DIGITAL
TRANSFORMATION
IN HEALTH CARE

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Healthcare is becoming part of information technology.

Bill Maris, Founder, Google Ventures

Biography

- Medical Director, Digital Medicine, Amgen

- Former Director, Innovation, Kaiser Permanente

- Former Chief Innovation Officer, LongView Technology

- Co-founder, Health Fidelity, analytics startup

- Education

  – AB, Harvard | MD, UC San Diego | MBA, UC Berkeley

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When I think about my career, my successes are built on learning from failure.

Satya Nadella, CEO, Microsoft

Health Care in 2019

Cost Burden

- **US healthcare spending**
  - Projected to be $5.7T (19.6% GDP) by 2026

- 33% of healthcare spending is wasted

- 30% of bill is paid by patient

- 40% adults carry medical debt

- 27% have not filled prescriptions because of cost

- By 2020, 95% patients will fail to fully pay their medical bill

- **China** spent ¥5,687B ($853B) (7.0% GDP) in 2018
  - Hospital costs: 78.4% of total (*vs* 32% in US)
  - Primary care clinics:13.8% of total (*vs* 20% in US)
  - Other costs: 7.8% of total (*vs* 48% in US)

Disappointing Outcomes

- US spends more on health care than other developed countries (Europe, Japan)
- US spends 18% GDP; other countries spend ~11.5% GDP
  - 90% of US population covered, *vs* 99% in other countries
- Compared to other countries, US pays more for:
  - **Doctors** – GP salary $218K, nearly twice the average in other countries
    - Specialists and nurses also earn significantly more
  - **Medications** – $1,443 per person *vs* $749
  - **Healthcare administration** – 8% of expenditures vs 3%
- What are the results?
  - Utilization comparable, except more diagnostic tests
  - Less smoking in US, but more obesity, infant mortality
  - US life expectancy 78.8 years, *vs* 81.7 in other countries

Case Study

- John has a headache, sees a new doctor.

- Doctor orders tests and refers to the neurologist.

- Neurologist orders more tests. Some are redundant.

- John is prescribed medication that he is allergic to.

- He is hospitalized for a severe allergic reaction.

- He gets a hospital infection and stays for 2 weeks.

No preventive care or patient education
No coordination or information sharing
Costly consequences, loss of productivity

Top 3 Priorities

REDUCING COST

- Too much unnecessary medical care – 33% costs wasted
- Wrong incentives – volume (fee-for-service) rather than value
- Lack of cost transparency and market competition

IMPROVING QUALITY

- Avoidable harm – 1 in 4 Medicare patients harmed during hospital stay
- Care is not personalized or coordinated, thus not optimal
- Patient behavior may cause issues

IMPROVING SERVICE

- Access to health care difficult for some people
- Fragmented ecosystem with limited information sharing
- Not patient-centric or customer-friendly, leading to inefficiencies and errors

Changing the Direction of Health Care

Accountable Care Orgs (ACOs)

- Capped amount paid by Medicare to healthcare network that agrees to provide care that meets quality standards
- Network pays out of pocket if costs more, but keeps profit if costs less

Value-based payment

- Payer pushback against cost of care and cost of medicines
- Payers want real-world evidence (RWE) of value
- Risk-sharing contracts

