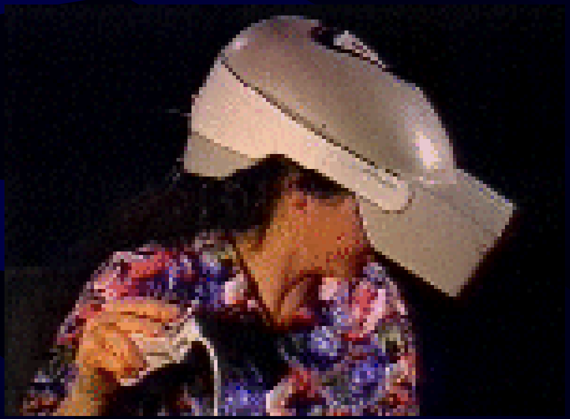
Stereo-based Hand Gesture Tracking and Recognition in Immersive Stereoscopic Displays

Habib Abi-Rached

Thursday 17 February 2005.

Objective

- Mission: Facilitate communication:
  - Bandwidth.
  - Intuitiveness.
  - Efficiency.

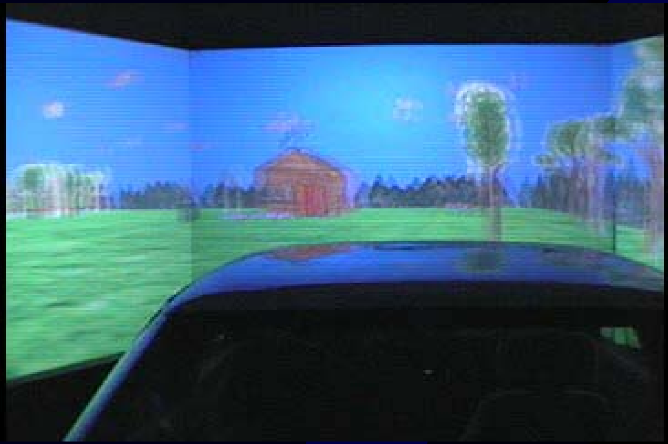


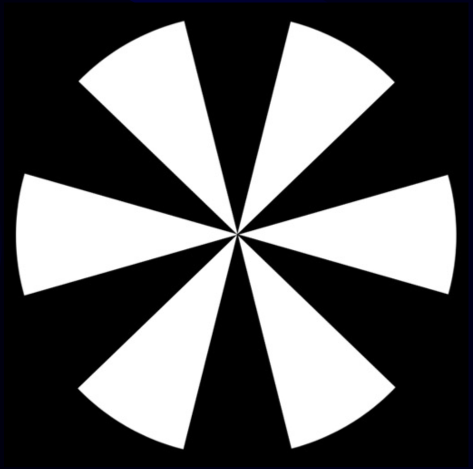
- Means:
  - Visual (Displays, HMD …).
  - Gestural.

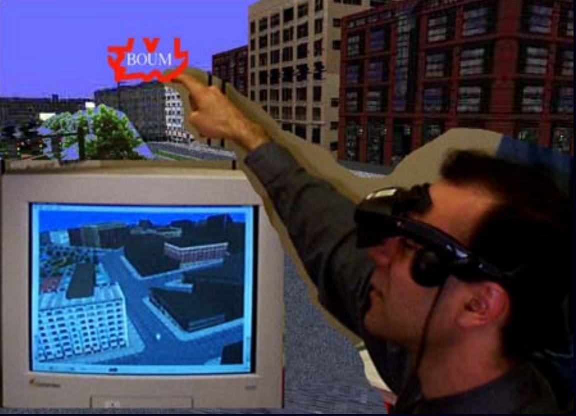
Initial Exploration. (Kodak).

- Domes.
- Driving simulators.
- Cave like environments.

➢ *Simulator sickness.*

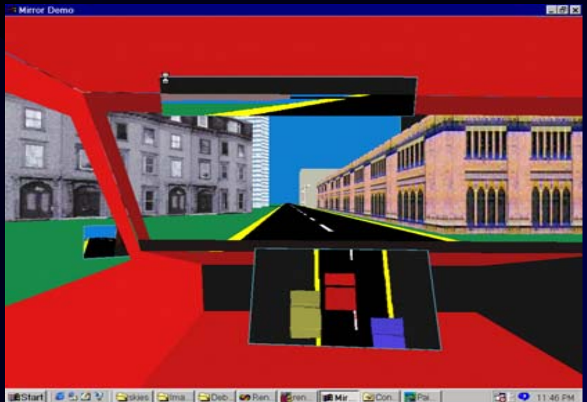






Initial Exploration. (Ford).

- Accuracy of the user's mental models based on visual displays.
- Usefulness of stereo displays.



Limitation of Current Technology.

- Limited efficiency.
  - Mouse Keyboard…
- No 3D. (Monitors).
- Small FOV. (Monitors).
- Few Degrees of Freedom. (Joysticks, Mice).
- Limited intuitiveness.
- Physical connection.
  - (Gloves, Mice, HMD, phantom, polhemus).
- Precision depends on distance.



Hand Gestures

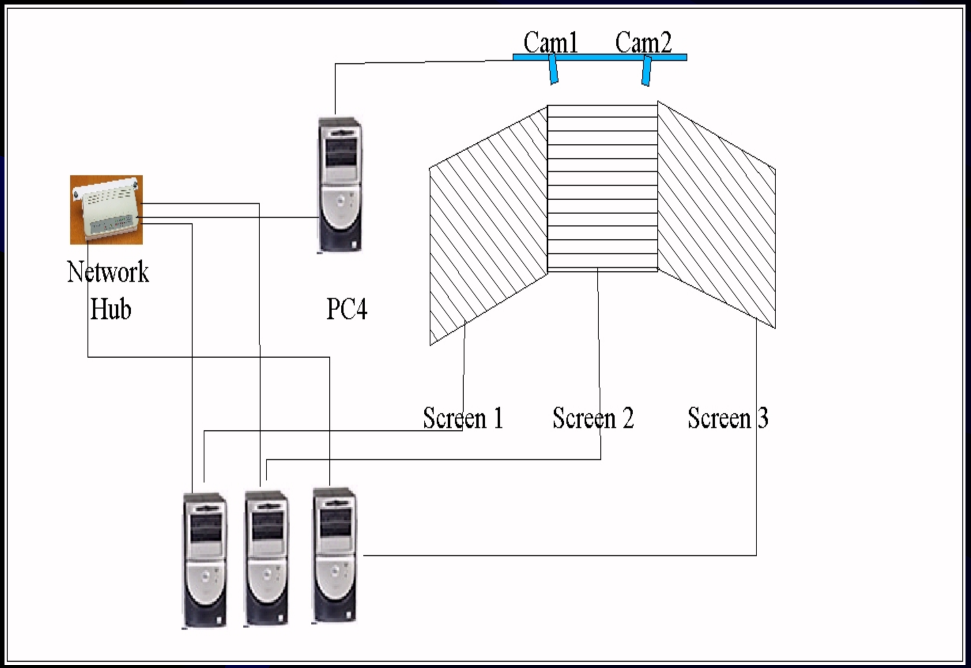
- Human-computer interaction (HCI) has become an increasingly important part of our daily lives.
- Keyboards and mice are the most popular mode of HCI.
- Virtual Reality and Wearable Computing require novel interaction modalities with following characteristics:
  - in a way that humans communicate with each other.
- Hand gesture is a natural and intuitive communication mode.
- Other applications: Sign Language Recognition, video transmission, and so on.

Introduction

- Vision-based recognition of dynamic hand gestures is a challenging interdisciplinary project.
  - hand gestures are rich in diversities, multi-meanings, and space-time variation.
  - human hand is a complex non-rigid object.
  - computer vision itself is a ill-pose problem.

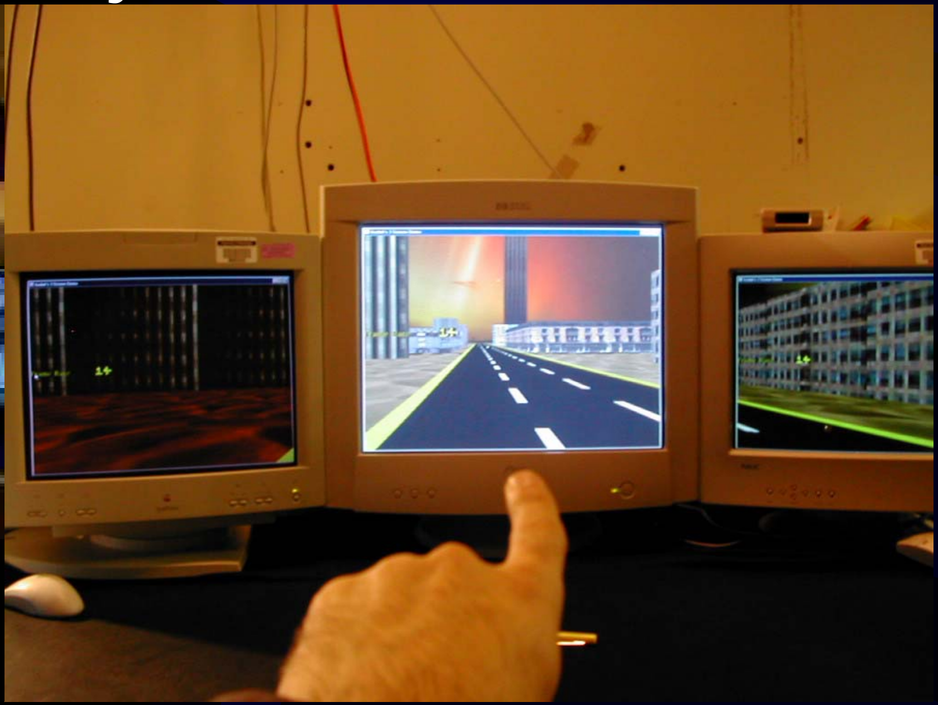
Our Approach.

- Inexpensive immersive PC-based gesture tracking / recognition System.



Gesture-based Interaction With 3D Displays.

- Intuitive interaction, easy to learn.

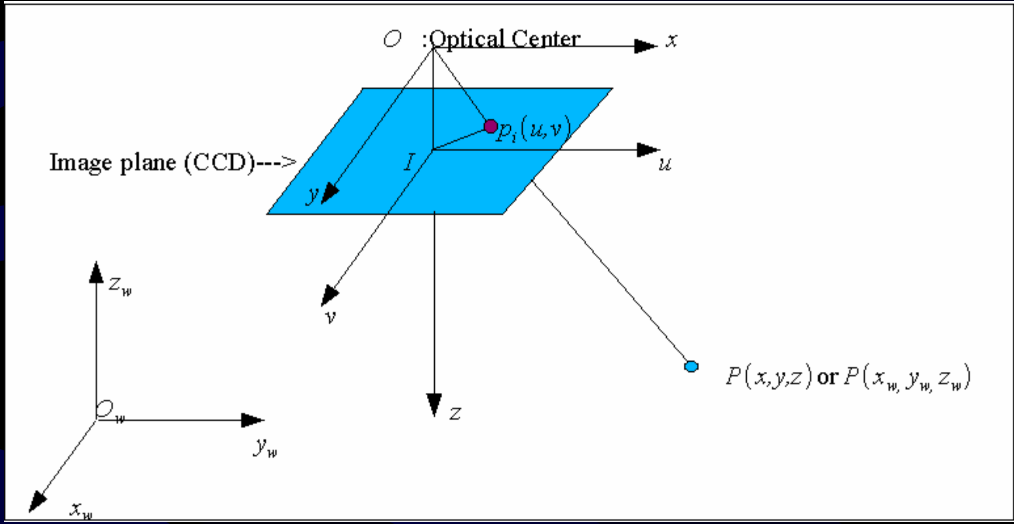
Previous Gesture tracking and recognition methods.

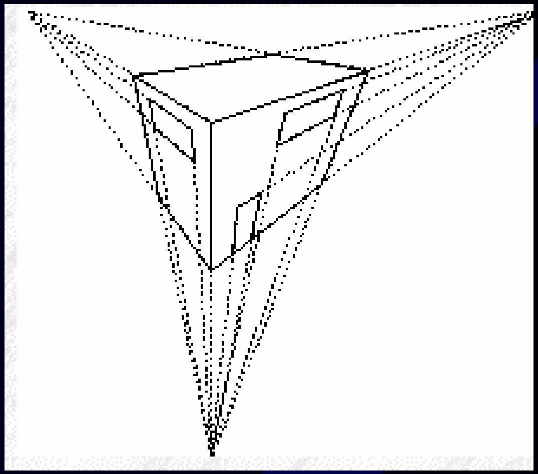
- Temporal modeling and recognition: *(Kendon-MIT)*.
- Spatial modeling and recognition:
  - Appearance-based approach:
    - Predefined static image templates. *(Freeman)*.
    - Deformable 2D templates. *(Taylor)*
  - 3D hand model
    - Volumetric models.
    - Physical models.
    - Skeletal models.

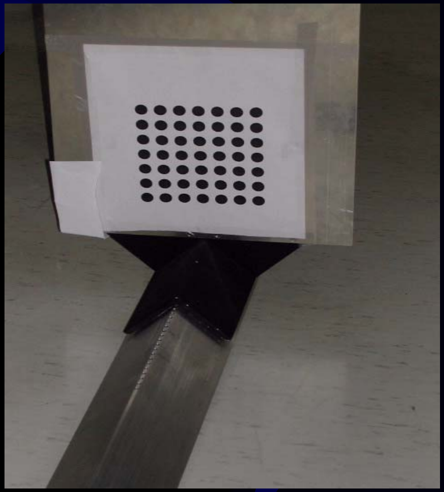
- Feature detection and recognition.
  - Huang (silhouette).
  - Darell (whole image).
  - Essa (spatio-temporal motion).

Calibration methods.

- Tsai method.
- Stringa method.
- Faugeras method.
- Caprile method.

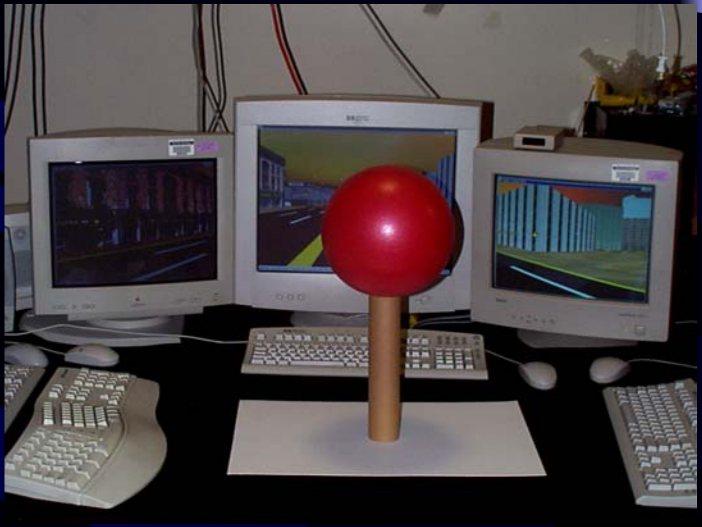


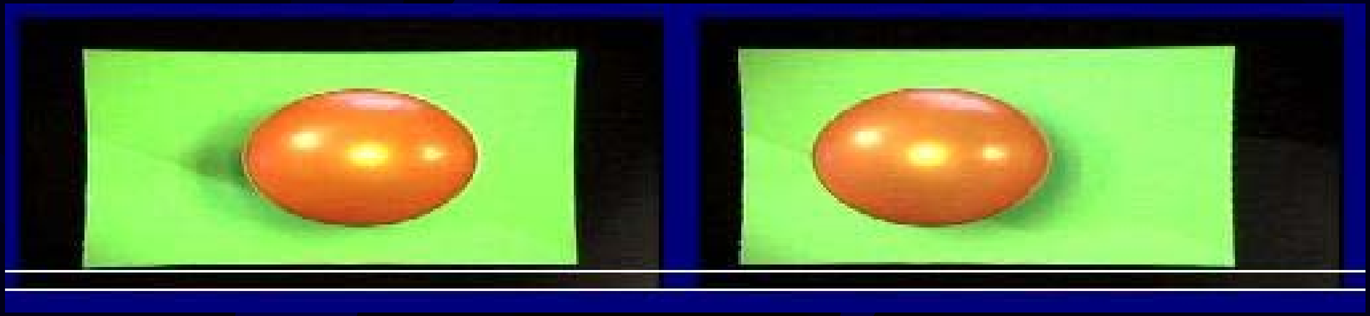




Why develop our own calibration.

