The AI CoPilot
A Research Roadmap

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What does a co-pilot do?

Commercial air transport operations requires 2 pilots:

1) A captain (PIC) who has full authority over all systems and operations.
2) A co-pilot who is fully qualified and authorized for all operations with the aircraft.

WHY?

1) **Flight Safety**: The captain and co-pilot monitor each others actions and procedures. The co-pilot is authorized to question any unsafe operations using a protocol of "assertive support".

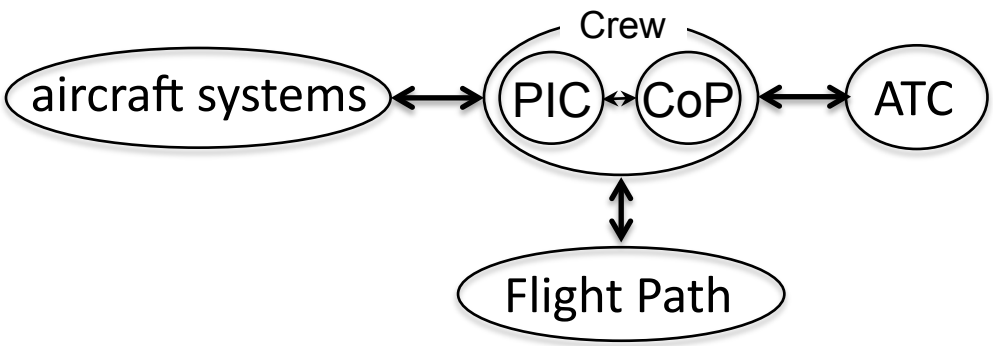
2) **Work Load management**: In times of high workload, the captain can delegate tasks to the co-pilot.

3) **Backup:** If the PIC is incapacitated, the co-pilot is authorised to take responsabilty for completing the flight.

Private aviation generally relies on single pilot operations, with much higher accident rates.

<u>Can we automate the co-pilot using generative AI?</u>

What does a co-pilot do?



PIC — Pilot in Command

CoP — Co-Pilot

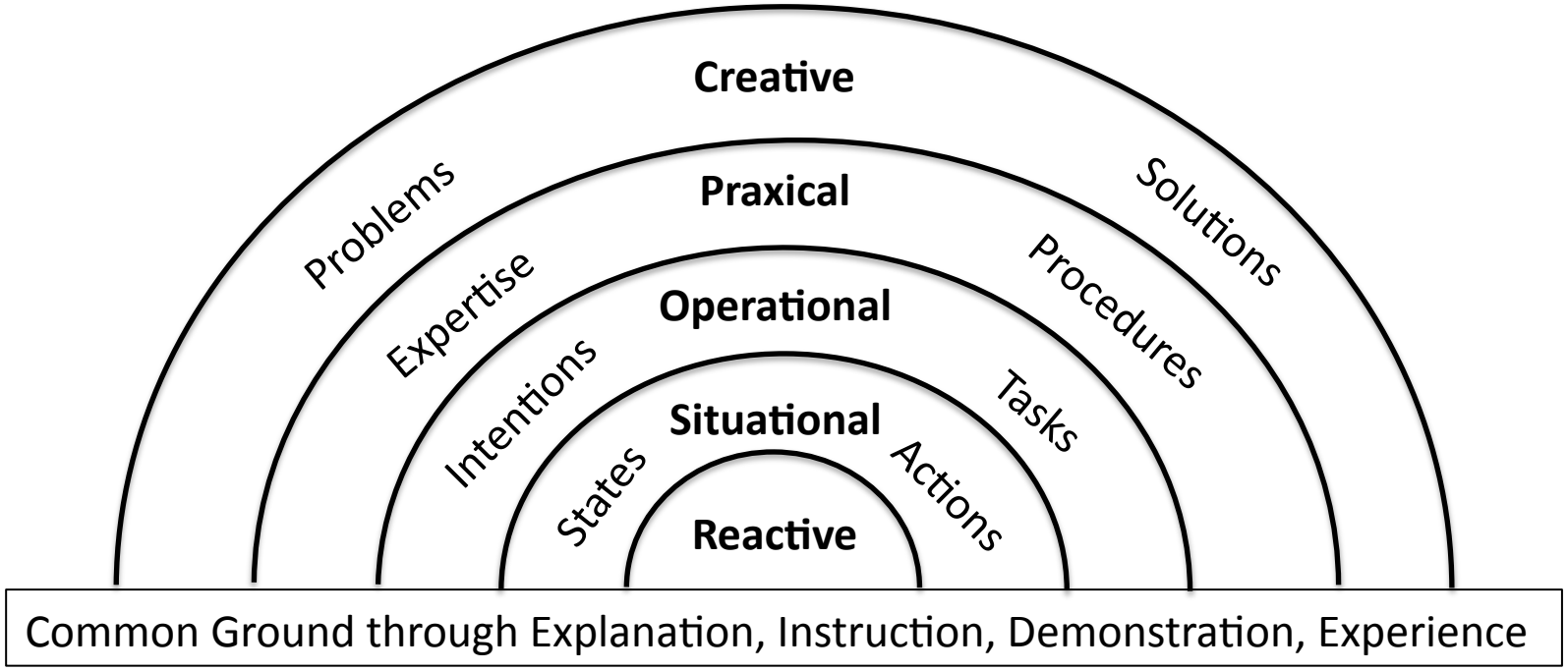
ATC — Air Traffic Control and other Aircraft

Flight Path — Flight Path And Airspeed

The Pilot and Co-pilot form a **collaborative crew** to assure the safe and successful outcome of the flight.

