Hidden Markov Models as a Tool to Measure Pilot Attention Switching

Miwa Hayashi, Charles M. Oman
Dept. of Aeronautics & Astronautics
Massachusetts Institute of Technology
Cambridge, MA

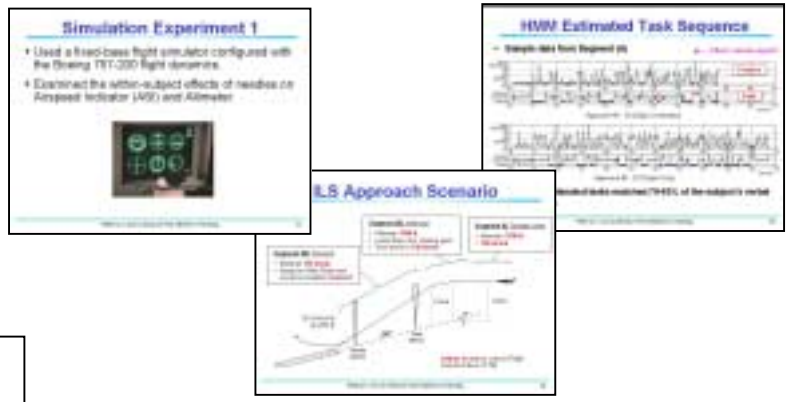
Michael Zuschlag
US. Department of Transportation
Volpe Center
Cambridge, MA

Eyes Tea Boston Meeting
Volpe Center
July 10, 2003

Contents

1) Hidden Markov Model Analysis

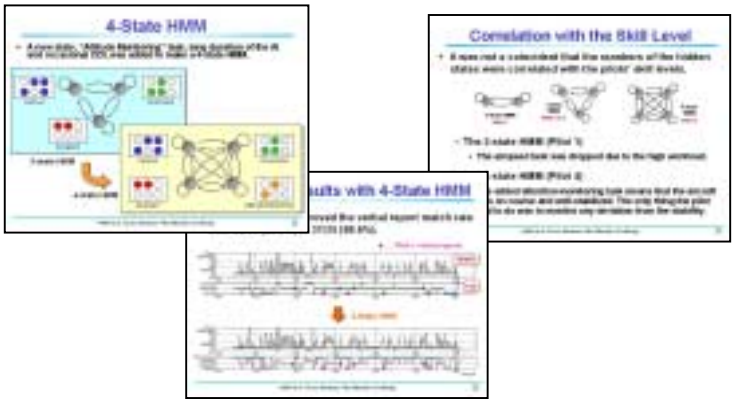
2) Simulator Experiment 1



1 2

3 4

3) Simulator Experiment 2

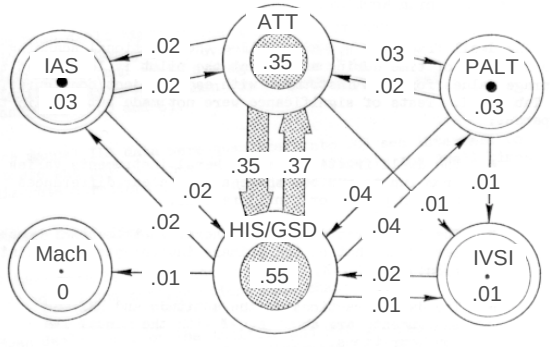


Question?

1) Hidden Markov Model Analysis

Past Eye Movement Studies

- **Many researchers have been interested in pilots' eye-movements**
  - For designing better displays
  - For developing better training programs

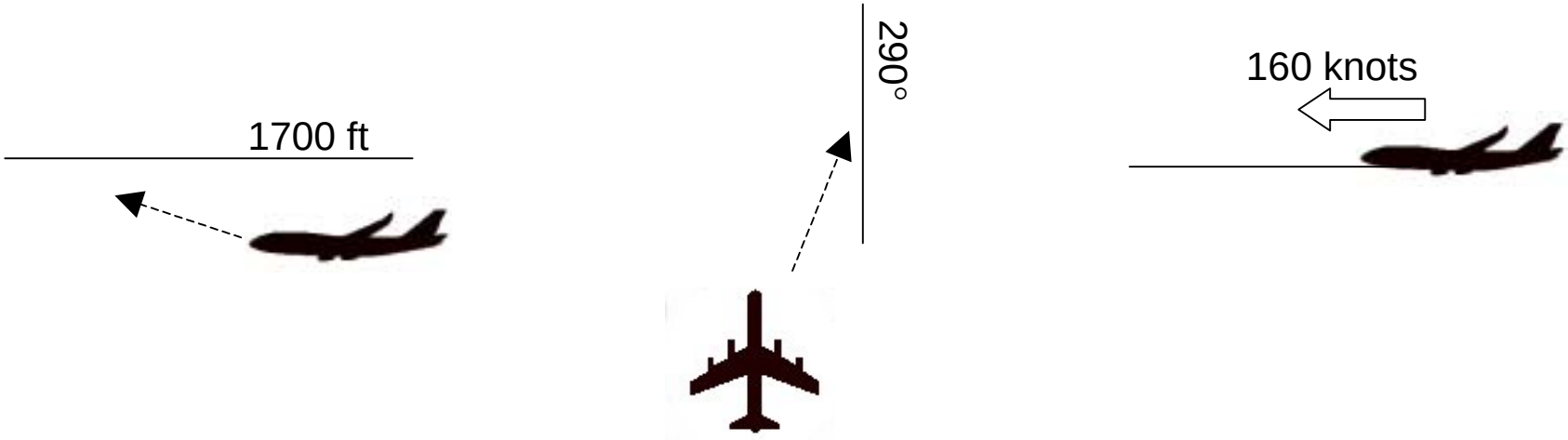


Ex.) Dwell Fractions and Link Values during ILS final approach (Weir & Klein, 1971)

- **Simple eye-movement statistics were measured.**
  - Fixation durations
  - Look rates
  - Link values (transition probabilities)

- **Sequential information of the eye-movement data was not used.**

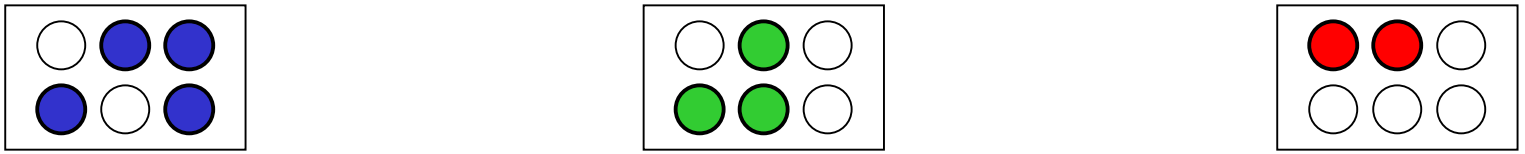
Instrument Flying is Multi-Axes Tracking



Vertical tracking (Altitude)

Horizontal tracking (Course)

Airspeed tracking



Each tracking task require different set of instruments.

