Artificial Intelligence and the Singularity

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"The person who says it cannot be done should not interrupt the person doing it" (Chinese proverb)
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Olivetti AI Center, 1987
Piero Scaruffi

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This is Part 4

• See http://www.scaruffi.com/singular for the index of this
  Powerpoint presentation and links to the other parts
  1. Classic A.I. - The Age of Expert Systems
  2. Modern A.I. - The Age of Deep Learning
  3. Theory: Knowledge-based Systems and Neural Networks
  4. Robots
  5. Bionics
  6. Singularity
  7. Critique
  8. The Future
  9. Applications
  10. Machine Art
Robots

A staging of Capek’s play R.U.R. (1921)

Lang’s Metropolis (1927)

Chaplin’s “Modern Times” (1930)
Robots

- Westinghouse’s Elektro (1939)
- Harvey Chapman's Garco (1953)
Robots

Estimated worldwide annual shipments of industrial robots

Source: IFR Statistical Department
Robots

1959: Joseph Engelberger deploys the industrial robot Unimate at General Motors

1969: Stanford Research Institute's Shakey the Robot
Timeline

1973: Ichiro Kato's Wabot, the first anthropomorphic walking robot
1984: Valentino Breitenberg's "vehicles"
1986: Jaime Carbonell's Prodigy planner
1986: Rodney Brooks' "dumb" robots
1991: Shuuji Kajita's and Kazuo Tani's LIPM
1991: Jean-Claude Latombe's Randomized Path Planner
1991: Masayuki Inaba's remote-brained robots
1993: Tom Mitchell's Xavier robot
1993: Ernst Dickmanns' robot car
1997: The first RoboCup, the "Robot Soccer World Cup"
1997: NASA's Mars Pathfinder deployed on Mars the first roving robot, Sojourner
1998: Sebastian Thrun's Minerva and Pearl robots
1998: Steven LaValle's and James Kuffner's as the Rapidly-exploring Random Trees (RRT) planner
2000: Honda's Asimo, Sony's Qrio and Hirochika Inoue's H6
2001: Humanoid Robotics Project in Japan
2003: Klaus Loeffler's Johnnie
2005: Jun-ho Oh's Hubo
2005: Sebastian Thrun's robot car Stanley
2006: Willow Garage
2007: Stanford's Robot Operating System
2010: PR2 robot
2010: James Kuffner coins the term "cloud robotics"
## Footstep Planning

### Motion planning is hard

<table>
<thead>
<tr>
<th>Problem</th>
<th>Complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sofa Mover (3 DOF)</td>
<td>$O(n^{2+})$ not implemented</td>
</tr>
<tr>
<td>Piano Mover (6 DOF)</td>
<td>Polynomial – no practical algorithm known</td>
</tr>
<tr>
<td>n Disks in the Plane</td>
<td>NP-hard</td>
</tr>
<tr>
<td>n Link Planar Chain</td>
<td>PSPACE-Complete</td>
</tr>
<tr>
<td>Generalized Mover</td>
<td>PSPACE-Complete</td>
</tr>
<tr>
<td>Shortest Path for a Point in 3D</td>
<td>NP-hard</td>
</tr>
<tr>
<td>Curvature Constrained Point in 2D</td>
<td>NP-hard</td>
</tr>
<tr>
<td>Simplified Coulomb Friction</td>
<td>Undecidable</td>
</tr>
</tbody>
</table>
Robots

1969: Miomir Vukobratovic's ZMP method
1973: Ichiro Kato's Wabot, the first anthropomorphic walking robot
Robots

1979: Tokuji Okada’s robotic hand with three fingers
Robots

1981: Raoul Tubiana shows that the human hand has 22 degrees of freedom

1982: Kenneth Salisbury (Stanford) & Jet Propulsion Laboratory prove the minimum number of degrees of freedom required for grasping an object is 9

1984: Robotic hand by Stephen Jacobsen (Univ of Utah) & MIT
Robots

- Valentino Breitenberg’s “vehicles” (1984)
  - Vehicle 1: a motor and a sensor
  - Vehicle 2: two motors and two sensors
  - Increase little by little the circuitry, and these vehicles seem to acquire not only new skills, but also a personality.
Robots

1986: Jaime Carbonell's Prodigy planner
1986: Rodney Brooks' "dumb" robots

1991: Shuuji Kajita's and Kazuo Tani's LIPM
1991: Jean-Claude Latombe's Randomized Path Planner
1993: Masayuki Inaba's remote-brained robots
Robots

