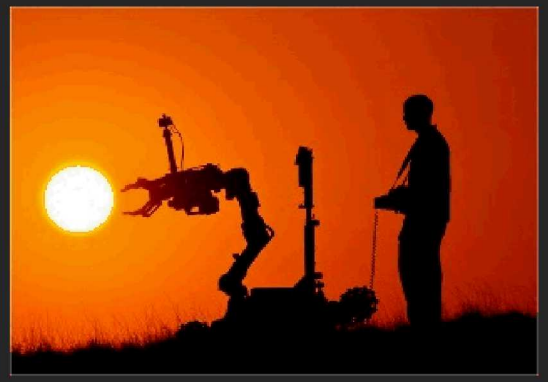
SAND2019-5192PE

Exceptional service in the national interest

Small Unmanned Aerial Systems (sUAS) Overview

Jonathan R. Salton, P.E.
Manager - Robotics & Counter Robotics R&D
High Consequence Automation & Robotics

May 2019

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Sand No. SAND2019-3938 PE

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Intro to UAS

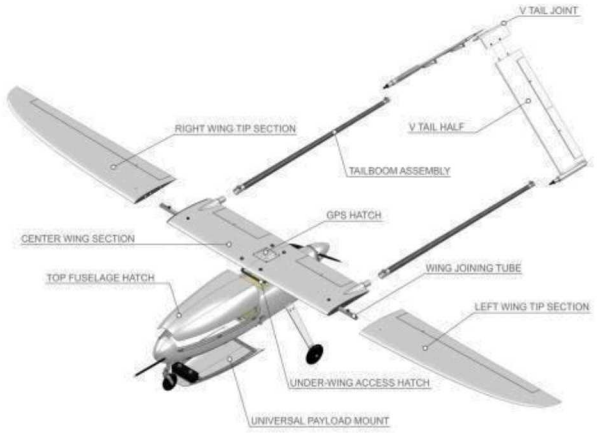
Flying Robots

Unmanned Aerial Systems

- Small UAS are considered category 1 & 2 (<55 lbs. gross weight) and include fixed wing planes

Why so popular now?

- Proliferation of low cost, high performance electronics
- Tipping points in batteries and sensors
- Technology convergence from other application spaces
- In the crawl-walk-run of current autonomy revolution, air domain is the easiest first step



UAV/Drone?

Unmanned Aerial Vehicle

We're not talking about toys, are we?

Not any more!

Source: Youtube.com

Multi-rotor

Fixed Wing

What Makes It a System?

UAV - Vehicle

Payload

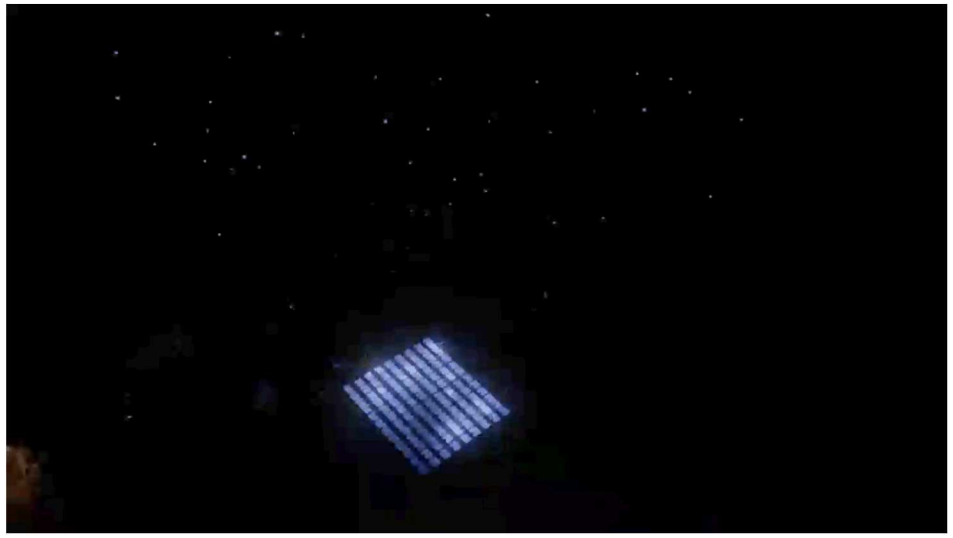
Unmanned Aerial
SYSTEM

Human Interface - Hand Controllers

Base Station
(optional)

Open Source Enables New Capabilities

Hexakaidecacopter – lifting a person



Intel Fields 500 Small UAS for a light show

Dual Use Technologies are evolving faster than our ability to counteract them!
(Especially Aerial Autonomy)

Flying Super Computers?

Skydio R1
(autonomous 4K camera drone with onboard Jetson computer)

Issues with Small UAS

Policy, Legal, and Technical Challenges

Policy

UAS are the fastest growth sector within the US aviation industry!

- Almost 2,000,000 sold in the U.S. in 2015, ~4,000,000 in 2017, still climbing
- Near misses happening regularly
  - Dozens > 9,000 ft. AGL (hobbyist/recreationalist ceiling is 400 ft.)
  - First mid-air collision with manned aircraft in 2017

Current UAS Technologies were not developed to comply with existing FAA airworthiness standards

Privacy/Safety Concerns

Legal

What is trespassing with small UAS?

Delicate balancing act: public/privacy concerns vs. national security?

Technical

Technology revolution has moved development from graduate laboratories to high school student basements

- Additive manufacturing
- Open source software
- Ubiquitous, cheap, miniaturized, advanced capability integrated control hardware/firmware

Current research is poised to continue transforming this landscape (rapid evolution!)

Detection and timely assessment of small UAS at range is challenging with no silver bullet solution

