Medical Imaging, User Interfaces, Artificial Intelligence, and Normal Failure

A New Way of Seeing

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Medical Imaging

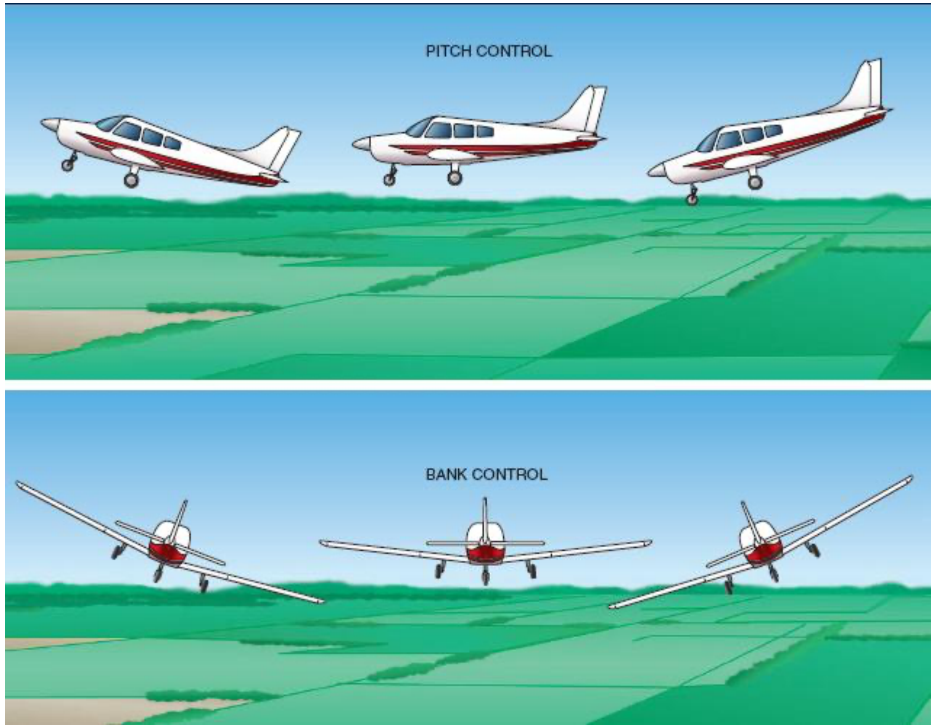
- Increasingly sophisticated equipment producing increasingly sophisticated images
- Ability of human operators, radiologists, etc. to accurately interpret the images is deficient
  - Outcomes are worsening despite the increased use of the technology
- What lessons from UI/UX experience in other areas can we bring to health informatics
  - Optimal information presentation within high workload/high stress situations
  - Normal failure
- Can artificial intelligence and machine learning improve things?
  - Or just make them worse?

The role of information in doing our jobs

- A pilot’s most important job is to maintain control of the aircraft’s attitude
- A doctor’s most important job is to do no harm
- Both pilots and doctors rely on experience, intuition, senses, and technology to do their jobs
- Both pilots and doctors can fail at their job if any of the above fail them

Ascertaining aircraft attitude

- Loss of attitude control ends in one of two ways:
  - Recovery
  - Crash
- The human body does not contain biological technology to independently determine attitude ("which way is up?"). Attitude can only be inferred visually – by seeing a horizon.
- Many situations inside an aircraft give the pilots no visible horizon (in clouds, at night, etc.). These are termed "instrument conditions."
- Average time between loss of horizon and loss of control is less than 1 minute, IRRESPECTIVE OF PILOT EXPERIENCE OR QUALIFICATIONS



Ascertaining patient condition

- Misunderstanding of patient condition ends in one of two ways:
  - Recovery
  - Death
- The human body does not contain biological technology to independently determine patient condition (”what’s going on?”). Condition can only be inferred visually – by seeing the body
- Many situations inside the human body give the doctor no visible assessment (obscured by flesh, organs, etc.)

