Mixed Scale Motion Recovery

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Ph.D. Oral Presentation

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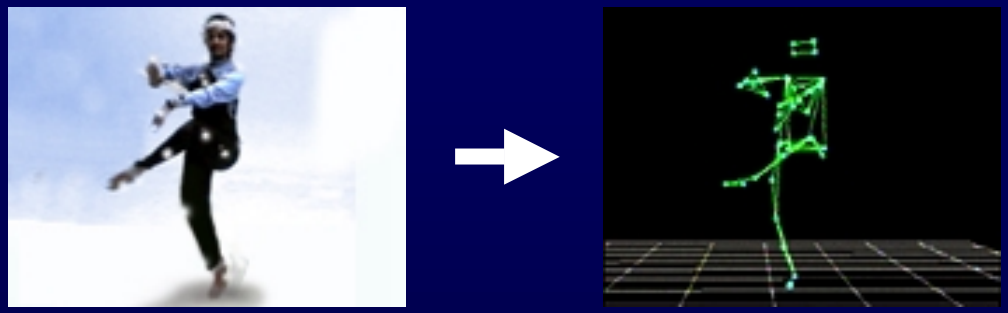
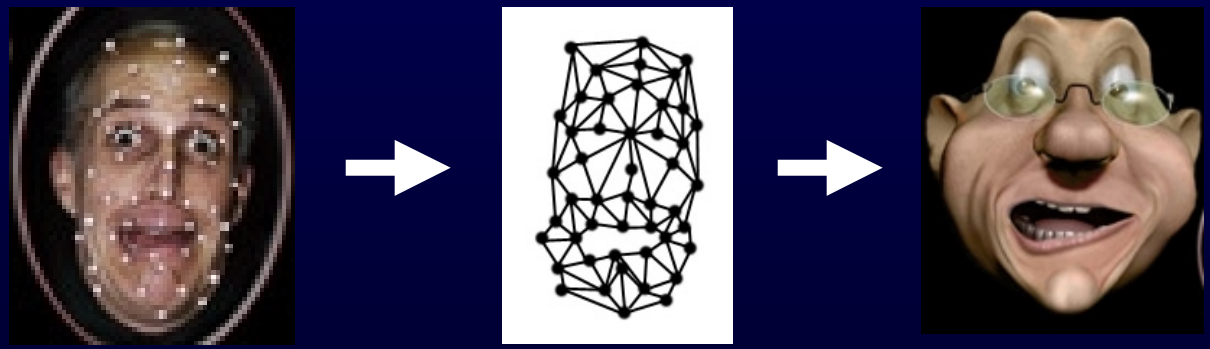
High level goal

- **Recover motion**
  - Large working volume
  - Extreme detail

Current technology

- Acquire real motion as computer model

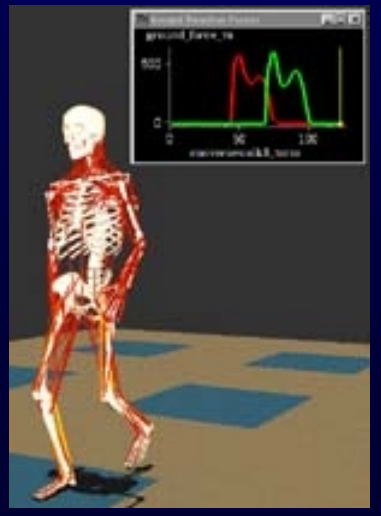




- Fixed resolution vs. range ratio

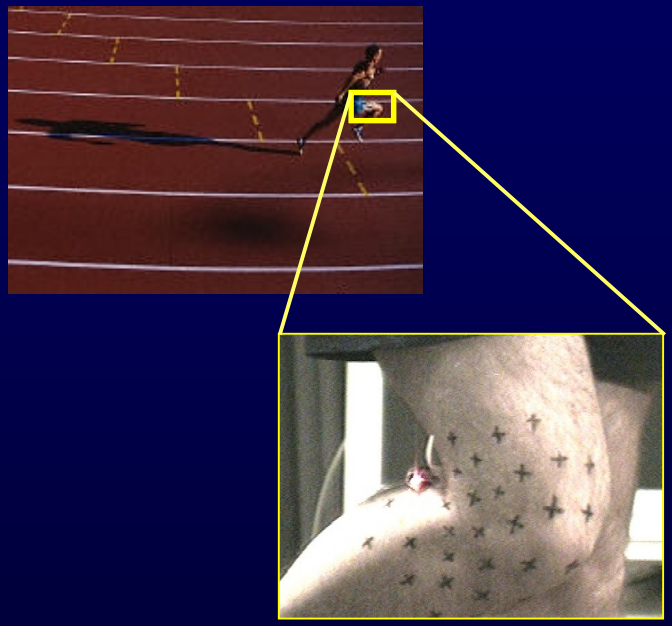
Applications of motion recovery

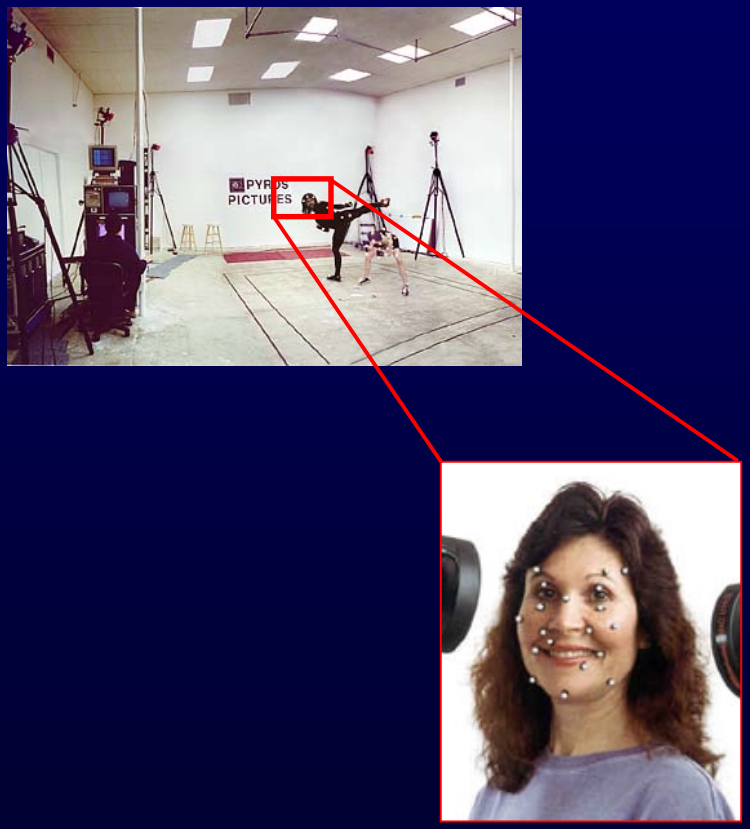
- Animation
- Athletic analysis
- Biomechanics



Mixed scale domains

- Detailed motion within a larger volume



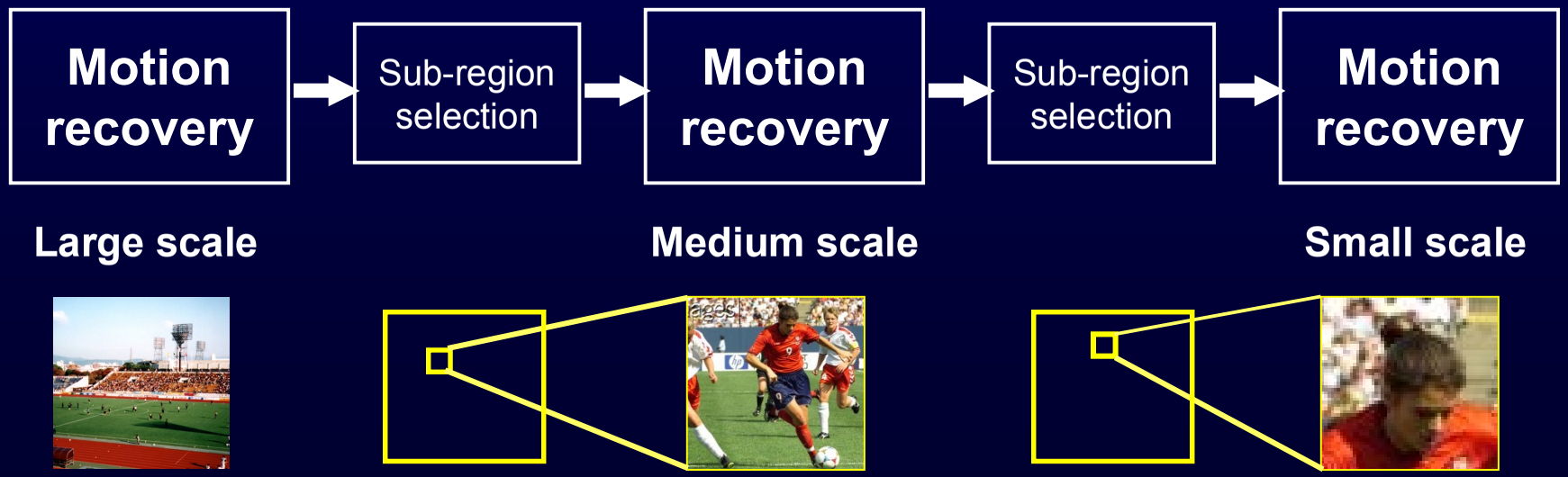


Problem domain characterization

- **Multiple scales of motion**
- **At individual scales**
  - Working volume is local
  - Working volume is moving

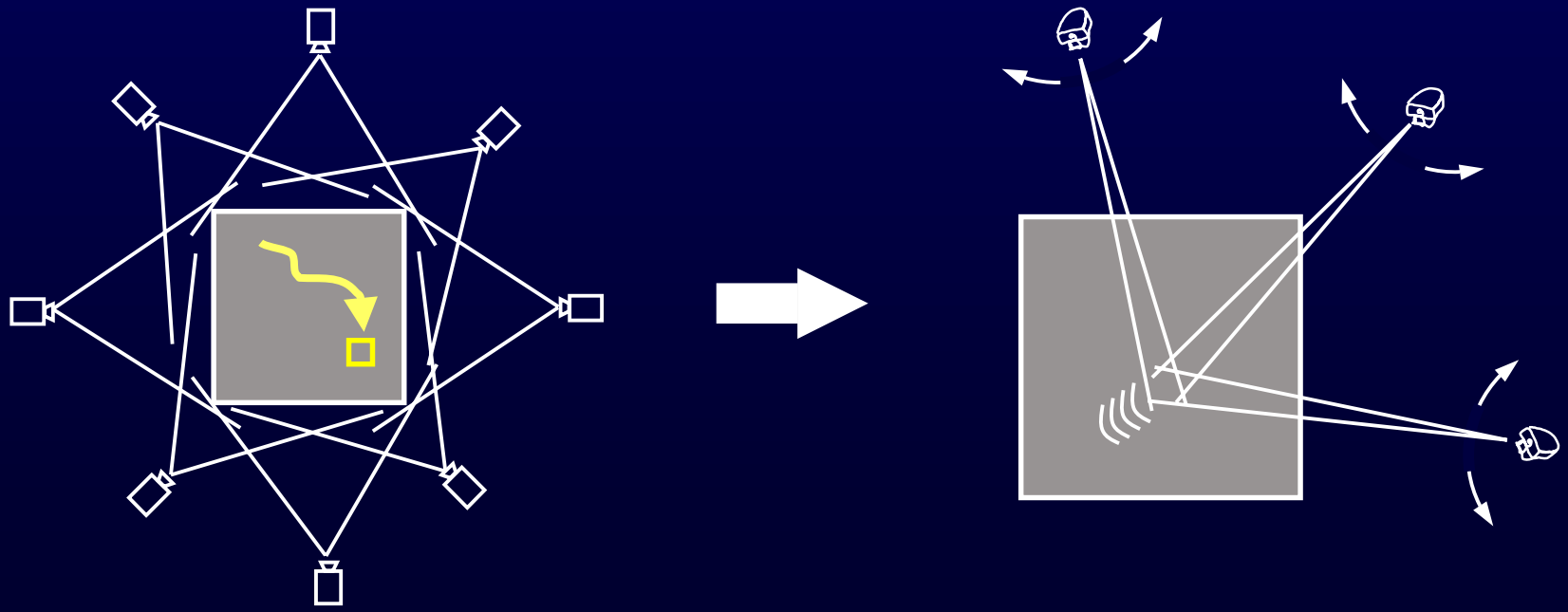
Hierarchical paradigm

- **Explicitly expresses motion hierarchy**
  - Motion recovery drives sub-region selection
  - Sub-region selection defines next scale
- **Multiple designs possible within framework**



