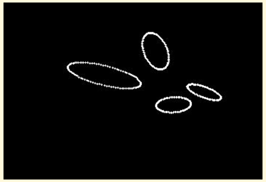
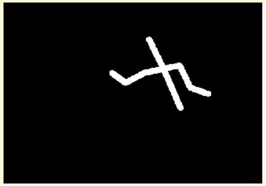
Home Page
Title Page
Page 1 of 35
Go Back
Full Screen
Close
Quit

Markerless Motion Capture using Monocular Videos: A Case Study for Bharatanatyam



by
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July, 2004

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Overview

- Introduction
- Our Approach
- Design of the System
- Results of Implementation
- Conclusions

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Video Processing using Computer Vision

- Video contains a lot of data – in space as well as time

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Video Processing using Computer Vision

- Video contains a lot of data – in space as well as time
- One frame $= 320 \times 240 = 76,800$ pixels
- Considering 30 frames per second, 10 second video contains $76,800 \times 30 \times 10 = 23,040,000$ pixels
- Consider 16 million colors (24-bit) for each pixel....
- Information Overflow makes the problem difficult
- Need intelligent methods to decide
  - What is important and useful?
  - What is junk?

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Home Page

Title Page

Page 4 of 35

Go Back

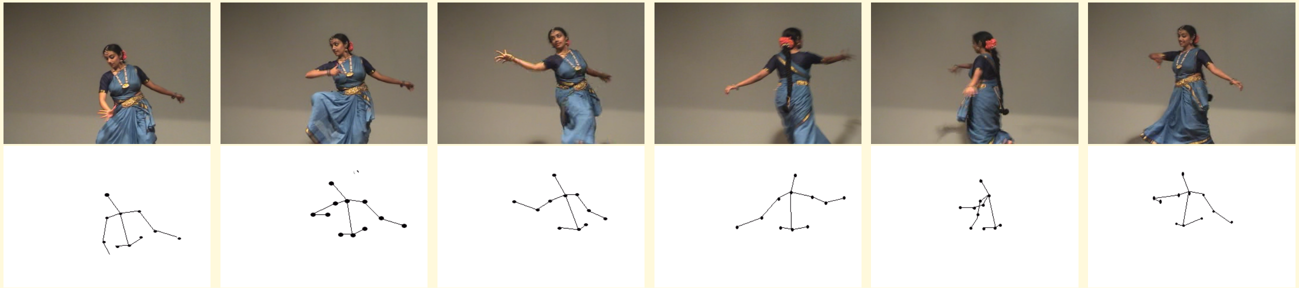
Full Screen

Close

Quit

1. Human Motion Capture

- Process of recording human body movements to get a compact representation of human skeleton and its motion
- Recovery of global position and orientation of a subject and various body parts and joints in 3D space



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Mechanical Method of MoCap

- Exoskeleton attached to movable parts and joints of human body

- Measure the movements of corresponding parts and produce appropriate signals

- *Drawback* –
  Heavily obstructs body movements

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Marker-based Multi-camera system of MoCap

- Done in special MoCap labs
- Dark colored clothes required
- White reflective markers attached to clothes of performer at joint locations
- These markers are viewed through multiple cameras
- *Drawback* – Highly tailored environment

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Stages in Marker-based method

- Tracking of body parts
  - Image processing to locate the markers' positions in various viewpoints
  - Establish correspondences

Stages in Marker-based method

- Tracking of body parts
  - Image processing to locate the markers' positions in various viewpoints
  - Establish correspondences
- Reconstruction of skeleton
  - Construction of 3D structure from 2D projections
  - Establish motion parameters

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Limitations of Marker-based Method

- **Expensive** – Requires specialized studios, multiple cameras, etc.

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- Solution – *Markerless Motion Capture using a single camera*

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2. Markerless Monocular MoCap

- Develop algorithms for obtaining motion capture data in a generalized environment

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- Develop algorithms for obtaining motion capture data in a generalized environment
  - No special studio required
  - Using a single camera
  - No artificial aids like markers, calipers
  - No restriction on clothes
- Using Bharatanatyam as an example

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New Challenges

- Image processing (Tracking) becomes difficult
- A lot of clutter needs to be removed

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New Challenges (Contd.)

