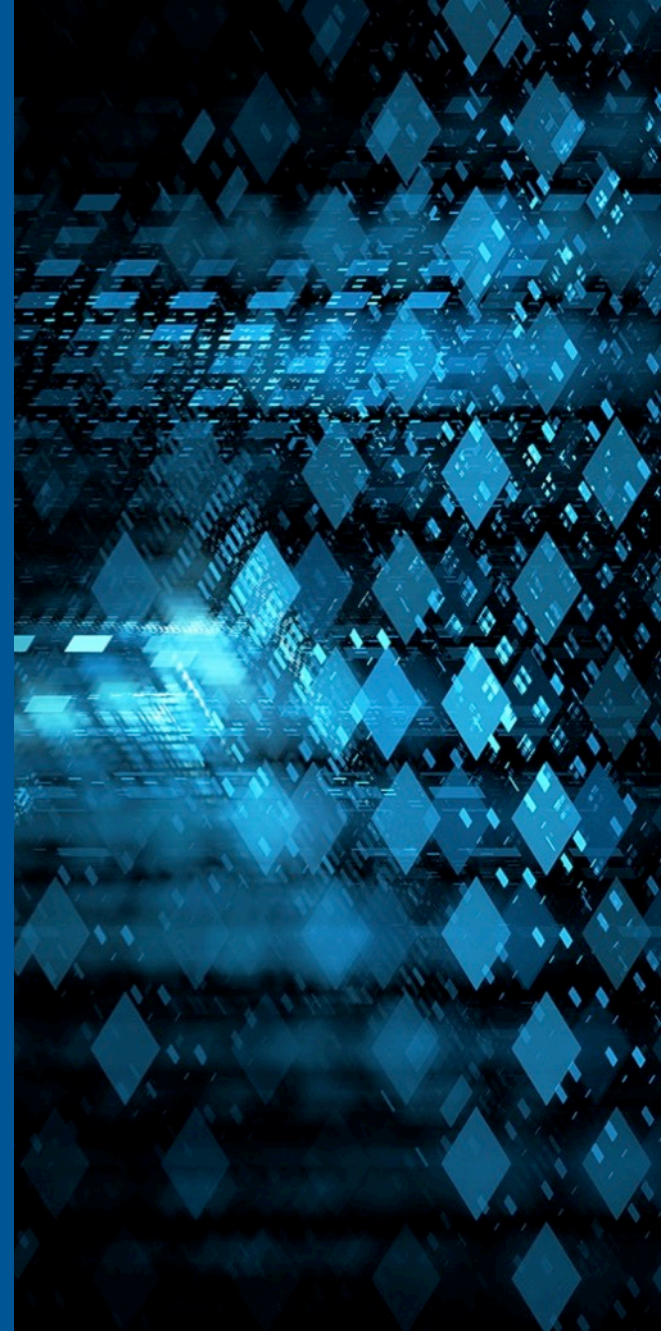


# Systems Engineering and Autonomy: Opportunities and Challenges

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# Why Increase Autonomy?

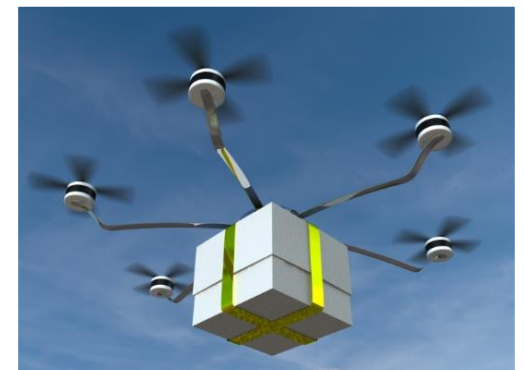
Speed

Volume

Danger

Persistence

Communication issues



# Our systems are increasingly autonomous

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.”

