Systems Engineering and Autonomy: Opportunities and Challenges

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Why Increase Autonomy?

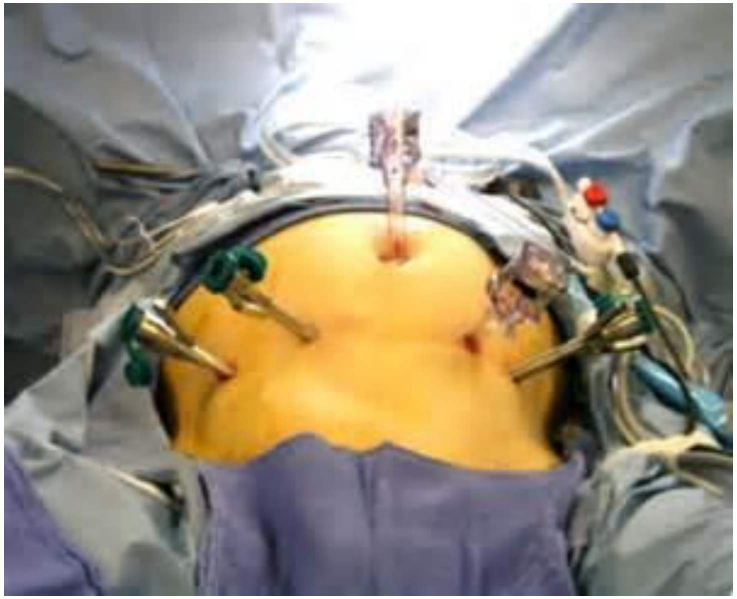
Speed

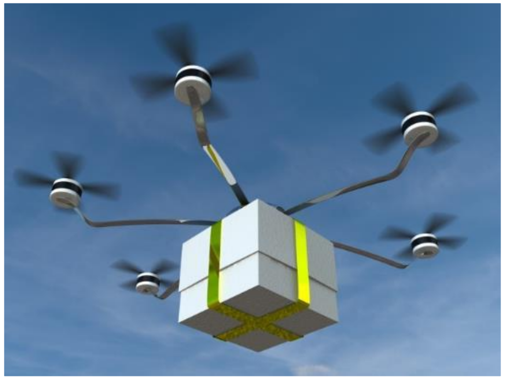
Volume

Danger

Persistence

Communication issues





Our systems are increasingly autonomous

2020

Algorithmically driven agents will work in 5% of economic transactions.

20% of all business content will be authored by machines.

6 billion connected things will be requesting support.

50% of the fastest growing companies will have fewer employees than smart machines.

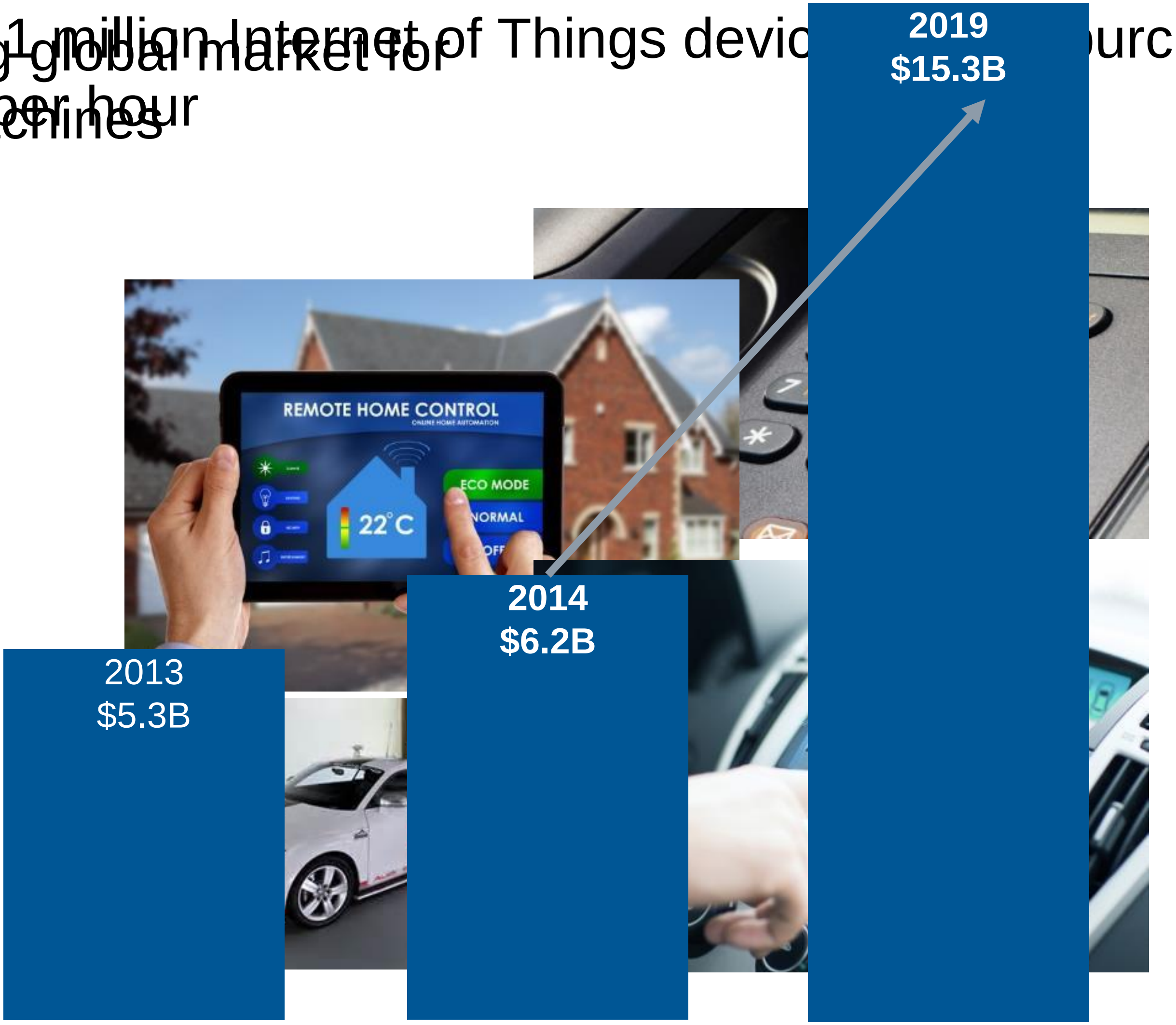
More than 3 million workers globally will be supervised by “robobosses.”

Source: Gartner Research, *Top Strategic Predictions for 2016 and Beyond*, October 2015.

Autonomy is also becoming big business

By 2021, 1 million Internet of Things devic urchased and installed per hour

A growing global market for smart machines



Source: Report of a 2016 briefing by Daryl Plummer, vice president, distinguished analyst and Gartner Fellow at Gartner Research.

Source: Gartner Research, *Top Strategic Predictions for 2016 and Beyond*, October 2015.