- Reconstruction too becomes difficult
- Recover the depth information lost during recording
- Creating 3D from 2D !!
- Depth values have to be valid and consistent with each other

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Our approach

- Tracking
  - Use Domain-specific knowledge
  - Information about traditional dress of Bharatanatyam

Our approach

- Tracking
  - Use Domain-specific knowledge
  - Information about traditional dress of Bharatanatyam
- Reconstruction
  - Given a 2D projection, no. of possible 3D poses is finite.
  - For n links (limbs), max 2^n poses possible.
  - Many poses impossible to achieve physically. Discard them.
  - Build a weighted graph of valid poses and find minimum weight path across the sequence. This gives the smoothest motion sequence.

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Human Motion Capture
Markerless Monocular . . .
Phase I: Tracking
Phase II: Reconstruction
Conclusions

Home Page

Title Page

Page 13 of 35

Go Back

Full Screen

Close

Quit

What others have done

- Silhouette shape analysis
- Multiple camera voxel data
- Using motion library
- Factorization

3. Phase I: Tracking

- What we have is a grid of pixels
- What we want is the locations of joints
- Points to be considered
  - Projection Model
  - Human Model
  - Key Feature Tracking
  - Bodyparts Labeling
  - Locating Endpoints (Joints)

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Assumptions

- Only a single person (dancer) in scene
- Dancer always in the view of camera
- Background is static
- No camera motion
- Lighting changes are limited
- Distance between dancer and camera is large

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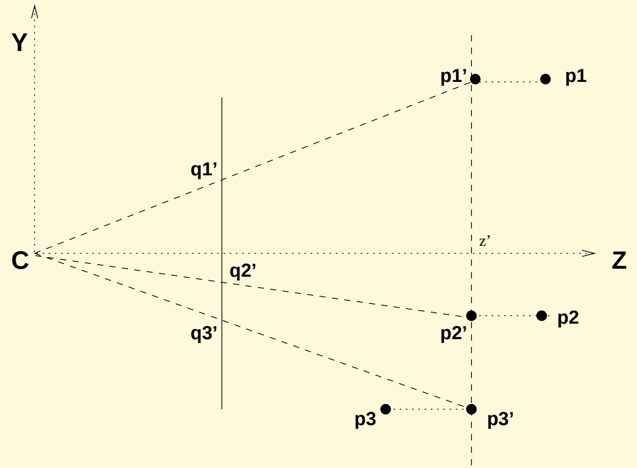
Scaled Orthographic Projection

- A simple approximation to perspective projection
- Can be used
  - When the range of depth values of a scene is small compared to distance from camera
  - Distance between object and camera is large compared to size of object



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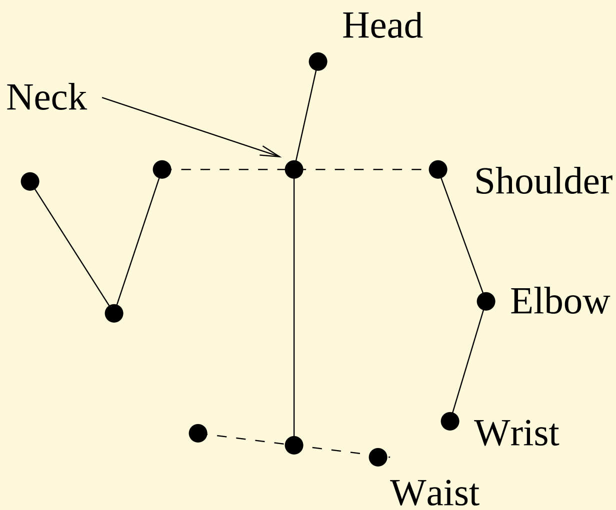
Human Model and Key features

- We use stick-figure representation
- Represent joints as points, bones as lines



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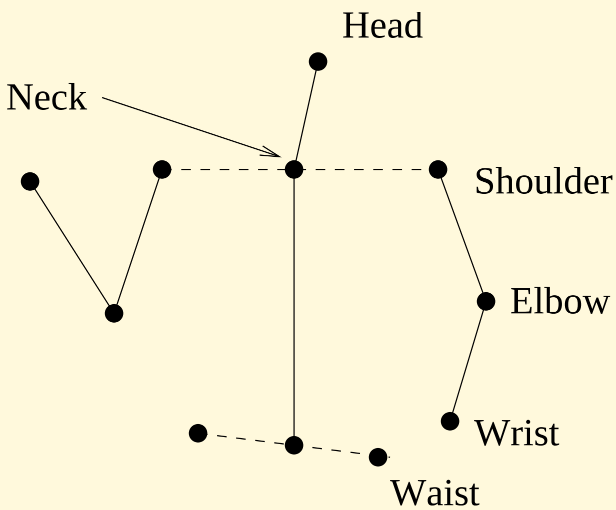

