anatomies.
  - Joint angle variations
    - Sinus functions with varying amplitudes and frequencies for the humanoid's global translations and the humanoid's pelvic motions ;

- periodic functions based on control points and interpolating hermite splines. They are applied to the hip flexion, knee flexion, ankle flexion, chest torsion, shoulder flexion, and elbow flexion.

- Techniques for the locomotion of virtual humans
  - Key-framing technique
    - It allows an animator to specify key postures at specific key times.
    - Using appropriate software (e.g., Autodesk's 3ds Max or Maya), skilled designers can control the motion in detail.
    - It is labor-intensive, as any motion parameter change entails the animators to modify every key-frame.

- Kinematics approaches
  - Motions are generated by giving a predefined set of foot positions (footprints) and timing information.
  - These data are generally computed by a motion planning technique, which has to be as interactive as possible to be comfortable for animators.
- Dynamics approaches
  - It describes a motion by applying physics laws, thus producing physically correct animations.
  - Due to the difficulty of determining the influence of each parameter on the resulting motions, the produced animation lacks realism, e.g., symmetrical leg motions.

- Locomotion based on PCA (principal component analysis)
  - PCA is a statistical method that can be used to either compress the data or emphasize similarities between input data for motion generationd with control parameters such as age or gender.
    - It considers a person posture, or a body pose, in a given key-frame be defined by the position and orientation of a root node and a vector of joint angles.
      - It represents a motion with an angular motion vector μ, which is a set of such joint angle vectors measured at regularly sampled intervals.

- The input motion-capture data space is computed with the input motion matrix M composed of all motion vectors μ from a database with k subjects.
- The basis vectors describing the input data space are the m first orthogonal principal components necessary to compute an approximation of the original data.

– Approximation equation for motion

$$\theta \simeq \theta_0 + \sum_{i=1}^{m} \alpha_i e_i$$

- M's 1st eigenvectors $E = (e_1, e_2, \ldots, e_m)$
- coefficient vector $\alpha = (\alpha_1, \alpha_2, \ldots, \alpha_m)$

◦ Generating locomotion sequences with high-level parameter update:

(1) Creation of a motion database

– Device: an optical motion-capture system and a treadmill

- Subject: difference in age and gender
- Parameters:
  - walking — 3.0–7.0 km/h with increments of 0.5 km/h
  - running — 6.0–12.0 km/h with increments of 1.0 km/h

(2) Sequences segmentation into cycles

- Four cycles are selected.
- One cycle includes two steps, starting at right heel strike.

(3) Locomotion Alignment

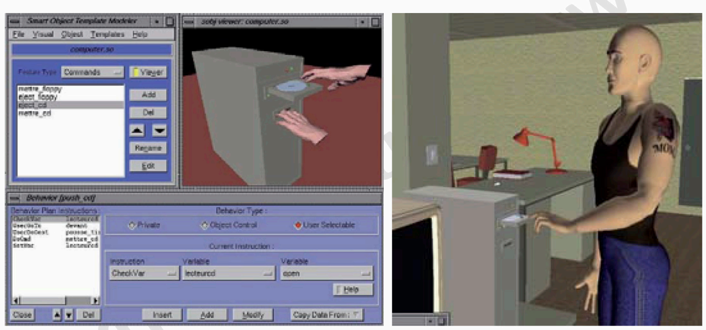
- Motion data about cycles are converted to joint angle space asrepresented by axis angles.

4. Virtual Human-Object interaction

- Feature Modeling and smart objects
  - Modeling for animation
    - Grasping needs to calculate hand-joint movements and consider the reaching motion of arm and body.
    - Realistic grasping also requires significant input about the semantics of the object.
    - The main criterion is that the grasp must look, though difficult to be, realistic.
  - Specification of object behavior
    - Techniques of virtual human-object interaction techniques bridge the gap between high-level AI planners and the low-level actions for objects.