Some autonomous systems may be expert software systems

Finance

Medicine

Real-time Process Control

. . . while others are very real, such as robots and UAS

These smart machines are more than *automated* systems

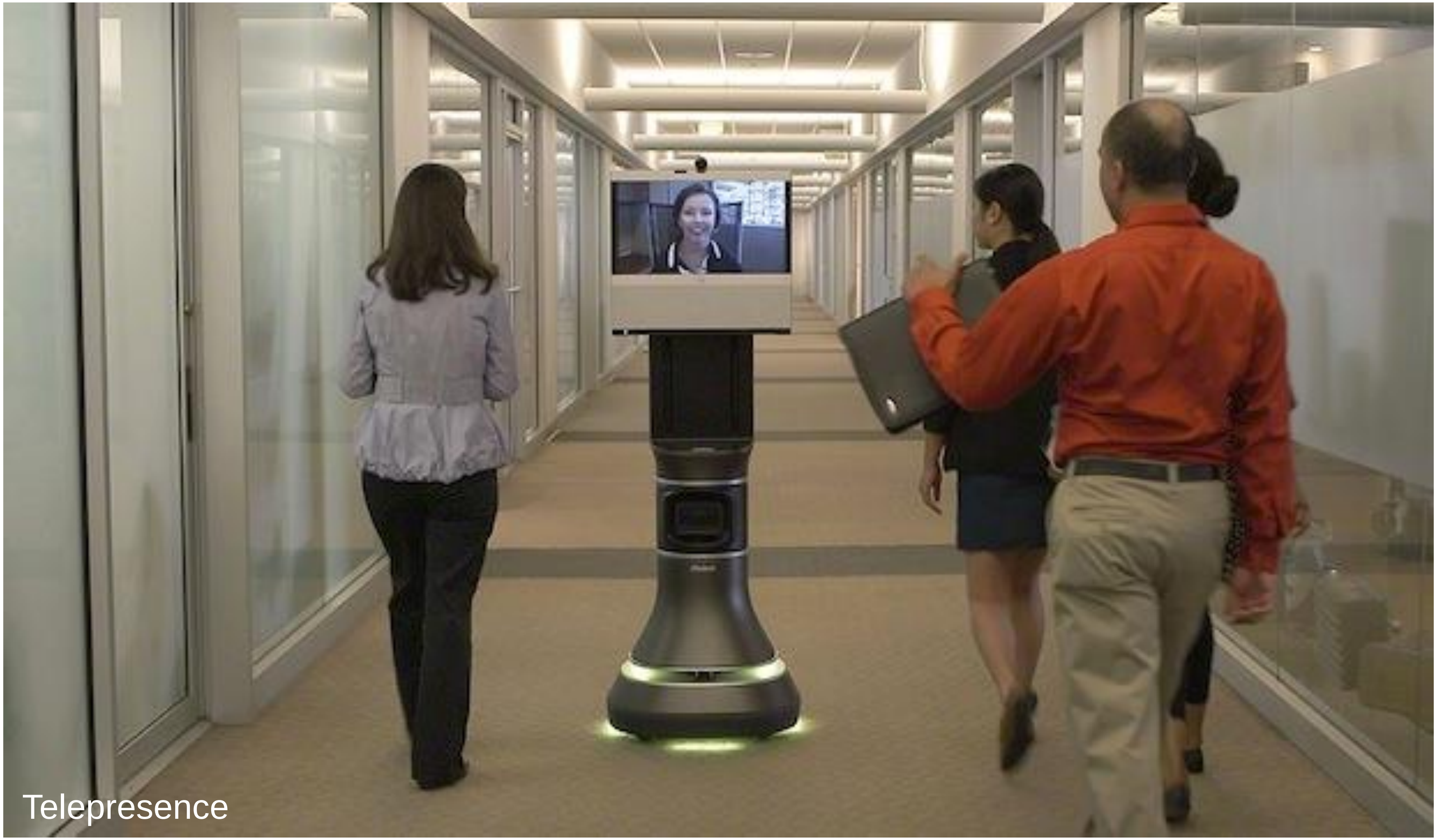
Automated teller machine

Autopilot

Automated building cleaning system

Automated pharmaceutical manufacturing

. . . and more than *virtual reality* devices



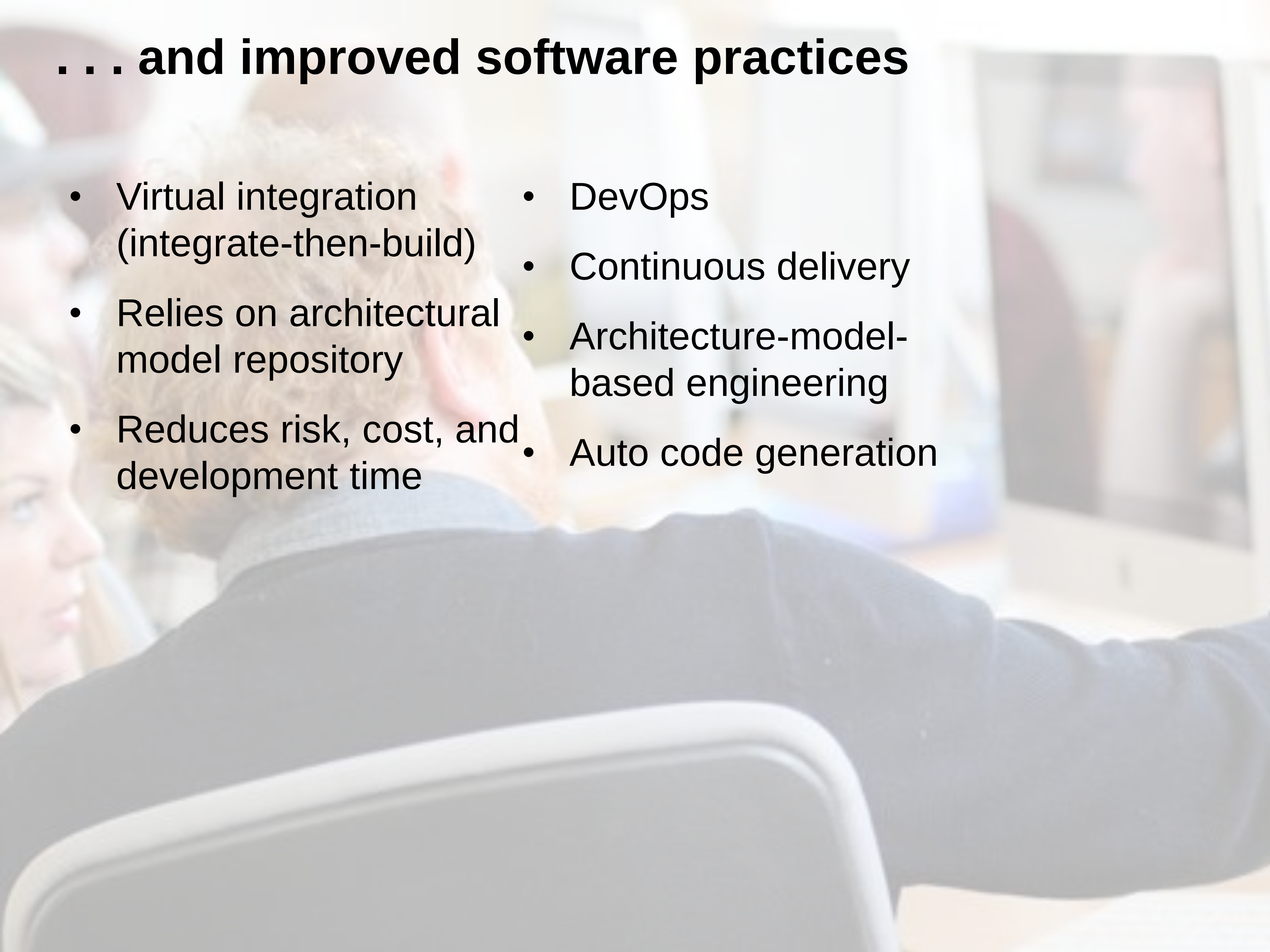
Telepresence

Autonomous systems in use today are the result of decades of R&D

R&D areas include

- Digitization of sensors
- Adaptive algorithms
- Natural user interfaces
- Machine learning
- Machine vision

. . . and improved software practices



- Virtual integration (integrate-then-build)
- Relies on architectural model repository
- Reduces risk, cost, and development time

- DevOps
- Continuous delivery
- Architecture-model-based engineering
- Auto code generation

