Orchestrating Symbiosis: Foundational technologies for Human and Robotic Shared Control – Exploring the Framework

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Outline

- The Problem Space
- Exploring the Framework for understanding
- Reality Check
- Conclusion

The Problem Space . . .

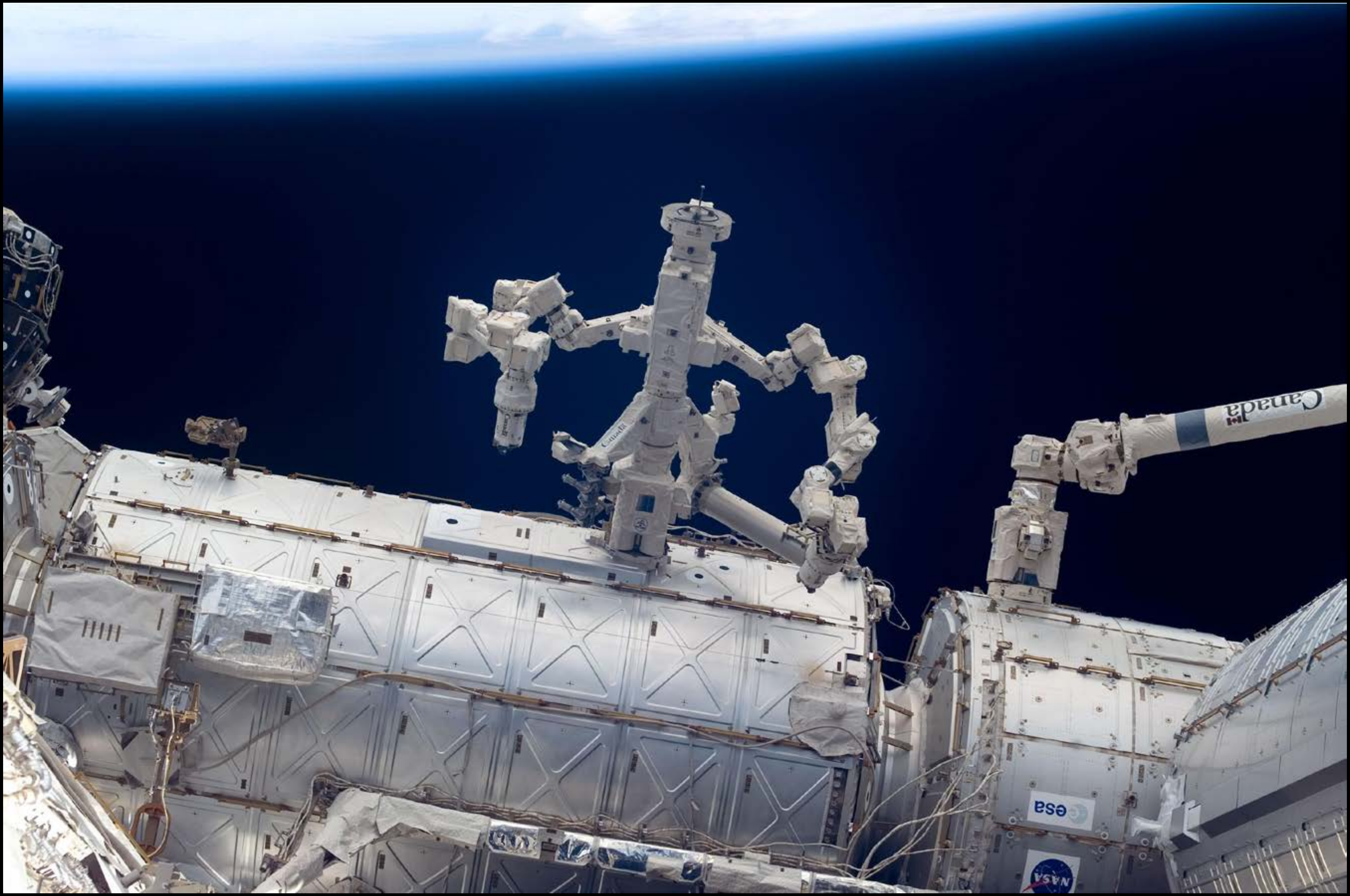
- N-Dimensional interaction problems (i.e., an arbitrary number of objects interacting in an arbitrary number of ways) are a class of problems for which the generalized solution space is typically computationally intractable in any time frame.
- Space automation and robotics present a subset of these problems that exacerbates the situation by requiring near real-time solutions in many instances.

Reality is not a convenient problem or solution space . . .

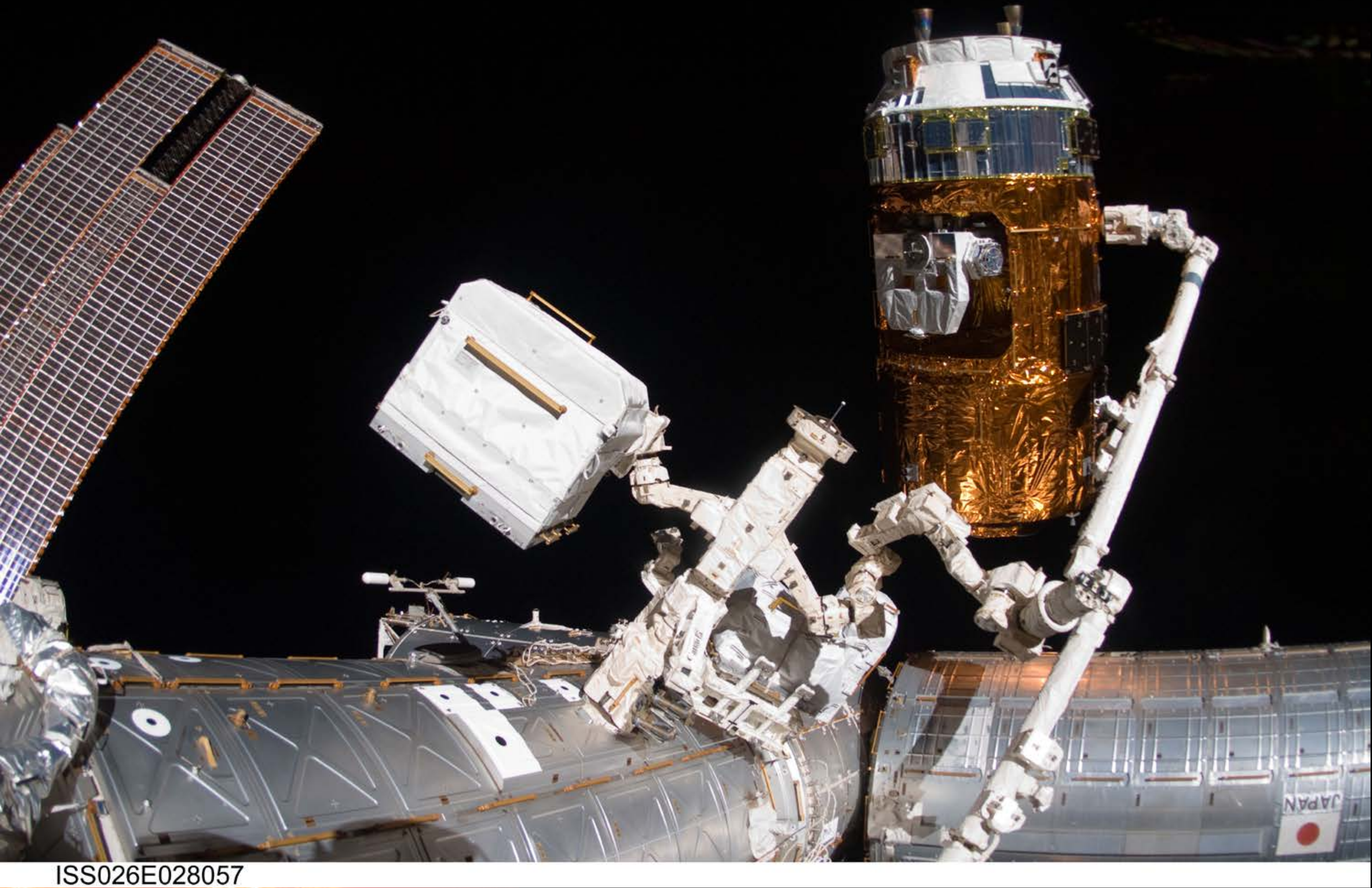
Finding Nexus . . .