Neutralization is problematic due to policy and collateral damage

- CONUS operations may limit use of some technologies

Not just a UAS issue

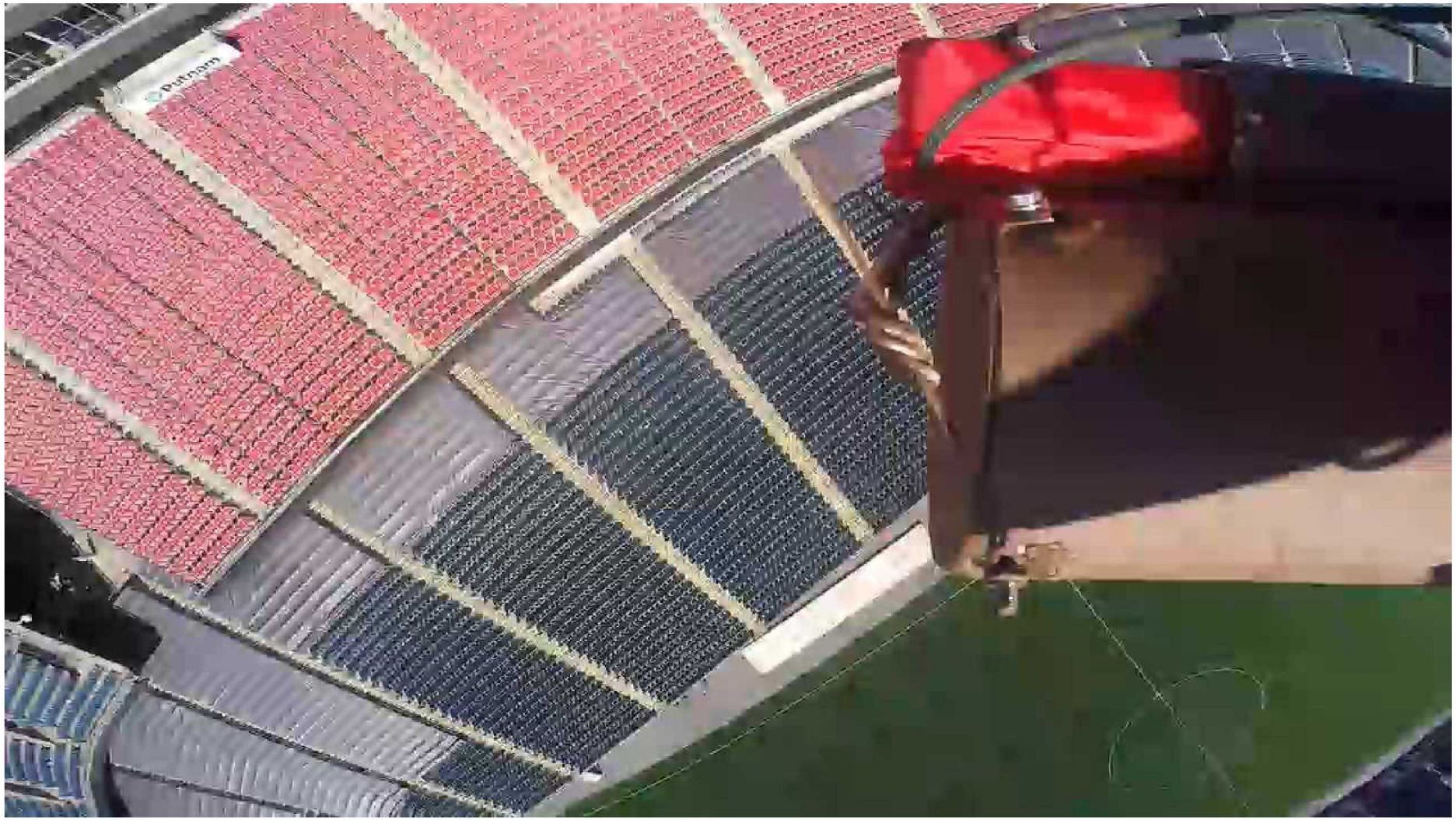
- Multi-modal, advanced autonomy, no RF link to exploit…

Approx. Payload = 9 lbs

Example #1 of Makeshift Capability

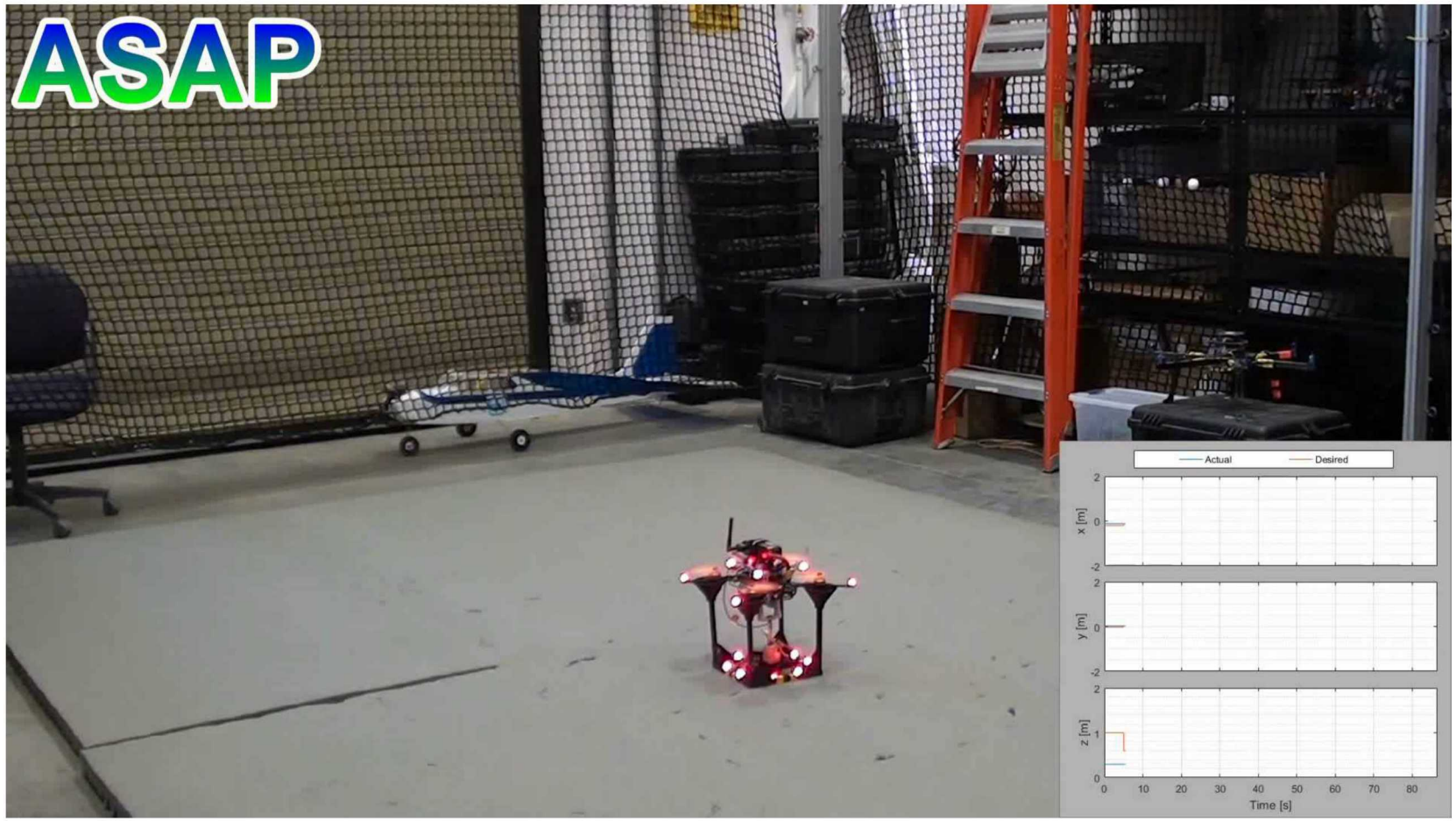
Infrared camera from Hex tracking jogger @ ¼ mile

