

Reliable Autonomous Robotics: Perception, Learning, and Trust

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The fields of robotics and autonomy have seen tremendous advances in the past decade+...

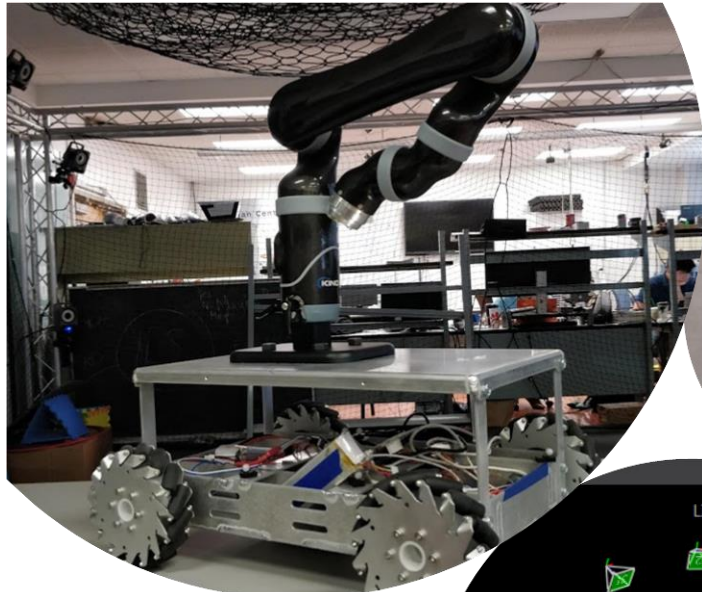
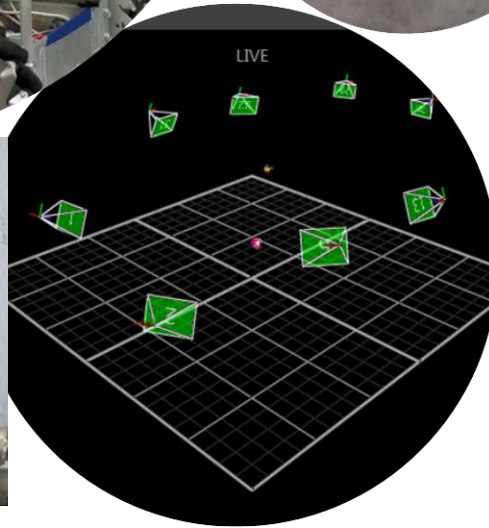


Image credit: NASA



Heterogeneous Robotic systems: Land, Air, and Space Robotics, Swarms

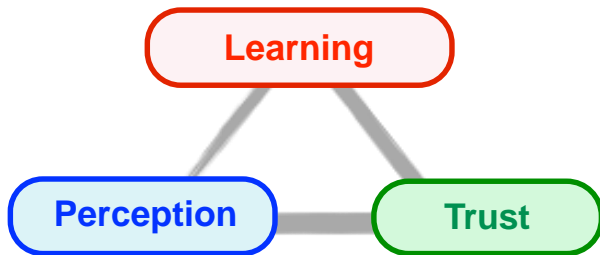
Shared-**autonomy**, and cooperative-control

Machine Learning

Assured Positioning, Navigation, Timing (APNT), **GPS-denied** Navigation; Simultaneous Localization and Mapping (**SLAM**)

Rapid Real-time Trajectory Generation (**Path-Planning**); Sense-and-Avoidance

How can we affordably build **trustworthy** autonomous systems?



Major challenges for autonomous systems ...

- Operate within *dynamic*, *contested* environments
- Adapt for *unexpected* tasking
- Verifiability and quantifiable *trust metrics* for safe operations
- Deployment at *scale*



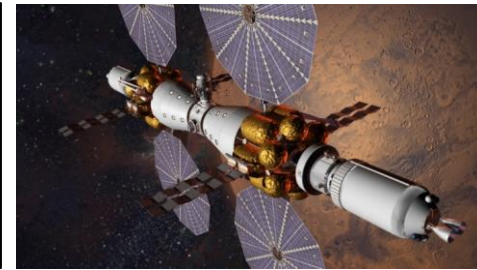
Multi-Variant UxV Swarms for Safety Critical Inspections