Technology to the rescue -- flying

- Denial of Vision (DoV) issues in flying (i.e. no horizon) pressed for the need to develop technology that could present an *artificial horizon*
- The criticality of an accurate artificial horizon pressed for the need to develop technology that could redundantly provide horizon information
  - To verify (legitimate) horizon information coming from primary source
  - To provide backup horizon information if the legitimacy of the primary source comes into doubt

User Interface of a Typical Aircraft – Attitude Control

Attitude

A1H	Primary Attitude (Horizon)
A2S	Secondary Attitude (Speed)
A2T	Secondary Attitude (Turn)
A3A	Tertiary Attitude (Altitude)
A3D	Tertiary Attitude (Direction)
A4H	Quaternary Attitude (Horizon)

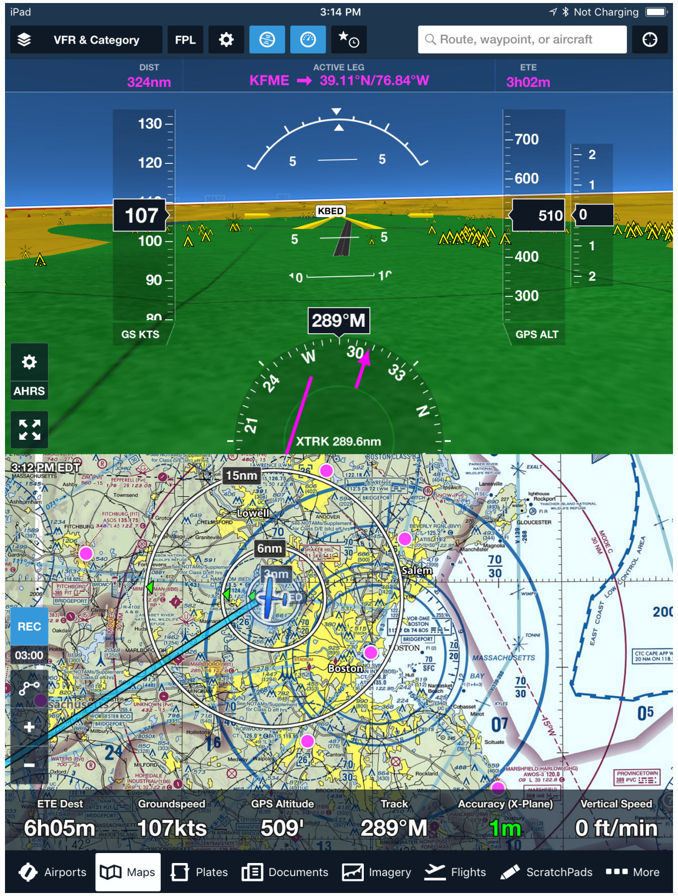
Performance

M1P	Primary Mechanical (Engine Power)
M1I	Primary Mechanical (Inst. Power)
M1E	Primary Mechanical (Electric Power)
M2P	Secondary Mechanical (Engine Power)

How control is maintained

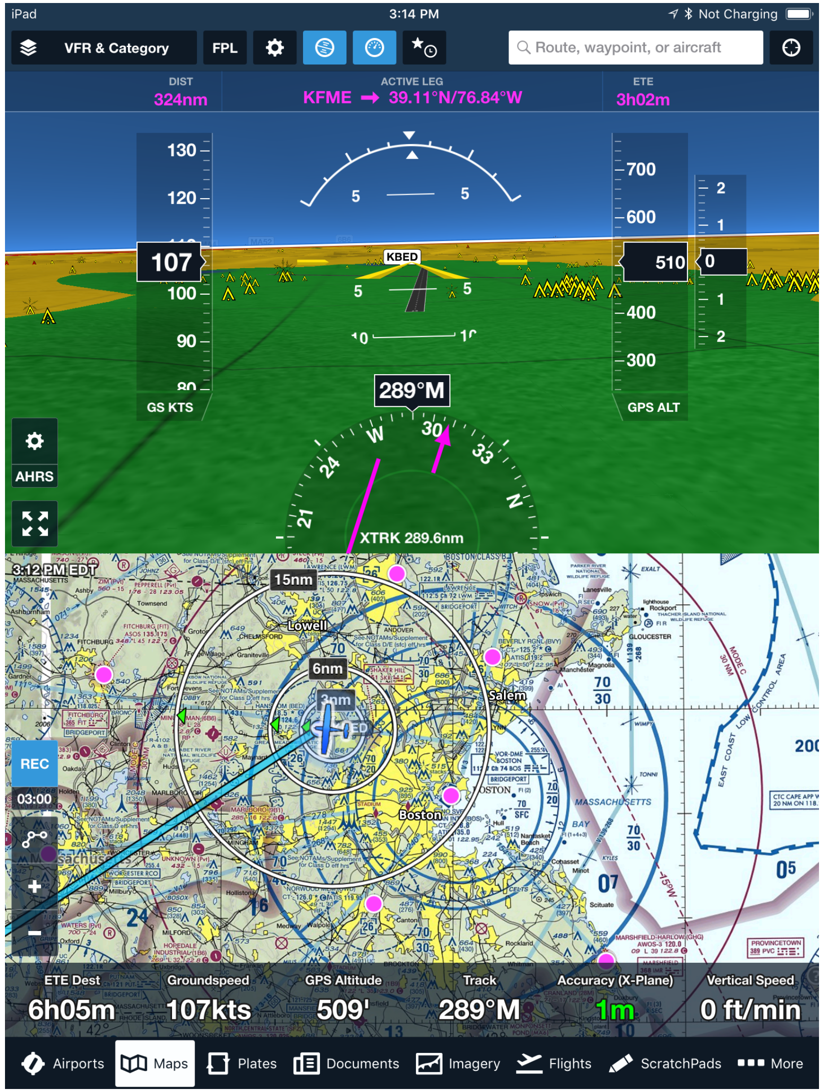
- The attitude indicator (A1H, also referred to as the artificial horizon) is top and center on the panel. It provides the best visual approximation of the real horizon. The artificial ground on the indicator is painted brown and the artificial sky is painted blue. Ideally all the pilot needs to do it keep the blue on top and the brown on the bottom
- However, the instrument is subject to a number of failure modes both mechanical and in its interpretation. Because of the criticality of maintaining attitude, pilots are taught to obtain attitude information from other, secondary, instruments.
- Primarily these are A2T (turn) and A2S (speed). Pilots are taught to use the turn instrument to determine if the aircraft is in a bank and the speed instrument to determine if the aircraft is pitched up or down