Example #2 of Makeshift Capbility

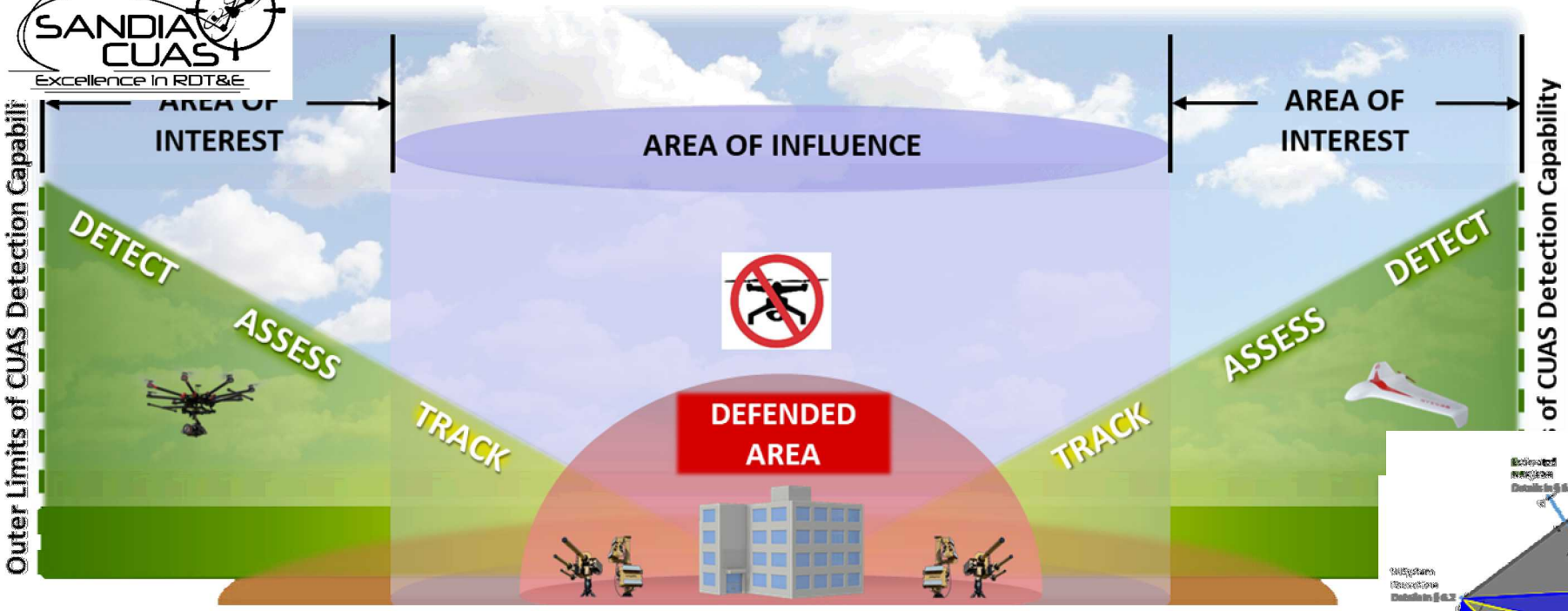


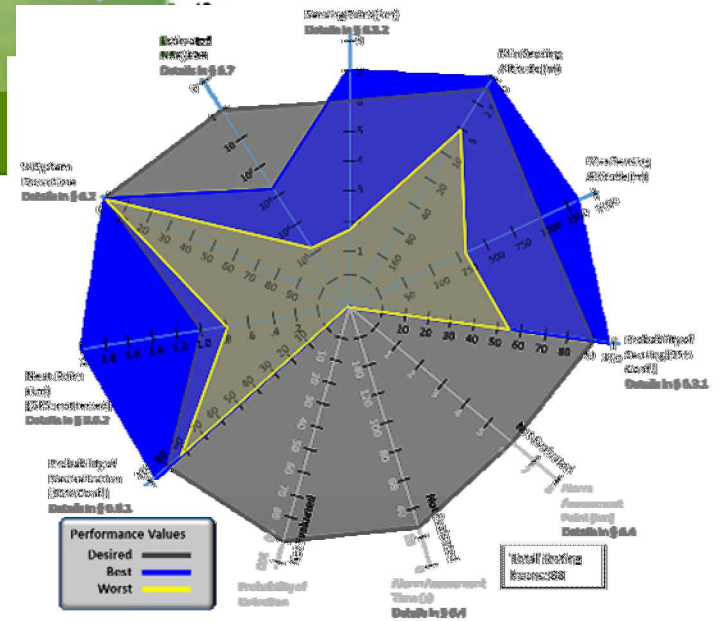
Examples of UAS Autonomy

Flight controller capabilities, swarming behaviors, collective intelligence



Scientific Approach to Testing & Evaluation



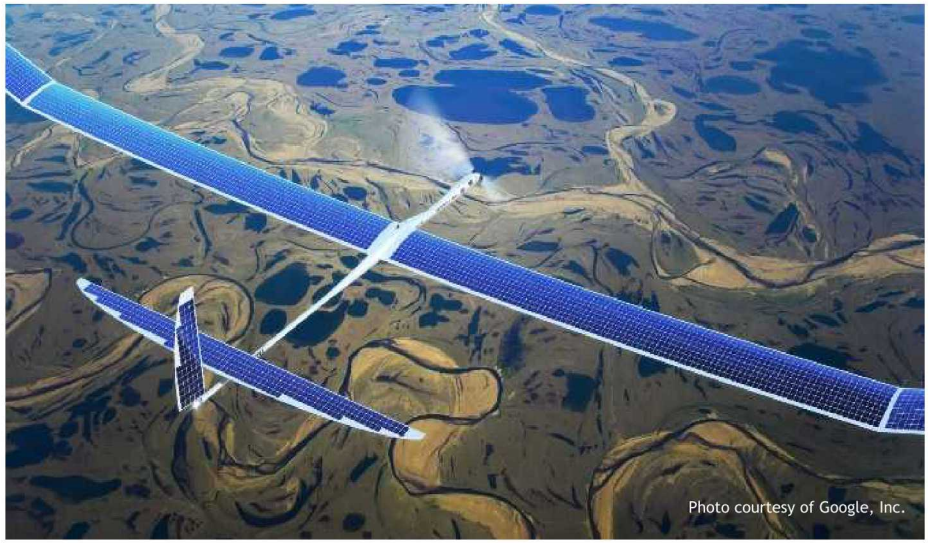


- Notional representation of system evaluation -

Looking Ahead

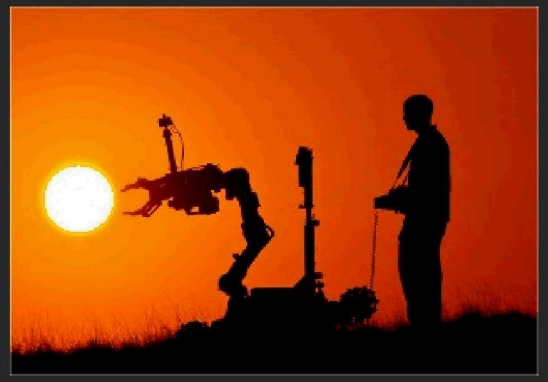
- Continued rapid technology evolution
  - No comm link
    - No signal to sense or manipulate
    - Attribution?
  - Rapid, reactive control
    - Low and fast
    - Randomized behavior from blue perspective
  - Push button swarms
    - One person controlling many platforms
    - Synchronized missions miles apart
    - Dynamic objectives
- Continued convergence = surprise (opportunity)
- Multi-purpose platforms (additive mfg.)

Google: Internet from the Sky



QUESTIONS?

Exceptional service in the national interest

Autonomy Intuition

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High Consequence Automation & Robotics

May 2019

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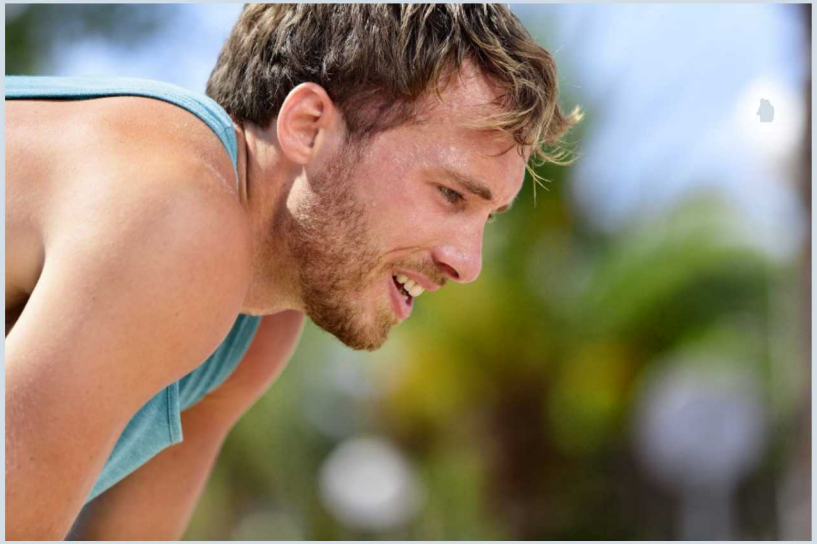
AUTOMATION/AUTONOMY DEFINED