- Nexus in this case is the intersection between *theoretical constructs* of knowledge-based-systems and space systems engineering reduced to *practice*.
- XISP-Inc mission development efforts can be viewed as a set of *conceptual threads* intended to draw out the confluence of interests *needed to bias work towards better outcomes* for Cislunar and beyond space missions.
- The process goal is to *reverse engineer the desired outcomes* by orchestrating a combination of technology development “push” and mission requirements “pull”

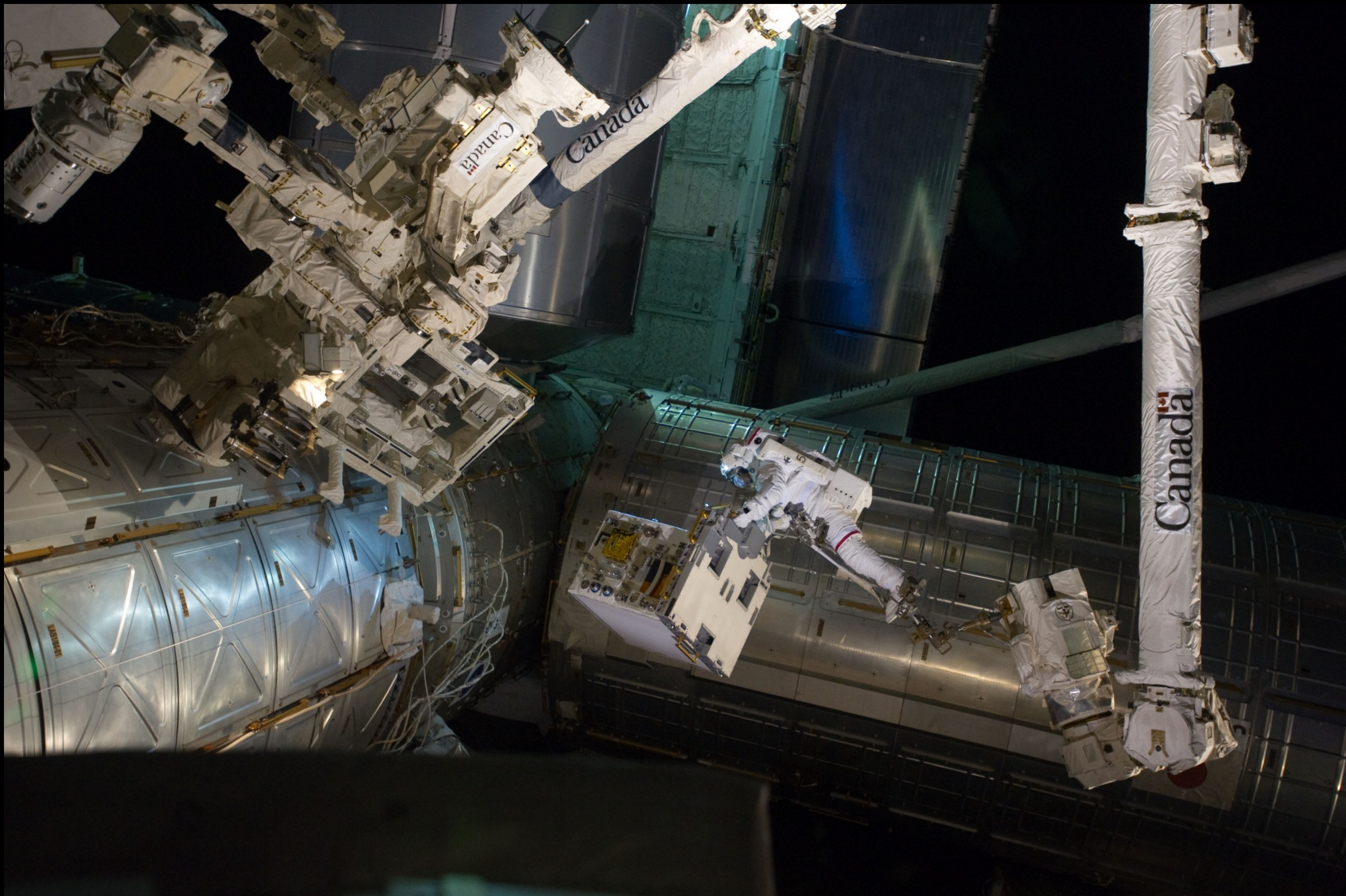
Extra Vehicular Robotics . . .



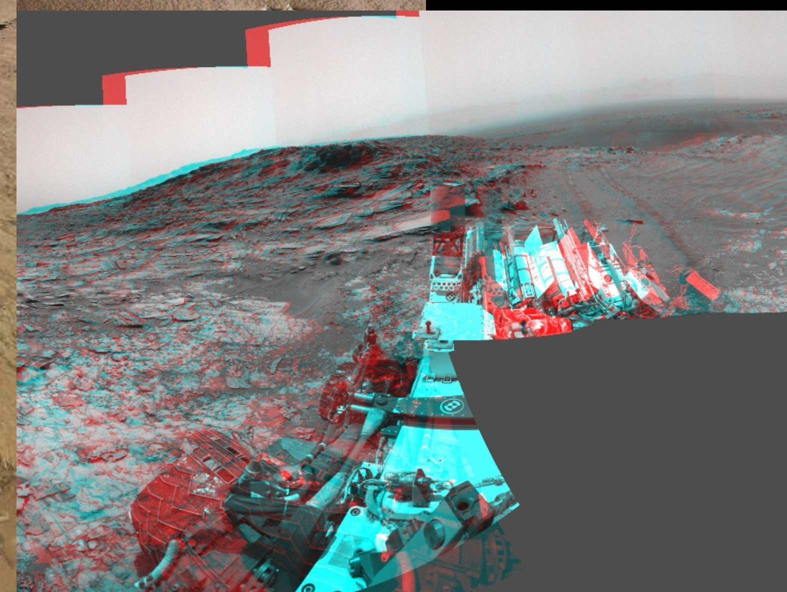
EVR Tasking . . .



Robotics & EVA Crew . . .