Attention: Serial or Parallel?

- **An adequate approximation :**

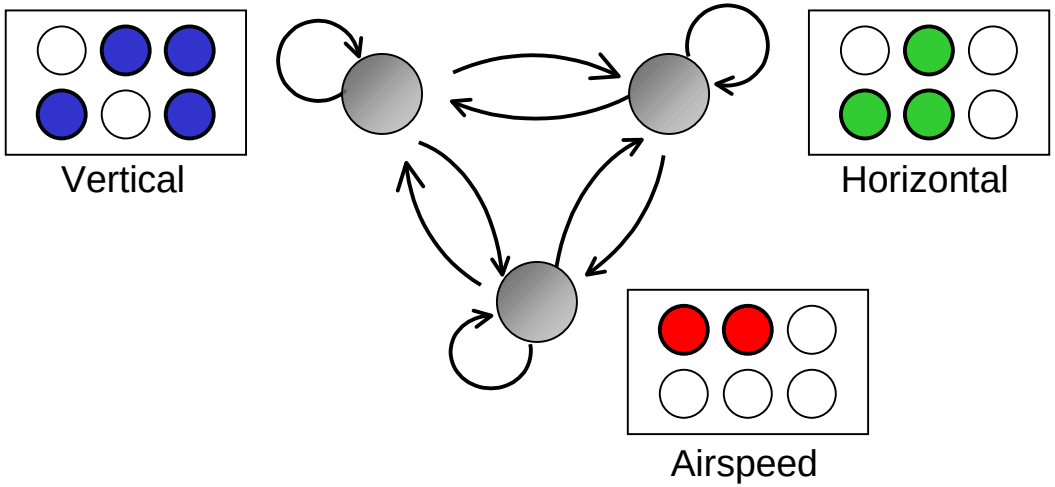
  Pilots attend each tracking in a serial manner rather than in a parallel manner.

  – Supporting facts:

    - Accurate instrument reading requires foveal fixation, which takes place one at a time.
    - No single instrument represents the aircraft situation alone; thus, instruments have to be crosschecked and interpreted.

Hidden Markov Models (HMM)

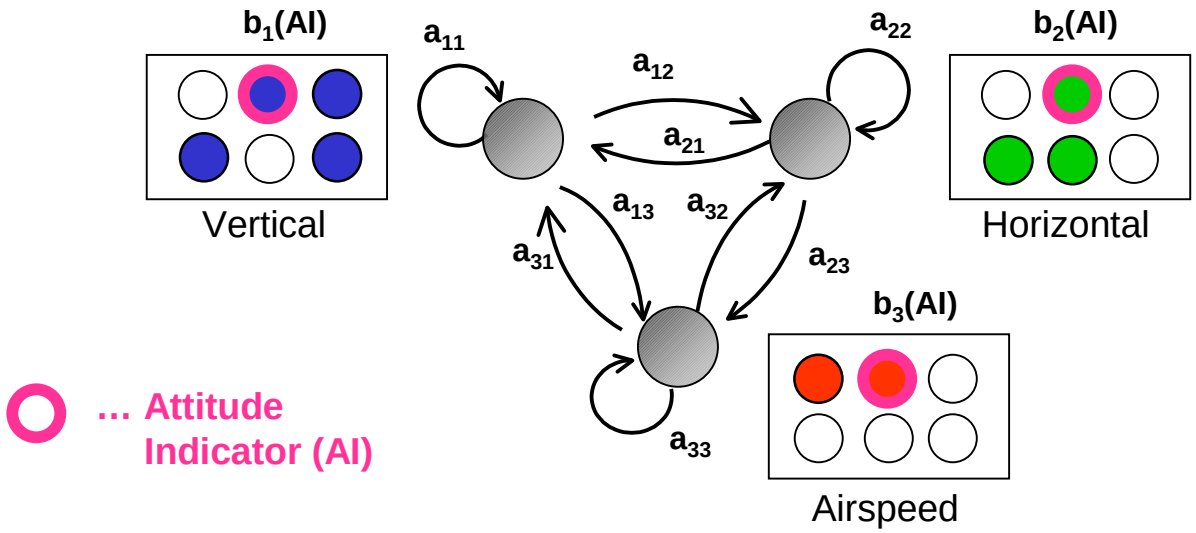
- **Layered stochastic processes of HMM**
  - Hidden state transition process (Markov process) → Tracking tasks
  - Observation process → Instrument fixations



- **Given an observation sequence, the HMM computes the most-likely estimates of**
  - Transition probabilities between hidden states
  - Observation symbol probabilities within each hidden state
  - Sequence of hidden state

HMM (Cont'd)

- **What about the overlapped observations?**



HMM estimates the sequence of hidden states that maximizes the probability of the observation sequence obtained.

Advantages of HMM Analysis

- **The attention process (i.e., tracking tasks attended) is considered a Markov process.**
  - Past studies computed “Link Values”, which was equivalent to computing the Markov matrix of the instrument fixation process.
- **The HMM analysis estimates the time history of the tracking tasks the pilot attended.**
- **The HMM analysis can treat overlapped instrument cases.**

How can the HMM analysis be any use for Human Factors research?

2) Simulator Experiment 1

Simulation Experiment 1

- Used a fixed-base flight simulator configured with the Boeing 757-200 flight dynamics.
- Examined the within-subject effects of Airspeed Indicator (ASI) and Altimeter needles.