- Key features are the points to be tracked across the sequence
- All joints in the stick-figure
- Head, Shoulder, Elbow, Wrist, Waist

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Feature Tracking

We need to track the features across the sequence and mark them accordingly

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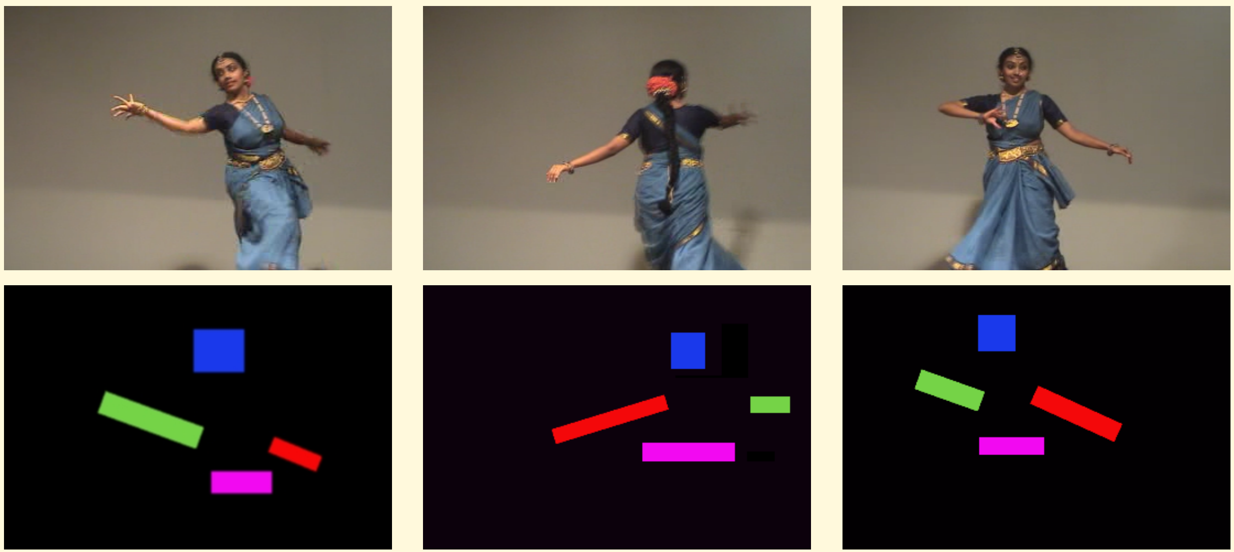

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Skin color model

- We use *skin color model* to detect these features
- According to skin color model, normalized color components of skins of people of different races, genders, complexion are similar
- RGB components are normalized as follows

$$r = \frac{R}{(R+G+B)};\; b = \frac{B}{(R+G+B)}$$

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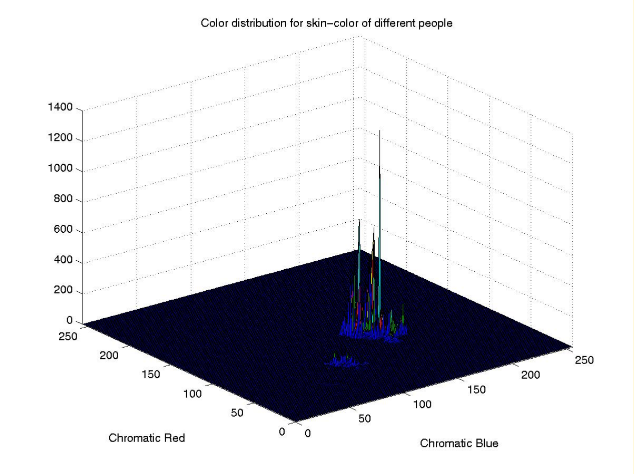
$$r = \frac{R}{(R+G+B)};\ b = \frac{B}{(R+G+B)}$$

- Plot color histogram of r and b from distribution of skin color of different people.
- This histogram is clustered



Skin Color Model (Contd.)