. . . As well as the convergence of software capabilities

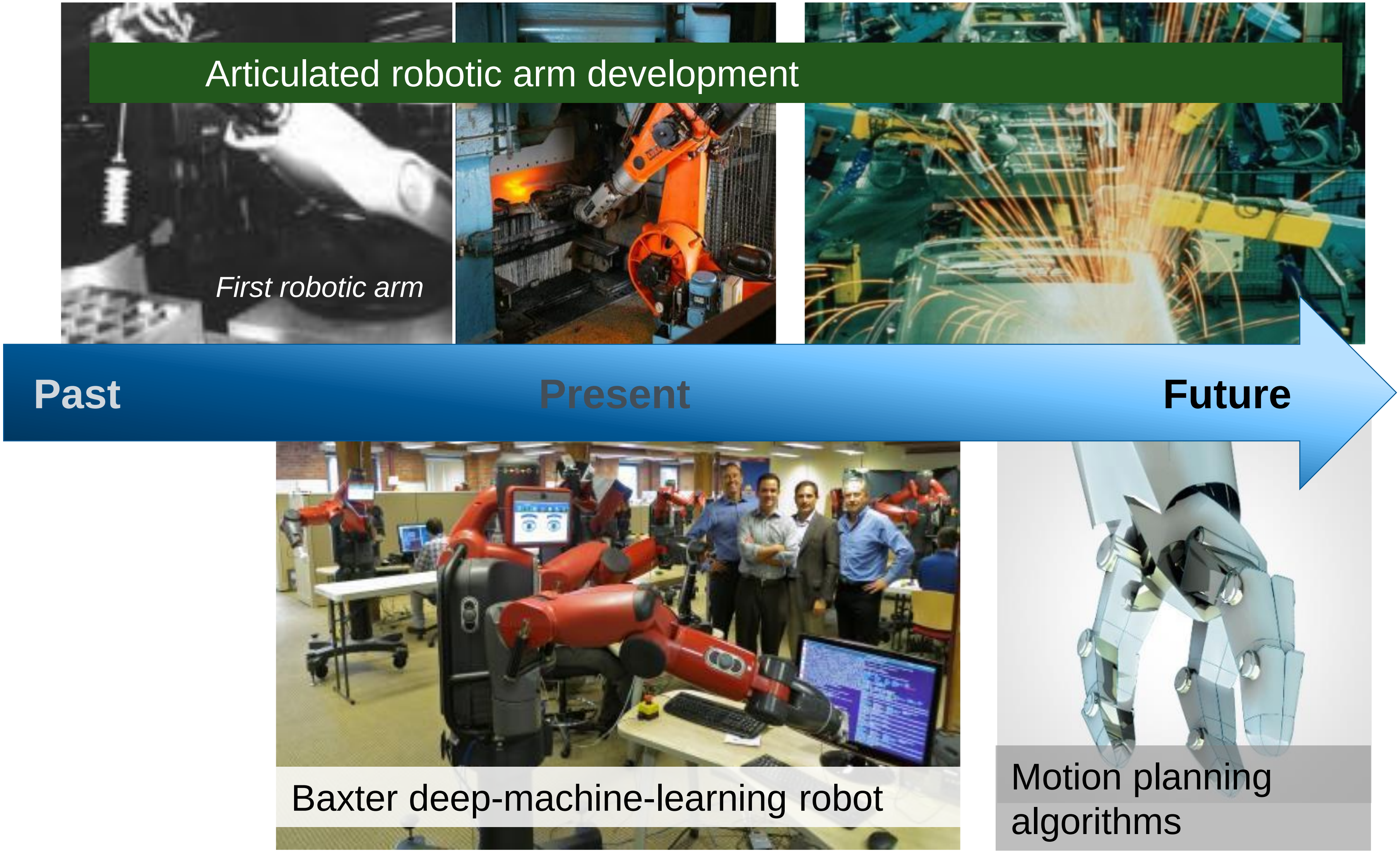
2007: DARPA Urban Challenge

> “This car is the holy grail of autonomous driving.”

Prof. Raj Rajkumar, co-director, CMU-General Motors
Autonomous Driving Collaborative Research Lab

2014: Autonomous Cadillac SRX

Autonomous systems improve productivity



Articulated robotic arm development

First robotic arm

Past

Present

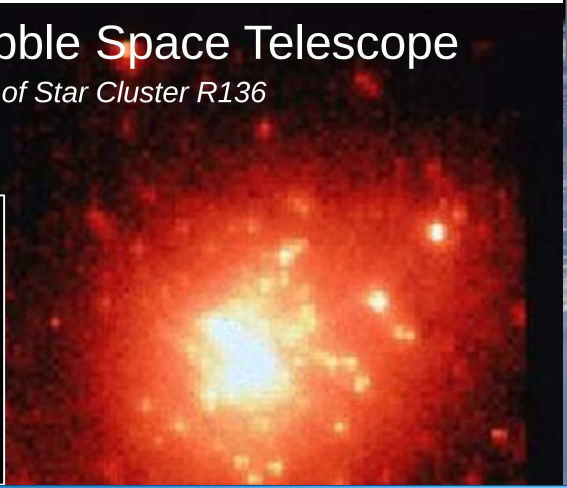
Future

Baxter deep-machine-learning robot

Motion planning algorithms

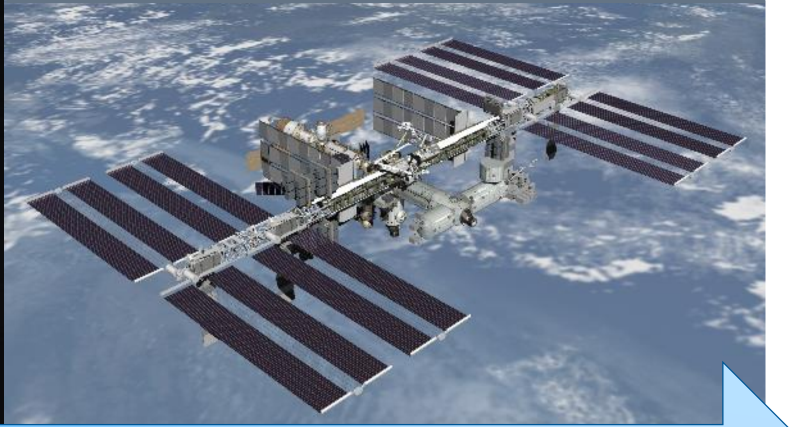
They can operate continuously

Sputnik



Hubble Space Telescope

View of Star Cluster R136

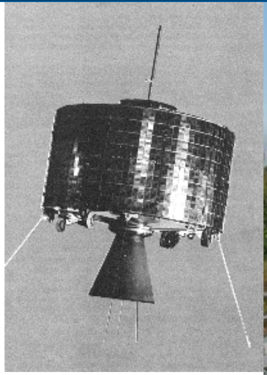


International Space Station

Past

Present

Future



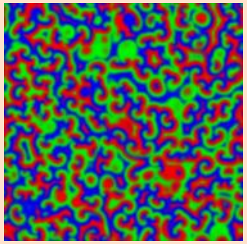
Syncom 3

Driverless metro lines

(pictured: Copenhagen)

Soft robots: change shape and move via their own internal energy

Bio-inspired prototype "soft robot" material with greater dexterity and mobility (U. of Pitt.)