Displays

- Displays examined: D1 vs. D2

D1 : Digits & Needles

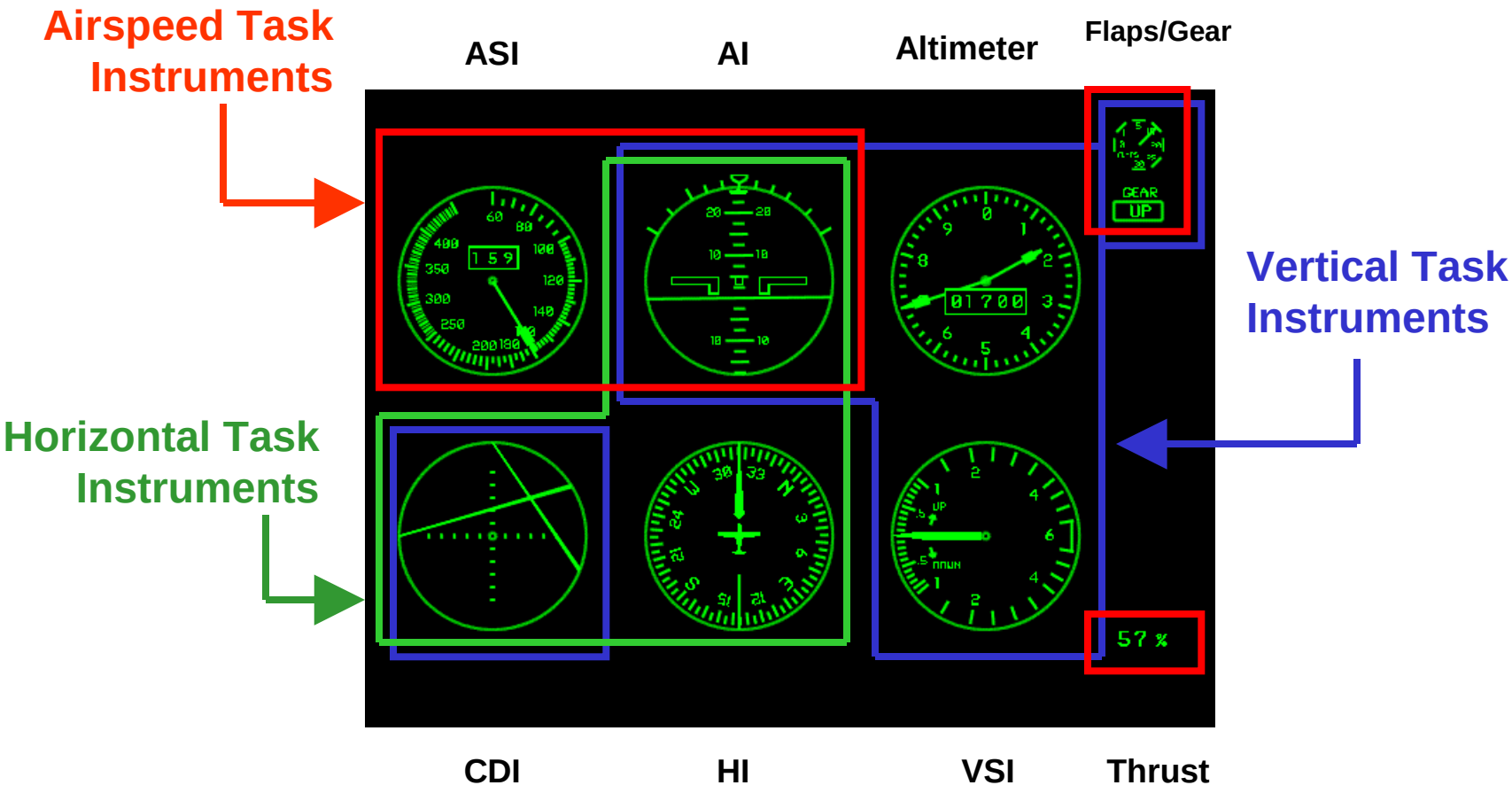
Needles removed

ASI

Altimeter

D2 : Digits Only

Instrument Grouping



ILS Approach Scenario

Segment (i): Straight Level

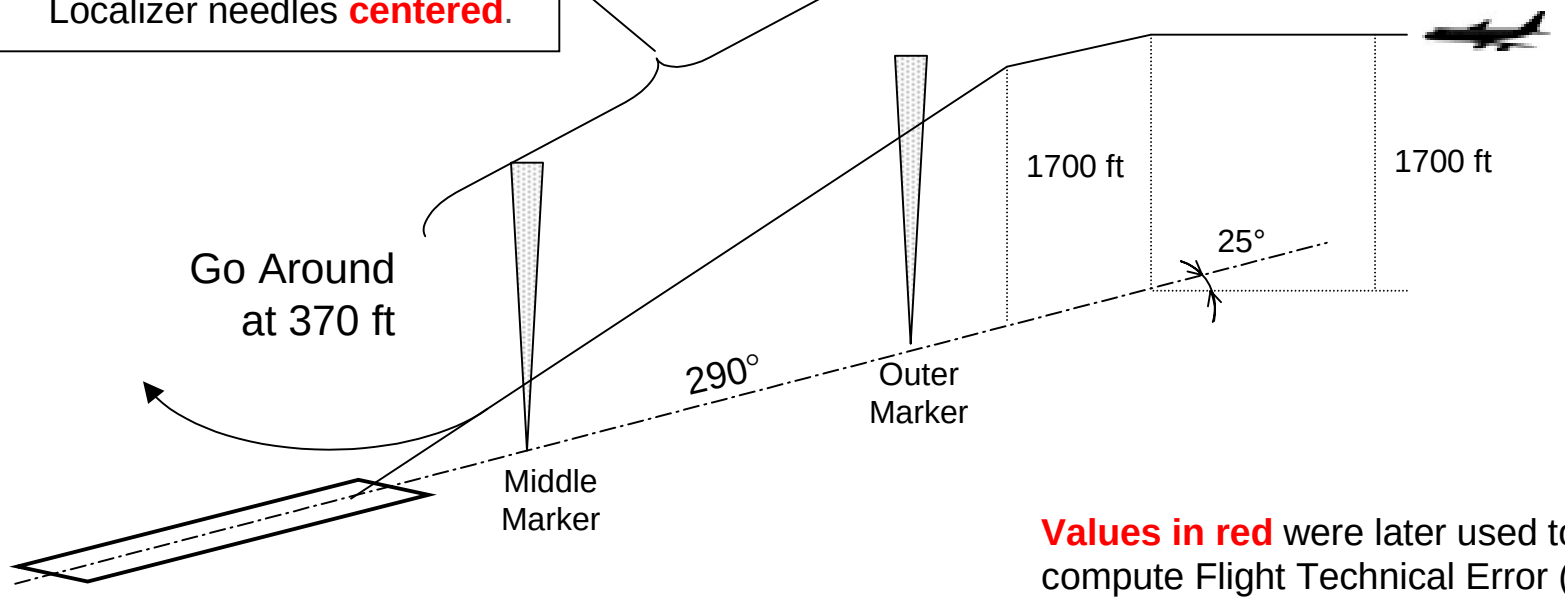
- Maintain **1700 ft**.
- **160 knots**.

