Decision-Making in the Space Domain

13 August 2024

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THE SMEAD PROGRAM Explore. Achieve. Lead.

A Day Without Space

[A Day Without Space (2014)]
[Forbes (2023)]
[Kratos (2024)]

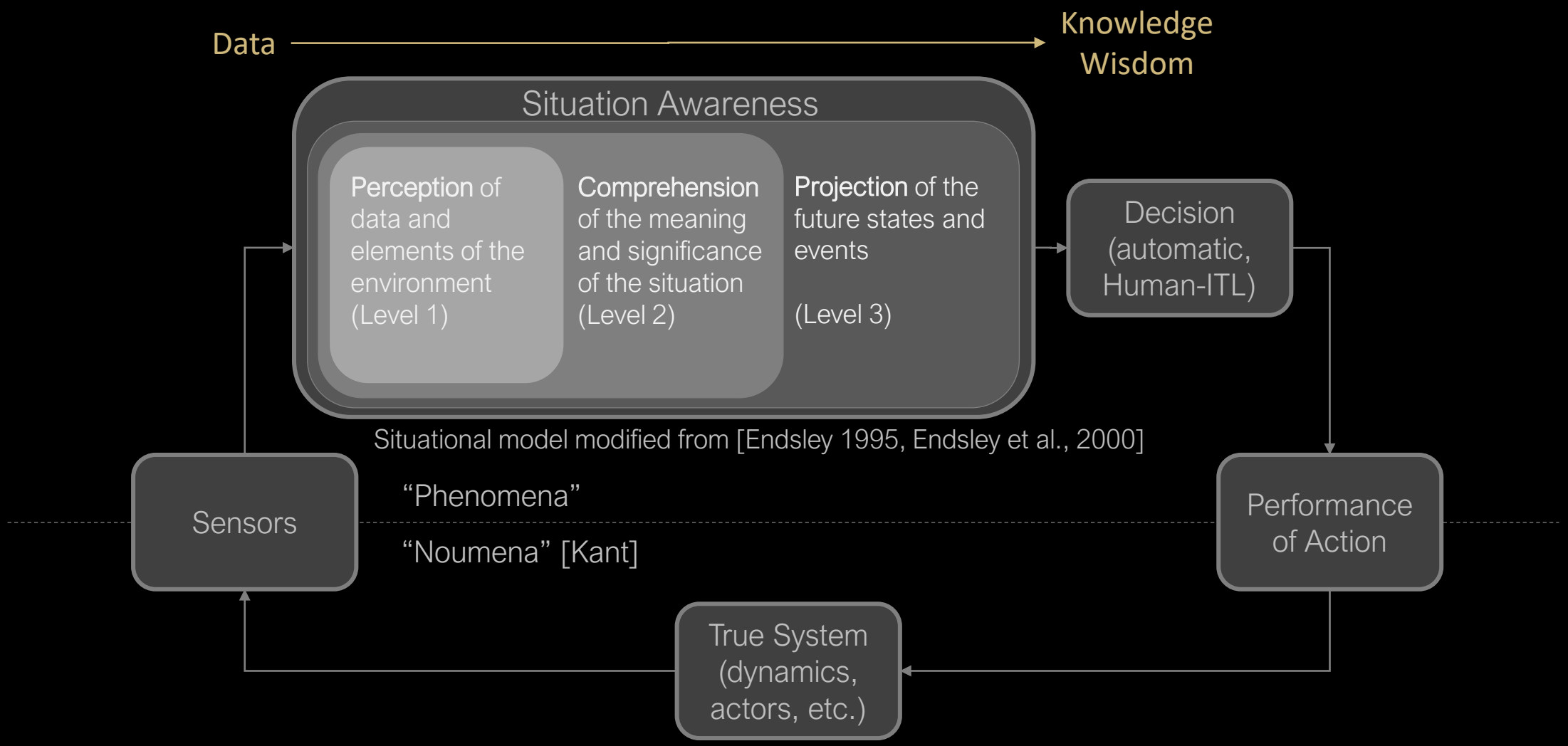
- Space is central to our way of life
  - Everyday people, companies, and governments depend upon it

Weather Prediction?
Navigation (GPS)?
Power Grid?
National Security?
Dozens of nation-states
Commercial actors
Financial transactions?
Public Transport / Air Travel?

