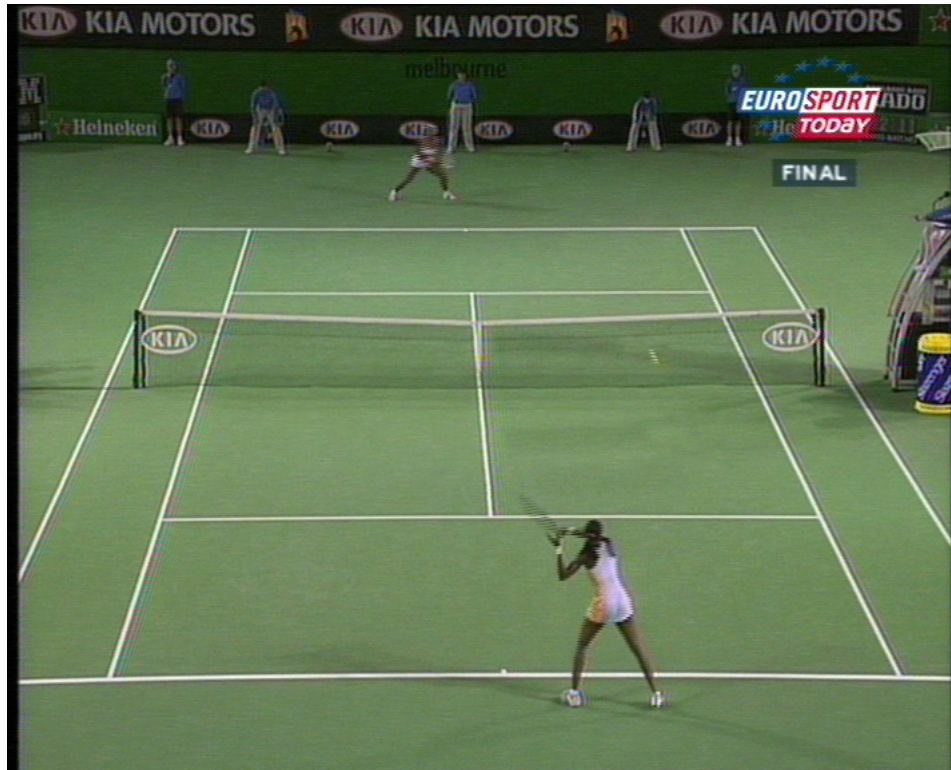


# Understanding tennis



# Tennis browser

The screenshot displays a software interface for a tennis match. On the left, a 'Match tree' panel shows a hierarchical view of the match progress:

- Match 0
  - Set 0 : 0
    - Game 0 : 1
      - Point 0 : 15
      - Point 15 : 15
      - Point 30 : 15
      - Point 30 : 30
      - Point 30 : 40
        - Serve Fail1S
        - Serve PtFar
      - Point 40 : 40
      - Point 40 : A
      - Point Game far
    - Game 0 : 1
      - Point 0 : 15
      - Point 0 : 30

Below the match tree are two checkboxes:  Player track and  Ball track, with a 'Show' button underneath. A 'Time: 00:00:00:00' display is also present.