Real Attitude Control with Synthetic Vision



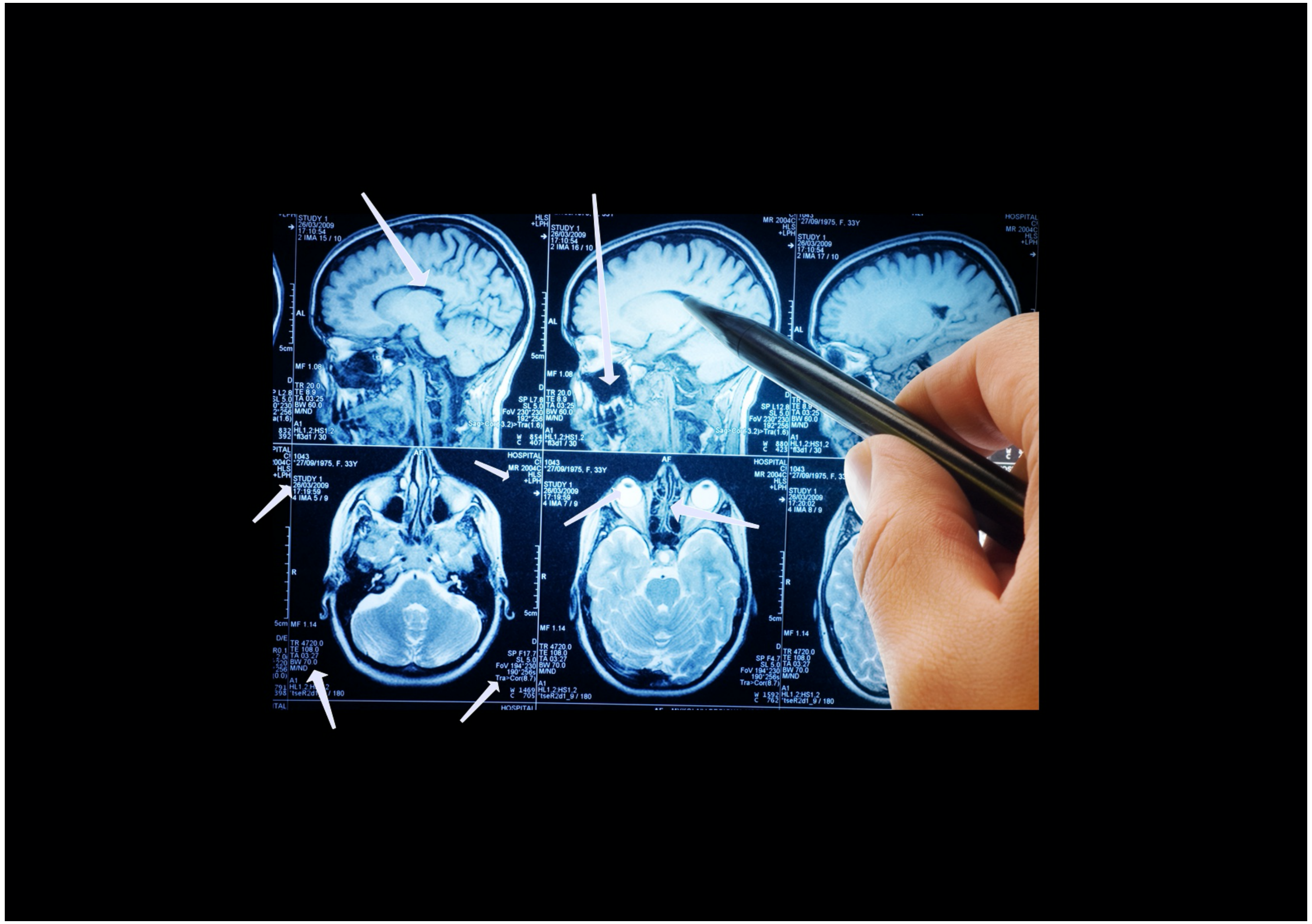
- In aviation, the latest technology delivering an “artificial horizon” is something called “synthetic vision.”