- In feature modeling, object models contain more than geometric information.
  - Smart objects provide not only the geometric information necessary for drawing them on the screen, but also semantic information useful for manipulation purposes.
    - For example, in a CAD/CAM application, the definition of an object may contain instructions of how a certain part of the object is to be assembled.
  - Different kinds of information
    - Manipulation: e.g., where and how to approach to manipulate the object or to position the hands to grasp it.

- Animation: e.g., a door opening.
- general nongeometric information associated with the object, e.g., weight or material properties.

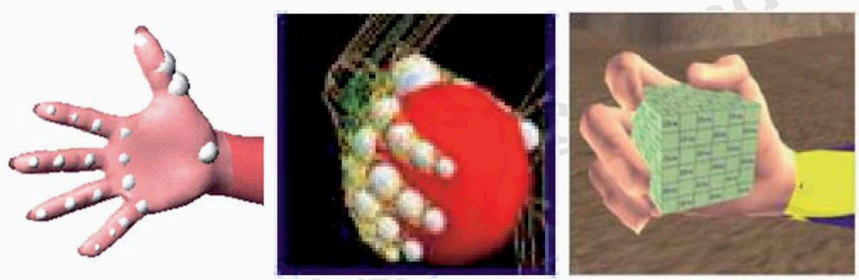


- The semantic information in the smart object is used by the virtual characters to perform actions on/or with the object, such as grasping it, moving it, and operating it (e.g., a machine or an elevator).

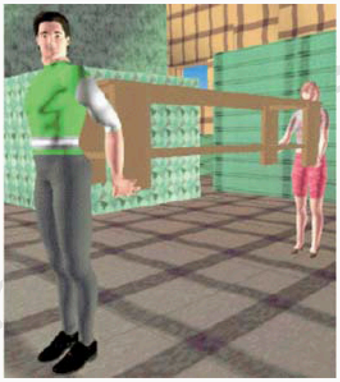
- Grasping
  - Heuristic grasping decision
    - The system can decide the grasp based upon a grasp taxonomy.

- Use a pinch for small objects.
- Use a two-handed grasp for large objects.

- Arm posture can be decided with inverse kinematics.
- Multisensor hand



  - Multisensors are considered as a group of objects attached to the articulated figure.
  - A sensor is activated with collision.
- Multiagent grasp
  - Object's weight and geometry is distributed over several hand support points of different agents.



- Motion Planning
  - Collision avoidance is necessary for the believability of the virtual environment with motions of virtual human.
    - For known environment, collision avoidance can be taken care of during the design stage.

- Methods based on probabilistic roadmaps are particularly suitable for structures many degrees of freedom.
  - A probabilistic roadmap is a data structure (graph) used to capture the connectivity of the search space.
    - Graph nodes correspond to randomly sampled configurations of the robot (e.g., joint angles).
    - An edge between two nodes means that the robot is able to move between corresponding configurations by means of a local planner.
  - Visibility-based roadmap construction techniques aim at reducing the number of nodes while the rapidly exploring random trees focus on exploring the configuration space with increased number of nodes.

- ◦ Motion planning in interactive applications
  - – The random distribution of configurations is biased to favor postures useful for reaching and grasping.

- . The path of the object to be moved is computed using the random tree algorithm.
- . An inverse kinematics algorithm generates poses that match the object position and orientation.

- ◦ Dynamic roadmaps can be used for changing virtual environment.

5. Facial Animation

- The goal of facial animation systems has always been to obtain a high degree of realism using optimum-resolution facial mesh models and effective deformation techniques.
- Facial animation systems
  - ◦ Facial Action Coding System (FACS) defines fundamental basic actions known as Action Units.

– A repertoire of 46 action units can be regarded as a "kit" for creating and compositing facial expressions.

– Each action unit describes the contraction of one facial muscle or a group of related muscles.

◦ Typical facial animation steps

(1) Define a parameterized animation structure.