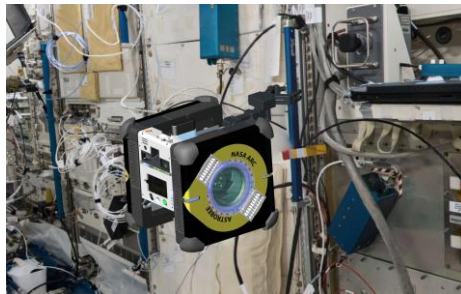
C-130 Aircraft



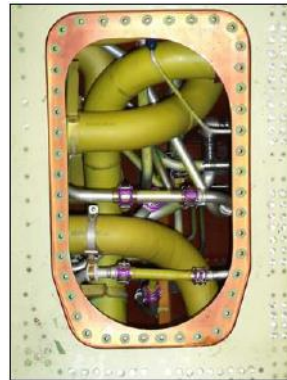
F-35 Aircraft



Mars Base Camp



Astrobee for ISS (NASA Ames)



Extremely tight spaces

Inspections are human intensive, expensive, unsafe
Damage assessments are subjective, unreliable

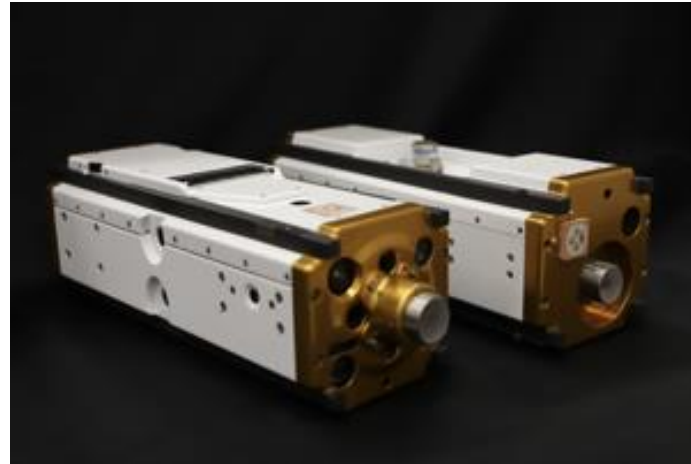
(Successful) Robotics Applications:

- Multi-variant autonomous agents: drones, snakes, crawlers, cube-sats
- Sensory scoring transforms, objective evaluations for high-confidence situational awareness

[Almeida, Akella, ACC-2018]

Space Robotics – Vision-Based Navigation

SEEKER, a NASA X-Project that began in 2017, is an external, free-flying robot poised to make its first test inspection in orbit with the Cygnus cargo resupply vehicle on its return flight from the International Space Station



Schematic view of Seeker and Kenobi. Kenobi will act as a translator between Cygnus and Seeker, storing all of Seeker's valuable data. Image Credit: NASA

SEEKER uses monocular vision for real-time pose estimation (at 1Hz) relative to Cygnus

Launched by NASA on 17 April 2019

Coordinated Electronic Attack

AFRL Counter Program
CODE, DARPA

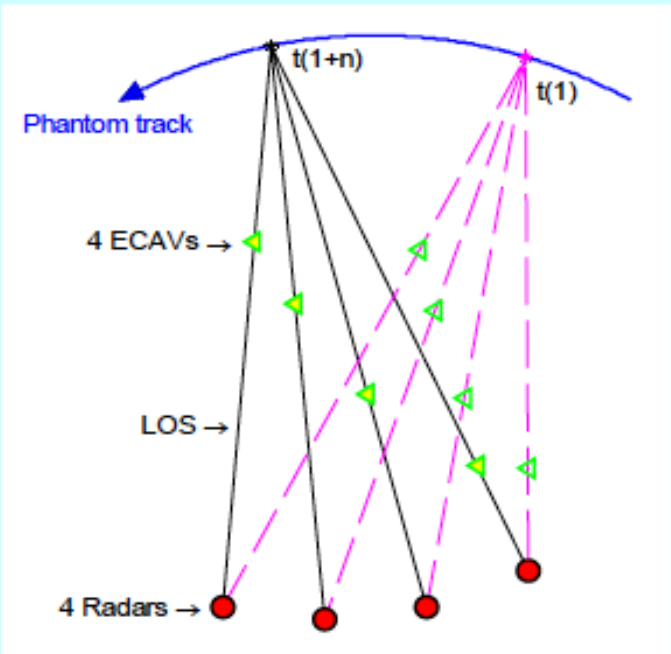
- **Research Objective** – To negotiate coherent phantom tracks linking together specified waypoints with minimum shared (global) information
- **Focus** – Optimal performance at both individual vehicle and team levels subject to flight dynamic constraints, radar's pulse agility characteristics, and robustness to enemy tactics