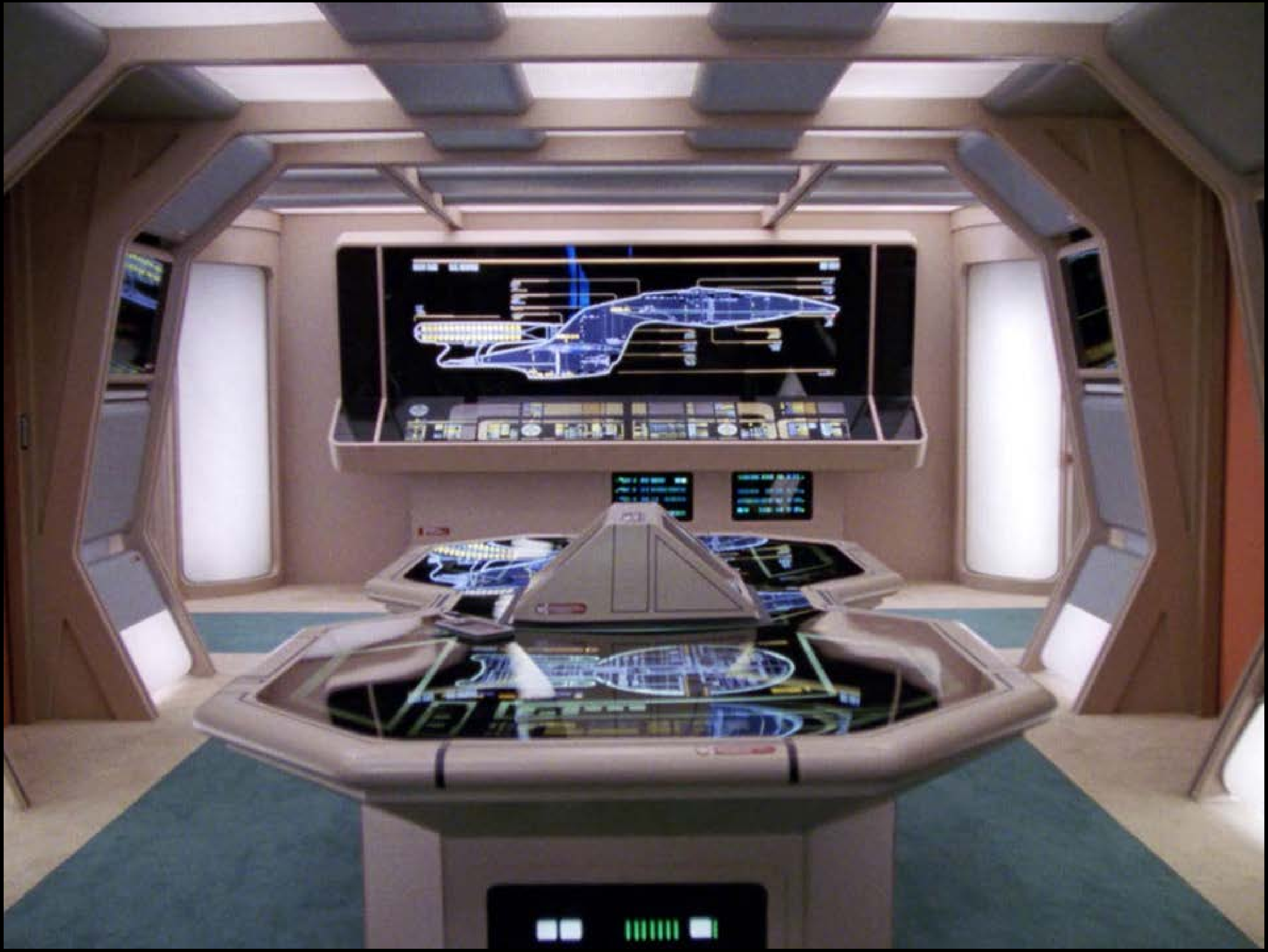


So you want to roam . . .

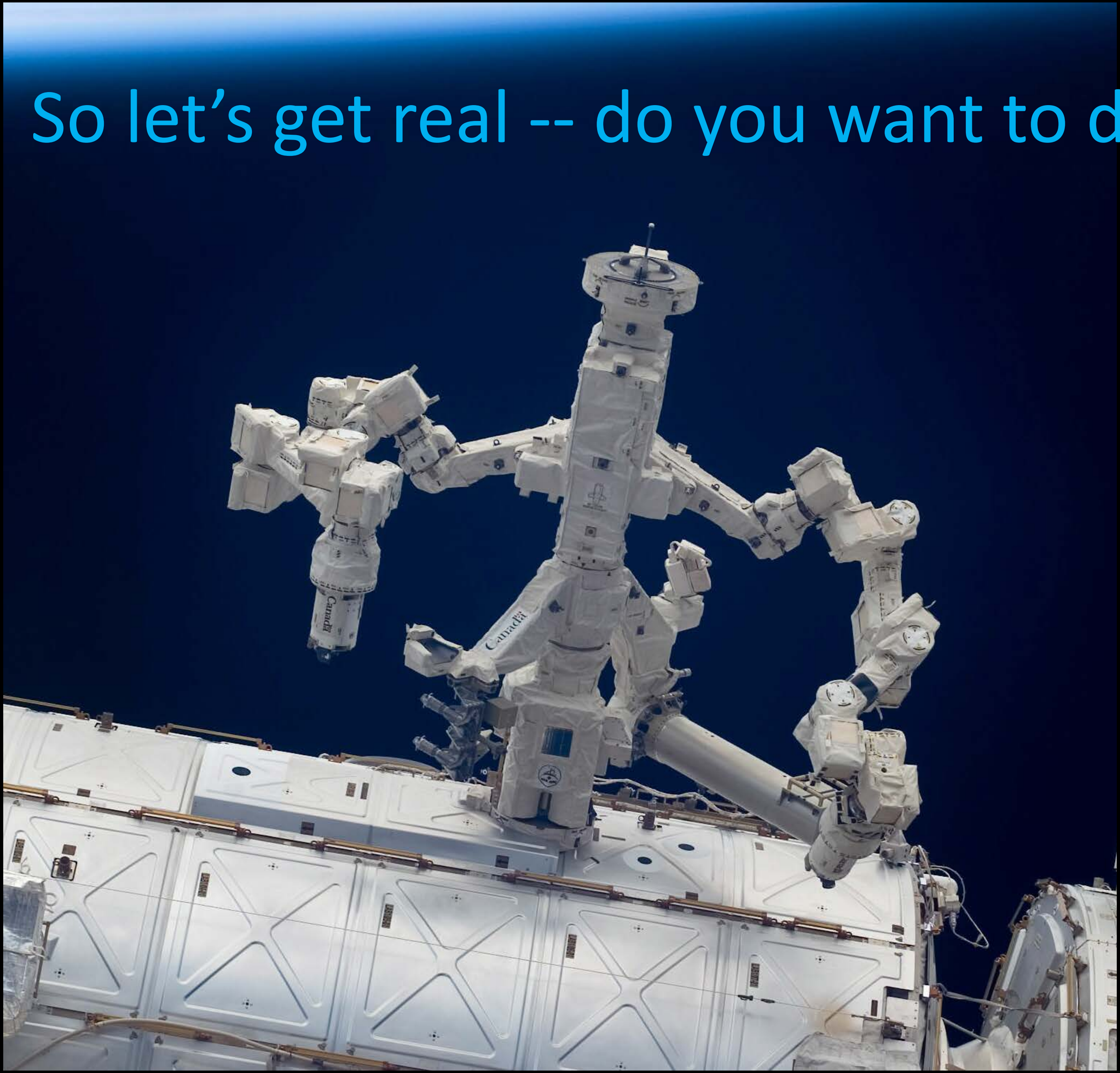


Going to Low Earth Orbit and Beyond . . .

Perhaps even run a starship?

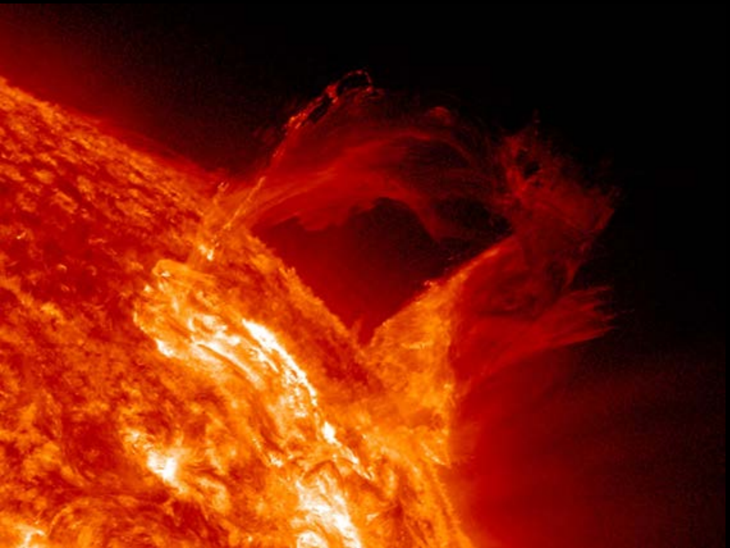


So let's get real -- do you want to dance?



