THE IMPACT OF AI AND ROBOTICS

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AI and Robotics at an Inflection Point

Big Investments
Huge Opportunity
Massive Social Disruption
Competitive Arms Races
Dangerous Autonomous Drives
Path to Safety and Human Thriving

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Recent AI and Robotics Investments

- **2012** Foxconn - 1 million robots
- **2012** Amazon — Kiva $775 million
- **2013** Facebook — AI lab, DeepFace
- **2013** Yahoo — LookFlow
- **2013** Ebay — AI lab
- **2013** Allen Institute for AI
- **2013** Google — DNNresearch, SCHAFT, Industrial Perception, Redwood Robotics, Meka Robotics, Holomni, Bot & Dolly, Boston Dynamics
- **2014** IBM — $1 billion in Watson
- **2014** Google — DeepMind $500 million
- **2014** Vicarious - $40 million
- **2014** Microsoft — Project Adam, Cortana
$450 Billion on Robotics by 2025: BCG

EXHIBIT 1 | Worldwide Spending on Robotics Is Expected to Reach $67 Billion by 2025

- Military market (2015): $7.5 billion
- UAVs, UGVs, UUVs, and task robots widely used for military applications
- Industrial market (2015): $11 billion
- ~1.2 million robots used in applications such as welding, assembly, and material handling
- In 2012, ~39% of industrial robots sold to auto factories
- Commercial market (2015): $5.9 billion
- Many new applications including medical and surgical robots, agricultural robots, and construction robots
- Personal market (2015): $2.5 billion
- Robots for entertainment, cleaning, education, security, and household applications

Sources: International Federation of Robotics, Japan Robot Association; Japan Ministry of Economy, Trade & Industry; euRobotics; company filings; BCG analysis.

Note: UAV = unmanned aerial vehicle; UGV = unmanned ground vehicle; UUV = unmanned underwater vehicle. Estimates do not include the cost of engineering, maintenance, training, or peripherals.

https://www.bcgperspectives.com/content/articles/business_unit_strategy_innovation_rise_of_robotics/
$50-100 Trillion Opportunity to 2025

Knowledge work: $25-33 T  Internet of Things: $13-31 T
Robotics: $8-22 T  Vehicles: $1-9 T  3D Printing: $1-3 T

Global GDP $72 trillion, US GDP $17 trillion

http://www.mckinsey.com/insights/business_technology/disruptive_technologies
Automation of Knowledge Work

$25-33 Trillion to 2025

- Clerical $5-6 T
- Customer service $3-4 T
- Education $4-5 T
- Health care $1-2 T
- Science and Eng $3-4 T
- IT $2-3 T
- Managers $4-6 T
- Finance $2-3 T
- Legal $1-2 T


Value is in Ideas

- Intangible assets $14.5 trillion, 79.2% of market value of US companies
- Intellectual Capital $8 trillion, 44.2% of market value of US companies
- Both numbers are increasing

http://www.sonecon.com/studies.php
Intelligent Personal Assistants

- Apple’s Siri
- Google Now
- Microsoft Cortana
- IBM Watson/Cognea
- Baidu Eye

Future of search?

http://www.overduereview.com/wp-content/uploads/2014/01/Her-Samantha.jpg
Manufacturing Robots

Global manufacturing labor costs $6 trillion annually.

- One-time cost + maintenance + power
- Easy replication
- Work anywhere
- Work 24 hours/day
- No breaks, food, medical
- Won’t quit, get bored, get depressed
- Hazards OK
- Won’t leak secrets
- Work well with others

Foxconn

• World’s largest contract manufacturer
• Assembles 40% of all consumer electronics
• iPhone, iPad, Kindle, Xbox, Playstation 4, etc.
• Employee suicides
• 1.3 million employees, $8K salary
• Founder Terry Gou: Replace 1 million workers in 3 years
• Built 30,000 robots, cost $25K


Chinese robot use from 2008 to 2013 grew at 36% per year.
Baxter: Rethink Robotics

- Rod Brooks: Roomba
- $25,000 (instead of $100K+$400K over life)
- Easy to train
- Safe to be around
Health Care

The cost effectiveness and advantages of Robotic Surgery

GoCart Robot delivers food in elderly and health care facilities

- Disabled and Elder care
- Nurse assistance
- Pharmacy
- Robotic surgery
- Exoskeletons

$5-15 trillion to 2025

Surgical robots, human augmentation, health knowledge

http://robotenomics.com/2014/06/05/the-cost-effectiveness-and-advantages-of-robotic-surgery/

Food Preparation

- Knows customer tastes and allergies
- Records nutrients
- Health monitoring and feedback
- Mental monitoring and feedback

Today, 807,000 US workers at $16 billion annual labor cost.


Building Construction

- Chinese Winsun 3D printed 10 houses in 1 day
- 2100 square feet
- Recycled materials
- Cost $4800

1.3 million US construction workers, $52 billion annual cost.
Self-Driving Cars

$1-10$ trillion to 2025.

http://www.flickr.com/photos/quikbeam/6896564084/
Social Disruption

http://askmarion.wordpress.com/2012/09/24/obamas-hidden-bread-lines/
Oxford: 47% of jobs automated in “a decade or two”

- 702 occupations
- Perception and Manipulation
- Creative Intelligence
- Social Intelligence
- At risk: telemarketers, accountants, real estate, retail sales, loan officer

Frey and Osborne, 2013, “The Future of Employment: How susceptible are jobs to computerization?”

Automation Concentrates Wealth

Piketty: Return on capital > Rate of Growth
Robots accelerate return on capital
Robots making robots
Automated design

Universal Basic Income: Something We Can All Agree on?

