Slide Credit: Don Fussell

CS354 Computer Graphics Character Animation and Skinning

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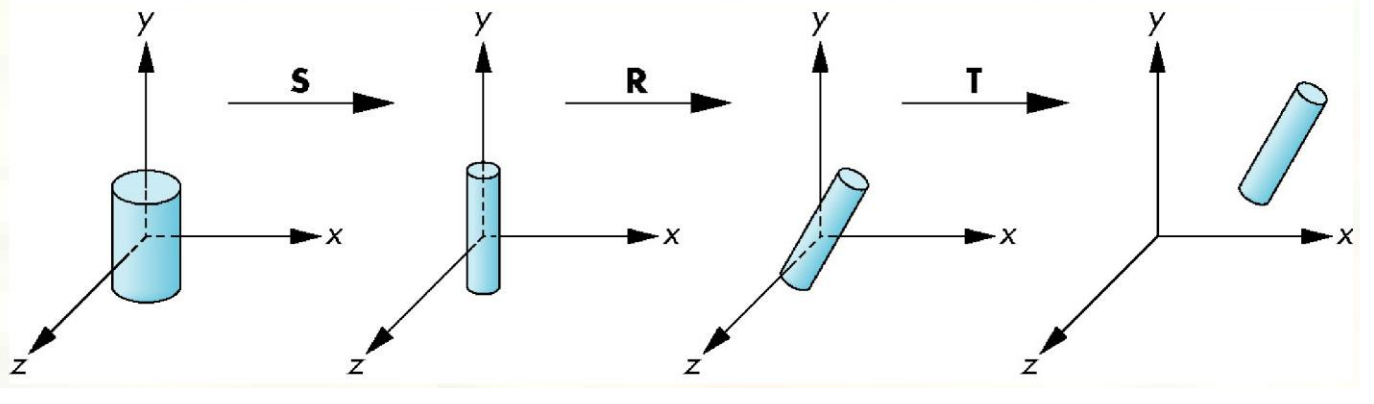
Instance Transformation

- Start with a prototype object (a symbol)
- Each appearance of the object in the model is an instance
  - Must scale, orient, position
  - Defines instance transformation



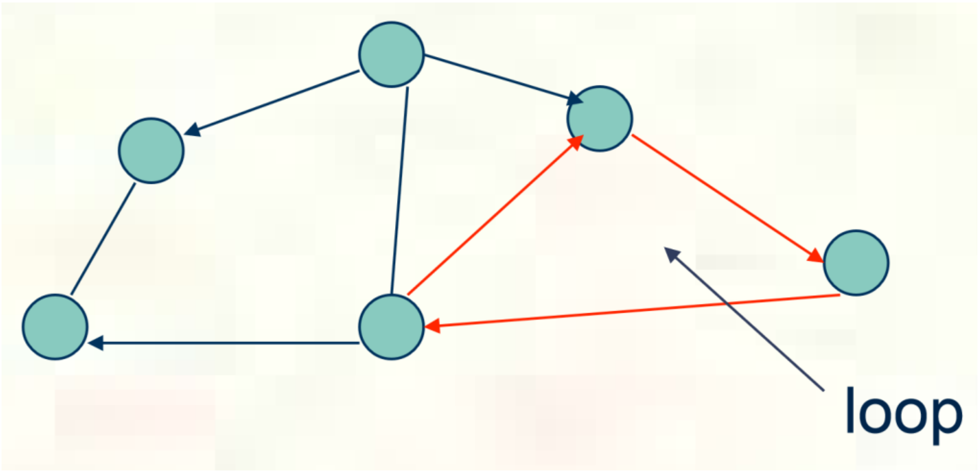
Structure Through Function Calls

```
car(speed){
     chassis()
     wheel(right_front);
     wheel(left_front);
     wheel(right_rear);
     wheel(left_rear);
}
```

- Fails to show relationships well
- Look at problem using a graph

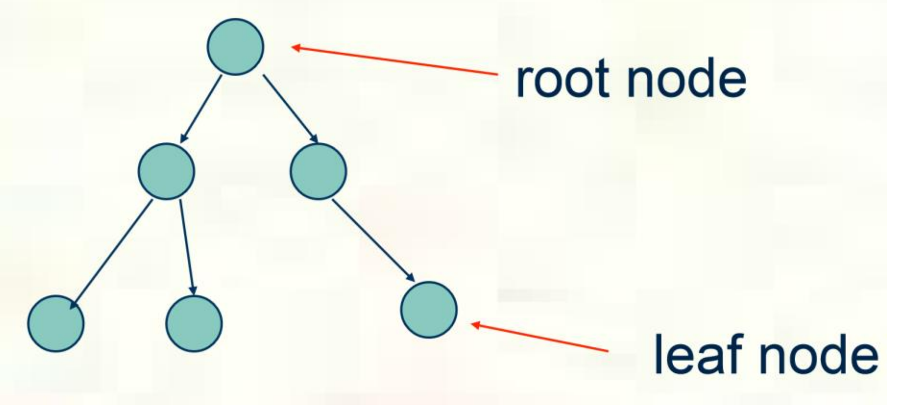
Graphs

- Set of nodes and edges (links)
- Edge connects a pair of nodes
  - Directed or undirected
- Cycle: directed path that is a loop

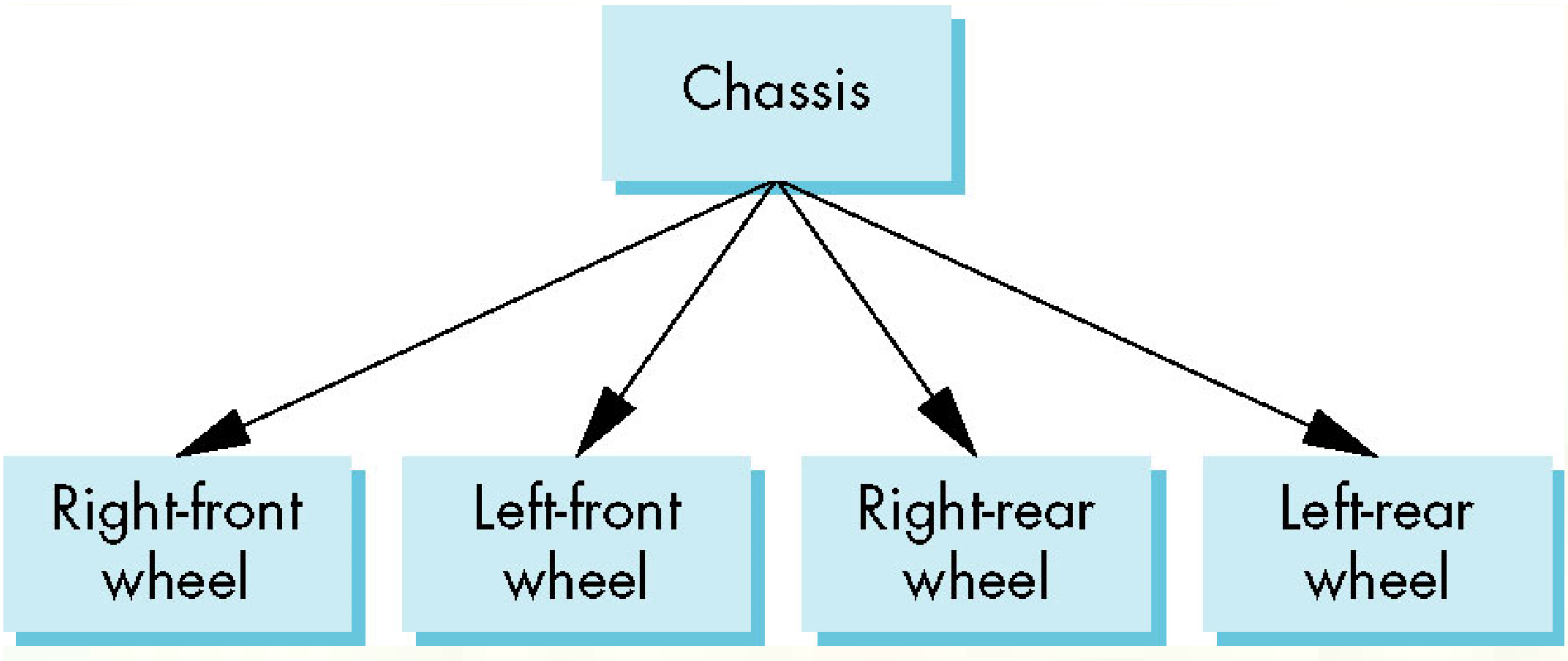


Tree

- Graph in which each node (except the root) has exactly one parent node
  - May have multiple children
  - Leaf or terminal node: no children