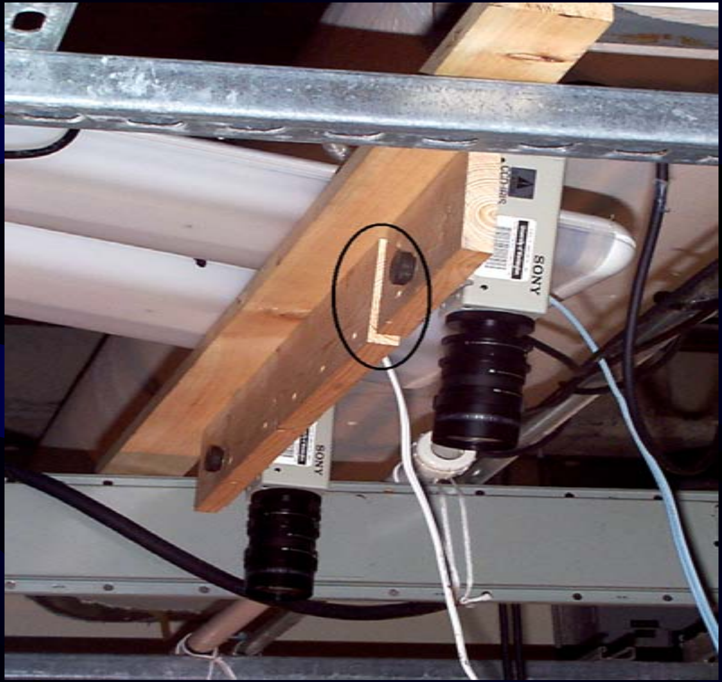
- Simple, inexpensive calibration tools.
- One iteration.
- Orthographic cameras.
- Vertical cameras.

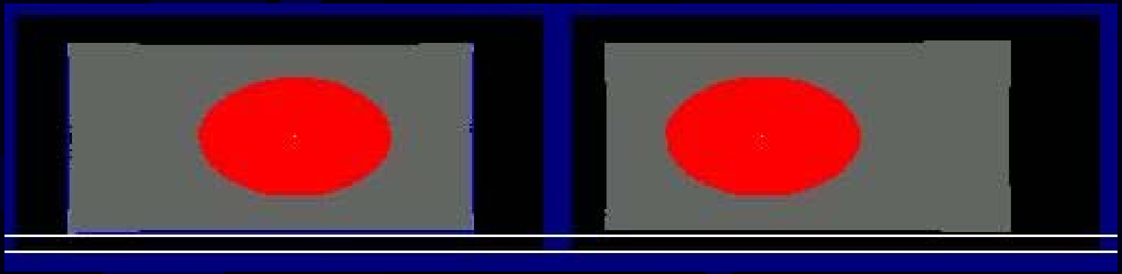




Why develop our own calibration.

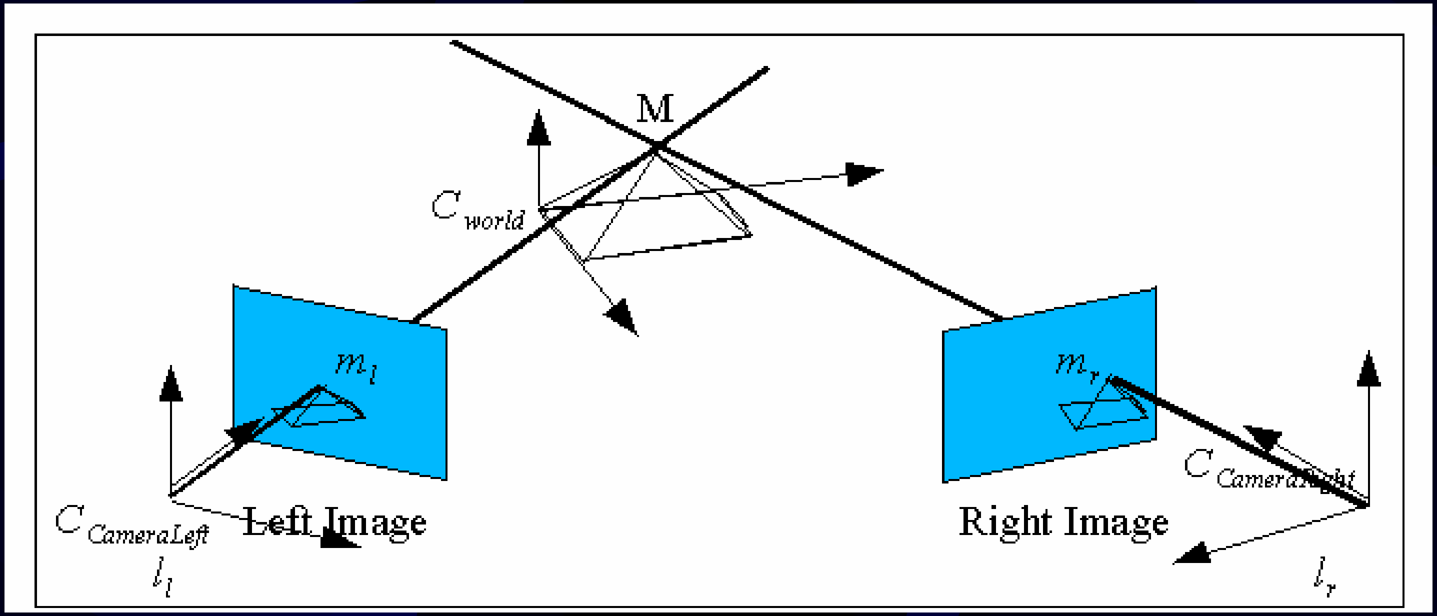
- Faster stereo reconstruction
  – Orthographic projection.
  – Simple complexity.
  – No rectification phase.





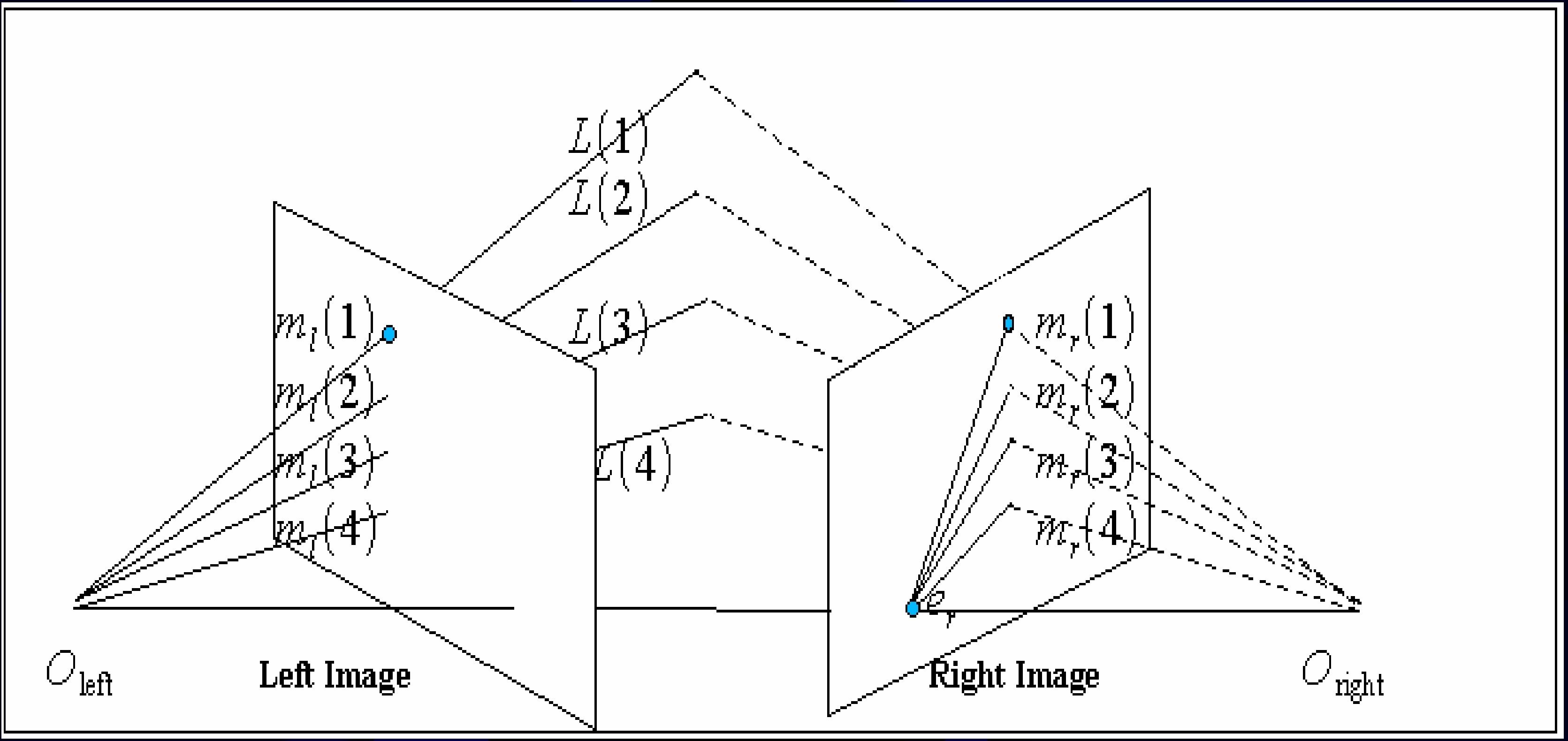
Stereo Reconstruction.

- Matching process.
- Triangulation.



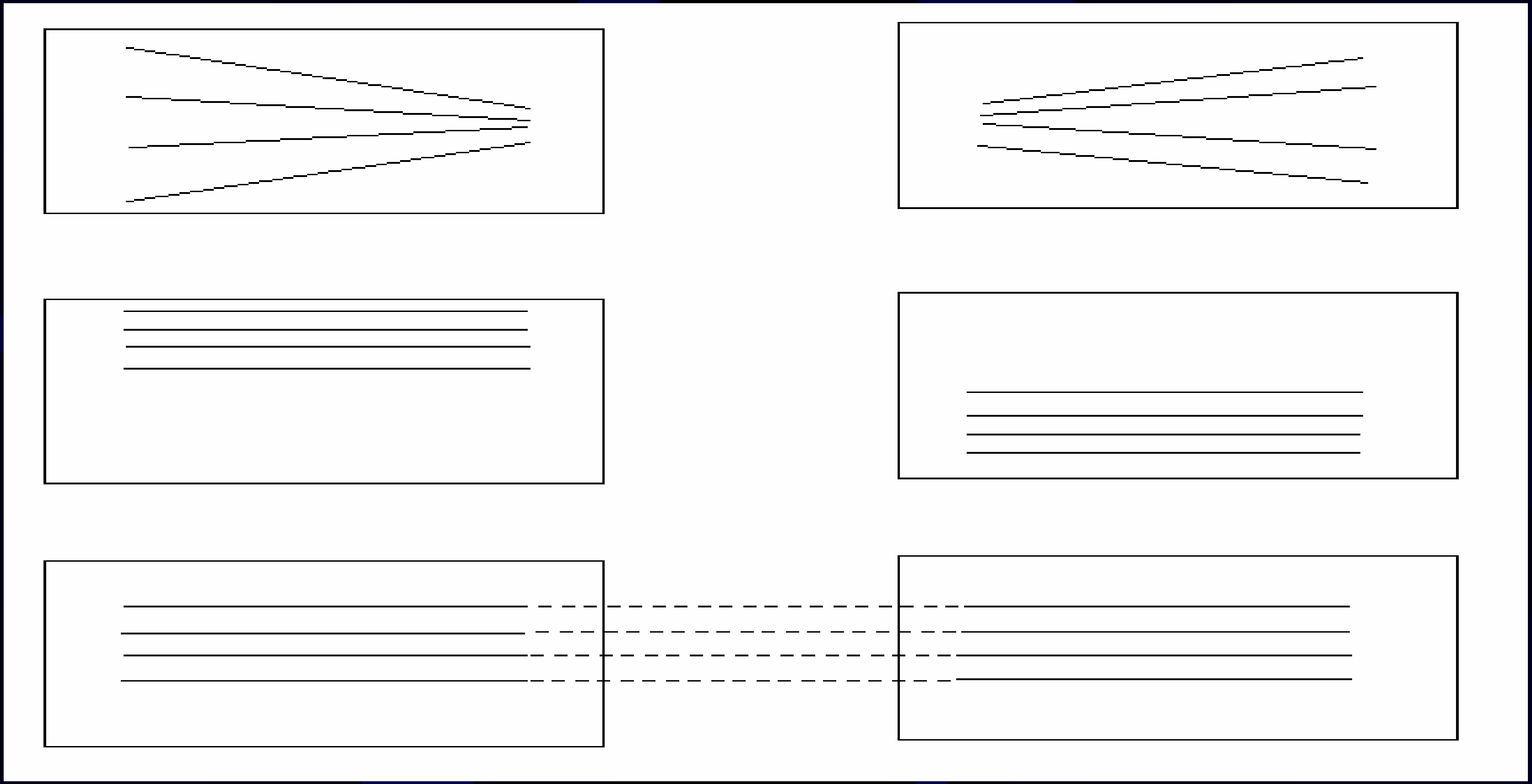
Epipolar lines.

- One dimensional search.