We approximate the color distribution to a Gaussian model $G(m, C)$ with

mean, $m = E\{x\}$, where $x = \begin{bmatrix} r \\ b \end{bmatrix}$

covariance, $C = E\{(x - m)(x - m)^T\}$

Skin Color Model (Contd.)

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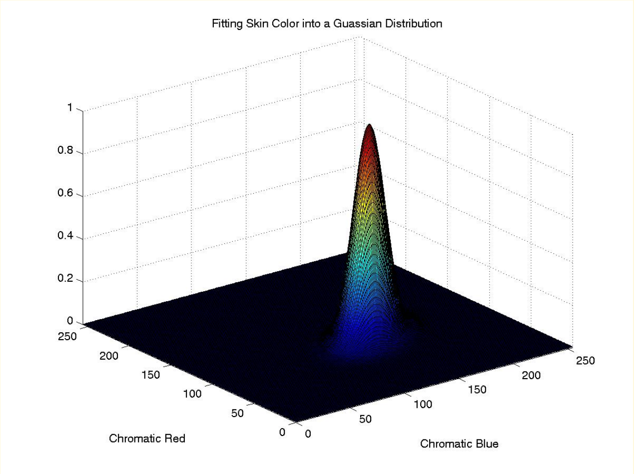

mean, $m = E\{x\}$, where $x = \begin{bmatrix} r \\ b \end{bmatrix}$
covariance, $C = E\{(x-m)(x-m)^T\}$

- Likelihood of each pixel belonging to skin is given as

$$\text{likelihood} = P(r,b) = exp[-0.5(x-m)^T C^{-1}(x-m)]$$

- This number is thresholded to get the skin regions

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Results of skin detection

Note that the golden belt in the waist region is also detected as skin color region.

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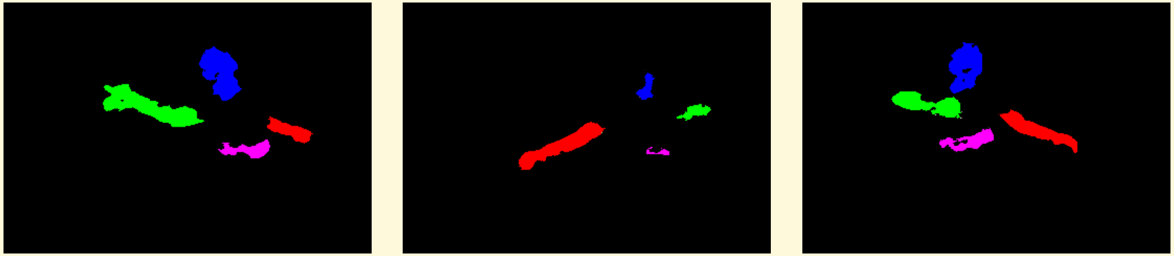
Labeling body parts

- After morphological operations, different blobs of skin colors are formed. Only large blobs are maintained
- Blob labels are initialized in the first frame
- These are tracked using the motion factor and proximity to previous frame's blobs
- Blobs may get merged or broken



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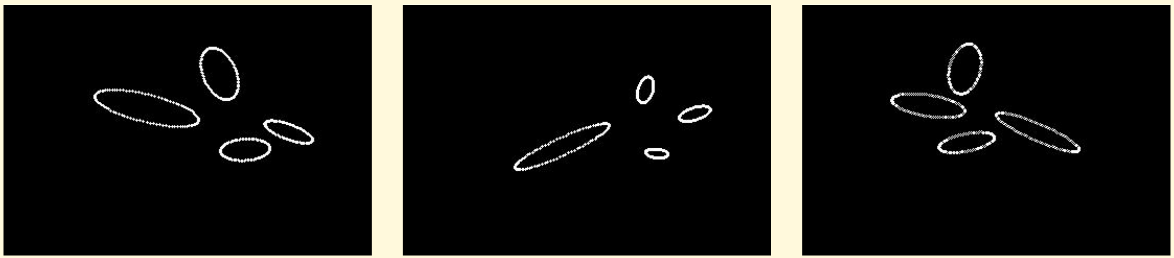
Fitting ellipses to blobs

- Ellipses fitted around the boundary of blobs, using algebraic fit algorithm
- Endpoints of major axis are endjoints of limbs



