Artificial Intelligence - The Future of Space Communications

National Aeronautics and Space Administration

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WHAT MAKES A SYSTEM COGNITIVE?

Cognition

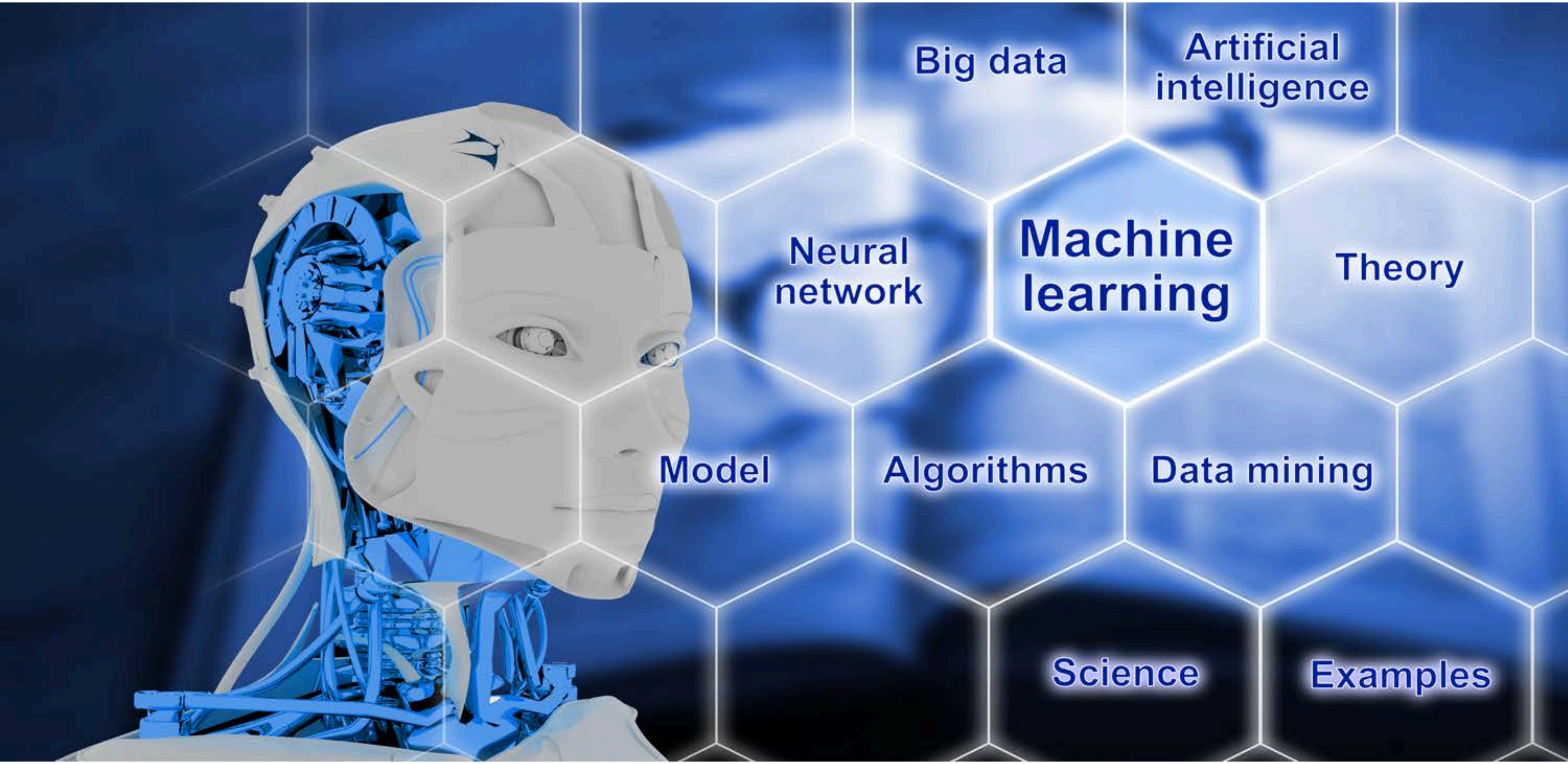
Cognition is the process of acquiring knowledge and understanding through thought, experience, and sensing.

Artificial Intelligence

Computers that possess intelligence to learn like humans have what we call artificial intelligence.