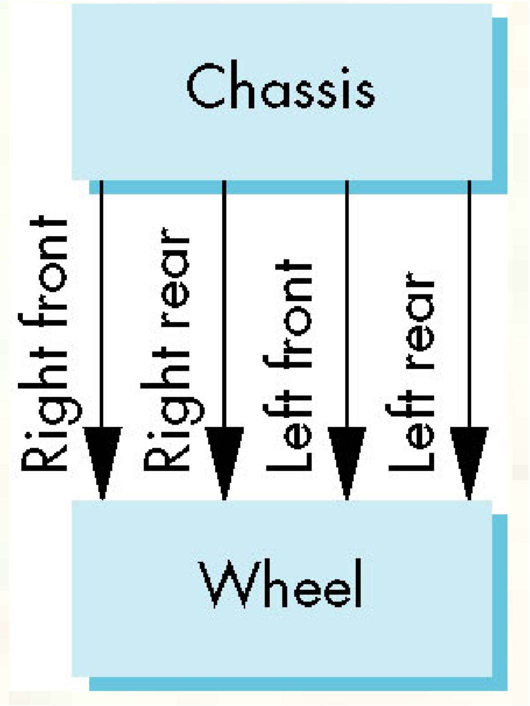


Tree Model of Car



DAG Model

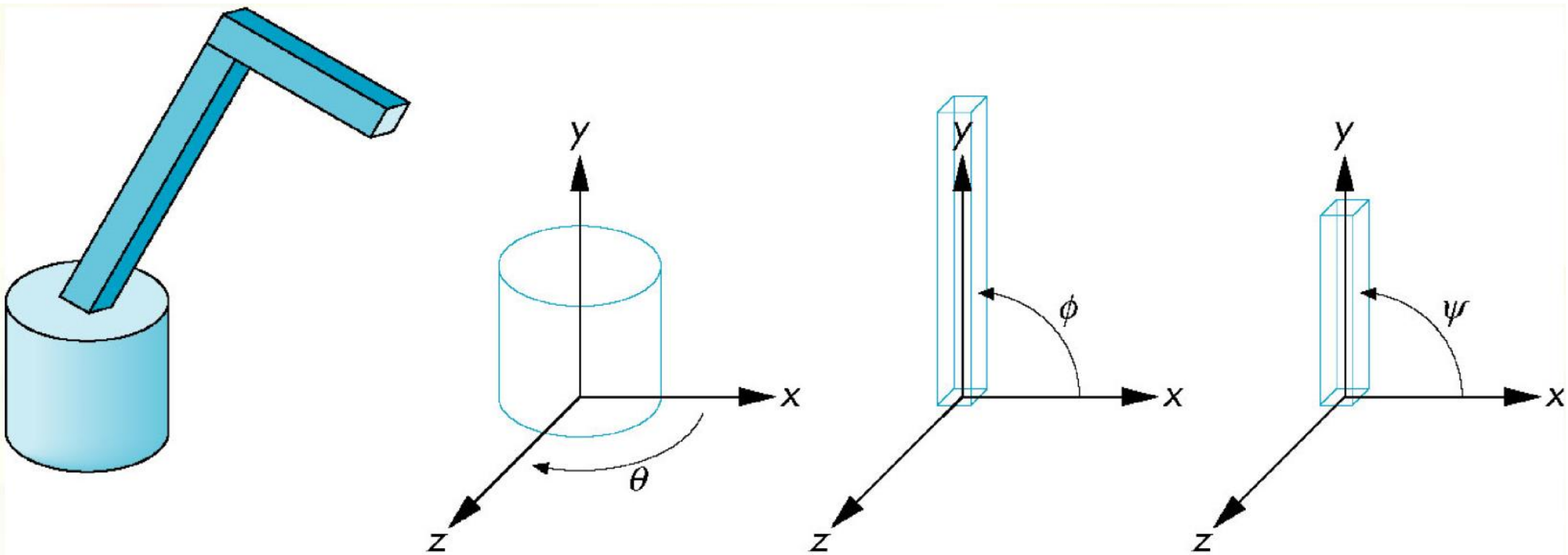
- If we use the fact that all the wheels are identical, we get a directed acyclic graph
  - Not much different than dealing with a tre



Modeling with Trees

- Must decide what information to place in nodes and what to put in edges
- Nodes
  - What to draw
  - Pointers to children
- Edges
  - May have information on incremental changes to transformation matrices (can also store in nodes)

Robot Arm

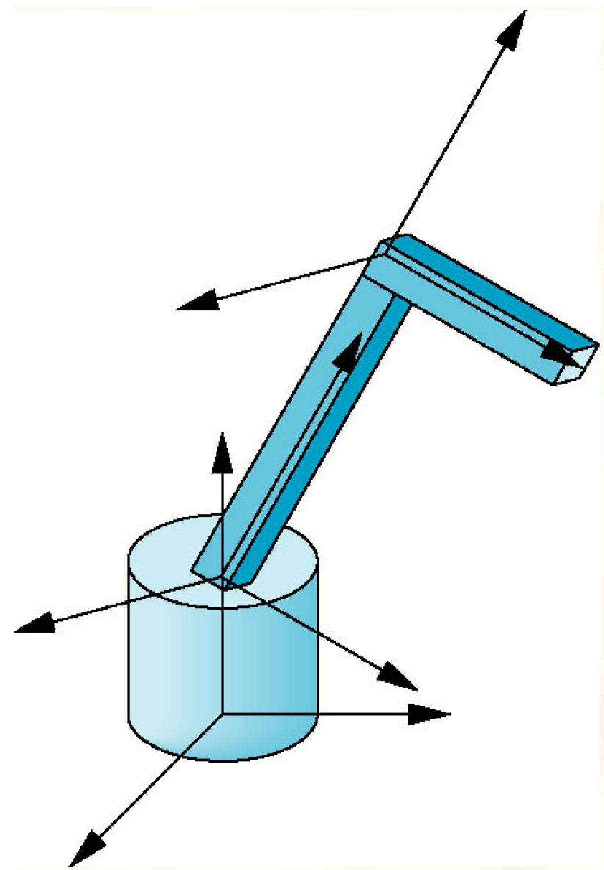


robot arm

parts in their own coodinate systems

Articulated Models

- Robot arm is an example of an articulated model
  - Parts connected at joints
  - Can specify state of model by giving all joint angles



Relationships in Robot Arm

- Base rotates independently
  - Single angle determines position
- Lower arm attached to base
  - Its position depends on rotation of base
  - Must also translate relative to base and rotate about connecting joint
- Upper arm attached to lower arm
  - Its position depends on both base and lower arm
  - Must translate relative to lower arm and rotate about joint connecting to lower arm