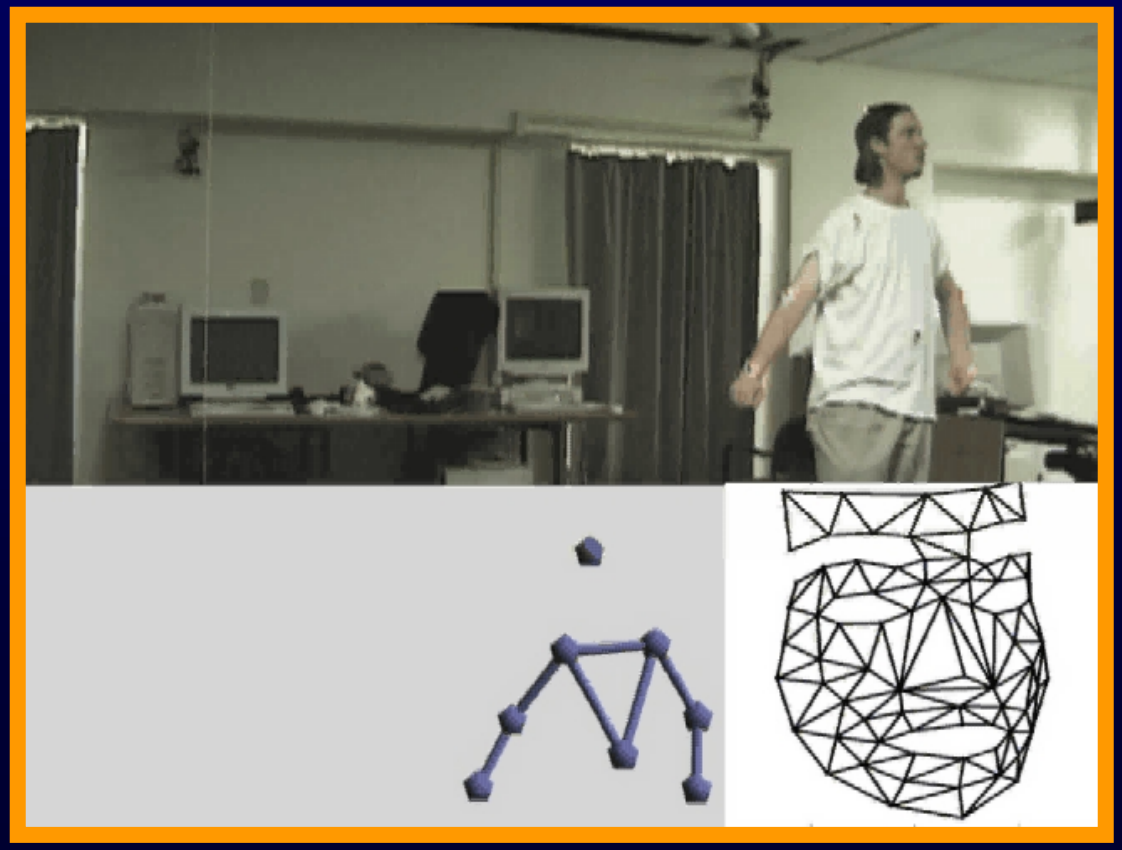
My design

- **Multi-camera large scale recovery**
  - Covers large volume
  - Robust to occlusion
- **Pan-tilt multi-camera small scale recovery**
  - Automated camera control
  - High resolution imaging



Demonstration of my system

- Body moves on room size scale
- Face deforms on much smaller scale
- Simultaneous capture

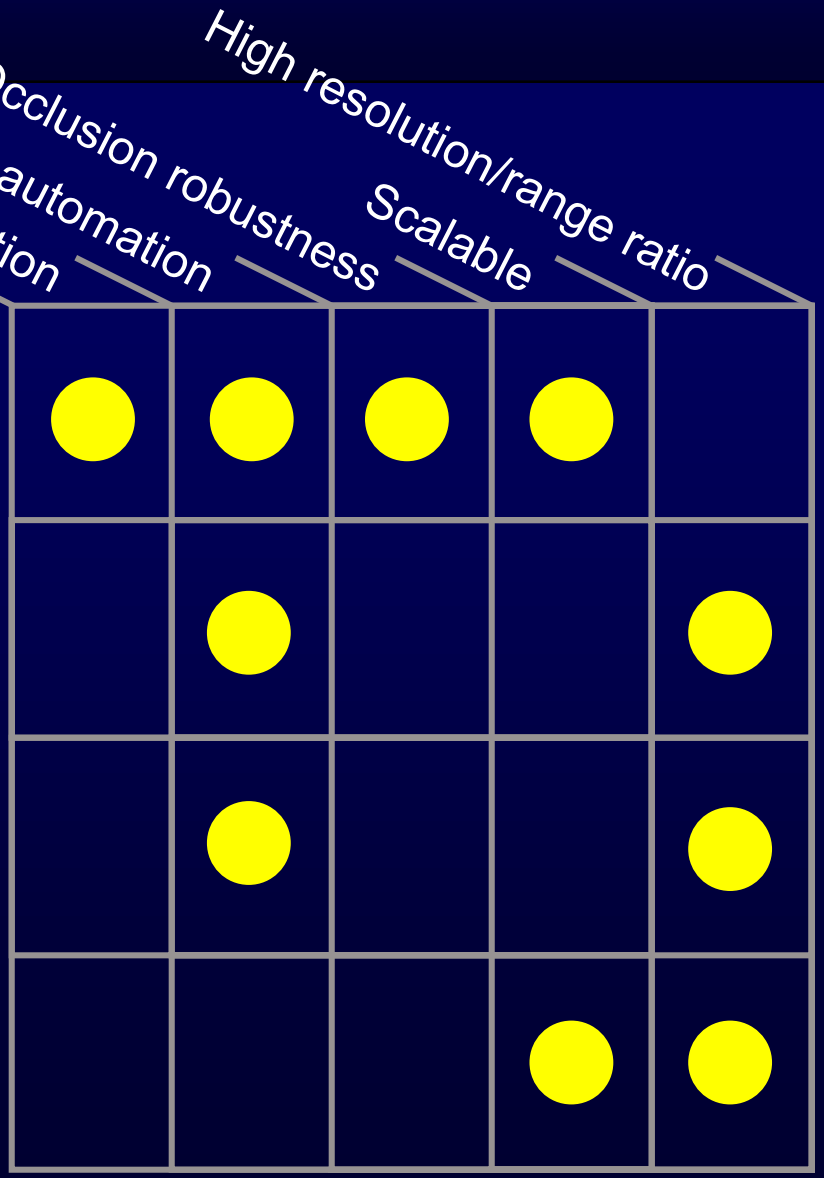


Desirable system properties

- High resolution/range ratio
- Scalable
- Occlusion robustness
- Runtime automation

Related Work

- **Traditional motion recovery**
  - [Vicon] [MotionAnalysis] [Guenter98]
- **Simple pan/tilt systems**
  - [Sony EVI-D30] [Fry00]
- **2D guided pan/tilt systems**
  - [Darrell96] [Greiffenhagen00]
- **Human controlled cameras**
  - [Kanade00]



Contributions

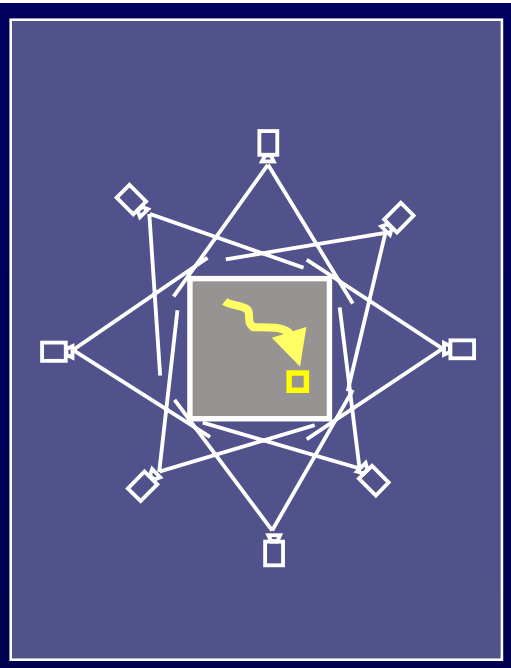
- **Framework for mixed scale motion recovery**
  - Hierarchical paradigm
  - Data driven analysis
  - Model based solutions
- **Specific system design**
  - High resolution/range ratio
  - Scalable
  - Robust to occlusion
  - Automated
- **Application to simultaneous face-body capture**

Talk outline

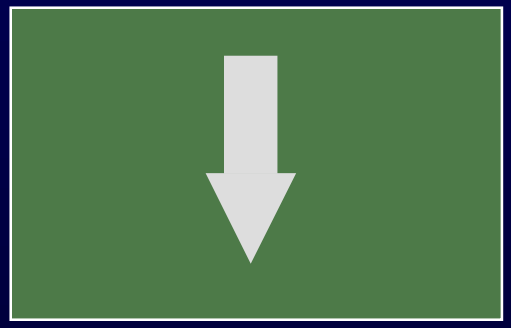
- Introduction
- Framework
  - Hierarchical paradigm
  - Data driven analysis
  - Model based solutions
- System implementation
  - Large scale recovery
  - Sub-region selection
  - Small scale recovery
- End-to-end video
- Summary and future work