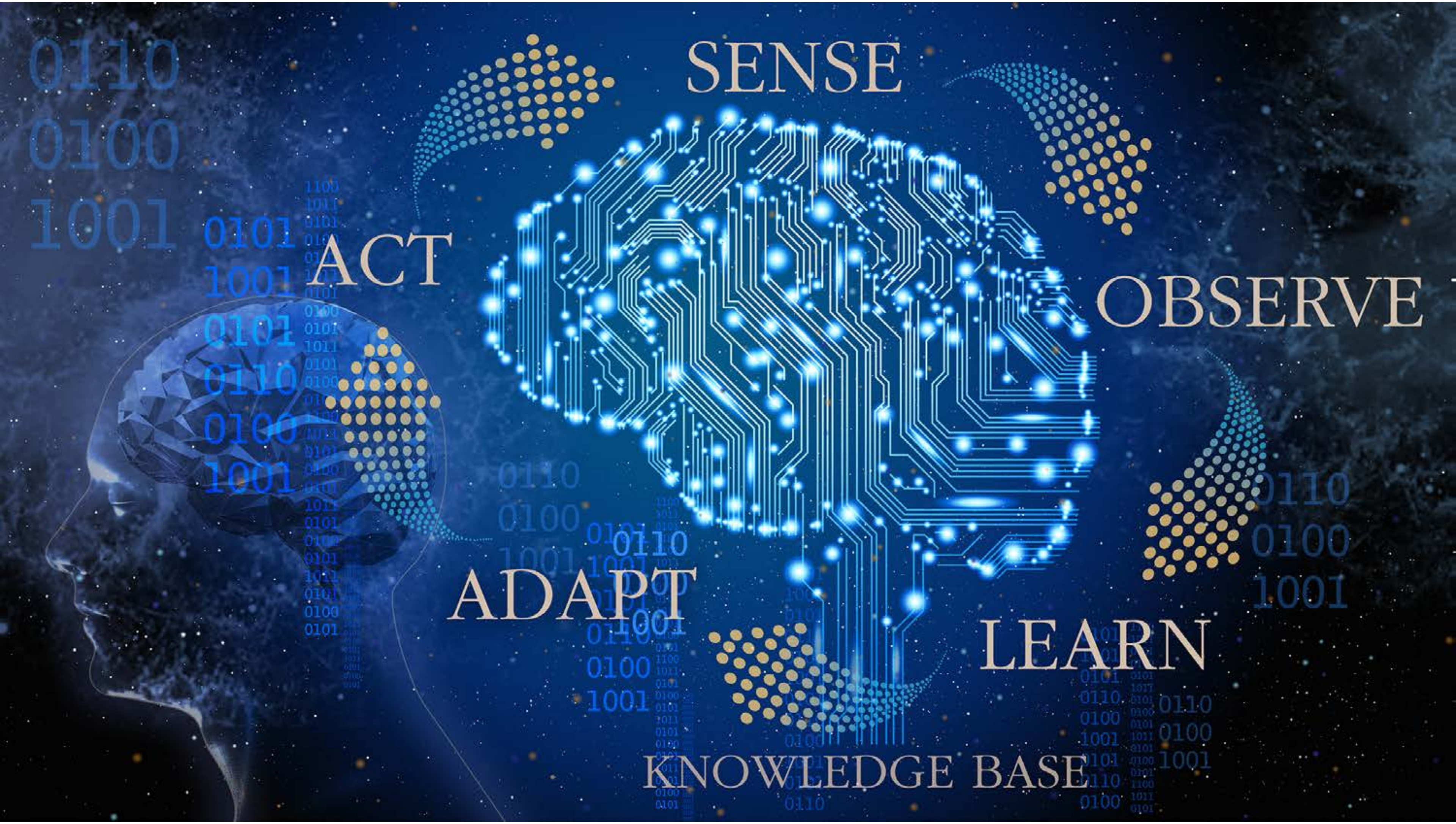
Machine Learning

We don't want to program computers for every possible action, so we use a type of artificial intelligence called *machine learning,*



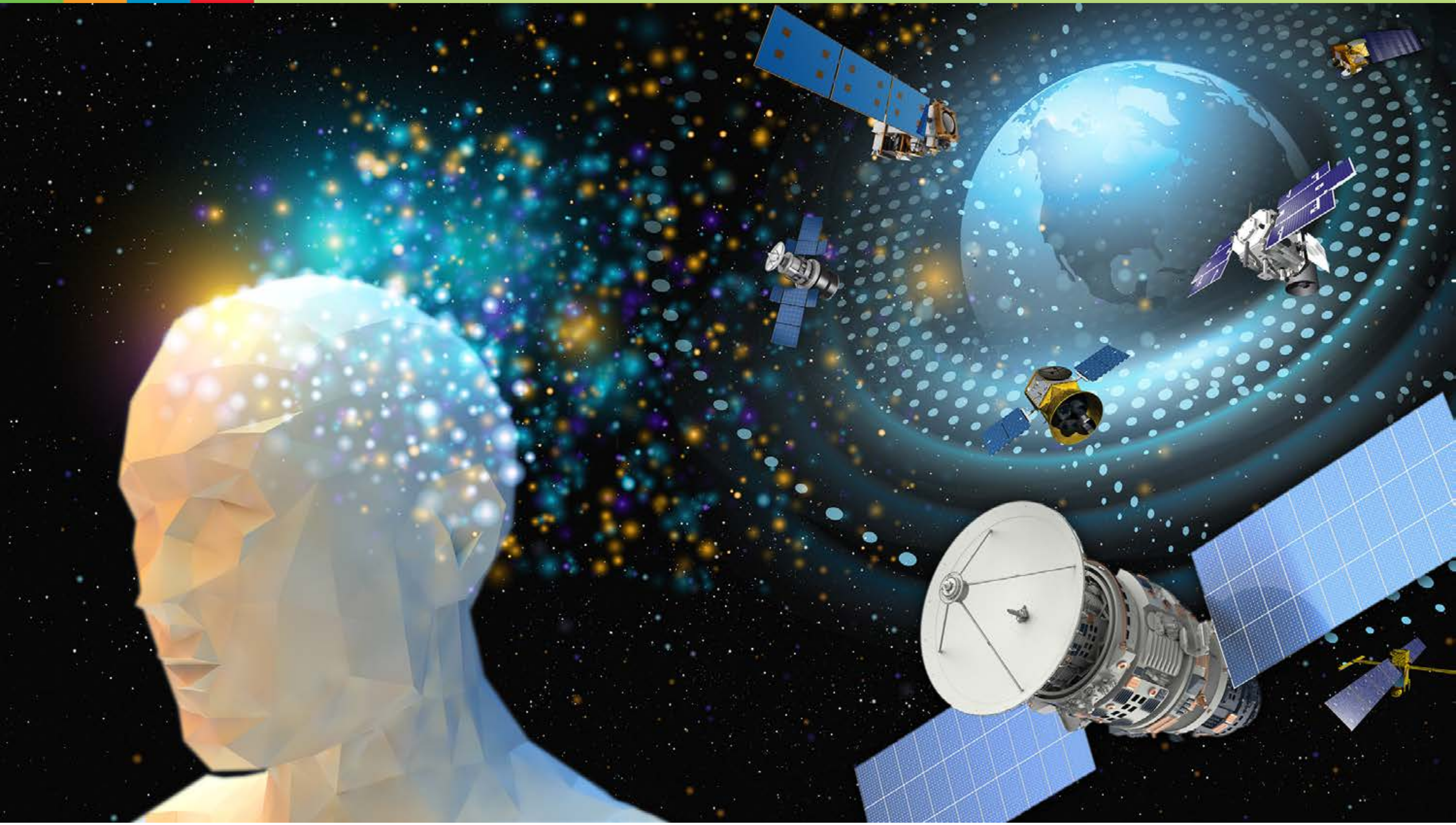
that is, computers can learn and adapt to their environment, without being explicitly programmed with every possible option.