Potential Applications

- Detection and suppression of enemy air defense systems
- Safe ingress and egress for time window critical strike packages

Coordinated Electronic Attack:
Conceptual illustration of a team of Electronic Combat Air Vehicles (ECAVs) cooperatively generating a phantom track through range delay deception techniques



Unmanned Systems – Offboard Commands



RELIABLE COMMUNICATION
WITH A REMOTE CONTROL
CENTER IS CRITICAL.



WHILE COMMUNICATION
TECHNOLOGY CAN MAKE THE
COMMUNICATION RELIABLE,
CAN IT ALSO BE MADE SAFE?



CAN THE CHANNEL BE SPIED
ON?



CAN THE INFORMATION ON
THE CHANNEL BE SPOOFED?

Can all data types
be encrypted
efficiently?

Can the encryption
run on small
computers?

Can multiple nodes
be supported?

Will the latencies
affect the system?

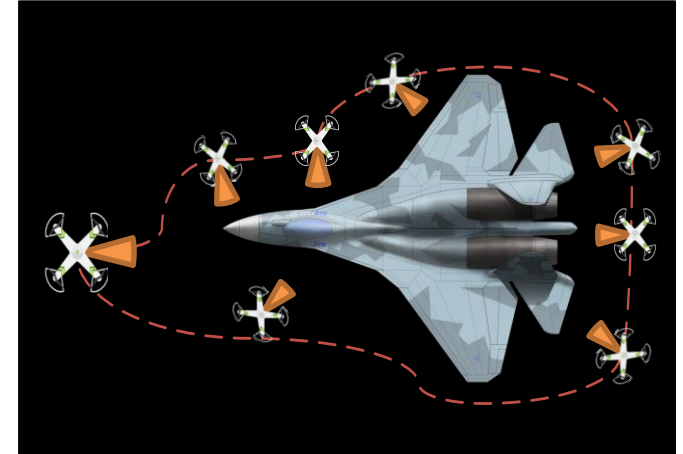


Human-in Loop Secure Communications

FACE: Future Airborne Capability Environment (GDMS; US Army)

FACE conformant Unmanned Air Vehicle (UAV) ground control system enabled by the CoreDX Data Distribution Service (DDS) Middleware.

CoreDX DDS is based on open standards and **provides secure real-time communication services with low-latencies and high throughput.**



[Almeida, Moghe, Akella, ICRA-2019]