Relation of system to hierarchy

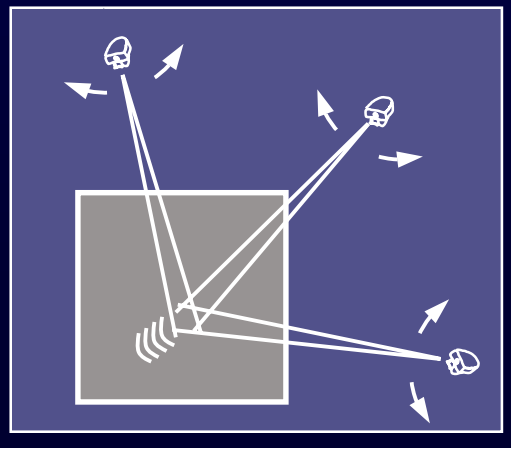
Large scale
motion recovery



Sub-region selection



Small scale
motion recovery

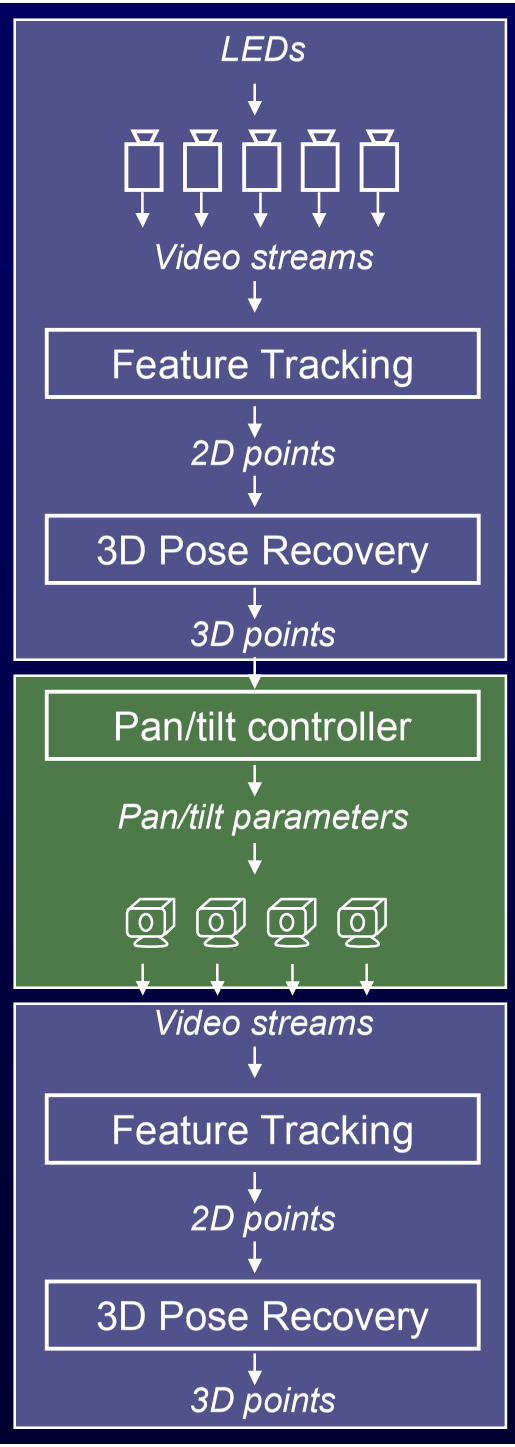


System overview

Large scale
motion recovery

Sub-region selection

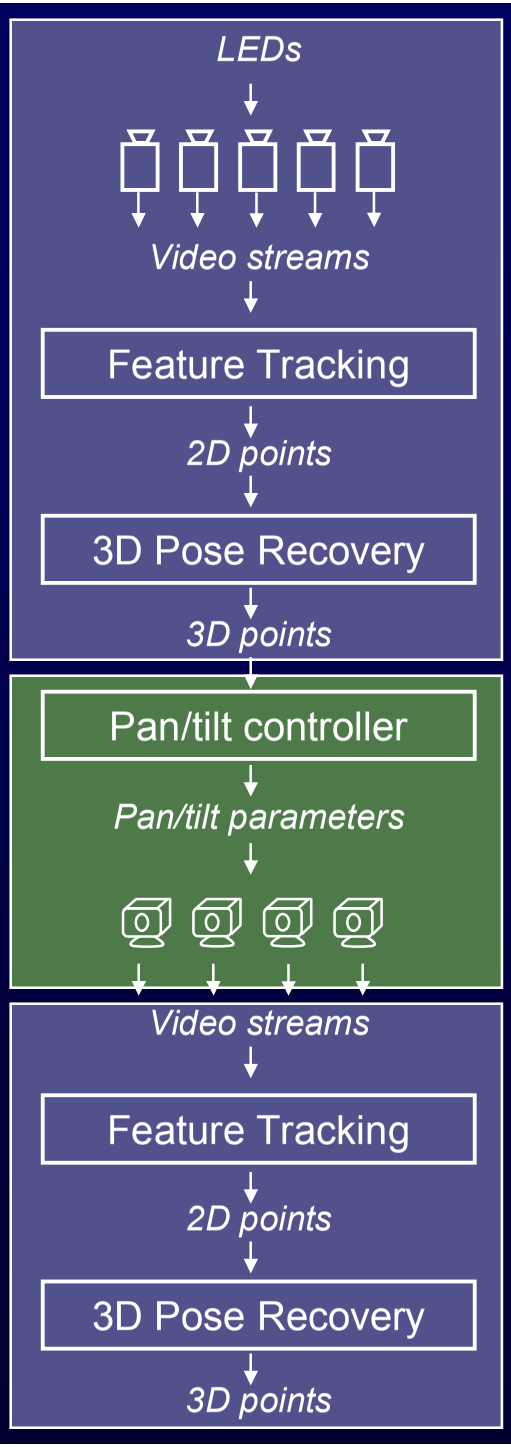
Small scale
motion recovery



Interface is the challenge

- Large/small scale similar
- Interface requirements differ

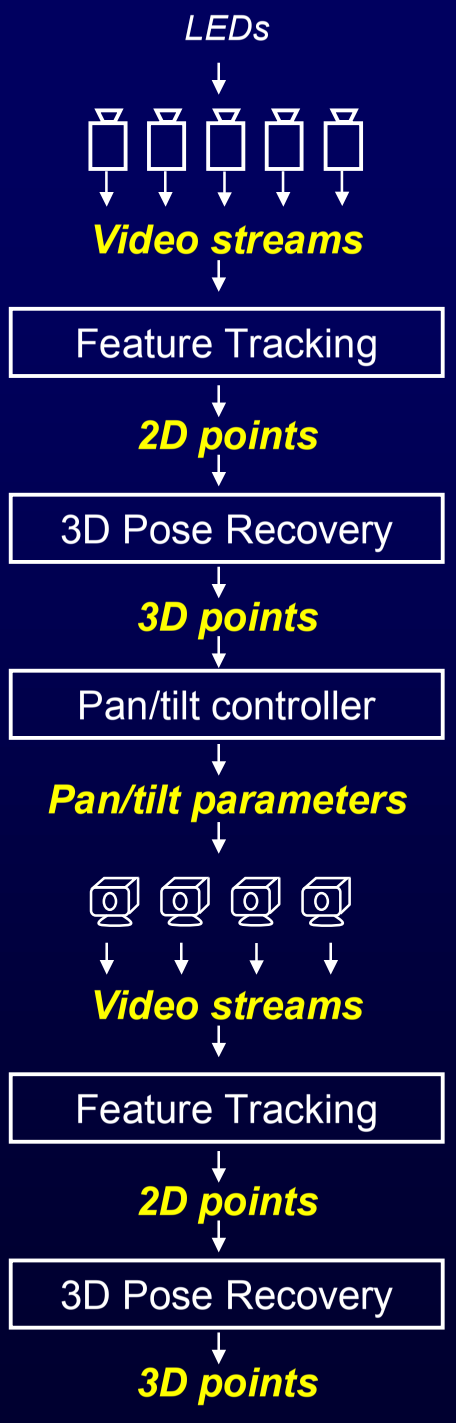
Interfaces



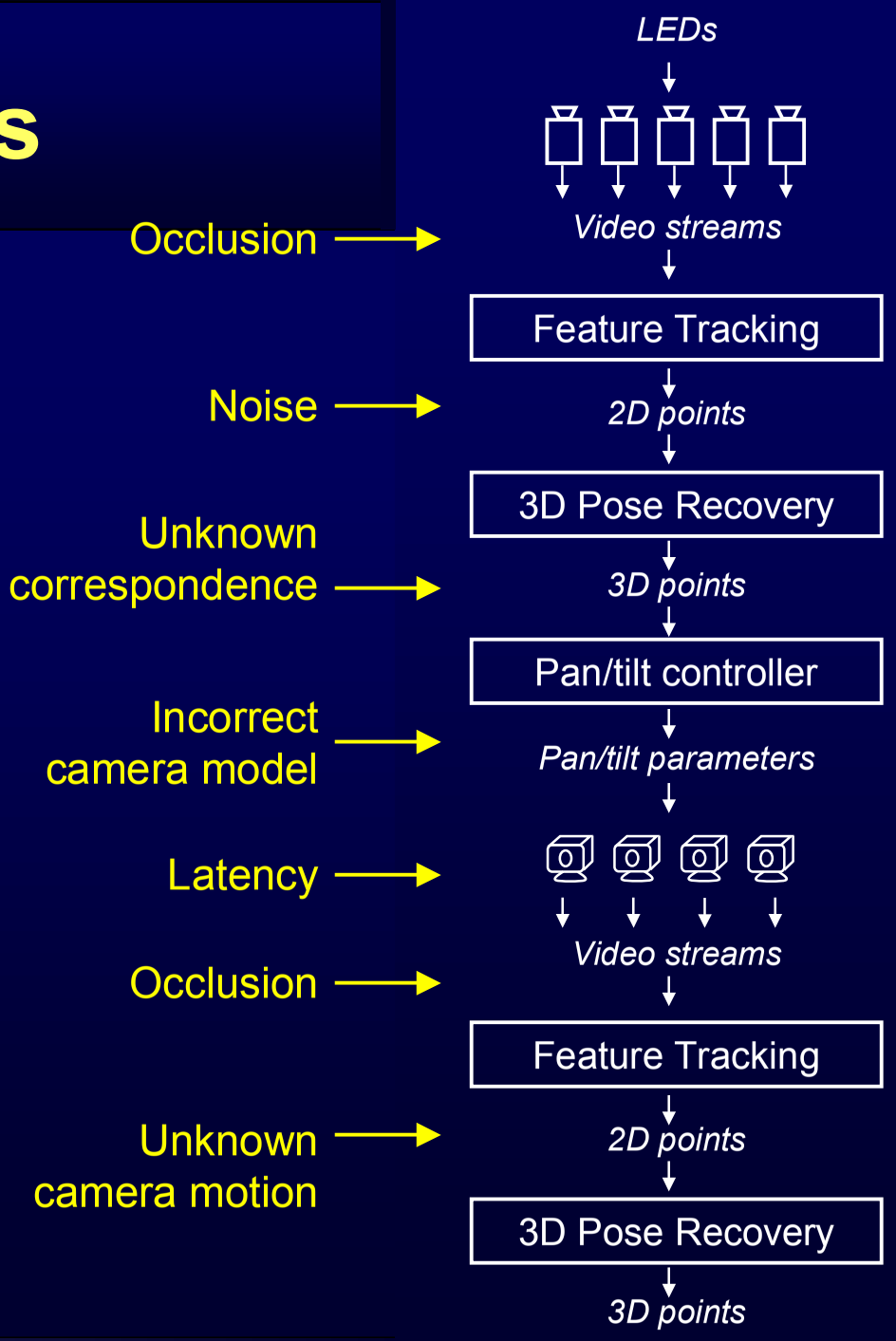
- Interface critical in end-to-end system
- Often ignored in individual components