Required Matrices

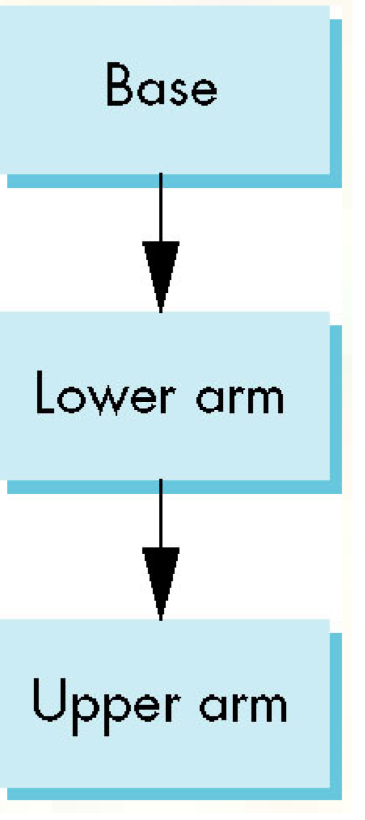
- Rotation of base: $\mathbf{R}_b$
  - Apply $\mathbf{M} = \mathbf{R}_b$ to base
- Translate lower arm <u>relative</u> to base: $\mathbf{T}_{lu}$
- Rotate lower arm around joint: $\mathbf{R}_{lu}$
  - Apply $\mathbf{M} = \mathbf{R}_b \mathbf{T}_{lu} \mathbf{R}_{lu}$ to lower arm
- Translate upper arm <u>relative</u> to upper arm: $\mathbf{T}_{uu}$
- Rotate upper arm around joint: $\mathbf{R}_{uu}$
  - Apply $\mathbf{M} = \mathbf{R}_b \mathbf{T}_{lu} \mathbf{R}_{lu} \mathbf{T}_{uu} \mathbf{R}_{uu}$ to upper arm

OpenGL Code for Robot

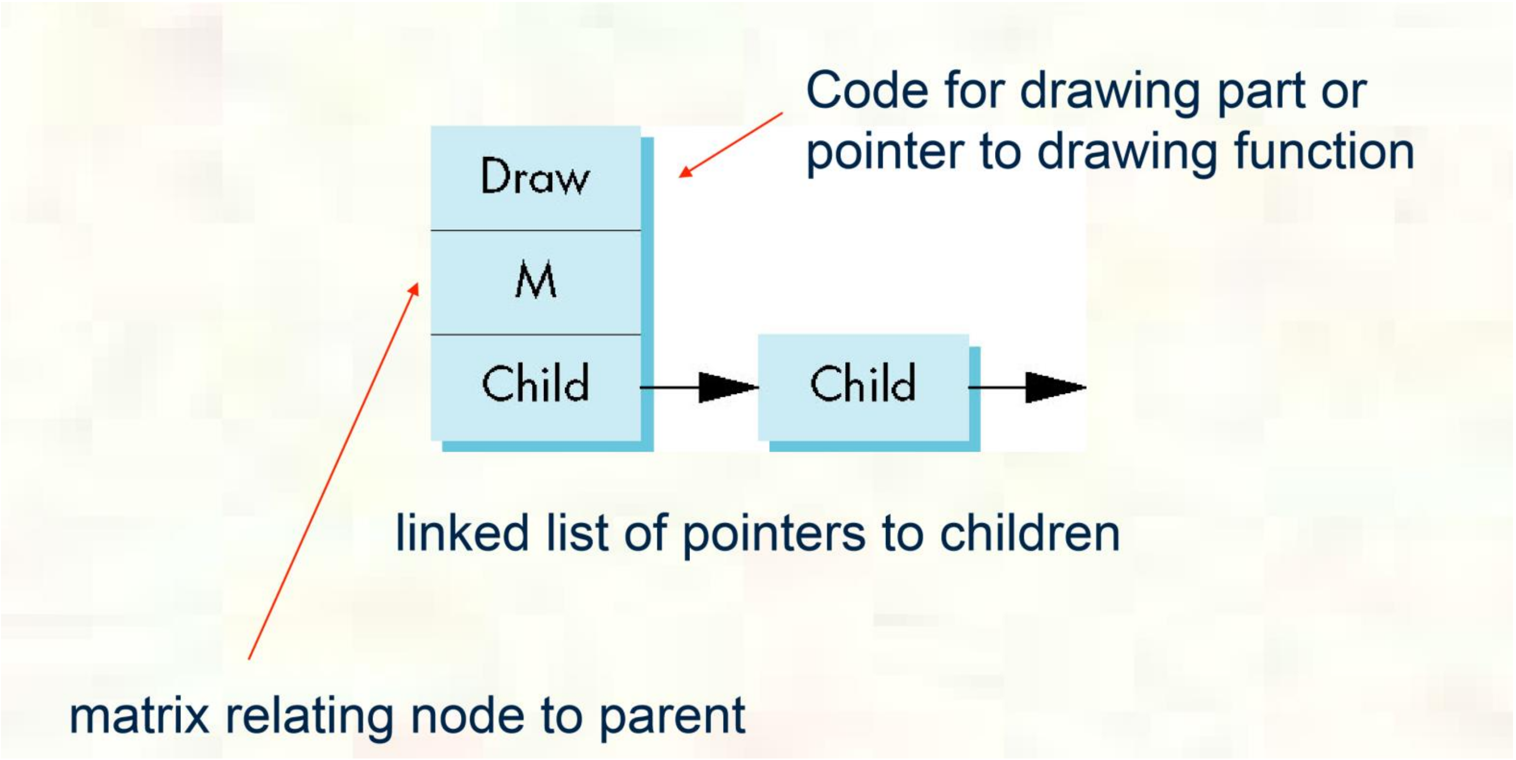
```
robot_arm(){
    glRotate(theta, 0.0, 1.0, 0.0);
    base();
    glTranslate(0.0, h1, 0.0);
    glRotate(phi, 0.0, 0.0, 1.0);
    lower_arm();
    glTranslate(0.0, h2, 0.0);
    glRotate(psi, 0.0, 0.0, 1.0);
    upper_arm();
}
```

Tree Model of Robot

- Note code shows relationships between parts of model
  - Can change "look" of parts easily without altering relationships
- Simple example of tree model
- Want a general node structure for nodes