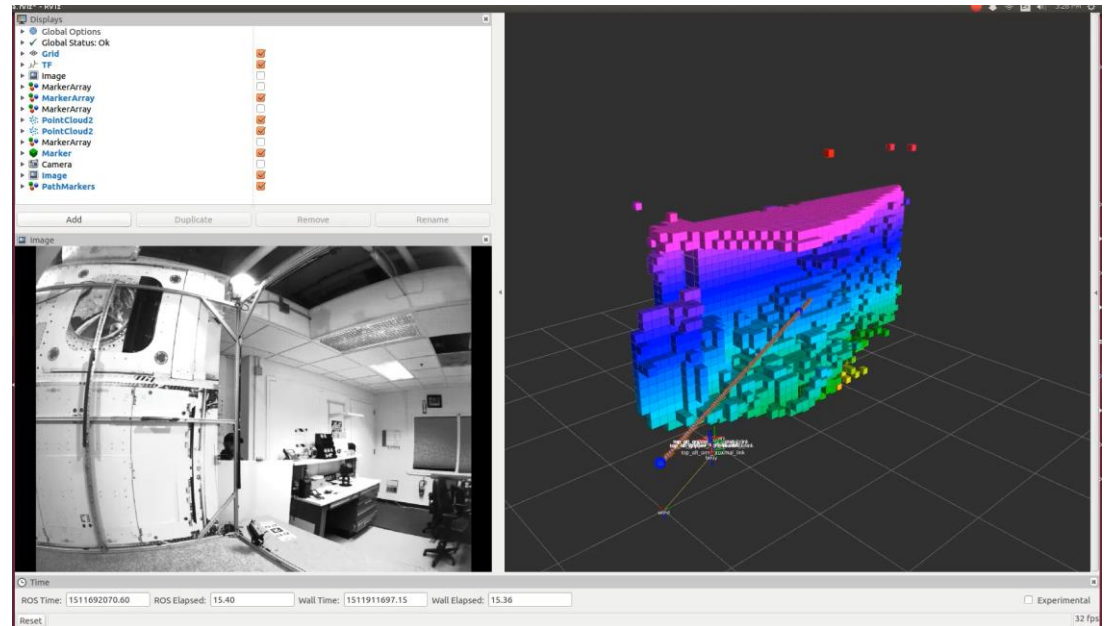
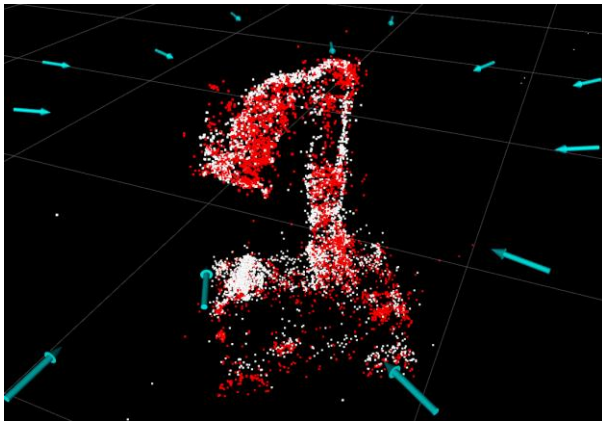


- Ground control applications such as QGroundControl and Mission Planner rewritten with DDS as the core to support auto mission uploads and graphical position tracking by ground pilots.
- The DDS based Ground Control Software is **modular** and **scalable**: it can support simultaneous operation of multiple UAVs.
- The DDS wrapper has also been applied to **enhanced autonomy** functions such as live-video transmission, onboard path-planning, and collision-avoidance technologies.



Mapping for Collision Avoidance

Voxel maps are used as an occupancy map for **collision detection** and **avoidance**

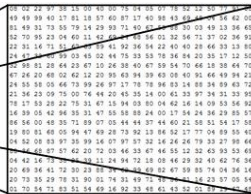


[Almeida, Akella, GNC-2018]

Map updates probabilistically: whenever something new shows up within the scene
Obstacles upon the map are inflated for safety considerations

Computer Vision for Object Detection, Localization

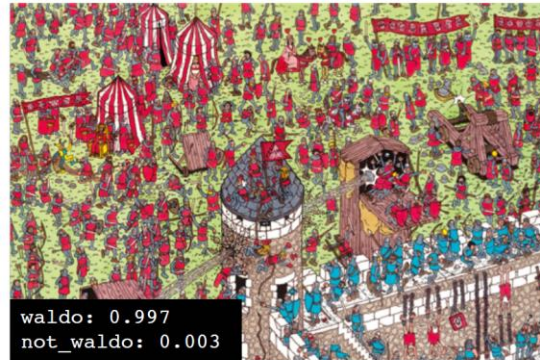
- Image Classification
- TensorFlow with ObjectDetection API
- Segmentation: You Only Look Once (YOLO)



What the computer sees

image classification → 82% cat
15% dog
2% hat
1% mug

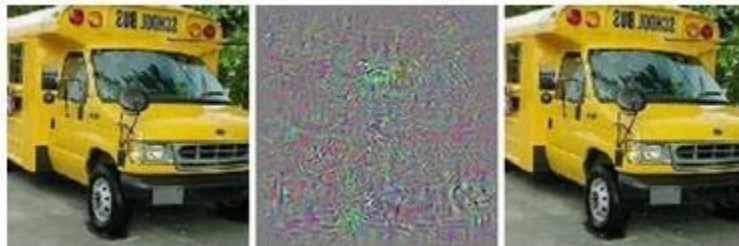
Image: Google



Before
(No Bounding Box)



