KEY FRAME AND PAINTING SYSTEMS

Review of Computer-assisted Animation Activities

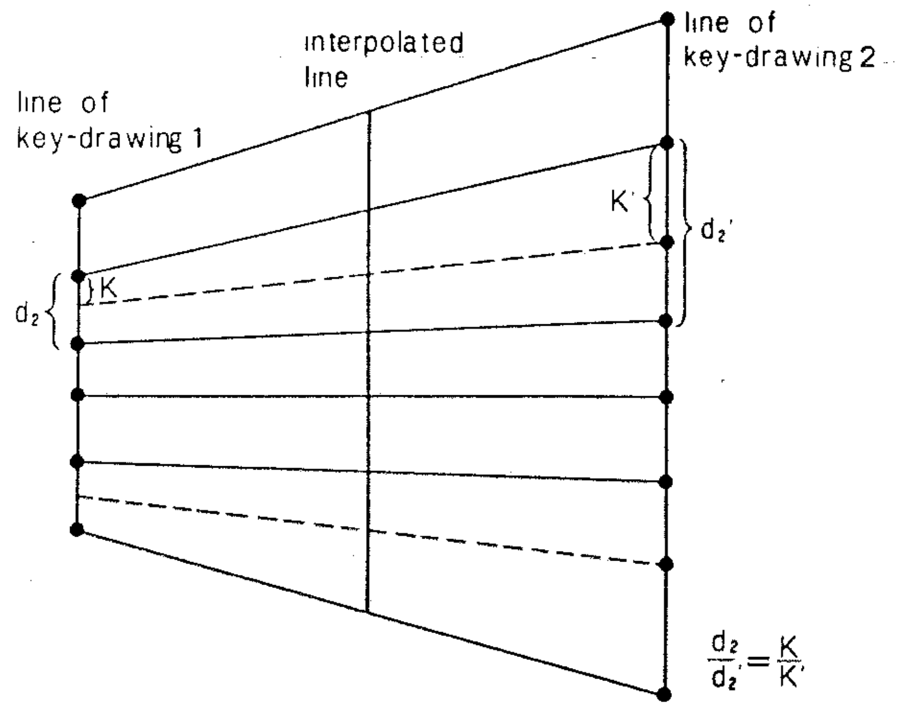
- input of drawings
- production of in-betweens
- specification of motion of an object along a path
- coloring drawings and creating backgrounds
- synchronizing motion with sound
- initiating the recording of a sequence on film

Input of Drawings

- historically
  - different objects or parts of objects are recorded on different cels
- with a graphics editor
  - the designer creates, modifies, deletes, saves and retrieves drawings
  - both free-hand drawings and regular drawings can be created
  - drawings can be improved, by smoothing for example

In-betweening

- the major advantage provided by the computer (given two key frames)
- if correspondence between key frames is well-defined, drawings between key frames are calculated by computing linear distances between corresponding points



- key drawings are decomposed into cels
  - in-betweens are calculated by interpolating between cels
  - cels are composed of strokes defined as sequences of line segments

Algorithm for interpolating from cel C1 with N1 strokes to cel C2 with N2 strokes

If N1 = N2, in-betweens can be calculated

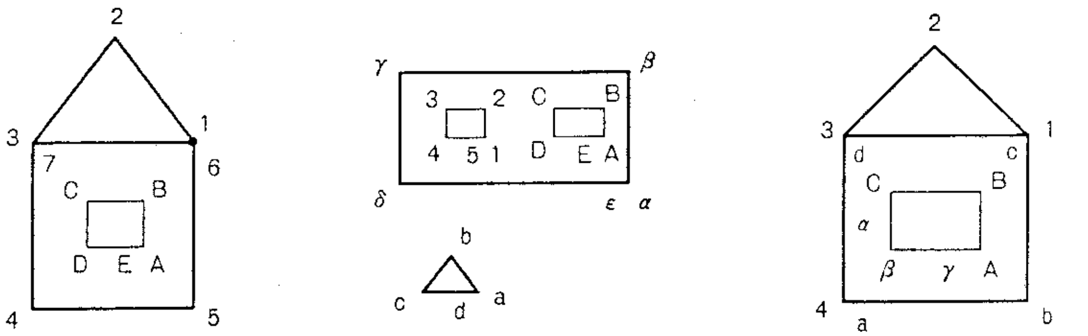
Else preprocess (for cels with different numbers of strokes)

In N2 > N1, interchange

Add N1-N2 strokes to C2

N1 mod N2 strokes of C2 are broken into (N1 div N2) + 1 strokes

the other strokes of C2 are broken into N1 div N2 strokes



2 strokes
1234567 : ABCDE

4 strokes
12345 : ABCDE : abcd : αβγδε

1234 : abcd : ABC : αβγ

N1 = 4 and N2 = 2

2 strokes of the leftmost figure are broken into 2 strokes each, to produce the rightmost figure

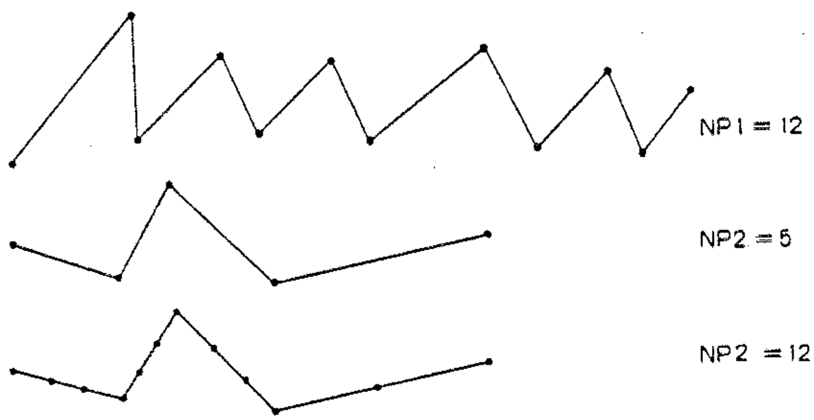
Preprocess two corresponding strokes with different numbers of points

if NP1 > NP2

RT := (NP1 - 1) div (NP2 - 1)