(2) Define "building blocks" or basic units of the animation in terms of these parameters

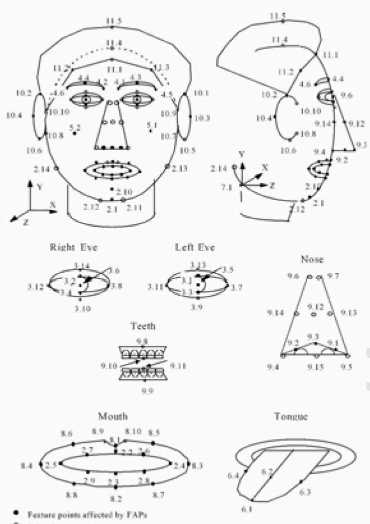
– e.g., static expressions and visemes (visual counterparts of phonemes), which are also the most challenging task in facial animation.

(3) Use these building blocks as key-frames and define various interpolation and blending functions on the parameters to generate words and sentences from visemes and emotions from expressions.

– The interpolation and blending functions contribute to the realism for a desired animation effect.

(4) Generate the mesh animation from the interpolated or blended key-frames.

- The Facial Definition Parameters (FDPs) are defined by the locations of the feature points and are used to customize a given face model to a particular face.
  - FDPs contain 3D feature points such as mouth corners and contours, eye corners, and eyebrow centers.
    - FAPs are based on the study of minimal facial actions and are closely related to muscle actions.
  - Each FAP value is simply the displacement of a particular feature point from its neutral position expressed in terms of the Facial Animation Parameter Units (FAPU).



- The FAPUs correspond to fractions of distances between key facial features (e.g. the distance between the eyes).

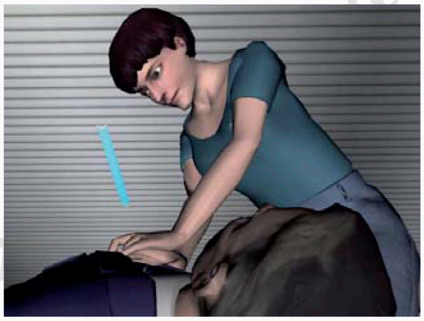
- It is possible to mix emotions with speech in a natural way, thus imparting to the virtual character emotional behavior.

6. Autonomous Characters

- Autonomous virtual characters in simulation
  - They serve for a variety of purposes, including education and training, treatment of psychological problems, and emergency preparedness.
    - Interactive manual:
      - An autonomous character plays an expert, showing the user how to proceed with, e.g., repairing a copy machine.
    - Virtual therapy

- To overcome a fear of public speaking, the patient performs while immersed in a virtual environment consisting of a seminar room and a virtual audience, which can react to the user in an autonomous way.

- Virtual trainer



- A user is learning basic life support procedures.

- Properties of Autonomous Virtual Characters
  - An AVC must be able to perceive its environment and decide what to do to reach an intended goal. The decisions are then transformed into motor control actions, which are animated so that the behavior is believable.
  - Four properties that determine how AVCs make their decisions:
    - Perception
      - Perception of the elements in the environment gives AVCs an awareness of what is changing.
      - An AVC continuously modifies its environment, which, in turn, influences its perceptions.

      - AVCs should have sensors that simulate the functionality of their organic counterparts, mainly for vision, audition, and tactile sensation.
      - Rather than biological accuracy, the modeling of sensors needs to focus on their functionality and how their filter the information flow from the environment.
    - Adaptation and intelligence
      - Adaptation and intelligence define how the character is capable of reasoning about what it perceives.
      - An AVC determines its action by reasoning about what it knows to be true at a specific time.
      - Its knowledge is decomposed into its beliefs and

internal states, goals, and plans, which specify a sequence of actions required to achieve a specific goal.

– Memory

- It is necessary for an AVC to have a memory so that similar behaviors can be selected when predictable elements reappear.
- Octree can be used to represent the visual memory of an actor in a 3D environment with static and dynamic objects.

– Emotions:

- An emotion is an emotive reaction to a perception that induces a character to assume a physical re-

sponse, facial expression, or gesture or to select a specific behavior.