- Our vulnerability to disruptions in space is extreme
  - National actors, solar flares, space debris, etc.
  - ~10,000 active spacecraft, 40,000 objects > 10cm, millions of smaller debris
- Decision-making in the Space Domain keeps 'A Day Without Space' from happening

"14 of the 16 critical infrastructures designated by the Department of Homeland Security rely on 24/7 GPS to operate for the country." (USSF Col Wray, Forbes 2023)

What Should We Do?



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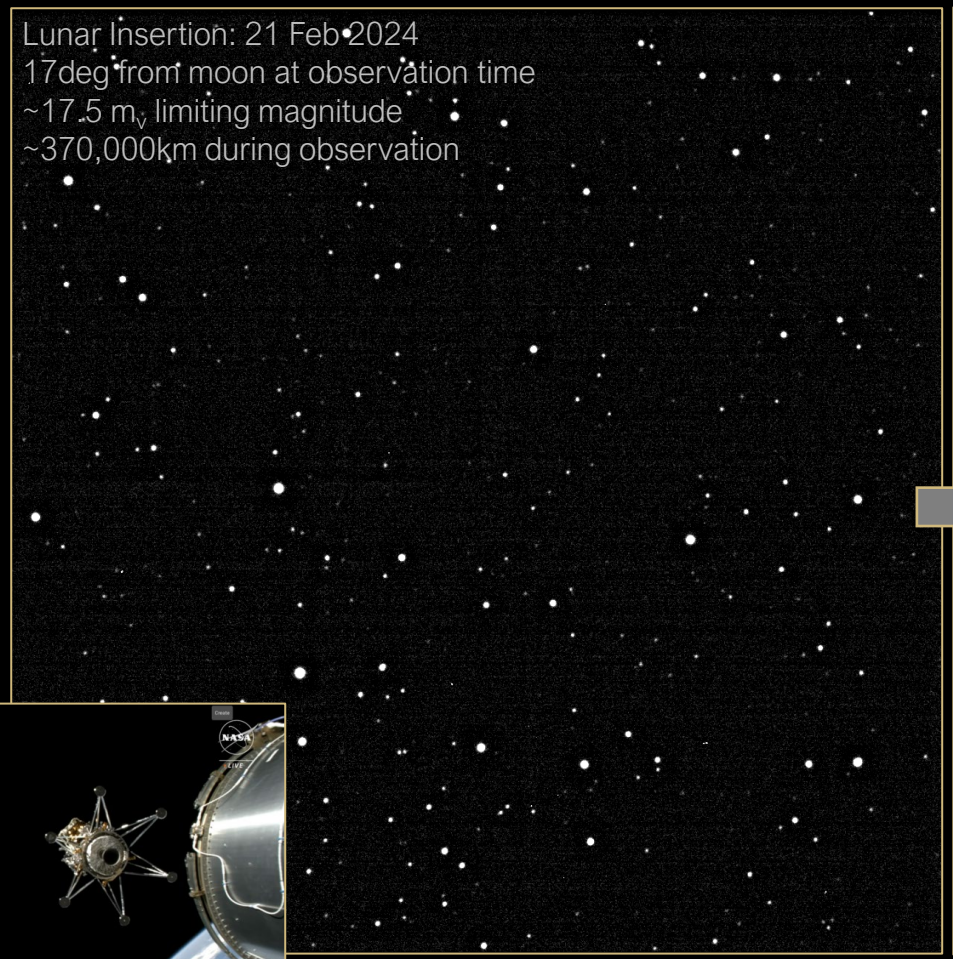
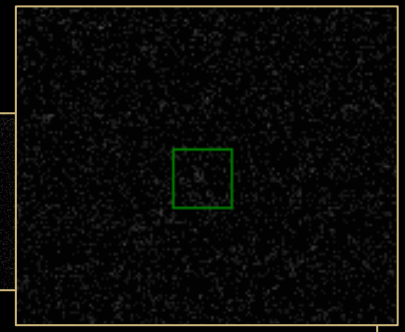
Is Space Situational Awareness Hard?