# Autonomy is also becoming big business

By 2021, 1 million Internet of Things devices will be purchased and installed per hour

2019  
\$15.3B



# Some autonomous systems may be expert software systems



Finance



Medicine



Real-time Process Control

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



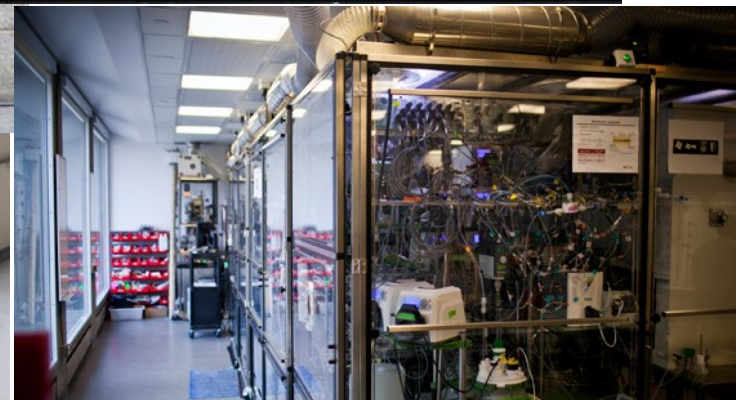
# These smart machines are more than *automated* systems



Automated teller machine



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



# ... 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

Hubble Space Telescope

View of Star Cluster R136



International Space Station

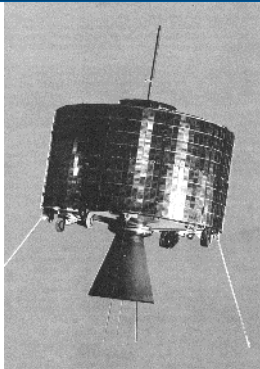


Sputnik

Past

Present

Future



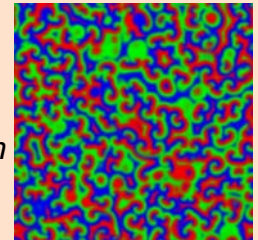
Syncom 3



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



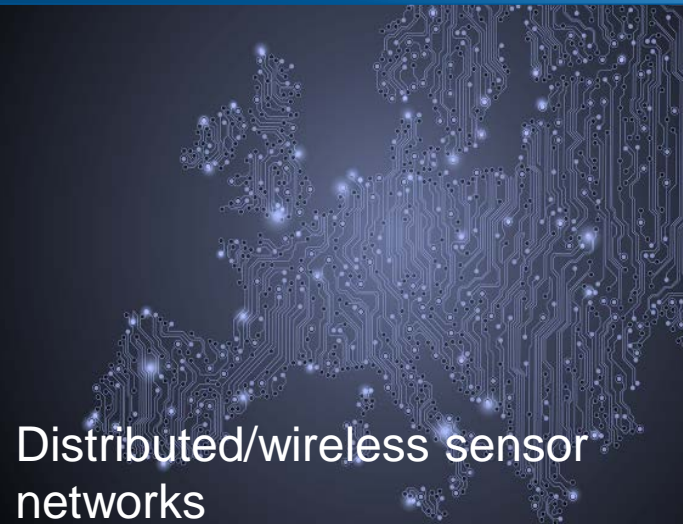
Advancements in sensing technologies

Past

Present

Future

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



# 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

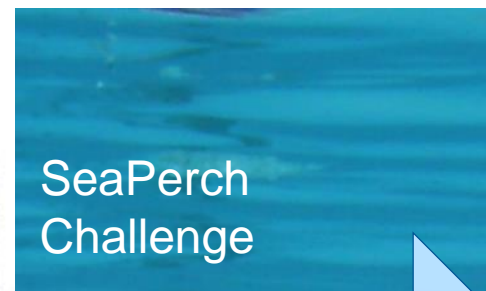


Memorial Sloan Kettering Cancer Center trains Watson to help oncologists make more nuanced treatment decisions more quickly