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Human Motion Capture
Markerless Monocular . . .
Phase I: Tracking
Phase II: Reconstruction
Conclusions

Home Page

Title Page

Page 24 of 35

Go Back

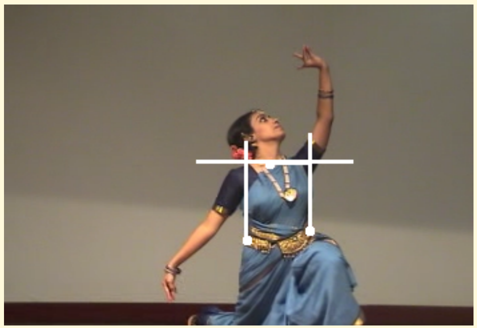
Full Screen

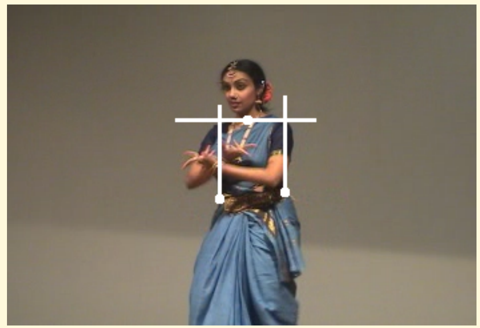
Close

Quit

Shoulders’ Position

- *Observation* – In most cases, except when the body is tilted, the position of the shoulders is exactly above the waist region end-points and in horizontal line with the lower end of the neck.





- Needs improvement.
- We currently use manual adjustment.

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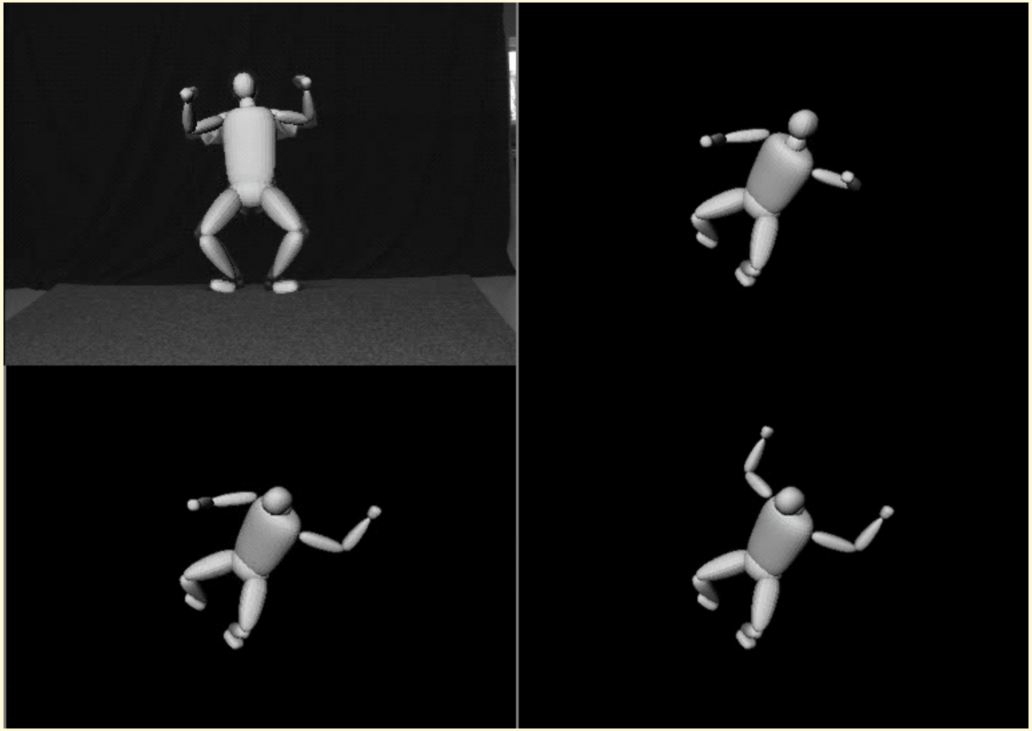
4. Phase II: Reconstruction

- What we have is 2D projections of joints in all frames
- What we want is 3D positions of joints in all frames