Data flow

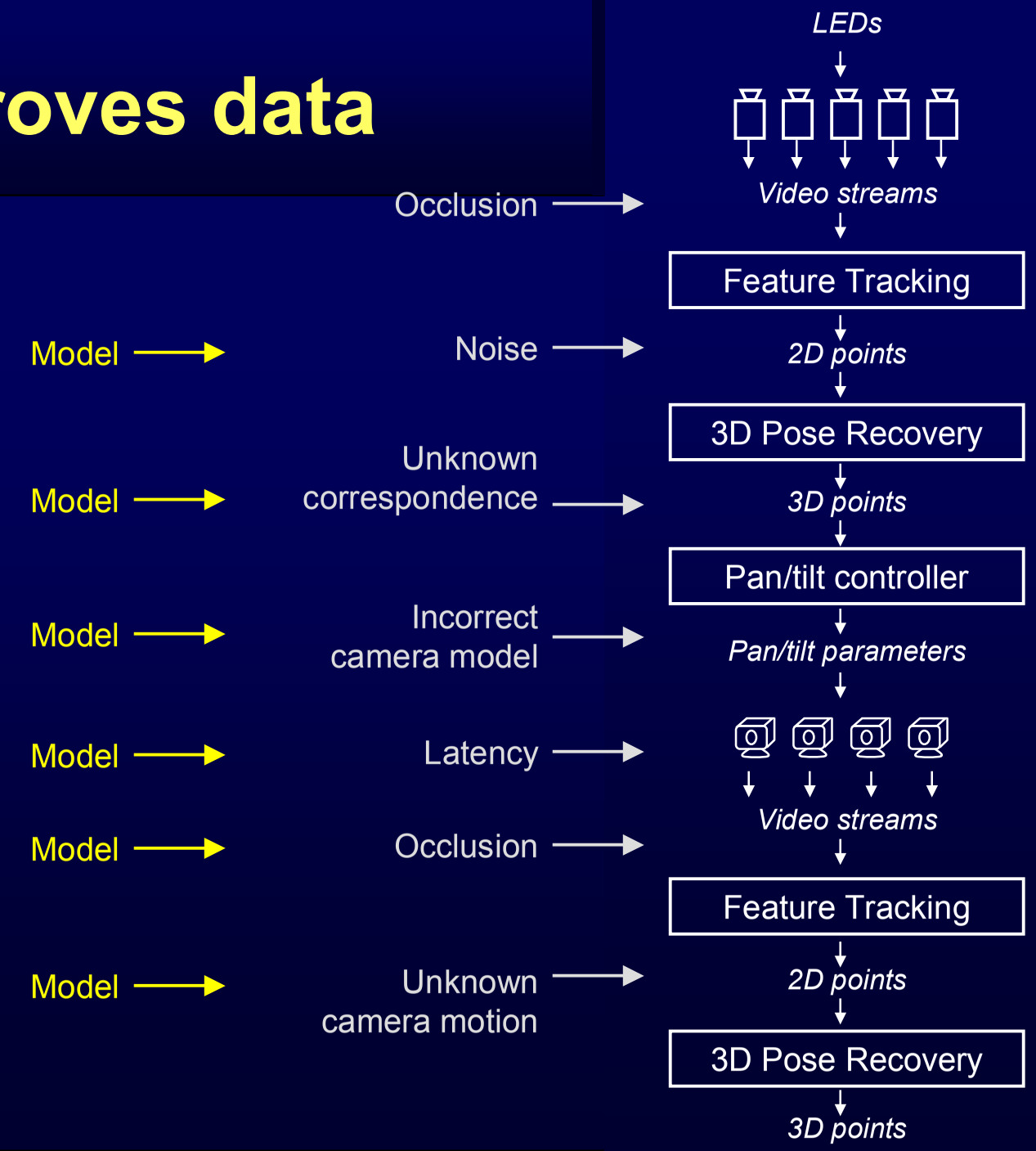
- System viewed as data flow
- Clean interface (data) desirable



System challenges



Model improves data



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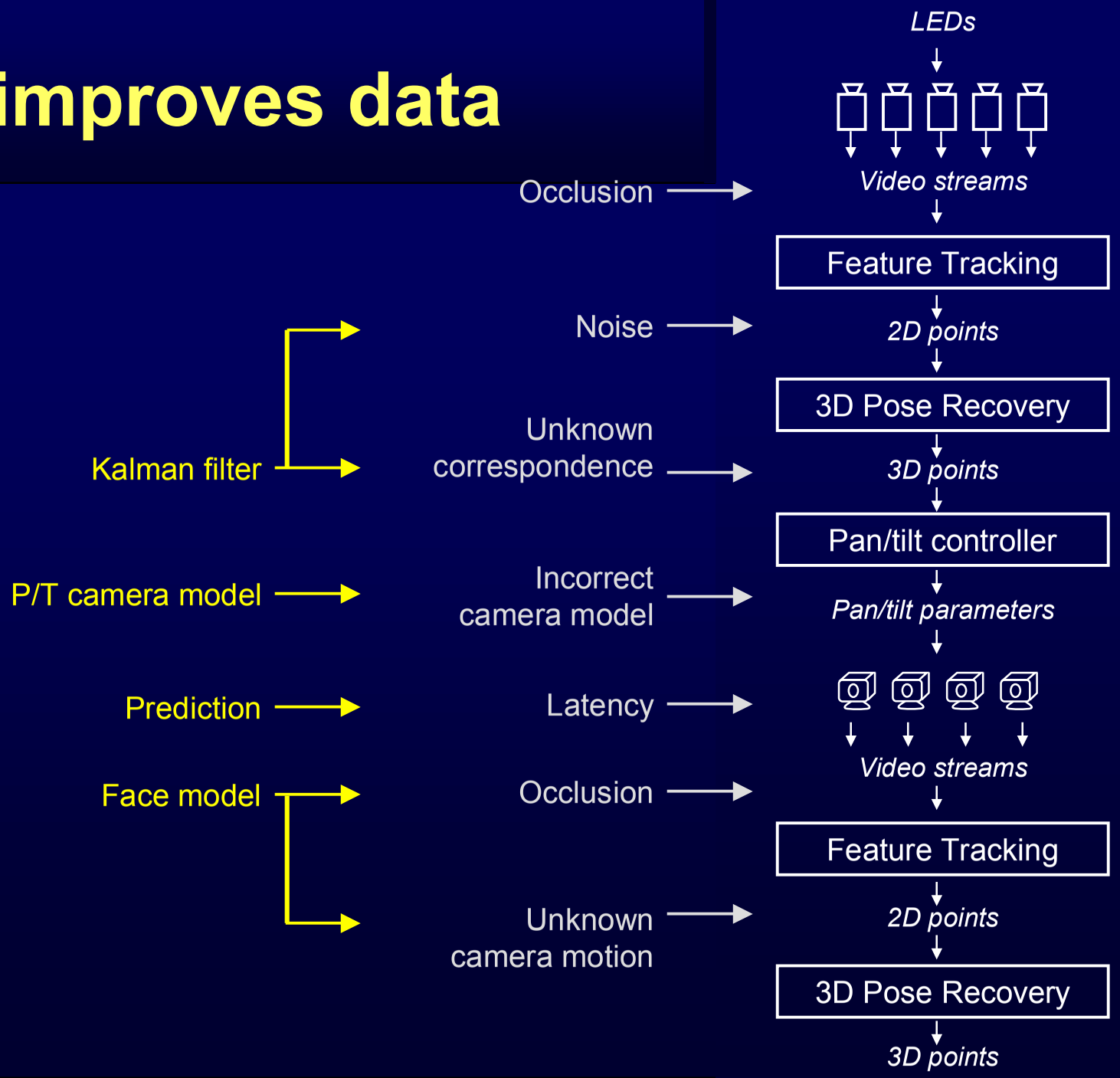
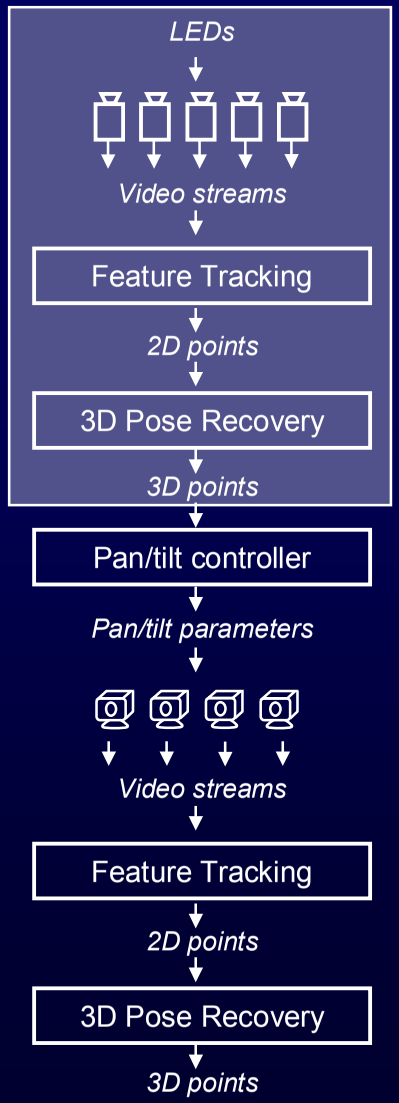


Talk outline

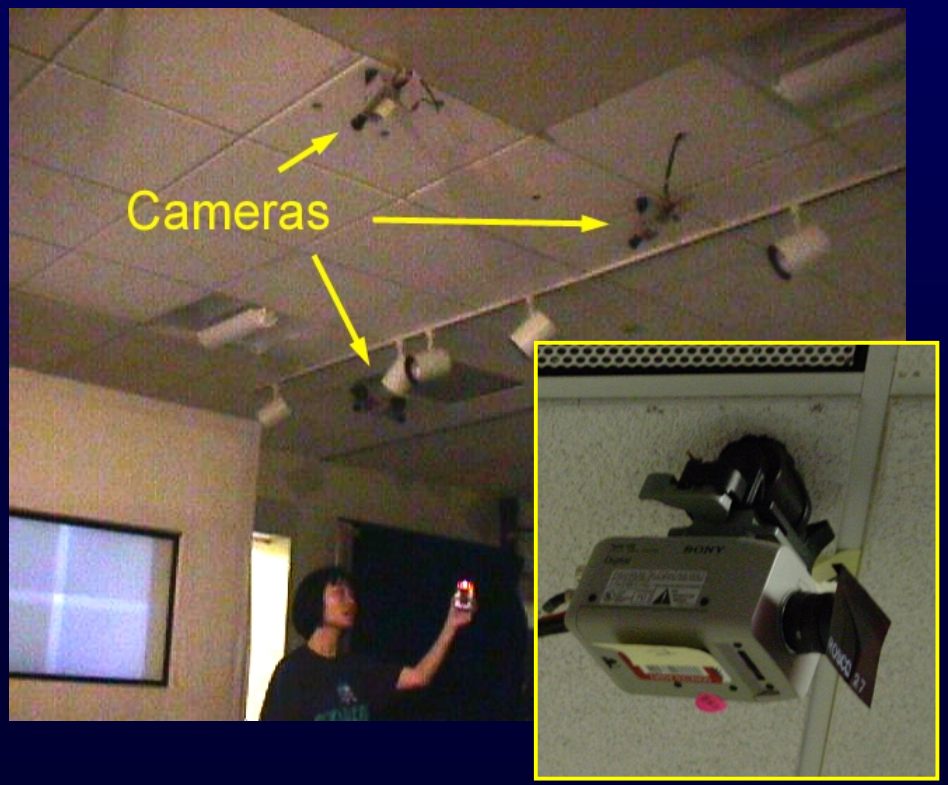
- Introduction
- Framework
  - Hierarchical paradigm
  - Data driven analysis
  - Model based solutions
- **System implementation**
  - Large scale recovery
  - Sub-region selection
  - Small scale recovery
- End-to-end video
- Summary and future work