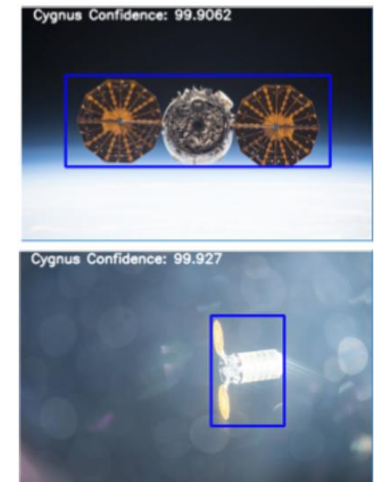
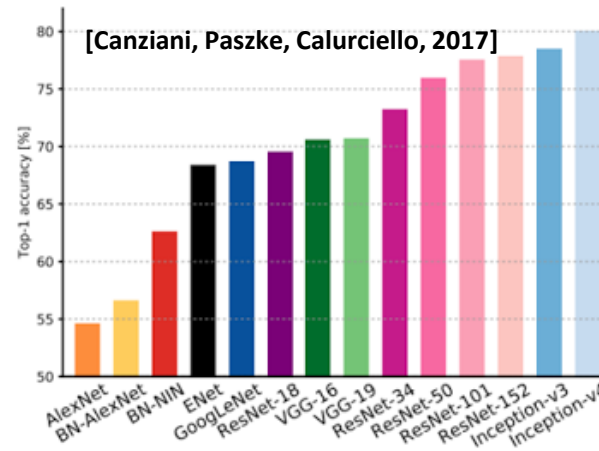
After
(Bounding Box)



[Correct

+ Noise =

Ostrich]



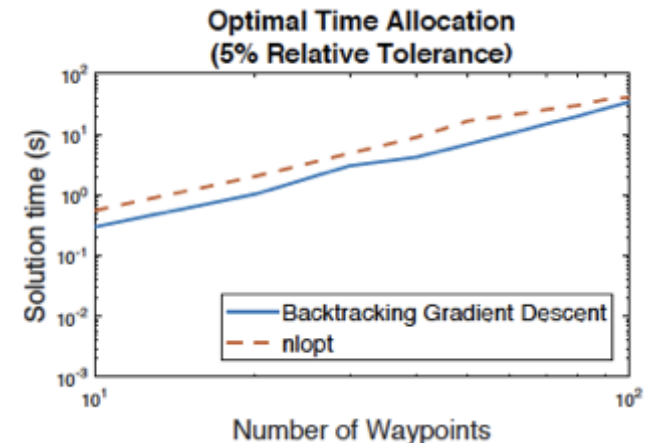
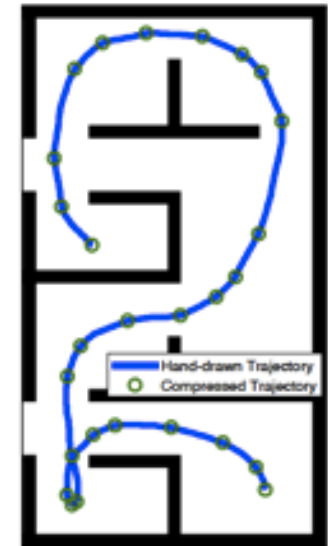
Real-time Path-Planning via Machine Learning

Can machine learning techniques help (onboard) path-planning?

- Indirect methods are physics-based
- They provide a sophisticated mathematical framework that enables the analytic compression of an optimal trajectory into a single, small vector of information