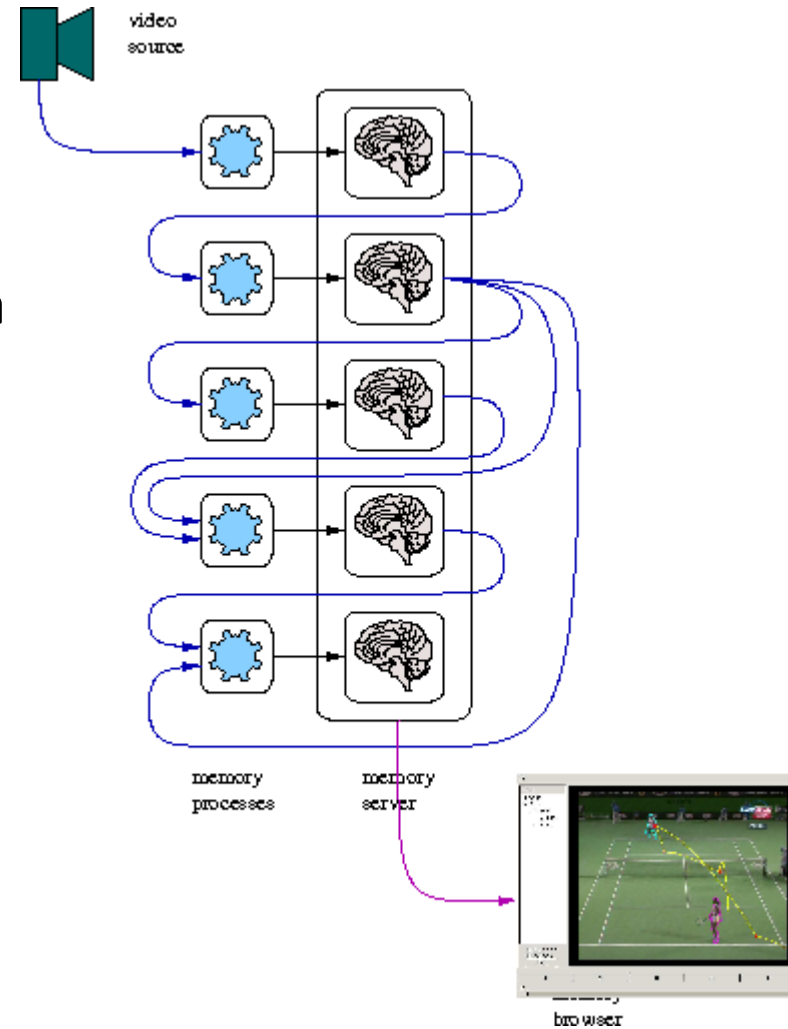
The main video player shows a tennis match in progress. A player in a cyan outline is positioned at the top of the court, and another player in a magenta outline is at the bottom. A yellow dashed line with red square markers tracks the ball's path from the cyan player, over the net, and towards the bottom of the court. The background features 'EUROSPORT TODAY' and 'FINAL' branding.

At the bottom of the interface is a video control bar with standard navigation icons (back, stop, play, forward) and a progress slider.