HEERMANN PERSPECTIVE – AN ENGINEERING APPROACH



The Body sweating is an automatic function. (Autonomic Response)

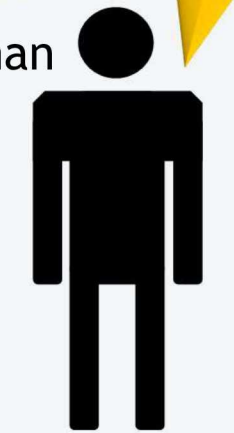
It is the response of the body to maintain it's temperature

The choice to move into the shade to get out of the sun is Autonomy

It is reasoning about the environment and interacting with the environment

Extramural Interacting

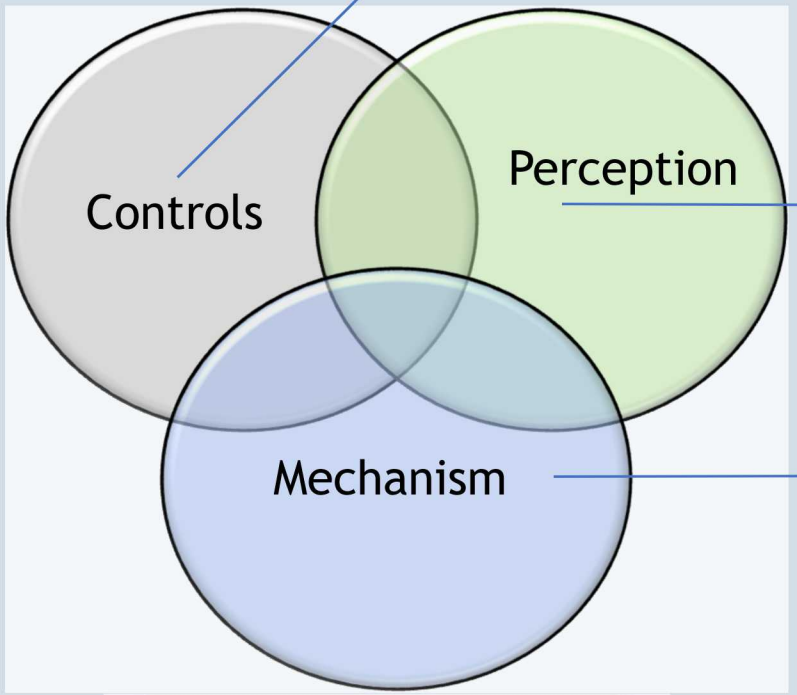
What is Autonomous?



Foundational Concept #1

Autonomy knowledge can be embodied in physical structures

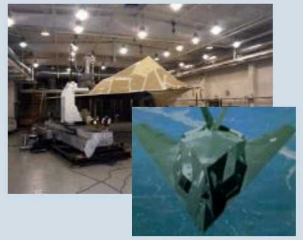
ROBOTICS IS THE INTEGRATION AND BALANCING OF THREE KEY TECHNOLOGIES



Foundational Concept #2

Robotics solves problems by combining and trading-off between three technology areas

Wheeled Hopping Robot



F-117 Robotic Coating System

Sandia Hand

Stage Right

Weapons Demilitarization

Walking Robots

SAFETY IS AN IMPORTANT ELEMENT OF TRUST IN MACHINES

Safety Hierarchy

Most Effective

Safe Design: Nasty cut, but severed foot hazard is eliminated

More Effective

Guard: Barrier to protect foot from contacting blade

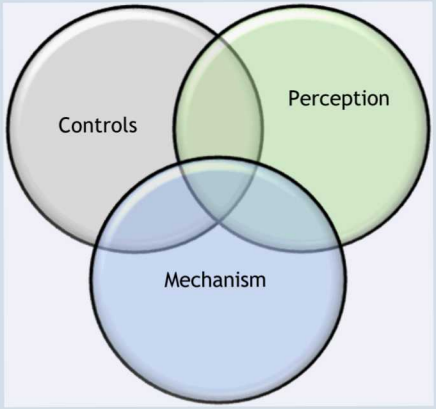
Least Effective

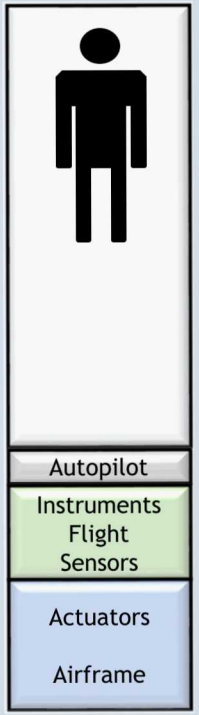
Warning: Don't place your foot in blade

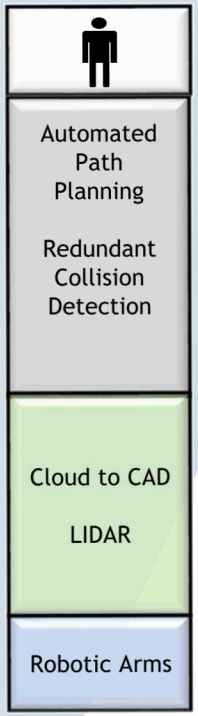
Foundational Concept #3

- **Consider how safety is assured**

ESTABLISHING TRUST



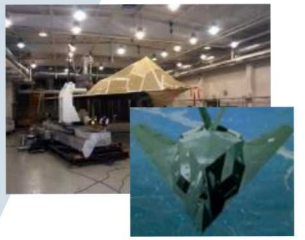




Standard Automobile

Cessna 182 Airplane

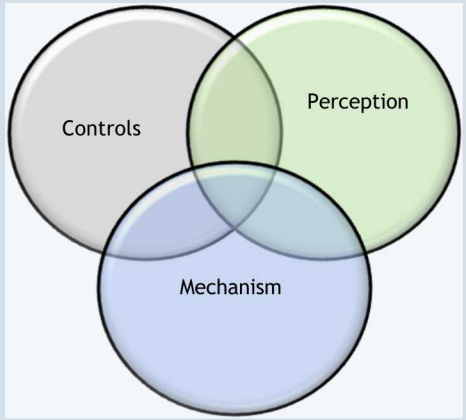
Space Shuttle

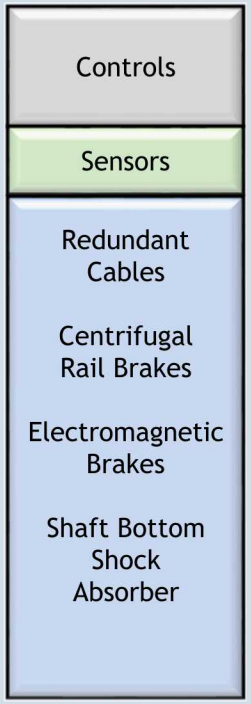


F-117 Robotic Coating System

Autonomous Automobile

FULLY TRUSTED MACHINES ?