RS := (NP1 - 1) mod (NP2 - 1)

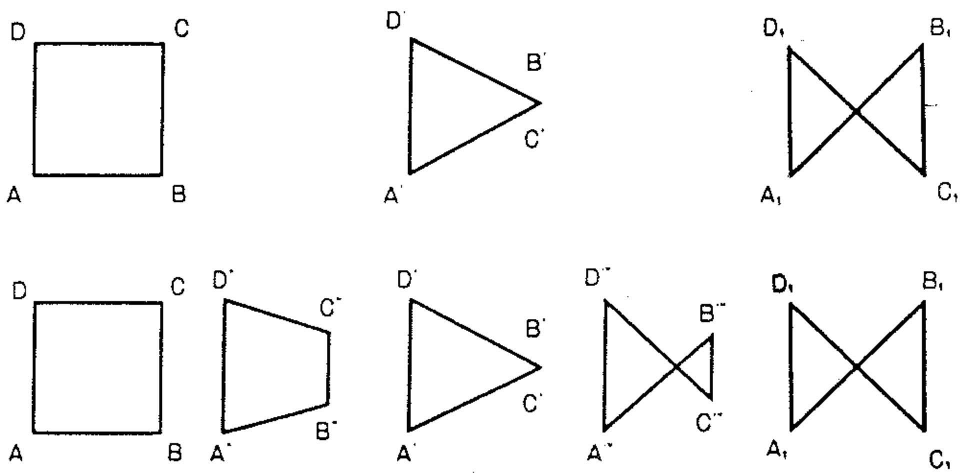
add RT points to the first RS line segments of the stroke of the second cel and RT - 1 to the others



NP1 = 12 and NP2 = 5

two points are added to the first three line segments
and one to the last

Linear Interpolation Between Two Corresponding Drawings



- other divisions result when nonlinear interpolation laws are used

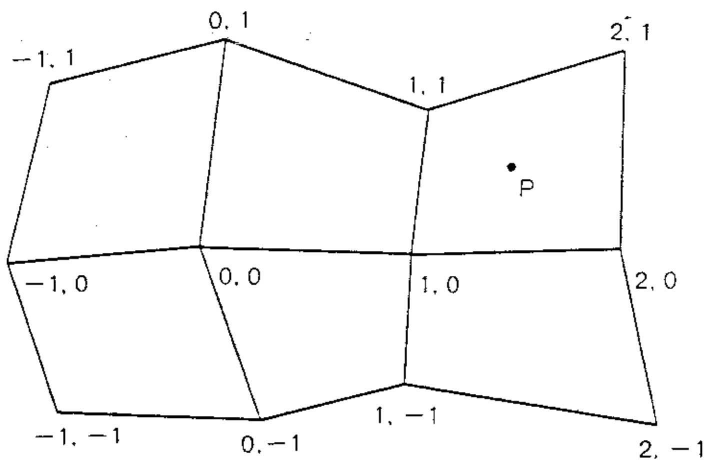
The Laws of Animation

- four fundamental laws of linear interpolation: motion between two key frames can
  - occur at a constant speed
  - accelerate
  - decelerate
  - accelerate and then decelerate

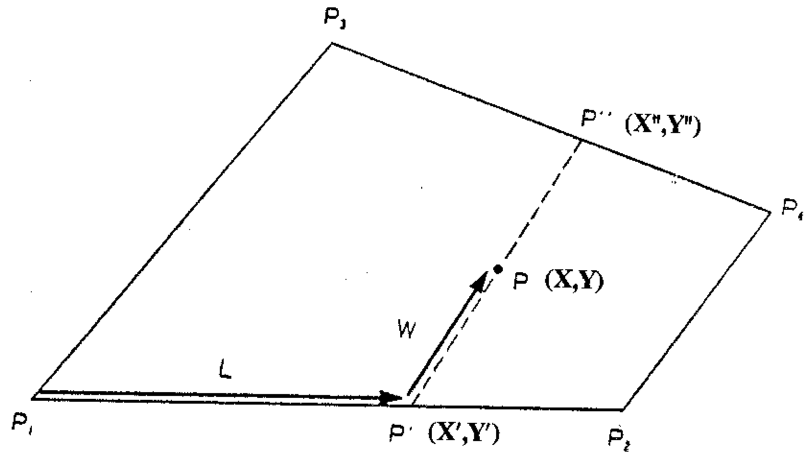
```
function LAW(OP:INTEGER; MAXVAL,FRACT:REAL):REAL;
begin
   case OP of
      1: (* constant velocity *)
         LAW := MAXVAL*FRACT;
      2: (* acceleration *)
         LAW := MAXVAL*(1-COS(PI*FRACT/2));
      3: (* deceleration *)
         LAW := MAXVAL*SIN(PI*FRACT/2);
      4: (* acceleration then deceleration *)
         LAW := MAXVAL*(1-COS(PI*FRACT))/2
   end
end.
```