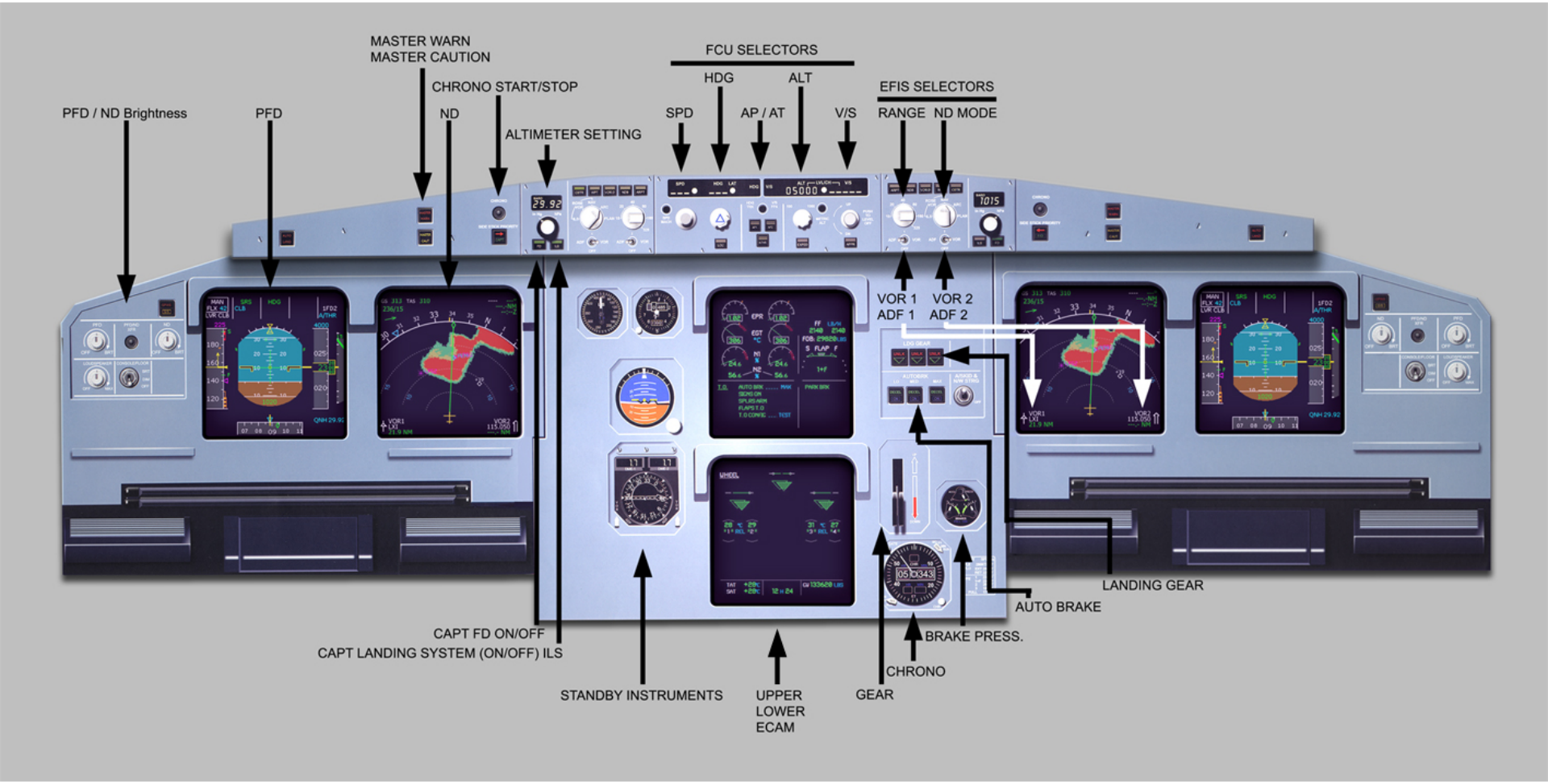
They interact with Aircraft Systems to control the flight path and airspeed in collaboration with ATC.

The Humane AI Net
Hierarchical Framework for Collaborative AI



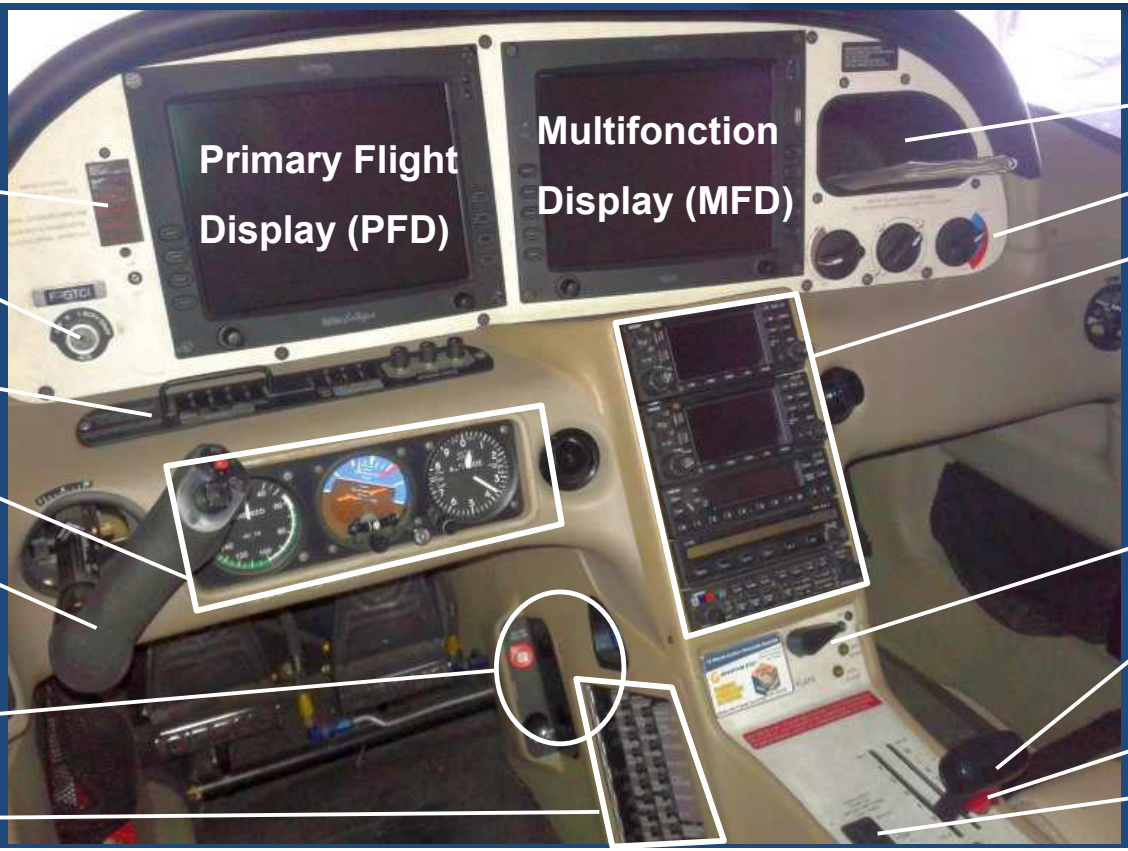
- Collaboration is a process where two or more agents work together as partners to achieve a shared goal.
- The Humane AI net Research Roadmap formulates collaboration as a hierarchy of perception-action cycles.