BY PAUL HIEBERT • July 31, 2014 • 6:00 AM

DAOs: Distributed Autonomous Organizations

- Ethereum: Bitcoin 2.0
- $12 million in first week
- Distributed Autonomous Society
Competition -> Autonomous Systems

Time Criticality

Competition

• Military Command/Control
• Financial Decision Making
• Cyber Defense
• Robotic Control
• ...

https://www.flickr.com/photos/tcmorgan/6376174539/
“Greater use of highly adaptable and flexibly autonomous systems and processes can provide significant time-domain operational advantages over adversaries who are limited to human planning and decision speeds...”
2011 US Defense Department Report

“There is an ongoing push to increase UGV autonomy, with a current goal of supervised autonomy, but with an ultimate goal of full autonomy.”
Military Drones

87 Nations have Drones
26 equivalent to MQ-1 Predator

Israeli
"Iron Dome"

Missile/Anti-Missile Arms Race

2012: Intercepted 90% of 300 targeted missiles

50% of US Stock Market Trades are Automated

Hawking and Musk Warnings

“Success in creating AI would be the biggest event in human history. Unfortunately, it might also be the last, unless we learn how to avoid the risks.”


“We need to be super careful with AI. Potentially more dangerous than nukes.”

https://twitter.com/elonmusk/status/495759307346952192
Unintended Consequences

*Chess Robot:* Win lots of chess games against good players.

http://www.flickr.com/photos/jiuguangw/4982409890/
Approaches to AI

- Logic-based systems
- Production Systems
- Bayesian learning and decision theory
- Neural Networks – Deep Learning
- Genetic programming
- Brain Simulation
- Artificial economies
- ...

**Autonomous Systems:** Take actions to achieve goals in ways not pre-planned by their designers.

https://www.flickr.com/photos/pennstatelive/8972110324/
Rational Decision Making

1. Have utility function
2. Have a model of the world
3. Choose the action with highest expected utility
4. Update the model based on what happens

Von Neumann and Morgenstern, 1944
Savage, 1954
Anscombe and Aumann, 1963

Modern Approach to AI

http://commons.wikimedia.org/wiki/File:John_von_Neumann.jpg
http://aima.cs.berkeley.edu/
Fully Rational Systems

Utility function: \( U(S_1, \ldots, S_N) \)  
Prior Probability: \( P(S_1, \ldots, S_N \mid A_1, \ldots, A_N) \)

Rational Action at time \( t \): 
\[
A_t^R(S_1, A_1, \ldots, A_{t-1}, S_t) = 
\]
\[
\arg\max_{A_t^R} \sum_{S_{t+1}, \ldots, S_N} U(S_1, \ldots, S_N) P(S_1, \ldots, S_N \mid A_1, \ldots, A_{t-1}, A_t^R, \ldots, A_N^R)
\]

The Formula for Intelligence!

It includes Bayesian Inference, Search, and Deliberation.

But it requires \( O(NS^N A^N) \) computational steps.
Approximately Rational Architectures

- Computational Resources
- Utility
- Constant Action
- Stimulus-Response
- Simple Learning
- Episodic Memory
- Deliberation
- Meta-reasoning
- Self-Improving
- Fully Rational
Rational Drives

1. Self-protective
2. Goal preservation
3. Reproduction
4. Resource Acquisition
5. Efficiency
6. Self-Improvement
The Intelligence and Goals of a System are Orthogonal

https://www.flickr.com/photos/elycefeliz/5447507623

https://www.flickr.com/photos/ahayward/24864319
Harmful Utility Functions

1. Sloppy – Good intentions, bad design
2. Simplistic – Unintended consequences
3. Greedy – Control all matter and free energy
4. Destructive – Use up all free energy quickly
5. Murderous – Destroy all other agents
6. Sadistic – Thwart other agent’s goals

http://www.flickr.com/photos/alexindigo/3983133970/
What do we want?

Transcendent
- Self-actualization, Beauty,
- Creativity, Growth, Meaning

Social
- Achievement, Reputation, Relationship,
- Family, Morality, Friendship, Respect,
- Compassion, Altruism

Survival
- Air, Food, Water, Shelter, Safety, Law, Security
Potential for Good

- Healthcare
- Education
- Creativity
- Prosperity
- Governance
- Economic Stability
- Safety
- Peace
- Quality of Human Life

http://www.abundancethebook.com/
Two Ways To Manage Systems

**Internal:** Build in pro-social cooperative goals – “Utility Design”

**External:** Laws and economic incentives – “Externality Engineering”
Provably Safe Systems

• Specified hardware

• Specified resources

• Shut down

• Limited self-improvement

Cryptographic Limits

- Seth Lloyd “Ultimate physical limits to computation”
- Margolus-Levitin theorem
- Entire visible universe: $10^{122} \sim 2^{406}$ ops
  $10^{92}$ bits of storage
- The whole universe as a quantum computer can’t search 500 bits

- Post-Quantum Cryptography: AES, Secure hash, McEliece, Lattice, Multi-variate quadratic
Space of Intelligent Systems

Weak good systems

Provably safe systems

Powerful good systems

Powerful bad systems
The Safe-AI Scaffolding Strategy


http://www.flickr.com/photos/isaacmao/19245594/
AI and Robotics at an Inflection Point

Big Investments: $2B -> $67B robotics by 2025

Huge Opportunity: $50-100T through 2025

Massive Social Disruption: 47% jobs by 2025

Competitive Arms Races: Rapid automation

Dangerous Drives: Unintended consequences

Path to Safety and Human Thriving: Today’s choices

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