Possible Node Structure

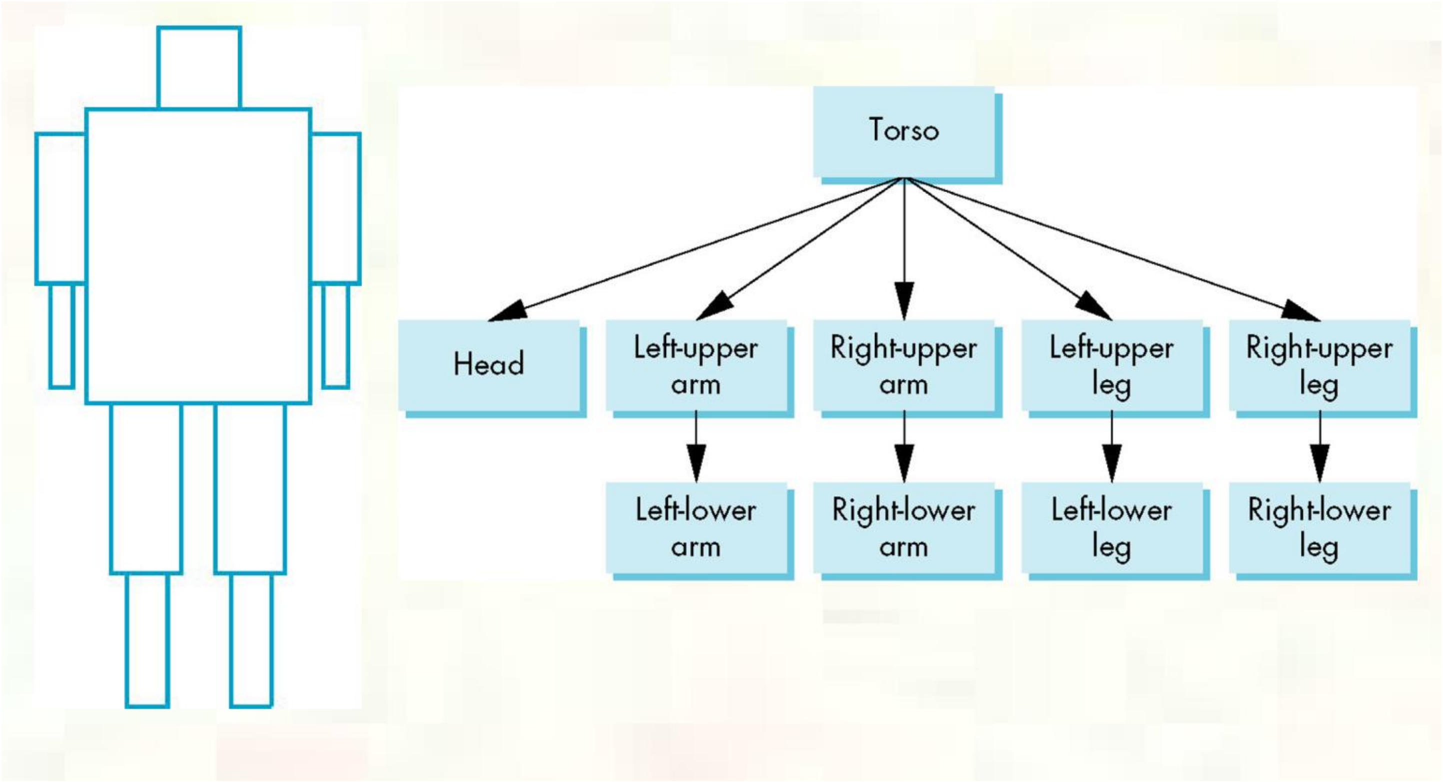


Generalizations

- Need to deal with multiple children
  - How do we represent a more general tree?
  - How do we traverse such a data structure?

- Animation
  - How to use dynamically?
  - Can we create and delete nodes during execution?

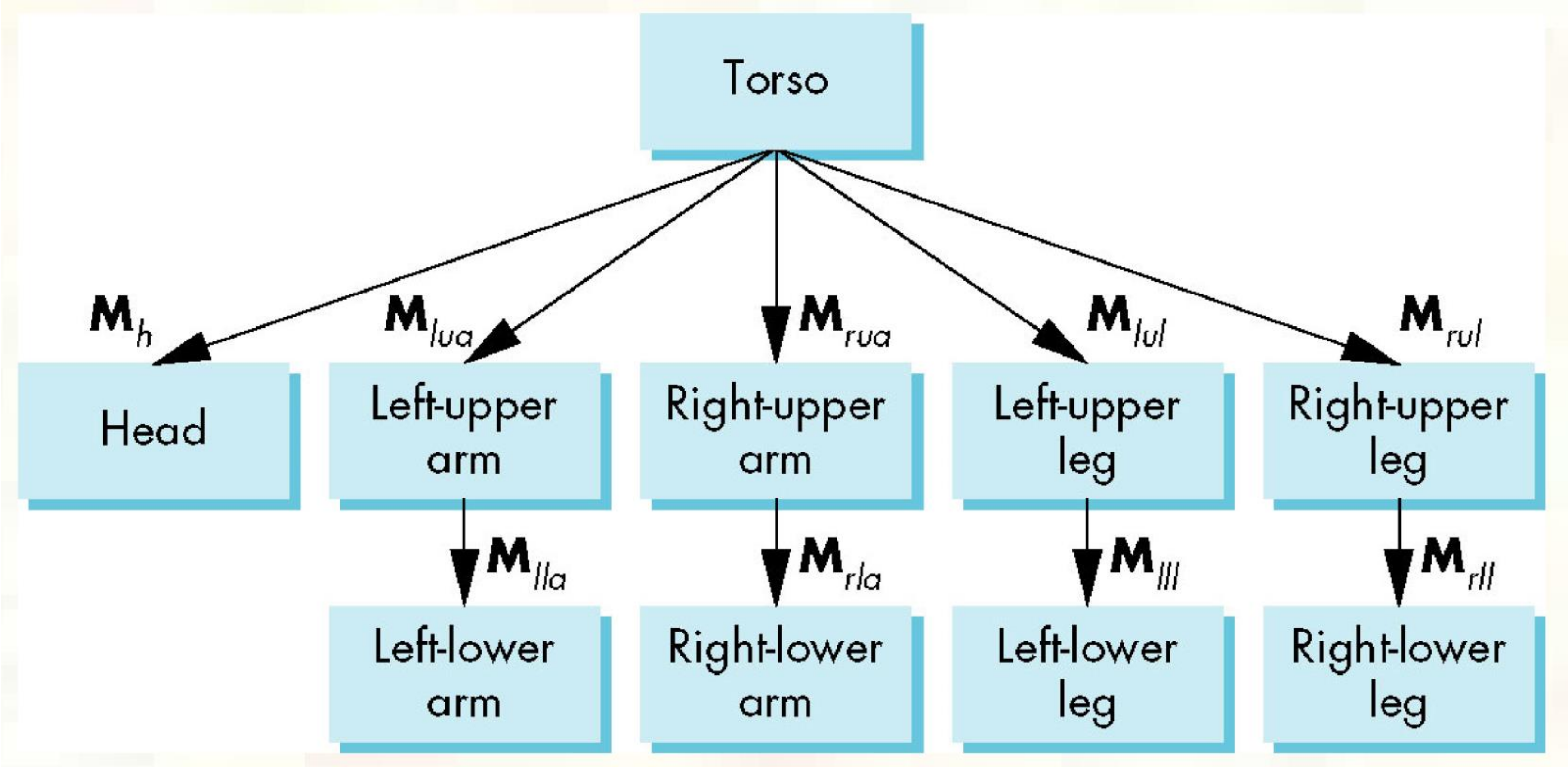
Humanoid Figure



Building the Model

- Can build a simple implementation using quadrics: ellipsoids and cylinders
- Access parts through functions
  - torso()
  - left_upper_arm()
- Matrices describe position of node with respect to its parent
  - M_{lla} positions left lower leg with respect to left upper arm

Tree with Matrices



Display and Traversal

- The position of the figure is determined by 11 joint angles (two for the head and one for each other part)

- Display of the tree requires a graph traversal
  - Visit each node once
  - Display function at each node that describes the part associated with the node, applying the correct transformation matrix for position and orientation

Transformation Matrices

- There are 10 relevant matrices
  - M positions and orients entire figure through the torso which is the root node
  - M_h positions head with respect to torso
  - M_{lua}, M_{rua}, M_{lul}, M_{rul} position arms and legs with respect to torso
  - M_{lla}, M_{rla}, M_{lll}, M_{rll} position lower parts of limbs with respect to corresponding upper limbs

Stack-based Traversal

- Set model-view matrix to M and draw torso
- Set model-view matrix to $M\ M_h$ and draw head
- For left-upper arm need $M\ M_{lua}$ and so on
- Rather than recomputing $M\ M_{lua}$ from scratch or using an inverse matrix, we can use the matrix stack to store M and other matrices as we traverse the tree

Traversal Code

```
figure() {
    glPushMatrix()
    torso();
    glRotate3f(…);
    head();
    glPopMatrix();
    glPushMatrix();
    glTranslate3f(…);
    glRotate3f(…);
    left_upper_arm();
    glPopMatrix();
    glPushMatrix();
```

save present model-view matrix

update model-view matrix for head

recover original model-view matrix

save it again

update model-view matrix for left upper arm

recover and save original model-view matrix again

Analysis

- The code describes a particular tree and a particular traversal strategy
  - Can we develop a more general approach?