The A320 Avionics Panel

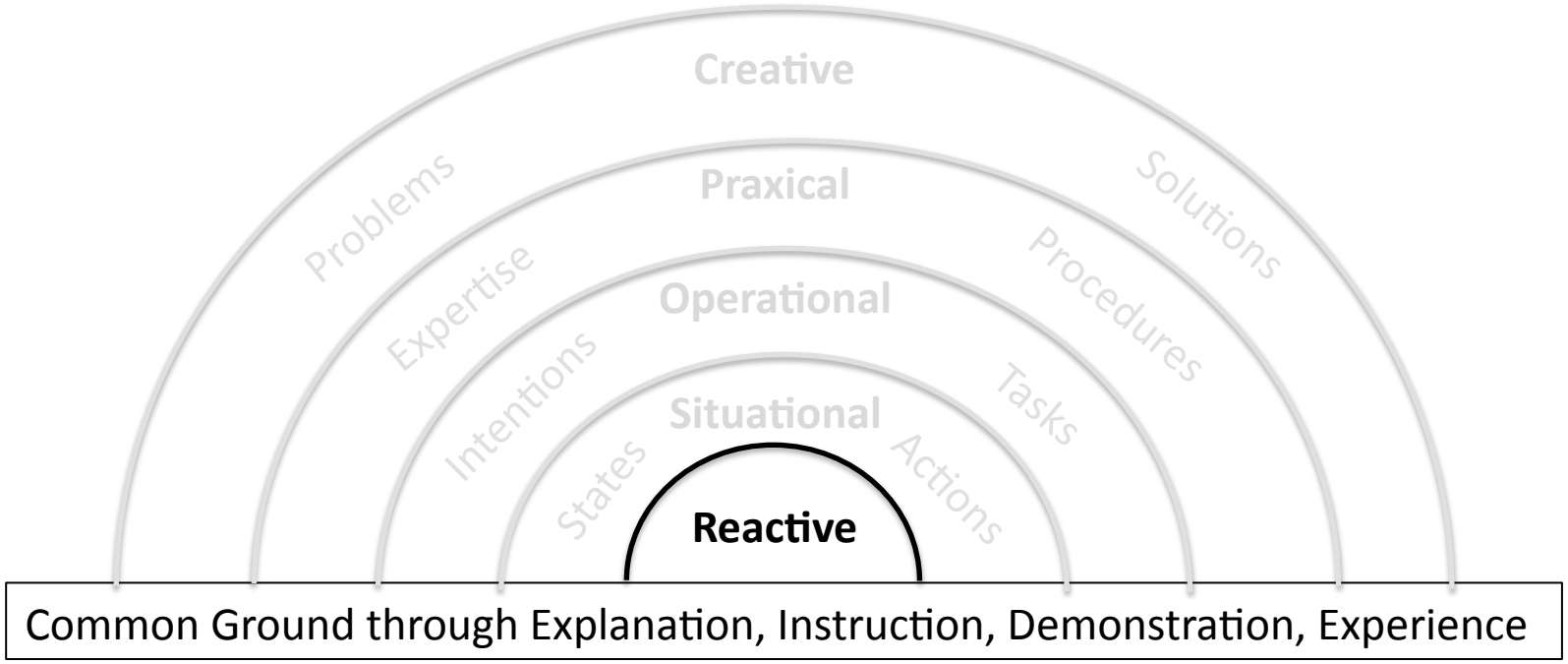


Cirrus SR20 – F-GTCI

The Cirrus / Avidyne Integra
Glass-Cockpit for General Aviation



Reactive Collaboration



Reactive Interaction: Tightly coupled perception-action involving two or more agents.

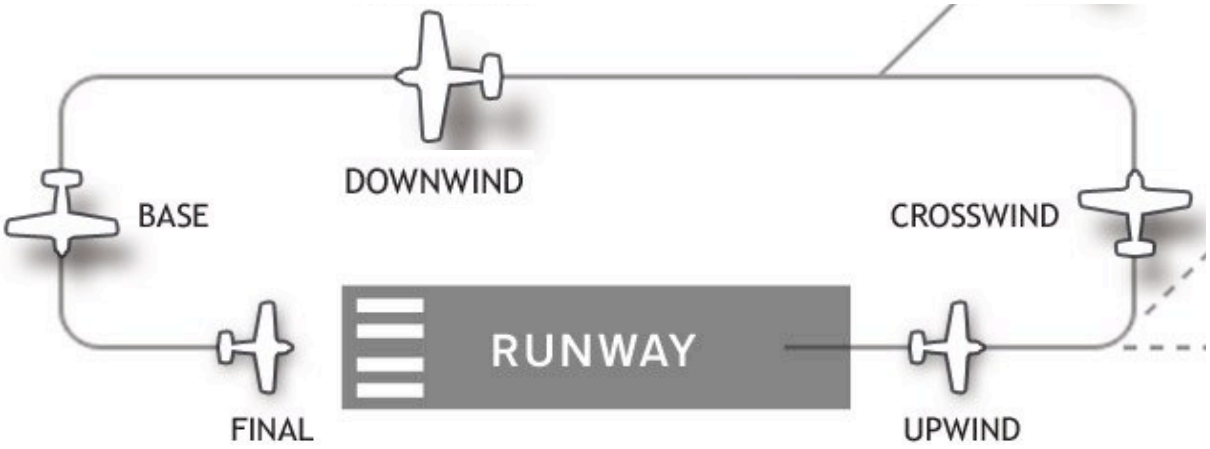
Reactive Collaboration: A form of interaction where two or more agents act to achieve a shared goal.

Collaborative interactions are mediated by spoken language interactions

In aviation, collaborative interactions are mediated by spoken language dialogue using formal protocols.

Protocols simplify interactions by providing a script that prescribes a limited set of messages that a participant should expect to receive, and a limited number of responses that should be communicated in response.

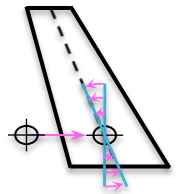
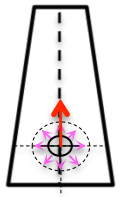
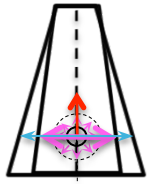
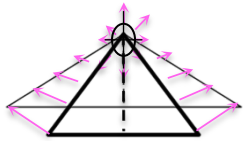
Reactive Collaboration: Aviation Scenario



Pilot: Cirrus F-CI Downwind Runway 04 for a Landing. full-stop.
Tower: F-CI, Number 2, Report Final
Pilot: Number 2, will report Final, F-CI
…
Pilot: Cirrus F-CI. Final Runway 04
Tower: F-CI, Cleared to land Runway 04.
Pilot: Cleared to land Runway 04. F-CI.

Dialogue with ATC follows a well defined formal protocol with a restricted vocabulary, Protocol has been designed to minimize errors in a noisy, highly distractive environment.