Skeleton Techniques

- problems with in-betweening
  - each point moves along a straight line (all points move according to the same law)
  - a discontinuity exists at each key frame
- Burtnyk and Wein use "skeletons" of figures for in-betweening
  - the animator creates several key frames consisting only of skeletons (which are much easier to draw)
  - key frames have much more similarity, yielding smoother motion
- ideally, a skeleton is a network of quadrilaterals
  - a change of one unit occurs between vertices



- the relative coordinates L and W of a point P are the fractional distance along each axis



$$P' = P1 + L(P2 - P1)$$

$$P'' = P3 + L(P4 - P3)$$

$$(X - X'')/(Y - Y'') = (X - X')/(Y - Y')$$

$$W = [X - X1 - L(X2 - X1)]/[(X3 - X1) - L(X2 - X1 - X4 + X3)]$$

derivation:

$$X = X' + W(X'' - X')$$

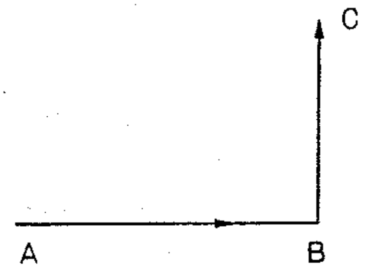
$$= X1 + L(X2 - X1) + W[(X3 + L(X4 - X3) - X1 - L(X2 - X1)]$$

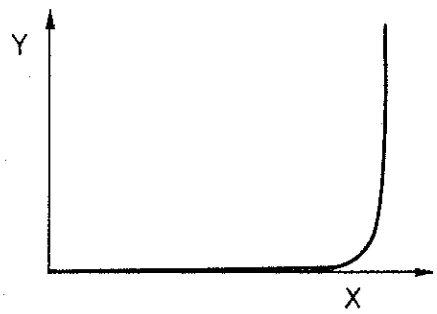
or

$$X - X1 - L(X2 - X1) = W[(X3 - X1) - L(X2 - X1 - X4 + X3)]$$

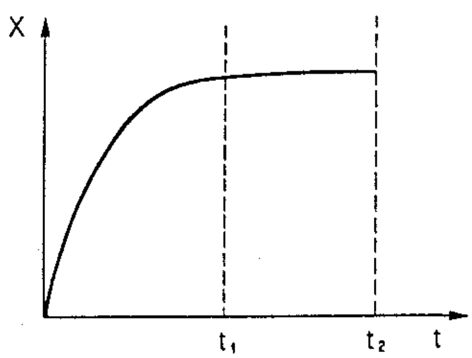
The Path of Motion and P-curves

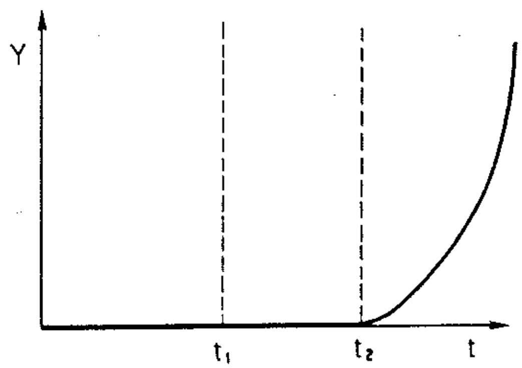
- linear interpolation is unsuitable for classical movements involving a modification of location
    - one solution is to program all the laws of movement, which, at best, is difficult to do
    - an alternative is path descriptions and P-curves
- a P-curve describes the trajectory of a point and its location in time
    - trajectory alone gives no indication of time



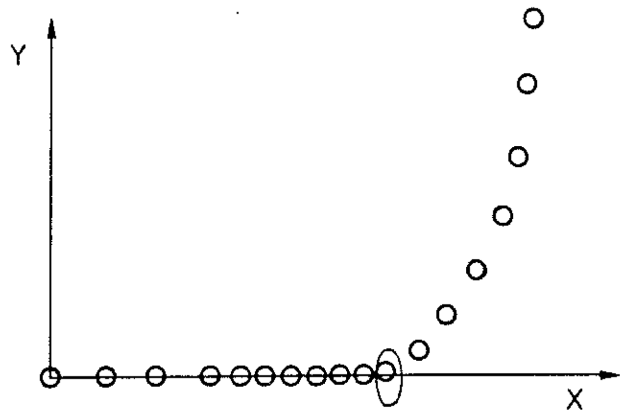


- additional curves can show the variations of X and Y with respect to time



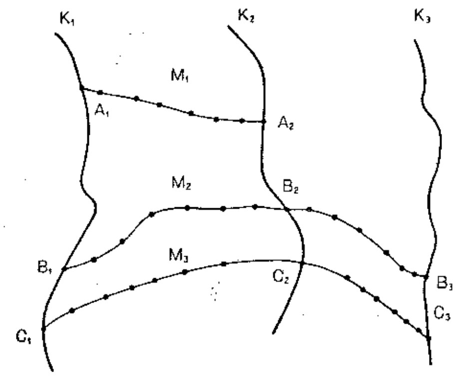


- a P-curve shows the shape of the trajectory as a trail of symbols equally spaced in time