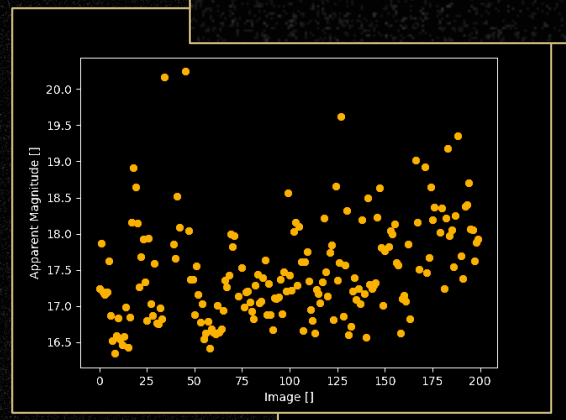
Low-SNR Multi-Target Tracking (Sith, IM-1 & R/B, 19 Feb 2024)

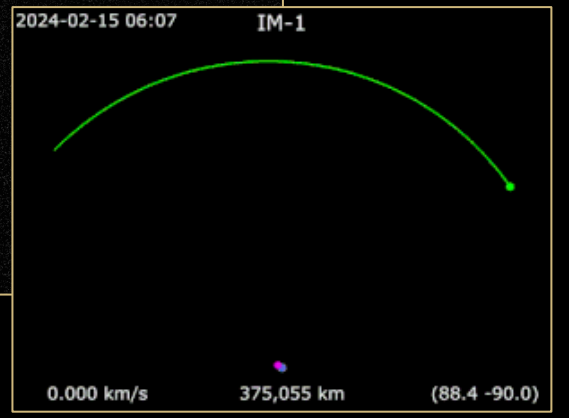
Lunar Insertion: 21 Feb 2024
17deg from moon at observation time
~17.5 m_v limiting magnitude
~370,000km during observation



After background & star subtraction
Falcon 9 2nd State highly visible
IM-1 glinting, then dropping below 1-2 SNR







Contact: Dr. Jill Bruer (AFRL/RV)

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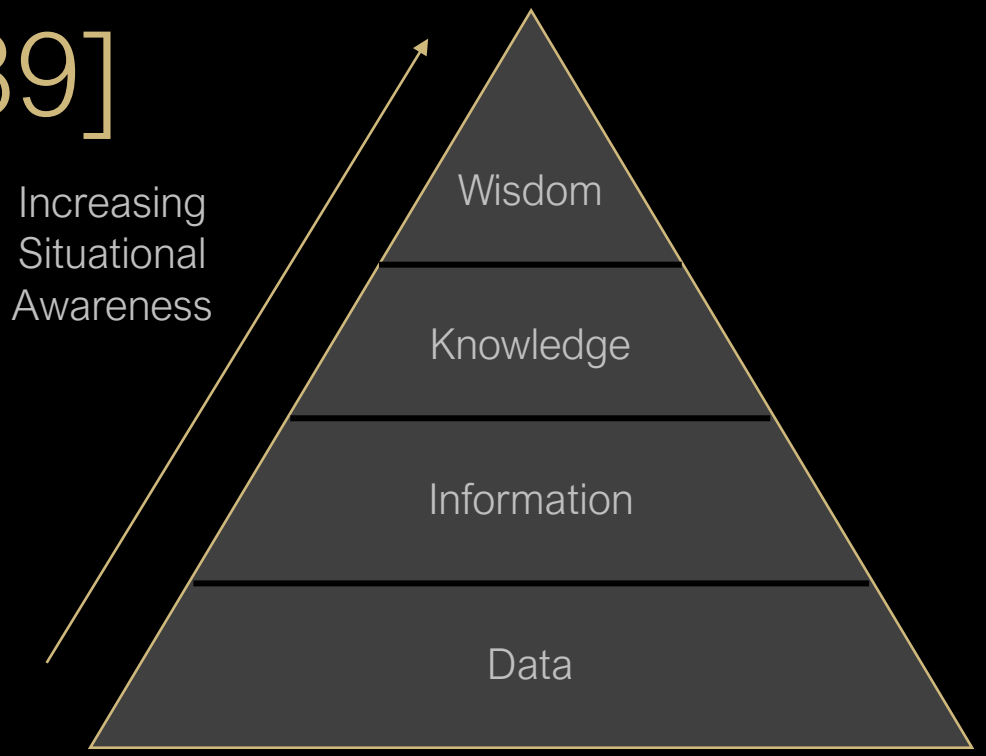
DIKW Pyramid [Ackoff, 1989]