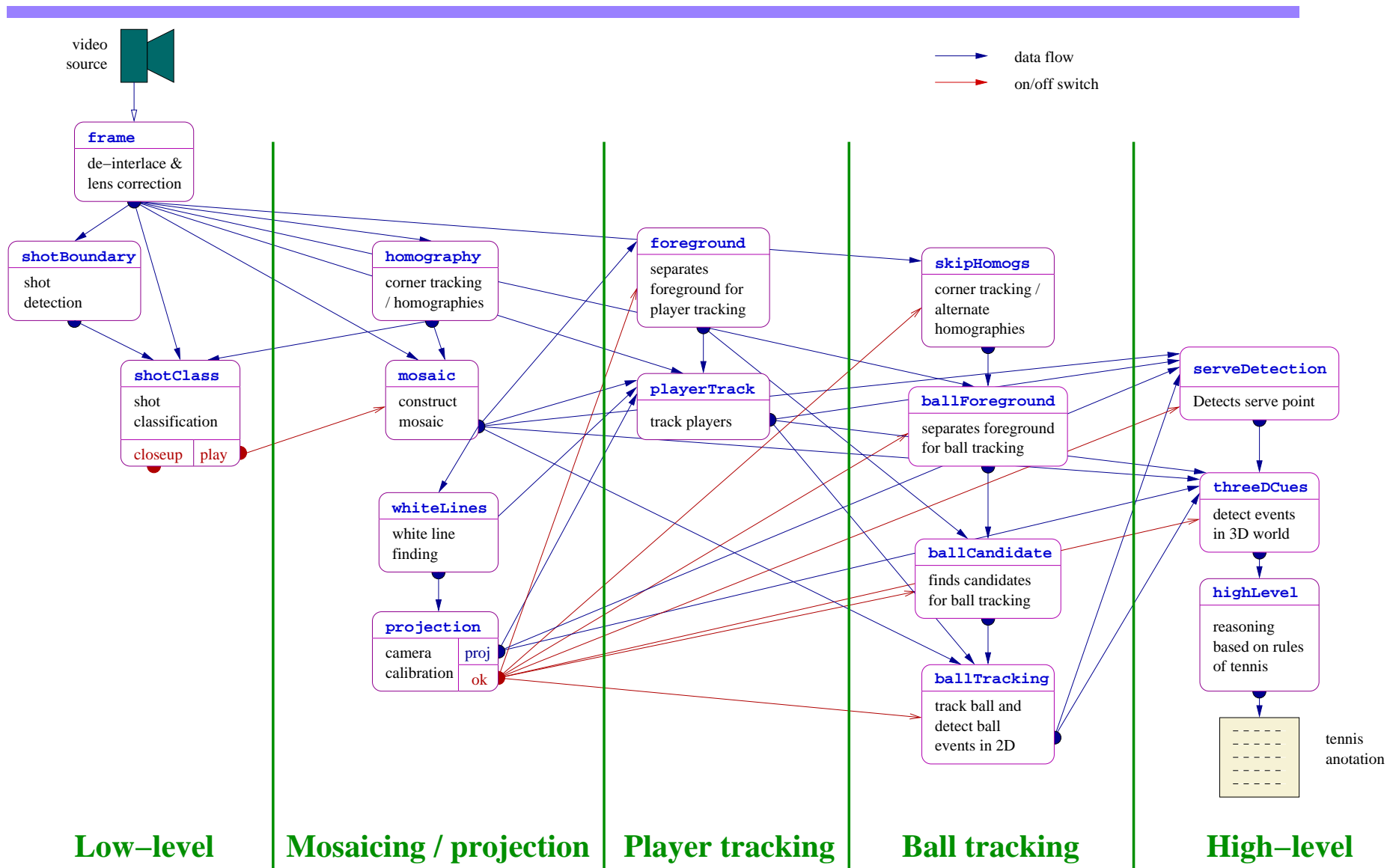
# Memory system

System is in two parts:

- annotation  $\longleftrightarrow$  short-term memory
- browsing  $\longleftrightarrow$  long-term memory



# Tennis annotation

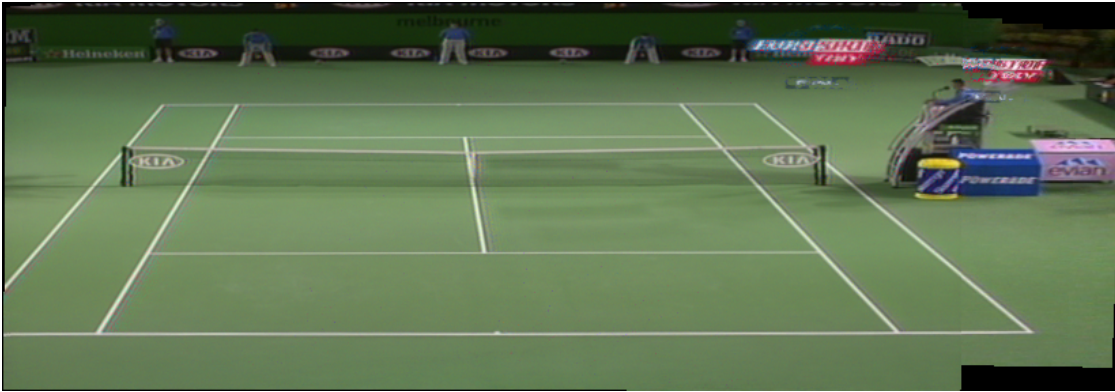


kill application

# Low-level processing: mosaicking

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Removes moving foreground objects:



- Warp fields onto common coordinate system
- Combine pixels at each location using median filter

# Player tracking

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- Background subtraction:  
subtract motion-compensated mosaic from field