Landing an Aircraft:
Visual Sensorimotor Reactive Control

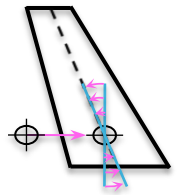
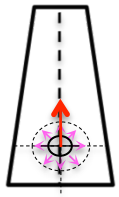
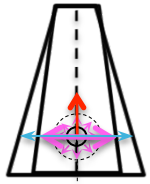
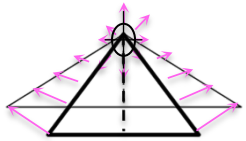
				
Horizontal position	Directional Alignment	Stabilised Descent	Flare	Vacate Runway

Each phase involves sensorimotor control based on visual motion
In parallel: Spoken language interaction with tower

Pilot: F-CI, on Final Runway 04.
Tower: F-CI, Cleared to land Runway 04.
Pilot: Cleared to land Runway 04. F-CI.

During Landing the sensorimotor channels for vision and motor control are near saturation. Only auditory channel is available for collaborative dialogue.

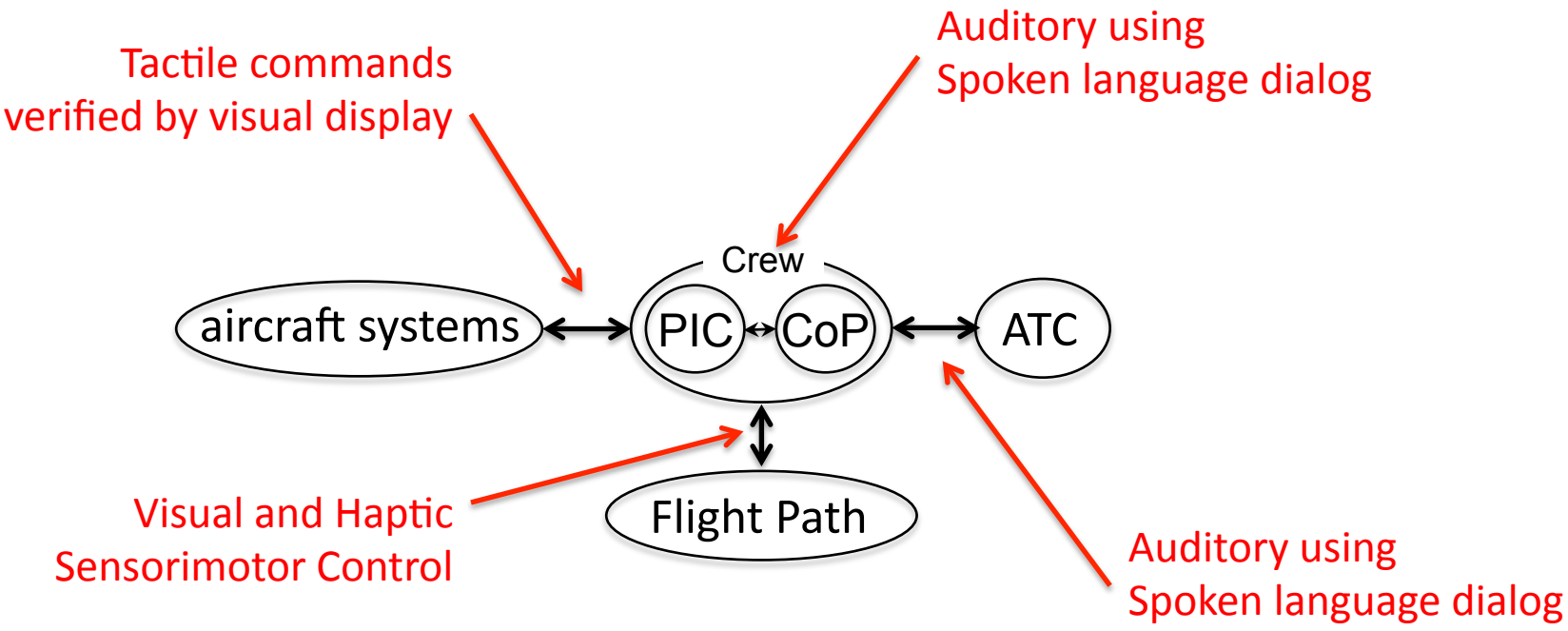
The co-pilot monitors the actions of the pilot

				
Base Leg 85 Kts	Final 80 Kts	Short Final 75 Kts	Touch down < 67Kt	Roll out < 20 kts

When landing Pilots can become fixated on trajectory and neglect airspeed.

Pilot: F-CI on Final Runway 04.
Tower: F-CI, Cleared to land Runway 04.
… (airspeed > 100 Kts)
Co-pilot to Pilot: Sir. Airspeed is too high. Go-around.
Pilot: F-CI. Going-around.
Tower: Roger. Report Downwind Runway 04.
Pilot: Report Downwind Runway 04, F-CI