They increase information sharing

Aquila drone

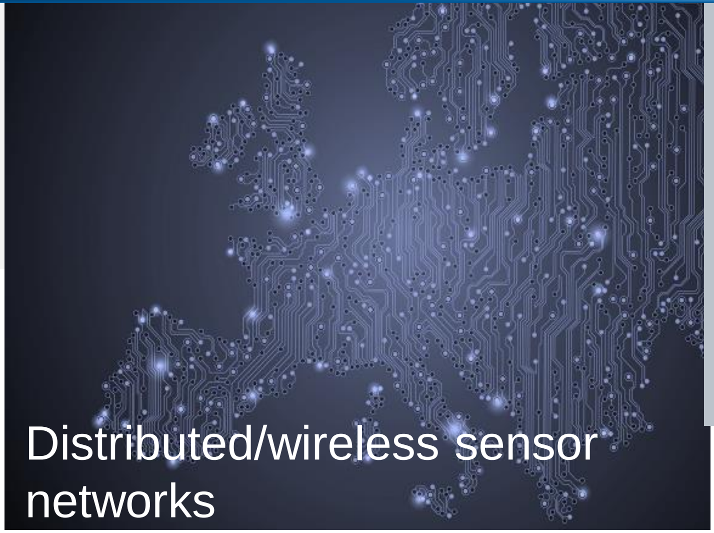
Global Hawk

Mapped damage to help target relief efforts after earthquake in Haiti

Advancements in sensing technologies

Past **Present** **Future**

- *Originally a battlefield target designator*
- *Now used to bring Internet access where none exists*



Distributed/wireless sensor networks

They can process tremendous volumes of data

Stanley

Winner of 2005 DARPA grand challenge

Watson

2,800 microprocessors, with capacity to handle 80 trillion operations per second

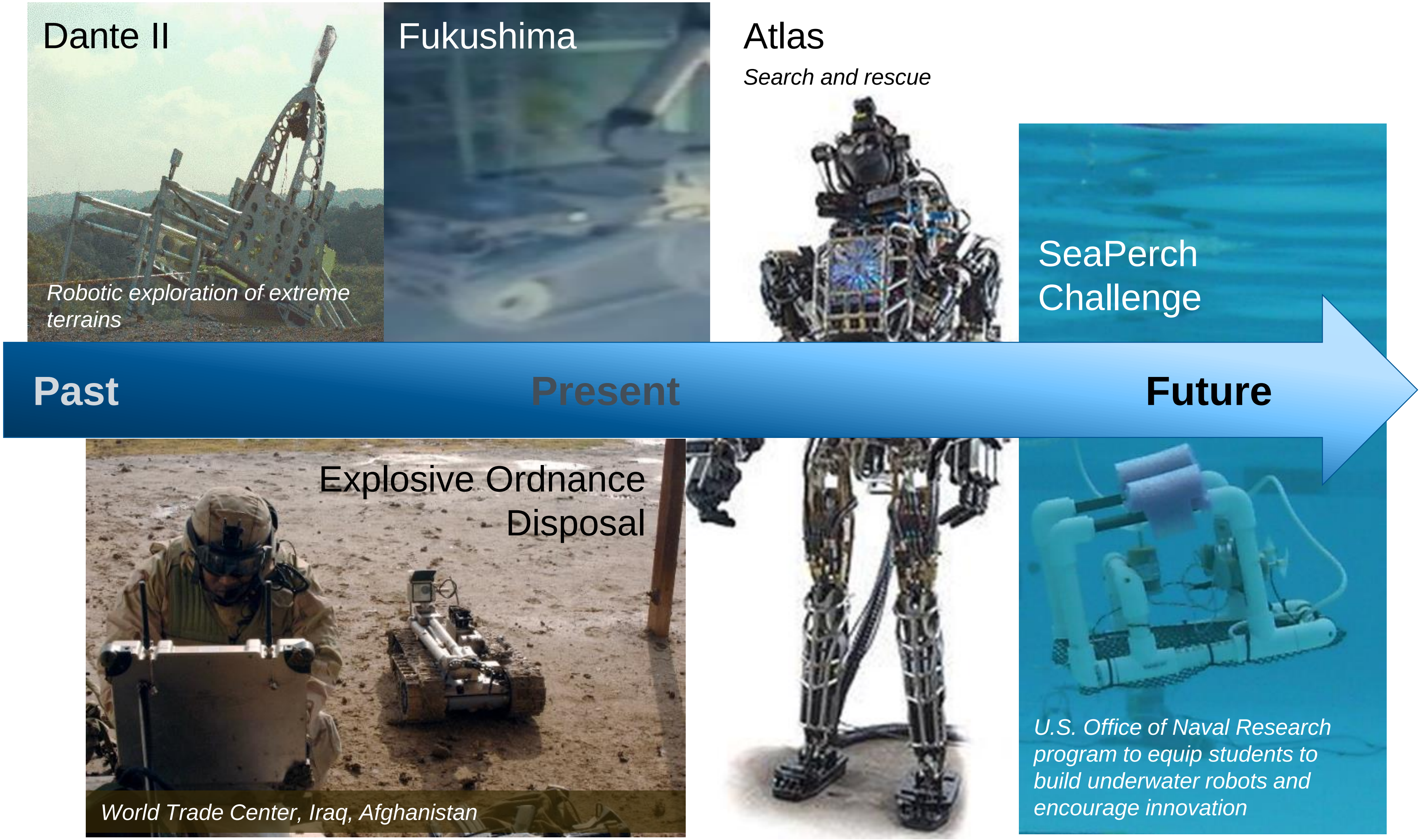
Past **Present** **Future**

Diagnostic expert systems

Deep Blue

Memorial Sloan Kettering Cancer Center trains Watson to help oncologists make more nuanced treatment decisions more quickly