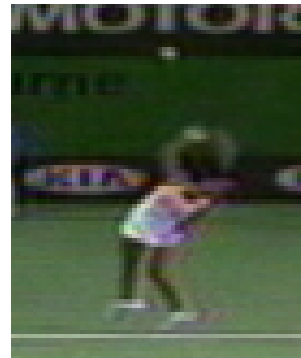


- Simple tracker to track 2 largest blobs (CONDENSATION-based)

# Ball tracking: the problems

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- Very small size



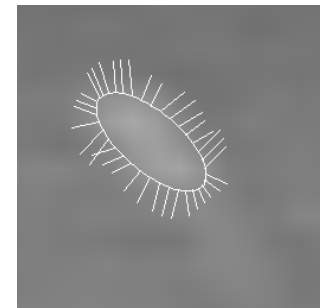
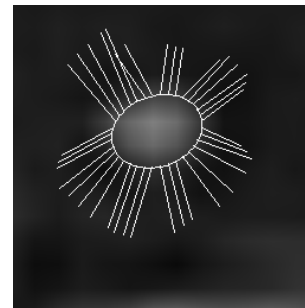
- Motion blur, motion deformation
- Abrupt motion change, occlusion, ...

# Ball tracking: the solution (1)

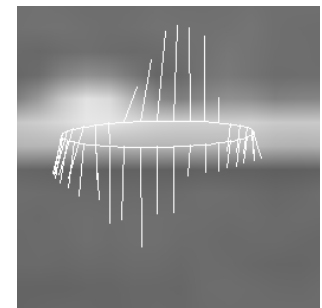
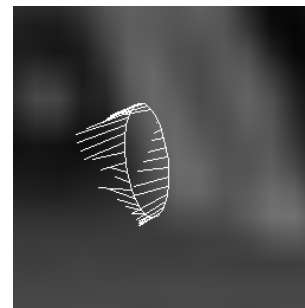
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- Background subtraction: motion-compensated field differencing
- Blob classifier (SVM: gradient + size + colour)

– ball-originated blobs



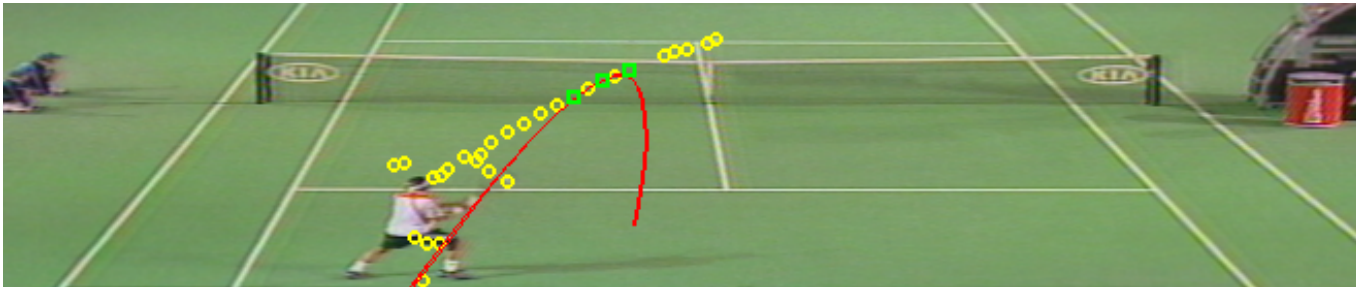
– clutter-originated blobs



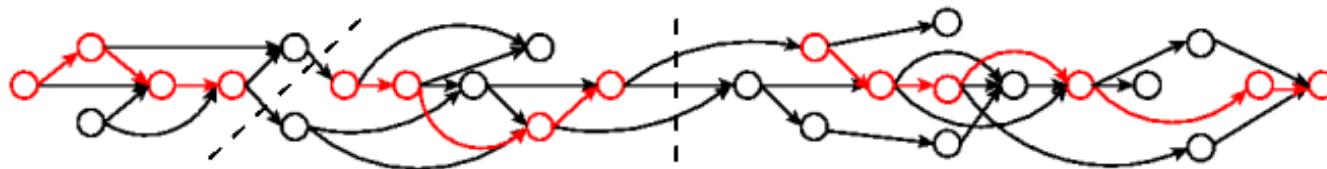


## Ball tracking: the solution (2)

- Ball candidate tracking: a layered data association scheme
  - “tracklets” are “grown” from ball candidates