Sensori-motor channels for Collaborative Interaction

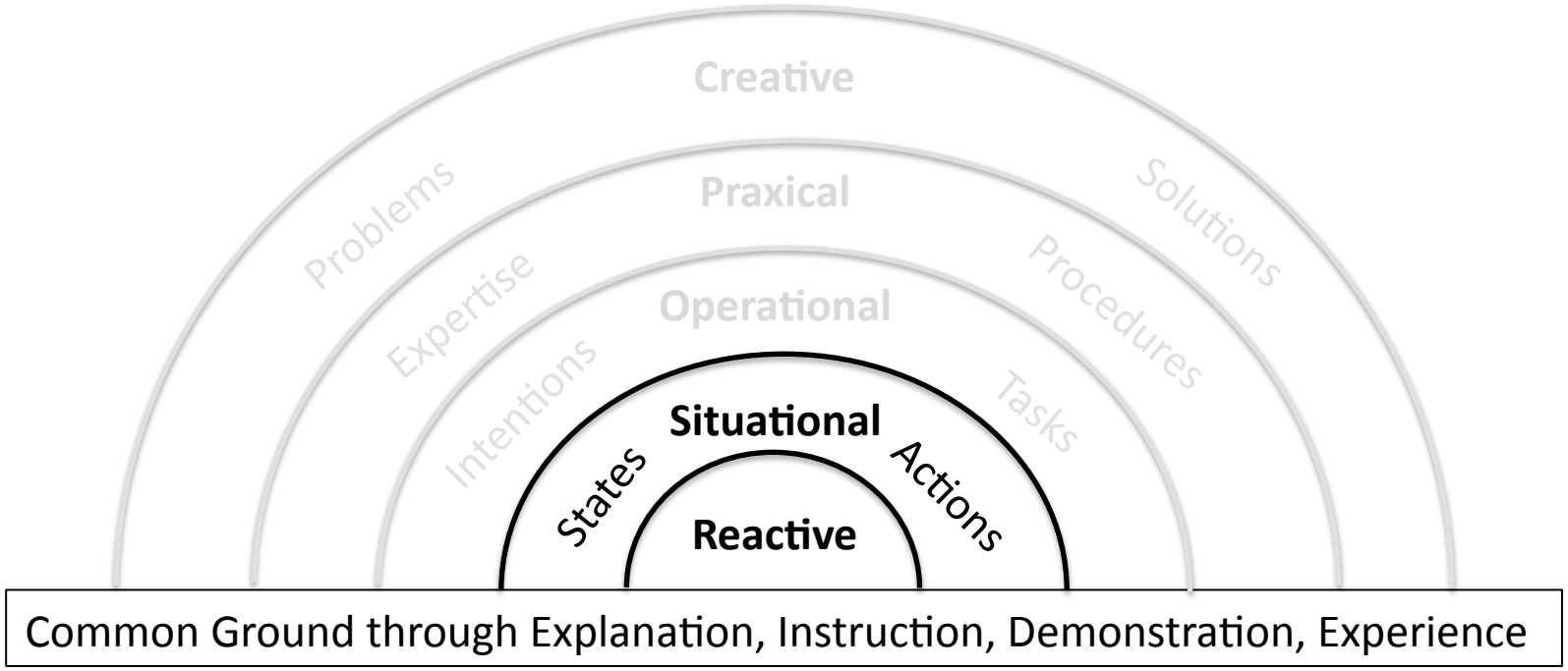


Reactive Abilities Required for Landing an Aircraft

1) Visual control of lateral, vertical and forward motion using pitch, roll, and power
2) Spoken language interaction with Tower and/or other aircraft.
3) Context-aware situation modeling

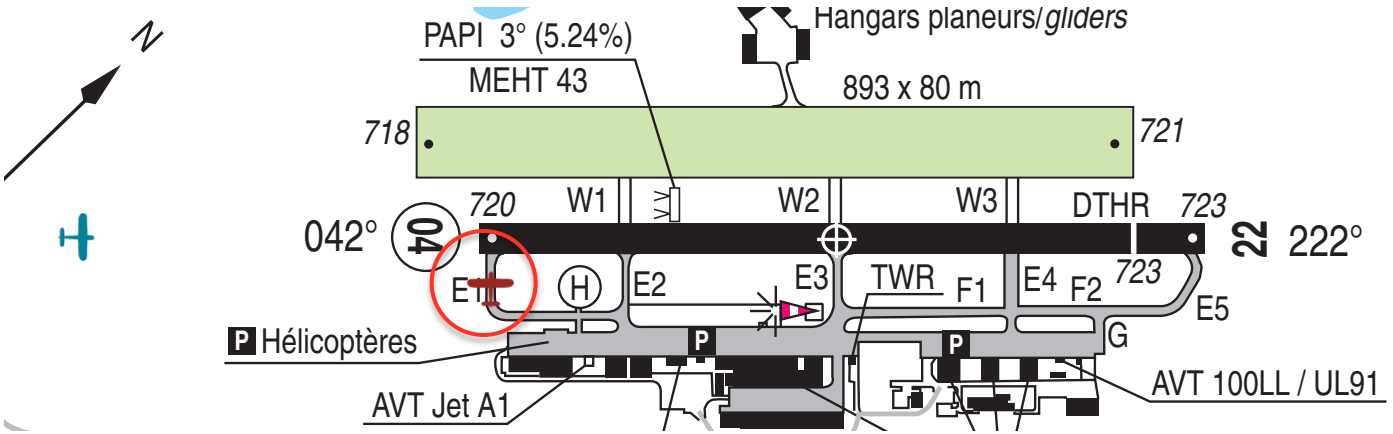
Function	Human Pilot	Today's Avionics
Communications	Spoken language interaction with ATC	Mode S Transponder, ADSB
Pilotage	Visual Control of Pitch, Roll and Power	Gyroscopic control of pitch, roll, heading Pressure based measurement of airspeed, altitude and variations
Navigation	Situation-aware maneuvering	GNSS based waypoint navigation, Terminal procedures (ARINC Segments)
Operation	context-aware systems management	Digital control of power plant (FADEC) Sensor based engine monitoring

Situational Collaboration



Situational Collaboration: Perception and action are mediated by shared awareness of situation

Situation Aware Interaction



Pilot: Cirrus F-CI. Holding point E1. Ready for departure runway 04
Tower: F-CI, after the aircraft landing on final, line up and wait runway 04, after.
Pilot: After the aircraft landing on final, line up and wait runway 04, after. F-CI

The Pilot and ATC share a Situation Aware Interaction:
Perception, action and interaction
mediated by shared awareness of situation.

Awareness in Human Factors

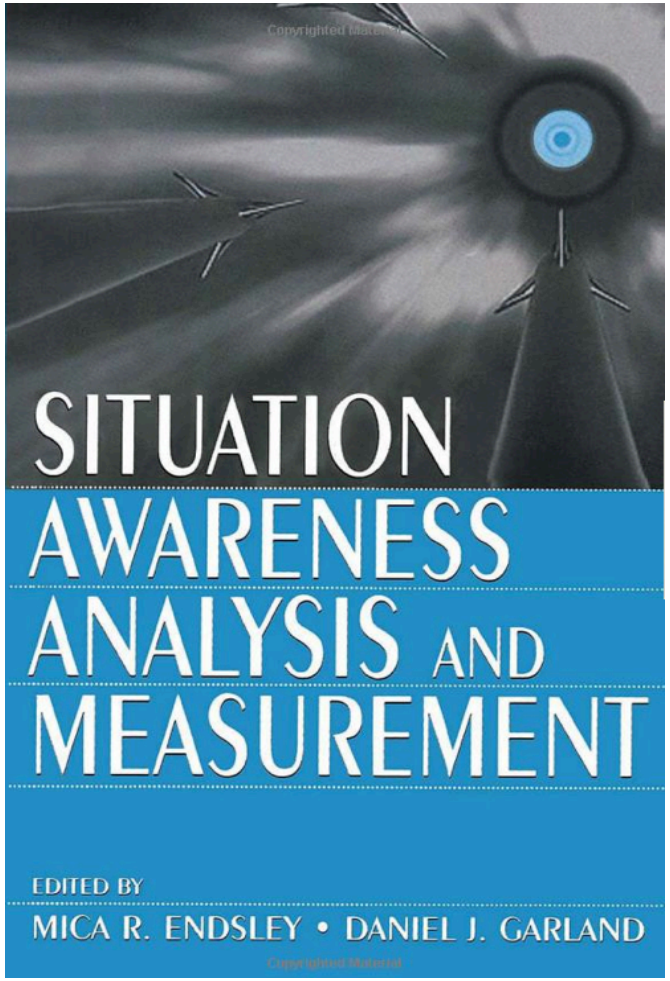
Models of awareness have been studied and applied for human factors in aviation since at least 1914.