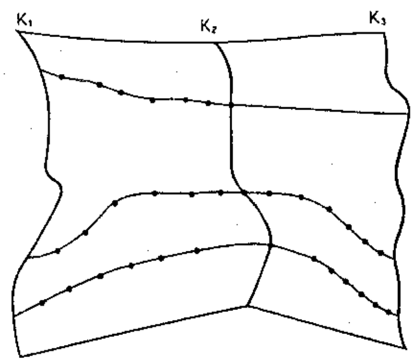


In-betweening Using Moving Point Constraints

- in-betweening often provides bad results due to linear interpolation
- even nonlinear interpolation produces variations in time only, but not in space
- moving point constraints reduce motion discontinuities at key frames by allowing multiple, nonlinear paths and speeds of interpolation
    - a curve varying in space and time is associated with some points of the animated object
        - it's called a moving point
        - it controls the trajectory and dynamics of the point similarly

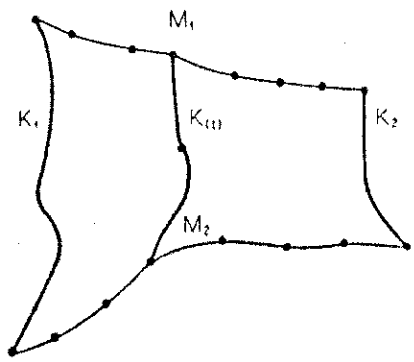


Three Key Frames (K1, K2 and K3)
and Three Moving Points (M1, M2 and M3)



The Complete Network

- consider one patch defined by four curves, involving parts of two key frames K1 and K2 and two moving points M1 and M2
    - the curve K(t) between K1 and K2 can be found using the Miura algorithm
        - K1 and K2 are approximated by two line segments L1 and L2 with the same endpoints
        - a transformation T1 is found which transforms L1 into L(t), where L(t) approximates K(t)
        - a transformation T2 is found which transforms L2 into L(t)
        - T1 and T2 are composed of translation, rotation and/or scaling
        - K(t) = (1 - t)T1 + tT2



- **another technique uses Coons patches**
  - **each patch is defined by its four boundaries and normal derivative functions at these boundaries**
  - **interpolation is performed by calculating a surface which satisfies the boundary conditions**

Coloring Techniques

- standard fill algorithms can replace traditional hand coloring

Paint Systems

- much more than an interactive system with area filling using coloring facilities

- typically a menu-driven program for handpainting two-dimensional images

- typically inclusions

  - different modes of painting

    - simple

    - rubber stamping

    - smearing

    - filtered

    - antialiased

  - automatic filling

  - brush creation and storage

  - palette creation and storage

  - picture storage

  - action recording

  - input scanning

  - drafting aids (smoothing, for example)

MODELED ANIMATION

Introduction

- the computer becomes more than a support, playing a basic role in the creation of the three-dimensional world

    - it creates the multiple components of a three-dimensional world

    - it renders them in perspective, a task which is manually untractable

        - a 1 hour 20 minute film with 24 frames per second requires 115,200 individual frames!

- three main activities

    - object modeling: constructing three-dimensional objects by digitizing, graphics editing or programming

    - motion specification and synchronization

        - changing and coordinating the positions and/or shapes of objects in the scene over time

          and/or

        - simulating camera adjustments over time

    - image rendering: using computer graphics techniques to produce images

Object Representations

- wire-frame representations
- surface representations
- volume representations

Object Creation

- 3D digitization
- 2D digitization and 3D reconstruction
- object modeling
  - create 3D objects
  - modify them using geometrical transformations
  - assemble them into more complex objects
- procedural modeling
  - represent object procedurally, retaining essential global object coherence information
  - change the model, as needed, by changing its parameters
  - simulate time-dependent behavior, as appropriate

Motion Specification

- stretching, twisting, bending and changing of cartoon shapes using interpolation techniques

- movement along p-curves

- synchronization and parallelism

    - for example, causing the wheels of the car to rotate as the car is translated - treating the car as an **actor type** and the wheels as **animated types**

Motion Control in 3D Animation

- two types of 3D computer animation
  - keyframe animation
  - algorithmic animation
- keyframe animation - two fundamental approaches
  - keyframe images are interpolated to produce in-betweens
    - also called image-based keyframe animation or shape interpolation
    - linear interpolation
      - lacks smoothness
      - produces discontinuities in speed of motion
      - produces distortions in rotations
    - nonlinear interpolation is partially satisfactory
  - parameter interpolation
    - also called parametric keyframe animation or key-transformation animation
    - keyframes are specified by an appropriate set of parameter values
    - parameters are interpolated
    - images are constructed from the interpolated parameters

- **algorithmic animation**
  - **also called modeled animation or procedural animation**
  - **motion is algorithmically described**
  - **physical laws can be applied to parameters**
- **a unified view**
  - **image-based keyframe animation**
    - **actors are characterized by vertices**
    - **motion is specified by keyframes**
      - **each keyframe contains values corresponding to the vertices**
    - **in-betweens are calculated by interpolation**
  - **parametric keyframe animation**
    - **actors are characterized by parameters**
    - **motion is specified by key values for each parameter**
    - **in-betweens are calculated by interpolation**
  - **algorithmic animation**
    - **actors are objects with a motion defined by a list of transformations**
    - **transformations are defined by parameters**
    - **parameters change during animation according to physical laws**

	Animation quality	CPU time	Human intervention	Versatility	Source of difficulty
Shape interpolation	Depends on the number of key-frames	Depends on the number of points and the type of interpolation law	Very long; lack of creativity	Very bad	Often unrealistic excep with many key-fram or a complex interpolation law
Parametric interpolation	Depends on the number of key-values	Depends on the number of parameters	Shorter, more creative	Better	To find the best parameters
Kinematic algorithmic animation	Depends on the laws, but often unrealistic	Depends on the laws, but not very expensive	May be difficult; depends on the human interface	Very good	Realistic laws are not so easy to find
Dynamic algorithmic animation	Very realistic	Very expensive	May be limited	Good	Complete dynamics-based models are too expensive for large sequences