Cognitive Engine



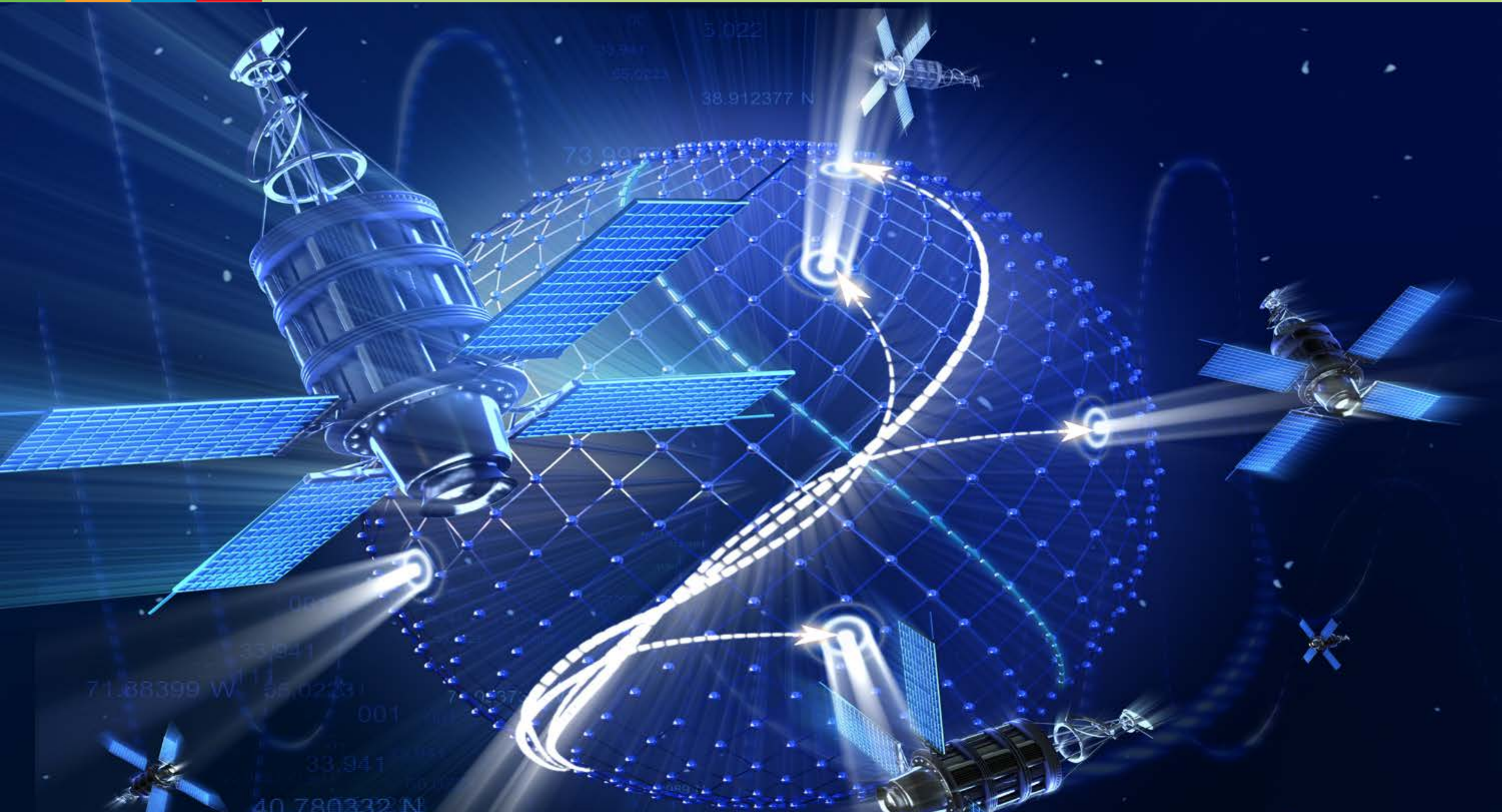
Cognitive engines offer robustness for space communications

Intelligence, Artificially



…the impact of ***artificial intelligence*** *is here and now*

Cognitive Technologies



The recent development of cognitive technologies is an advancement in the architecture of future communications systems.

Data Flow from Space to the Ground via NASA's Space Network

Each communication asset, each radio, is itself a sensor that provides a unique perspective from a given position in the universe. By harnessing all of this combined information, better decisions can be made about how data moves between space vehicles and the researchers and scientists on the ground.

There is much research in cognitive applications for space for DoD purposes, but no one but NASA is addressing the high data rate return portion that NASA needs.

Current Methods

System-wide Intelligence

Overview
Cognitive Communications

Objective

The project will develop cognitive communication technologies to **increase mission science return** and **improve resource efficiencies**. By merging space communications and machine learning, we aim to increase the **efficiency**, **autonomy**, and **reliability** of the SCaN next generation architecture.