Segment (ii): Intercept

- Maintain **1700 ft**.
- Lower flaps and landing gear.
- Slow down to **130 knots**.

Segment (iii): Descent

- Maintain **130 knots**.
- Keep the Glide Slope and Localizer needles **centered**.



Values in red were later used to compute Flight Technical Error (FTE).

Data Collection

- Subject: A former military P-3 pilot
- Six data-taking approaches were performed alternating D1 and D2 on successive approaches.

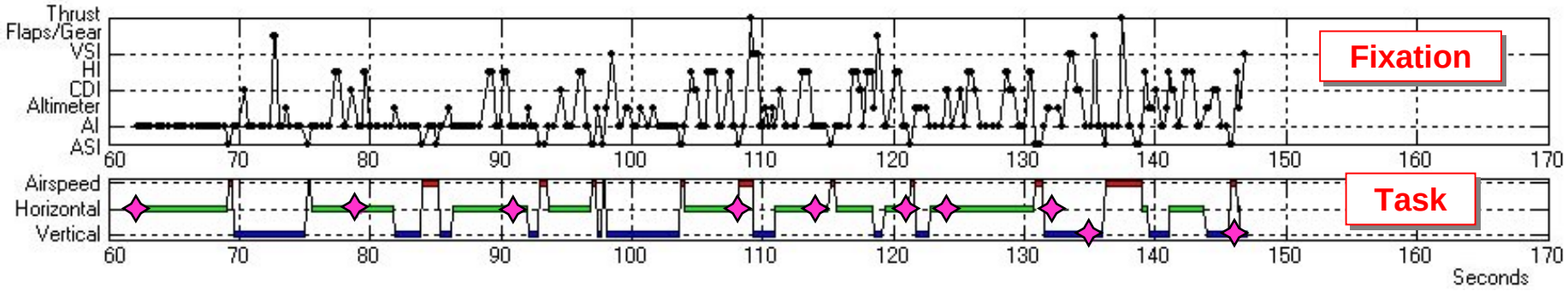
Approach #	1	2	3	4	5	6
Display	D1	D2	D1	D2	D1	D2

- Data collected:
  - Flight data (altitude, airspeed, glide slope & localizer deviations)
  - Eye-movement data
  - Modified Bedford subjective workload score
  - Subjective preference of the displays
  - Verbal reports of the tasks being attended

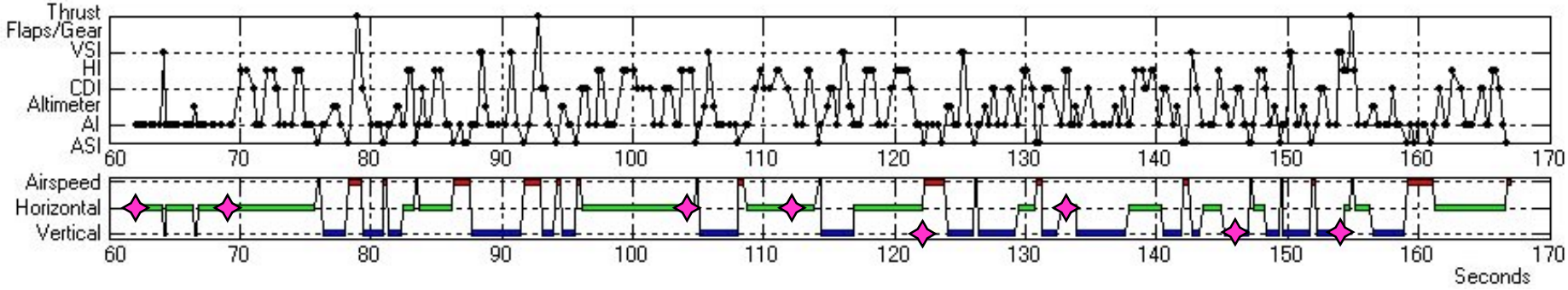
HMM Estimated Task Sequence

- **Data from Segment (ii) - Intercept**

✦ … Pilot's verbal reports



Approach #1 - D1 (Digits & Needles)

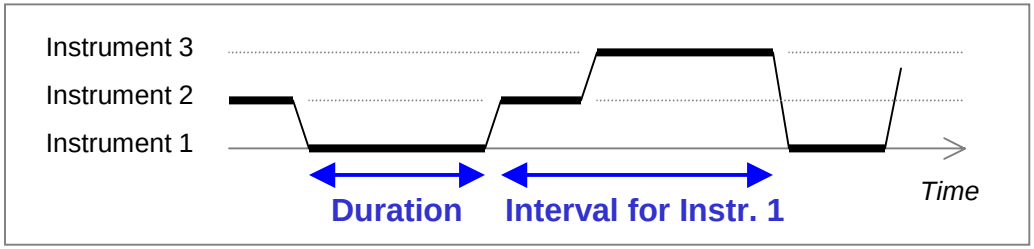


Approach #2 - D2 (Digits Only)

- **The HMM estimated tasks matched 79-92% of the subject's verbal task reports.**

Analyzing Fixation & Task Sequences

- **Analyzing sequence data**
  - **Durations & intervals**



  - **Look rates (visits to the instrument / sec.) & Task rates (occurrence of the task / sec.)**

Analysis Results

- **When D2 (Digits Only) was used;**
  - The vertical-task instruments and airspeed instruments were fixated significantly shorter.
  - But, the vertical-task durations and intervals were maintained about the same levels as when D1 was used.
- **In Segment (ii), when D2 was used,**
  - The vertical and horizontal tasks were frequently interrupted by brief sampling of ASI (airspeed task).