DEXTRE is missing something?

- The Special Purpose Dexterous Manipulator (SPDM) aka DEXTRE was designed to have an Advanced Vision Unit (AVU)
- The AVU was to provide a near realtime state model of the systems-of-systems that made up the SPDM – effectively an autonomic nervous system
- In addition, it would have the ability to dynamically build up a world model of an assigned task area and it’s intersection with the environment
- The combination of these two capabilities with the appropriate sensors/cameras/tags/targets/interfaces and the as-built documentation of the International Space Station was intended to support a mutable locus of control between full teleoperation and full autonomy



The AVU was intended to allow the SPDM to effectively break dance with an EVA astronaut rather making paint drying seem like a spectator sport.

DEXTRE is missing something? - 2

- Alas, it was estimated proximate to 1995 that implementing the AVU as intended would only take 25 times the anticipated available computational capacity of the International Space Station (ISS).
- However, implementing the AVU using 2016 technology should and would be a much more straight forward proposition given . . .
  - Multiple space qualified multi-core thermally managed processors
  - Highly reliable registered Error Correcting Code (ECC) memory
  - Solid state data storage systems
  - Open source multi-threaded operating system amenable to near-realtime operations
  - Multi-fault tolerant virtualizable functions and a generalized control architecture designed for failure tolerance
  - Pervasively networked environment with access to as-built configuration data and relevant ISS operations and environmental data

The same logic is applicable to any EVA/IVA robotics as well any advanced automated system

Making It Real . . .

The order of the problem to be solved must be reduced to something tractable

- Breakup problem space into many sub-problems suitable for parallel processing
- Focus on the sub-problems that matter
- Use boundary conditions, initial conditions, symmetry, known geometry, established datums, etc. to further reduce complexity

The key is to propagate constraints as rapidly as possible

Orchestrating Symbiosis:

Foundational technologies for Human and Robotic Shared Control

- **PROBLEM:** Living and working in space environments requires a partnership between humans, robotic, and automated systems.
- **HYPOTHESIS:** A mutable locus of shared control is required between:
    - Remotely Supervised, Teleoperated, Physically Present, and Autonomous Operations
    - Ground and Inflight Operations
    - Scheduled and Dynamic Operations
    - Defined and Sensed Environments
    - Referenced, Predicted, and Sensed Geometry
- **OUTCOME:** Orchestrating symbiosis addresses established problems and provides a framework for addressing emergent ones that biases operational outcomes towards success by enabling a mutable locus of shared control.

Making It Real . . .

A mutable locus of control is required between:

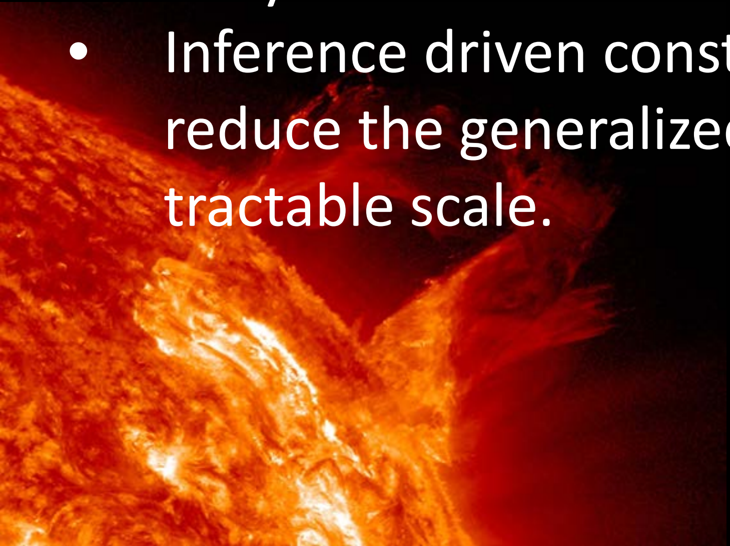
- Teleoperated and Autonomous Operations
- Ground and Inflight Operations
- Scheduled and Dynamic Operations
- Defined and Sensed Environments
- Referenced/Predicted/Sensed Geometry
- Toggled and Shared Control

This necessitates near realtime state models of the involved systems and the environment

Making It Real . . .

- N-Dimensional interaction problems do not have to be intractable.
- With appropriate metadata, transforms can be applied.
  - *Data is a set of ordered symbols*
  - *Information is Data in context*
  - *Knowledge is Information in perspective*
  - *Wisdom is Knowledge in reflection*
- Problems of interest can be recast and structured as:

  (Items(Attributes(Values)))   -- LISP transform
- They can then be modeled as a set of process flow problems.
- Inference driven constraint propagation can then be applied to reduce the generalized solution space to a computationally tractable scale.



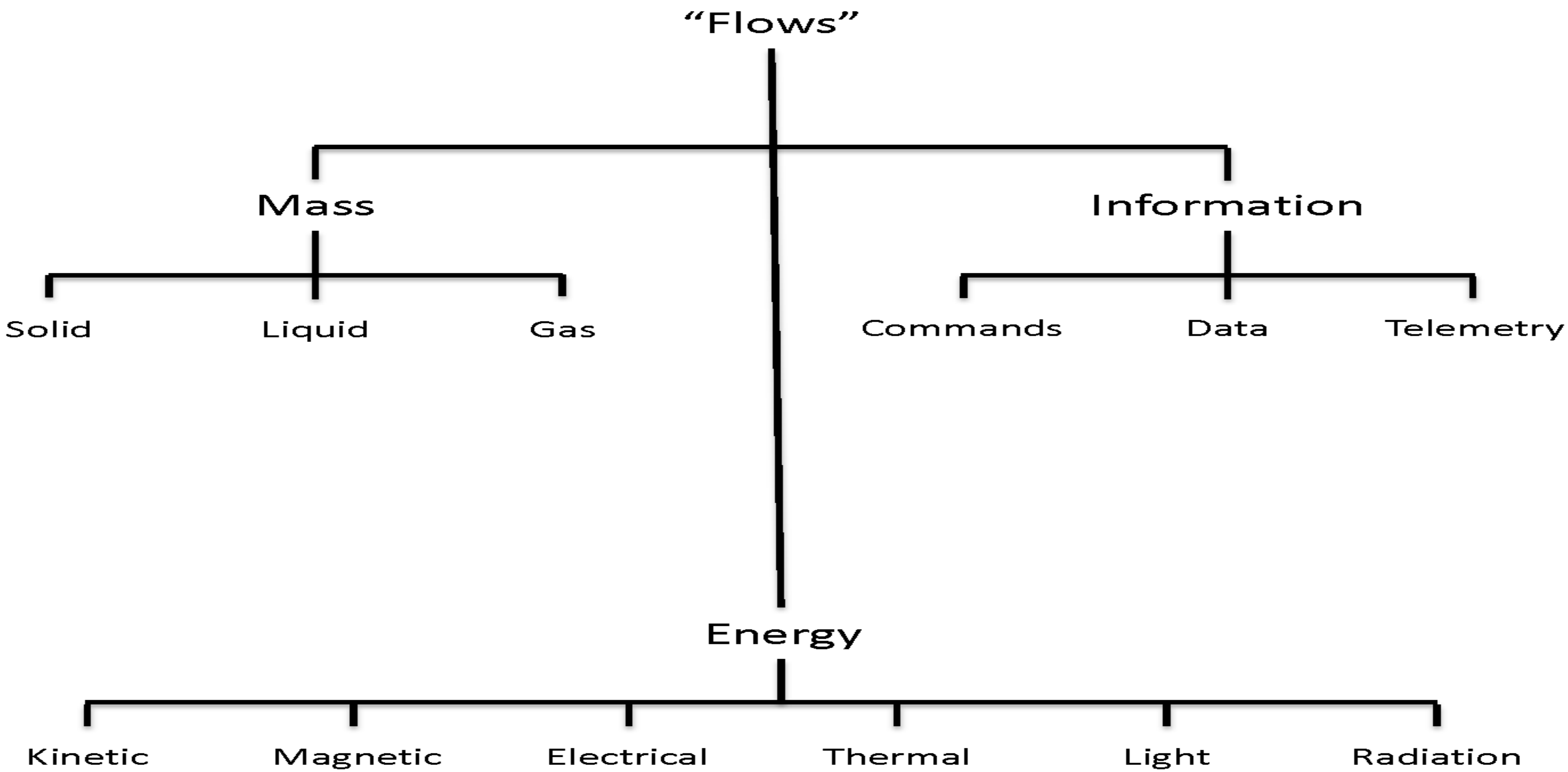
The structure and ordering of knowledge makes a very real difference . . .