- **Cognitive Links Capability**
  - Maximize throughput and avoid spectrum interference
  - Cooperatively share spectrum with neighbors
  - Sense incoming signals and configure the radio
- **Cognitive Networks Capability**
  - Decentralized, service-based network architecture
  - "Drop data anywhere" – data reassembly for customer
  - Seamless integration of commercial providers
- **Cognitive Systems Capability**
  - Automatically schedule SN, NEN, and commercial services
  - System-wide cost & load balancing and diagnostics
- **Cognitive Hardware Capability**
  - Neuromorphic & memristor-based processors
  - Cognitive algorithms on cubesats & low SWaP radios

Cognitive Communications
Cognitive Links

Adaptive coding and modulation with cognitive engines

- *Choose optimal settings by predicting channel conditions*
- *Eliminate the need for calculating precise link budgets*

Self-configuration of radio by modulation recognition of signal

- *Perform signal recognition that allows self-configuration and link acquisition even with noise or weak signal*

Cognitive compensation for propagation and nonlinear channel effects

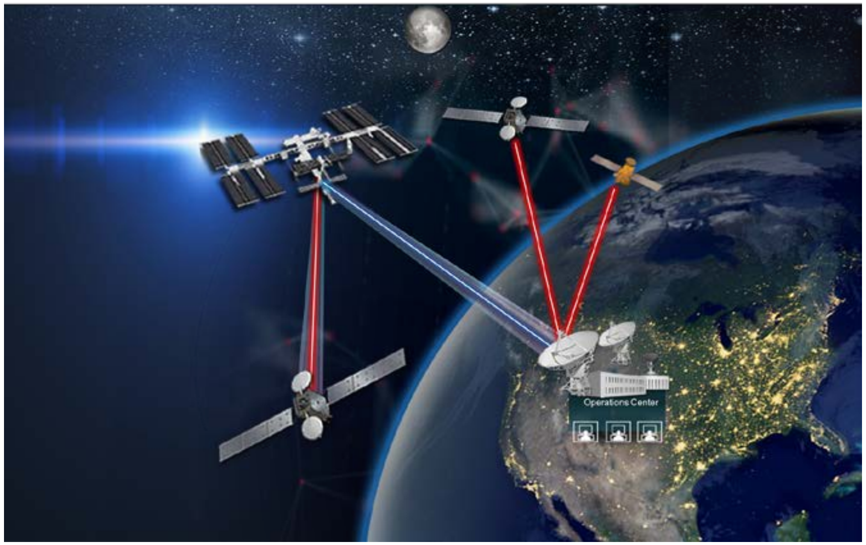
- *Classify overall channel degradation by its component effects and mitigate each one appropriately*
- *Learned communication channel optimization*

Radio Frequency (RF) interference mitigation

- *Automatically sense and avoid spectrum interference by changing frequency, bandwidth, and data rate*
- *Cognitive engines will help to identify and remove interference*

Optimal hand-off between Free Space Optical and RF links

- *Integrate FSO and RF seamlessly to form a unified transport*



The key is to optimize the links, to maximize the data throughput, and do it autonomously rather than manually scheduled.

Cognitive Communications
Cognitive Networks

Cross-layer optimization and discovery of network devices

- *Autonomously assign Quality of Service metrics to user data*
- *Discover capabilities of user radios on SCaN network*

Drop user spacecraft data to any space or ground asset

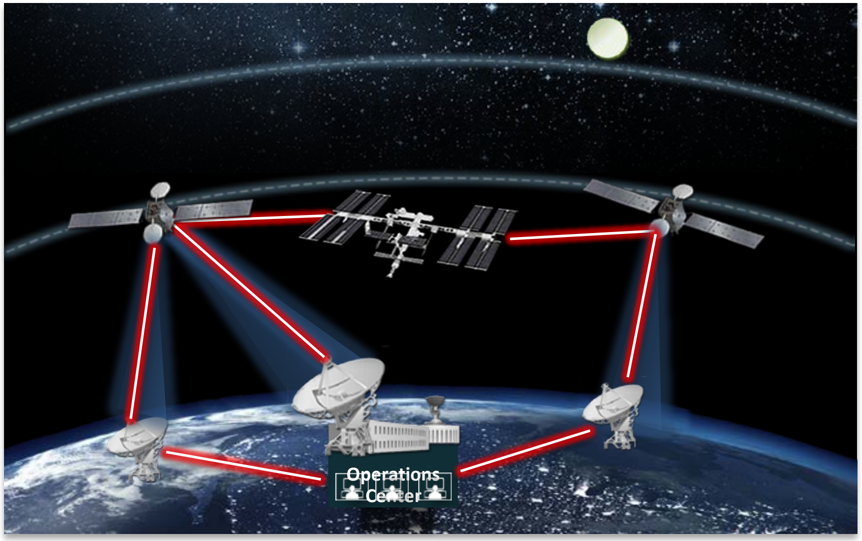
- *Improve network management and responsiveness*
- *Eliminate the need for reserving specific assets for customers*

Delay and disruption tolerance (DTN) over multiple hops

- *Apply CE to determine the optimal route through a space network with infrequent or distant nodes*

Network security for integration of commercial providers

- *Protect user data and provide flexibility when using third-party transport services*