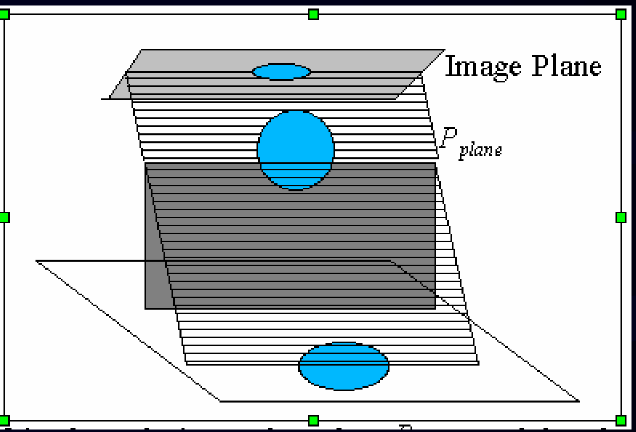


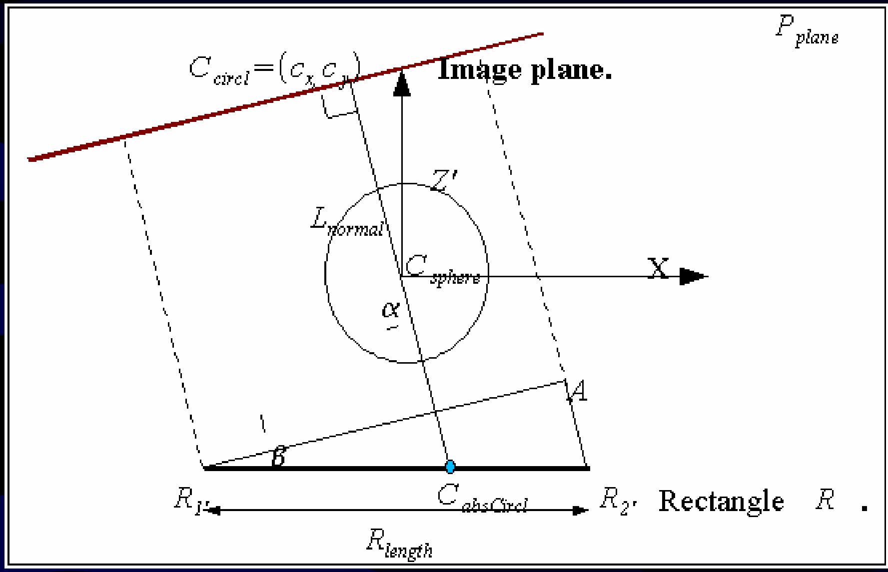
Rectification phase.

- Straightening, Blending and Shifting.



Camera Calibration Method.



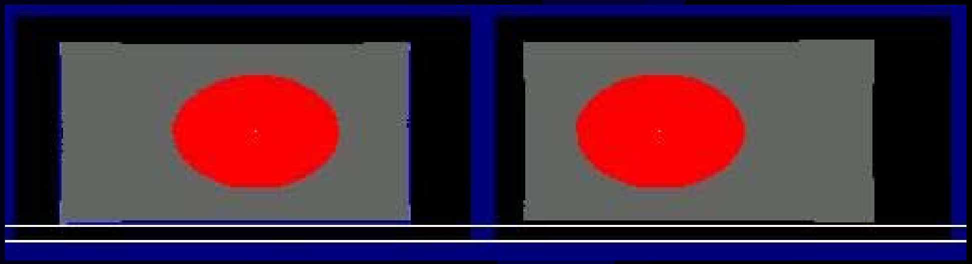


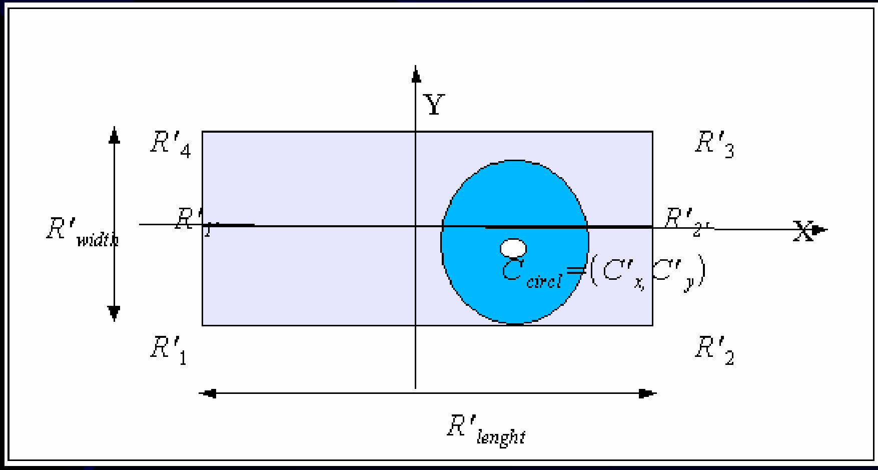
- Intrinsic parameters

$$p_w = \frac{d}{p_u} \quad , \quad p_h = \frac{d}{p_v}$$

- Extrinsic parameters

$$\frac{R'_{lenght}}{R_{lenght}} = \frac{R'_{width}}{R_{width}} = \frac{C'_x}{C_{ax}} = \frac{C'_y}{C_{ay}}$$





State of the the Art of Hand Gesture Recognition

- Hand gesture taxonomy and interaction model
- Hand gesture modeling
- Hand gesture Analysis
- Hand gesture recognition techniques

Taxonomy of Gesture for Human-computer Interaction

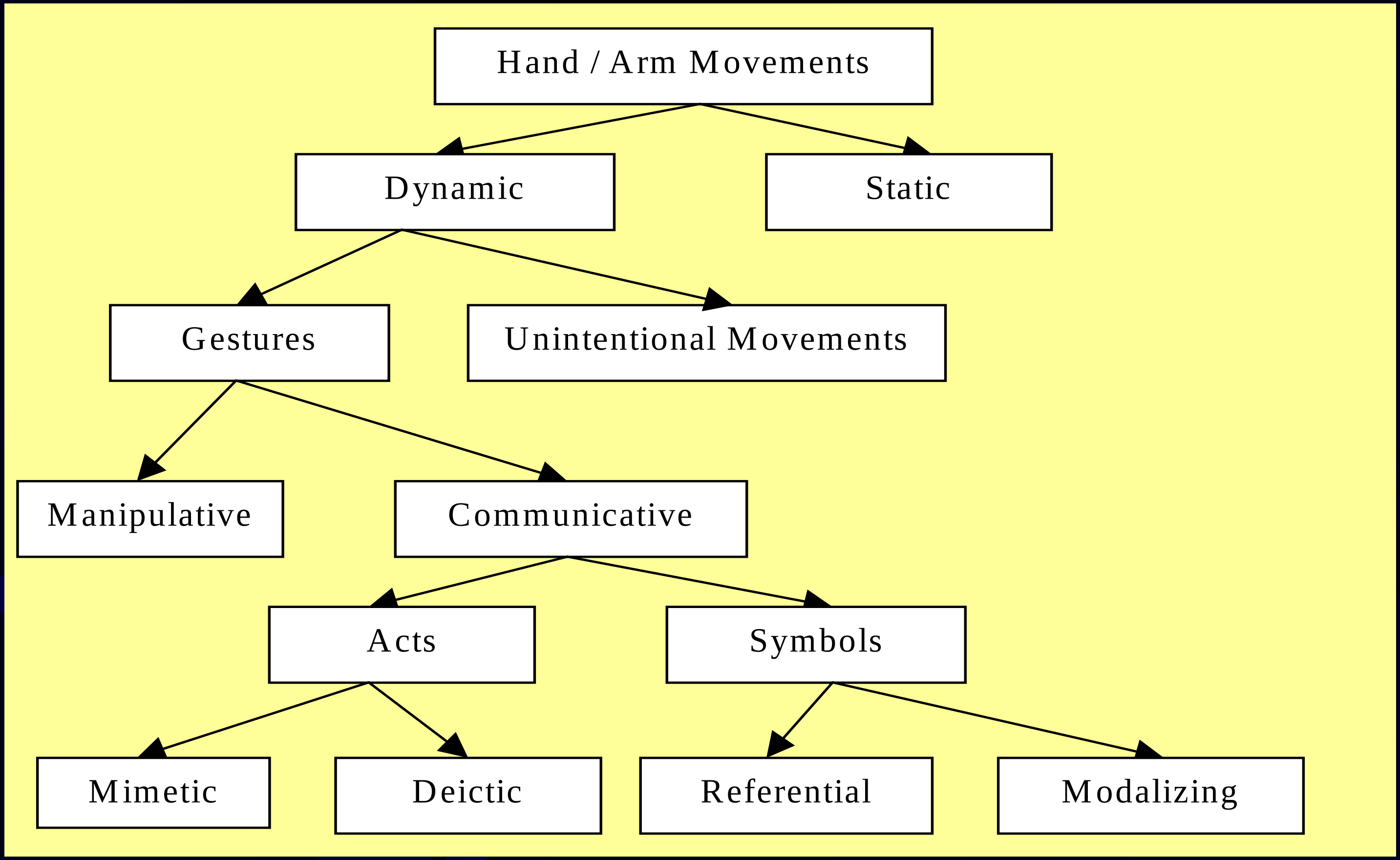


Fig.1: A Taxonomy of hand gestures for Human-computer Interaction. Meaningful gestures are differentiated from unintentional movements. Gestures used for manipulation of objects are separated from the gestures which possess inherent communicational character. Symbols are those gestures having a linguistic role. They symbolize some referential action or are used as modalizers, often of speech.

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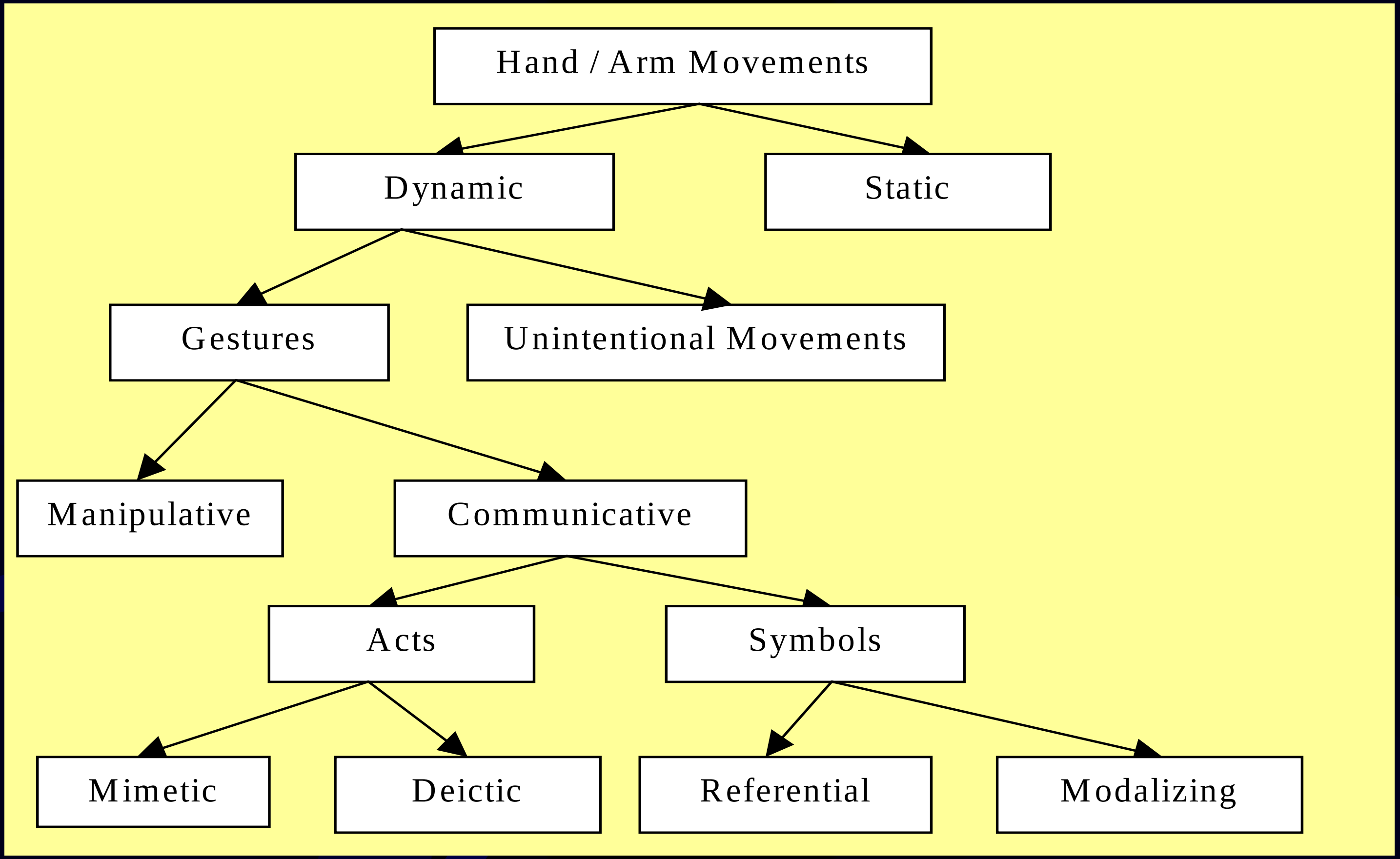
Taxonomy of Gesture for Human-computer Interaction



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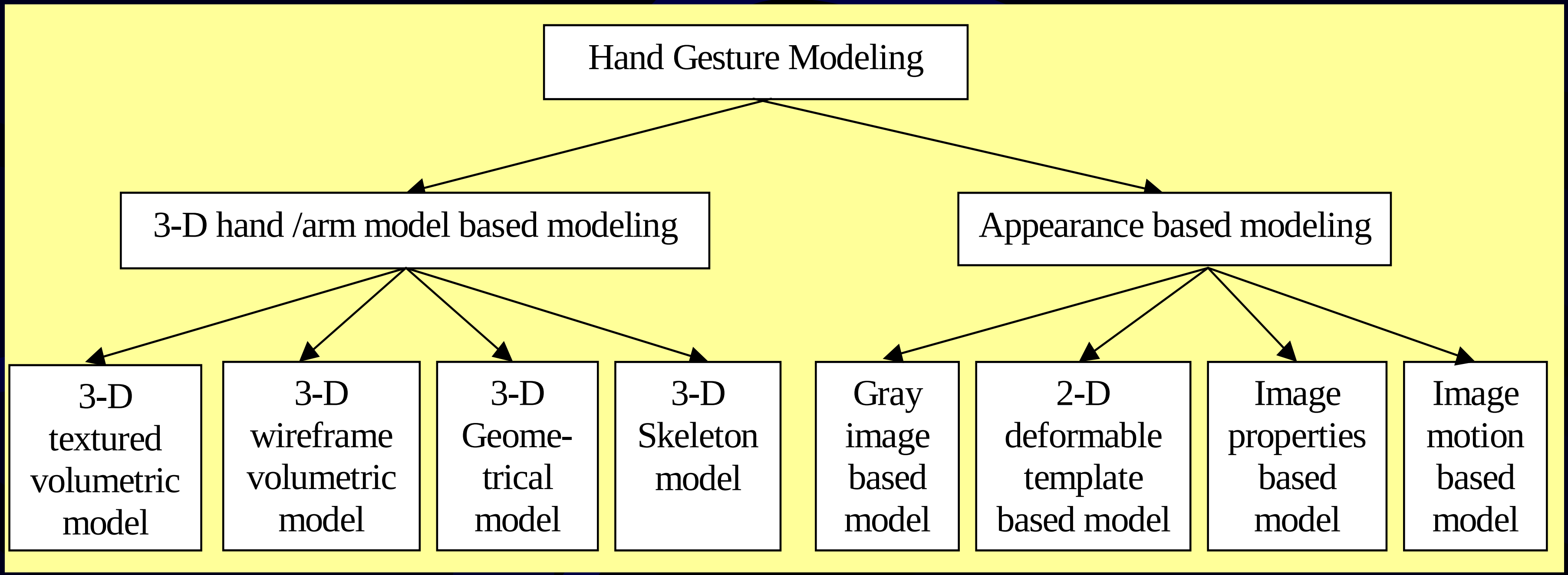
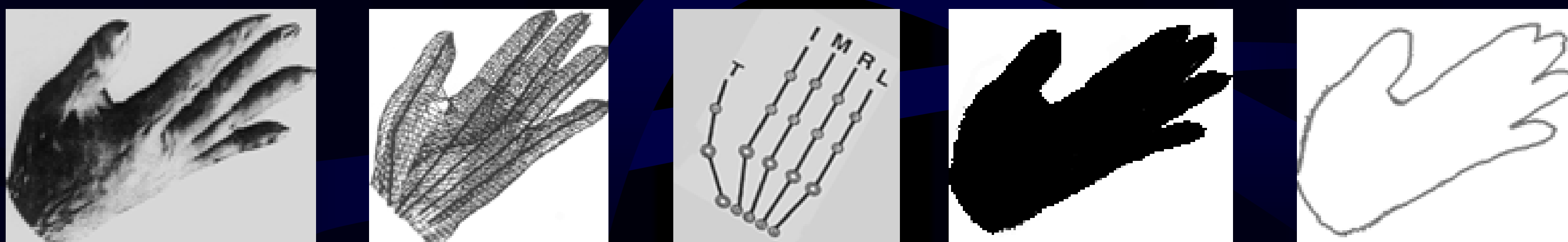
Hand Gesture Modeling



Classification of hand gesture models

Hand Gesture Modeling



(a) (b) (c) (d) (e)

Fig.3: Representing the same hand posture by different hand models. (a) 3-D textured volumetric model; (b) 3-D wireframe volumetric model; (c) 3-D skeletal model; (d) Binary silhouette; (e) Contour model.