1993: Tom Mitchell's Xavier

Joseph O'Sullivan / Sebastian Thrun
Reid Simmons / Manuela Veloso

Tom Mitchell

[Diagram of Xavier with labeled sections: User Interface (WWW and Zephyr), Task Planning (PRODIGY), Path Planning (Decision-Theoretic Planning), Navigation (POMDP), Obstacle Avoidance (CVM), Interprocess Communication and Synchronization (ICA), Hardware / Servo-Control (Commercial).]
Robots

• Ernst Dickmanns’ “robot car” (1994)
Robots

1998: Sebastian Thrun's Minerva and Pearl
1998: Steven LaValle's and James Kuffner's Rapidly-exploring Random Trees (RRT) planner
Walking Robots

2000:
- Hirochika Inoue's H6
- Sony's Qrio
- Honda's Asimo

Asimo over the years
Walking Robots

Honda's Asimo

Evolution of robot models leading up to ASIMO
“E2”: Model in 1989
“E6”: Model 1993
“P2”: The first humanoid robot Honda unveiled

Takenaka
Robots

2000: Cynthia Breazeal's emotional robot, "Kismet"
2003: Hiroshi Ishiguro's Actroid, a young woman
Robots

2003: Klaus Loeffler’s Johnnie
2005: Jun-ho Oh's Hubo
2005: Sebastian Thrun’s robot car Stanley
Robots

Special purpose robots:
2001: NEC PaPeRo (a social robot targeting children)
2007: RobotCub Consortium agreement, the iCub (for research in embodied cognition)
2008: Aldebaran Robotics' Nao (for research and education)
2010: NASA's Robonaut-2 (for exploration)
Robots

General-purpose robots:
2006: Willow Garage
2007: Stanford’s Robot Operating System
2010: PR2 robot
2012: Open Source Robotics Foundation
Robots

Domestic robots:
2005: Toyota's Partner (designed for assistance and elderly care applications)
2007: Toyota’s nursebot Robina
Robots

Modular self-configuring robots

- Toshio Fukuda’s CEBOT (Japan, 1988)
- Satoshi Murata's M-TRAN (Japan, 1999)
- Daniela Rus’ M-blocks (MIT, 2010)
Robots

2005: Boston Dynamics' quadruped robot "BigDog"
2008: Nexi (MIT Media Lab), a mobile-dexterous-social robot
2010: Lola Canamero's Nao, a robot that can show its emotions
2011: Osamu Hasegawa's SOINN-based robot that learns functions it was not programmed to do
2012: Rodney Brooks' hand programmable robot "Baxter"
Cloud Robotics

2010: James Kuffner coins the term "cloud robotics"
See Part 8
Robots
• Darpa Challenge 2015
Industrial Robots

- Asia holds the leadership in industrial robots: in 2014 Asia bought 139,300 industrial robots (more than half the world's total), +41%, of which
  - 57,096 in China (+41%)
  - 29,300 in Japan (+17%)
  - 24,700 in Korea (+16%)
  - 6,900 in Taiwan (+27%)
  - compared with
    - 26,200 in the USA (+11%)
    - 20,100 in Germany (10%)
    - 6,200 in Italy (+32%)
    - Very small numbers in the rest of Europe
The most complex robot • The airplane • DARPA’s Aircrew Labor In-Cockpit Automation System (ALIAS)
Robots

- Toys: most robots are an evolution of Pinocchio, not of Shakey
Domestic Robots

• Research and Markets estimates that the personal robotics industry could be worth as much as $34 billion by 2022
• Luna (2011)
• Jibo (2014)
Domestic Robots
Domestic Robots

• The robot that follows you
Domestic Robots

Industrial-Robot Firm
Kuka Looks to Automate the Home
Robots

• Consumer robots: cheap, unstructured environment
• Industrial robots: expensive, precise, structured environment
• Service robots: midprice, somewhat structured environment
Customer-service Robots

• Robots for the service industry
  – Pepper (Japan, 2014)
  – Savioke (Sunnyvale, 2013)
Customer-service Robots

Knightscope's K5 robot security guard at the Stanford Shopping Center (2016)
Savioke's robot concierge Botlr at the Aloft hotel in Cupertino (2016)
Simbe's robot clerk Tally at a Target store in San Francisco (2016)
Robots
Robots

Smart Tissue Autonomous Robot
(Peter Kim, Washington, 2016)
Robots

- Domestic Robots
Robots

- Robots for an aging society (social companion robots)

Percentage of population over 80

- Japan
- N Europe
- USA
Robots

• Domestic Robots

Toyota Partner Robot
HSR (Human Support Robot)