They will work where we cannot safely go



Dante II

Robotic exploration of extreme terrains

Fukushima

Atlas

Search and rescue

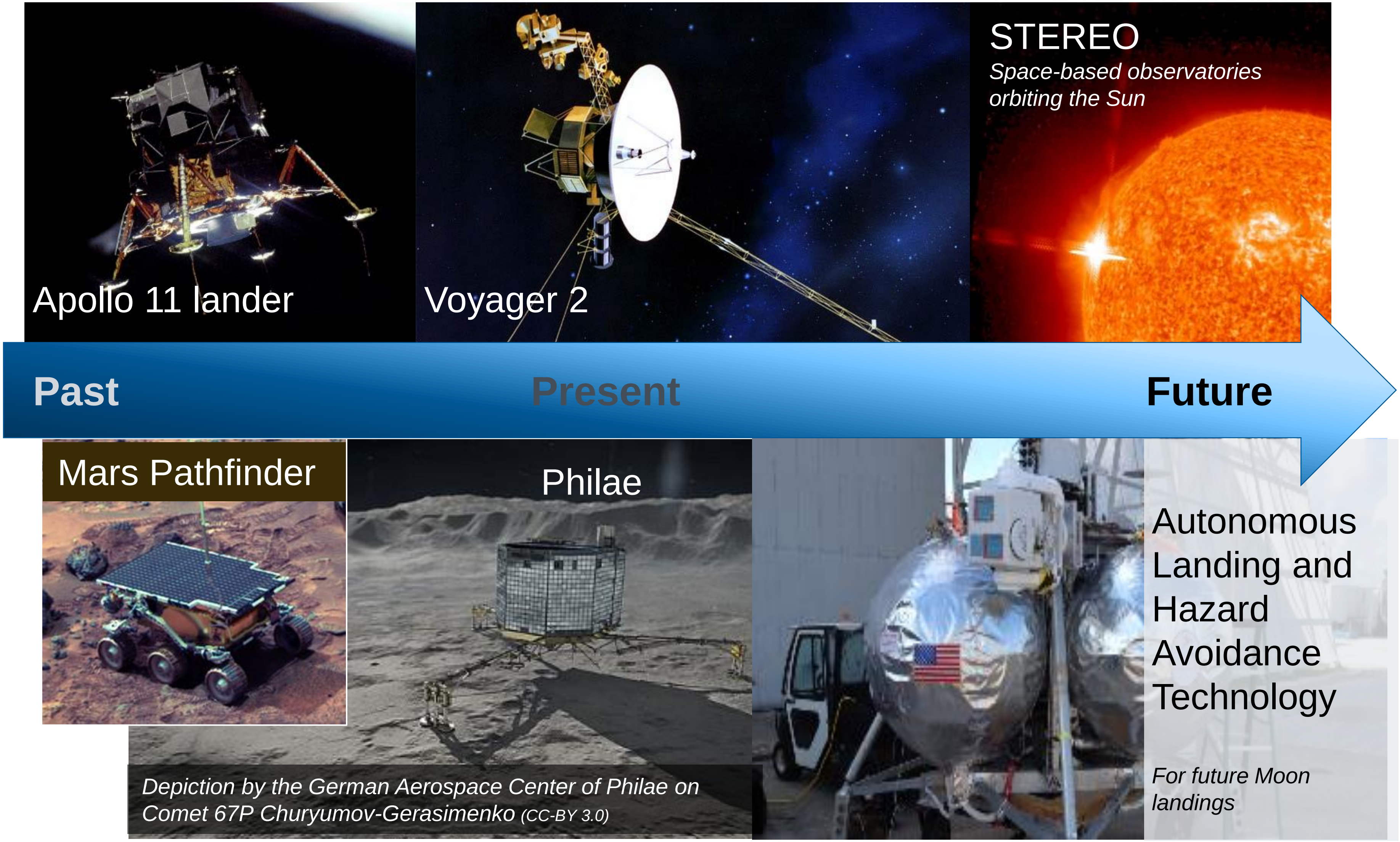
SeaPerch Challenge

Explosive Ordnance Disposal

World Trade Center, Iraq, Afghanistan

U.S. Office of Naval Research program to equip students to build underwater robots and encourage innovation

We use them to explore the universe



Apollo 11 lander

Voyager 2

STEREO

Space-based observatories orbiting the Sun

Past

Present

Future

Mars Pathfinder

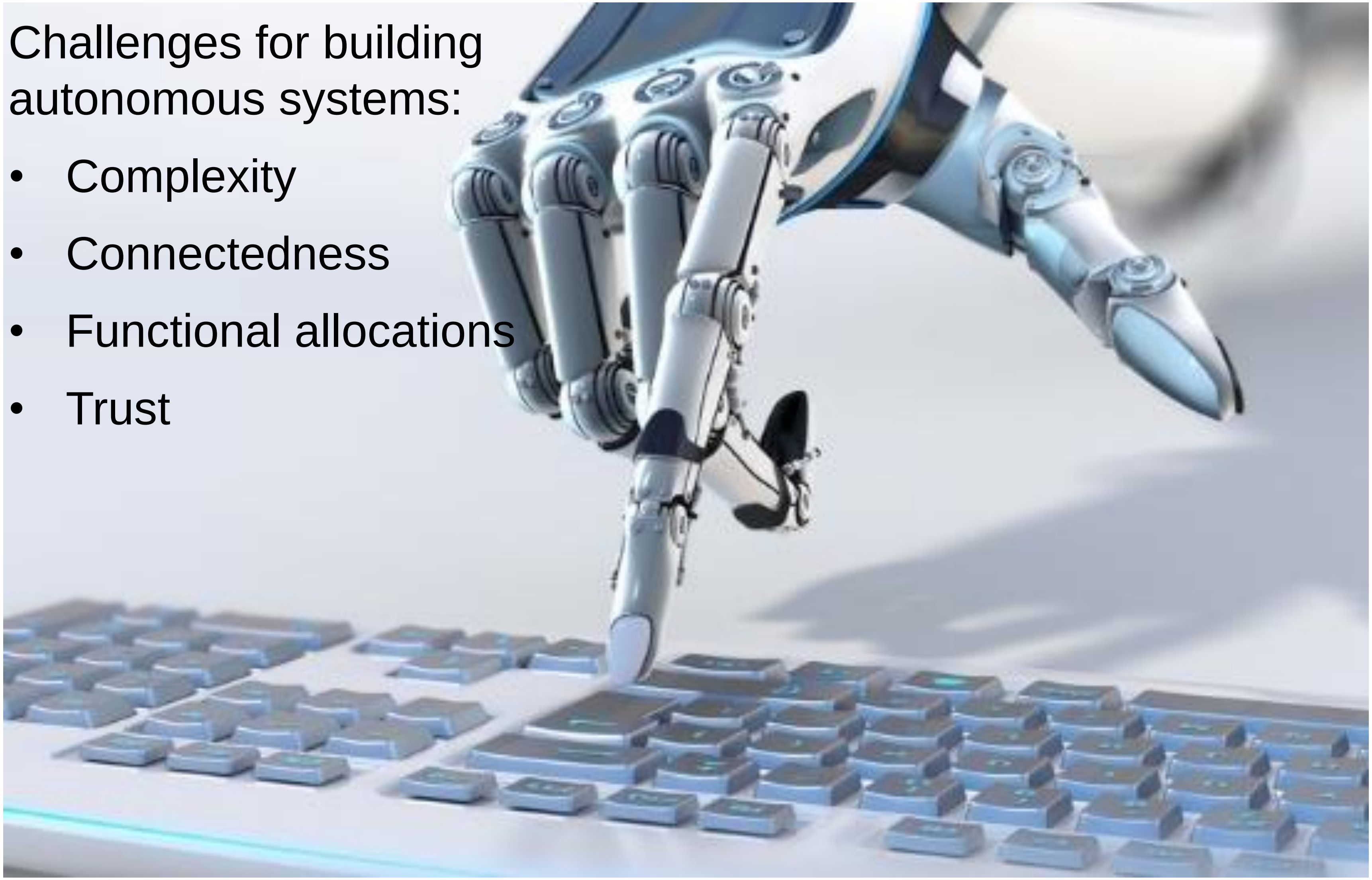
Philae

Depiction by the German Aerospace Center of Philae on Comet 67P Churyumov-Gerasimenko (CC-BY 3.0)