# They will work where we cannot safely go



Atlas  
*Search and rescue*



Past

Present

Future



# We use them to explore the universe



Apollo 11 lander



Voyager 2



**STEREO**

Space-based observatories orbiting the Sun



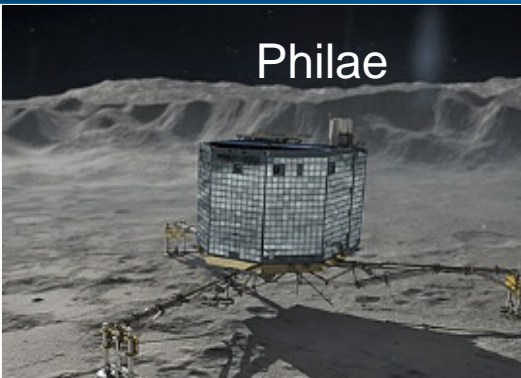
**Past**

**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

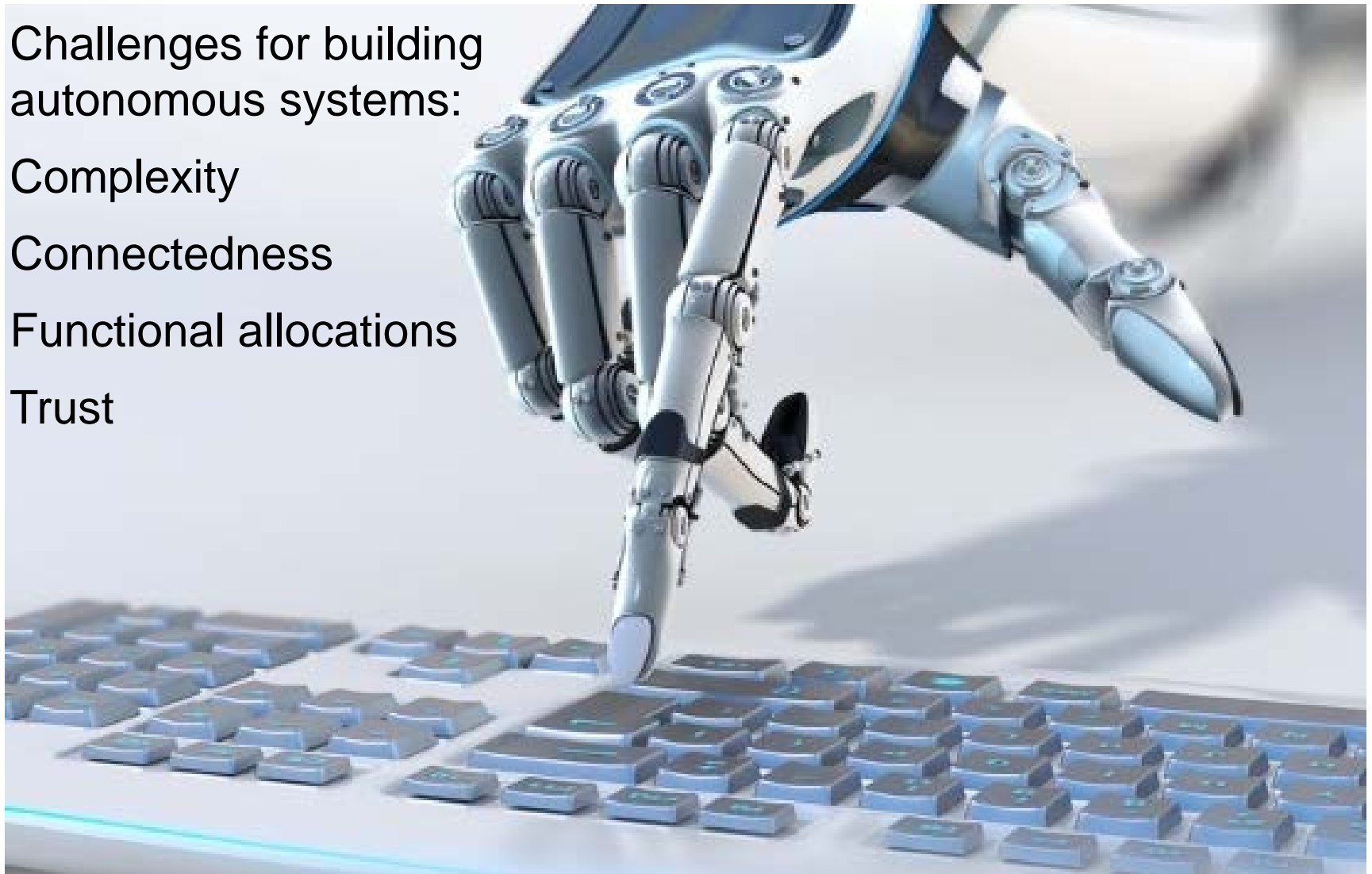
Challenges for building  
autonomous systems:

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

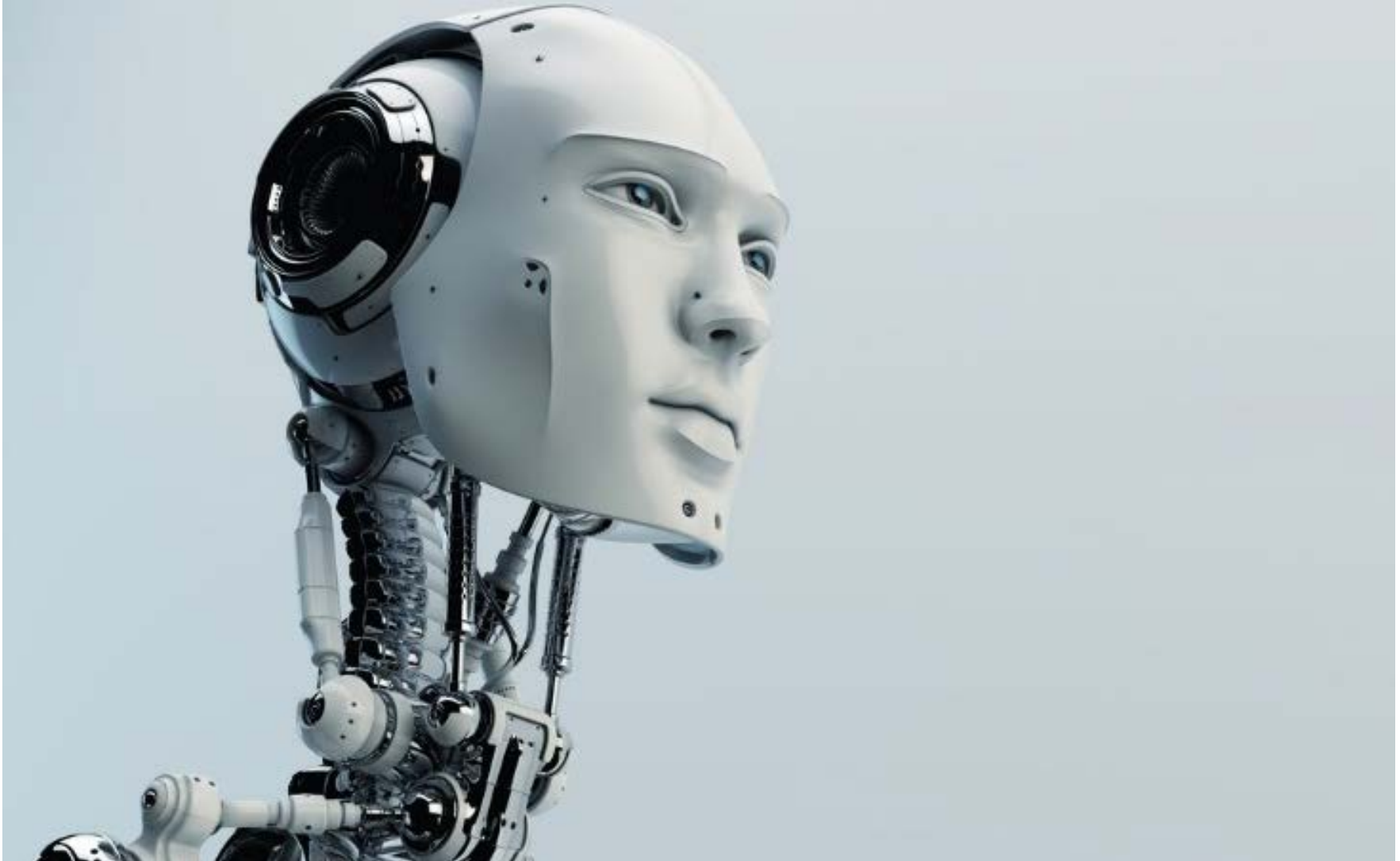
Human/computer allocations may be dynamic