Building Near-Realtime State Models . . .

- Systems-of-systems can be bounded as a finite set of state transitions
- Systems can be modeled as a set of flows across defined interfaces
- A taxonomy of flows can be defined as either energy, mass, or information and then further subdivided into individual types
- Each type of flow can be defined by a specific set of qualitative and quantitative attributes, independent of the source and terminus

Each set of characterized flows can be associated with corresponding states and allowable transitions.

Figure 10.
Sub-System "Flow" Taxonomy



Asimov's Three Laws of Robotics:

First Law

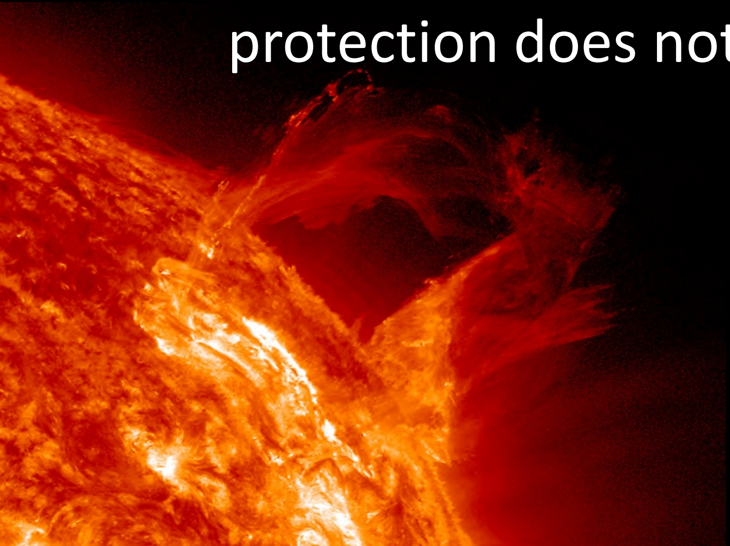
- A robot may not injure a human being or, through inaction, allow a human being to come to harm.

Second Law

- A robot must obey the orders given it by human beings except where such orders would conflict with the First Law.

Third Law

- A robot must protect its own existence as long as such protection does not conflict with the First or Second Laws.



Zeroth Law

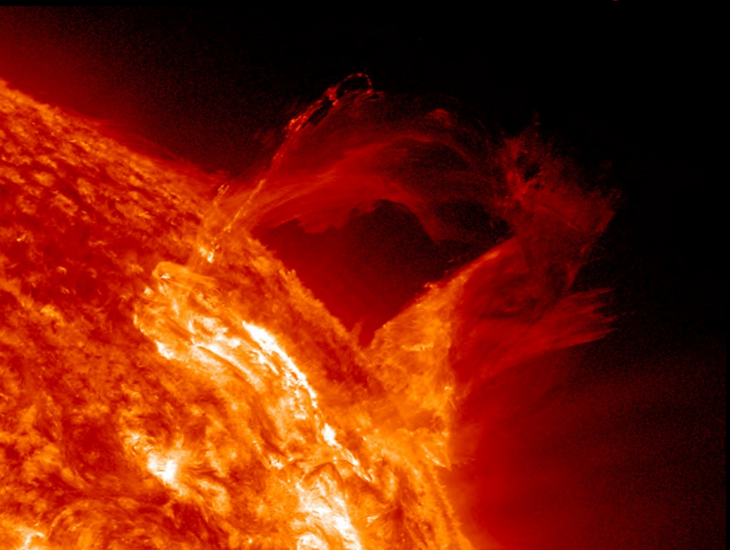
A robot may not harm humanity, or, by inaction, allow humanity to come to harm.

A robot may not harm humanity, or, by inaction, allow humanity to come to harm.

Asimov’s Zeroth Law of Robotics:

- A robot may not harm humanity, or, by inaction, allow humanity to come to harm.

➔ *It turns out that both humans and robots can make bad choices. Accordingly, we must teach both to be able to work together to make better choices or deal with the consequences of either or both them failing to be responsible moral actors.*



A Different Perspective . . .

Why Space!?

Why Space

A poem by Gary P. Barnhard
Art by Azuma Makoto

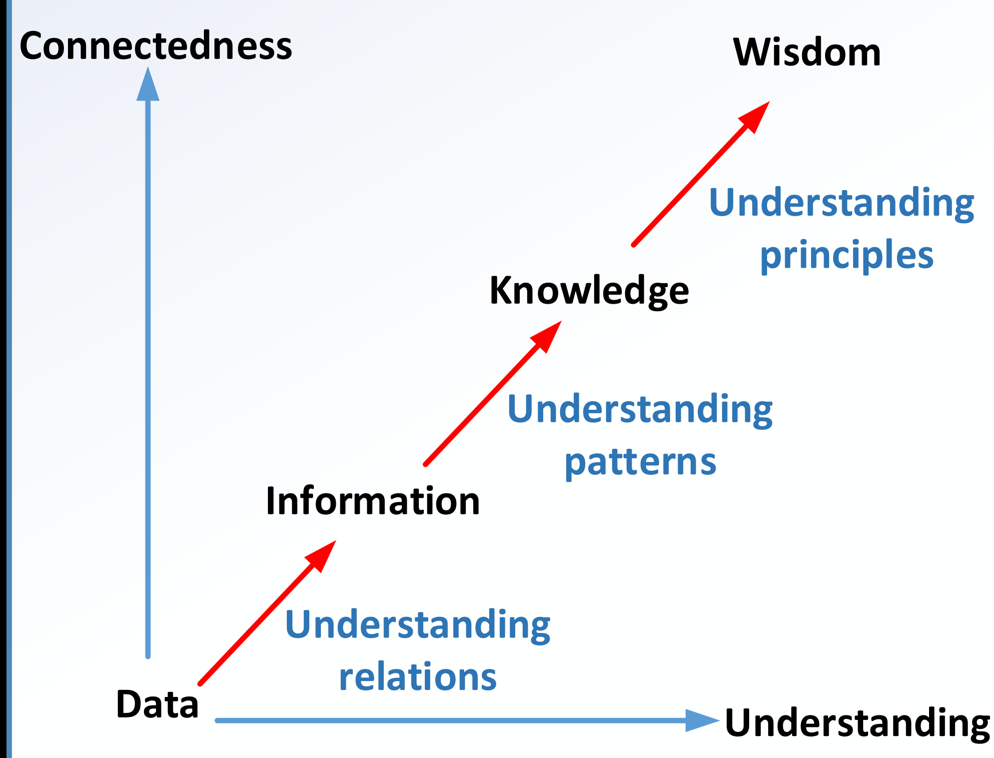
The shortest path between any two points, physically or conceptually
is not always a straight line and the answers that we have
to this question are no exception.
Accordingly, we must come to learn from the myriad of patterns that
can offer us knowledge which transformed by understanding can over
time yield wisdom.
Consider then these perspectives . . .
We are drawn to bear witness to the unimaginable magnificence
of the Universe which unfolds at every scale.
We are driven by our nature to know all that is knowable.
We strive so that we may yet stand on the threshold of eternity
We dare to boldly go where no one has gone before
We seek to understand and nurture life in its manifold forms
We search for the wisdom that will enable us to transcend our terrestrial
travails so that we may yet transform our tomorrows.