Robina

medical and nursing care
Robots

Warehouse helpers
  Amazon’s Kiva
  Fetch
  Magazino’s Toru
Robots

• Robots for an aging society (social companion robots)
  – Mobiserv “social companion robot” that encourages the elderly to eat healthily and exercise (Europe, 2013)
  – Paro the cuddly seal robot (USA, 2014)
  – RoBear robot nurse (Japan, 2015)
  – RoboCoach (Singapore, 2015)
Robots

- Robots for an aging society

**If you had a choice, where would you prefer to die?**

2016, % replying

- In a hospital
- In a nursing home
- In a hospice
- At home
- Somewhere else
- Other*

**Among those who have experienced the death of a relative, where did your relative die?**

Source: Kaiser Family Foundation/The Economist

*Depends/Not sure/Declined to answer
Robots

• Robots for dangerous jobs (explosives, radioactive areas, other planets)
Robots

• Domestic Robots

Toyota Partner Robot
HSR (Human Support Robot)

2012

2007

Robina

medical and nursing care
Educational Robots

• Robots for education
  – Roboterra
Bay Area robotics

- Willow Garage: Savioke; Suitable Technologies; Fetch Robotics; Redwood Robotics; Simbe; etc.
- SRI: Grabit, Intuitive Surgical.
- Otherlab: Pneubotics
Cobots

- Universal Robots at BMW (2013)
Bay Area robotics

- Pneubotics: metal-less "soft" robots (capable, for example, of handling food).
Robots

2015: Selma Bringsjord’s robot solves the “wise men” riddle
Robots

2015: $1 billion investment in robotics in the USA, of which 3/4th in the Bay Area

2015: Toyota Research Institute (TRI), with a $1 billion 5-year budget, headed by former DARPA executive Gill Pratt and based at Stanford and MIT
Robots

Future applications:
- Surgery (Intuitive Surgical, Verb Surgical)
- Cars
- Agriculture
- Mining
- Exoskeleton
- Older care
- Cleaning
- Inspection
- Underwater
Robots

Future applications:

Surgery

DaVinci surgeon assistant (Intuitive Surgical, 2000)

Verb Surgical: Google + Johnson & Johnson (2015)

Smart Tissue Autonomous Robot (Peter Kim, Washington, 2016)

GOOGLE’S VERILY IS SPINNING OFF ‘VERB,’ A SECUREIVE ROBOT-SURGERY STARTUP
Robots

Trends

• nanorobots for eye surgery
• microrobots for construction
• soft robots for food handling, quasi-organic robots with flexible actuators (Pneubots)
Robots

Grasping technology
• Picking up things that the robot has never seen before
• And learning to pick up hard and soft objects in different ways
• Self-supervised learning of grasp poses
• Convolutional Neural Networks are de facto standards for computer vision
• Ashutosh Saxena (Cornell, 2014)
• Abhinav Gupta (Carnegie Mellon, 2015)
• FANUC/Preferred Networks (2015)
• Google Brain (2016)
Case study: Japan

Takayama Festival of Mechanical Puppets
Case study: Japan

• Joruri/ puppet theater (~1650)

• “Automated mechanisms, or karakuri, were originally separate from the puppets, used only in stage machinery or in robot dolls that performed between acts. But the machinery eventually found its way into the bodies of the puppets” (Chris Bolton)
Case study: Japan

- Oriza Hirata’s robot theater

“I, Worker” (2008)

“Sayonara” (2010)
Case study: Japan

• The uncanny valley
  – Ernst Jentsch: “On the Psychology of the Uncanny” (1906)
Case study: Japan

- The uncanny valley
  - Japanese robots tend to be female because they look less threatening
$450 Billion on Robotics by 2025: BCG

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

Global robotic market ($billions)

<table>
<thead>
<tr>
<th>Year</th>
<th>Military</th>
<th>Industrial</th>
<th>Commercial</th>
<th>Personal</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>7.4</td>
<td>3.4</td>
<td>2.3</td>
<td>1.8</td>
</tr>
<tr>
<td>2005</td>
<td>10.8</td>
<td>5.2</td>
<td>5.1</td>
<td>1.1</td>
</tr>
<tr>
<td>2010</td>
<td>26.9</td>
<td>15.1</td>
<td>5.1</td>
<td>1.0</td>
</tr>
<tr>
<td>2015E</td>
<td>42.9</td>
<td>26.9</td>
<td>11.2</td>
<td>2.5</td>
</tr>
<tr>
<td>2020E</td>
<td>66.9</td>
<td>42.9</td>
<td>16.5</td>
<td>4.5</td>
</tr>
<tr>
<td>2025E</td>
<td>80.0</td>
<td>66.9</td>
<td>24.4</td>
<td>9.0</td>
</tr>
</tbody>
</table>