Safe modes desirable

Possibility of high-level commander's intent



# Trust is a Major Issue



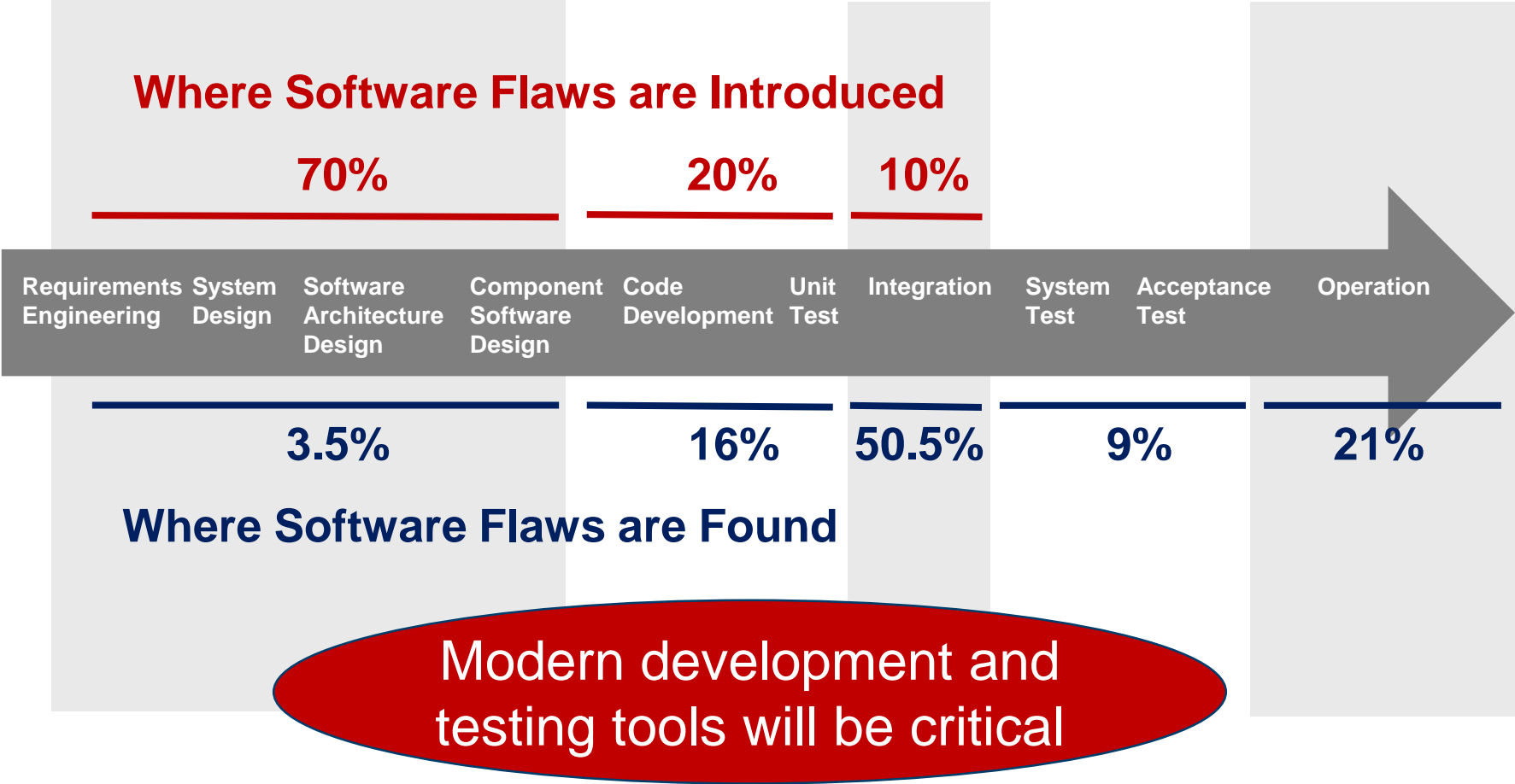
# Components of Trust



# Familiarity



# Recognize that Software Quality Is More Crucial than Ever



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

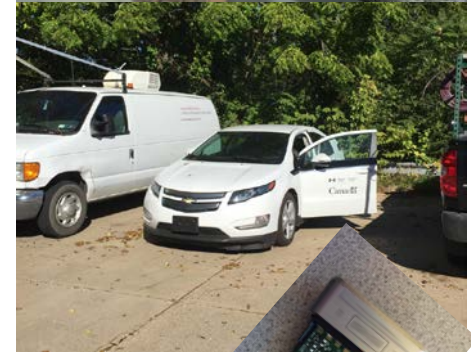
- Volume, speed, persistence

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



# 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

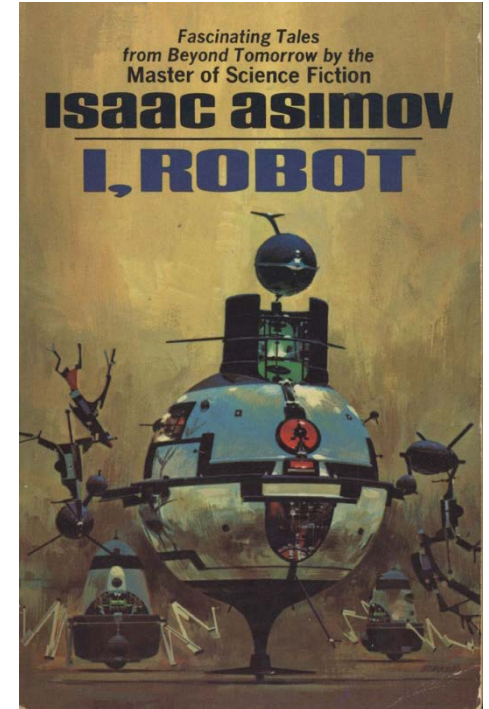
# Autonomy with Context

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



How do we understand: “Why did the robot do that?”