Comparison of Animation

- three-dimensional shape interpolation
  - the major problem is not the interpolation, but achieving correspondence between two three-dimensional objects
    - the objects may have a different number of vertices
    - the objects may have a different number of facets
    - corresponding facets may have different numbers of vertices
  - approach
    - achieve a logical correspondence between facets
    - achieve a correspondence between the vertices of these facets
      - **main elements** are facets (or vertices) of one figure (or facet) which are transformed into vertices of a resulting facet
      - **extra elements** are facets (or vertices) which gradually disappear (xor appear)
    - construct the in-between figures
  - steps
    - achieve the correspondence between facets
    - achieve the correspondence between vertices
    - build the in-between facets

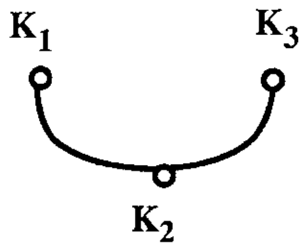
- better approach: find a piecewise continuous interpolation such as an interpolating spline

  - a cardinal spline

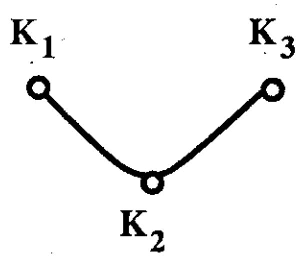
  - a Catmull-Rom spline

  - a Kochanek-Bartels spline

    - **tension** controls how sharply the curve bends

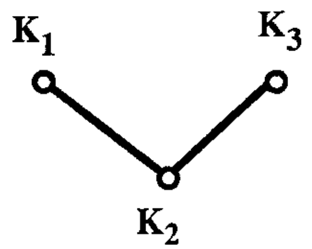


less tense

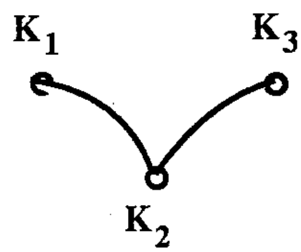


more tense

    - **continuity** in direction of speed and motion (or discontinuity, at the point of impact of a bouncing ball, for example)

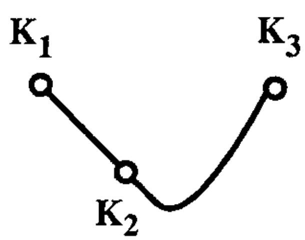


more continuous



less continuous

    - **bias** controls the direction of the path as it passes through a point



- **splines in keyframe animation**
  - **the general interpolation problem: given n data points, find a polyline or curve passing through these points**
    - **two extreme cases**

    1) **join adjacent pairs of points**

    2) **find a polynomial of degree n-1 that passes through all the points**
       - **high degree polynomials tend to oscillate**
       - **high degree polynomials are computationally expensive**

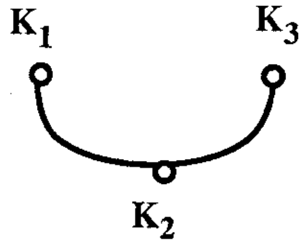
. better approach: find a piecewise continuous interpolation such as an interpolating spline

- a cardinal spline

- a Catmull-Rom spline

- a Kochanek-Bartels spline

  . **tension** controls how sharply the curve bends



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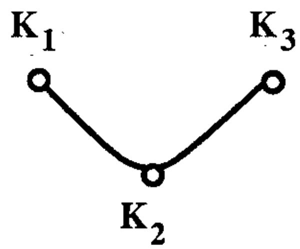

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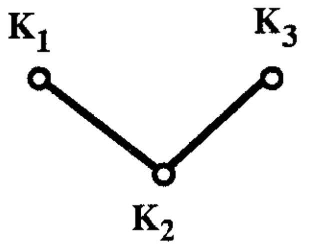
  . **continuity** in direction of speed and motion (or discontinuity, at the point of impact of a bouncing ball, for example)



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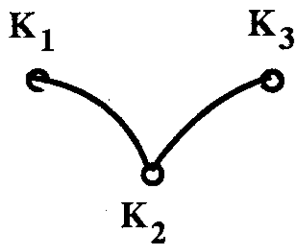

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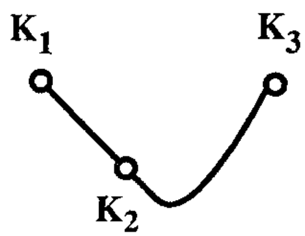


HUMAN MOTION AND ANIMATION

Stick, Surface and Volume Models

- modeling realistic human forms is challenging and difficult for two reasons
  - the human body is not composed of simple geometric and mathematical pieces
  - the movement of joints must reflect muscle action
    - computer models are much less satisfactory than projections of real movements - called rotoscopy
- three methods for modeling the human body in three dimensions
  - stick figures
  - surface models
  - volume models

Stick Figures

- a collection of body segments and joints
- contacts and sometimes twists are impossible to represent

Surface Figures

- skeletons surrounded by planar or curved patches
- Boeman (Boeing Corporation) is a 50th percentile three-dimensional, 23-joint human model
  - he can reach for objects (a basket, for example) if a mathematical description of the object and the task is provided
  - collisions are identified
- Buford (Rockwell International) is a 50th percentile three-dimensional, 15-link human model
- Cyberman (Chrysler Corporation) was created to study the position and motion of automobile drivers
- Combiman (Aerospace Medical Research Center), an adjustable-percentile, 35-link model, was designed to test human access to objects in a cockpit
- Sammie (University of Nottingham) is a 21-rigid-link, 17-joint model
  - choice of types: slim, fat, muscled
  - well-developed vision system
  - complex objects can be manipulated