Gesture Analysis

1 Gesture detection and feature extraction

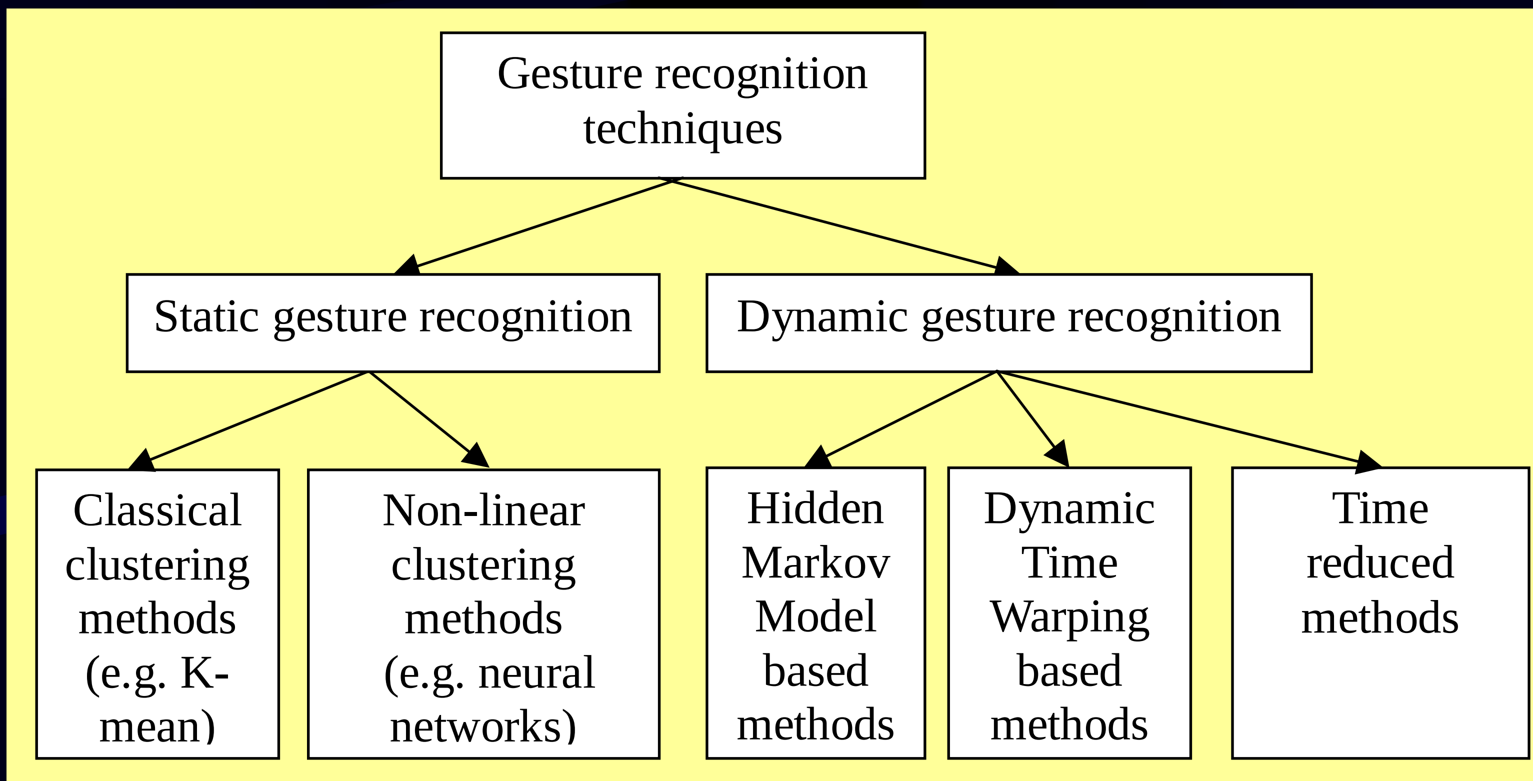
- skin color clues based approaches
- motion clues based approaches
- multiple clues based approaches
- features include gray image, binary silhouette, moving region, edge, contour, and so on.

Gesture Analysis

Recovering gesture model parameters

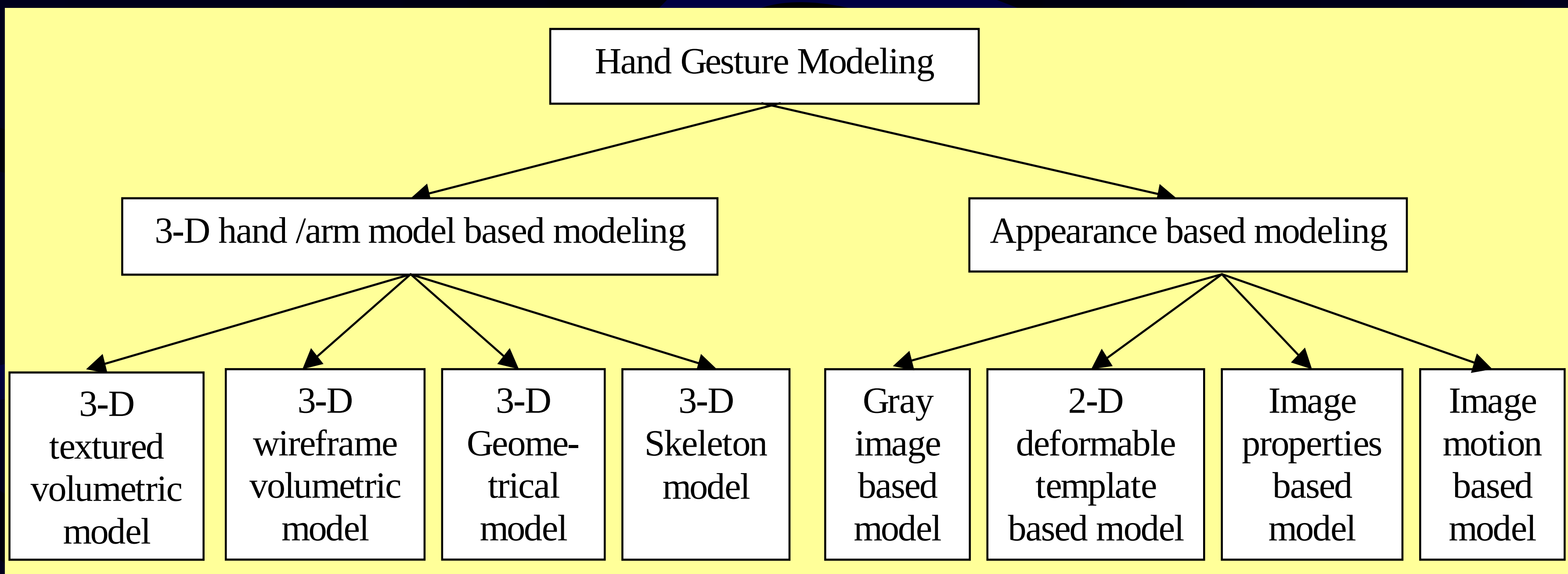
- Estimation of 3-D hand /arm model parameters
  - two sets of parameters: angular (joint angles) and linear (palm dimensions)
  - the initial parameter estimation
  - the parameter update as the hand gesture evolve in time.
- Estimation of appearance based model parameters
  - image motion estimation (e.g. optical flow)
  - shape analysis (e.g. computing moments)
  - histogram based feature parameters (e.g.)
  - active contour model.

Gesture Recognition Techniques



Classification of hand gesture recognition techniques

Hand Gesture Modeling



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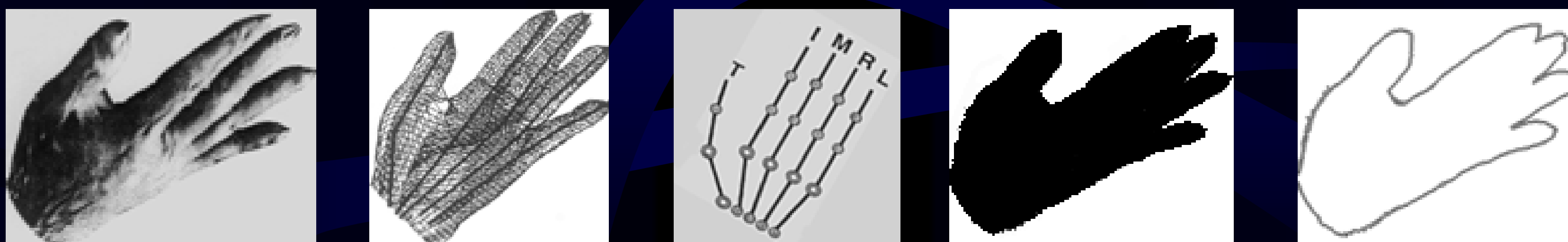
Hand Gesture Modeling



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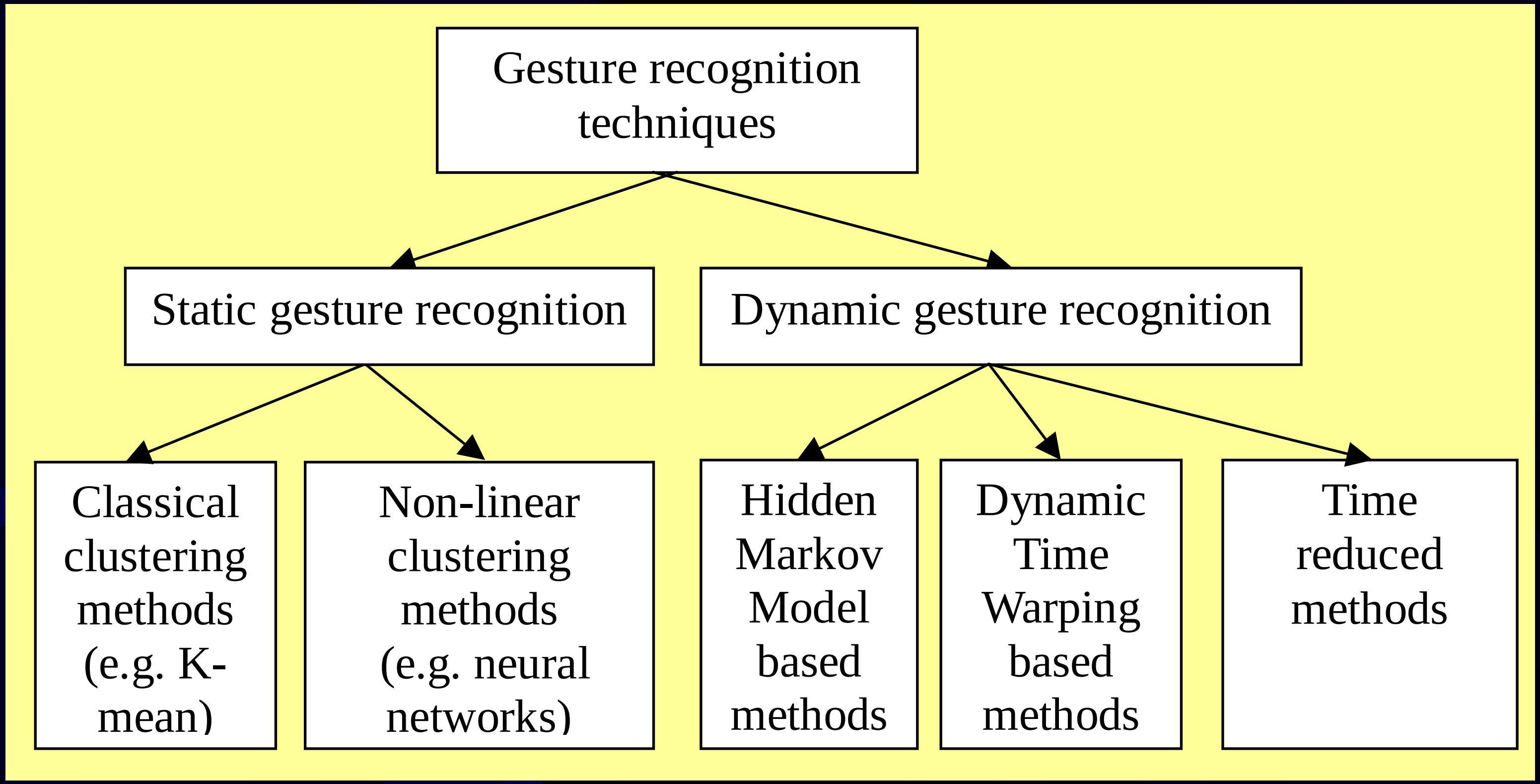


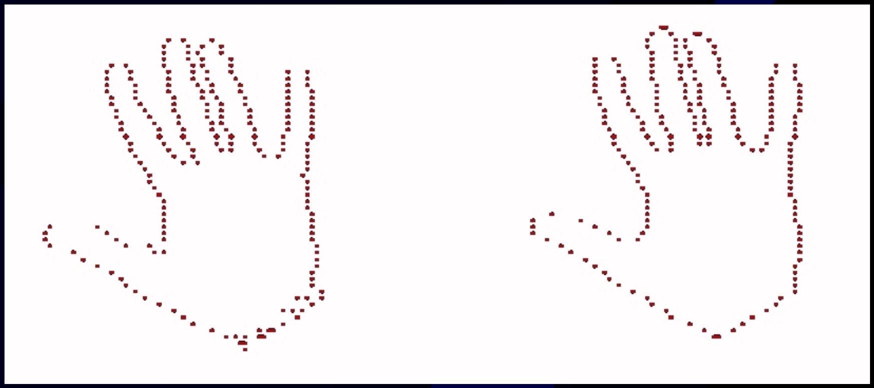
Classification of hand gesture recognition techniques

Stereo-Reconstruction.