CAGR, 2000–2025E (%)
- 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/
Ten Trends of Robotics

1. Robots for hire the same way you hire a Uber/Didi car. Anybody can offer a robot for a task at an hourly price.

2. The recruiter of the future will need to know how to recruit robots, not just humans.

3. The “robotics talent crunch”: skyrocketing salaries for robot designers and related jobs

4. Ubiquitous sensors and transmitters to provide the robots with information about the environment
Ten Trends of Robotics

5. Robots for an aging society (social companion robots)

Percentage of population over 80

<table>
<thead>
<tr>
<th></th>
<th>2015</th>
<th>2030</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Japan</td>
<td>12</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>N Europe</td>
<td>8</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>USA</td>
<td>4</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

RIKEN BRAIN SCIENCE INSTITUTE
Ten Trends of Robotics

6. Kits for self-driving features
   - Comma.ai (San Francisco, 2015)
   - Tesla + MobilEye (2016)
   - Nvidia + Mercedes (announced in 2017)
7. “Collaborative intelligence”: robots that can self-organize to solve a problem
   – Harvard Univ
   – Eliseo Ferrante (Belgium)
Ten Trends of Robotics

8. Turning a smartphone into a robot
   - Cellbots (2010) by a group of makers in Silicon Valley
   - Your phone can be the robot: it has touch, hearing, speech, many more senses... but no legs
   - Solution: an Android phone connected to an Arduino with wheels
Ten Trends of Robotics

8. Turning a smartphone into a robot

Robot Intelligence:

- Dexterity
- Mobility
- **Wireless networking**
- **Cloud Robotics**
- **Big Data and Machine Learning**
- **Object Recognition**
- **Speech-to-Speech**
- **Real-time Image-Based Language Translation**
Ten Trends of Robotics

9. Cloud Robotics

- A shared knowledge database that organizes information about the world in a universal format
- A library of programs that can be executed remotely (a “skills library”)
- Masayuki Ibana (Tokyo Univ): the “remote brain” (1993)
- James Kuffner (CMU): “cloud robotics” (2010)
- Ryan Hickman (Google): “cellbots” (2010)
Ten Trends of Robotics

• Benefits of cloud robotics
  – The robot as a “thin” client
  – Longer battery life
  – No need for software updates
  – Adaptability to complex situations
  – Collective progress of cloud-enabled robots
  – Large-scale deployment of data-sharing robots
Ten Trends of Robotics

9. Clouds for robots
   – Knowledge sharing among machines – Wikipedia for robots
   – RoboEarth by EU (2010); Rapyuta by EU (2013)
   – Open Ease at University of Bremen (2015)
Ten Trends of Robotics

9. Cloud robotics
   • Cloud Computing + Virtual Reality = Faster training of robots
     – DexNet 1.0 (2015): thousands of 3D models
     – Ken Goldberg (2017): robots practice using virtual objects in a simulated world
Ten Trends of Robotics

10. Learning robots

• Robots that can turn high-level descriptions into specific actions (eg RoboHow, 2012)

• Learning from human demonstrations and advice, not just by imitation (eg RoboBrain at Stanford, 2014)

• Robots that teach other robots? (Stephanie Tellex’s “Million Object Challenge”, 2016)
Ten Trends of Robotics

10. Learning robots
   • Using VR to train robots
     – Ken Goldberg
     – Suzanne Gildert’s Kindred.ai
     – OpenAI
Ten Trends of Robotics

1. Robots for hire
2. Robot recruiters
3. Robotics talent crunch
4. Responsive environment
5. Companion robots
6. Assisted driving
7. Collaborative intelligence
8. Cellbots
9. Cloud robotics
10. Learning robots
Dexterity of Robots

- Dexterity of robots
  - Abhinav Gupta (Carnegie Mellon Univ)
  - Ashutosh Saxena (Cornell Univ)
  - Sergey Levine (Google Brain)
What else?

LSR 2017
INTERNATIONAL CONGRESS
ON LOVE AND SEX WITH ROBOTS
Do robots steal our jobs?

- The countries with the highest number of robots...
Do robots steal our jobs?

- ... are also the countries with the lowest unemployment
Do robots steal our jobs?

- They already stole millions of jobs: the traffic guards!
Next…

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