- **Data** includes raw observables, calibrated and cleaned
- **Information** is processed data (e.g., tracks, orbits, characterizations)
- **Knowledge** is actionable information; information processed and packaged to enable individual or organizational decision-making
- **Wisdom** is the abstraction of knowledge across situations and domains



- **[D]ata** can be used to create information; **information** can be used to create knowledge, and **knowledge** can be used to create **wisdom**." (pg. 164, *The wisdom hierarchy: representations of the DIKW hierarchy*, emph. added)
- Many other aspects to consider
  - Explicit vs. Implicit knowledge / wisdom

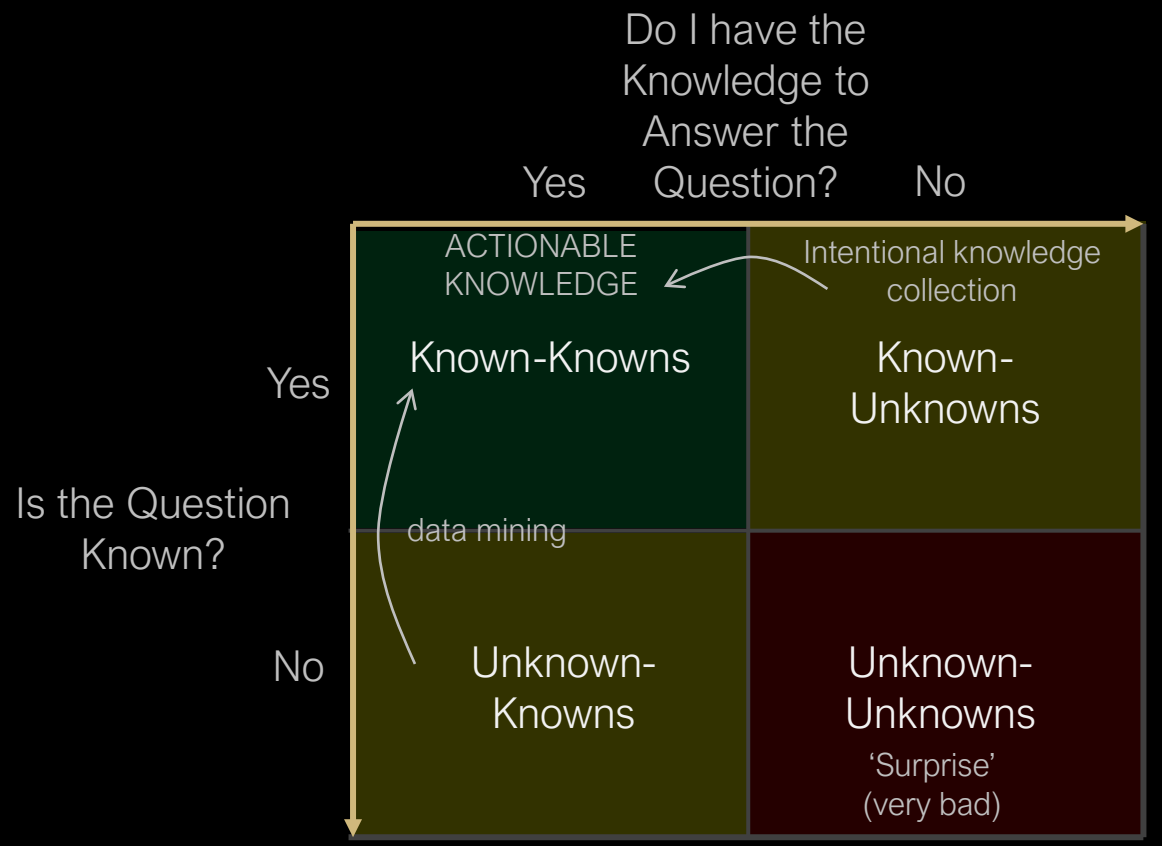
"[**Knowledge**] is only valuable if it can change [a] **decision**." (pg. 116, *Maxims on Thinking Analytically,* emph. added)

"Don't wait for [**Knowledge**] if it won't change [a] **decision**." (pg. 120, *Maxims on Thinking Analytically,* emph. added)