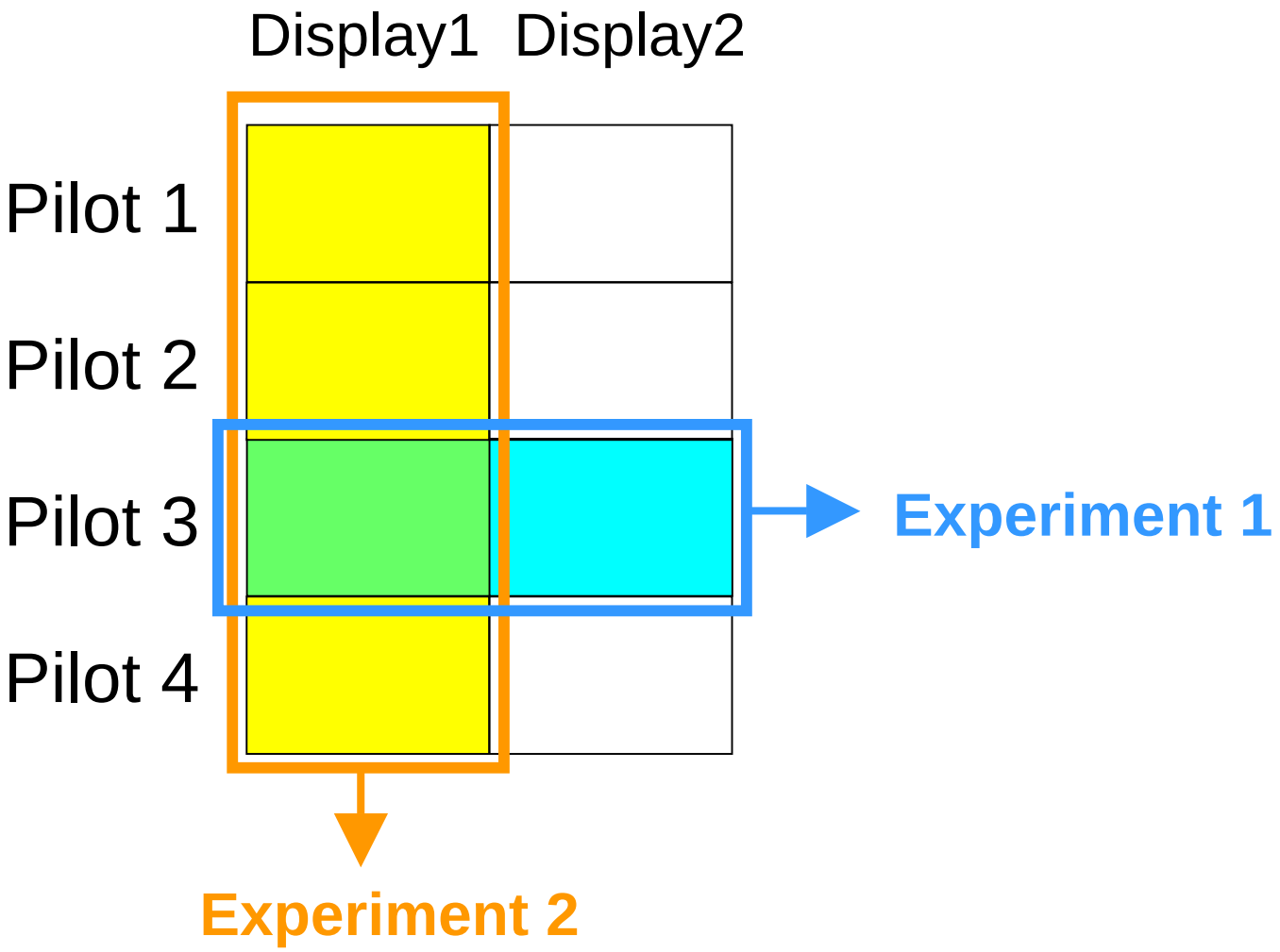
Other Data

- Subjective workload scores and Flight Technical Error (FTE) showed no significant display effect.
- Subject preferred D1 (Digits & Needles) over D2 (Digits Only).

- The invariance of the task durations and intervals may explain the little effects on the FTE and workload.
- Being forced to alter the scanning strategy may have caused the pilot's preference for D1.

3) Simulator Experiment 2

Experiment 1 & 2

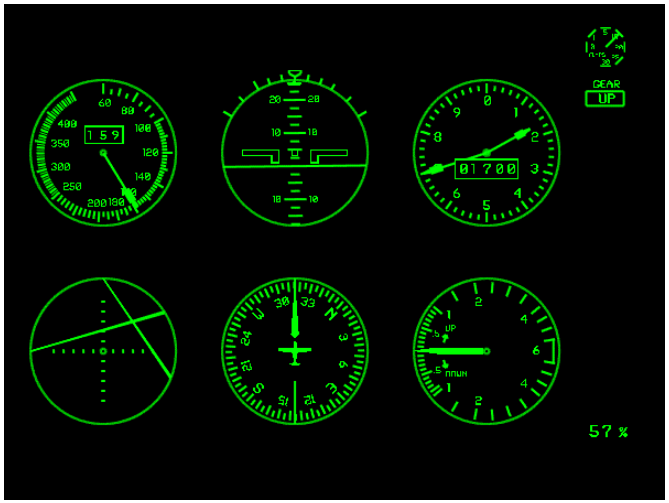


Simulator Experiment 2

- **4 pilot subjects of different skill levels:**
  - Pilot 1 : Private pilot with Instrument rating (250 hours).
  - Pilot 2 : Certified Flight Instructor - Instrument (700 hours).
  - Pilot 3 : Military P-3 pilot (1050 hours).
  - Pilot 4 : Air Transporter Pilot (3500 hours), had flown B757.

- **All pilots used the Display 1 (D1).**

- **Each pilot flew 3 approaches.**



D1 : Digits & Needles

Estimation Results with 3-State HMM

- **First, 3-state HMM was applied.**
- **All showed good matches with the pilots' verbal reports, except the Segment (iii) of Pilot 4.**

The Number of Verbal Reports Matched / Total Number of Verbal Reports (%)