Autonomous Landing and Hazard Avoidance Technology

For future Moon landings

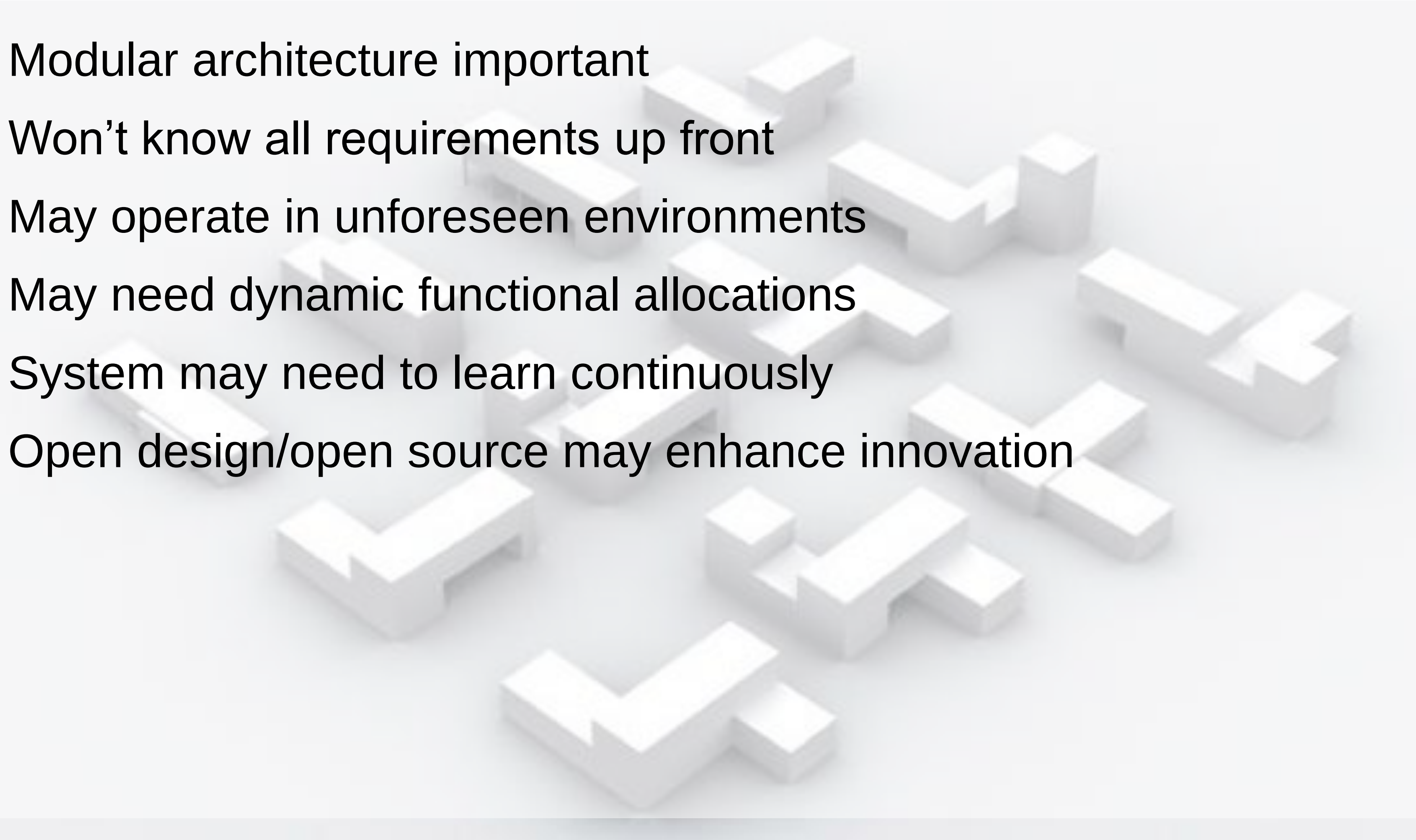
Systems Engineering and Autonomy



Challenges for building autonomous systems:

- Complexity
- Connectedness
- Functional allocations
- Trust

Autonomy Design Concepts



Modular architecture important

Won’t know all requirements up front

May operate in unforeseen environments

May need dynamic functional allocations

System may need to learn continuously

Open design/open source may enhance innovation

Impact of Complexity

Emergent behavior

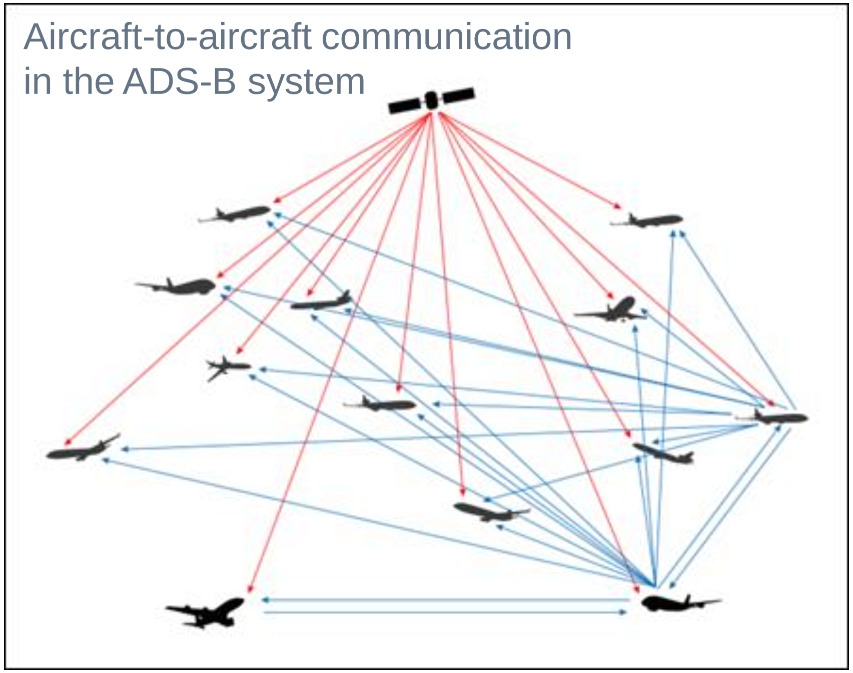
Continuous and asynchronous delivery

System will continuously change

System boundary may be hard to define

Human/machine interface issues

Impact of Connectedness



System boundary ever-changing

New interfaces the norm rather than exception

Large attack surface for vulnerabilities

Coupling issues

Information overload and interface to human team members

Functional Allocation Issues

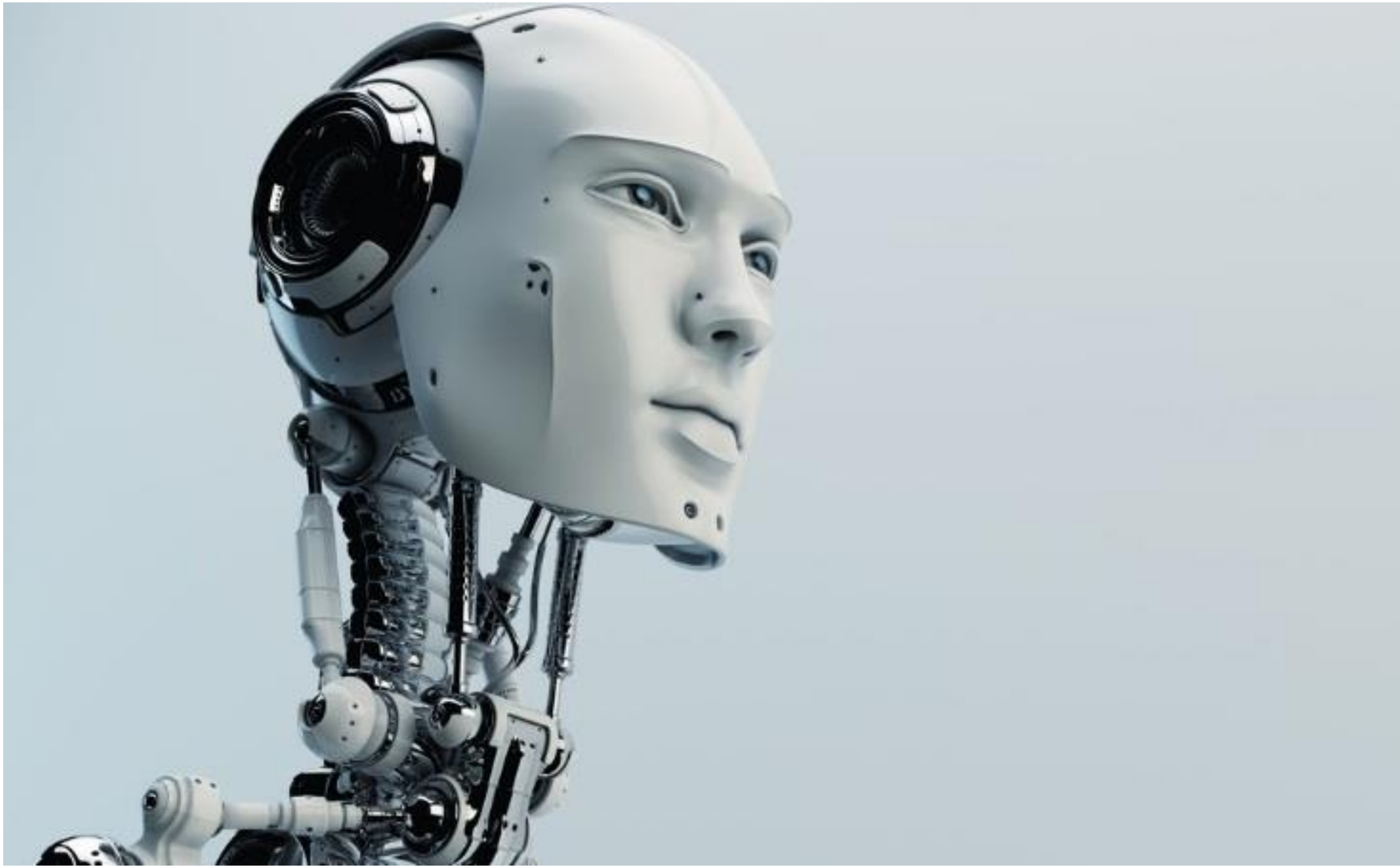
Human/computer allocations will evolve with time