21st Century Cures Act & PDUFA

- FDA must consider RWE & patient input in drug approval process

Consumer-driven plans

- Increase consumer choice and responsibility

Other proposals

- Single-payer
- Single-rate setting
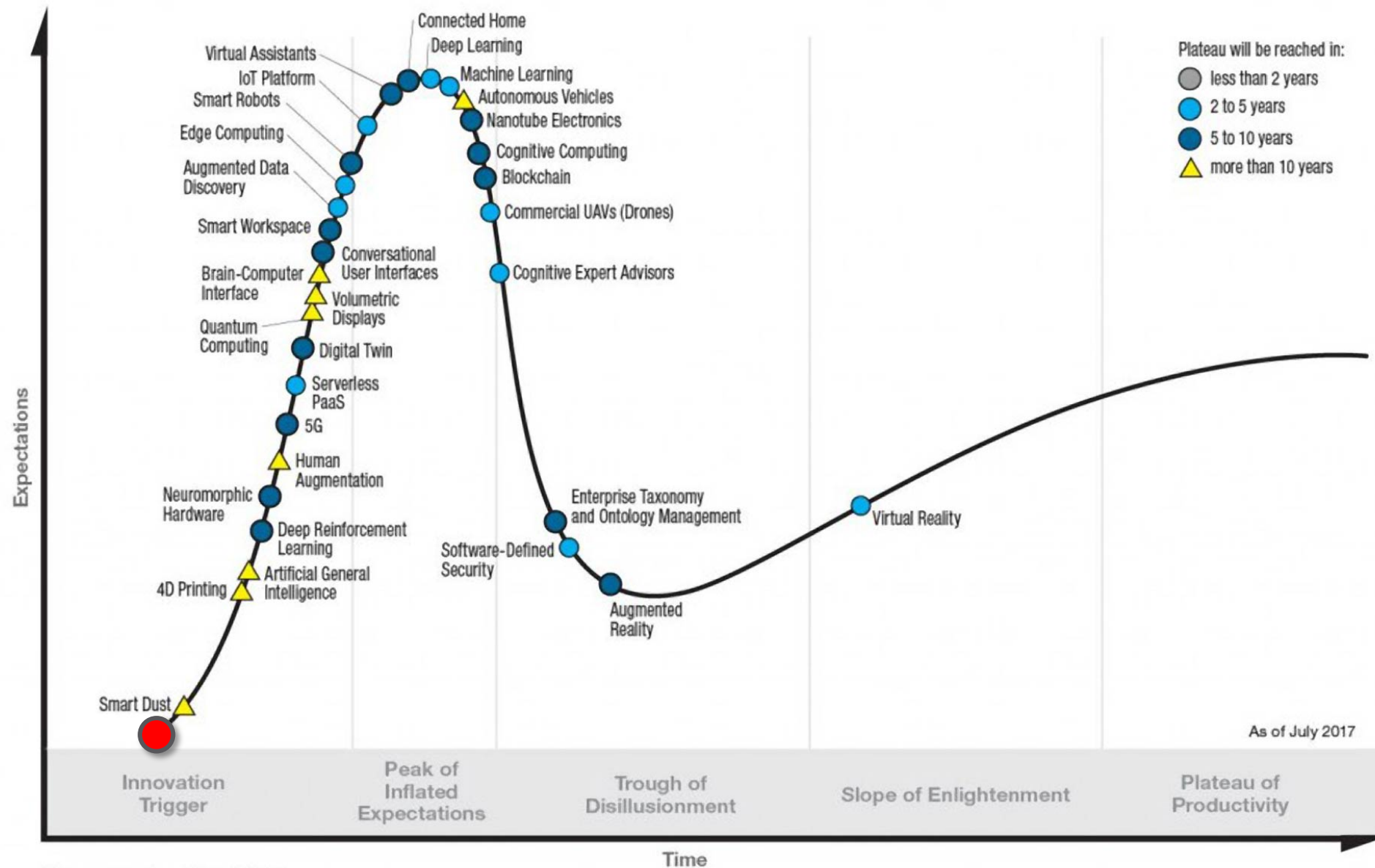- Public health plan option
- Malpractice reform

Role of Technology

Recent Drivers of Healthcare Transformation

Quality, Affordability, and Service Redefined

Increasing Pace of Technological Innovation

Virtualization of Care

Increasing Focus on Wellness

Rise of the Consumer

Value-Based Care

Gartner Hype Cycle for Emerging Technologies, 2017

Plateau will be reached in:
- ◯ less than 2 years
- ◯ 2 to 5 years
- ● 5 to 10 years
- △ more than 10 years

Connected Home
Deep Learning
Virtual Assistants
IoT Platform
Machine Learning
Smart Robots
Autonomous Vehicles
Edge Computing
Nanotube Electronics
Augmented Data Discovery
Cognitive Computing
Blockchain
Smart Workspace
Commercial UAVs (Drones)
Conversational User Interfaces
Brain-Computer Interface
Volumetric Displays
Cognitive Expert Advisors
Quantum Computing
Digital Twin
Serverless PaaS
5G
Human Augmentation
Neuromorphic Hardware
Deep Reinforcement Learning
Enterprise Taxonomy and Ontology Management
4D Printing
Artificial General Intelligence
Software-Defined Security
Virtual Reality
Augmented Reality
Smart Dust