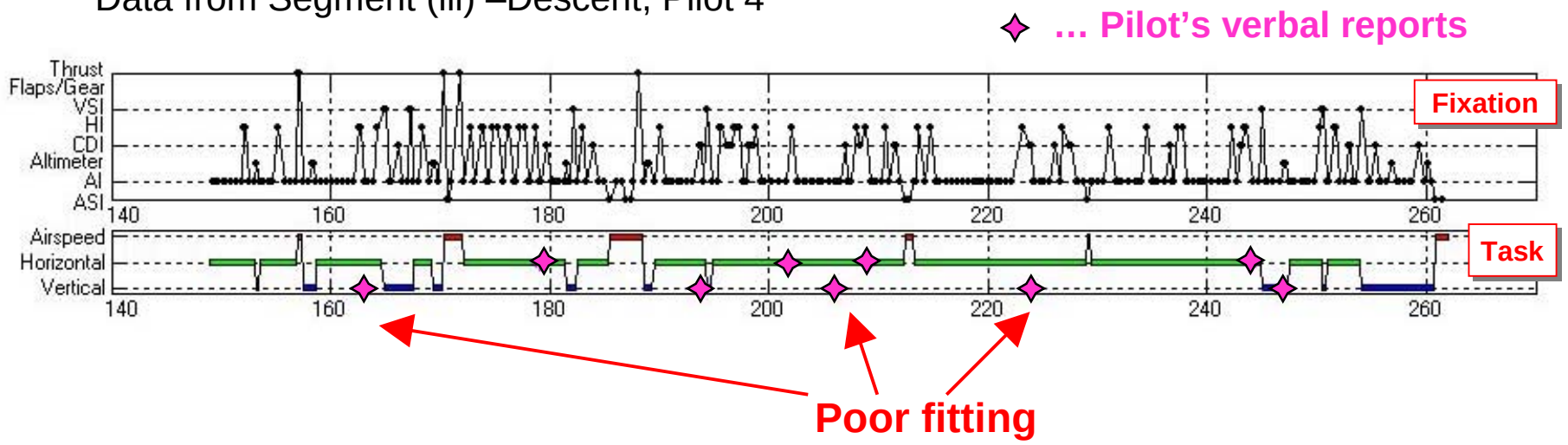
	Segment (i) Straight Level	Segment (ii) Intercept	Segment (iii) Descent
Pilot 1	13/13 (100%)	23/25 (92.0%)	55/63 (87.3%)
Pilot 2	27/27 (100%)	39/43 (90.7%)	37/41 (90.2%)
Pilot 3	28/28 (100%)	26/32 (81.3%)	41/45 (91.1%)
Pilot 4	13/15 (86.7%)	29/31 (93.6%)	22/35 (62.9%)

Poor fitting?

Missed Detections in Pilot 4 Data

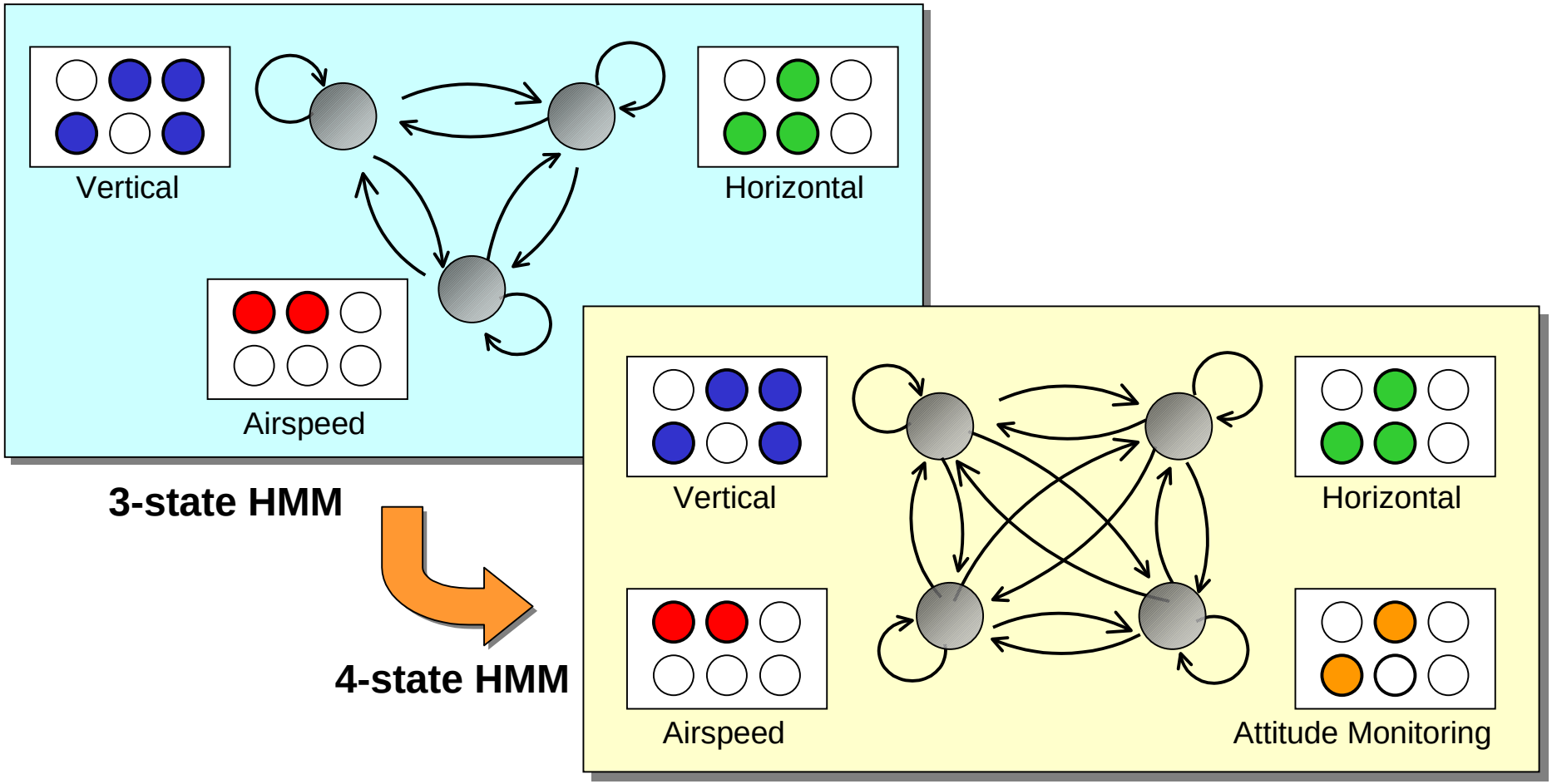
- **Most of the missed detections in the Segment (iii) of Pilot 4 occurred when the AI was looked at for long duration with occasional looks for the CDI.**
- **The pilot reported pitch-related tasks (vertical task), and the HMM estimated the horizontal task.**
- **In a post experiment interview, the pilot said he looked at both pitch and bank in these points.**