Levels of Understanding

Levels of Understanding[6]

- ♦ Data is a set of ordered symbols
- ♦ Information is Data in Context
- ♦ Knowledge is Information in Perspective
- ♦ Wisdom is Knowledge in Reflection

The difference between data, information, knowledge and wisdom[7,8,9]



Knowledge Levels

LINGUISTIC

The linguistic level is the most abstract level of knowledge within a given framework. Understanding is predicated on the morphology and syntax of the language employed.

CONCEPTUAL

The conceptual level of knowledge consists of ideas expressed in structured syntax within a given framework.

EPISTOMOLOGICAL

The epistemological level of knowledge contains the structure and ordering of knowledge within a given framework.

LOGICAL

The logical level of knowledge consists of what are correct or reliable inferences within a given framework.

IMPLEMENTATION

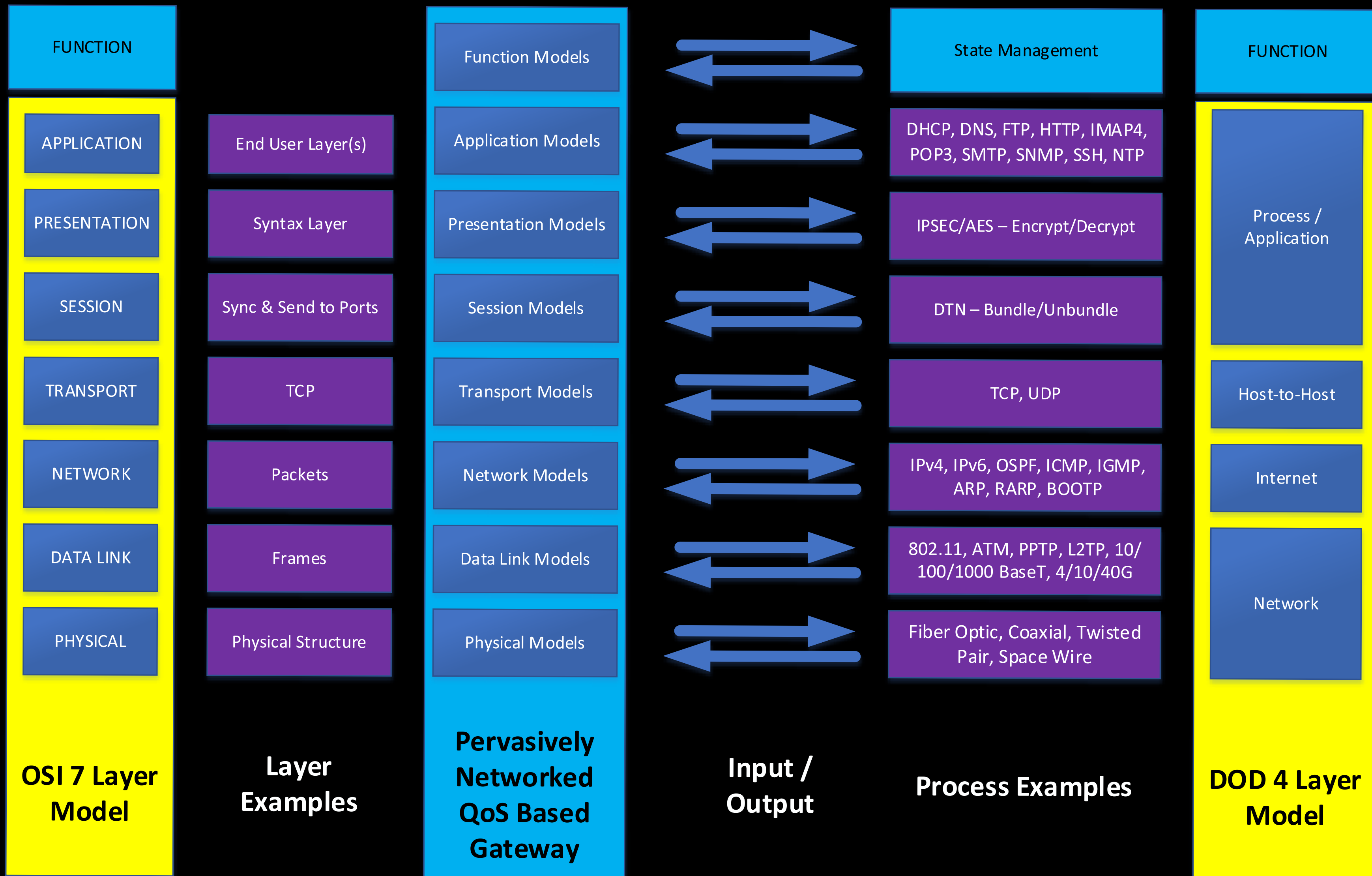
The implementation level is the least abstract level of knowledge within a given framework.

Note: Knowledge levels adapted from work by Brachman.
Level descriptions are the responsibility of the author.