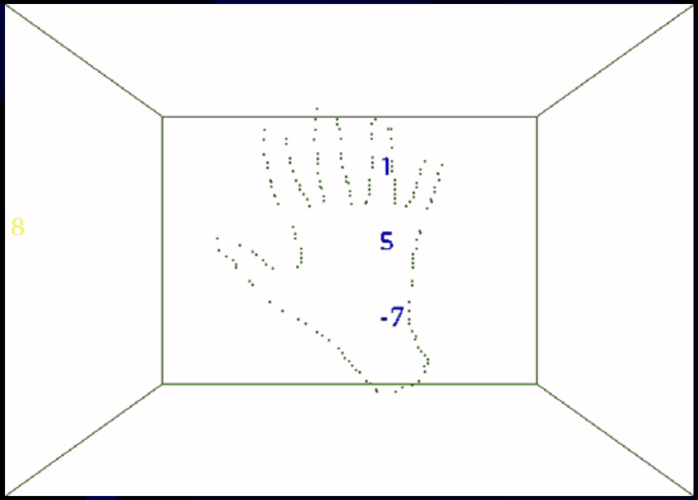
- Simple matching.

- Thresholding.

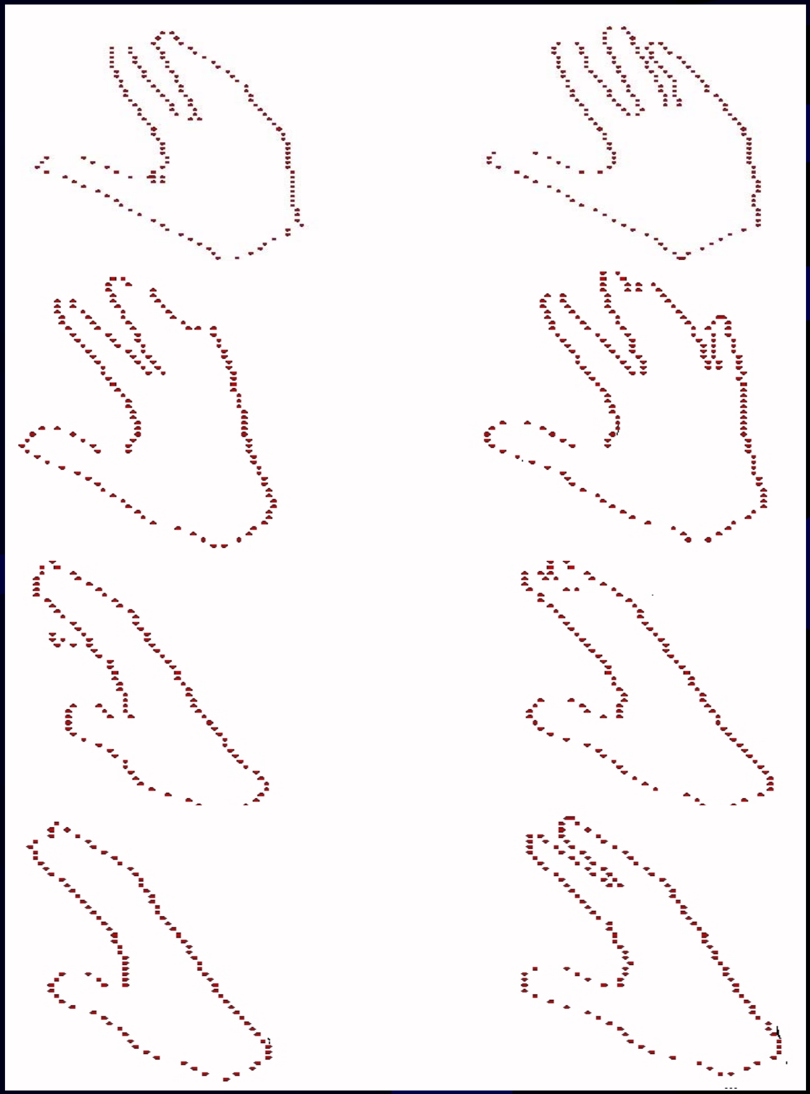
- Fast reconstruction.

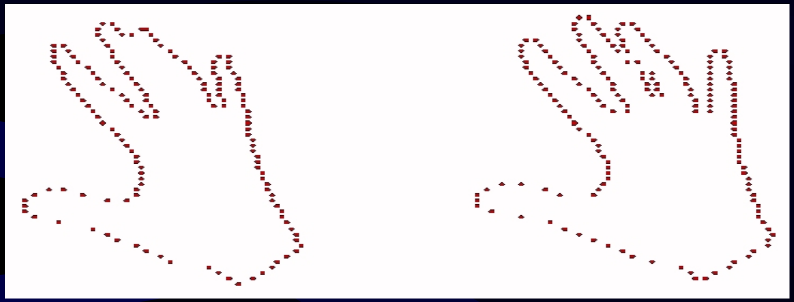


- 3D reconstruction.

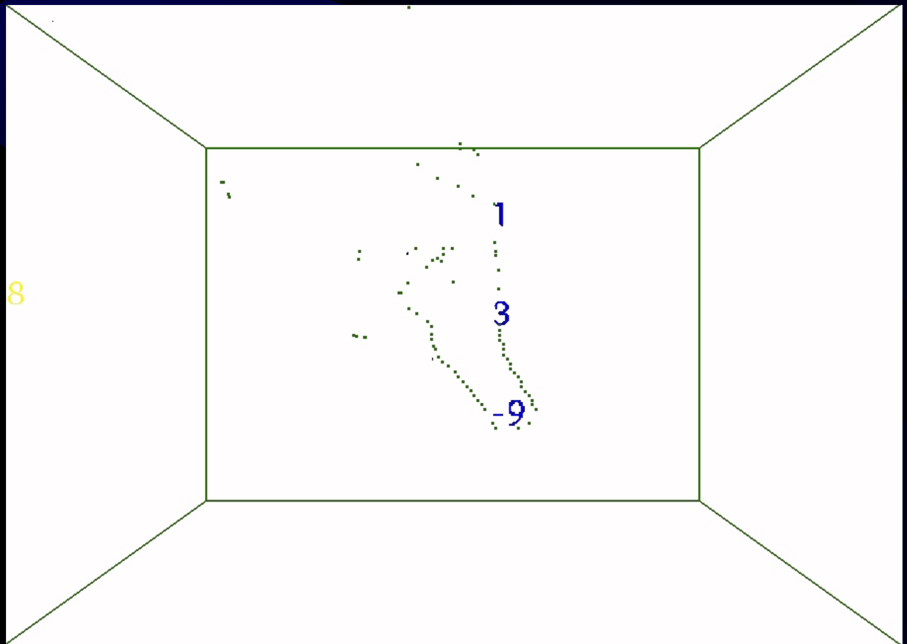


Problems.





- Order constraint, occlusion, merging.

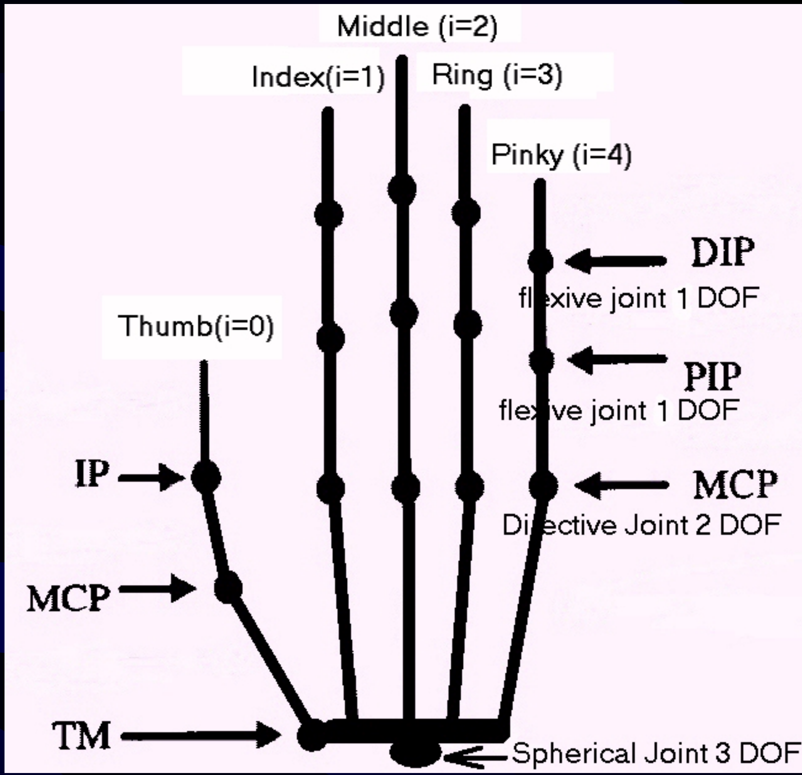


Hand Modeling.

- Dynamic Constraints for all four fingers.

$$\vartheta_{DIP.fe}(i)=\frac{2}{3}\vartheta_{PIP.fe}(i)$$

$$\vartheta_{MCP.aa}=\frac{\vartheta_{MPC.fe}}{90}\left(\vartheta_{MPC,converge}-\vartheta_{MCP.aa,s}\right)+\vartheta_{MCP.aa,s}$$



- Static Constraints for all four fingers.

$$0\le\vartheta_{DIP.fe}(i)\le s_{max}\left(\vartheta_{DIP.fe}(i)\right)\quad with\quad s_{max}\left(\vartheta_{DIP.fe}(i)\right)=90$$

$$0\le\vartheta_{PIP.fe}(i)\le s_{max}\left(\vartheta_{PIP.fe}(i)\right)\quad with\quad s_{max}\left(\vartheta_{PIP.fe}(i)\right)=110$$

$$0\le\vartheta_{MCP.fe}(i)\le s_{max}\left(\vartheta_{MCP.fe}(i)\right)\quad with\quad s_{max}\left(\vartheta_{MCP.fe}(i)\right)=90$$

$$-1\le\vartheta_{MCP.aa,o}(2)\le 1$$

$$-15\le\vartheta_{MCP.aa,o}(1,3,4)\le 15$$

- Kush, Wu.
- Agee 1982.

Dynamic Constraints.

- For separate fingers.

Index finger (i=1):

$$d_{max}(\vartheta_{MCP.fe}(1)) = min(\vartheta_{MCP.fe}(2)+25 \quad , \quad s_{max}(\vartheta_{MCP.fe}(1)))$$
$$d_{min}(\vartheta_{MCP.fe}(1)) = max(\vartheta_{MCP.fe}(2)-54 \quad , \quad 0)$$

Middle finger (i=2):

$$d_{max}(\vartheta_{MCP.fe}(2)) = min(\vartheta_{MCP.fe}(1)+54, \vartheta_{MCP.fe} \quad , \quad \vartheta_{MCP.fe}(3)+20 \quad , \quad s_{max}(\vartheta_{MCP.fe}(2)))$$
$$d_{min}(\vartheta_{MCP.fe}(2)) = max(\vartheta_{MCP.fe}(1)-25 \quad , \quad \vartheta_{MCP.fe}(3)-45 \quad , \quad 0)$$

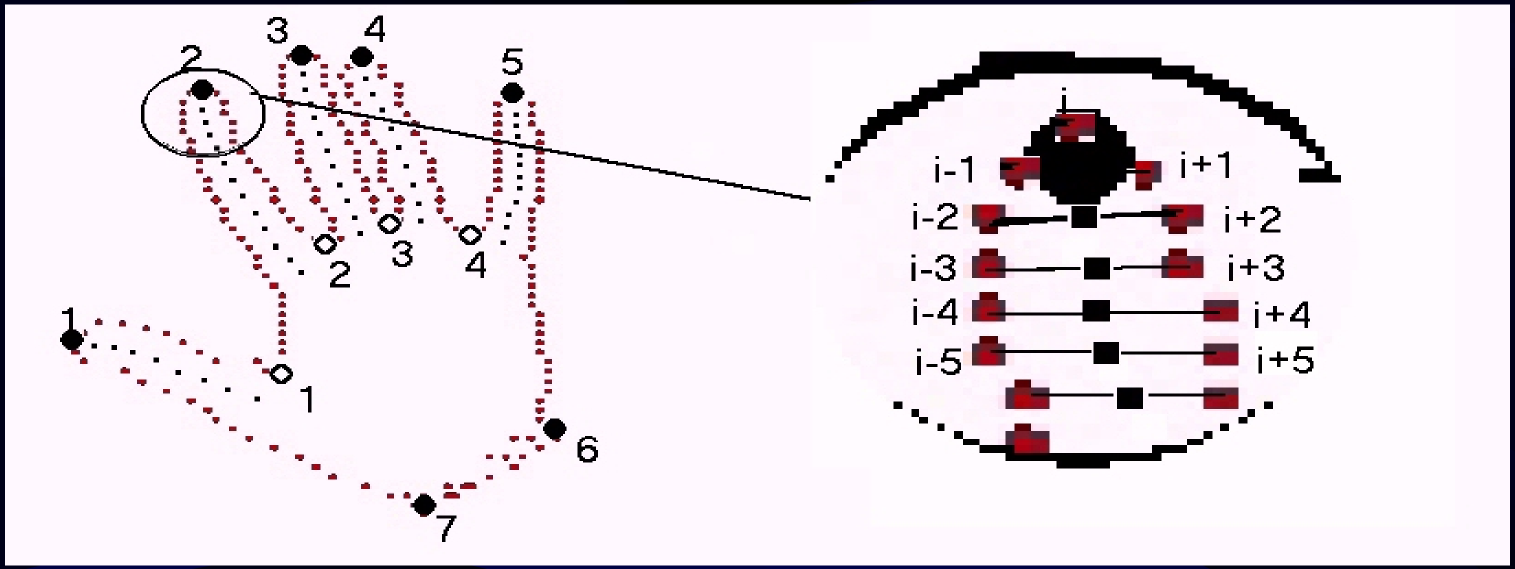
Ring finger (i=3):