Awareness (Endsley 00)

- Vigilance against danger or difficulty.
- Having knowledge of something.
- The ability to perceive, to feel, or to be conscious of events, objects or sensory patterns.
- Conscious of stimulation, arising from within or from outside the person

Situation Models:
a theory of human mental models

Mica Endsley, Ph.D., P.E.
PhD USC 1990
editor-in-chief of the Journal of Cognitive Engineering and Decision Making
President: SA Technologies
Specialty: Cognitive Engineering
Application Domain: Aviation and critical systems.



Situation Models:
a theory of human mental models

Situation Awareness : The Perception of [relevant] elements of the environment in a volume of space and time, the comprehension of their meaning and the projection of their status in the near future. (Endsley 2000)

Levels in Situation Awareness

1: Detection: Sensing of entities relevant to task

2: Assimilation: Associating perception with models that predict and explain.

3: Projection: Forecast events and dynamics of entities

M. Endsley, D. Garland, Situation Analysis and Awareness, Lawrence Erlbaum, 2000)

Situation Models:
a theory of human mental models

Situation Models are widely used in Cognitive Psychology to describe human abilities for

1) Providing context.
2) Interpreting ambiguous or misleading perceptions.
3) Reasoning with default information
4) Focusing attention for problem solving

Situation Models provide a conceptual framework for intelligent systems that collaborate with humans

Context Aware Situation Modeling

Situation: (a state) a set of relations between entities with associated behaviors.

(Human working memory is limited to 7±2 entities.)

Context: A state-graph of situations, with associated behaviors needed for task.

Context specifies the entities, relations, behaviors and state transitions relevant to as task domain.

Context Aware Situation Modeling

Modern Flight management systems (FMS) operate in fixed set of pre-programmed contexts:

(Example G430: Departure, En-route, Arrival and Approach)

The Air Crew (PIC and Co-pilot) must operate in an open-ended set of aviation contexts that include all possible threat (TEM) and unsafe emergency situations.

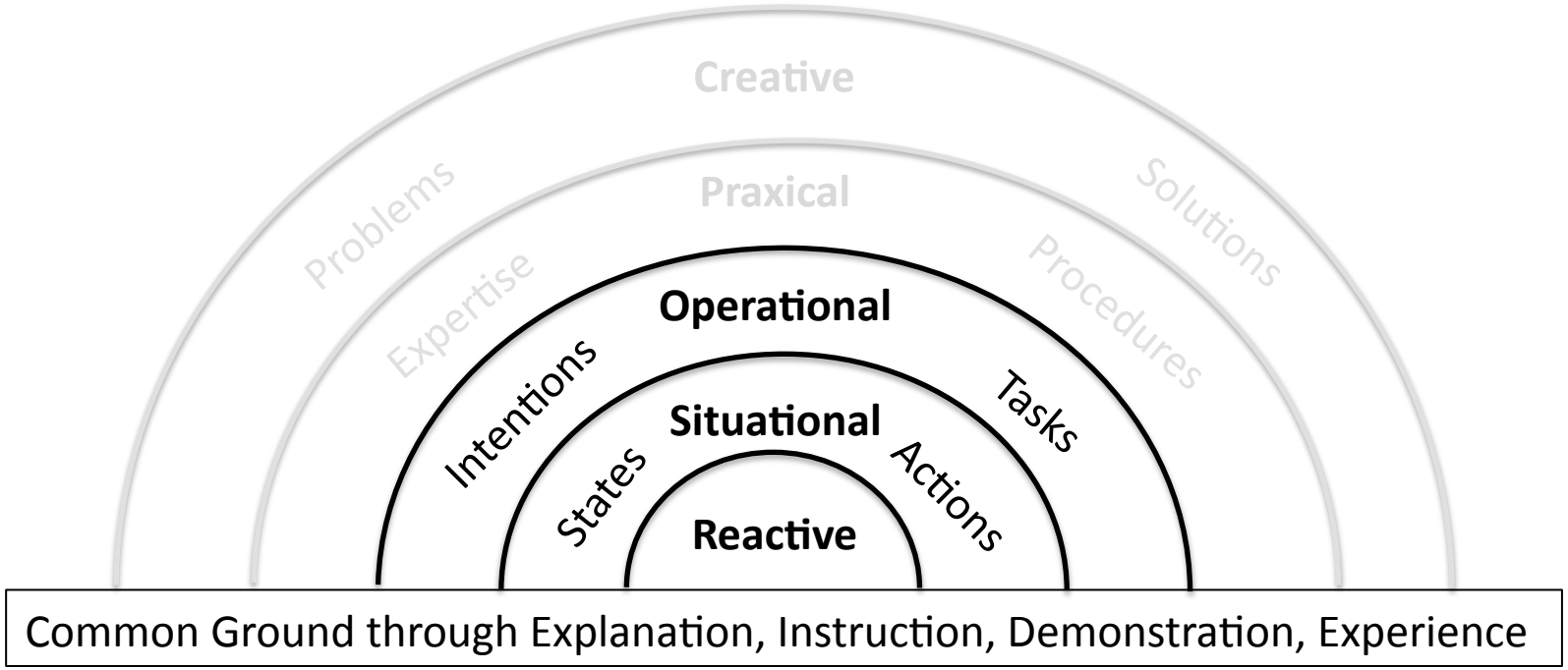
Technology for Situation-Aware Collaboration

Can we create technologies to permit humans and intelligent systems to share understanding of a situation in open domains ?

Yes! transformers trained with self-supervised learning provide the enabling technology for Situation aware collaboration.

- Entities and relations are represented by latent variables in a transformer.
- Perceptions are provided by stacked encoders.
- Behaviors are generated by stacked decoders.
- Linguistic symbols (words) and dialogue are easily attached during learning

Operational Collaboration



Operational Collaboration: Collaboration is mediated by shared authority over tasks and activities.

Operational Collaboration

Operational Collaboration: Collaboration is mediated by shared authority over tasks and activities.

Shared Authority is mediated by protocols and roles

Examples of human operational collaboration.

- Team sports
- Corporate structures
- Air Crew

Roles and Protocols

Authority: Liberty to take actions.

Roles: A set of behaviors (actions and reactions) expected of an individual who occupies a given social position.

Protocols: Rules that govern interactions between agents performing roles

Operational Collaboration

Shared authority over initiating or performing operations.