Human/computer allocations may be dynamic

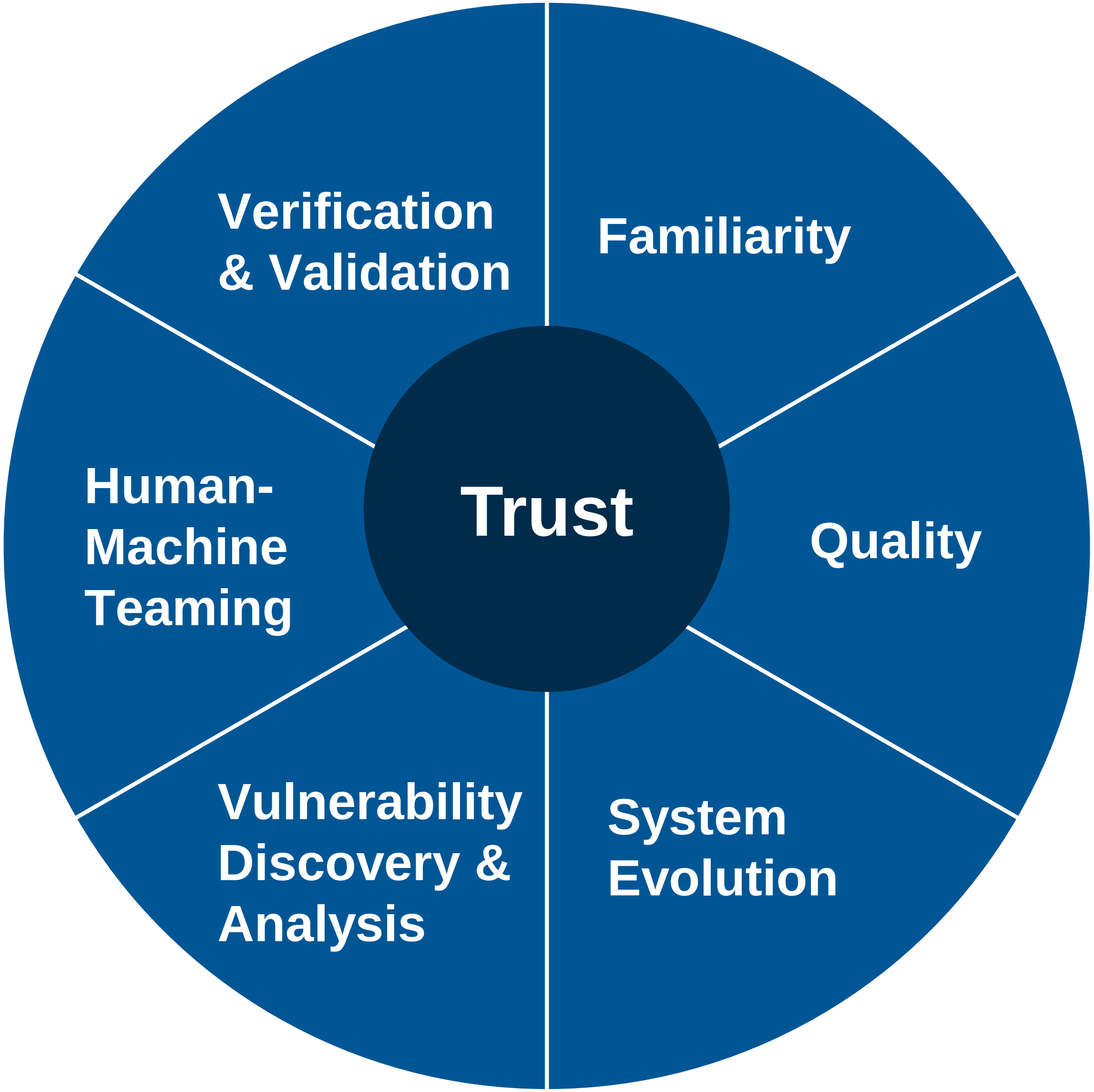
Safe modes desirable

Possibility of high-level commander's intent

Trust is a Major Issue

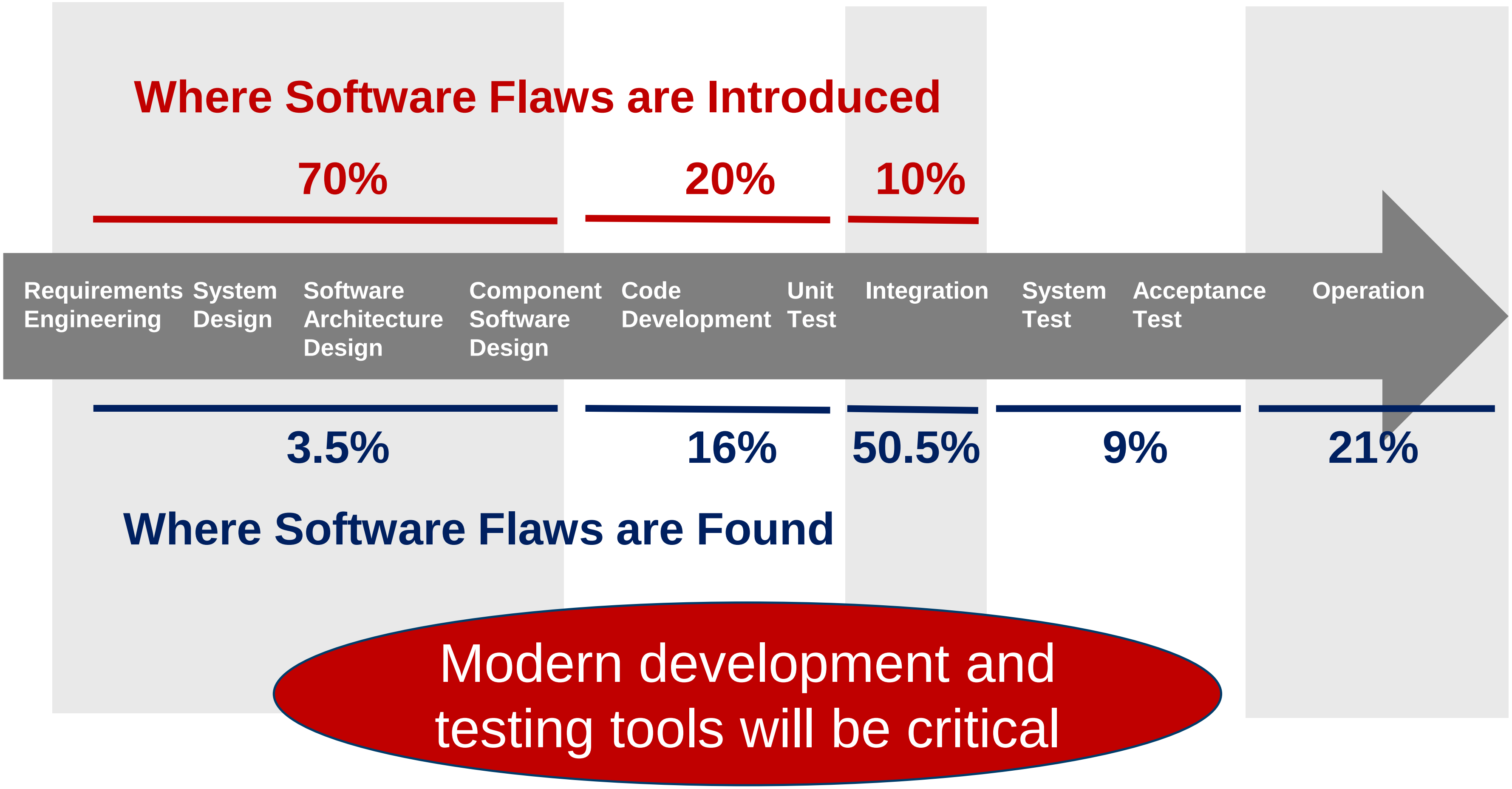


Components of Trust



Familiarity

Recognize that Software Quality Is More Crucial than Ever



Where Software Flaws are Introduced

70% 20% 10%

Requirements Engineering

System Design

Software Architecture Design

Component Software Design

Code Development

Unit Test

Integration

System Test

Acceptance Test

Operation

3.5% 16% 50.5% 9% 21%

Where Software Flaws are Found

Modern development and testing tools will be critical

Sources: *Critical Code*; NIST, NASA, INCOSE, and Aircraft Industry Studies

Plan for Software Maintenance and Evolution

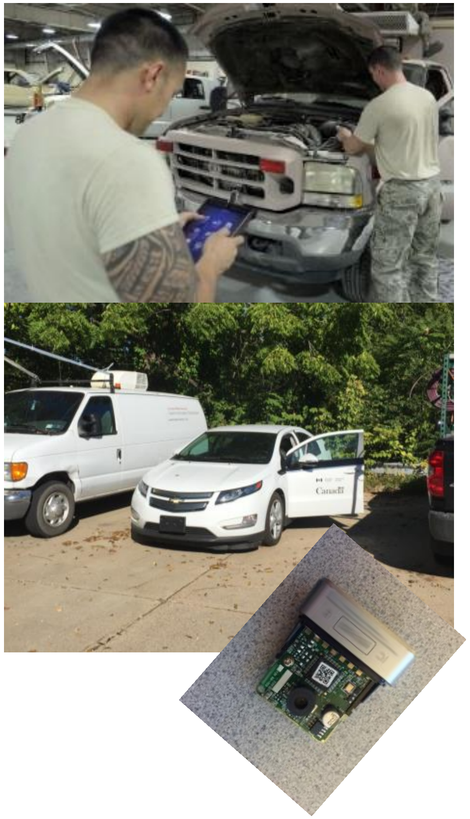
No break point where software is handed off for sustainment

Involves coordinating processes, procedures, people, and information

Challenges include

- rising costs
- dynamic operating environments
- legacy environments
- recertification

Cybersecurity and Autonomous Systems



Increased autonomy may help cybersecurity

- Volume, speed, persistence

But autonomous systems themselves will be vulnerable

- Normal software and system vulnerabilities
- Mis-training
- Spoofing
- Hidden modes

Vulnerabilities in autonomous control of cyber physical systems can have more dire consequences

- Need continuous red-teaming

New Verification & Validation Strategies

Blend development and operational tests

Use formal methods when practical

Adopt M&S in overall T&E program

Use Lincoln Lab sidecar approach

Continue to collect data past deployment

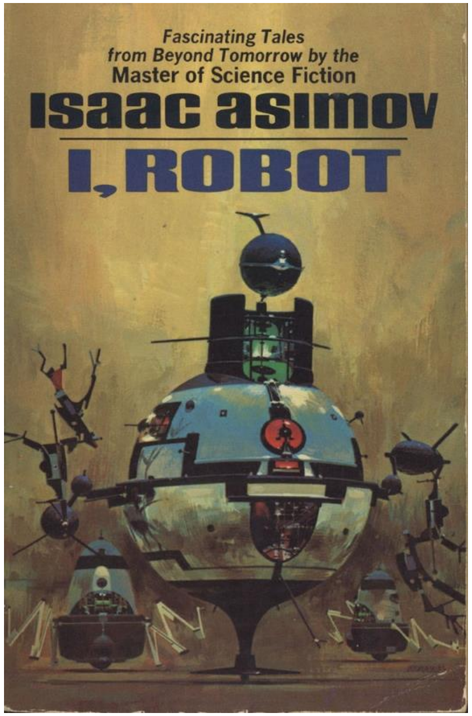
Human-Machine Teaming

In the real world, autonomy is usually granted within some context—explicit or implicit

- Parents and children
- Soldiers, sailors, marines, and airmen

How do we do this for machines?

- Explicit may be easy, but implicit is hard for machines
- Asimov's three laws
- Commander's intent
- Mission orders


