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.”

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 devices will be purchased and installed per hour.

A growing global market for smart machines:

- 2013: $5.3B
- 2014: $6.2B
- 2019: $15.3B

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
- Automated building cleaning system
- Automated pharmaceutical manufacturing
... and more than *virtual reality* devices
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

2014: Autonomous Cadillac SRX

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

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

Past  Present  Future

- Sputnik
- 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

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

**Past**

**Present**

**Future**

- Distributed/wireless sensor networks
- Mapped damage to help target relief efforts after earthquake in Haiti

Global Hawk

Advancements in sensing technologies
They can process tremendous volumes of data

Stanley
Winner of 2005 DARPA grand challenge

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

Watson

Past

Diagnostic expert systems

Present

Deep Blue

Future

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

Past

Stanley

Winner of 2005 DARPA grand challenge

Present

Deep Blue

Future

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

Fukushima

Atlas

Search and rescue

Dante II

Robotic exploration of extreme terrains

Past

Present

Future

Explosive Ordnance Disposal

World Trade Center, Iraq, Afghanistan

SeaPerch Challenge

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

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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  | Autonomous Landing and Hazard Avoidance Technology
*Depiction by the German Aerospace Center of Philae on Comet 67P Churyumov-Gerasimenko (CC-BY 3.0)*

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

- Verification & Validation
- Familiarity
- Quality
- System Evolution
- Vulnerability Discovery & Analysis
- Human-Machine Teaming
Familiarity
Recognize that Software Quality Is More Crucial than Ever

Where Software Flaws are Introduced

70%  
20%  
10%

Where Software Flaws are Found

3.5%  
16%  
50.5%  
9%  
21%

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

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 all the things we do now, 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 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