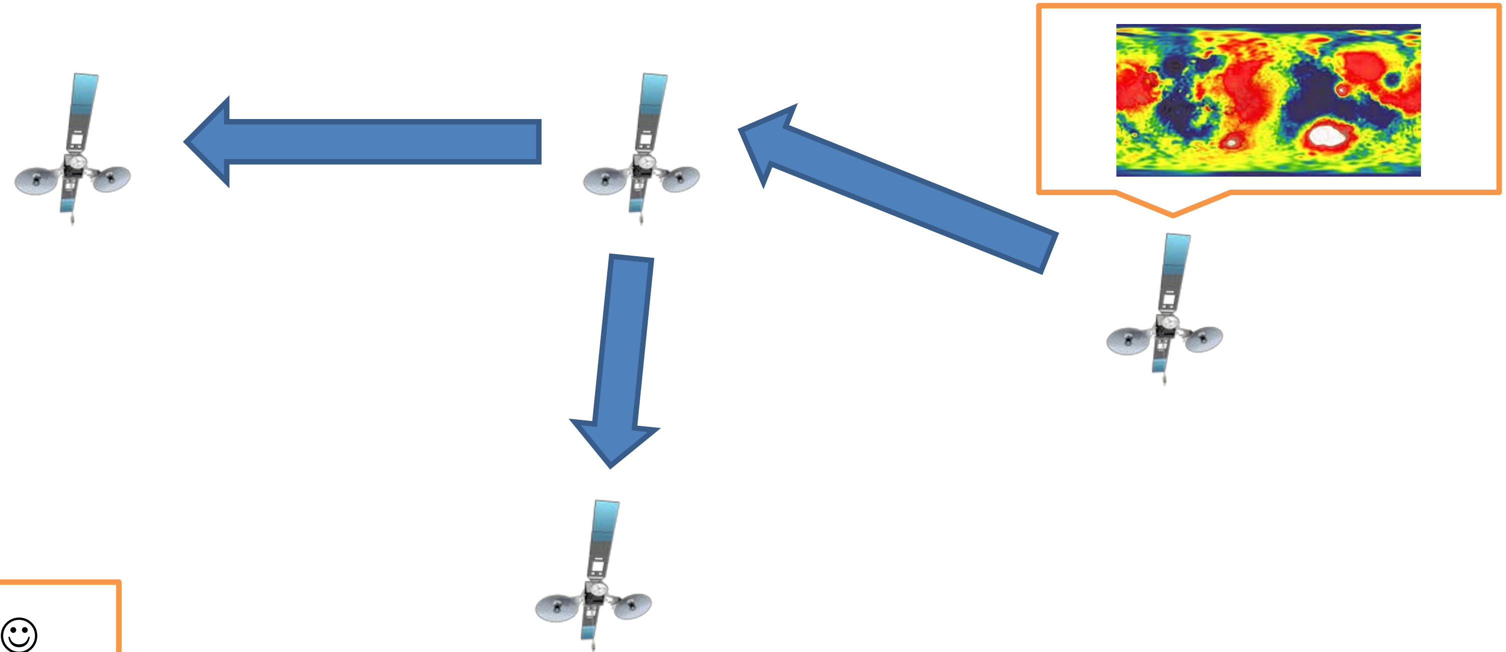


The key is that we are setting up for autonomous networks being created.

Drop Data Anywhere

Intelligently moving data through a future SCaN network from the science sources to the principal investigators, or to communicate with astronauts

Toward intelligent, predictive caching and data distribution …



EXPLORING! ☺

… that can take advantage of opportunistic links

Networking in space is coming soon and NASA will network with other space assets.

Drop Data Anywhere

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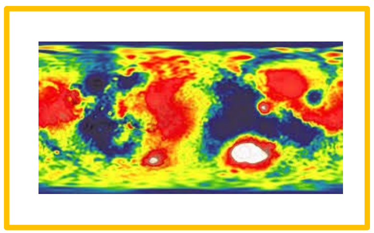


Can I please have a map?

… that can take advantage of opportunistic links

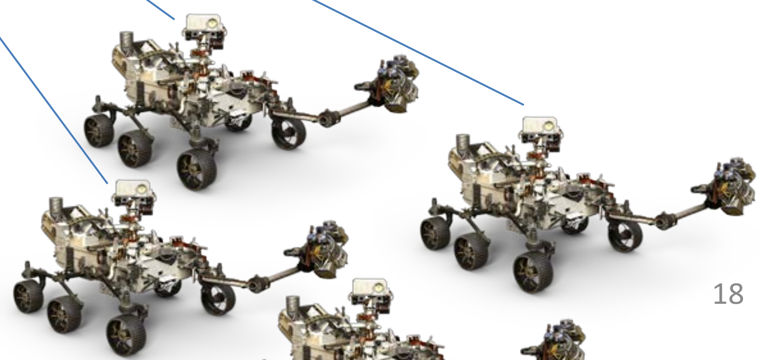
Meeting the Neighbors

Telling other agents we exist … and figuring out that they do, too

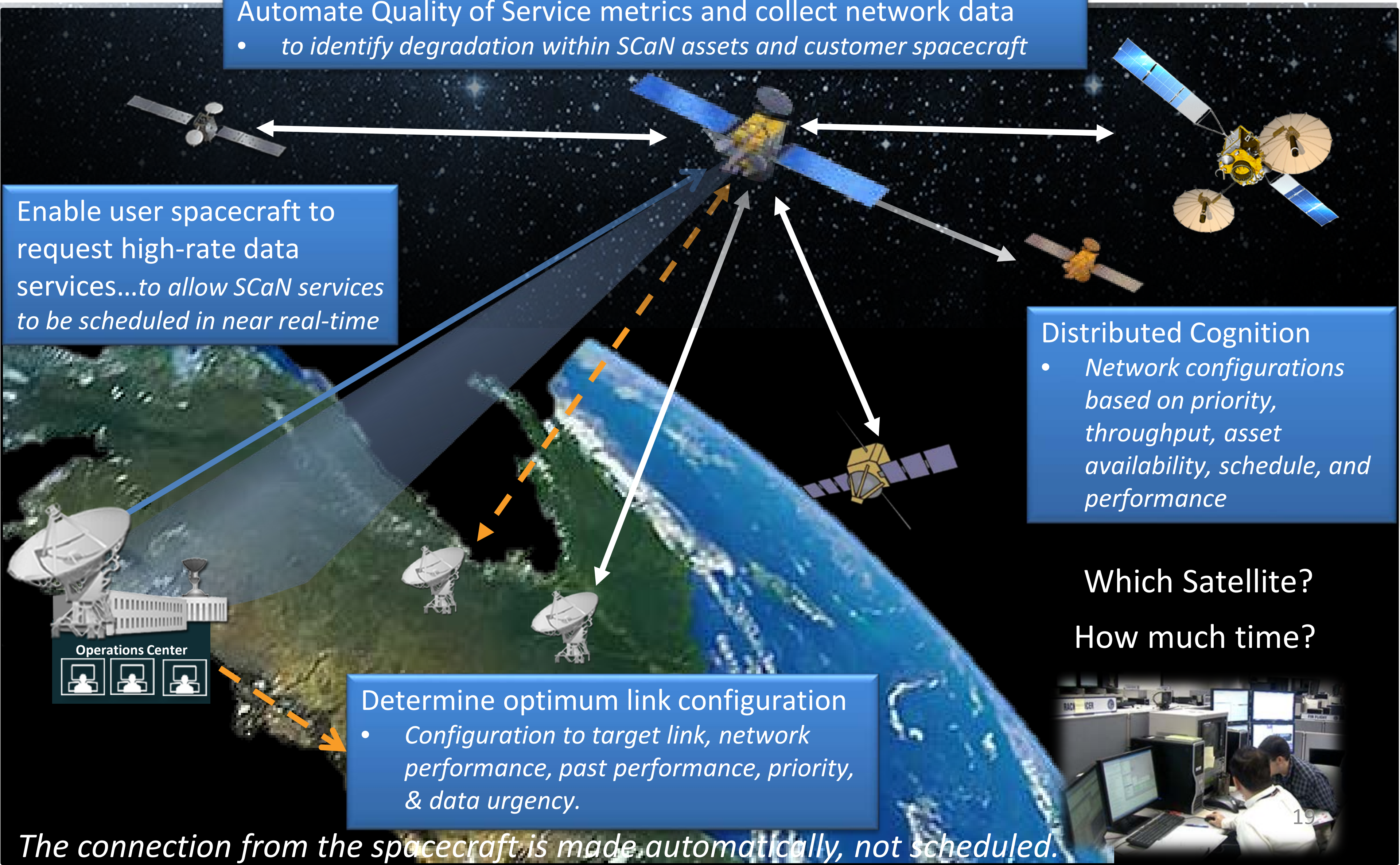
NO. YOU ARE NOT ALONE.
WE WILL ADD YOUR BIOLOGICAL AND TECHNOLOGICAL DISTINCTIVENESS* …