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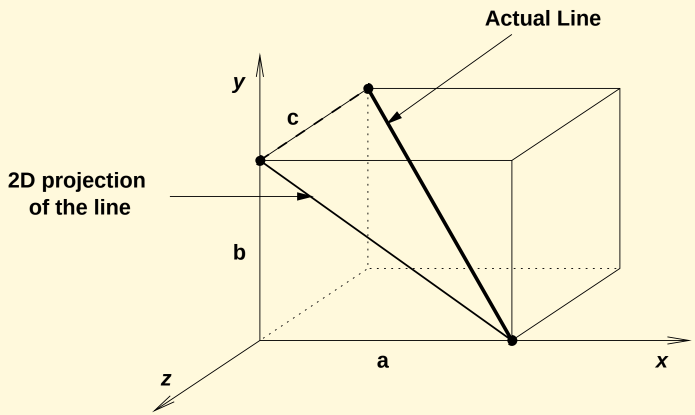
Calculating depth

- *Observation* – Given a sufficiently long sequence, each link becomes parallel or nearly parallel at least once.
- Using anthropometric data to adjust the length values
- Given the 2D length & 3D length, depth of link can be calculated using basic trigonometry.



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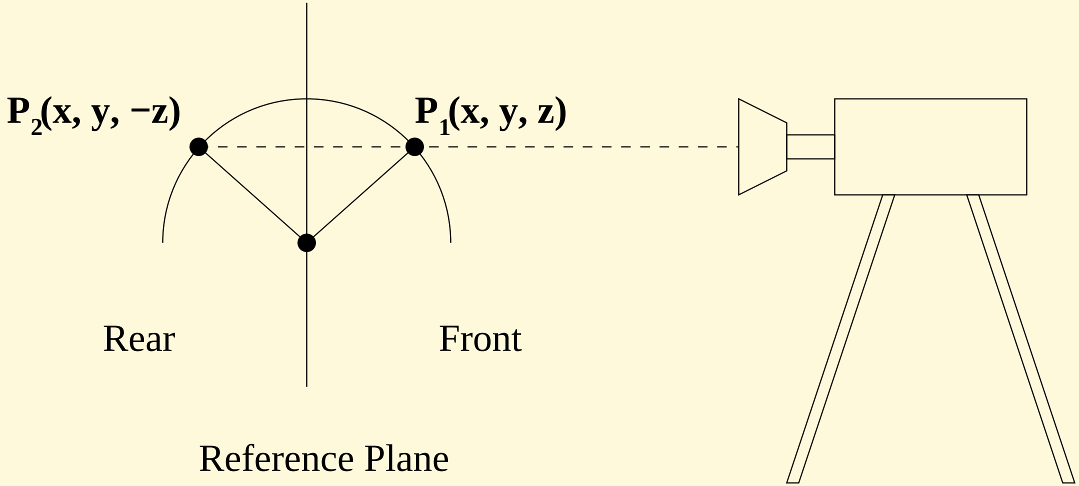
Reflective Orthographic Ambiguity

- For each link, there are two possibilities of z-values.
- One endpoint can be in front or in rear of the other endpoint.



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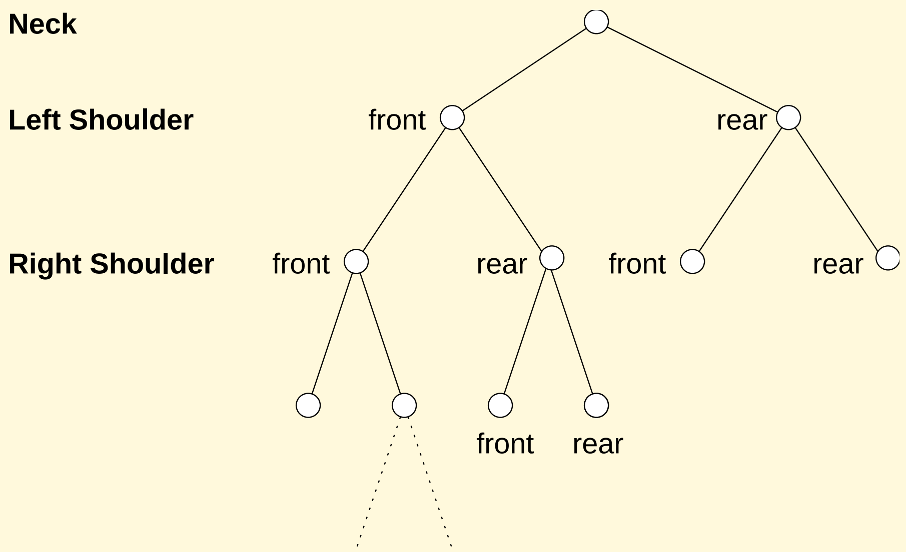
Pose Generation

- For each link, two possibilities $\Longrightarrow 2^n$ possibilities for n links.