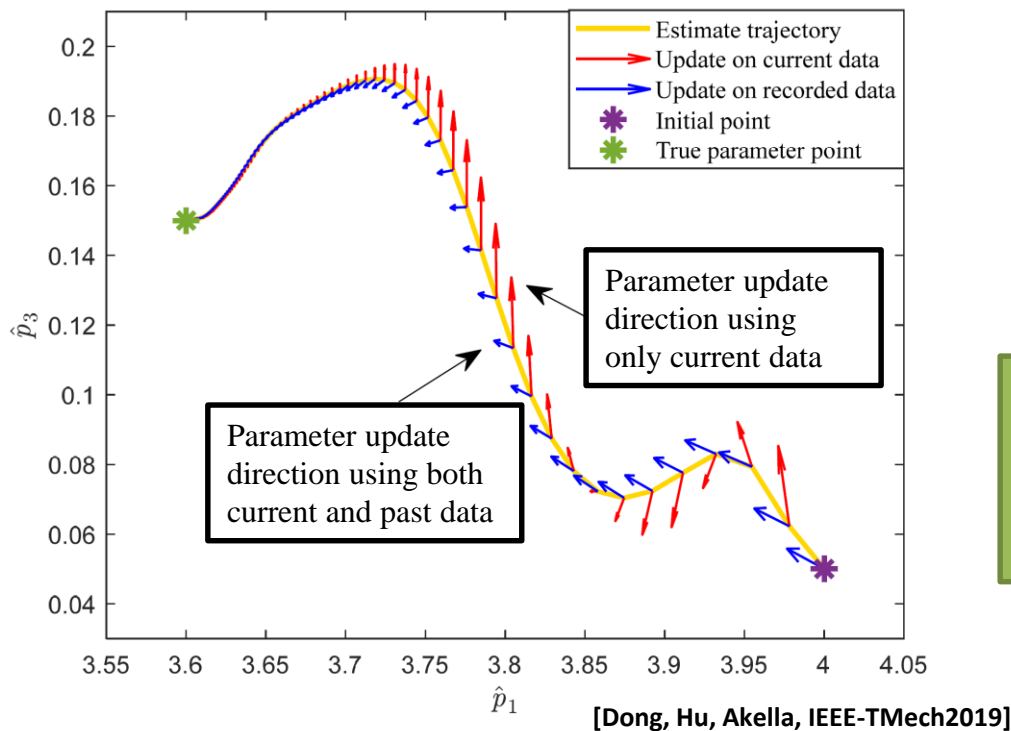
- The entire optimal trajectory can be analytically compressed into a single vector at the initial point of the trajectory
 - The information required at the initial point of the trajectory is doubled
- This relatively small amount of numerical information at the initial point of the trajectory can usually be easily predicted using machine learning



[Almeida, Moghe, Akella, ICRA-2019]

Learning and Adaptation for Self-Awareness

- Adaptive control is mature (>50 yrs; certainty-equivalence, robust-adaptive, I&I, L1...)
- Unsupervised learning is relatively harder, especially for real-time applications



Persistence of excitation (PE) plays a major role in convergence, its speed, and lack thereof.

Know your current state, but also make use of what you were doing in the past!

Perception: Look “Left or Look “Right”?

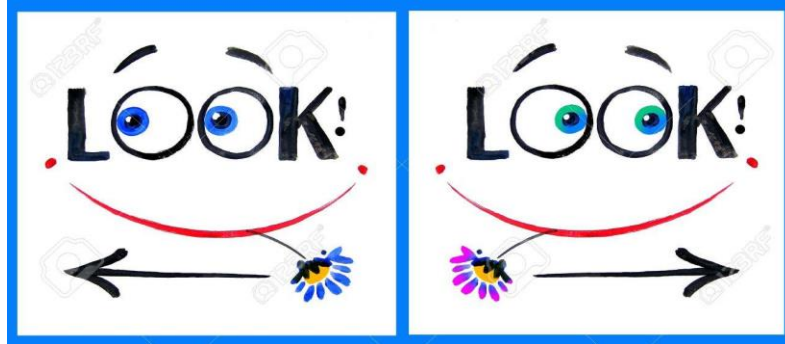
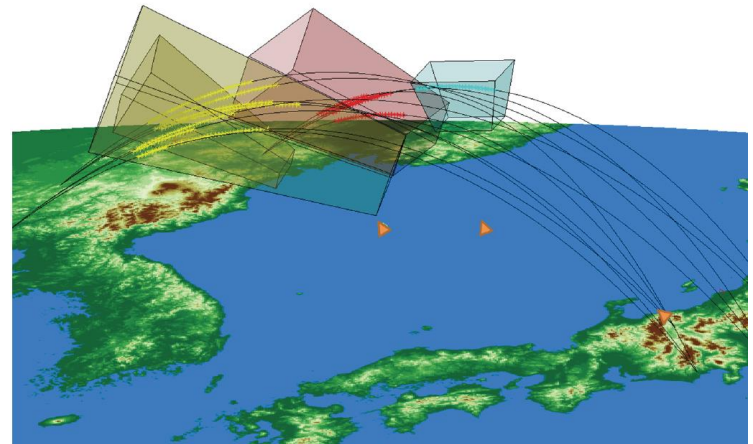