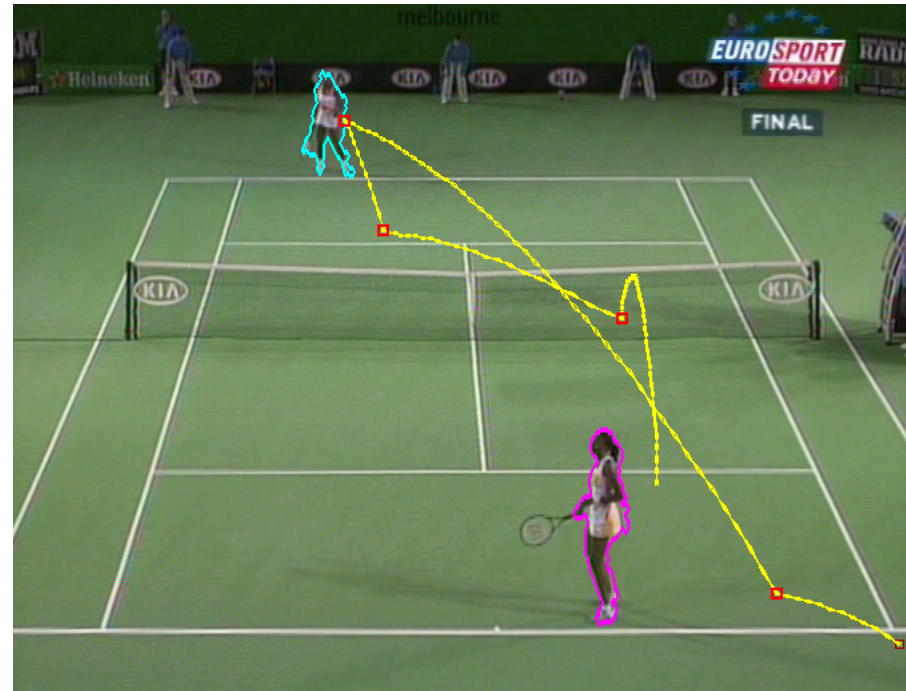


- and then linked using graph analysis



# Ball event detection / classification

- Ball event detector:  
looks for departures of  
track from 2nd order  
model

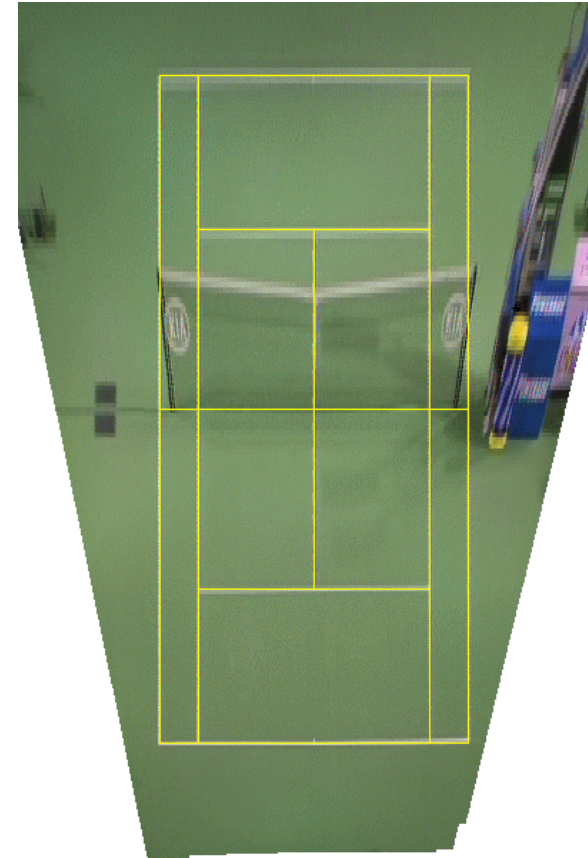


- Hit / bounce discrimination: combination of
  - ball velocity in 2-D, before and after event
  - spatial relationship between ball and player