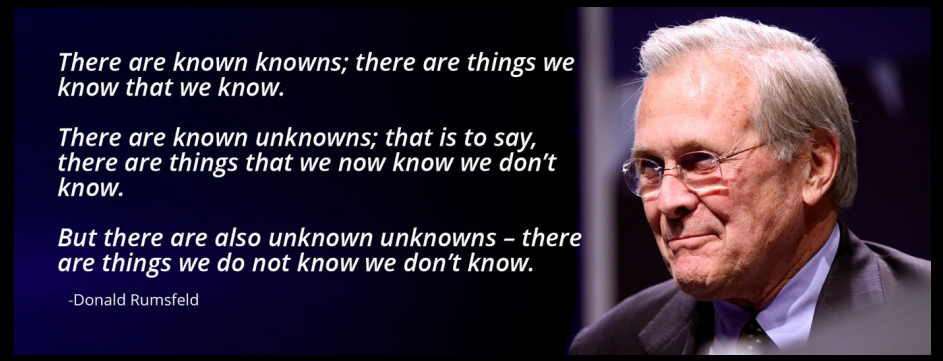
Epistemology and SDA

A fancy word for the study of knowledge

- One way to view Knowledge / Wisdom is as question-answer (question-knowledge) pairs
  - Question -> Answer
  - Ex.: “Is that object active?” -> “Yes”
- Our imagination has limits; we must actively select questions to answer
- Resources are limited; we must choose what data to collect
- We are in danger of…
  - Biasing ourselves
  - Experiencing tactical / operational / strategic surprise



Adaptation of the Johari Window [Luft & Ingham 1955]



A Working System!

- Can infer the current ’situation’ from collected sensor data
- First Principles!
  - Dynamics-, capabilities-, and phenomenology-based

- But…
  - That worked great until about 10 years ago
  - Human actors are unpredictable!
  - We’re only graduating ~100 astrodynamicists each year…
  - Spacecraft launches are exceeding all expectations
  - Spacecraft operations are increasingly automated
  - Space economic footprint headed to the ‘trillions’ by 2040
- We are headed for (already in?)
  - Cognitive overload
  - Too much data, information, knowledge and wisdom for decision-makers