Volume Figures

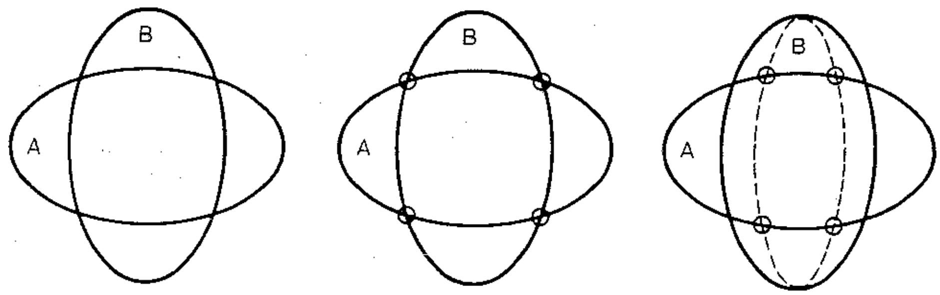
- a body composed of several primitive volumes (cylinders, ellipsoids and/or spheres)

- cylinders (curved surfaces) make hidden-surface removal very difficult; joints are difficult, too

- ellipsoid models

  - stick figures fleshed out by ellipsoids

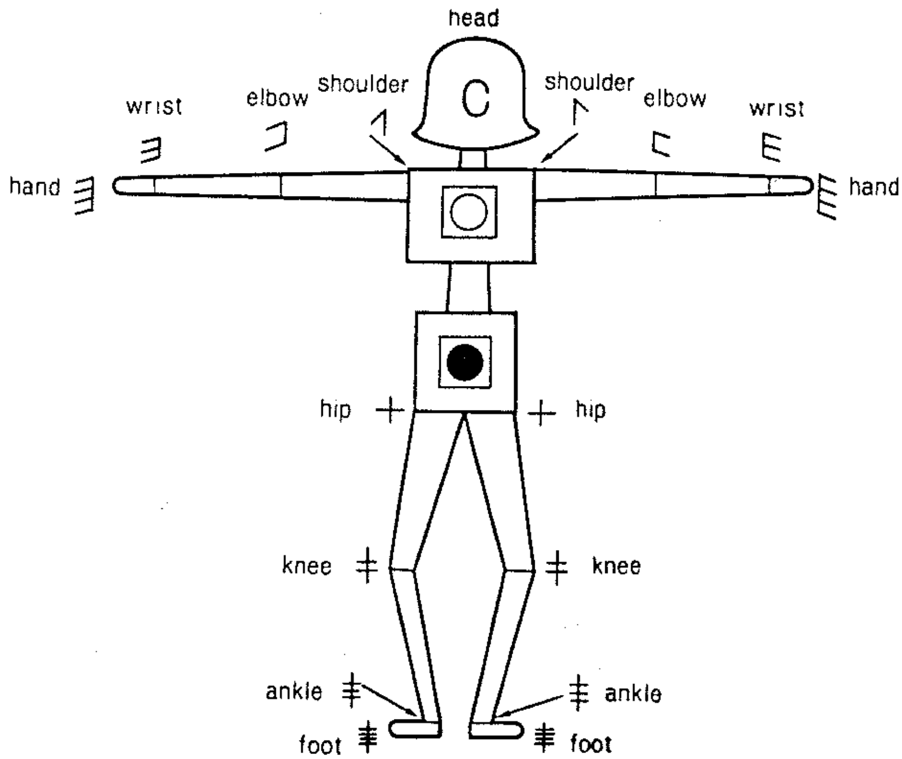
  - visible portions of ellipsoids are found by discovering obscuration points (b) and interpenetration points (c)



- sphere models
    - stick figures (skeletons) fleshed out by spheres (bubbles)
    - the skeleton is a set of joints and segments organized in a tree structure
        - nodes are segments
        - edges are joints
        - each segment is defined in its own local coordinate system
        - motion processing is limited to a segment and its subsegments
    - spheres offer four advantages
        - the projection is always a circle on a vector display or a shaded disk on a raster display
        - spheres have no privileged orientation
        - overlapping spheres have similar depths
            - and hence similar intensities
            - and hence appear to merge smoothly
        - hidden surface removal can be done with a z-buffer

Labanotation

- computer-modelled human motion can be improved by studying real human motion
- labanotation: viewing the body as a set of joints and connected limbs