I am alone ☹

* … to the network, obviously.

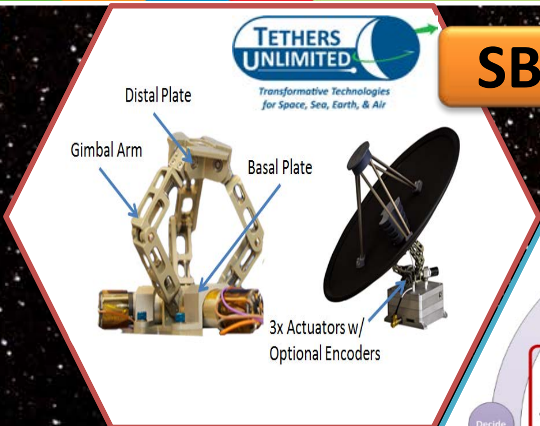


Cognitive Communications User Initiative Service

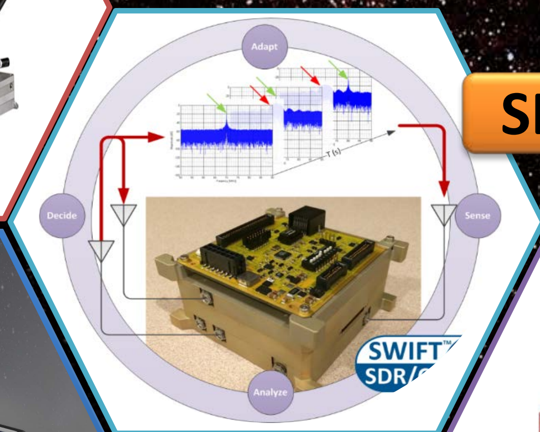


Cognitive Communications
Cognitive Hardware Capability

The key is to have our cognitive algorithms go into a variety of space communication products including those of industry partners.

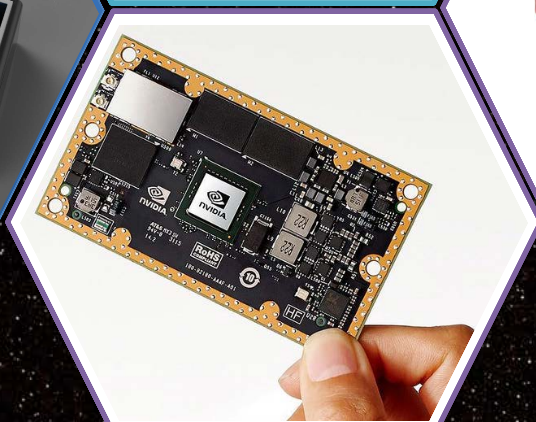


SBIR



SBIR

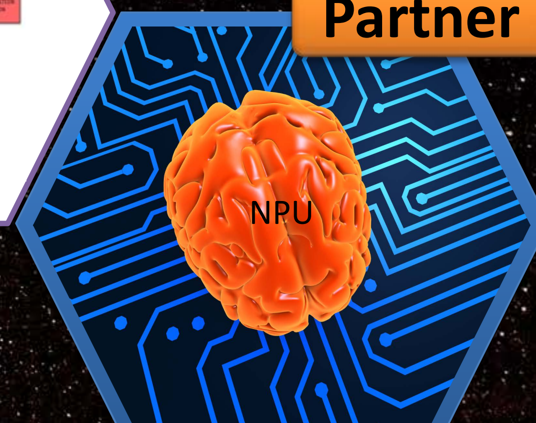
STTR



In-house

In-house

AstroSDR



Partner

Cognitive Communication Experiments

The experiments we are doing now are good demonstrations so that we can prove and later infuse these cognitive aspects into the Space Communications Next Generation Architecture.