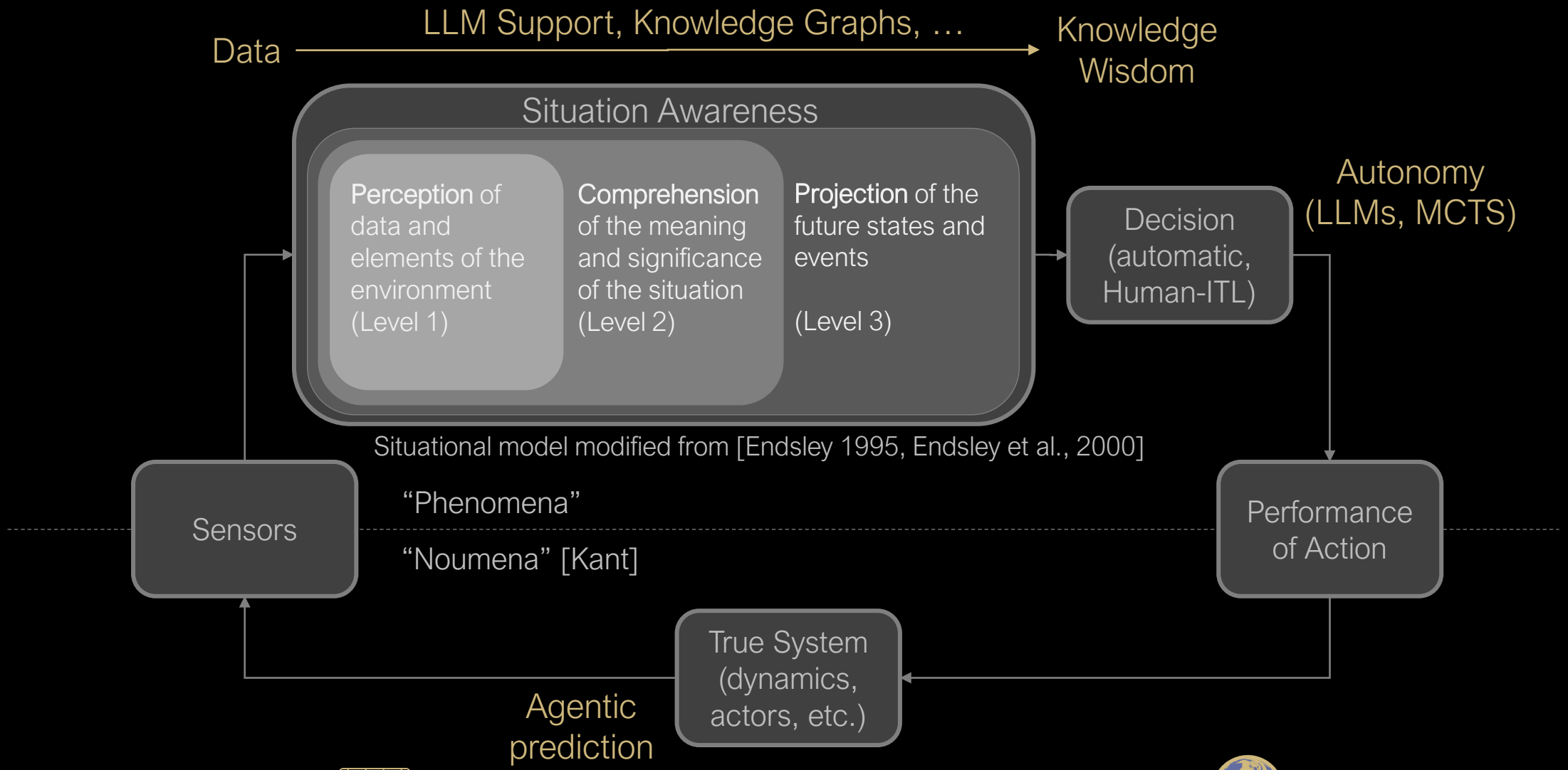
It's Not Just Physics

- Physics alone are *insufficient* to attain Space Situational Awareness
- Decisions are dominated by
  - Human factors for individual / exquisite spacecraft
  - Human factors and autonomous decision-making for large constellations (e.g., SpaceX Starlink)
- So, what do we do?
  - Human factors are not physics (surprise to us engineers!)
  - Human resources, even at the national level, are insufficient to meet this cognitive need

Large Language Models (LLMs) and Monte Carlo Tree Search (MCTS)

- Decision Support
  - Some low-level decision making (e.g., sensor tasking) can be nearly fully automated
  - Mixed human-agentic workflows enable human operators to focus on ‘higher level’ decisions
  - Especially decisions involving the application of ethics
- Decision Decentralization
  - Job is ‘too big’ for any single decision-maker or decision-center
  - DoD calls this ‘Mission Command’
- Creativity
  - LLMs are excellent at applying existing tools to ‘creatively’ explore *conceptual* spaces
  - Very good aid at identifying ’unknowns’; asking new questions, fusing existing non-pristine data

Where does this leave us?



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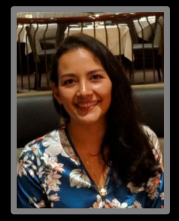
The most important people…

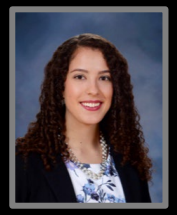
Current PhD Students



Karina Rivera
PhD Student
Expected 2024
Lead TA

Queenique Dinh
Co-Advised with Daniel Scheeres
PhD Student
Expected 2026
Funded GRA
Dean's Fellowship

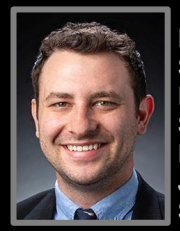
Liam Smith
Part-time PhD Student
Expected 2026
Amazon (Kuiper)



Eva Evans
Co-Advised with Daniel Scheeres
PhD Student
Expected 2027
Smead Scholar
Dean's Fellowship

Michael Sola
NDSEG Fellow
PhD Student
USMC (H. Dis.)
Expected 2027

Garrick Lau
PhD Student
Expected 2025
Funded GRA



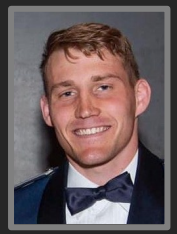
Ben Schmachtenberger
Part-time PhD Student
Expected 2026
Johns-Hopkins APL
Space Surveillance

Michael Klonowski
AMOS Best Studen Paper Award
PhD Student
Expected 2025
Funded GRA

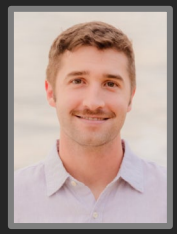
Katie Melbourne
Expected 2027
Funded GRA

Alec Liberman
NDSEG Fellow
PhD Student
Expected 2027

Commissioned Officers



Adam Wilmer
1st LT, USSF
PhD Student
Expected 2026



Zachary Funke
Maj, USSF
PhD Student
Expected 2027

Full-Time Researchers & Lab Mgmt.