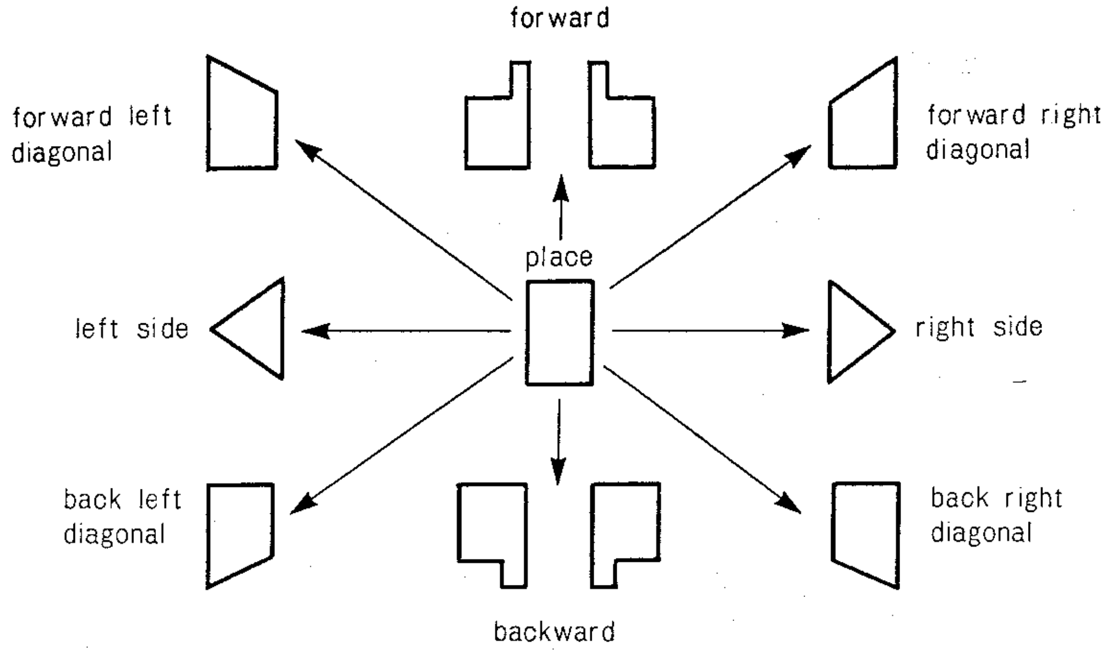


Joints

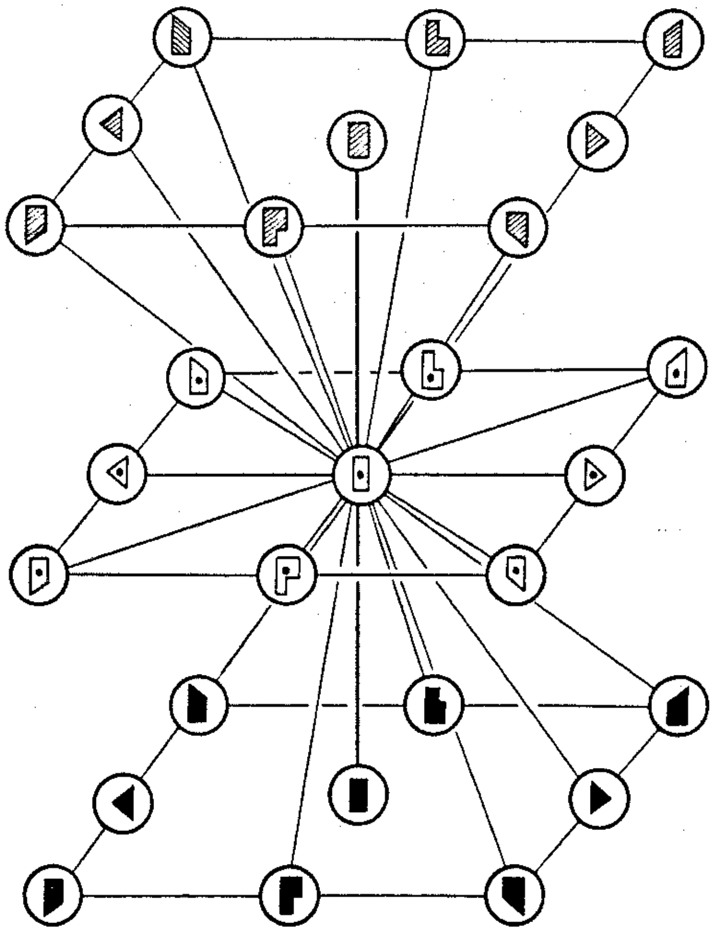
- for each, a position is specified with respect to a set of axes
- two joints with specific roles
  - distal joint: an active joint
    - further away
  - proximal joint: one from which movement is carried out
    - closer
- classification of operations for movement of a distal joint
  - direction signs for translation of joints
  - revolution signs for rotation of joints
  - facing signs for orientation of points on surfaces
    - orientation of a palm, for example
  - contact signs for the contact of two body parts or a body part and an object
  - shape signs for tracing the path or formation of a shape by some body part
- symbols describe operations
  - symbol shapes describe movement
  - intensity describes its level
  - size describes its duration

Directional Symbols

- **two-dimensional**

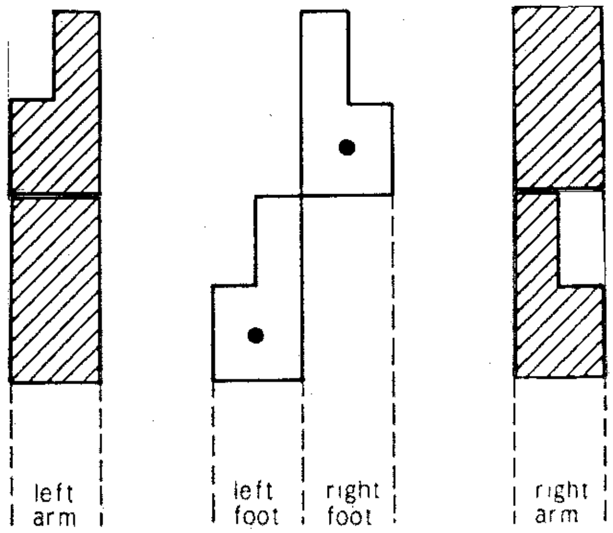


- **three-dimensional**



Directional Symbols, cont.