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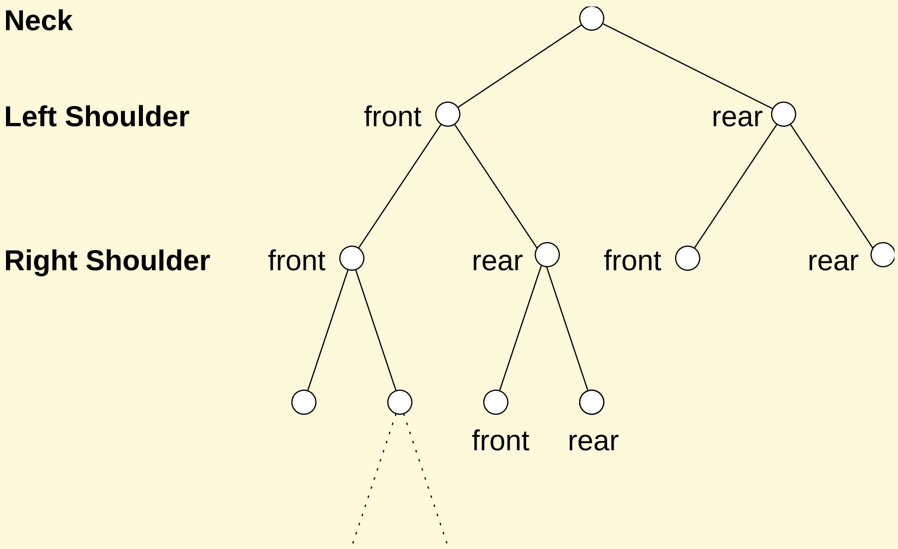

- Not all of 2^n poses are physically attainable.
- Need to put constraints to filter out impossible poses.

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Body Constraints

- Joint Angle Limits
  - Each joint of body has a maximum and a minimum limit of angle of bend.

Body Constraints

- Joint Angle Limits
  – Each joint of body has a maximum and a minimum limit of angle of bend.
- Collision Constraints
  – One body part cannot penetrate through another part.
  – Find distance between different links, they should be less that sum of corresponding radii.

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Graph Formulation

- What we have is a set of valid poses for each frame.

Graph Formulation

- What we have is a set of valid poses for each frame.
- What we want is a valid pose sequence across frames.

Graph Formulation

- What we have is a set of valid poses for each frame.
- What we want is a valid pose sequence across frames.
- We create a layered graph to model this situation.
- One layer for each frame.
- Each valid pose for a frame is represented as a node in the corresponding layer.
- Edges are put between nodes in adjacent layers of transition between those poses is possible.

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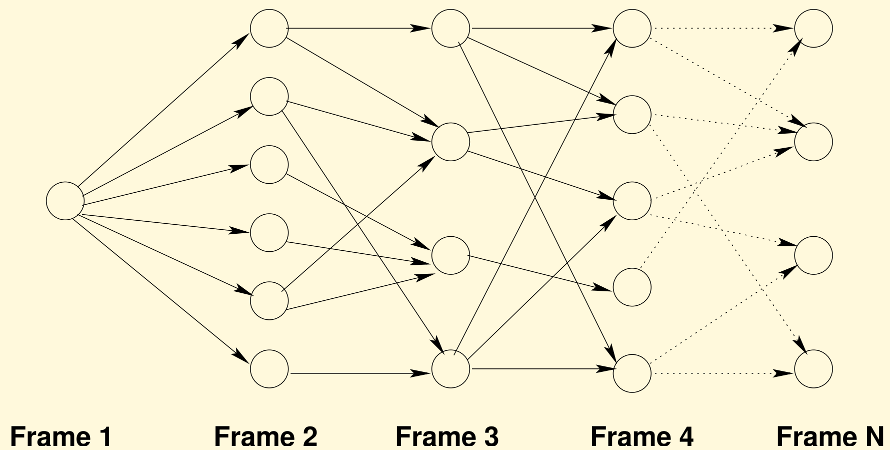
Graph Formulation (Contd.)