Real vs. Synthetic



This is an actual out-the-cockpit view of a recent landing I made in Boston vs. the Synthetic vision of the same landing that I could have used if visibility out the windshield wasn't good

User interface of an MRI machine – Patient Condition



Patient Condition

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Real vs. Synthetic

- NEED TO FIND COMPARATIVE IMAGES OF ACTUAL TISSUE VS. MRI IMAGES OF SAME TISSUE HERE

Failure To See The Forest Through The Trees

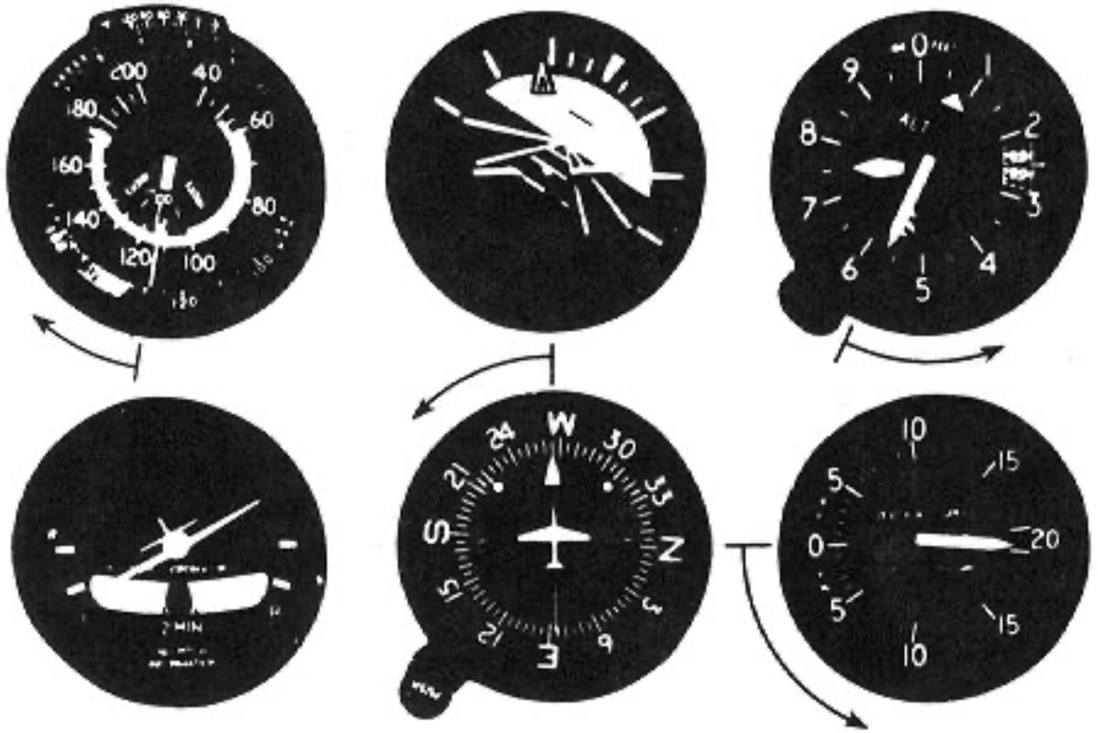


Figure 13–5 Unusual Attitude (Critical)

"OK, Mrs. Dunn. We'll slide you in there, scan your brain, and see if we can find out why you've been having these spells of claustrophobia."

Failure To See The Forest Through The Trees: The Human Factor

"A small glitch took Flight 447 down, a brief loss of airspeed indications—the merest blip of an information problem during steady straight-and-level flight. It seems absurd, but the pilots were overwhelmed.

In the cockpit, the situation was off the scale of test flights … each time Bonin happened to lower the nose … the stall warning sounded again—a negative reinforcement that may have locked him into his pattern of pitching up, assuming he was hearing the stall warning at all.