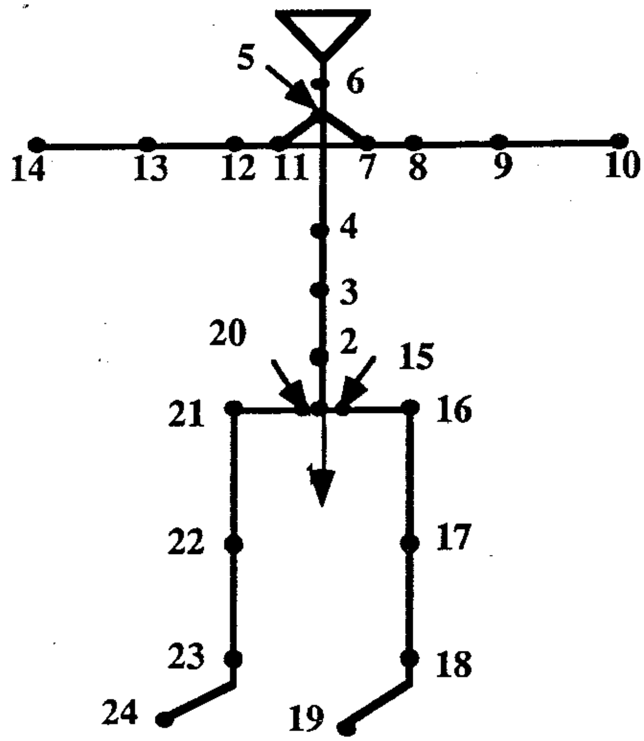
. a walking cycle



Parametric Keyframe Animation of Articulated Bodies

- keyframes consist of appropriate parameter values
- images are constructed from parameters which are interpolated
- for human animation, angles between various body parts are provided at certain times
    - a joint may have three kinds of position angles
        - flexion (rotation of a limb)
        - pivot (flexion axis rotation around the limb)
        - twisting (torsion of a limb)

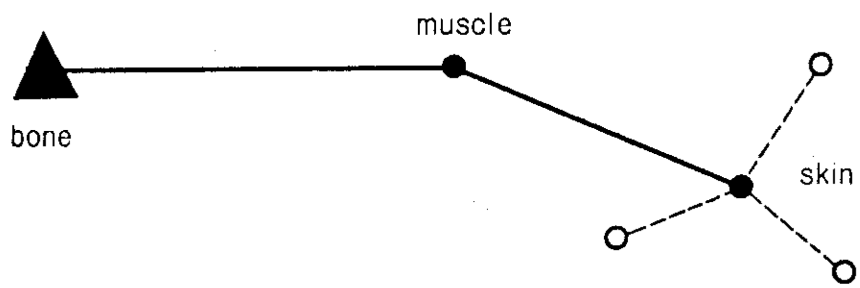
Name	Number	Angles
VERTEBRA 1	2	FTP
VERTEBRA 2	3	FTP
VERTEBRA 3	4	FTP
VERTEBRA 4	5	FTP
VERTEBRA 5	6	FTP
LEFT CLAVICLE	7	FP
RIGHT CLAVICLE	11	FP
LEFT SHOULDER	8	FTP
RIGHT SHOULDER	12	FTP
LEFT ELBOW	9	FT
RIGHT ELBOW	13	FT
LEFT WRIST	10	FP
RIGHT WRIST	14	FP
LEFT HIP	15	F
RIGHT HIP	20	F
LEFT THIGH	16	FTP
RIGHT THIGH	21	FTP
LEFT KNEE	17	F
RIGHT KNEE	22	F
LEFT ANKLE	18	F
RIGHT ANKLE	23	F
LEFT TOE	19	F
RIGHT TOE	24	F



Facial Animation

- two problems
  - a realistic image with natural-looking skin
    - texture mapping is one solution
  - the modeling of motion
    - numerous muscles to consider
    - interactions between muscles and bone structures
- Parke's two approaches to modeling motion
  - the key-frame approach
    - in-betweens are calculated by the computer
    - animation requires too many keyframes
  - the parameterized facial model
    - an appropriate set of facial parameters is based on
      - observation
      - underlying structures that cause facial expressions

- two classes of parameters
  - expression
    - the eyes (dilation, opening, direction of vision, etc.)
    - the mouth (jaw rotation, width of mouth, smiling, etc.)
  - conformation (skin color, eye color, neck dimensions, nose characteristics, etc.)
- interdependency of parts makes modeling motion difficult
- five types of operations determine the positions of the vertices of the polygons describing the face and the eyes
  - procedural animation for modelling the eyes
  - interpolation for the forehead, cheek bone region, neck and mouth
  - rotation for opening the mouth
  - scaling to control the relative sizes of facial features
  - position offsets for controlling the corners of the mouth or raising the upper lip



- **the Platt and Badler model**
  - **based on underlying facial structure**
  - **muscles and bones are simulated by a set of three-dimensional networks**
  - **the skin surface is defined by a set of 3D points which is movable**
  - **bones are rigid**
  - **muscles are group of points with elastic arcs**

- other models
  - Nahas et al. proposed a method based on B-splines
    - the face is digitized
    - a set of control points is determined for a 5-dimensional bicubic B-spline surface
  - Hill animated speech using speech synthesized by rules
  - Lewis and Parke automated lip synchronization
  - Waters represented the action of muscles using primary motivators in a nonspecific deformable topology of the face
    - linear/parallel muscles pull
    - sphincter muscles squeeze
    - influence depends on degree of contraction
  - Guenter proposed an interactive system for
    - attaching muscles and wrinkle lines to arbitrary rectangular face meshes
    - simulating contractions of those muscles