Data from Segment (iii) –Descent, Pilot 4



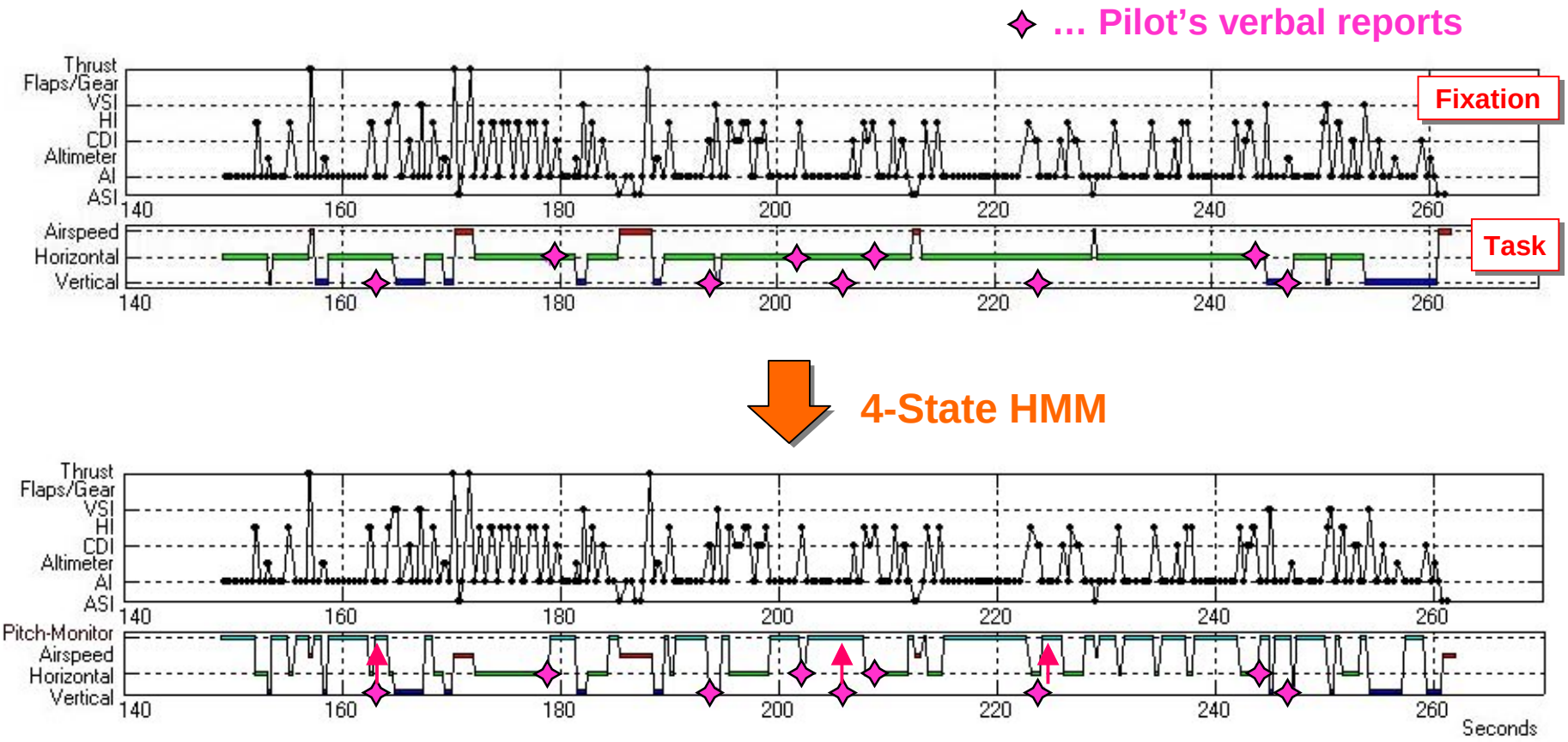
4-State HMM

- **A new state, “Attitude Monitoring” task, long duration of the AI and occasional CDI, was added to make a 4-state HMM.**



Estimation Results with 4-State HMM

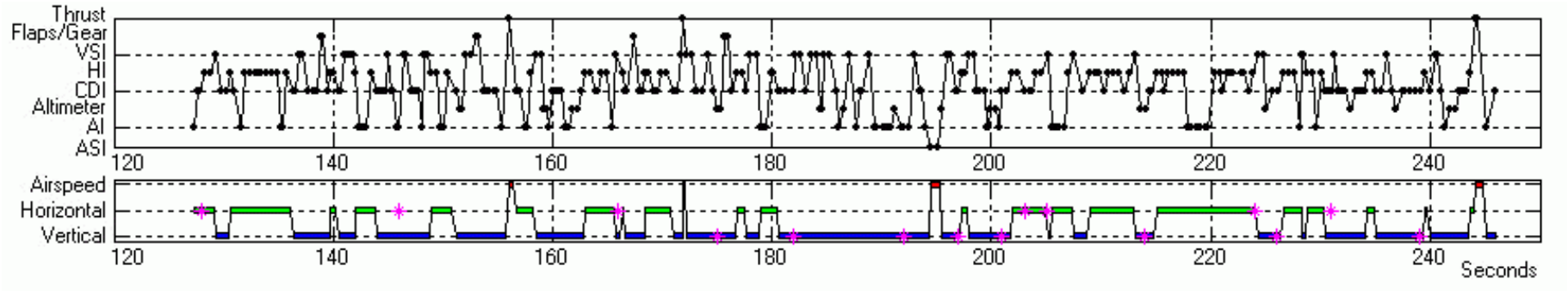
- **The 4-state HMM improved the verbal report match rate from 22/35 (62.9%) to 31/35 (88.6%).**



