The Challenges of Building and Testing Increasingly Autonomous Systems

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Once, computers were humans doing computing functions
More recently, humans built computers they operated
Now, computers operate themselves
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
... 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)
Replaces traditional build-then-test
Relies on architectural model repository
Reduces risk, cost, and development time
As well as the convergence of software capabilities

“This car is the holy grail of autonomous driving because it can do it all—from changing lanes on highways, driving in congested suburban traffic, and navigating traffic lights.”

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

- 1954: First robotic arm
- 1979: Articulated robot arm
- 2012: Baxter deep-learning robot
They can operate continuously

1957
Sputnik

1984
Landsat 5
Set record in 2013 as the longest-operating Earth observation satellite

1998
International Space Station

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
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<tbody>
<tr>
<td>1972</td>
<td>Aquila drone</td>
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<td></td>
<td>• Originally a battlefield target designator</td>
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<td>• Now used to bring Internet access where none exists</td>
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<td>2010</td>
<td>Disaster relief in Haiti</td>
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<td>Global Hawk mapped damage to help target relief efforts</td>
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**Distributed Sensor Network program**

- Explore challenges of distributed/wireless sensor networks, in partnership with MIT/LL, CMU and others

**Advancements in sensing technologies**

- Ushering in the Internet of Things
They can process tremendous volumes of data

1990s 2000s 2010s

1997
Deep Blue
Autonomous chess-playing computer; defeated world champion Garry Kasparov

2011-today
Watson
They will work where we cannot safely go

1994
Dante II
Robotic exploration of extreme terrains

2000s
Explosive Ordnance Disposal Robots
- World Trade Center
- Iraq
- Afghanistan

2011
Fukushima

1990s

2000s

2010s
We use them to explore the universe

1969
Apollo 11 Lander

1977 - today
Deep space probes

1997
Pathfinder


Voyager 2
The relationships between machines and people are moving from the cooperative to the co-dependent to the competitive. 

Gartner analysis
Our systems are increasingly autonomous

• Algorithmically driven agents, outside of human control, will participate in 5% of all 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 instances of smart machines
• More than 3 million workers globally will be supervised by “robobosses”
Autonomy is also becoming big business

Growing global market for smart machines

2013 $5.3B

2014 $6.2B

2019 $15.3B

CAGR: 19.7%

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

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One concern: economic disruption

The digital workforce

- Lower cost
- Easier to train
Autonomous systems do tedious, time-consuming tasks better

Drone delivery

Multi-function robots in manufacturing

Monitoring moisture levels in soil

3D mapping
They can also perform specialized jobs

- Performing surgery
- Controlling delivery of medicine
- Fighting fires

2013: BAE Systems conducted test flights of an unmanned passenger jet
One view: the digital workforce will eliminate human jobs

“Gartner predicts one in three jobs will be converted to software, robots, and smart machines by 2025.

New digital businesses require less labor; machines will make sense of data faster than humans can.”

—Peter Sondergaard, Gartner's research director

Some jobs humans may lose to autonomous systems

• Pharmacist
• Lawyer
• Paralegal
• Driver
• Astronaut
• Store Clerk
• Soldier
• Babysitter
• Rescuer
• Sportswriter
• Reporter
Alternate view: the digital workforce will create human jobs

They work faster and produce more, winning more orders.

Their higher productivity brings jobs back from lower wage competitors.

They provide an efficient test platform for innovation.

They save on costs because they perform dangerous tasks safely.

47% of devices (such as vending machines, washing machines, and aircraft) will be able to request support from human-operated businesses

Source: *Inc. Magazine*
Another concern: ethics of autonomy

Can we give autonomous systems an ethical framework and context?

What are the limits to autonomy—in conflict, in law enforcement?

How do autonomous systems impact privacy and civil rights?

Britain has a CCTV camera for every 11 people

Artist’s rendering of attack by drone swarm
Can an autonomous system choose the greater good?

Suppose an autonomous vehicle . . .

senses a ball rolling into the street in its lane . . .

. . . and semi-truck coming toward it in the other lane?
The next generation of algorithmically driven financial agents will be fully autonomous

- Accumulate and spend money
- Set up and participate in contracts
- Adapt, replicate, and create new autonomous systems
- Compete with bank accounts and other products offered by financial institutions
A new concern: personal drone ownership

GPS-guided flying robot available for as little as $300 USD
May be 1M drones owned by end of 2015
Most common use: Photo/videography

Issues
- Privacy
- Arming
- Interference with commercial aircraft

Christian Science Monitor, October 9, 2015
Some predict that autonomy will pose an existential threat

“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)

“Hope we’re not just the biological boot loader for digital superintelligence. Unfortunately, that is increasingly probable.” (Elon Musk)

“The development of full artificial intelligence could spell the end of the human race.” (Stephen Hawking)
Others say autonomy will enhance, extend human life

Ray Kurzweil

• By 2029, computers will be able to do all the things that humans do.

• “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.”
Neil Harbisson, human cyborg

Born color-blind, human cyborg Neil Harbisson has an antenna implanted in his skull that allows him to perceive colors as sounds on the musical scale.

“When I started to dream in color, I felt the software and my brain had united.”
How do we build trust?
Autonomous System Challenges

October 2015

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Vulnerability Discovery & Analysis
Human-Machine Teaming
Familiarity
Quality
System Evolution

Trust
Autonomous functionality is increasing and accelerating

- Trust, in many manifestations, is a central concern
- How can the ER community contribute to
  - building trust
  - understanding the limits to trust
  - making human-machine teams more effective