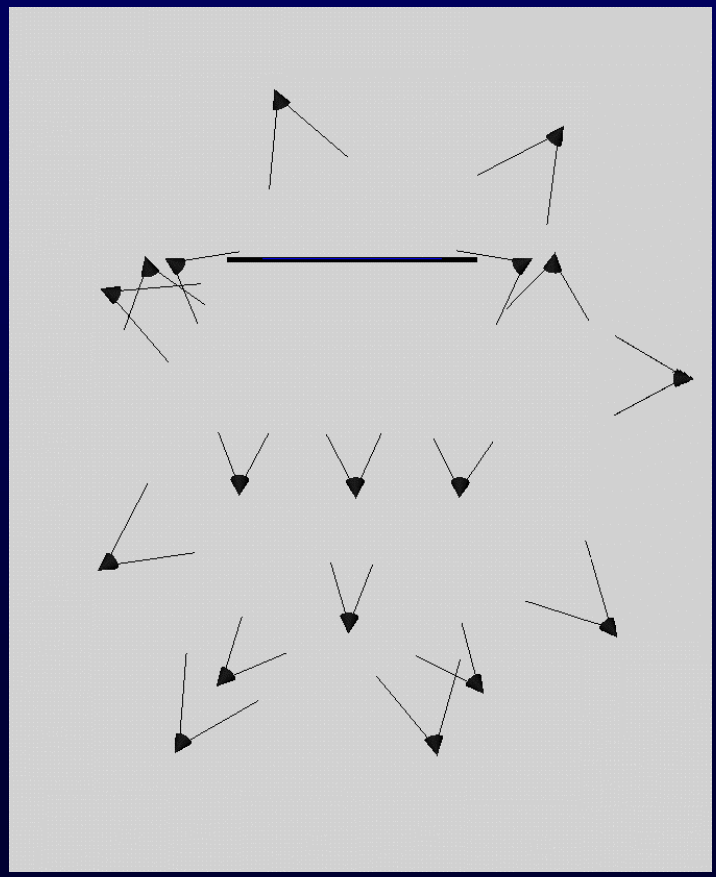
Large scale system



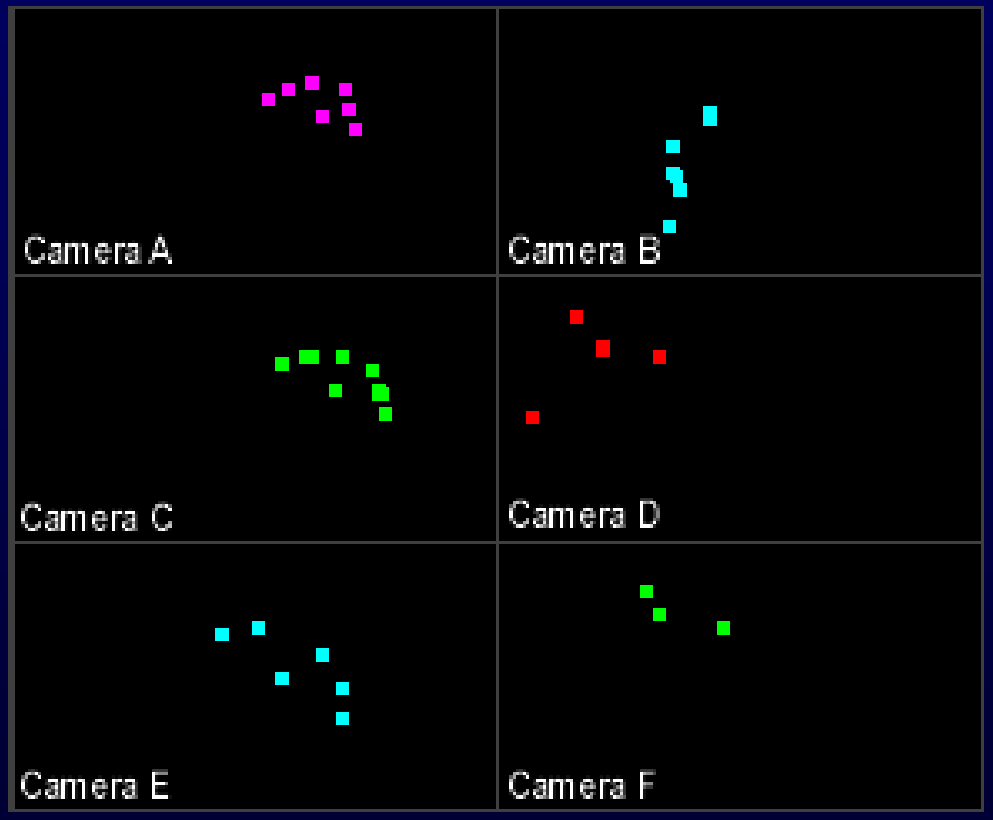
Large scale physical arrangement

- 18 NTSC cameras
- 18 digitizing Indys



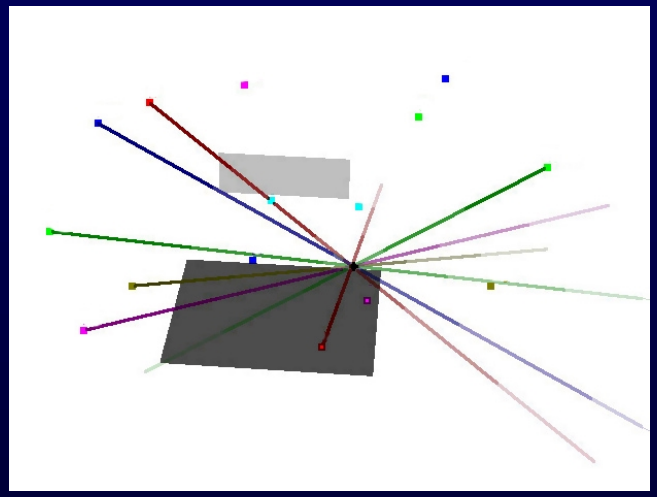


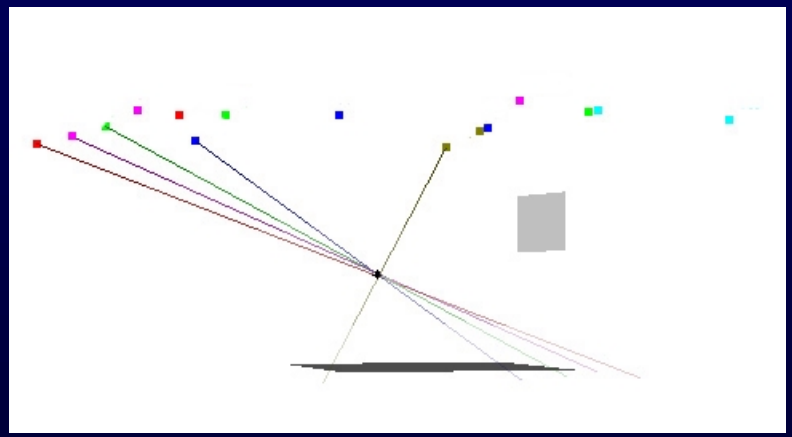
Large scale features



Large scale pose recovery

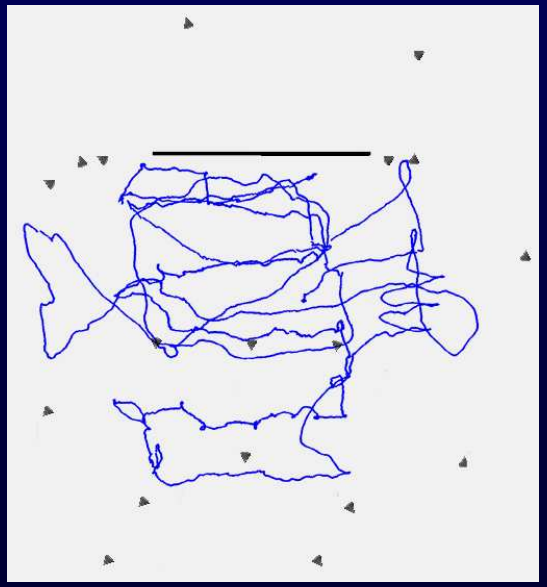
- Consider rays through observations
- Rays cross at 3D feature points

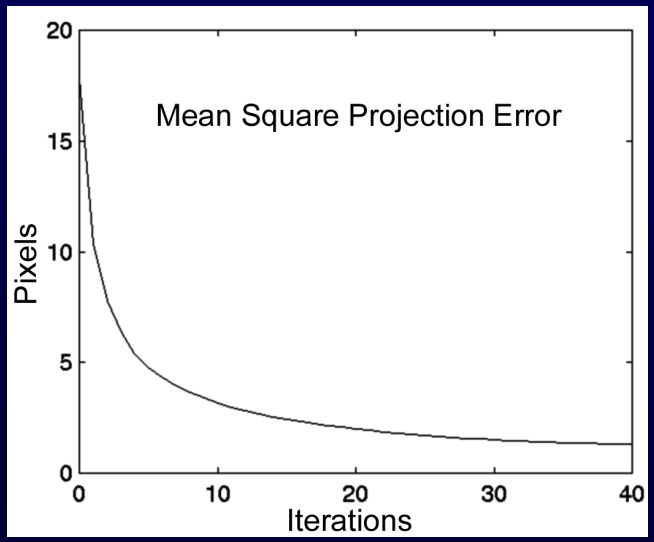




Calibrating wide area cameras

- **Jointly calibrated multiple cameras**
- **Iteratively estimate**
  - Camera calibration
  - Target path



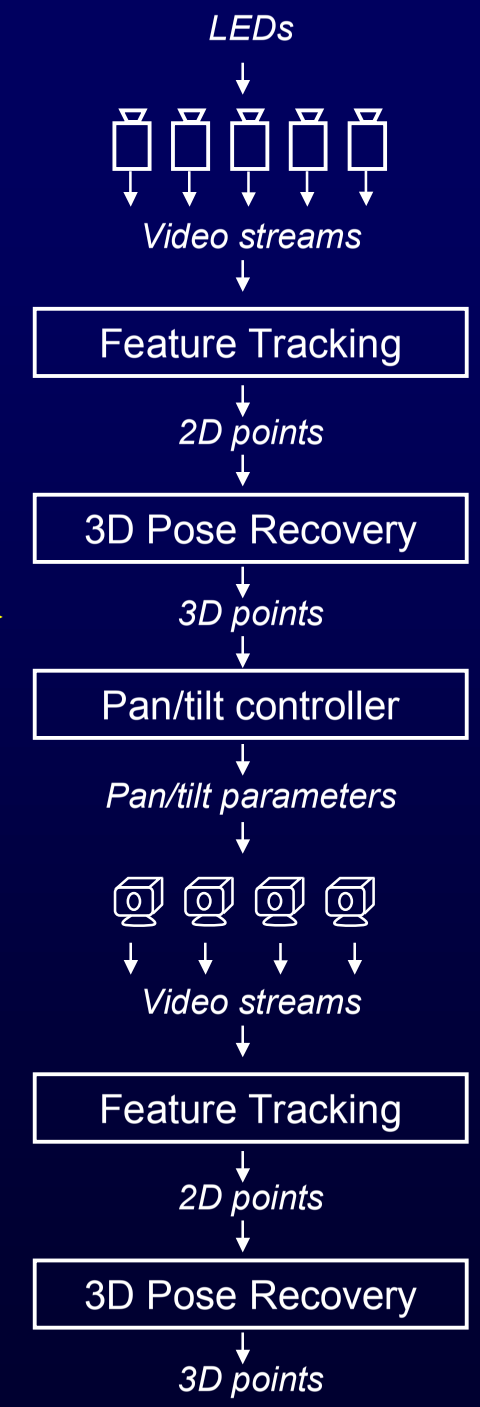


[Chen, Davis 00]