- Note that the sample code does not include state changes, such as changes to colors
  - May also want to use **glPushAttrib** and **glPopAttrib** to protect against unexpected state changes affecting later parts of the code

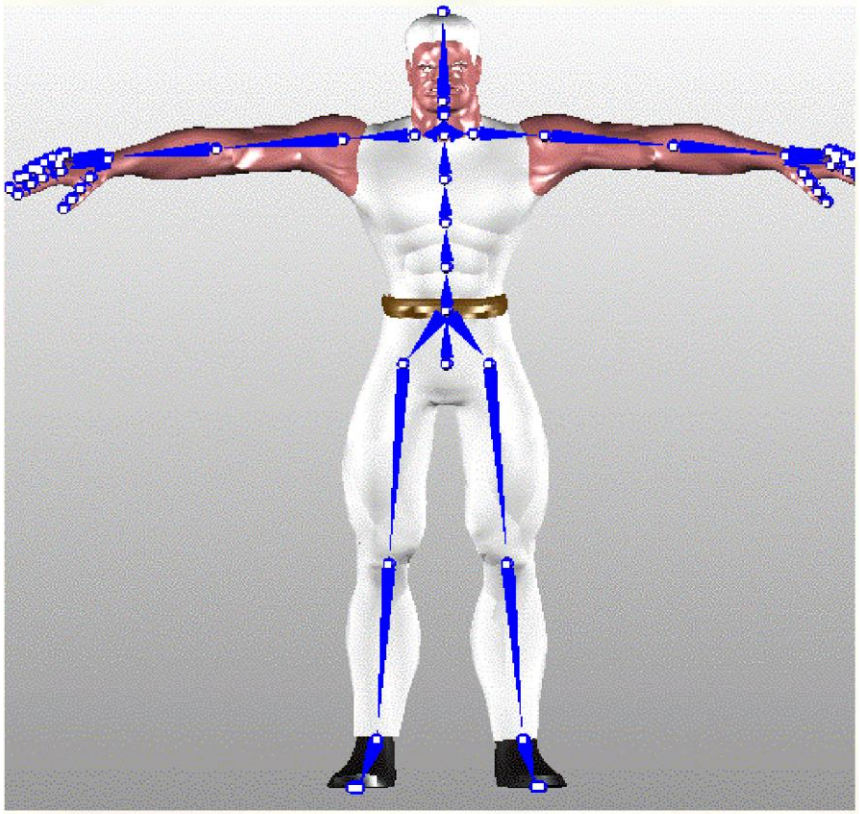
Skinning and Character Animation

Objectives

- Introduce the basics of character animation
- Introduce skinning
- Introduce basic linear blend skinning

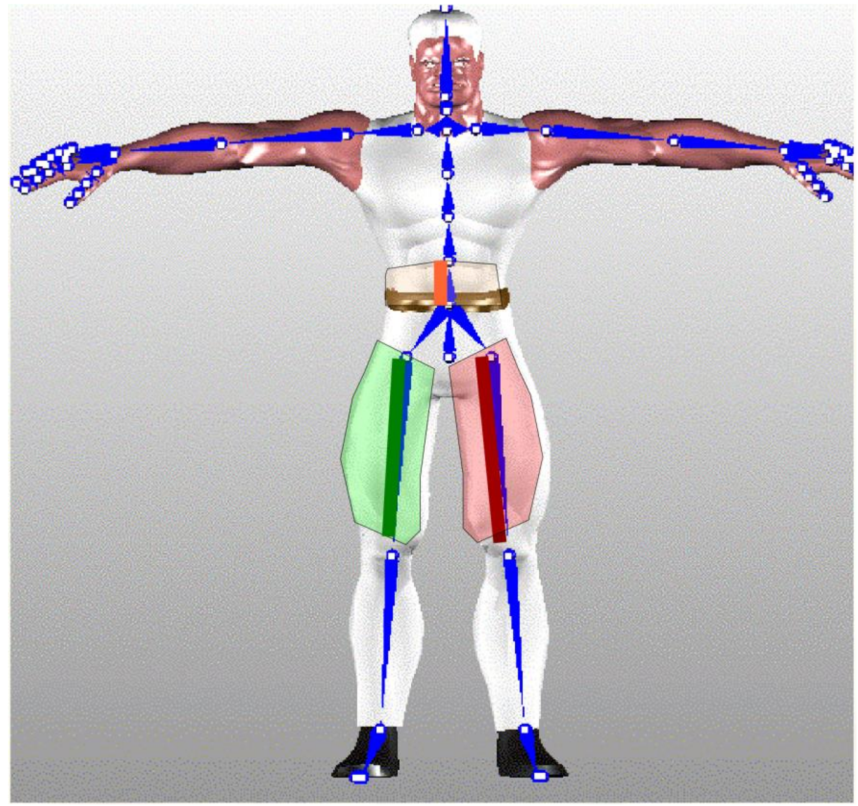
Character Animation

- Skeletons and skin
  - skeleton – a hierarchy of bones or joints
  - note arrows pointing from parent to child joint
  - skin – the polygon mesh defining the body surface



Binding

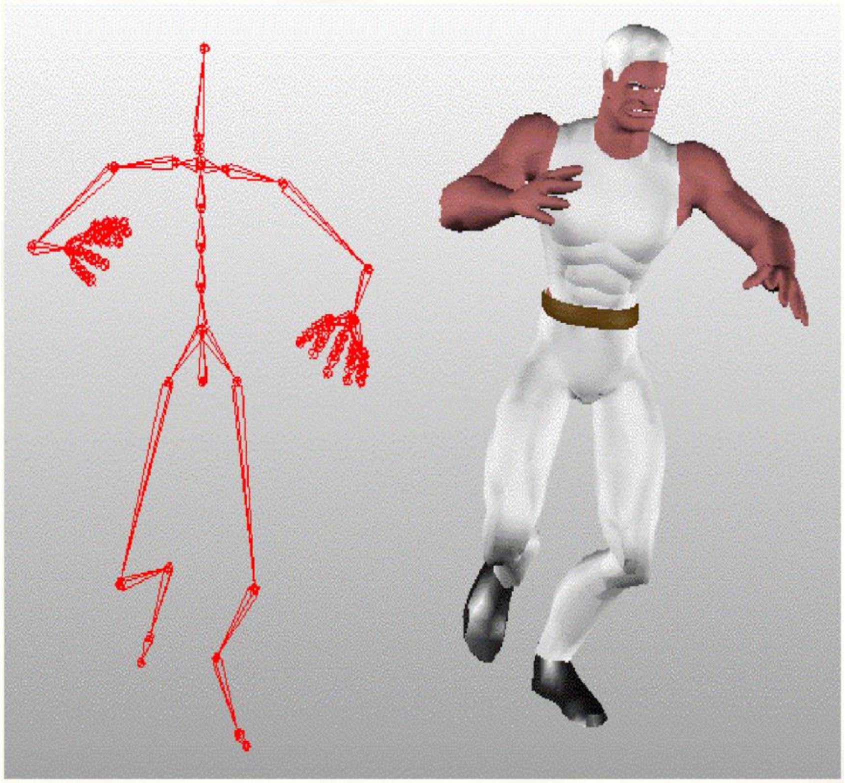
- Define transform between joint and skin spaces in rest or bind pose
- Associate skin vertices to subset of the joints