Examples:

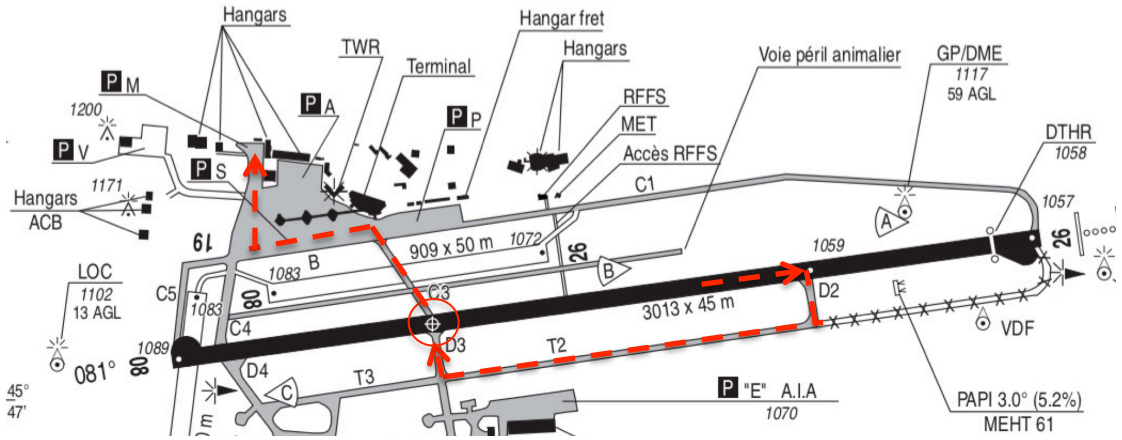
ATC and the PIC (in controlled airspace)

- ATC has authority over all operations in controlled airspace.
- ATC delegates authority to the PIC with clearances
- The PIC has the responsibility to act without a clearance when threatened with an unsafe situation.

PIC and co-pilot:

- The PIC has authority over all systems.
- The PIC can delegate authority to the co-pilot
- The co-pilot has responsibility to call attention to unsafe operations.

Operational Collaboration



Pilot: Clermont Tower, Cirrus F-GTCI. Runway 08 vacated at D2. Request taxi to parking Mike.

Tower: F-CI taxi to mike via T2, D3, C3, B and S .

Pilot: F-CI taxi to mike via T2, D3, C3, B and S.

… at D3

Co-pilot: Sir. Stop now. You are entering an active runway.

(Pilot to Co-pilot: oops. Stopping now.)

Pilot: Clermont Tower F-CI, at D3 Request Cross runway 08.

Tower: F-CI, maintain position. Aircraft on final.

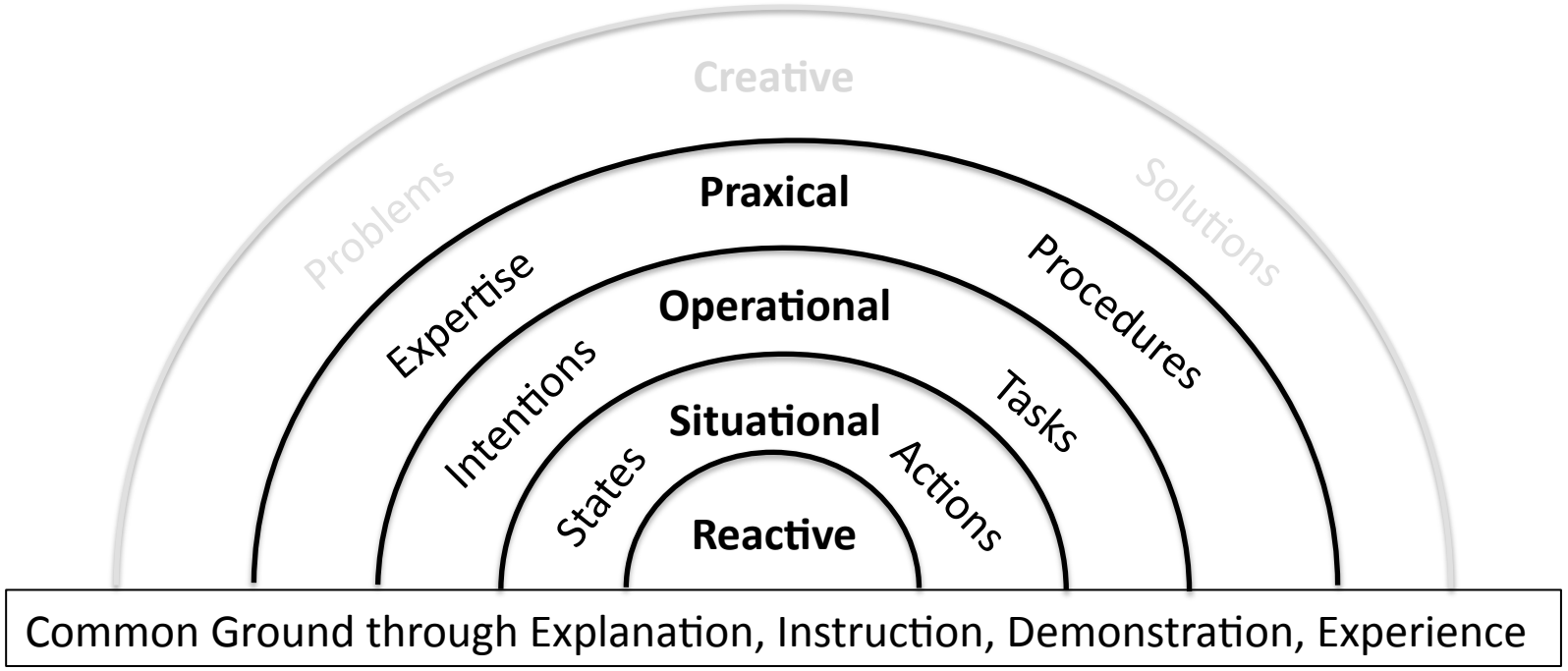
Required Operational Abilities for an AI co-pilot

Operation Abilities required for pilot and copilot

1) Spoken language interaction
2) Context aware situation modeling
3) Interaction using roles and protocols of PIC, co-pilot and ATC

Function	**Human Pilot**	**Today's Avionics**
Communications	Spoken language interaction with ATC and co-pilot	Mode S Transponder, ADSB, Graphics display
Context aware situation modeling	Abilities based on Training and experience	GNSS based navigation (position and charts)
Roles and protocols	Abilities based on training and experience	Interactive graphics
Operations	Context-aware systems management	Electronic checklists

Praxical Collaboration



Praxical Collaboration: Sharing of knowledge about how to act based on experience or training.

Praxical Collaboration

Praxical Collaboration:

Exchange of knowledge about how to attain goals and maximize value based on experience.

Examples:

- Sharing strategies for how to navigate in complex situations
- Explaining how to land an aircraft in a crosswind.

Praxical Collaboration

Praxical techniques for landing taught by instructors to student pilots:

How to land an airplane: Glide down the runway, cut the power and keep the wheels off the runway as long as you can.

How to land in a cross wind: Point the stick in the wind, apply opposite rudder and keep the nose on the end of the runway.

Praxical Collaboration

An AI copilot should act as an instructor:

- Monitoring pilots actions to guard against errors
- Offering practical advice on technique and procedures.