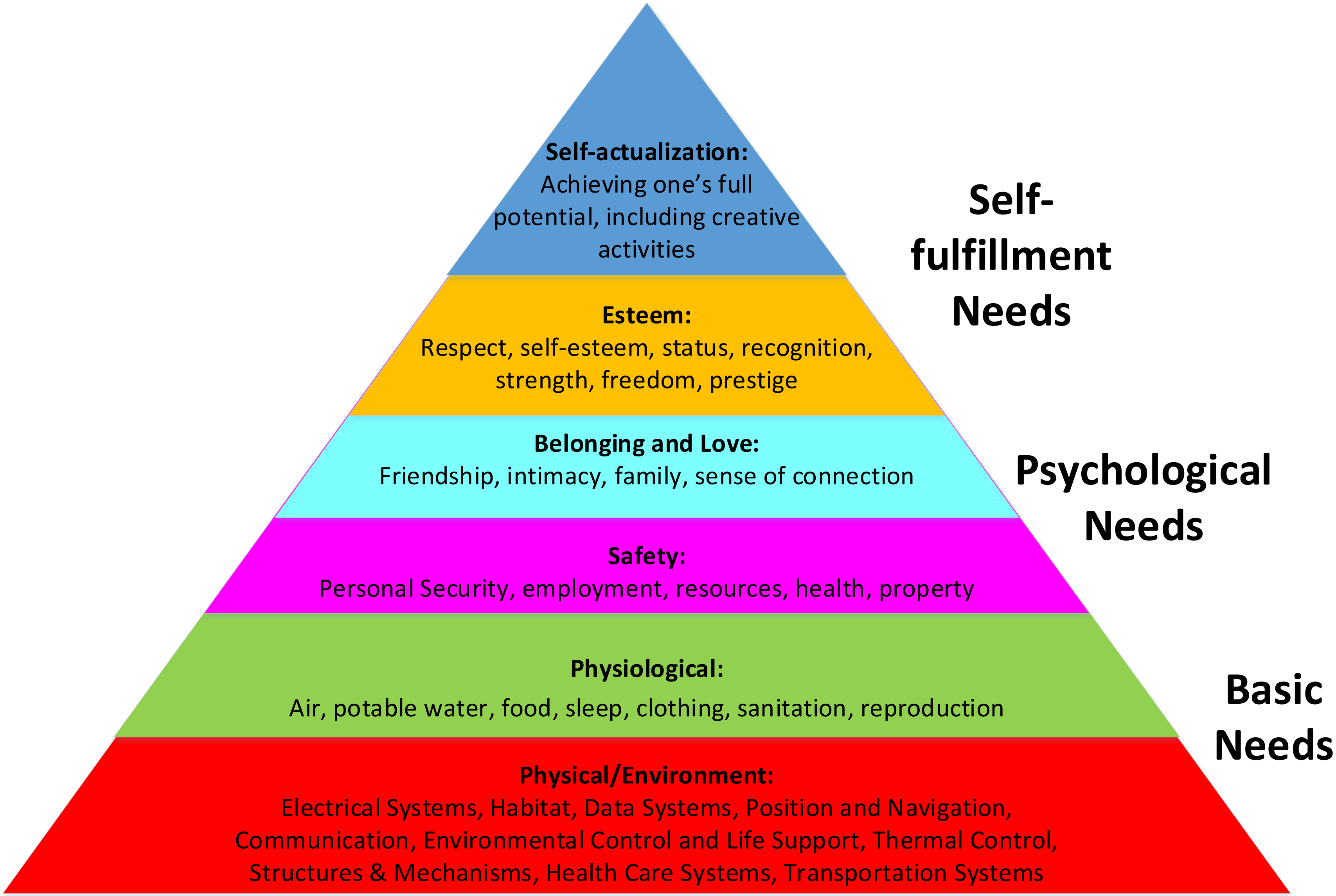
Knowledge Types . . .

KNOWLEDGE	LEVEL VALUES	ATTRIBUTES	ITEMS	MODELS	DATA SETS
LINGUISTIC	STATUS	DEFINITIONS	PURPOSES	FIDELITY	UTILITY
CONCEPTUAL	NATURE	APPLICABILITY	REQUIREMENTS	RATIONAL	DOMAIN
EPISTOMOLOGICAL	TYPES	CATEGORIES	HIERARCHIES	SCHEMAS	ORDER
LOGICAL	VALIDITY	ASSOCIATIONS	INTERFACES	RULES	CRITERIA
IMPLEMENTATION	DATA	VALUES	ATTRIBUTES	ITEMS	MODELS
NOTES:					
Knowledge levels adapted from Brachman.					
Knowledge types are an independent construct of the author.					
Visualizations (i.e. pictorial information} is treated as a knowledge representation mechanism rather than as a discrete knowledge type.					

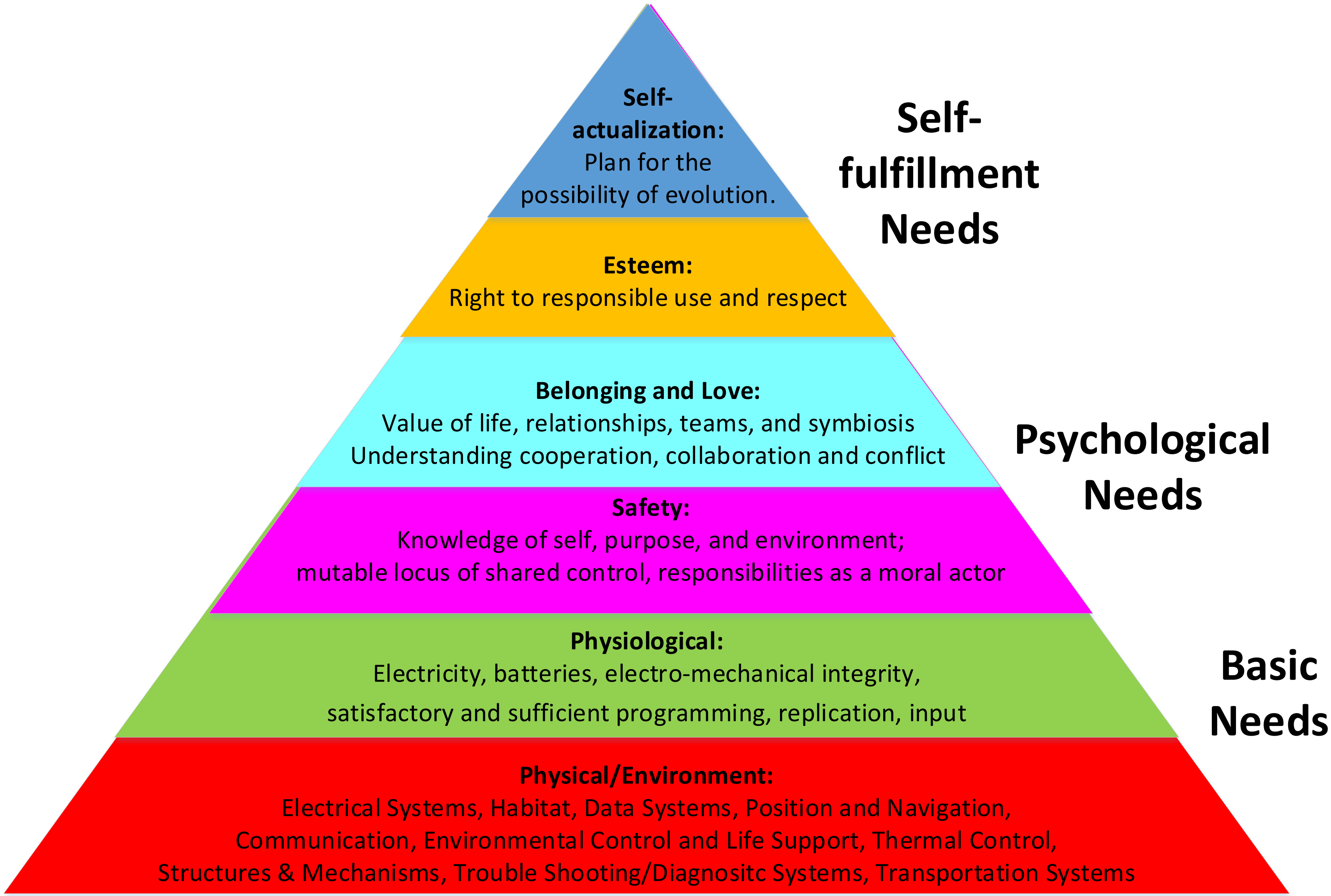
XISP-Inc Crosslink Protocol (XLINK)



Maslow's Hierarchy of Human Needs[5] updated for Cislunar Settlement



Barnhard's Hierarchy of Needs Analog for robotics and advanced autonoma



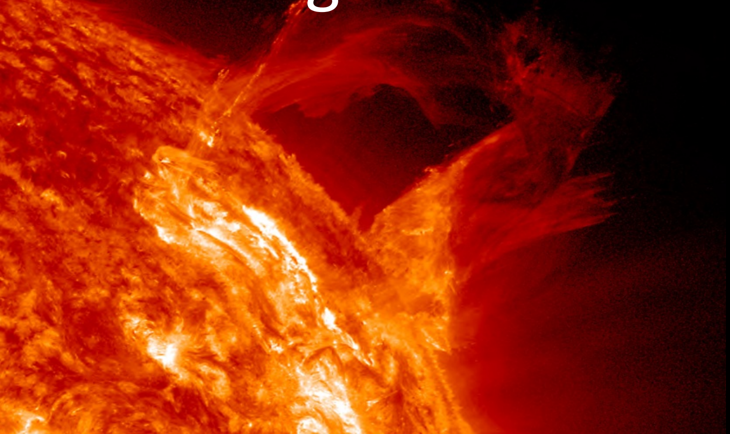
In Search of a Moral Compass

- A “Moral Compass” in this sense is defined as an internalized set of values and objectives that ***guide a person or entity with regard to ethical behavior and decision-making***.*
- If we build robots and/or other forms of autonoma ***without*** providing them ***a moral compass they will sooner or later act in a manner incompatible with our expectations.***