- Assign weights to edges
- Find minimum weight path from first to last layer, which gives optimal path

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Calculating Weights

- For jerk free motion, the change in angles, velocities should be as smooth as possible.
- Weight represent the difficulty of transition from one pose to another.
- Various possibilities tested
  - Change in depths of joints
  - Change in angles at joints
  - Change in velocities
  - Estimation based on velocity
- Last method produces the best results.

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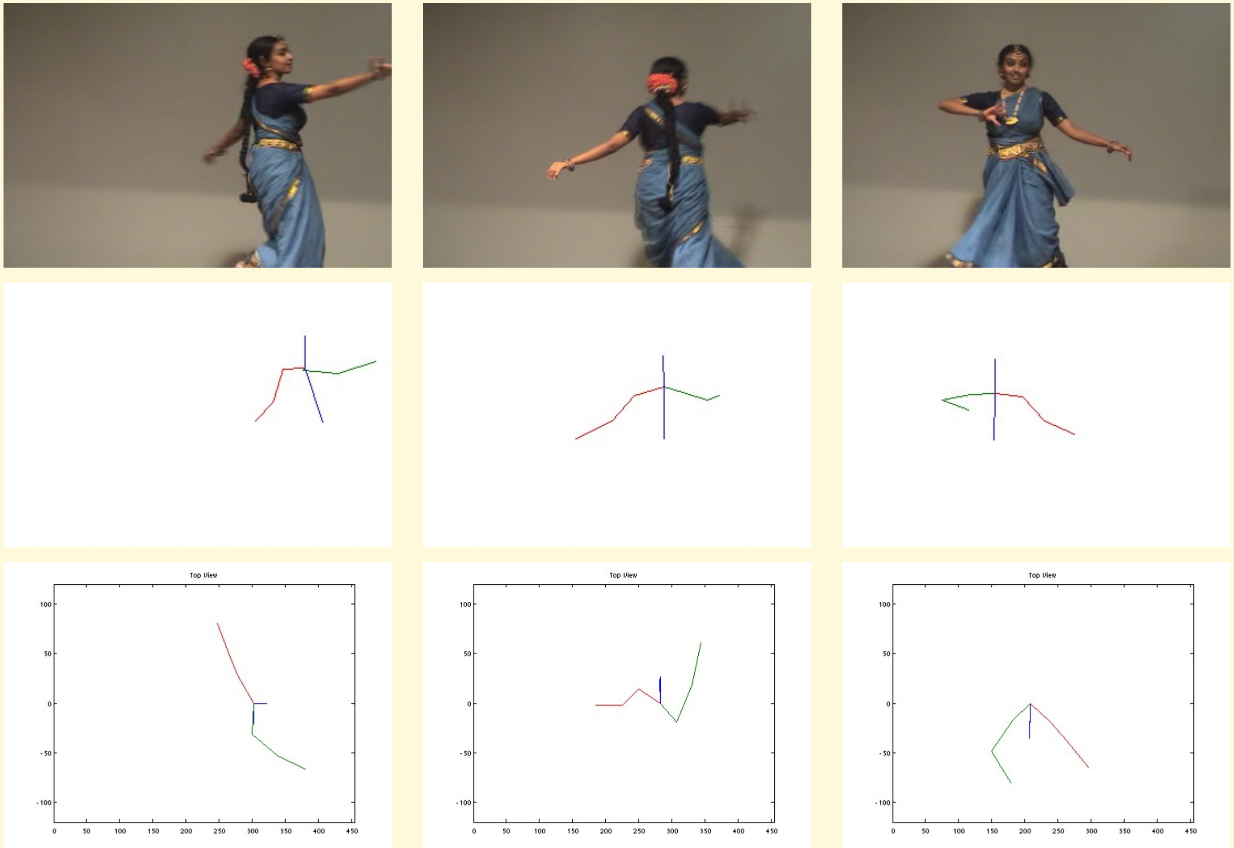
Final Results



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5. Conclusions

- Captured upper body motion for Bharatanatyam sequence
- Tracking done using the domain-specific knowledge
- Tracking is not completely automatic. We need some manual intervention for blobs labeling and final positions
- Reconstruction done using a graph-based approach
- Reconstruction produces accurate results in majority of frames

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THANK YOU !!

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