Fascinating Tales from Beyond Tomorrow by the Master of Science Fiction
ISAAC ASIMOV
I, ROBOT

Related to need for explainability and predictability

Trust and Autonomy

Trust is a barrier to adoption of autonomy and autonomous systems in DoD (and beyond) including

- Humans trusting systems
- Systems trusting themselves
- Systems trusting other systems
- Systems trusting humans

Autonomy poses an existential threat, some say

"Computers are going to take over from humans, no question. If we build these devices to take care of everything for us, eventually they'll think faster than us and **they'll get rid of the slow humans to run companies more efficiently.**"
(Steve Wozniak)

"The development of full artificial intelligence could **spell the end of the human race.**"
(Stephen Hawking)

"I hope we're not just the **biological boot loader** for digital superintelligence. Unfortunately, that is increasingly probable."
(Elon Musk)

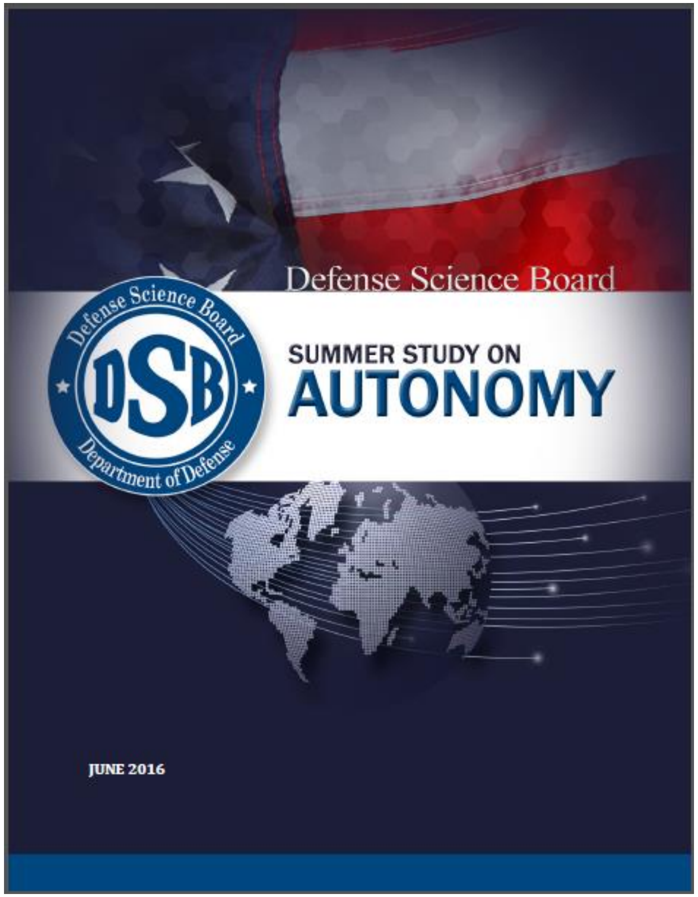
Others say autonomy will enhance and extend human life

“We're going to use those tools to make ourselves more expressive and more intelligent.”

“. . . by the 2030s we’ll be putting millions of nanobots inside our bodies to augment our immune system, to basically wipe out disease.”

(Ray Kurzweil)

DSB Recommendations



26 recommendations in three categories:

- Accelerate Adoption of Autonomous Capabilities
- Strengthen Operational Pull for Autonomy
- Expand Technology Envelope for Autonomous Systems

Summary

Increased autonomy and AI are coming—and coming fast

Solid system engineering will be even more important

Current tools and processes may not be sufficient

Transitioning will depend on establishing and building trust

- Complicated by non-deterministic techniques
- Complicated by systems that continue to learn
- Complicated by human-machine teaming

Solid system engineering will determine if we are creating C3PO and Johnny 5…

…or The Borg

AF archive / Alamy Stock Photo

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