Unknown correspondence

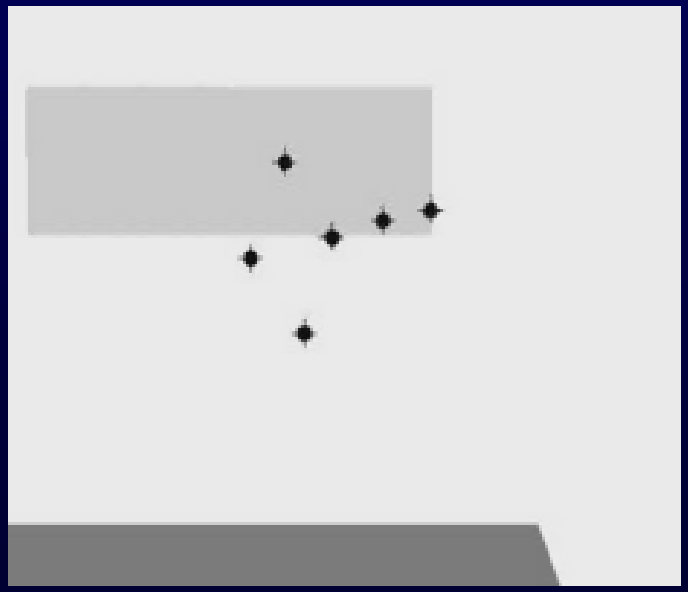
Kalman filter

Unknown temporal correspondence



Unknown temporal correspondence

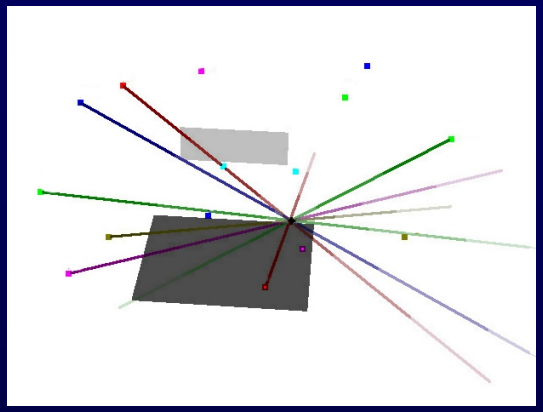
- Multiple 3D features recovered
- Which feature is the head?
- Each frame is independently derived



Dynamic motion model

- **Not single frame triangulation**

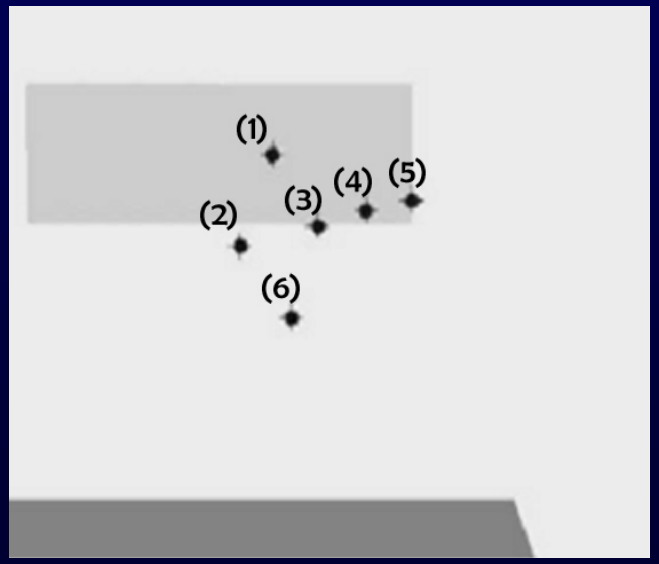
- **Dynamic motion model**
  - Model continuous motion
  - Update on each observation
  - Estimate position/velocity
  - Extended Kalman filter

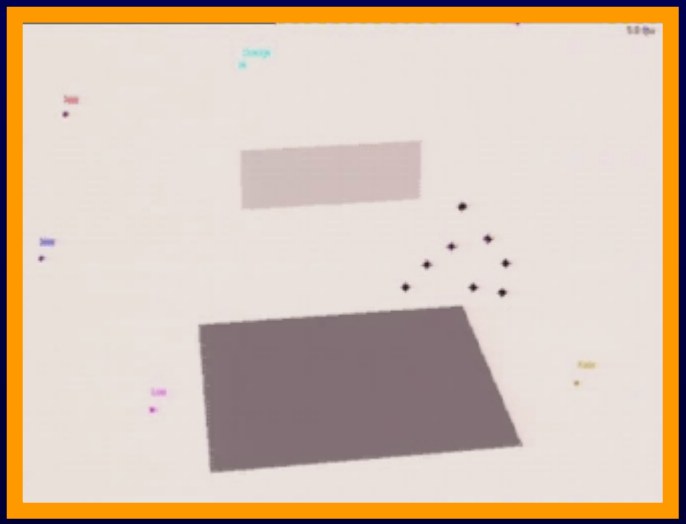


[Kalman 60] [Broida86] [Welch97]

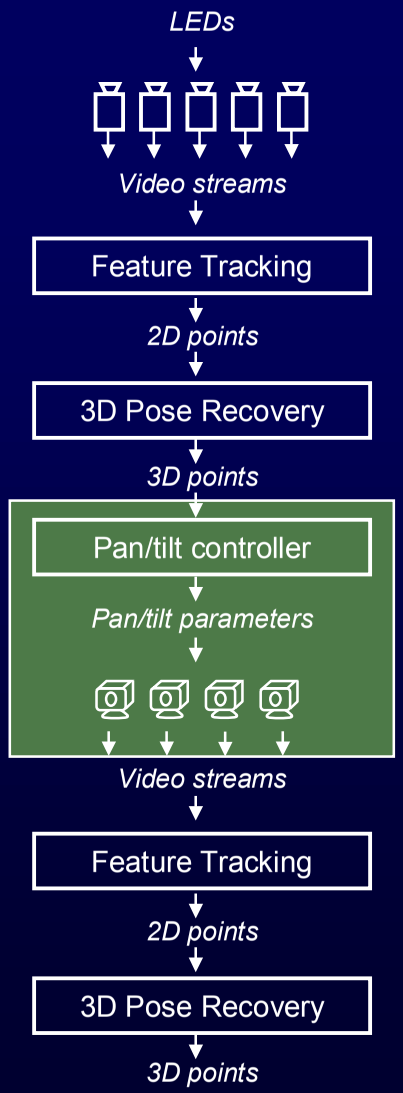
Benefits of motion model

- Feature IDs maintained
- Robust to short occlusion
- Synchronized cameras unnecessary



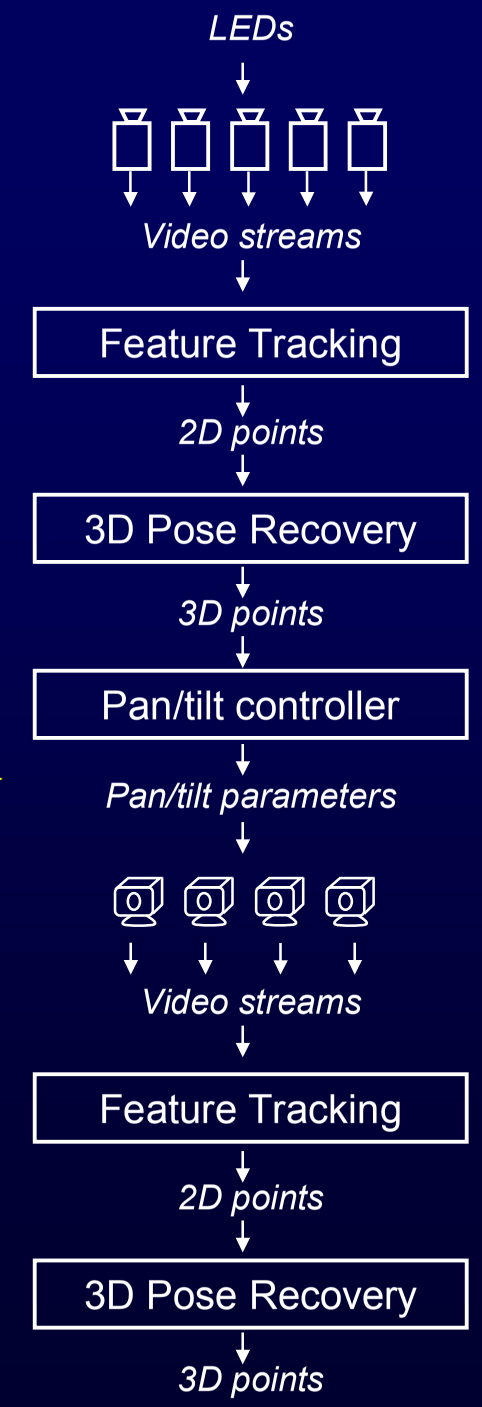


Sub-region selection



Simplistic camera model

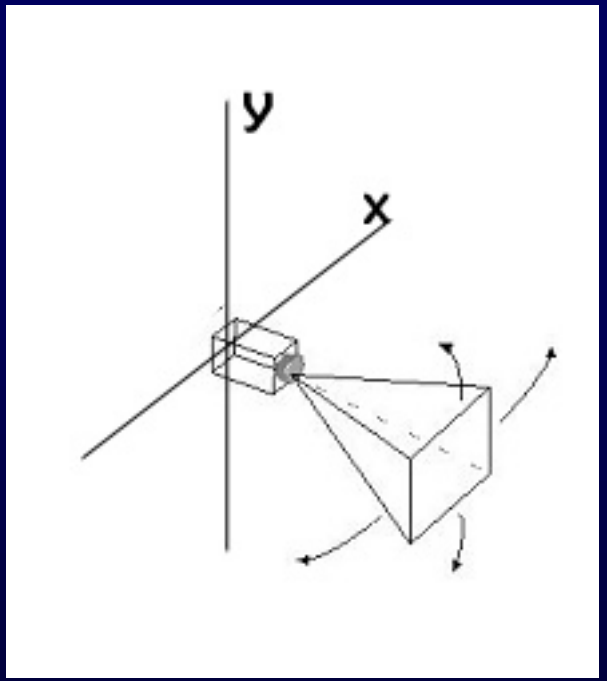
P/T camera model → Incorrect camera model →



Simplistic camera model

- Pan/tilt axes not aligned with optical center

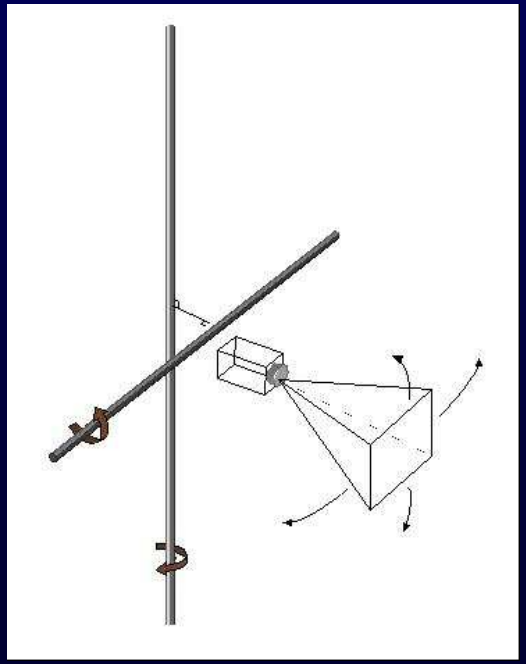
$$\begin{bmatrix} I_x \\ I_y \end{bmatrix} = \mathbf{C}\,\mathbf{R}_y\,\mathbf{R}_x \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$