- Multi-Objective Reinforcement Learning
- User Initiative Service
- Inferences Mitigation
- Drop Data Anywhere

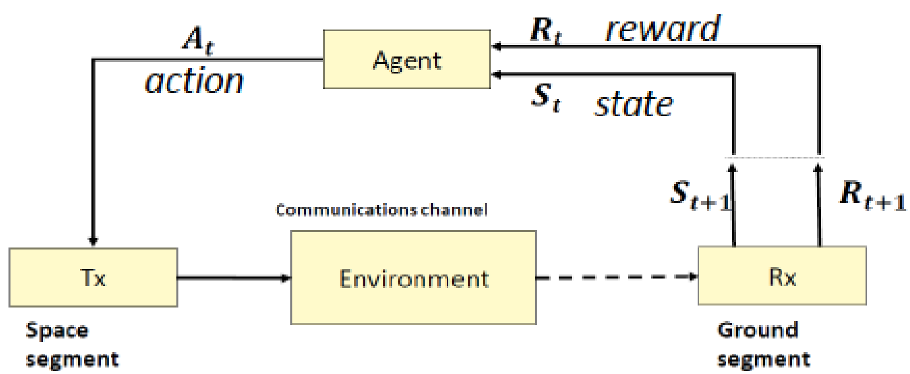
By merging space communications and machine learning:

- Aim to increase efficiency and autonomy.
- More reliable.
- Streamline the process by making it more transparent, less complex.

Cognitive Experiment with SCaN Testbed Multi-Objective Reinforcement Learning

Objective: P*rovide a proof-of-concept demonstration that reinforcement learning-based multi-objective optimization is feasible for satellite communication.*

Goal: Optimize a set of parameters as a function of other parameters:
Power, Bit Error Rate, Data Rate, SNR, Bandwidth, etc.
Action: Choose actions (change radio parameters) to bring state closer to the goal
State: Parameters that influence the communication parameters; some under the control of the cognitive engine and some are not.
Threshold: Value of parameters that satisfy the goal.
Reward: If threshold exceeded – action is part of goal set.



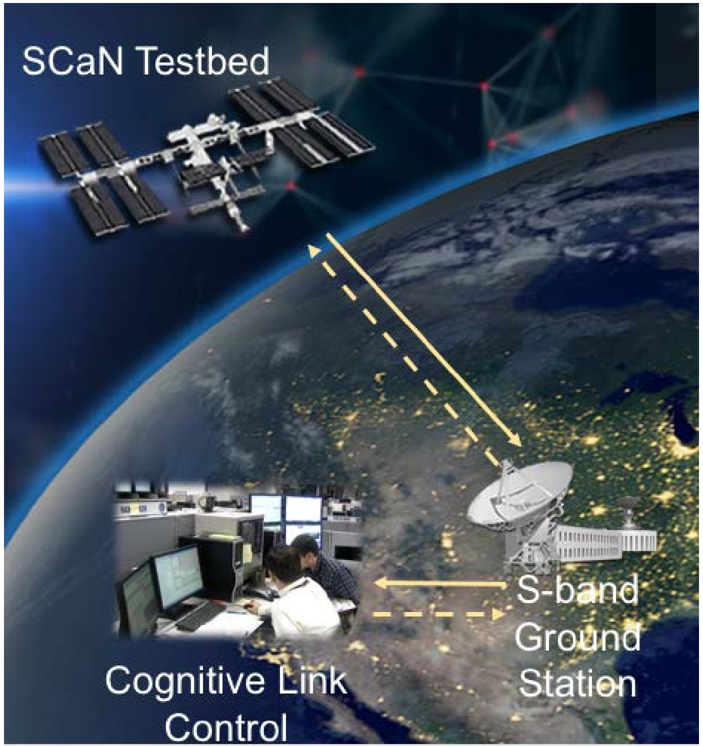
ref., ICSSC WPI paper AIAA 2016-5726

Requires more processing resources than off-line learning, but can adapt to a changing or unknown environment.

Multi-Objective Reinforcement Learning Testing Results

Experiment:

- 20 flight events with SCaN Testbed
- Cognitive Engine (CE) controls six knobs:
  - Throughput,
  - Bit Error Rate,
  - Bandwidth,
  - Spectral Efficiency,
  - TX Power Efficiency,
  - DC Power.
- Three mission profiles tested: Emergency, Power Saving, and Cooperation.
- Operates without pre-training, but training on completed passes improved performance.



Cognitive engine does better than traditional methods.

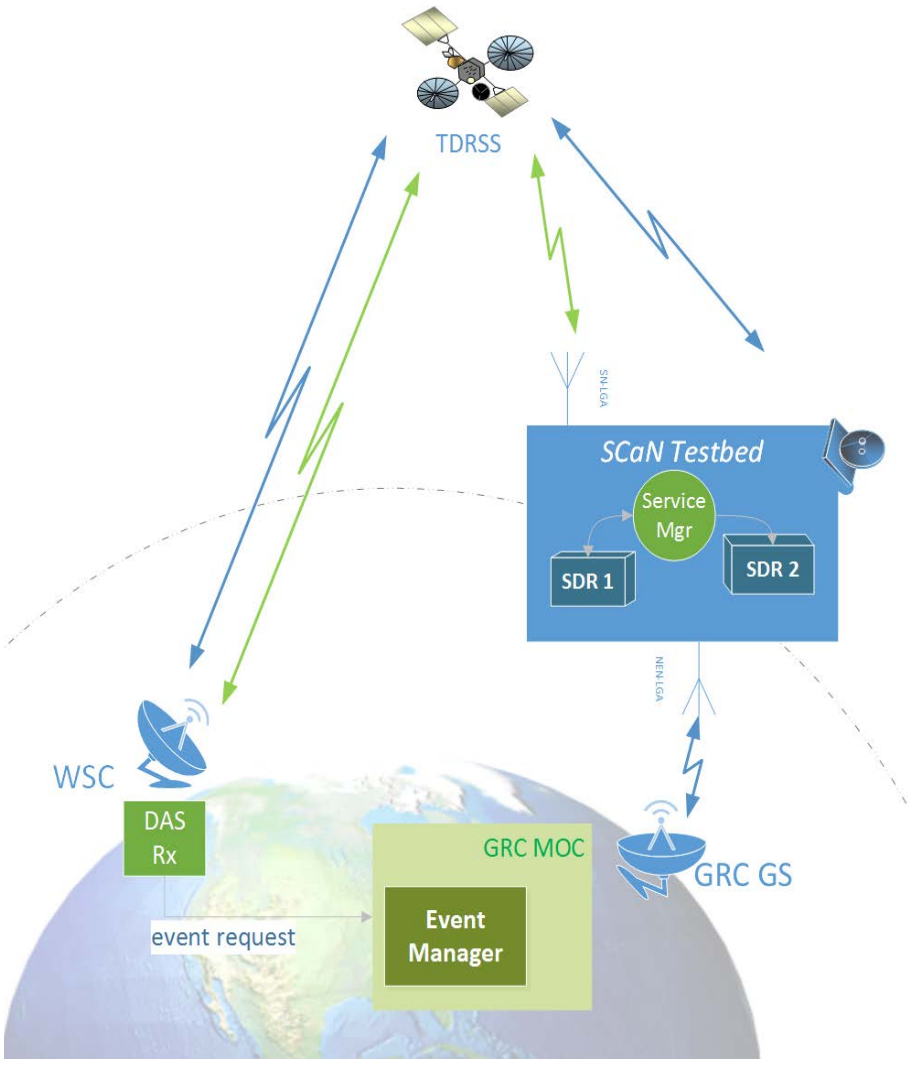
UIS Flight demonstration with SN Test Results