*ADAPTED FROM DICTIONARY.COM UNABRIDGED,
BASED ON THE RANDOM HOUSE UNABRIDGED DICTIONARY,

In Search of a Moral Compass

- We can ***mitigate*** the dangers to some degree ***by structuring the domain of action of an entity to be deterministic*** (i.e., established situations only – attempt to achieve zero ambiguity)
- ***This strategy inevitably fails because coping with reality necessarily entails solving emergent problems***.
- In order to solve emergent problems an entity needs to know not only how they can act but why they are taking an action.



Tacit Norms

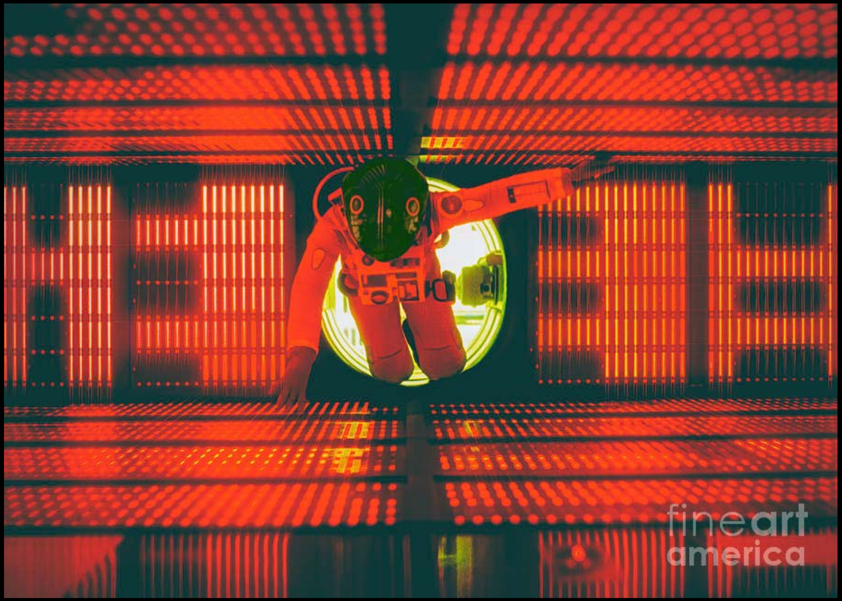
- Anthropomorphism is the attribution of human traits, emotions, or intentions to non-human entities.[1]
- It is considered to be an innate tendency of human psychology.[2]
- Accordingly, any entity intended to interact with humans must
  - establish mutual awareness,
  - a basis for communication, and
  - an ability to establish tacit norms of behavior.

[1] Oxford English Dictionary, 1st ed. "anthropomorphism, n." Oxford University Press (Oxford), 1885.
[2] Hutson, Matthew (2012). The 7 Laws of Magical Thinking: How Irrational Beliefs Keep Us Happy, Healthy, and Sane. New York: Hudson Street Press. pp. 165–81. ISBN 978-1-101-55832-4.

Alignment – It's a thing!

Art Credit: Nameless_ACG (333620)

Was HAL 9000 evil or a victim of bad programming?



What do you really expect?

www.tesla.com

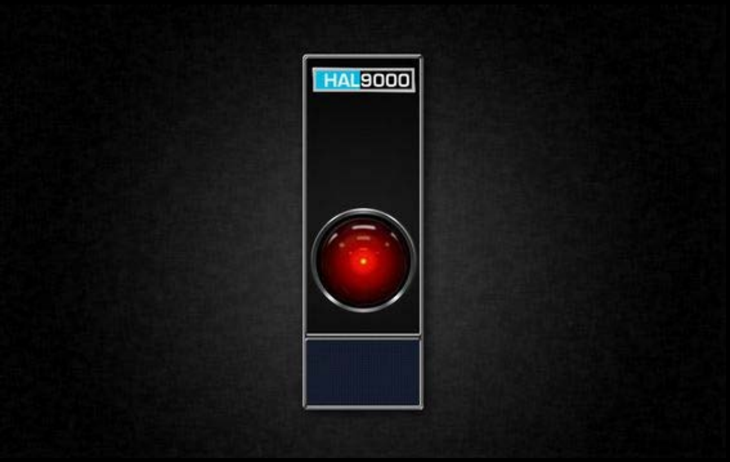
https://youtu.be/fn3KWM1kuAw

https://www.robotcompanion.ai/our-technology/

Reality Check

- Reducing the number of perceived “impossible things that have to be accepted before breakfast”* is a way of incrementally disabusing people of unfounded notions.

- Doing something real with the technology that is of demonstrable value can help to establish the confluence of interests necessary to mature the technology for more advanced applications.



* Allusion to “Alice in Wonderland” by Lewis Carroll. "Alice laughed: "There's no use trying," she said; "one can't believe impossible things."
"I daresay you haven't had much practice," said the Queen. "When I was younger, I always did it for half an hour a day. Why, sometimes I've believed as many as six impossible things before breakfast."

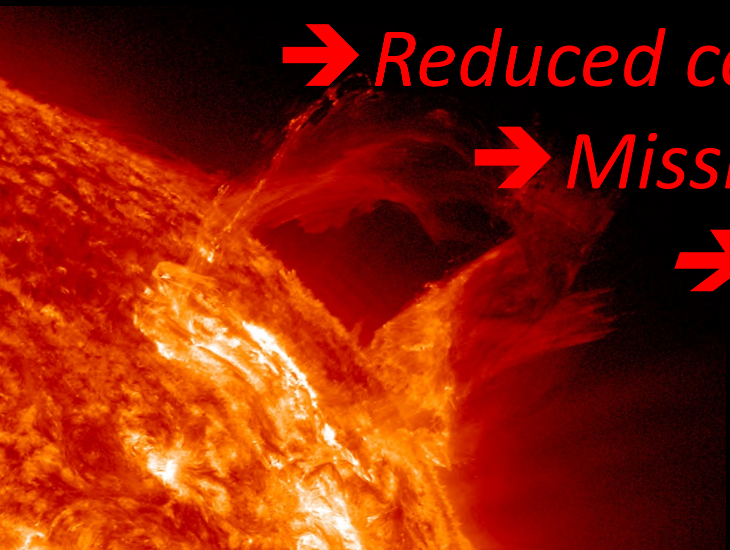
Conclusion → Technology "Push"

- An incremental investment in the development of near realtime state modelling capabilities that meet real mission requirements can serve as a foundational technology for evolving space automation and robotics capabilities.
- *This work can deliver:*

  → *Reduced cost, schedule & technical risk*

  → *Mission enhancing technology*

  → *Mission enabling technology*



Conclusion → Mission Requirements "Pull"

- Creating a foundation for a mutable locus of shared control is an investment in a positive future, not a dystopian one.
- How we come to own our own choices, to take responsibility for our own actions, to being stewards for life as we come to understand it, will be defining for our species.
- In the near term our success in building a symbiotic relationship between humans and autonoma will be a key driver in the development of Cislunar space.
- In the long term our success in same could prove to be a determining factor in the fate of our species.