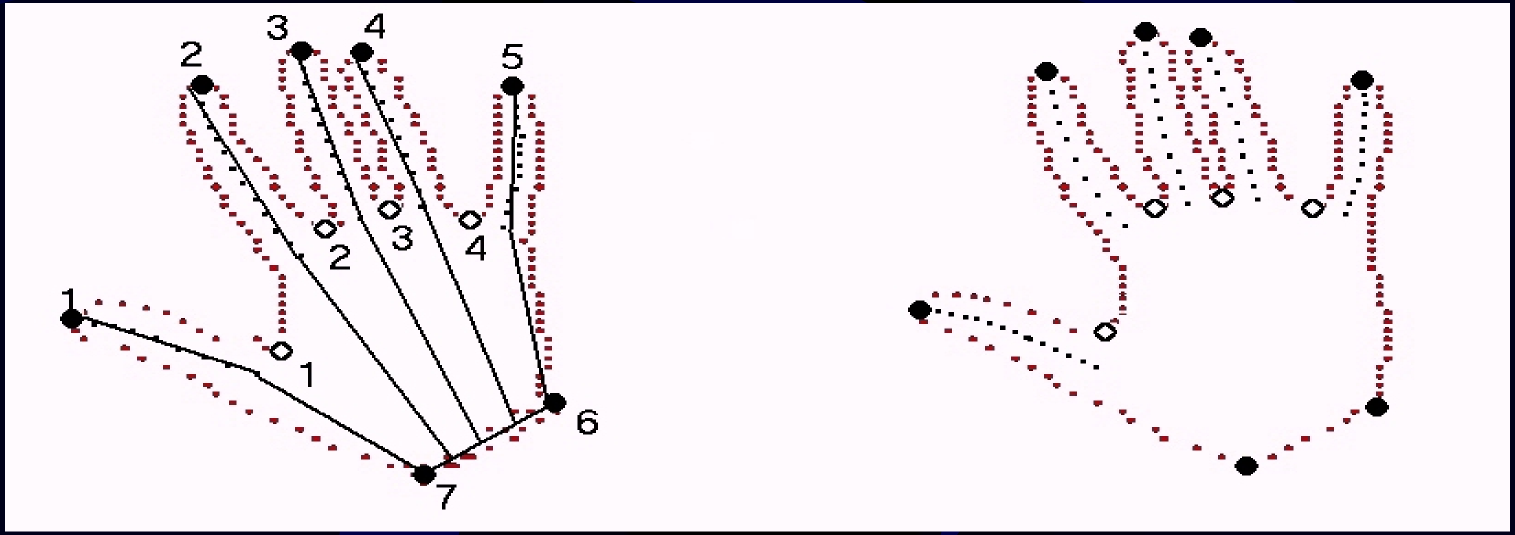
$$d_{max}(\vartheta_{MCP.fe}(3)) = min(\vartheta_{MCP.fe}(2)+45 \quad , \quad \vartheta_{MCP.fe}(4)+48, s_{max}(\vartheta_{MCP.fe}(3)))$$
$$d_{min}(\vartheta_{MCP.fe}(3)) = max(\vartheta_{MCP.fe}(2)-20 \quad , \quad \vartheta_{MCP.fe}(4)-44 \quad , \quad 0)$$

Pinky finger (i=4):

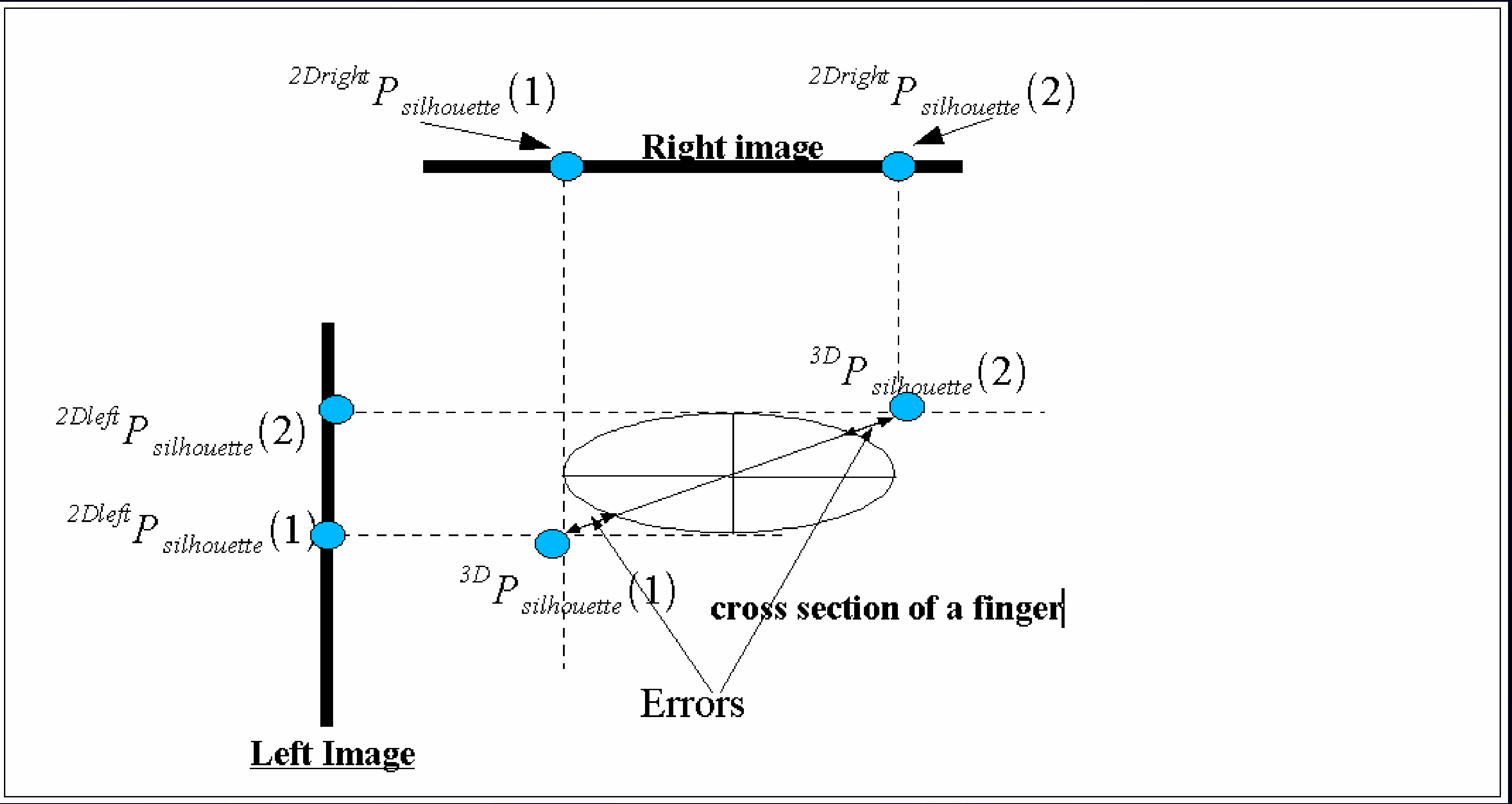
$$d_{max}(\vartheta_{MCP.fe}(4)) = min(\vartheta_{MCP.fe}(3)+44 \quad , \quad s_{max}(\vartheta_{MCP.fe}(4)))$$
$$d_{min}(\vartheta_{MCP.fe}(4)) = max(\vartheta_{MCP.fe}(3)-48 \quad , \quad 0)$$

Initial Pose of the Hand Model.



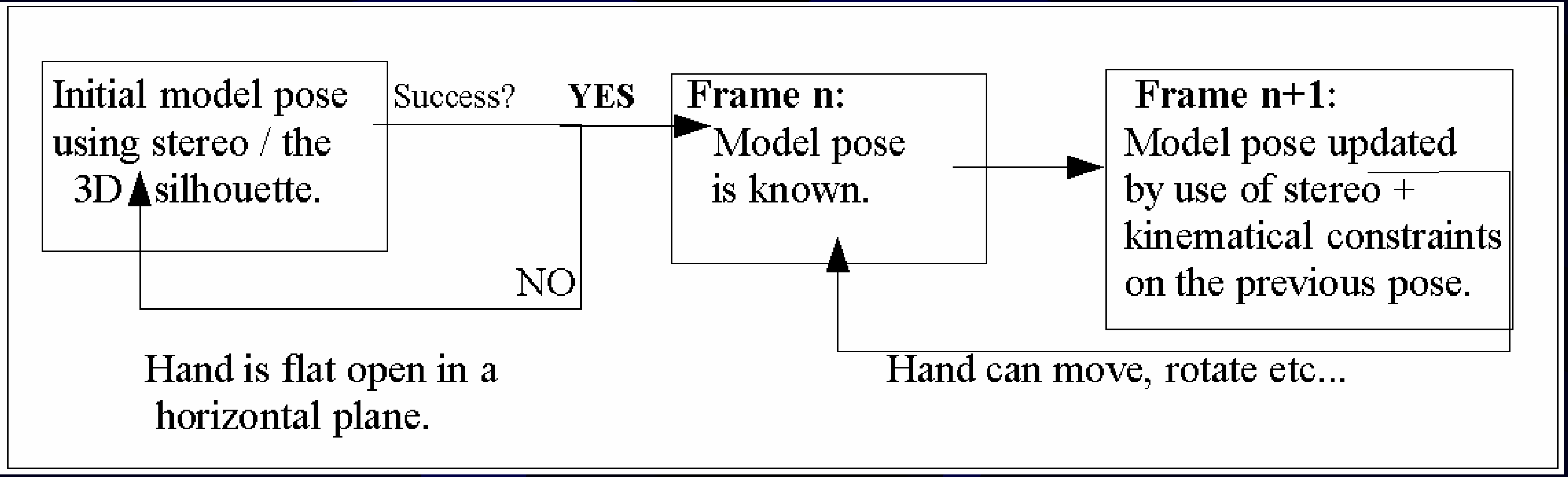


Precision of the Initial Pose.



Tracking the Hand.

- General Diagram:
  - Initial pose,
  - Real time tracking.



Linear Optimization.

- Frame N-1: Feature vector:

$$Hand_{pose}(N-1) = (\bar{\vartheta}_{DIP.fe}(i) , \bar{\vartheta}_{PIP.fe}(i) , \bar{\vartheta}_{MCP.fe}(i) , \bar{\vartheta}_{MCP.aa}(i) , \bar{\vartheta}_{IP.fe} , \bar{\vartheta}_{MCP.fe} \quad \bar{\vartheta}_{TM.fe} , \bar{\vartheta}_{TM.aa} , {}^{palm}\bar{B}.x , {}^{palm}\bar{B}.y , {}^{palm}\bar{B}.z , {}^{palm}\bar{B}.\vartheta , {}^{palm}\bar{B}.\alpha , {}^{palm}\bar{B}.\gamma)$$

- Frame N: Feature vector:

$$Hand_{pose}(N) = (\vartheta_{DIP.fe}(i) , \vartheta_{PIP.fe}(i) , \vartheta_{MCP.fe}(i) , \vartheta_{MCP.aa}(i) , \vartheta_{IP.fe} , \vartheta_{MCP.fe} \quad \vartheta_{TM.fe} , \vartheta_{TM.aa} , {}^{palm}B.x , {}^{palm}B.y , {}^{palm}B.z , {}^{palm}B.\vartheta , {}^{palm}B.\alpha , {}^{palm}B.\gamma).$$

- Minimization of:

$$z = \Sigma_i [\bar{\vartheta}_{DIP.fe}(i) - \vartheta_{DIP.fe}(i)] + \Sigma [\bar{\vartheta}_{PIP.fe}(i) - \vartheta_{PIP.fe}(i)] + \Sigma [\bar{\vartheta}_{MCP.fe}(i) - \vartheta_{MCP.fe}(i)]$$
$$+ \Sigma [\bar{\vartheta}_{MCP.aa}(i) - \vartheta_{MCP.aa}(i)] + \bar{\vartheta}_{IP.fe} - \vartheta_{IP.fe} + \bar{\vartheta}_{MCP.fe} - \vartheta_{MCP.fe} + \bar{\vartheta}_{TM.fe} - \vartheta_{TM.fe} + \bar{\vartheta}_{TM.aa} - \vartheta_{TM.aa}$$
$$+ {}^{palm}\bar{B}.x - {}^{palm}B.x + {}^{palm}\bar{B}.y - {}^{palm}B.y + {}^{palm}\bar{B}.z - {}^{palm}B.z + {}^{palm}\bar{B}.\vartheta - {}^{palm}B.\vartheta$$
$$+ {}^{palm}\bar{B}.\alpha - {}^{palm}B.\alpha + {}^{palm}\bar{B}.\gamma - {}^{palm}B.\gamma$$

Hand Modeling.

- Dynamic Constraints.

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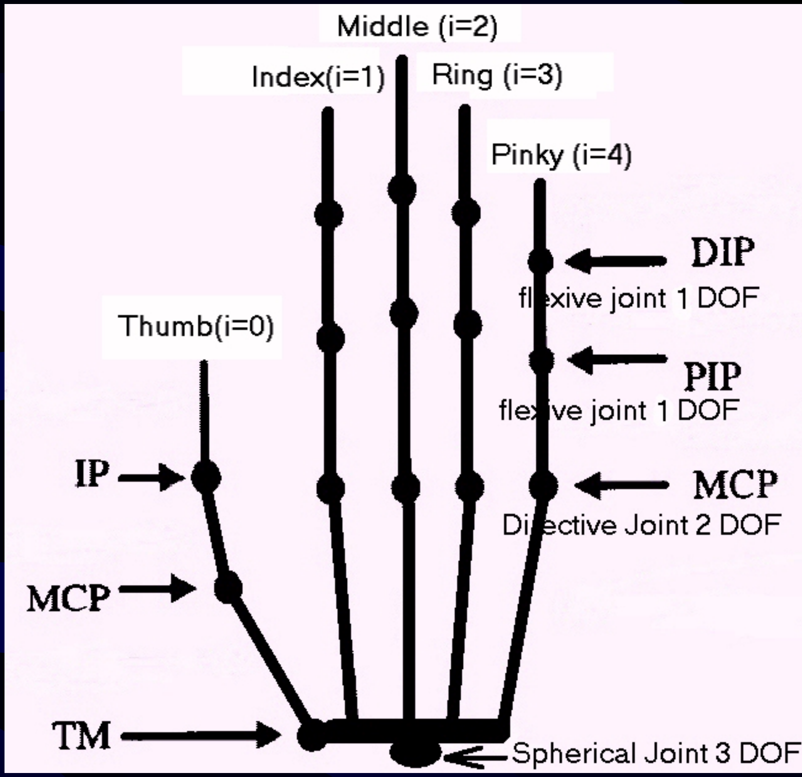
$$\vartheta_{MCP.aa}=\frac{\vartheta_{MPC.fe}}{90}\left(\vartheta_{MPC,converge}-\vartheta_{MCP.aa,s}\right)+\vartheta_{MCP.aa,s}$$



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Ring finger (i=3):