Explanations take the form of Narratives

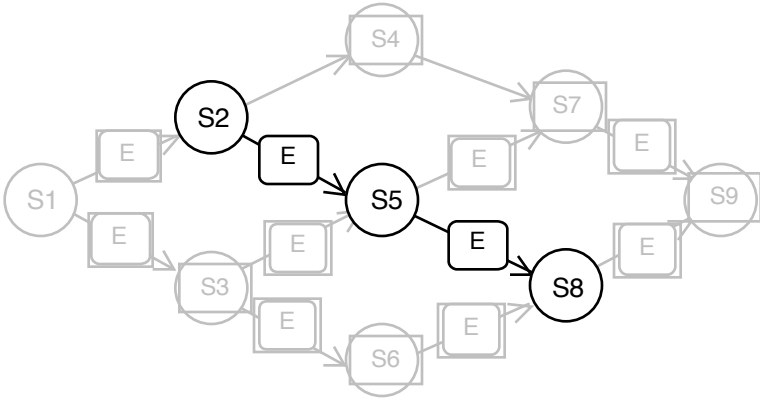
Calvin and Hobbs: Dad explains science

Narratives are **a temporally ordered sequence of situations**, possibly with branches and causal relations.

Example: Scientific Theories

- Narratives enable humans to provide descriptions for situations that are not directly observable, including hypothetical or abstract situations and situations that occurred in the past.
- Narratives enable humans to make predictions for situation that may occur in the future.

Praxical Collaboration: Narratives



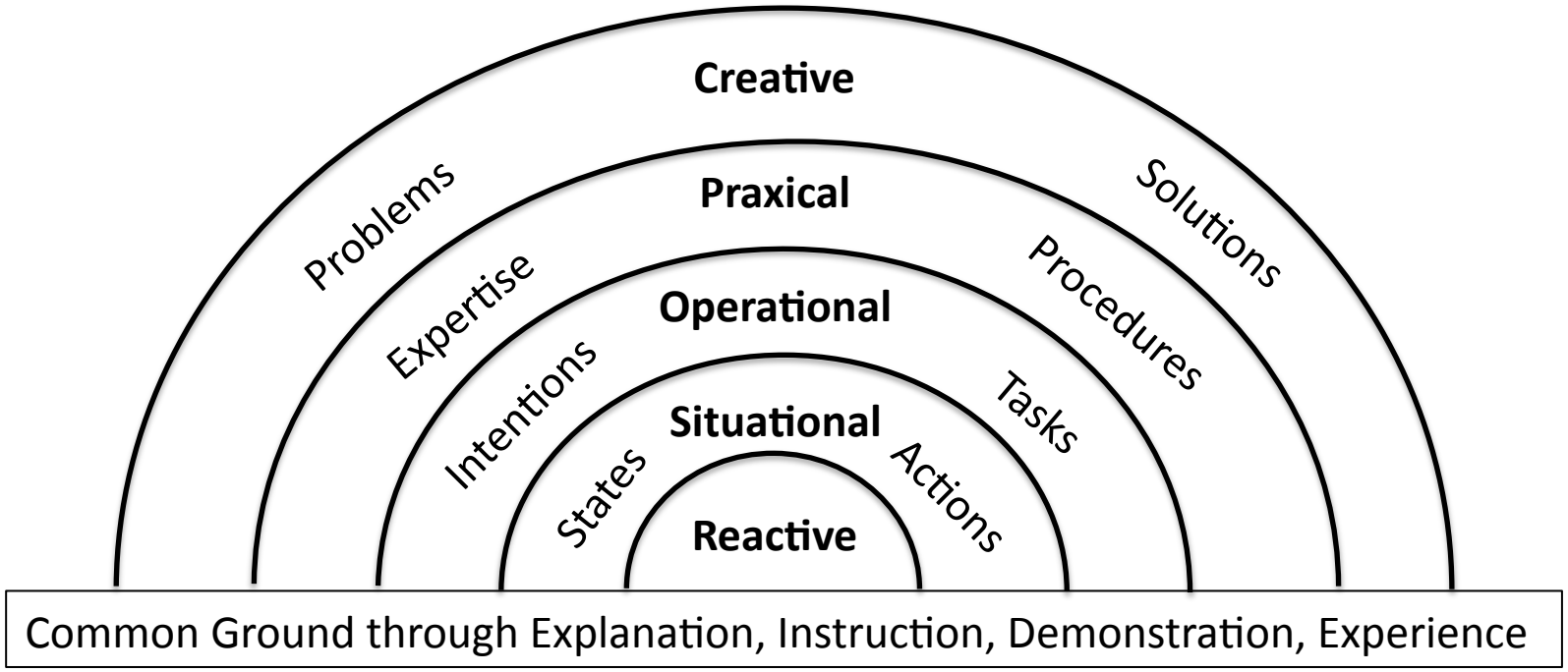
Stick in the wind with opposite rudder slides the aircraft sideways into the wind. Sliding sideways is called a “slip”. Control the slip by keeping the nose on the end of the runway.

A narrative represents possible paths through a situation graph.

Narratives describe the effects of actions and events on the path.

Modern generative AI can be used to provide explanations in the form of narratives.

Creative Collaboration



Creative Collaboration: Two or more partners work together to solve a problem or create an original artifact

Aviation Scenario: Engine Failure

Pilot: Lyon Approach. Mayday Mayday Mayday. F-GTCI engine failure. 35 miles South-east of Clermont Ferrand. altitude 7000 feet. 2 persons on board. Attempting an emergency landing. Mayday Mayday Mayday.

Co-pilot: Sir. Ambert has a 2500 ft runway and is 7 miles north west.

Pilot: Lyon Approach. F-GTCI attempting emergency landing at Ambert.

Copilot to Pilot: I have the emergency procedures for engine failure

Pilot to Copilot: Read me procedures

Co-pilot: Mix full rich. Switch Tanks. Boost on. Alternate Air open. Check ignition. Engage Starter.

(engine starts after switching tanks).

Pilot to copilot: It appears the fuel line from the left tank was blocked.

Pilot: Lyon Approach: F-GTCI. Cancel mayday. Engine restarted. Proceeding to Grenoble as filed.

Conclusions

- Pilot and CoPilot collaborate to achieve safe operations of a flight.
- During critical phases of flight, the visual and haptic sensori-motor systems of the pilot are near saturation. Only the auditory channel remains open for collaborative communications with the copilot or ATC.
- An intelligent CoPilot requires open-ended context-aware situation modeling.
- Operational safety requires pilot – copilot to use with formal protocols for collaboration and changes in role.
- An AI co-pilot should act as flight instructor, offering practical advice in the form of narratives.
- The Humane AI Hierarchical Framework for Collaborative AI provides a research roadmap to developing an AI copilot.
- Multimodal Generative AI provides a key enabling technology for an AI CoPilot.

The AI CoPilot
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