Animation

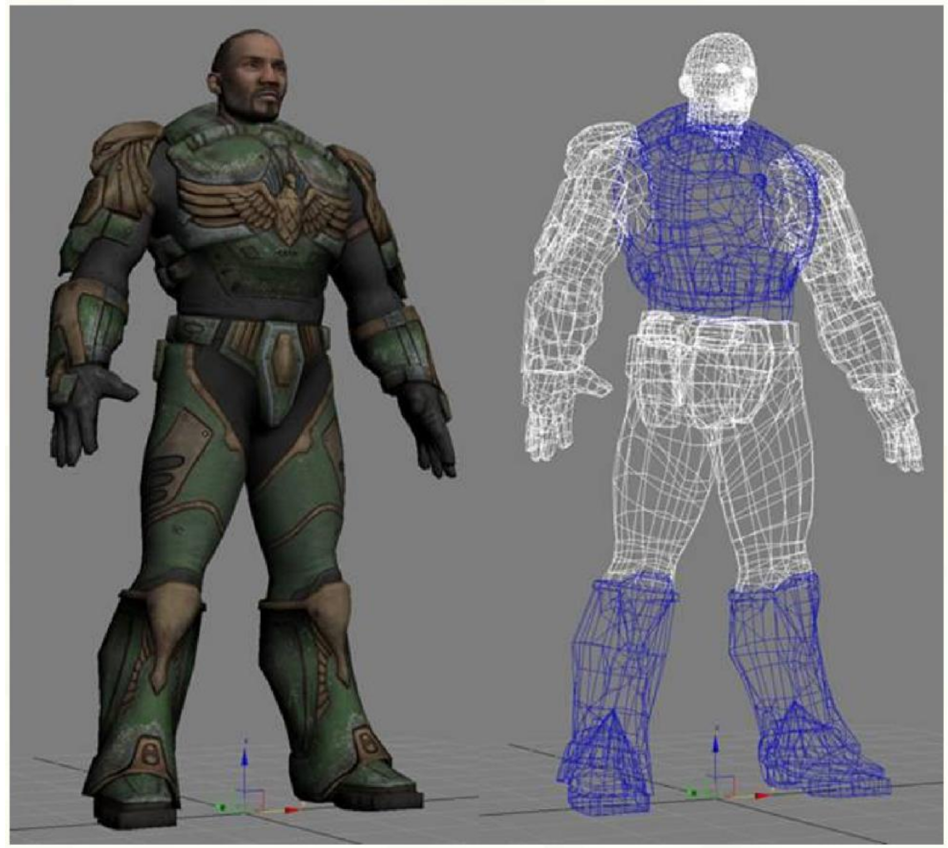
- Move the joints and the skin moves with them

- This deforms the mesh from its rest position



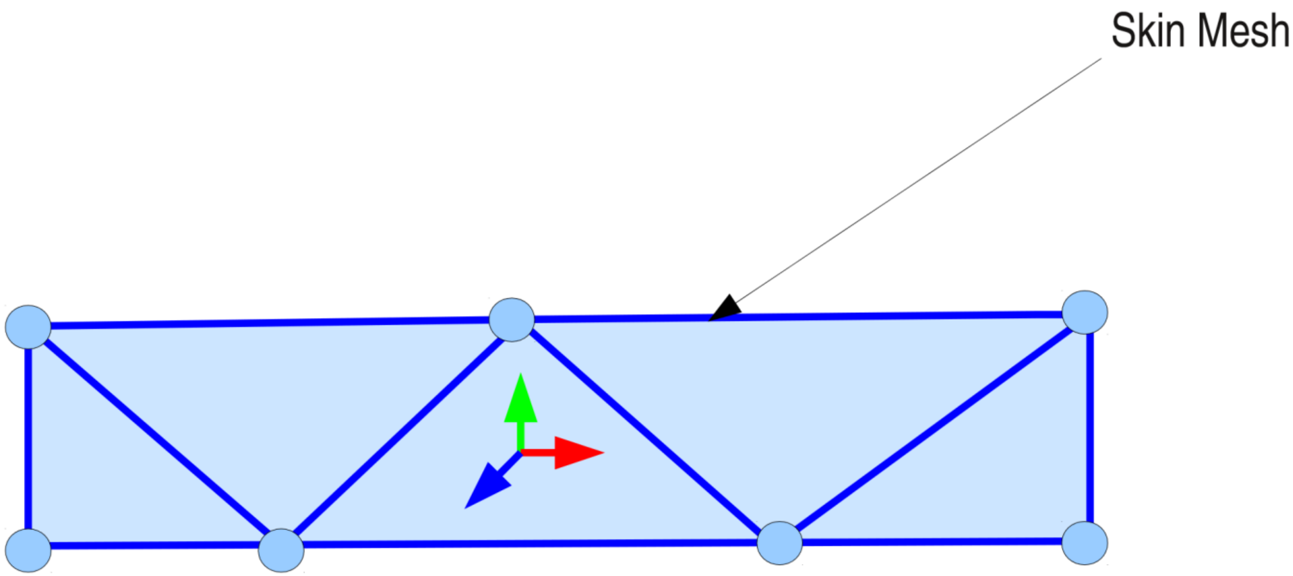
Skin

- Skin is a set of polygonal meshes
- A mesh is a collection of (connected) polygons



Skin

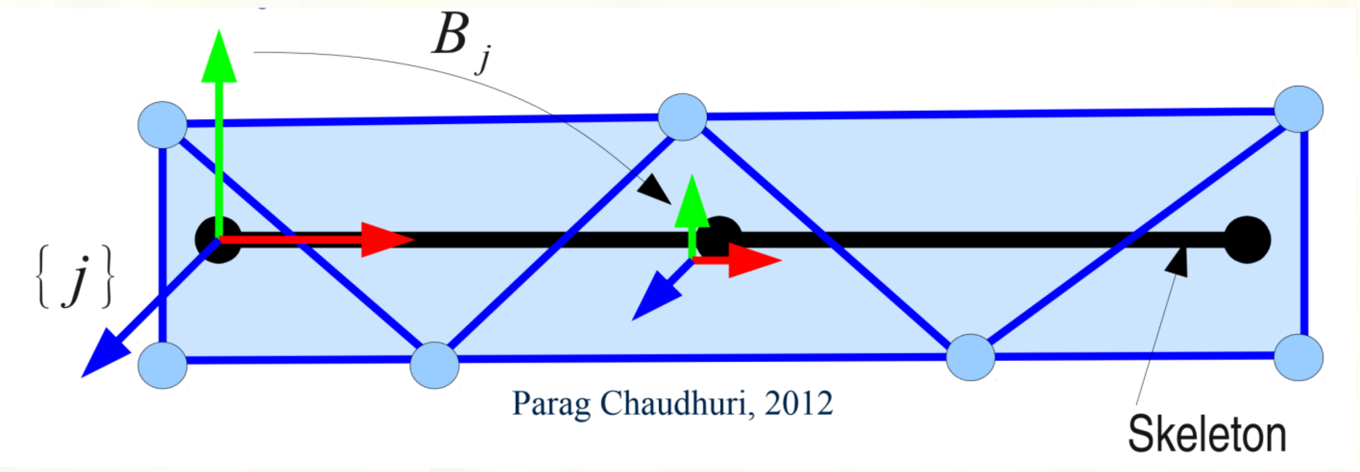
- A skin mesh is defined in its owe local frame