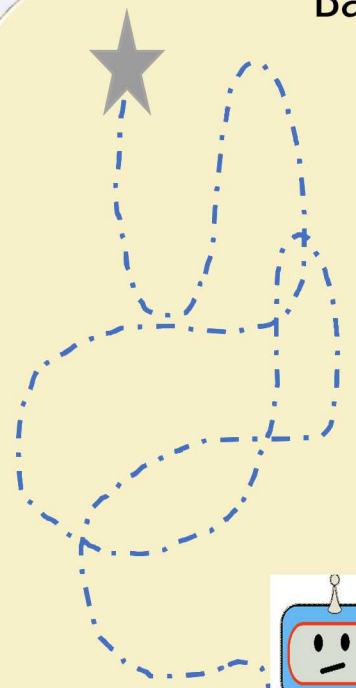


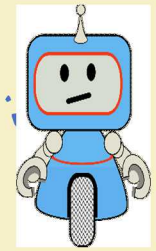


Elevator

Autonomous Automobile

Barriers to Trust of Autonomy



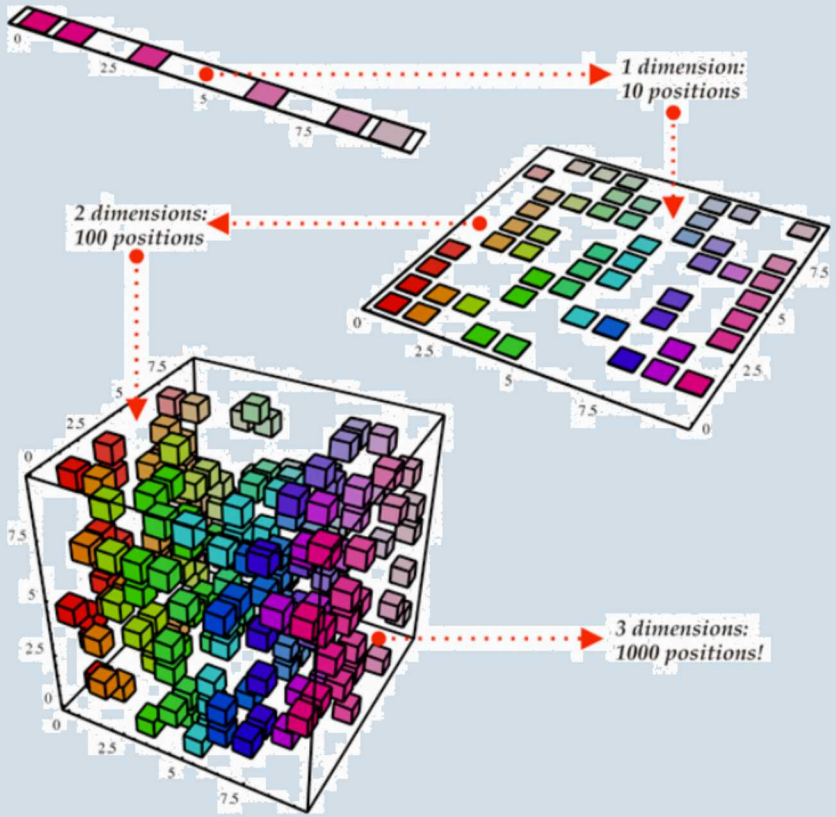


- Lack of human-analog sensing and thinking by the machine.
- Lack of self- or environmental awareness by the machine
- Low observability, predictability, directability, and auditability
- Low mutual understanding of common goals
- Ineffective interfaces
- Systems that learn

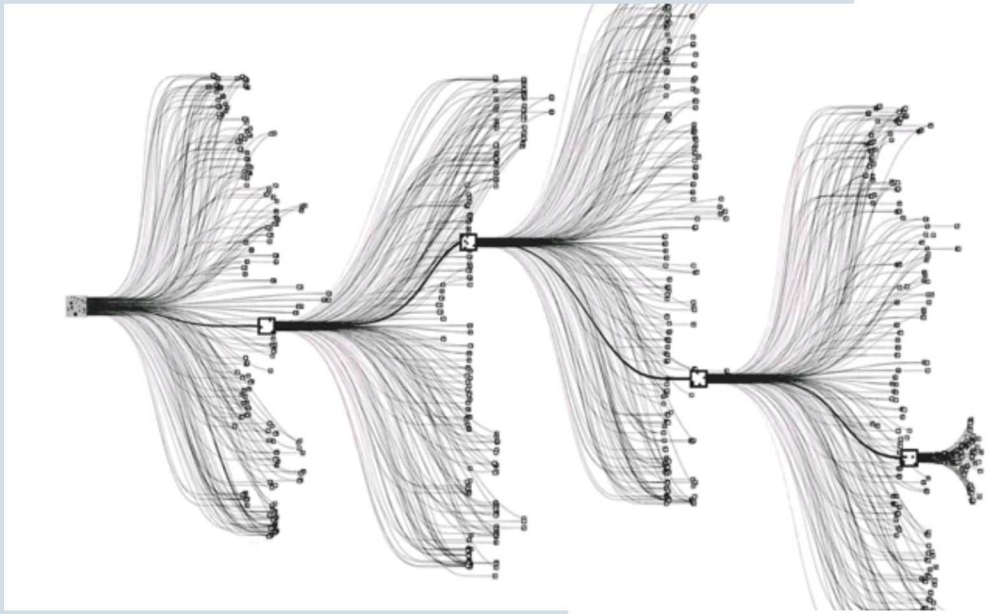
Defense Sciences Board 2016

Establishing Trust in Autonomy

Core Issue is Curse of Dimensionality



The machine learning technologies at the core of autonomy have too many possible states to check them all for “Untrustworthy conditions”.



Small section of the combinatorial game tree for the game of Go. The branching factor, or the number of possible moves in any position is about 200 for Go, which is an order of magnitude more complex than the 20 found in the game of chess. Courtesy Goggle’s DeepMind. https://blogs.loc.gov/maps/category/game-theory/

The universe has an estimated 1×10^{79} atoms

Deep Learning models have 1000’s of degrees of freedom – 1×10^{1000} possible states