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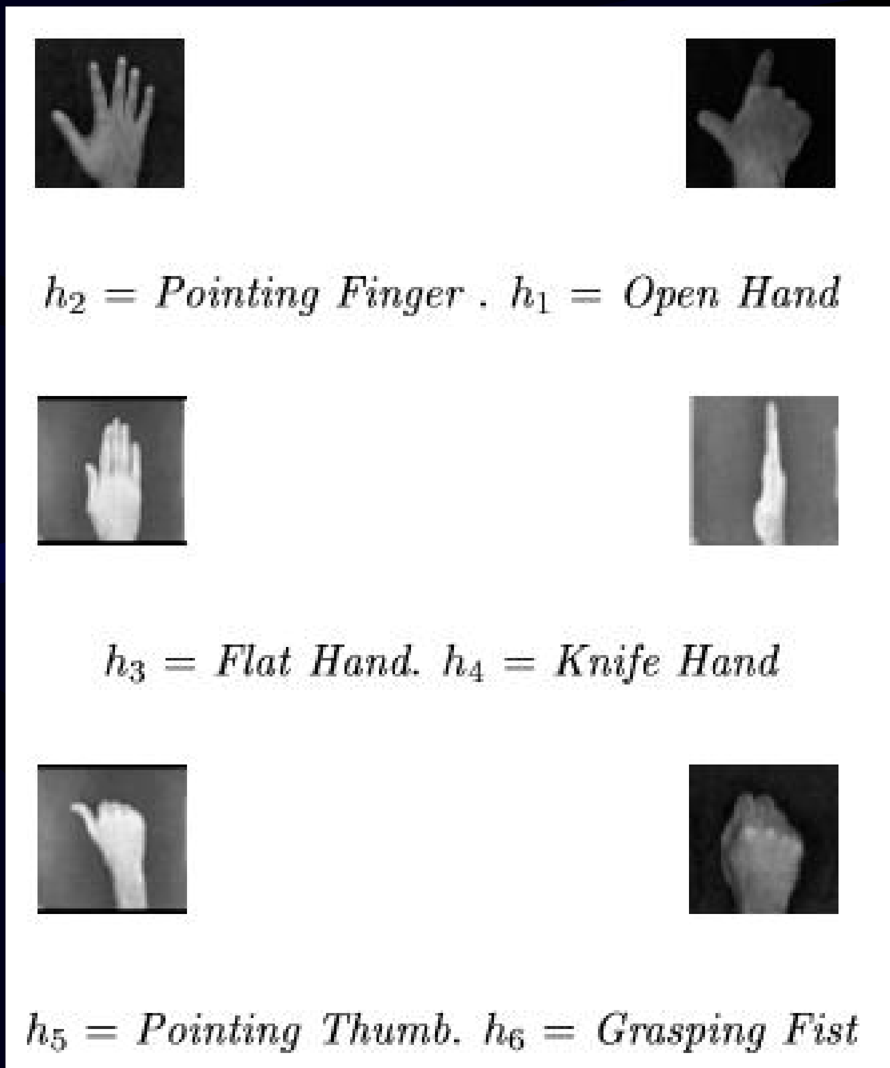
$$d_{min}(\vartheta_{MCP.fe}(3)) = max(\vartheta_{MCP.fe}(2)-20 \quad , \quad \vartheta_{MCP.fe}(4)-44 \quad , \quad 0)$$

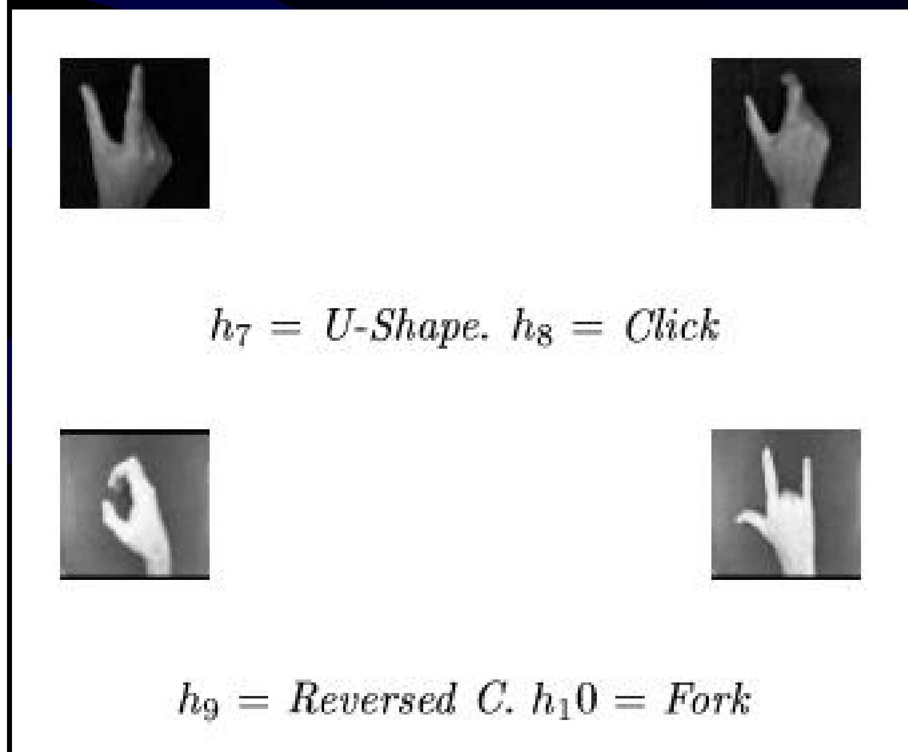
Pinky finger (i=4):

$$d_{max}(\vartheta_{MCP.fe}(4)) = min(\vartheta_{MCP.fe}(3)+44 \quad , \quad s_{max}(\vartheta_{MCP.fe}(4)))$$

$$d_{min}(\vartheta_{MCP.fe}(4)) = max(\vartheta_{MCP.fe}(3)-48 \quad , \quad 0)$$

SVM gesture recognizer.

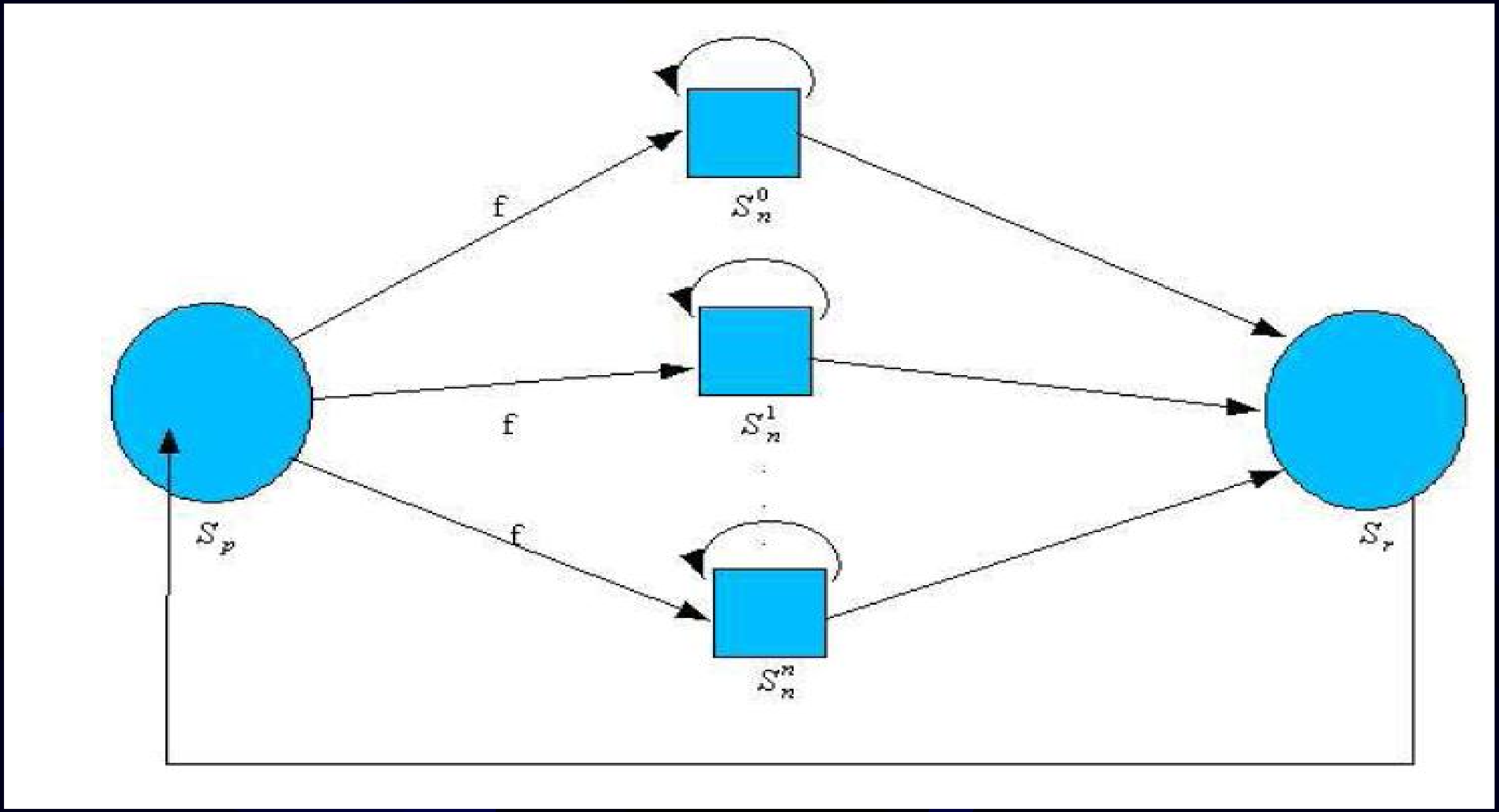




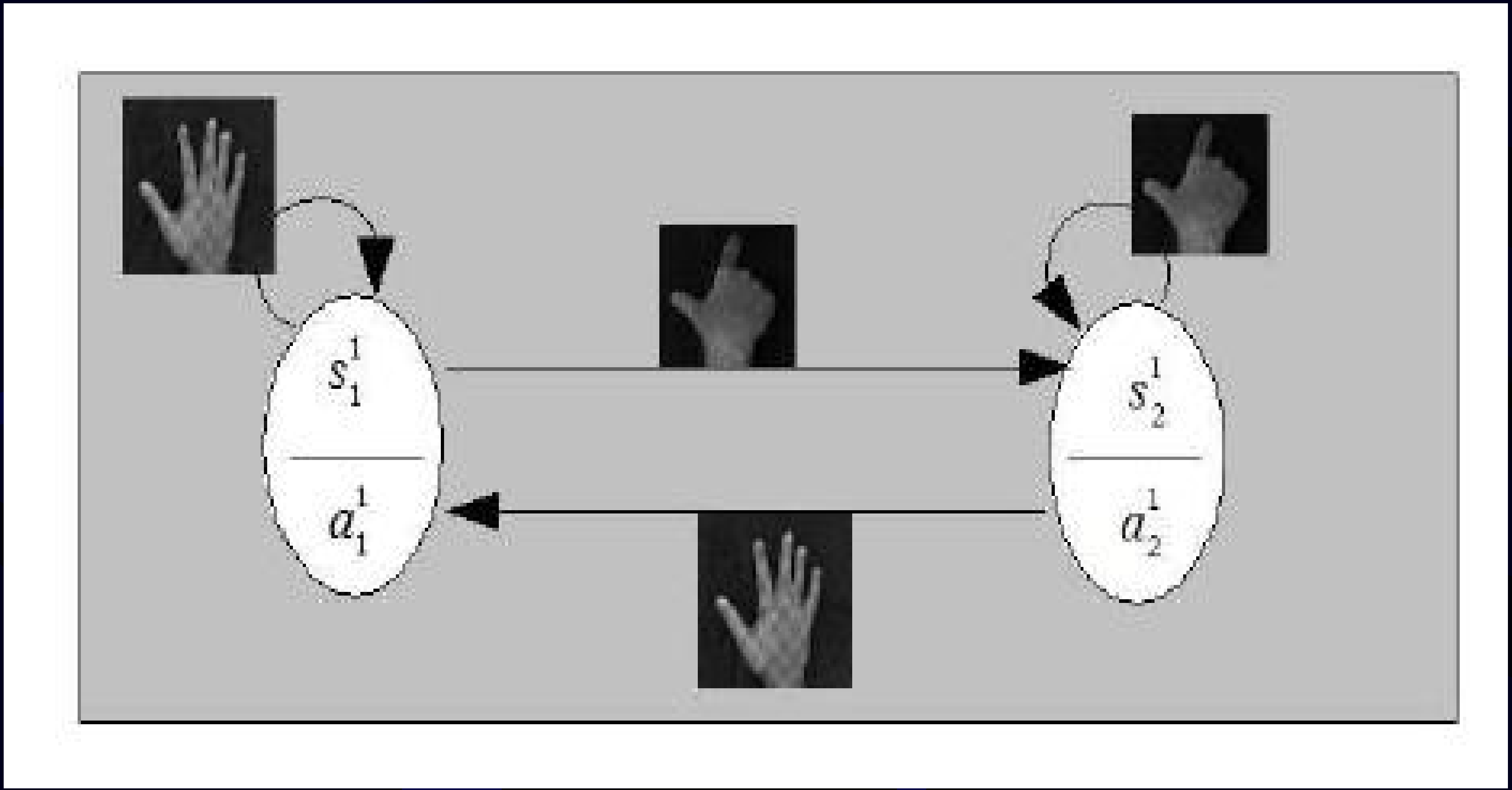
Gestural phases: Kendon.

- 1- Preparation phase: *prepares the hand from its idle state, by moving into a recognizable form.*
- 2- The Nucleus phase: *which has a definite form and is the peak or stroke of the gesture*
- 3- The retraction phase: *which usually returns the hand to the resting position.*

Super-State Machine.



Mini-State Machine S1.

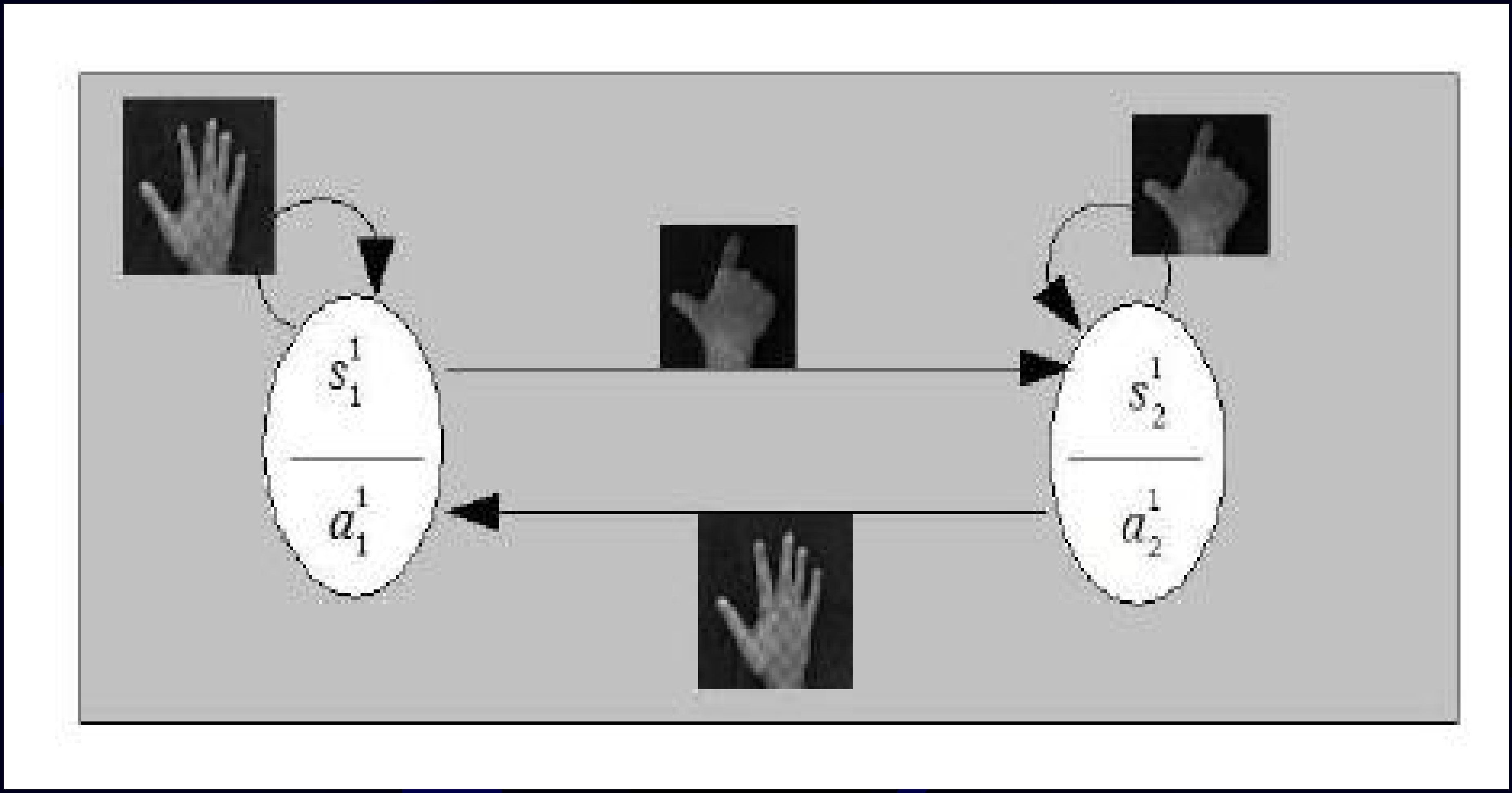


States and Input events.