Image: Google

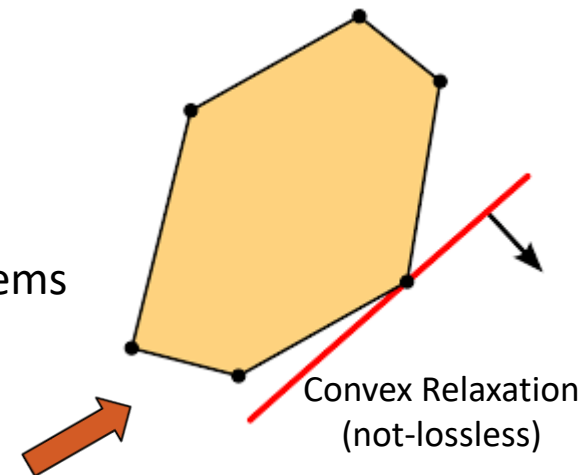


Is there any “optimal” way to utilize various available measurement streams in a non-myopic fashion?

- Opportunistic sensing, lots of available data, plug-and-play
- Each data set has its own associated cost and quality
- These are usually non-convex, mixed-integer, NP-hard problems

$$J = \frac{1}{2} \sum_{k=1}^N (\mathbb{E}\{\mathbf{x}_k^T Q_k \mathbf{x}_k + \mathbf{u}_k^T R_k \mathbf{u}_k\} + \beta I(\mathbf{x}_k; \mathbf{y}_k | \mathbf{Y}^{k-1}, \mathbf{U}^{k-1}))$$

[Tuggle, Akella, ASC-2018]



Perception: Collaborative Automated Sensing

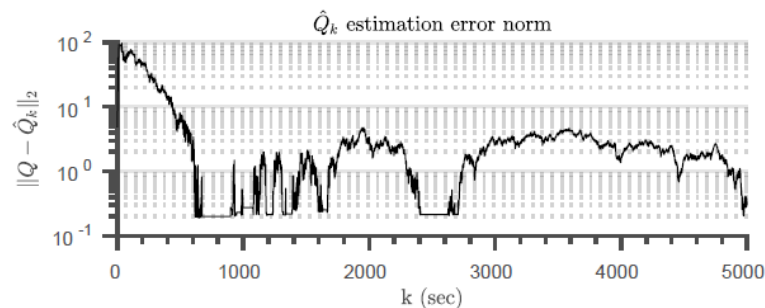
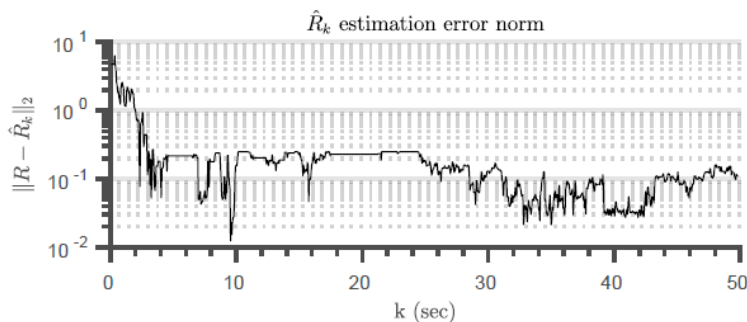
- A new sensor channel suddenly becomes available.
- But, its statistical properties are poorly determined.



Image: RadioNavigation Lab
UT Austin (Prof. Humphreys)

$$\begin{aligned}x_k &= Fx_{k-1} + w_{k-1}, \quad w_{k-1} \sim \mathcal{N}(0, Q), \quad x_0 \sim \mathcal{N}(m_x, P_0) \\y_k &= Hx_k + v_k, \quad v_k \sim \mathcal{N}(0, R)\end{aligned}$$

[Moghe, Akella, CDC-2018]



Learning-Oriented Path-Planning for Enabling Trust

Merriam-Webster

Trust: (a) assured reliance on the character, ability, strength, or truth of someone or something; (b) one in which confidence is placed