Expectations

Innovation Trigger | Peak of Inflated Expectations | Trough of Disillusionment | Slope of Enlightenment | Plateau of Productivity

Time

As of July 2017

3 Topics from the World of Digital Health

A Case of Exponential Synergy

01 Wearable Sensors
How are you doing at home?

02 Medication Adherence
How do we change behavior?

03 Artificial Intelligence (A.I.)
Could a robot be my doctor?

01
Wearable Sensors

Brief History of Wearables

A Timeline

Electric Hearing Aid
1898

Fitbit Activity Tracker
2009

Apple Watch
2015

1500
Wristwatch

1980s
Calculator Watch

2013
Samsung Galaxy Gear
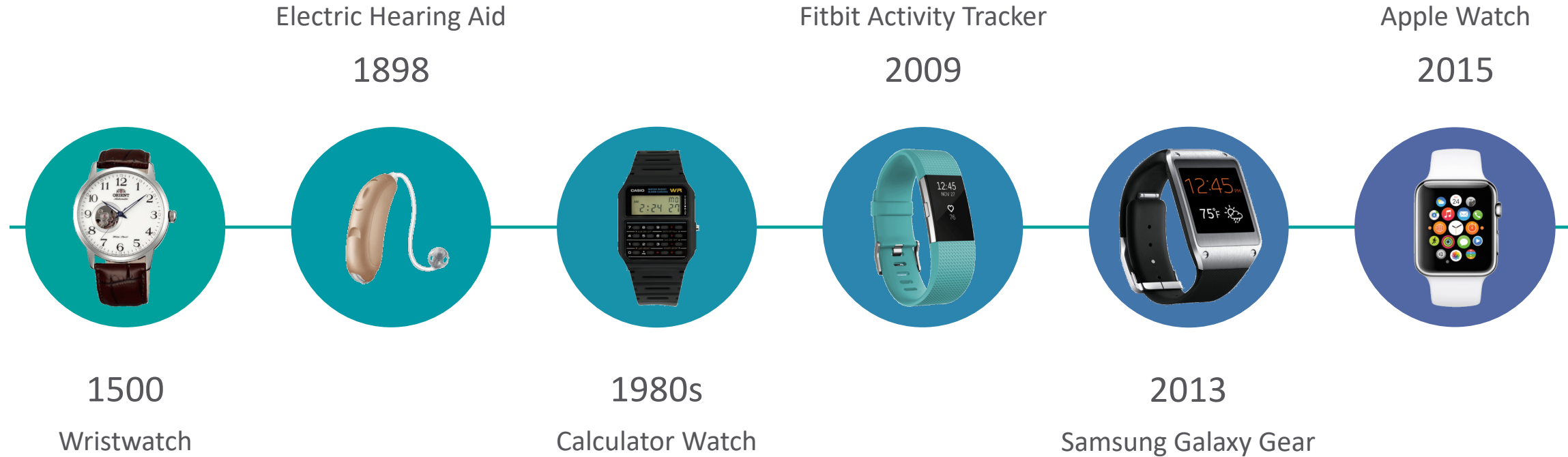
Next-Generation Wearable Sensors

Redefining 'Wearable'