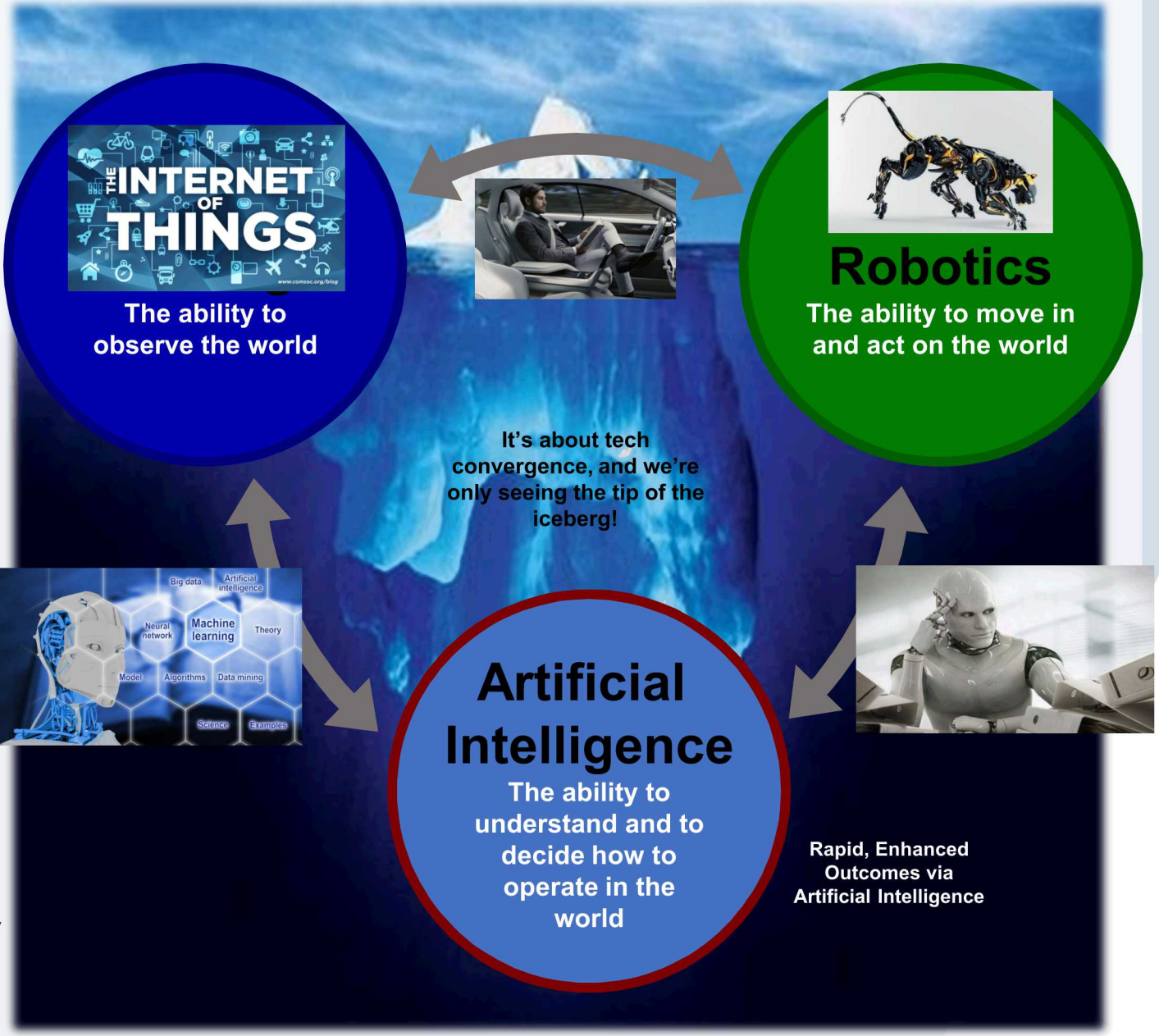
Core of Autonomy Revolution

Omniscience via the Connectedness of Everything

"Whoever leads in artificial intelligence will rule the world."
- **Vladimir Putin**, 9/4/17

"Competition for AI superiority at national level is the most likely cause of WW3."
- **Elon Musk**, 9/4/17

"Hackers have already started to weaponize Artificial Intelligence."
- George Dvorsky www.gizmodo.com, 9/11/17



Loyal, Fearless, Expendable Teammates via Robotics

Rapid, Enhanced Outcomes via Artificial Intelligence

"The global market for autonomous vehicles is projected to grow from $42 billion in 2025 to $77 billion by 2035."
– Boston Consulting Group

Autonomy Interaction Cycle

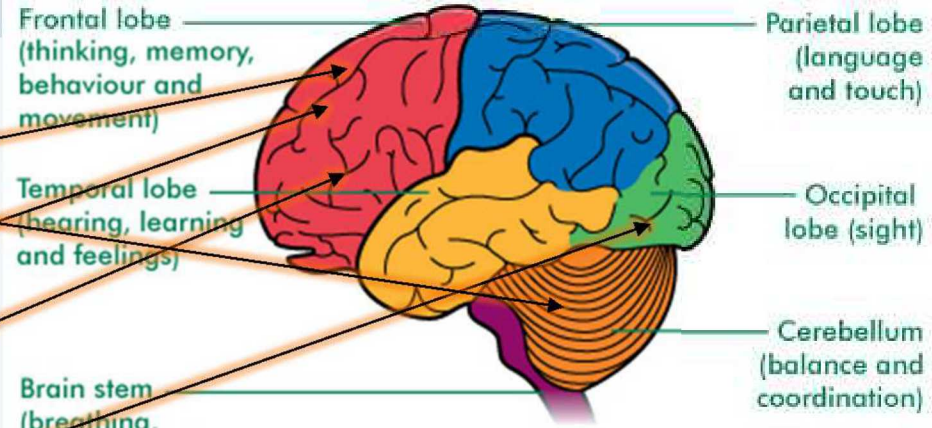
OODA Loop*

- Act
- Decide
- Orient
- Observe

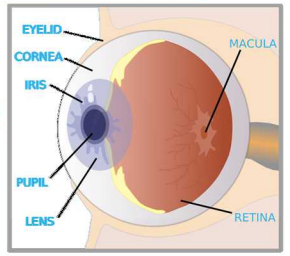
*USAF Colonel John Boyd

Interaction Cycle

- Act
- Decide
- Orient
- Perceive
- Sense



Eye

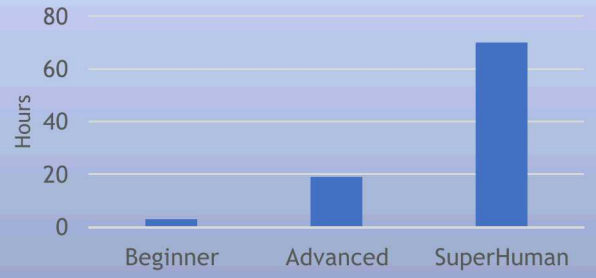


It takes many years for a human to become an expert in the Game of Go.

An important strength of the United States is our ability to rapidly develop and apply a diverse spectrum of new technologies faster than other nations

Numerous Autonomy Interaction Cycles

Google's *AlphaGo Zero* Training

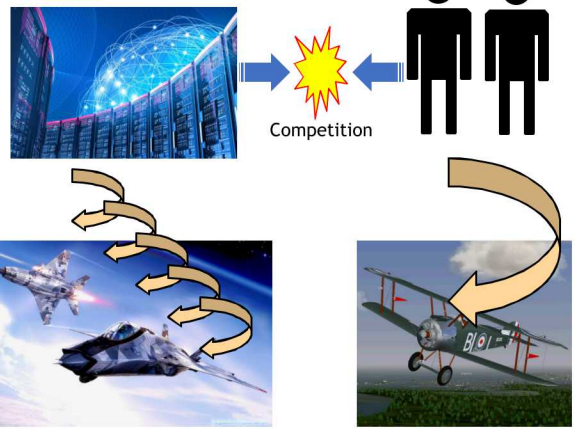


Performance Playing the Game Go

Artificial Intelligence can learn to beat any human player in less than 3 days

https://deepmind.com/blog/alphago-zero-learning-scratch/

AI is demonstrating potential to adapt much faster than humans
(i.e. Interaction loop is much short than human guided development)