# Relating 2-D events to the 3-D world

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Camera calibration:  
homography between mosaic image  
and court model

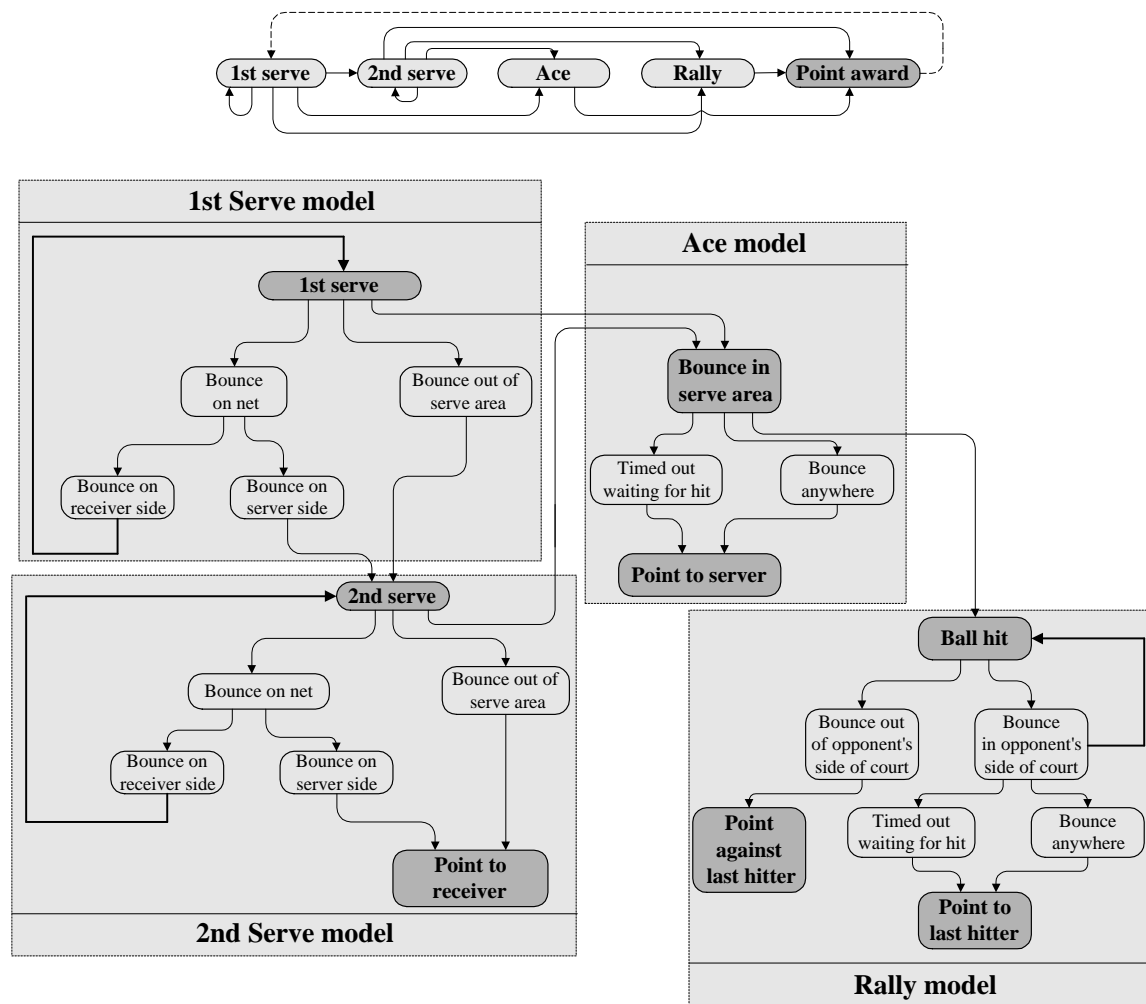


Using the camera calibration, we know  
where the ball is when it:

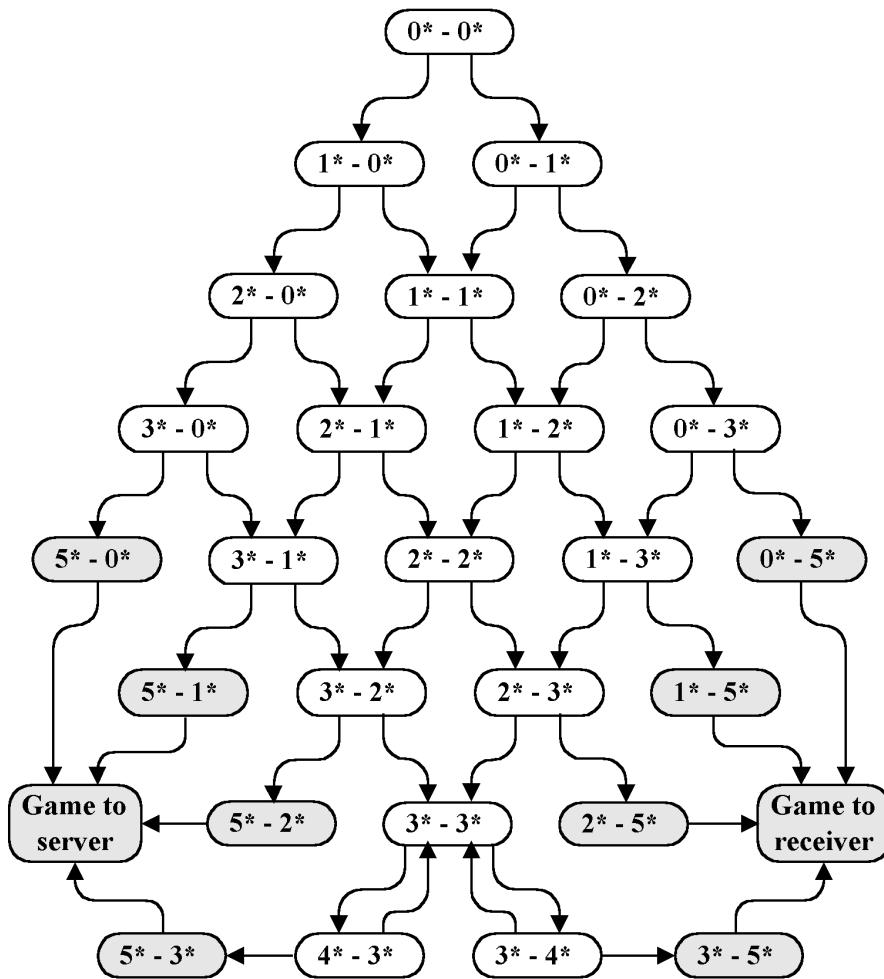
- (a) bounces — uses court model to determine bounce region
- (b) is hit (approximately, using players' feet position and height)

# Tennis rules to determine a point

Uses multi-layer HMM:



# Tennis rules to determine a game



For normal games only:  
This does not include tie-break games (although the structure is similar)

Set and match award follow similar patterns as well

Score notation (in all cases, noted as <Server> - <Receiver>):  
 0\* - 0 points; 1\* - 15 points; 2\* - 30 points; 3\* - 40 points;  
 4\* - Advantage point; 5\* - Game point

# Annotation results

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35 minutes of Australian Open Women's Final 2003:

Event type	Correctly awarded
Serves (single-level HMM)	56 / 80 (70%)
Points (multi-level HMM)	42 / 48 (87.5%)

65 minutes of Australian Open Men's Final 2003:

Event type	Correctly awarded
Serves (single-level HMM)	93 / 136 (68%)
Points (multi-level HMM)	74 / 99 (75%)

# Other tournaments

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Testing on other tournaments provided new challenges:

- Australian Open Men's final 2003: variable lighting → occasional failed foreground separation
- Wimbledon Men's semi-final 2005: variable grass court colour → incorrect shot classification
- Barcelona Olympics 1992: disappearing markings on clay court → occasional failed camera calibration