Dr. Casey Heidrich
NSTRF Fellow
GAANN Fellowship
PhD 2021
CU Boulder
Research Scientist

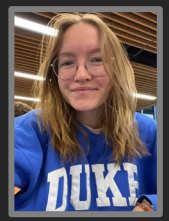
Madeline Job
VADeR Lab Manager
CU Boulder

Meaghan Allyn
STARLIT Outreach Project Manager
CU Boulder

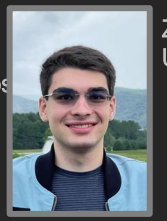
Jacob Shepherd
Project Manager
National Security Initiative, CU Boulder

Damennick Henry
Post Doctoral Scholar
Smead Scholar
PhD 2024
CU Boulder

Undergraduate Students

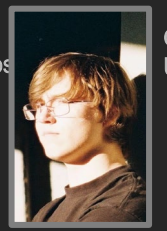


Chris Kuester
Lead
Undergrad Obs



Zack Goldberg
Undergrad Observer

Kyle Bowen
Undergrad Obs



Owen Schuler
Undergrad Observer

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ExoAnalytic

The National Academies of SCIENCES ENGINEERING MEDICINE

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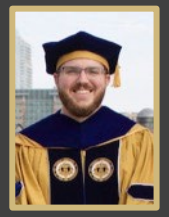
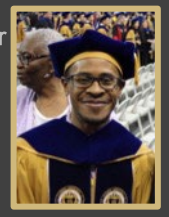
The most important people…

Graduated PhD Students

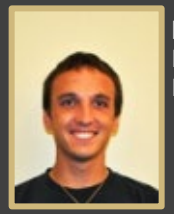


Dr. Ryan Coder
PhD 2016
Aerospace Corporation

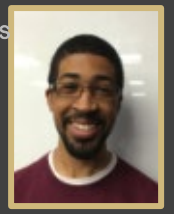


Dr. Johnny Worthy
PhD 2017
NSF, GEM Fellow
Lincoln Labs, Space Control

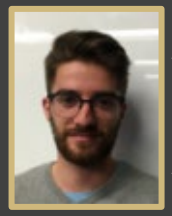
Dr. Timothy Murphy
PhD 2018
NSF Fellow
Aerospace Corporation



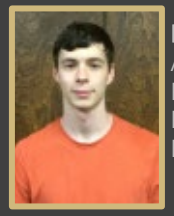
Dr. Andris Jaunzemis
PhD 2018
NSF Fellow



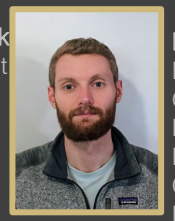
Dr. Julian Brew
PhD 2019
NSTRF Fellow
JHU APL



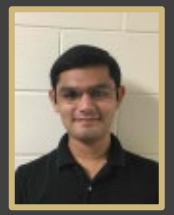
Dr. Daniel Aguilar-Marsillach
SSA Best Student Paper Award
PhD 2021
General Motors



Dr. Samuel Wishnek
AMOS Best Student Paper Award
PhD 2021
BAE (Ball)



Dr. Casey Heidrich
NSTRF Fellow
GAANN Fellowship
PhD 2021
CU Boulder
Research Scientist

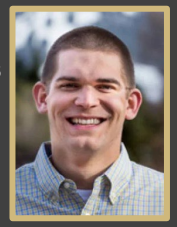


Dr. Shez Virani
NDSEG Fellow
PhD 2022
IC

Samuel Fedeler
PhD 2023
NSF Fellow
Draper Fellow
JHU APL

Previous Post Doctorate Researchers

Dr. Mark Moretto
PhD 2022
Astronomy Magazine's 25 Rising Stars in Astronomy
Asst. Prof., NCSU



Dr. Conor Benson
Smead Fellow
PhD 2021
Smead Scholar
Aerospace Corporation

Not Listed
25 graduated MS students
> 100 undergraduates

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Smead Aerospace
University of Colorado Boulder

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Thank you!

Moon, as seen from Panoptikon, 17 October, 2022

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