New Challenge to National Autonomy

U.S. Autonomy does not need to be challenged broadly

Challenged in key areas could have significant impact

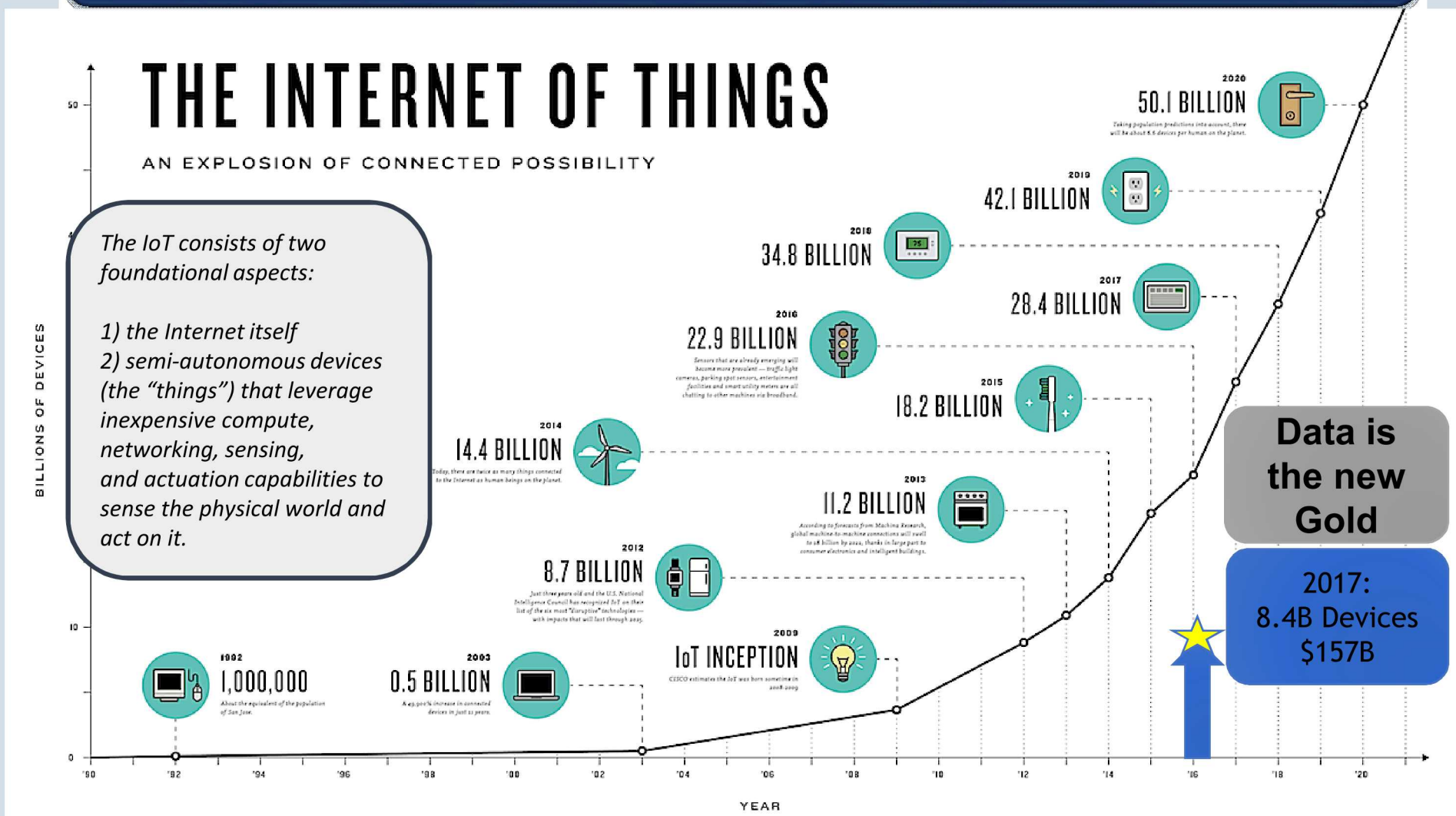
May not be possible to play catch-up (like Cold War)

Autonomy brings AI into the physical world

Backup Slides

AUTONOMY AT REST: INTERNET OF THINGS

The IoT will include 50 billion devices and each user of those gadgets will generate 1.5 gigabytes of data every day.



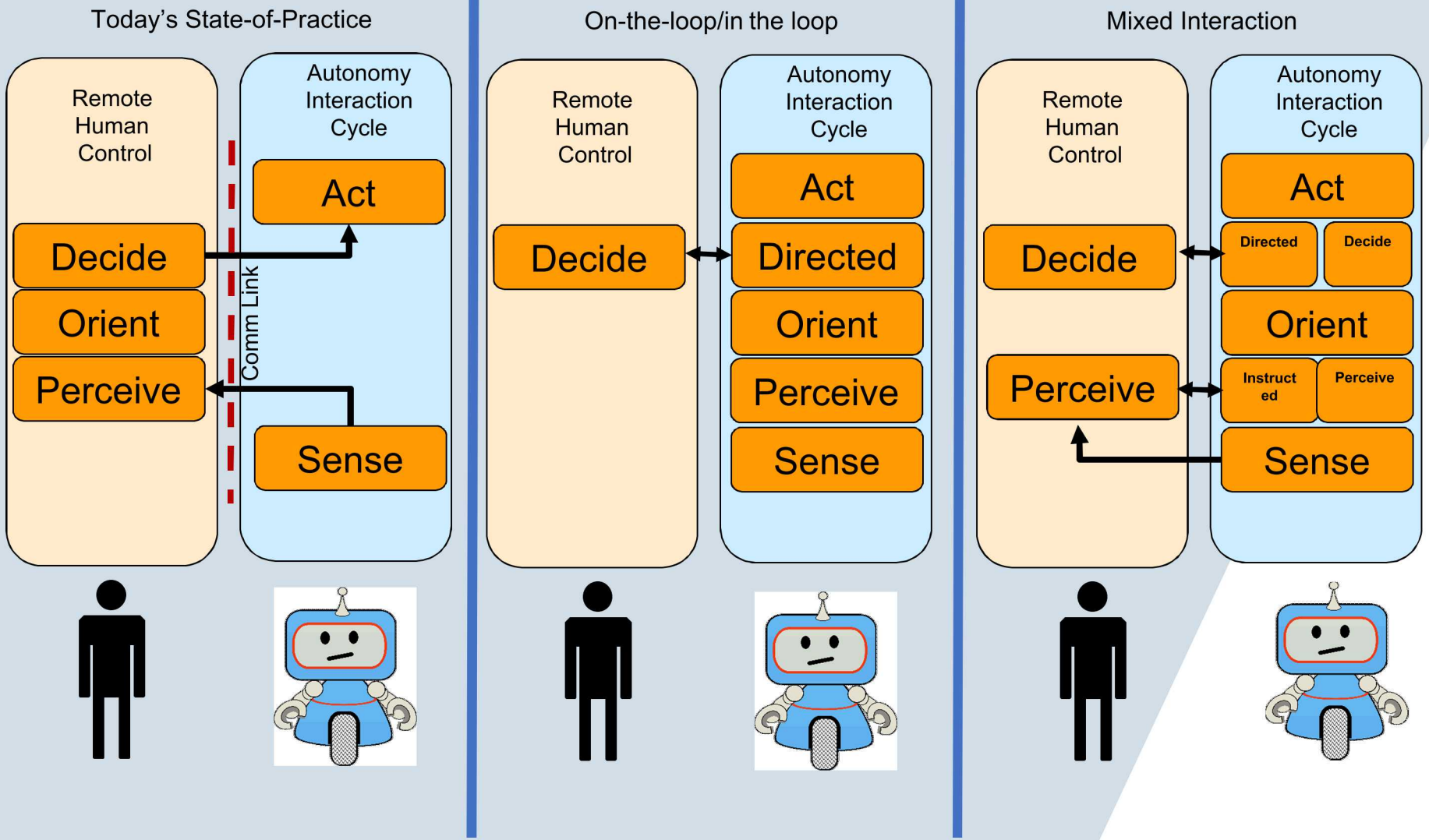
The IoT consists of two foundational aspects:

1) the Internet itself
2) semi-autonomous devices (the "things") that leverage inexpensive compute, networking, sensing, and actuation capabilities to sense the physical world and act on it.