Bonin said, "I have a problem—it's that I don't have a vertical-speed indication anymore!" Dubois merely grunted in response. Bonin said, "I have no more displays!" This was not correct. He had displays but didn't believe them. The descent rate was now 15,000 feet per minute."

Wolfgang Langewiesche, "The Human Factor." Vanity Fair, 9//17/2014

"Clearly, image quality, i.e., technical efficacy, con- tributes to diagnostic accuracy efficacy. But it also be- comes apparent that there may be a point beyond which improvement in technical efficacy no longer improves diagnostic accuracy efficacy. This illustrates the essential asymmetry in relationships between adjacent levels in the continuum of efficacy.

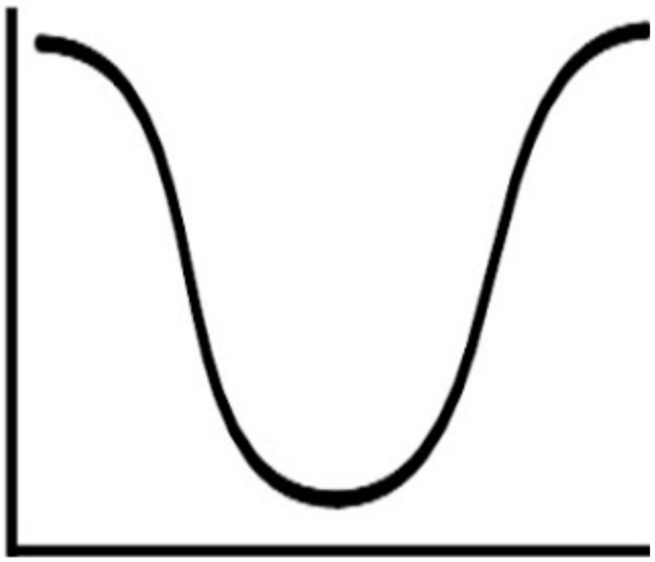
The image may have non-decisional impact as well. It is not uncommon to see clinicians place great value on results that do nothing more than reassure them. As such, measuring the impact of the imaging result on clinician thinking can be a complex and value-laden exercise.

[T]he most useful studies are those that directly measure the impact of new information (i.e., the imaging result) on the physician's subjective diagnostic probabilities."

Fryback, DG and Thornbury, JR, "The Efficacy of Diagnostic Imaging." Medical Decision Marking, May-Jun 1991

Normal Failure

- Normal Failure simply relates to the fact that system failures follow a Gaussian distribution ("Bathtub Curve") along a longitudinal axis. That axis could be:
  - Time
    - Relationship between infant mortality and old-age breakdown
      - Tacoma Narrows Bridge Collapse and I-35W Mississippi River Bridge Collapse
  - Complexity
    - Relationship between redundancy to prevent failures and failures due to that redundancy
      - ValuJet Crash
  - Information
    - AirFrance Flight 447 Crash



All This Machinery

- We have two examples of professions that utilize technology to augment human biological capability. Both examples focus on the biological limits of human vision and seek to circumvent those limits with machine-generated artificial or synthetic vision
- However, the positive augmentation has not come without cost:
    - Strong tendency towards providing too much raw information, leading to confusion and panic in non-nominal situations
    - Human tendency to use the results of the technology not in search of knowledge, but in search of bias confirmation
    - Vastly increased complexity enabling vastly greater failure modes
    - Subsequent counter-intuitive rise in aircraft accidents and poorer patient outcomes due to the “better technology.” This is called “Normal Failure.”

The Critical Difference Between the Industries

- Every mishap in aviation that results in aircraft damage or worse is investigated thoroughly
  - Goal of all investigations is to determine the cause and prevent recurrence
- There is no similar structure in medicine
  - Diagnostic failures in particular are never investigated
  - Diagnostic successes are never recorded

The Promise of Artificial Intelligence and Machine Learning Towards Improving Imaging Diagnostics

- Simplify the Information
  - Reduce confusion
- Eliminate Interpretation Bias
- Standardize Interpretations
- Synthesize data and results from prior diagnostic activity and bring that data to bear in making future diagnosis
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"Previous research has shown that AI is as good as or better than doctors at spotting problems in CT scans. Geoffrey Hinton, one of the pioneers of deep learning, told the New Yorker that because of the advances in AI, medical schools "should stop training radiologists now." Analyzing image-based data sets like x-rays, CT scans, and medical photos is what deep-learning algorithms excel at. And they could very well save lives."

https://www.technologyreview.com/the-download/609510/a-new-algorithm-can-spot-pneumonia-better-than-a-radiologist/

How that’s done

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