- The apparent emotions of an AVC and the way it reacts are what give it the appearance of a living being with needs and desires.
- AVC's visible emotions can provide designers with a direct way of influencing the user's emotional state.

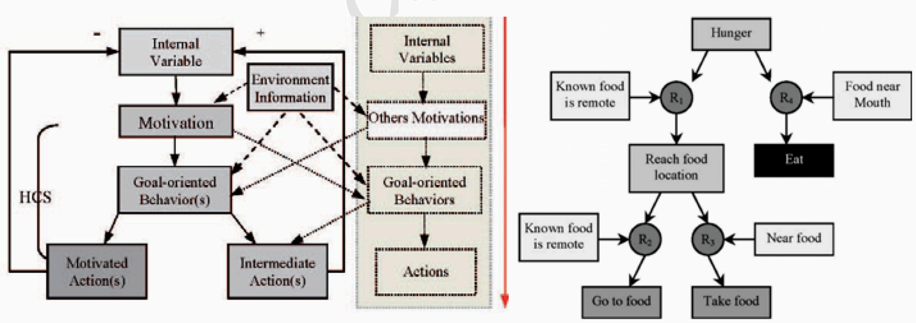
• Behaviors for Autonomous Virtual Characters

◦ Behaviors can range from very simple, like reflexes, to very complex, although it is not really clear what a complex behavior is.

– Reflexes

- Reflexes are unconscious movements regulated by the nervous system.
- The movement performed during a reaction depends on many factors, including physical characteristics (e.g., gender and age) and psychological parameters (e.g., personality and emotional state).

- Motivations
  - In common life situations, the actor senses and explores his environment to follow an action-selection mechanism that determines the suitable actions to take.
  - A simplified motivational model of action selection for virtual humans



◦ Social Behavior

– To realistically simulate how humans interact in a specific social context, it is necessary to precisely model the type of relationship they have and specify how it affects their interpersonal behavior.

– Factors of group behavior:

. power (dominance and submissiveness of the agents)

. attraction (friendliness and unfriendliness)

. instrumental control (hierarchical rank), and

. emotional expressiveness.

– The agents behavior within a group is highly dependent on their location in the sociometric structures but also on their own social identity.

. social-statistical variables: culture, gender, age

. agents' roles within the group: task role (e.g., function), socio-emotional role (e.g., confident), and status rating (prestige)

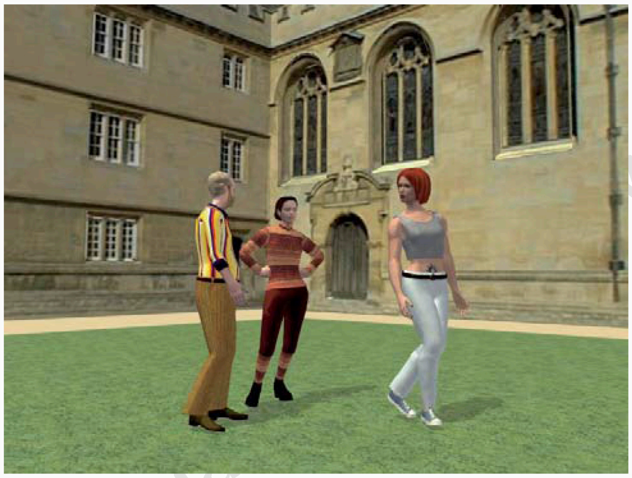
– Verbal (e.g. accent) and nonverbal (e.g., postures) communication

7. Crowd Simulation

- Rea-time interacting characters

  ◦ A small number of characters interacting with each other in, for example, a computer game.

  ◦ There is a need for fast and scalable methods to compute behavior, that can take into account inputs not known in advance and render large and varied crowds.



- Nonreal-time simulation
  - Simulation of crowds in movies or visualizations of, for example, crowd evacuations after offline model computations.

- Nonreal-time simulations know a full run of the simulated scenario (and therefore, for example, can run iteratively over several possible options selecting the globally best solution).