Parag Chaudhuri, 2012

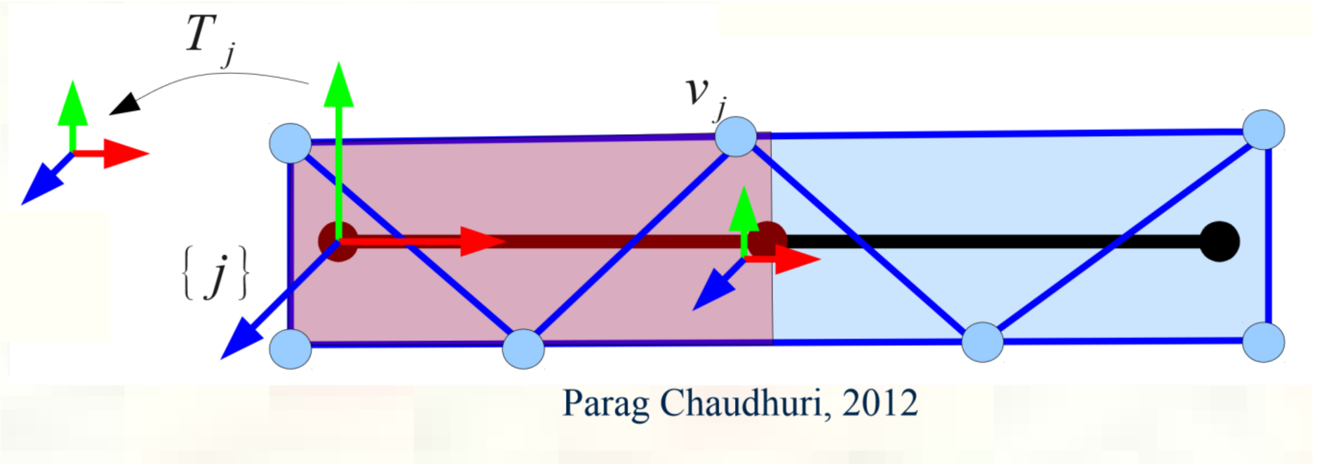
Binding

- Each joint (bone) has its own local frame
- Let B_j be the transformation from local joint frame j to the skin mesh local frame in the binding pose
- B_j is represented by a binding matrix



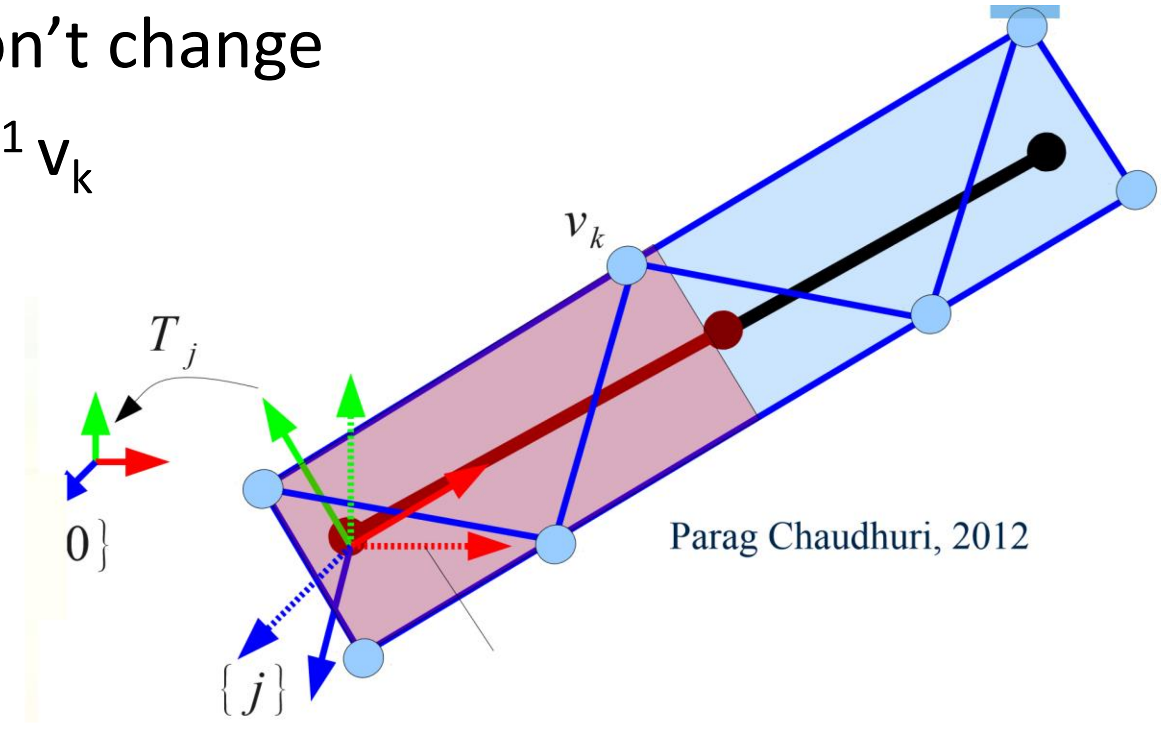
Rigid skinning – basic idea

- Associate a group of vertices to a single joint j
- Let T_j be the transformation from joint j local space to world space
- Then the skin vertex transform to world space for vertices v_k associated with joint j is $v_k^T = T_j B_j^{-1} v_k$



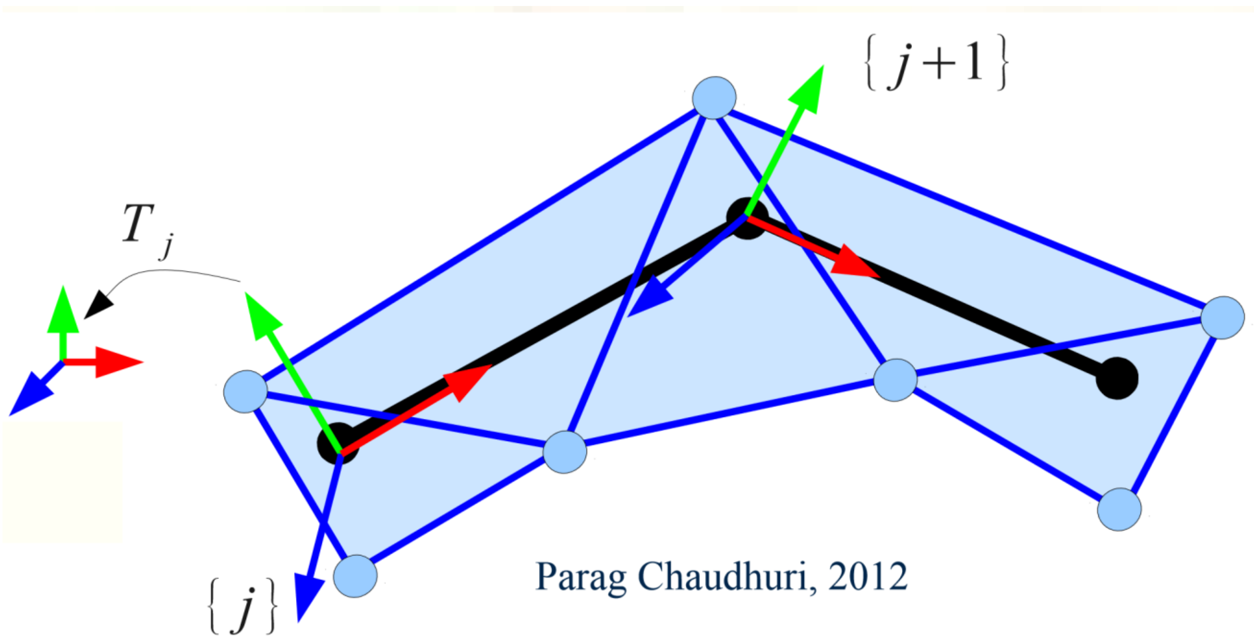
Joint motion

- When joint j moves, T_j changes and the skin vertices move with it
- The relative positions of the vertices in the local joint frame don't change
- $v_k^T = T_j B_j^{-1} v_k$



Problems with rigid skinning

- Simple but low quality because large distortions happen when bends form at joints