New camera model

- **Arbitrary pan/tilt axes**
- **Jointly calibrate axes and camera**
  - Observe known points from several pan/tilt settings
  - Fit data with minimum error

$$\begin{bmatrix} I_x \\ I_y \end{bmatrix} = \mathbf{C}\,\mathbf{T}_{pan}\,\mathbf{R}_{pan}\,\mathbf{T}_{pan}^{-1}\,\mathbf{T}_{tilt}\,\mathbf{R}_{tilt}\,\mathbf{T}_{tilt}^{-1} \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

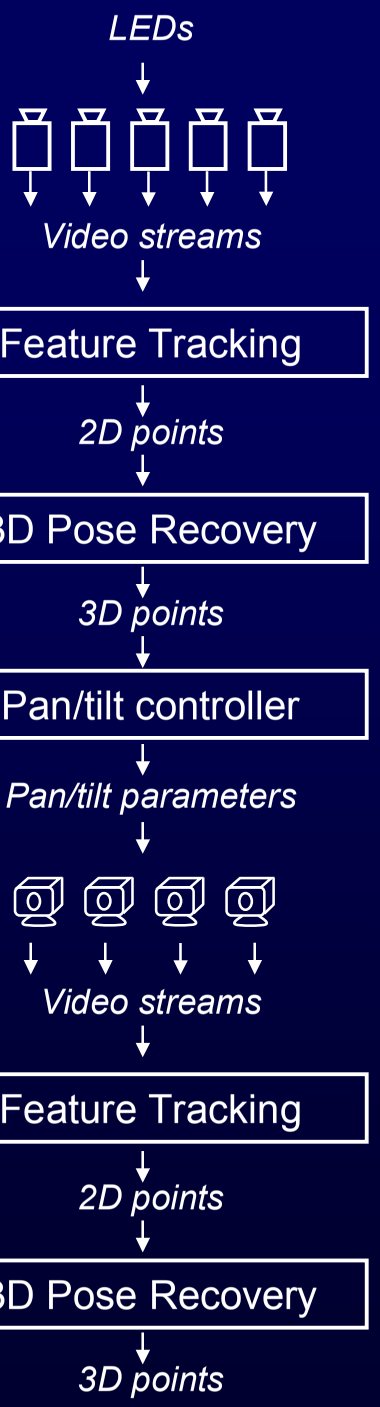


[Shih 97]

Latency

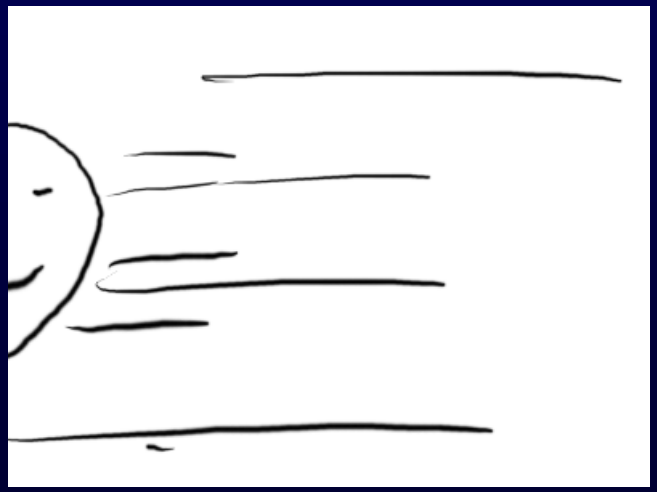
Prediction →

Latency →



Camera motor latency

- Empirically found 300ms latency
- High velocity targets leave frame
- Prevents accurate sub-region selection

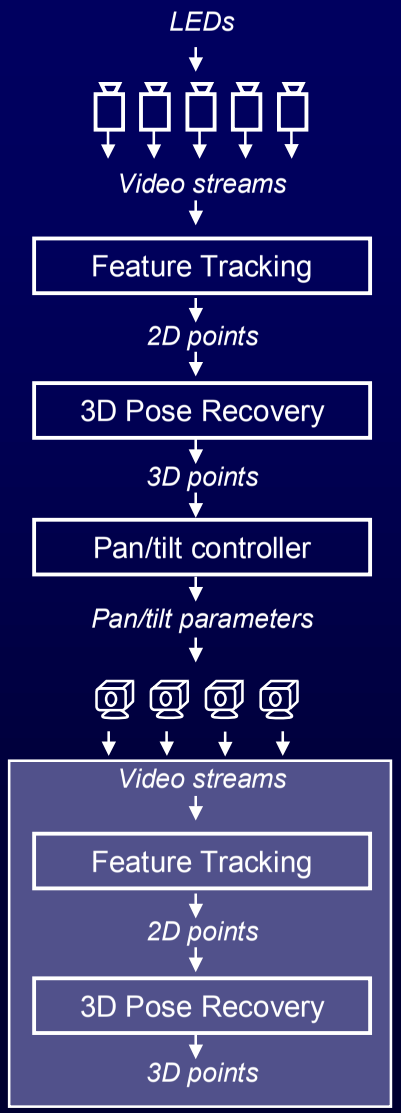


Target motion prediction

- Predict future target motion
- Point camera at predicted target location
- Use previous motion model
- High velocity objects successfully tracked