- $S^1 = \{s_1^1, s_2^1\}$ with s_1^1 is the moving state, and s_2^1 is the rotation or looking around state.

- I^1 is the input event set $I^1 = \{h_1, h_2\} \subset H$

Mini-State Machine S1.

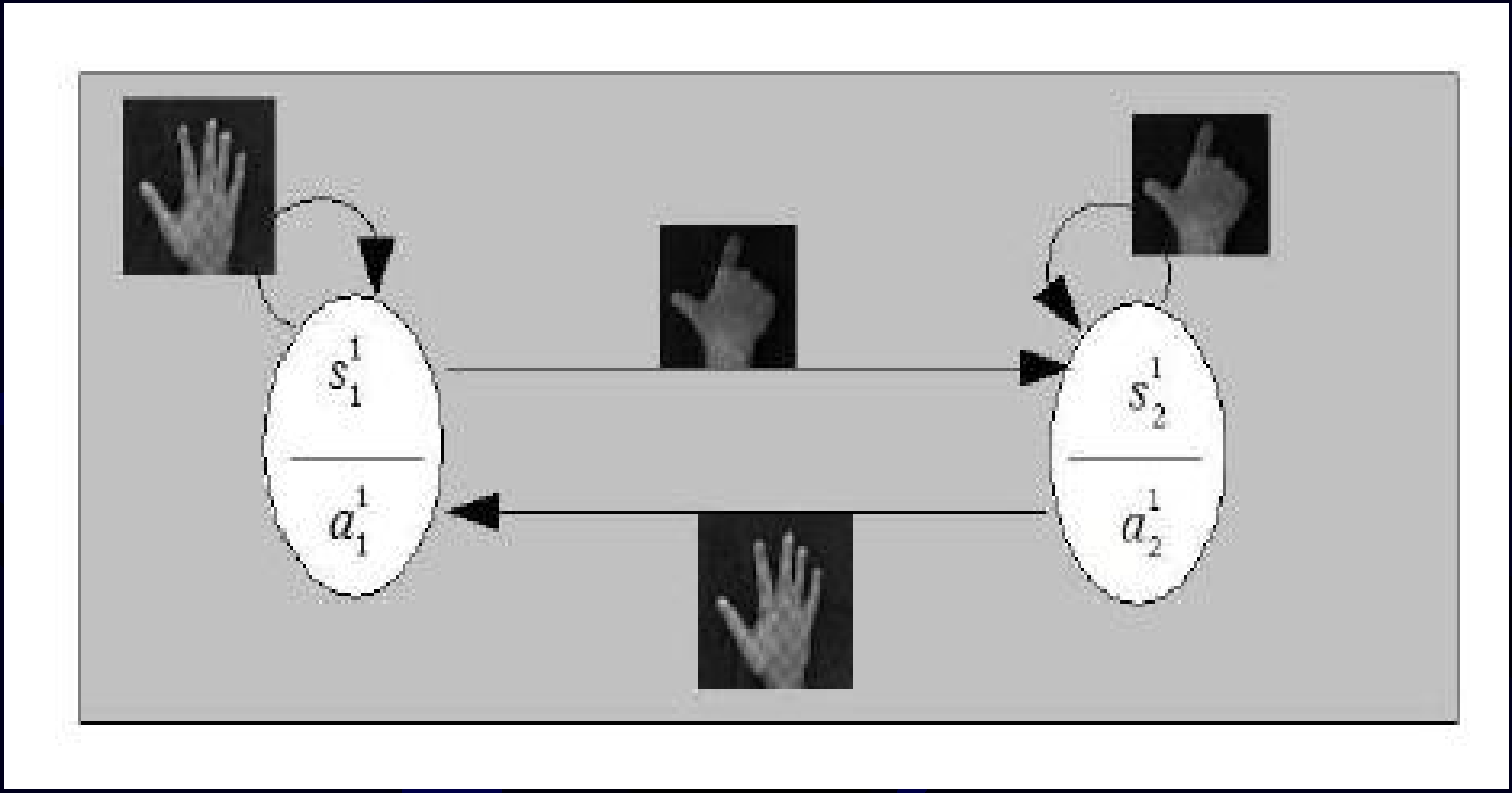


Actions

- $a_1^1 = a^1_{openhand} = g_1^1(p_1^1)$ is an action performed by the *open hand*, the action being translating the view point of the camera along the x, y, and z coordinates,

- $a_2^1 = a^1_{pointingfinger} = g_2^1(p_2^1)$ is an action performed by the pointing finger, the action being rotating the view point of the camera in pitch, yaw and roll.

Mini-State Machine S1.

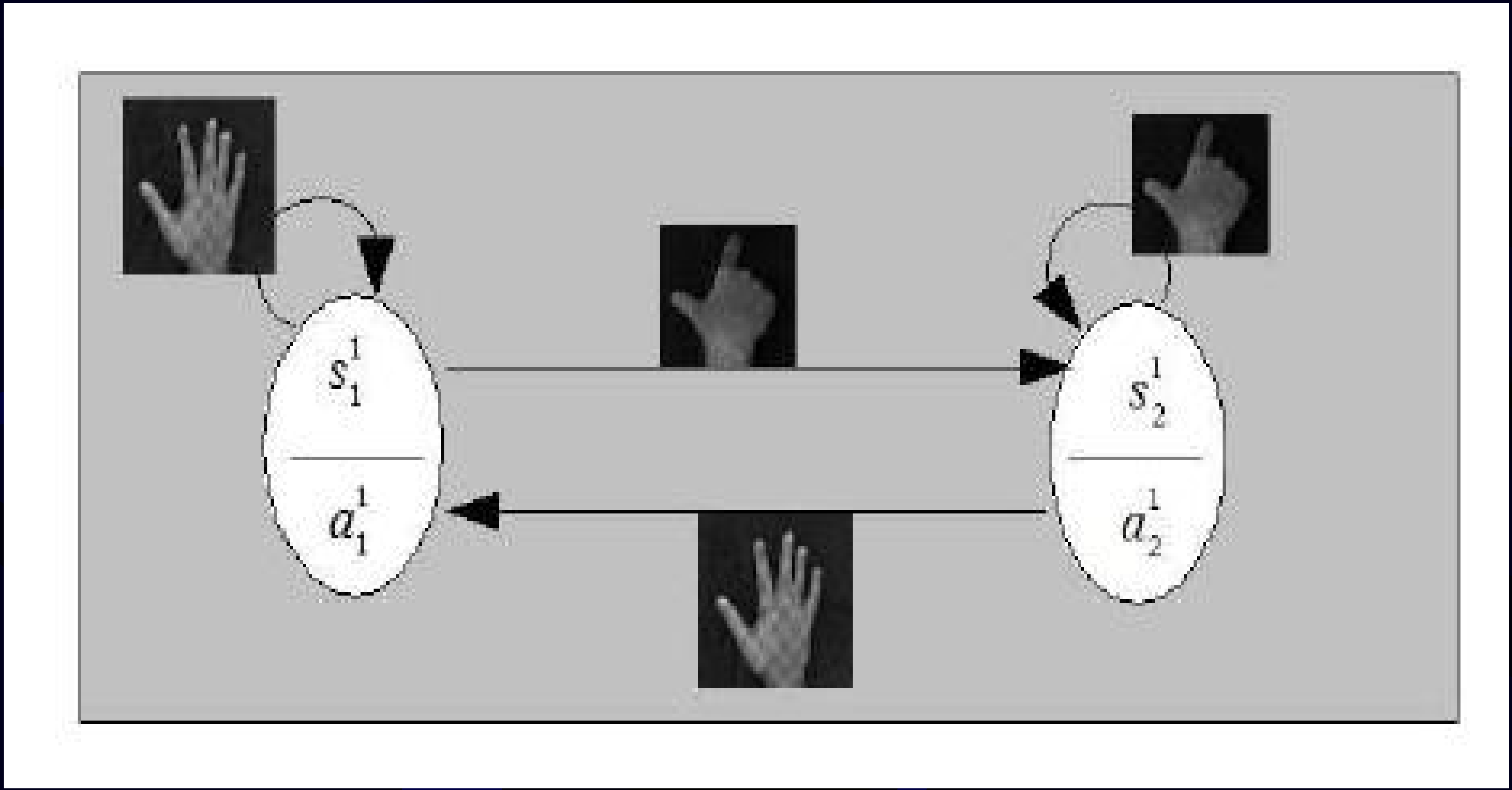


Parameters.

- $p_1^1 \in P$ with $p_1^1 = p_{openhand}^1 = (x, y, z)$ is the center of gravity of the static hand sign h_1 (*i.e. open hand*), in the absolute coordinate system and

- $p_2^1 = p_{pointingfinger}^1 = (\alpha, \beta, \gamma)$ be the direction of the pointing finger in static hand sign h_2 (*i.e. pointing finger*)

Mini-State Machine S1.

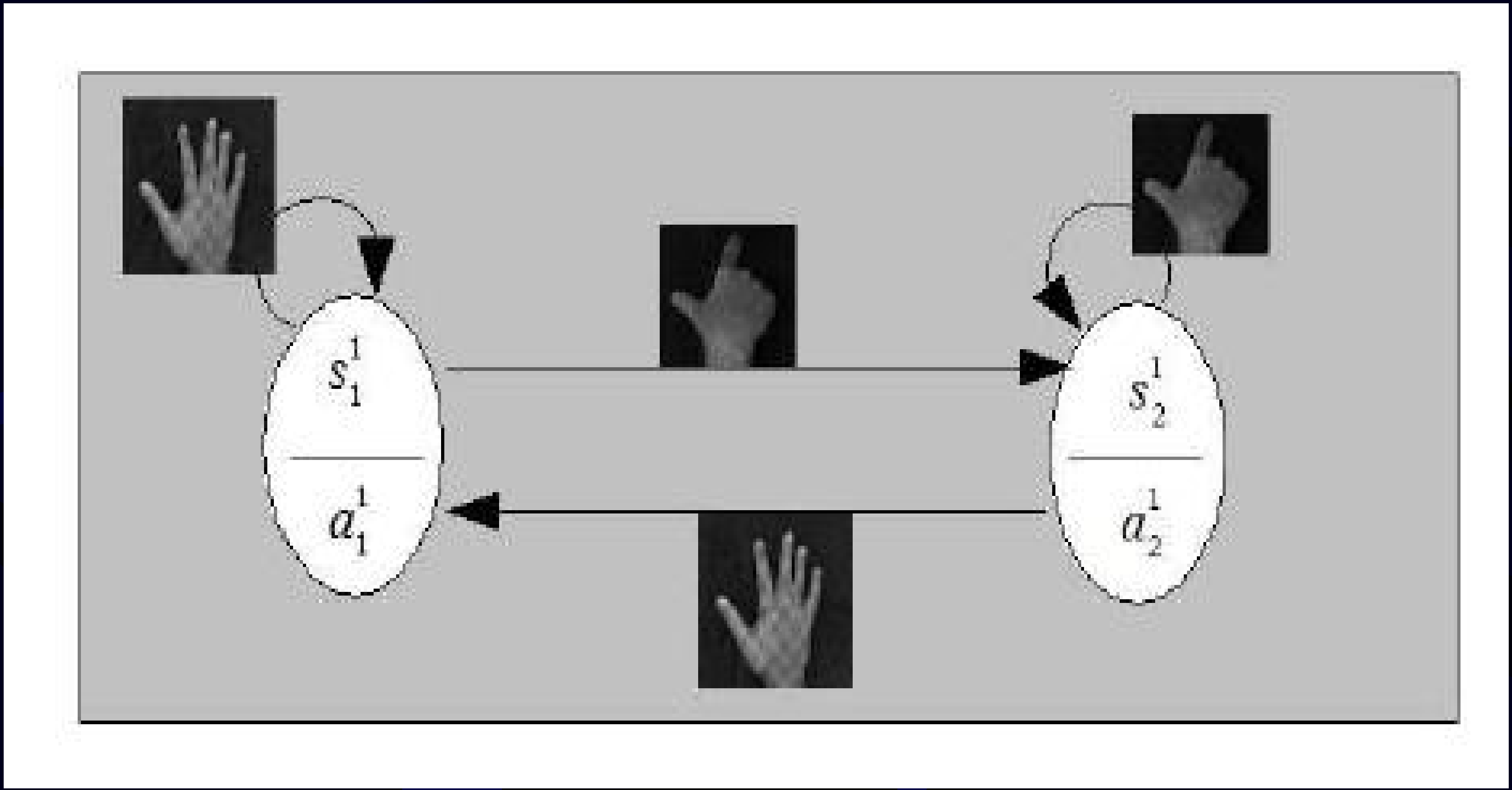


Functions.

- $g_1^1 \in G$ with $g_1^1 = g^1_{openhand} : p^1_{openhand} \rightarrow a^1_{openhand}$ in other words we can write: $g_1^1(p_1^1) = g_1^1(x, y, z) = \sqrt{(x^2 + y^2 + z^2)}$ = the velocity of motion of the virtual camera in the (x,y,z) direction = $a^1_{openhand}$.

- $g_2^1 = g^1_{pointingfinger} : p^1_{pointingfinger} \rightarrow a^1_{pointingfinger}$ in other words we can write: $g_2^1(p_2^1) = g_2^1(\alpha, \beta, \gamma) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & cos\alpha & sin\alpha \\ 0 & -sin\alpha & cos\alpha \end{pmatrix} \times \begin{pmatrix} cos\beta & 0 & -sin\beta \\ 0 & 1 & 0 \\ sin\beta & 0 & cos\beta \end{pmatrix} \times$ $\begin{pmatrix} cos\gamma & sin\gamma & 0 \\ -sin\gamma & cos\gamma & 0 \\ 0 & 0 & 1 \end{pmatrix} \times \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} = \begin{pmatrix} a_1 \\ a_2 \\ a_3 \end{pmatrix} = a_2^1$ which is the action of rotation of the camera in yaw, roll and pitch.

Mini-State Machine S1.



Compensatory. Pursuit.