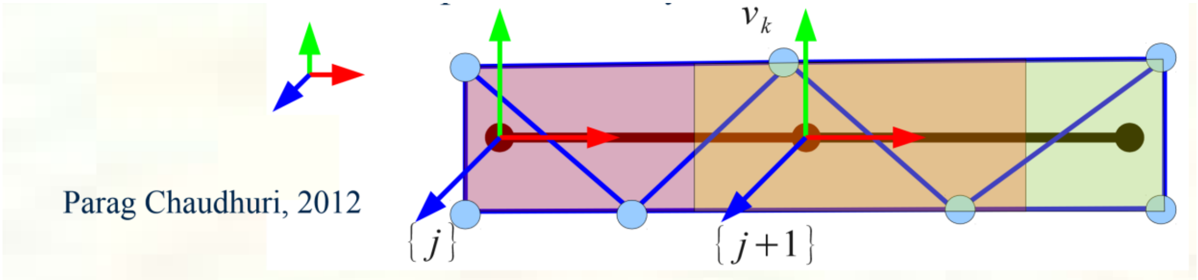
Linear Blending Skinning

- Adds flexibility to fix artifacts but still simple and fast
- Commonly used in games
- Vertices associated with multiple joints, not just one
- Vertex transform is a linear combination of the transforms associated with its joints. Each vertex has weights for this linear combination assigned to it

$$v'_k = \sum_i w_{i,k} T_i B_i^{-1} v_k$$

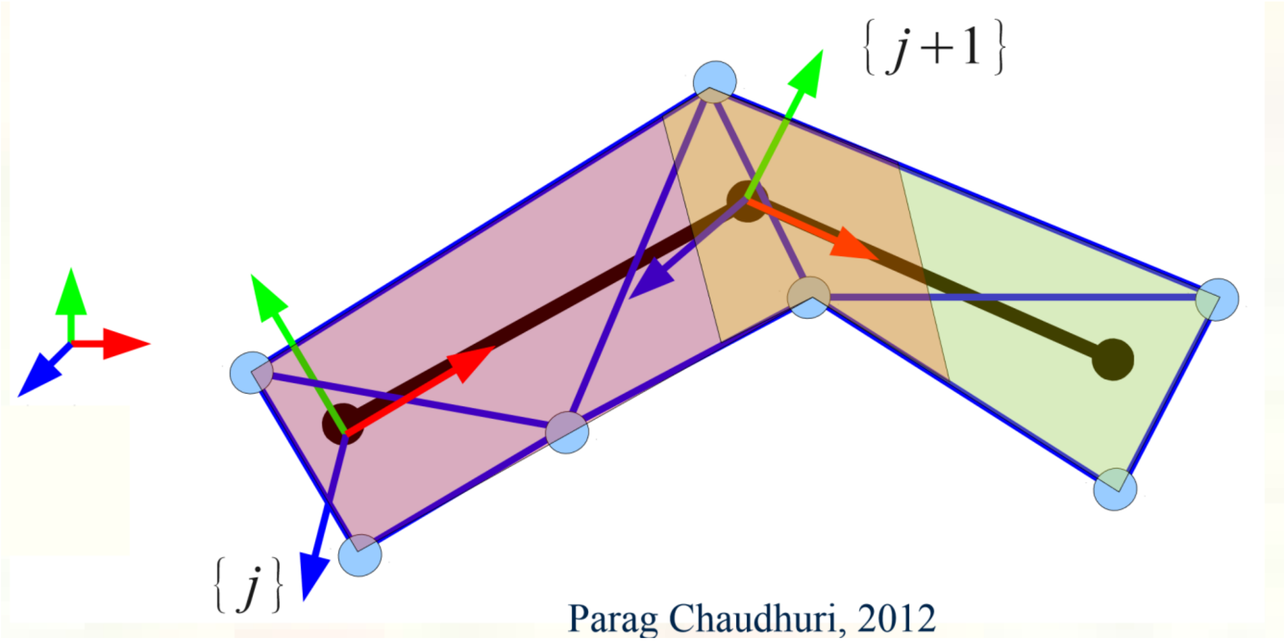
$$\forall k \sum_i w_{i,k} = 1 \text{ and } 0 \le w_{i,k} \le 1$$

- Vertex normal can be computed similarly



Fewer artifacts

- With proper weights many but not all artifacts are eliminated or improved



Linear blend skinning algorithm

- Skin::Update()
  - Compute $M_i = T_i B_i^{-1}$ for each joint. Note that B_i^{-1} can be precomputed and stored. For each vertex compute world position and normal.

- Skin::Draw()
  - Initialize ModelView matrix.
  - Draw skin polygons using global positions and vertices.

Problems

- Skin collapse at bends

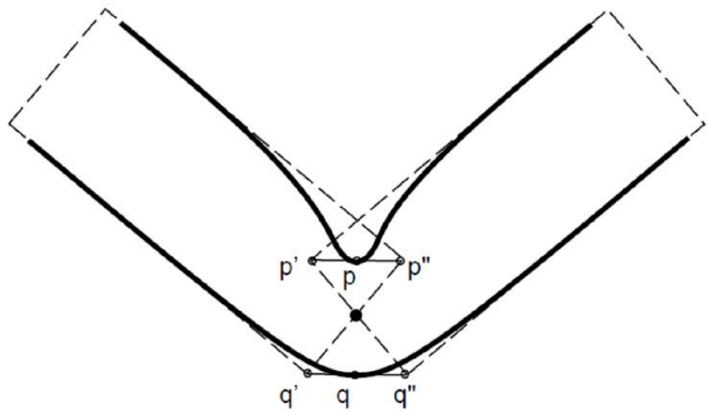
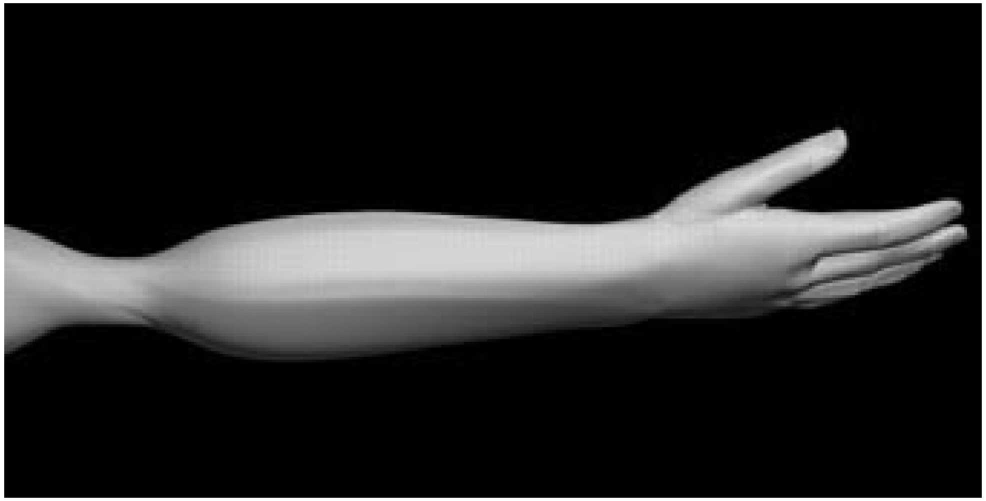


Figure 1: The skeleton subspace deformation algorithm. The deformed position of a point p lies on the line $p'p''$ defined by the images of that point rigidly transformed by the neighboring skeletal coordinate frames, resulting in the characteristic 'collapsing elbow' problem (solid line).

Pose Space Deformation: A Unified Approach to Shape Interpolation and Skeleton-Driven Deformation, Lewis, Cordner and Fong, SIGGRAPH 2000

Problems

- Skin collapses at twists



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Dual Quaternion Skinning

- Better solution, nearly as fast

Geometric Skinning with Approximate Dual Quaternion Blending, Kavan
Collins, Zara and O'Sullivan, ACMTOG 2008

Linear Blend Skinning

- Problems
  - Binding is difficult – what joints should each vertex be associated with?
  - Weight assignment is not intuitive and very time-consuming
  - Still have collapse with linear blend skinning
- Advantages
  - Simple
  - Fast
  - Easy GPU implementation