# New V&V 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

# Autonomy poses an existential threat, some say

“Computers are going to take over from humans, and the question is if we build these devices to take care of all the things 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)  
“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, extend human life

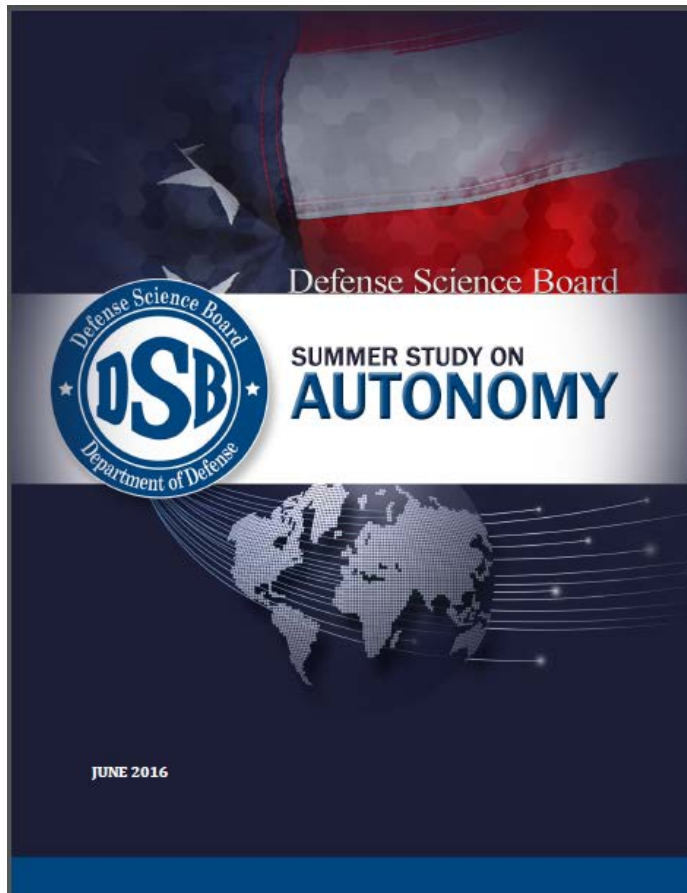
“We're going to use those tools to make ourselves more expressive and more intelligent.”

“. . . 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:

- Accelerating 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

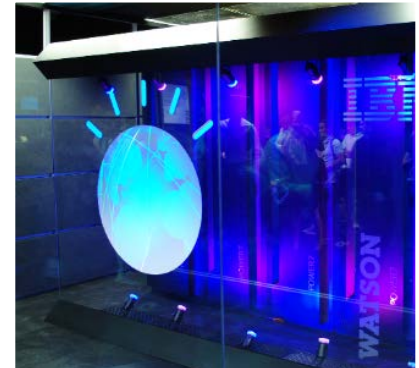
Solid system engineering will be even more important

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