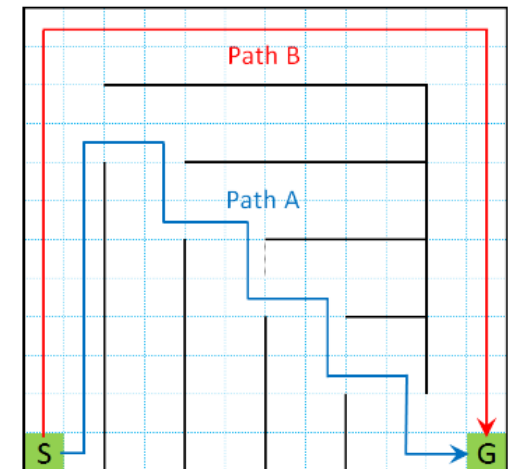
Google Images



Image: The Law Firm of *Salvis Juribus*

Fundamental question: what is trust in the context of autonomous agents?

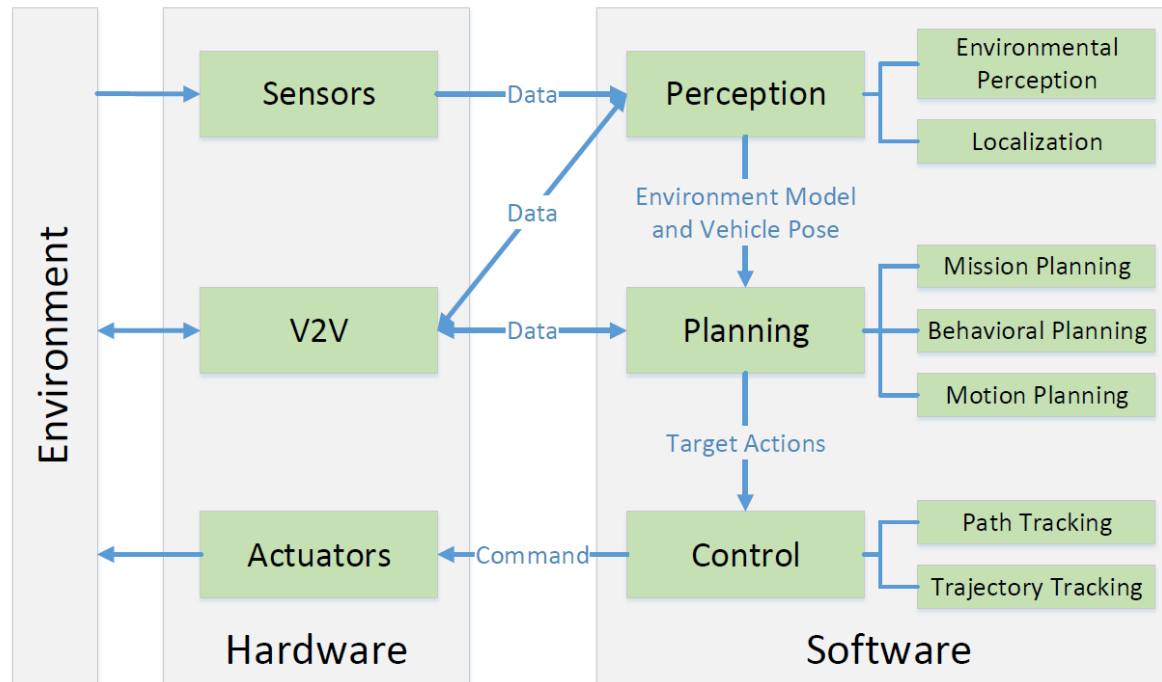
- Formulate the onboard path-planner to be learning-oriented and information-aware: self-awareness and goal-awareness; engage in safe exploration but make actions match goals; be open to feedback
- Take “detours” if necessary to allow for traversing “information-rich” areas



Path B: “Boring” – Safe
Path A: Involves “detours” - Faster

What Next? Where Next?

- Computers are faster, better, cheaper
- Robust communications are making available huge volumes of data
- AI algorithms are rapidly maturing (Deep Blue -> AlphaGo -> AlphaZero)



In the context of Aerospace/Robotic systems (perhaps more broadly as well), many open questions remain:

- Trust (quantifiable metrics)
- Liability, Insurability
- Ethics

Acknowledgements

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- Research Sponsors...



Thank you!