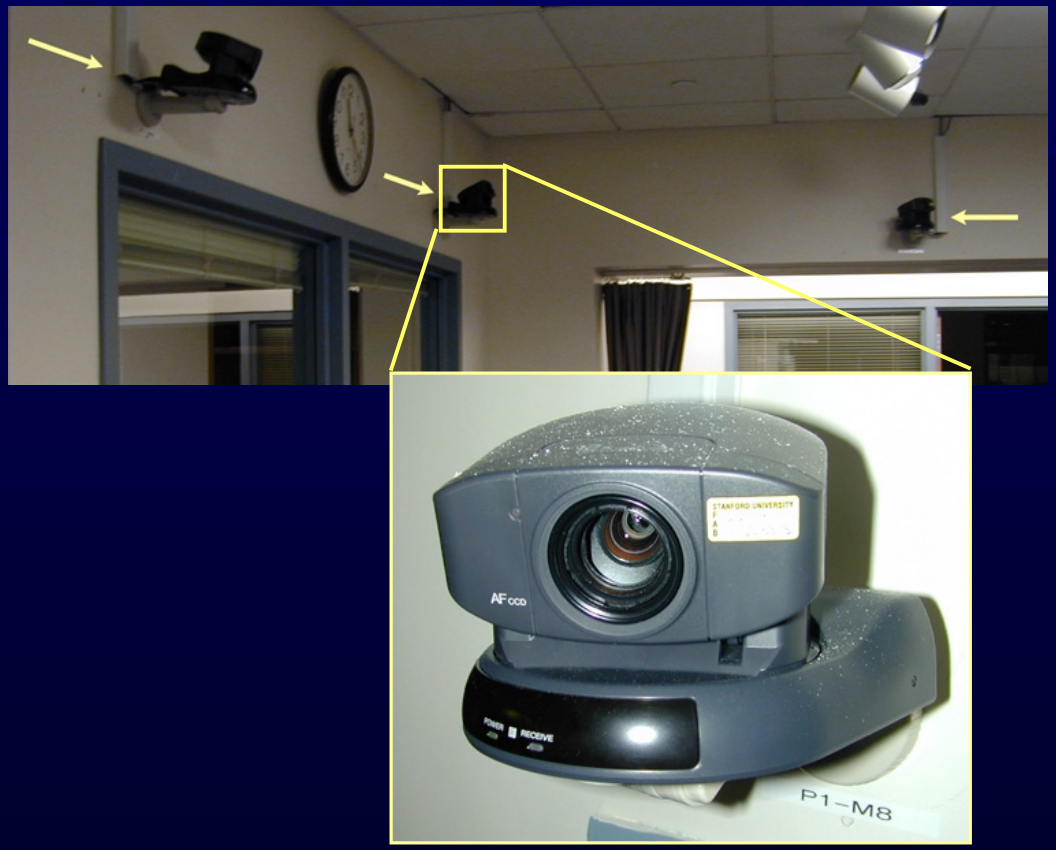
$$P' = P_i + \Delta t \bullet V_i$$

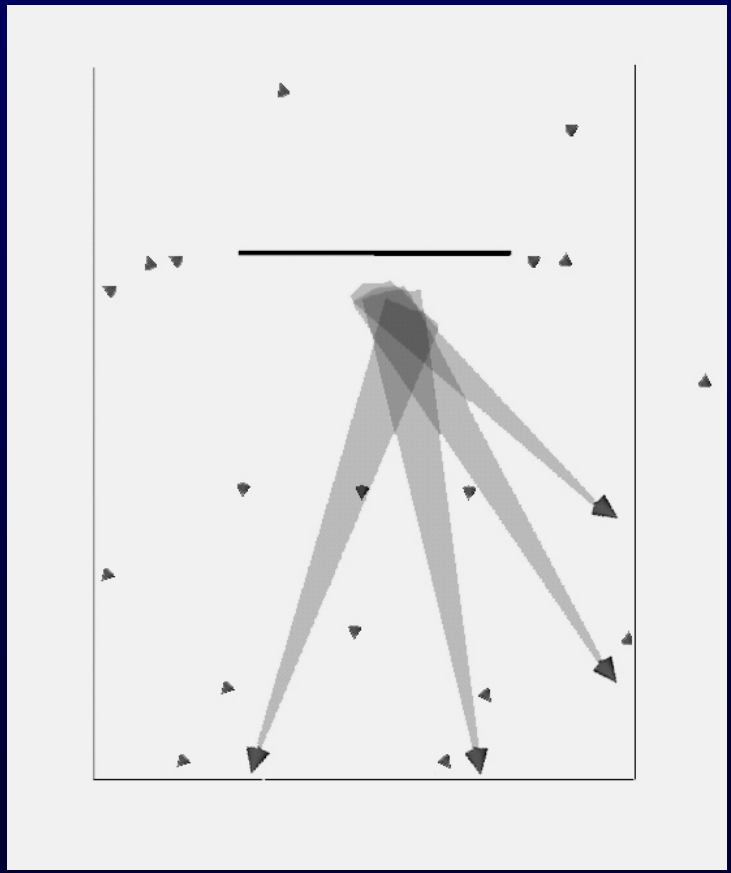
Small scale system



Small scale physical arrangement

- 4 Pan-tilt cameras point at sub-region
- 4 SGI O2s digitize video



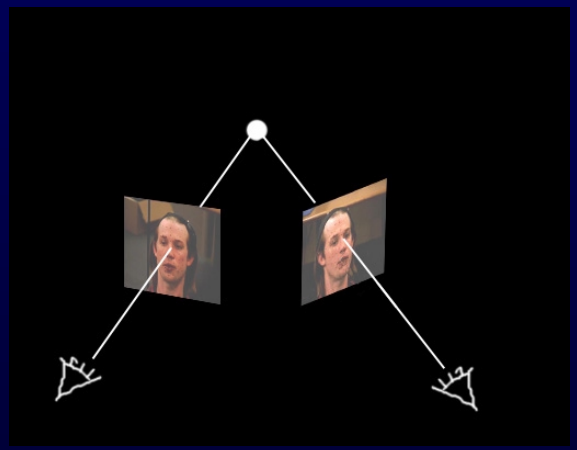


Small scale features

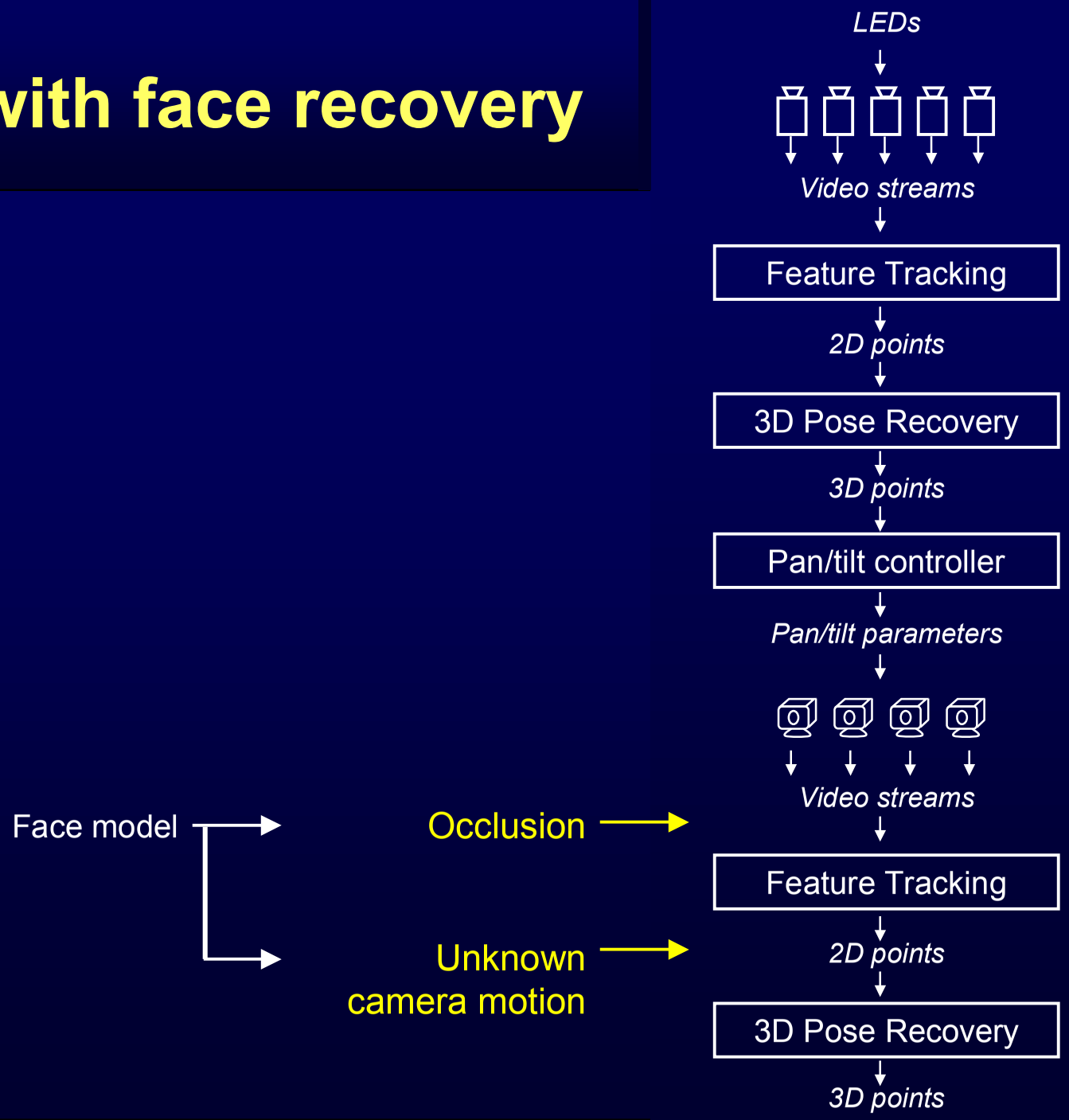
- Painted face features
- Image gradient feature tracking

[Lucas,Kanade 81] [Tomasi, Kanade 91]

Small scale pose recovery



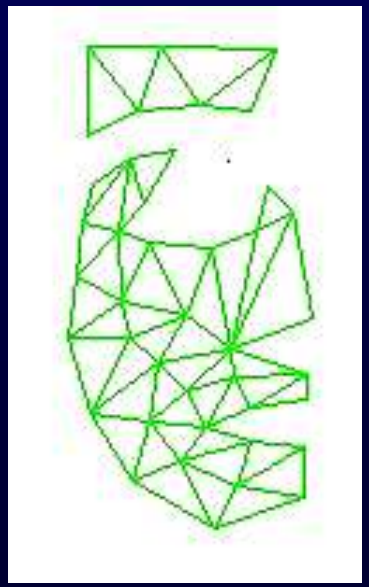
Problems with face recovery



Problems with face recovery

- **Self occlusion**
  - Many points not visible
- **Camera motion not known precisely**
  - Difficult to merge more than two views

View from one camera

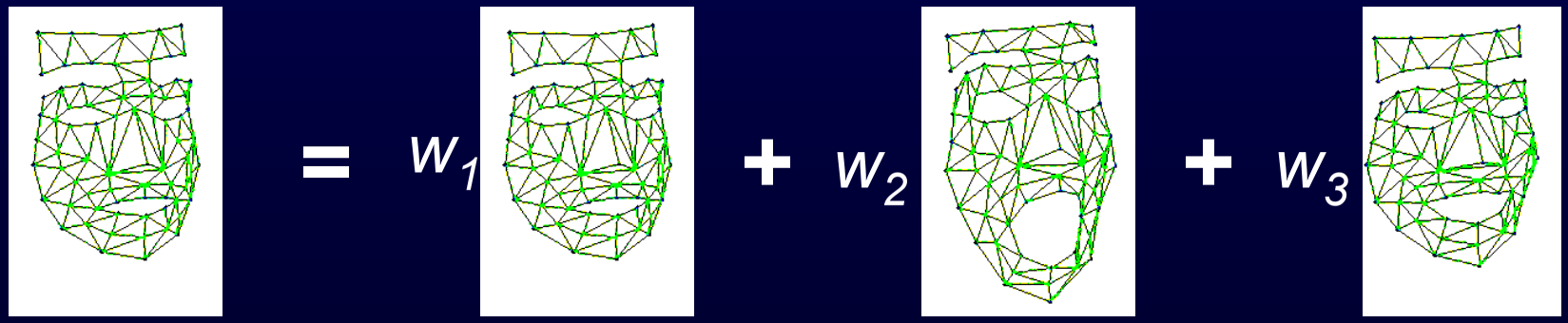


Recovered 3D geometry

Face model

- **Face model defines the set of valid faces**
  - Linear combination of basis faces
  - Capture basis set under ideal conditions
  - Basis transformation

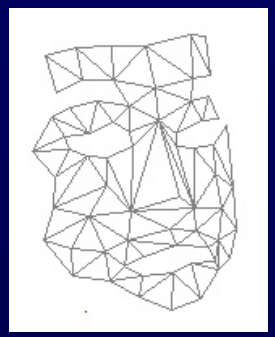
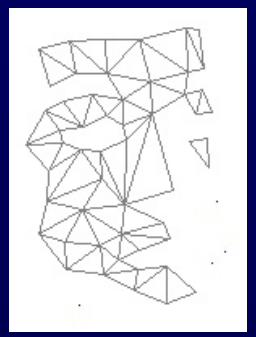
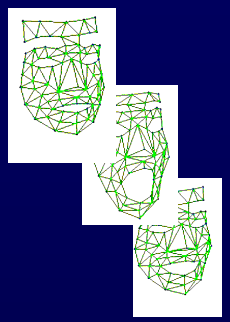
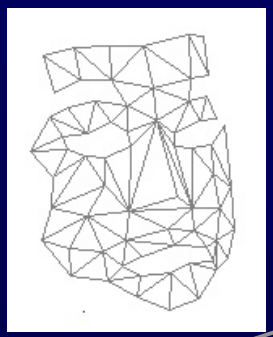
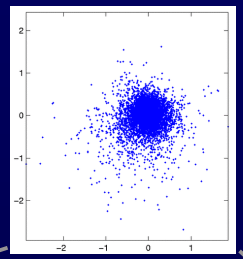
$$F = \sum w_i B_i$$



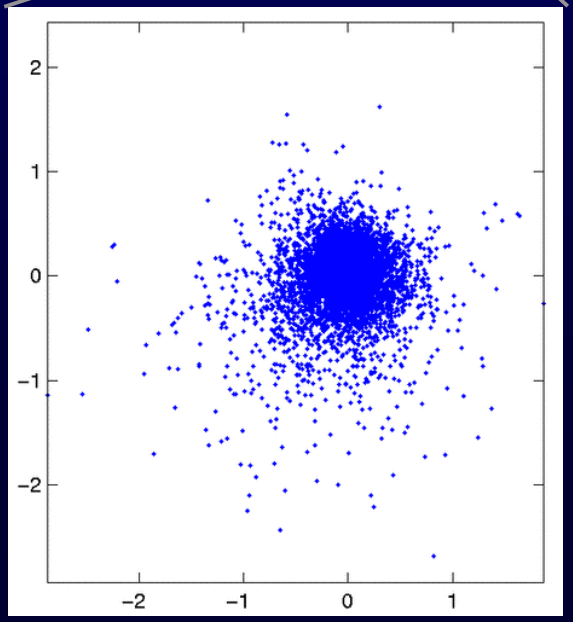
[Turk, Pentland 91] [Blanz,Vetter 99] [Guenter et.al. 98]

Model evaluation

Observe everything → Remove features → Fit to model → Reconstruct features → Evaluate error

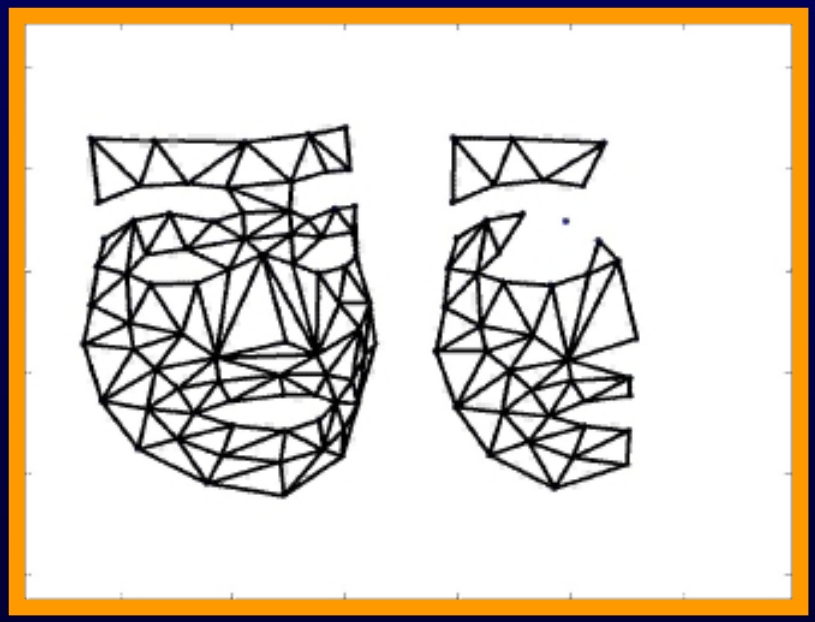
Mean error < 1.5 mm



Reconstructed face

- **Fit partial data to the model**
- **Use model to reconstruct complete geometry**

Reconstructed geometry from model



Recovered geometry from video

End to end video

Talk outline

- Introduction
- Framework
  - Hierarchical paradigm
  - Data driven analysis
  - Model based solutions
- System implementation
  - Large scale recovery
  - Sub-region selection
  - Small scale recovery
- End-to-end video
- **Summary and future work**

Summary of contributions

- **Framework for mixed scale motion recovery**
  - Hierarchical paradigm
  - Data driven analysis
  - Model based solutions
- **Specific system design**
  - High resolution/range ratio
  - Scalable
  - Robust to occlusion
  - Automated
- **Application to simultaneous face-body capture**

Future directions

- Application to other domains
- More levels of hierarchy
- Selection of multiple sub-regions
- Alternate system designs

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