Scheduling an Event:

- Requires coordination of a significant number of authorities.
- Schedule takes 3 weeks of preparation.
- Overall process is complex and requires much prior planning.

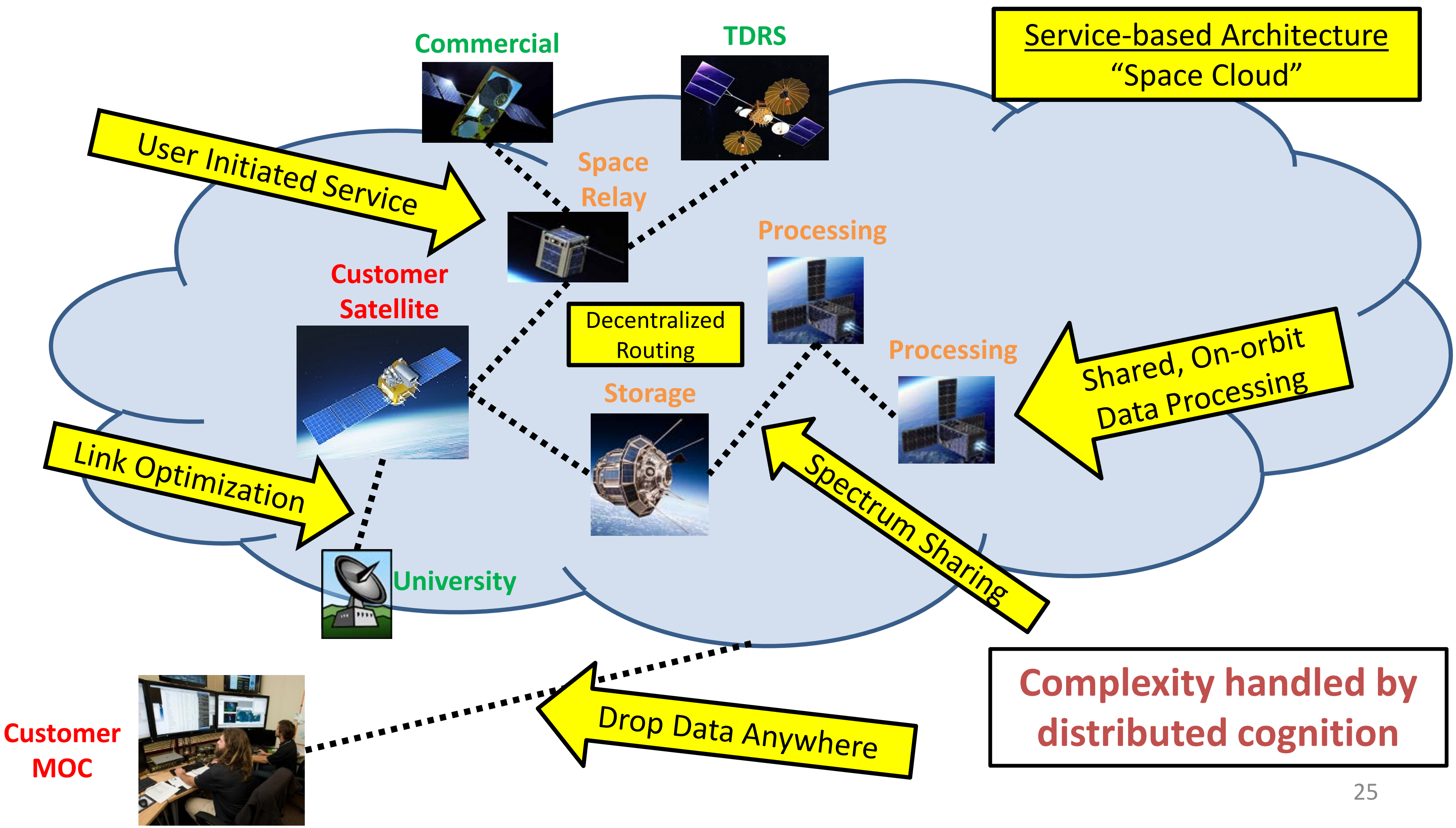
UIS Experiment:

- Require less coordination and more autonomous.
- Scheduled with as little as 15 minutes lead time instead of 3 weeks.
- Overall process is easier, less complex.



Future Architecture (Vision)
Cognitive Communications

SCaN as a communication, processing, and storage service provider



Summary

Large-scale

- Cognitive engines
- Artificial intelligence
- Machine learning

become feasible for implementation as computational power increases and cost drops.

➕

Radiation-Hardened

- Microprocessors
- FPGAs
- Memory
- Neuromorphic processor

enabled the creation of Software Defined Radio and transformed space communication

Cognitive communications is a natural merger of these two worlds, with promise toward increasing the efficiency, optimality, and reliability of our space systems.

Thank You!

COGNITIVE COMMUNICATIONS PROJECT