Data from Pilot 1

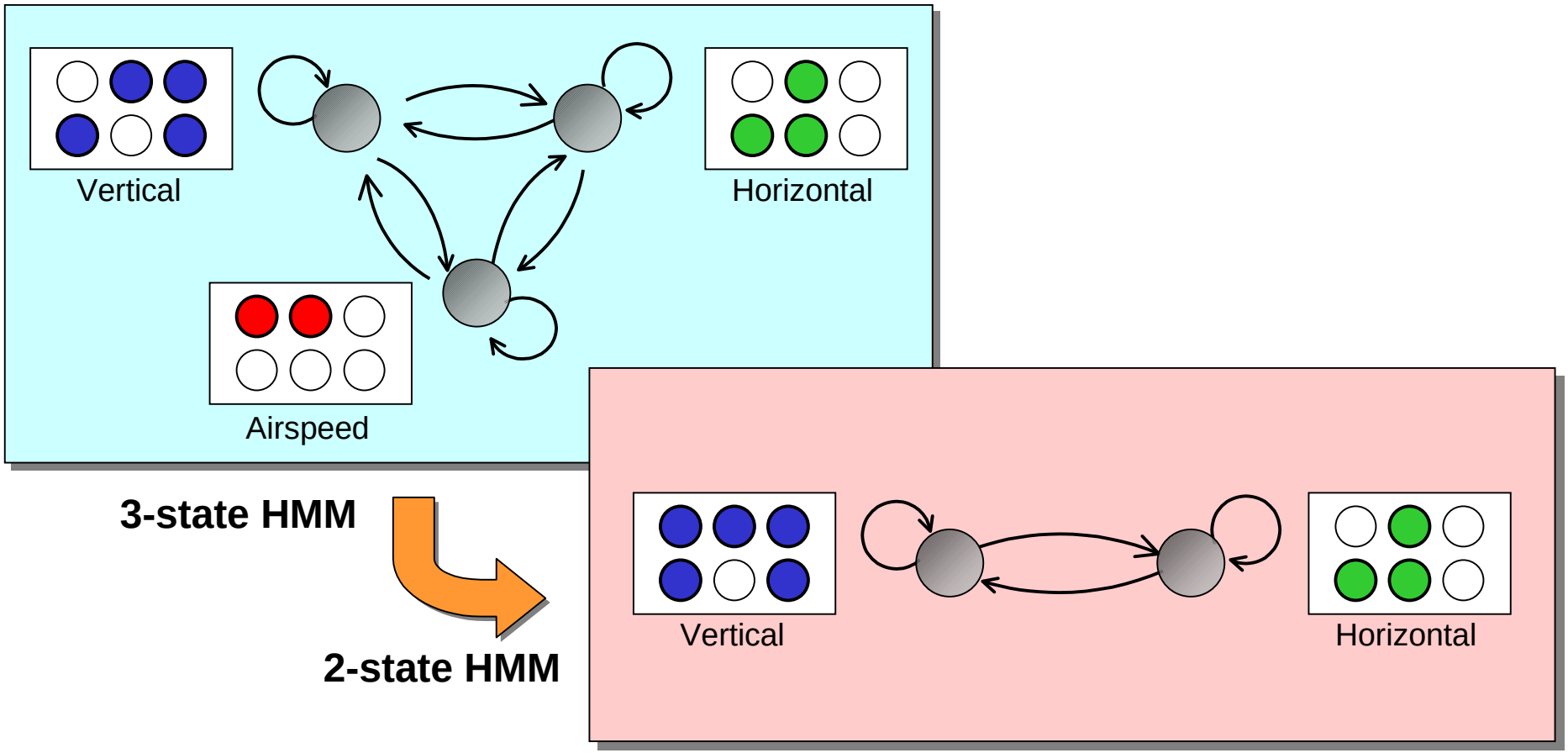
- **The Pilot 1 spend only 6.0% of the time for the airspeed task in Segment (ii), and 2.4% in the Segment (iii).**
- **The ASI was looked at for less than 1% in Segment (ii), and for 1.5% in Segment (iii).**
- **Thrust was changed several times, but the ASI was not necessarily looked at.**
  - The pilot used the thrust change mainly for the lift control?

Data from Segment (iii) –Descent, Pilot 1



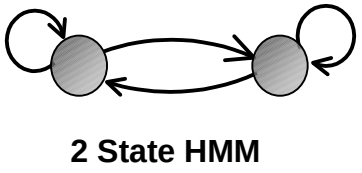
2-State HMM

- **The airspeed task was merged with the vertical task to make a 2-state HMM.**



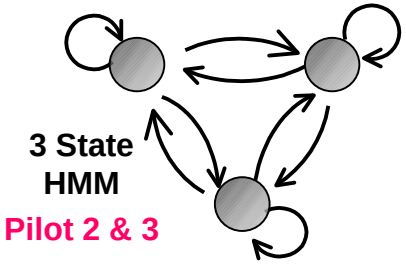
Correlation with the Skill Level

- **It was not a coincident that the numbers of the hidden states were correlated with the pilots' skill levels.**



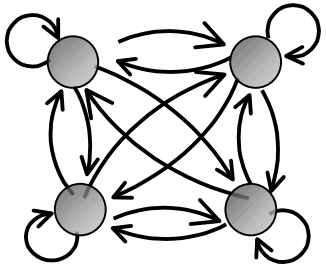
2 State HMM

Pilot 1



3 State HMM

Pilot 2 & 3



4 State HMM

Pilot 4

  - **The 2-state HMM (Pilot 1)**
    - **The airspeed task was dropped due to the high workload.**
  - **The 4-state HMM (Pilot 4)**
    - **The added attention-monitoring task means that the aircraft was on course and well-stabilized, and the pilot was simply monitoring any deviation from the stability.**

Summary of This HMM Study

- The concept of the HMM analysis and its benefits in the analysis of pilots' scanning and attention switching were presented.
- In the Experiment 1,
  - The HMM analysis results revealed subtle effects of display format difference within the subject.
  - It provided insights of how display format affected (or did not affect) pilot’s performance, mental workload, and display preference.
- In the Experiment 2,
  - Variations of the HMM structures that best described individual pilot’s data were derived.
  - The results showed correlation between the numbers of the hidden states and the pilots’ skill levels.

Hidden Markov Models as a Tool to Measure Pilot Attention Switching

— End of Presentation —

Please send questions & comments to
Miwa Hayashi (mhayashi@mit.edu)

References

- Hayashi, M., Oman, C. M., & Zuschlag, M. (2003, Apr. 14-17). Hidden Markov Models as a Tool to Measure Pilot Attention Switching during Simulated ILS Approaches. Paper published at the 12th International Symposium on Aviation Psychology. Dayton, OH.
- Rabiner, L., & Juang, B. H. (1993). *Fundamentals of Speech Recognition*. Englewood Cliffs, NJ, Prentice Hall.
- Weir, D. H., & Klein, R. H. (1971). Measurement and Analysis of Pilot Scanning Behavior during Simulated Instrument Approaches. *Journal of Aircraft, 8*(11), 897-904.