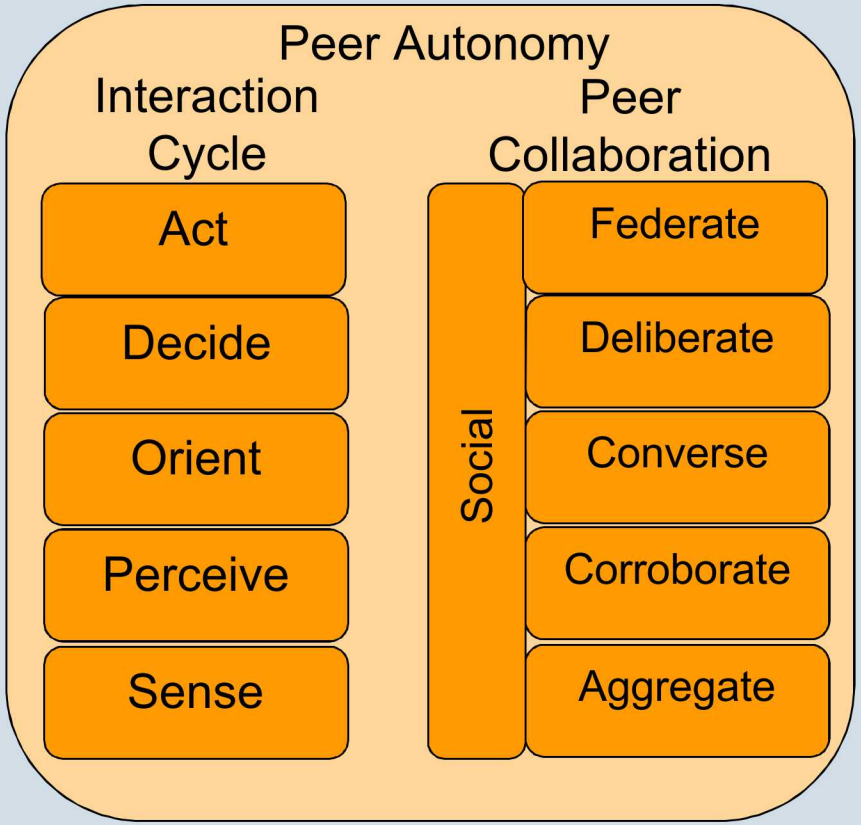
AUTONOMY IN MOTION: AUTONOMOUS VEHICLES LANDSCAPE

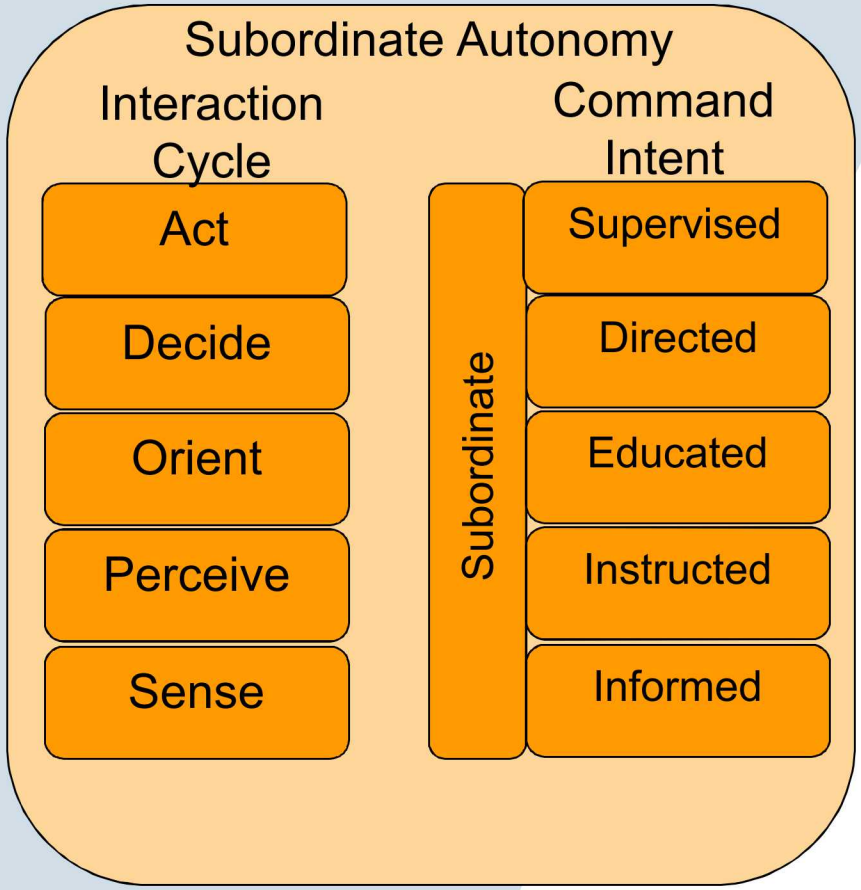
- *Autonomy brings together multiple disciplines, market sectors, etc.*
- *to create operational (and safe) systems*

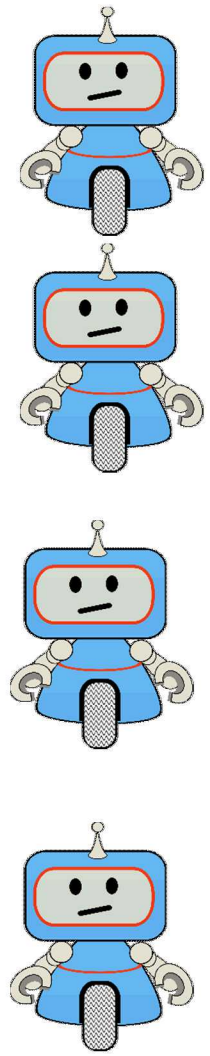
Interaction Models



Collaboration Models







SANDIA HIGH CONSEQUENCE AUTONOMY & ROBOTICS CAPABILITIES

PIONEERING & PATHFINDING

For over 3 decades, Sandia has pioneered **robotics** and **intelligent systems** technology.

- **1988** Ground Surveillance Robots
- **1989** Fire Ant – Tank Killing Robot
- **1990's** Hopping Robots
- **1990's** Micro Robotics
- **1990-2000's** Mobile Manipulation
- **1998-2002** Swarms
- **2002** Micro Assembly
- **2006** Golf Ball Hopping Robot
- **2012** Sandia Hand (30x less expensive)
- **2012** Guided 50 caliber bullet
- **2016** High Energy Efficient Walking Robot
- Numerous ongoing projects

Sandia Hand

Guided Bullet

Walking Robots

F-117 Robotic Coating System

Weigh and Leak Check System

Micro Robots Collected by Smithsonian

Golf Ball Hopper (Printed Explosives)

Strategic Reserve Stage Right, storage and monitoring

Weapons Demilitarization

Groundbreaking Robotics

Autonomy Enabled Mobile Sampling

HIGH CONSEQUENCE AUTONOMY

Sandia's Robotics team develops, delivers, and supports **fault-controlled, high consequence automation and autonomy.**

- Stage Right
- Weigh and Leak Check System
- Explosive Handling
- F-117 Robotic Coating
- Army Demilitarization Systems

Several systems operational for decades.

Engineered Safety with risk managed as high as one in a million ($1:10^6$)

SANDIA ROBOTICS' CORE CAPABILITIES

Swing-free ship offloading

Micro Robots Collected by Smithsonian

Strategic Reserve Stage Right, storage and monitoring

Weapons Demilitarization

Cybernetics

30 years of Field Robotics

Automation & Autonomy

Human-Machine Interface

Fail-Safe Design & Integration

Robust Manipulation

Unique Mobility

Advanced Controls

Machine Perception

Ground-Breaking Robots Collected by Smithsonian

Wheeled Hopping Robot

Sandia Hand

High Efficiency Walking Robot

*Beyond limited point solutions, Sandia develops **robust, fail-safe systems** by bringing together a suite of technology, tools, and skills.*