Oxitone 1000

Wrist-based pulse oximeter.
Measures HR, SpO2, activity.
FDA 510(k) cleared for HR May 2017.
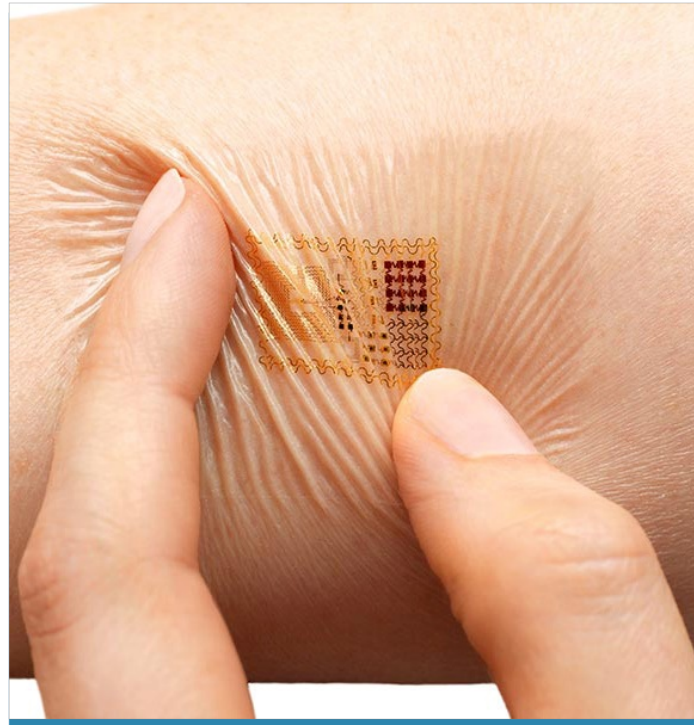
MC10 WISP Medical Tattoo

MC10's US product BioStamp nPoint measures HR, HRV, 1-lead ECG, EMG, sleep activity, posture.
FDA 510(k) cleared May 2018.
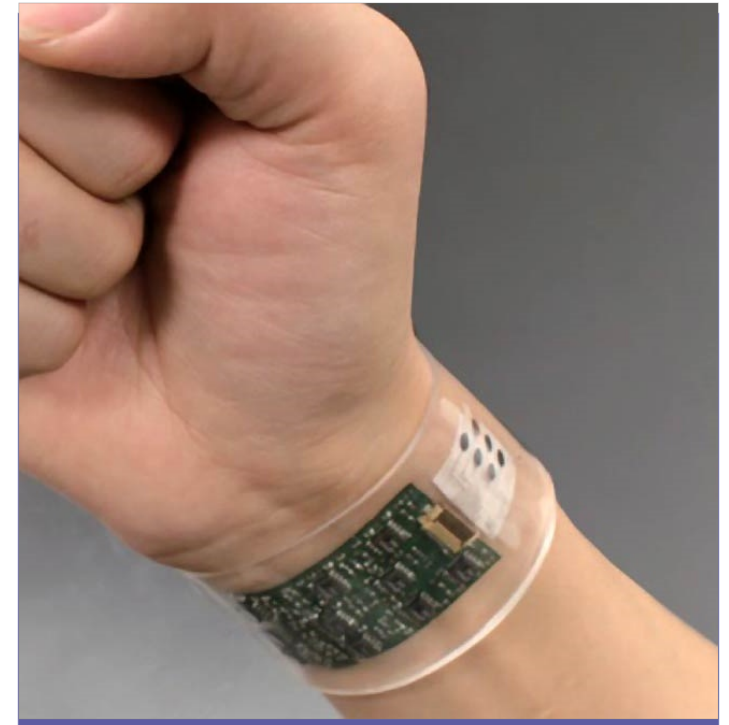
UC Berkeley Sweat Sensor

Measures electrolytes, glucose, lactate, small molecules (Prof. Ali Javey).
Research prototype.

Next-Generation Wearable Sensors

Redefining 'Wearable'

Sensible Medical SensiVest
Medical radar vest worn 90 seconds a day to measure lung fluid in heart failure patients as accurately as CT.
FDA 510(k) cleared August 2015.

toSense CoVa 2
Clinical necklace worn 5 minutes a day. Measures HR, HRV, RR, temperature, thoracic fluid levels, stroke volume, and cardiac output.
FDA 510(k) cleared January 2018.

Welt Smart Belt
Smart belt that measures waist size, eating, activity, sitting, gait, and fall risk. It could potentially warn you about eating too much.

Next-Generation Wearable Sensors

Redefining 'Wearable'

Veristride Biometric Insole

Pressure, gyroscope, accelerometer. Advanced analytics to measure gait and balance, and predict falls in the elderly. Registered with FDA.

Aerbetic Diabetic Sensor

Wristband that uses the AerNos gas sensor to detect early diabetic deterioration by analyzing body odor for certain molecules.
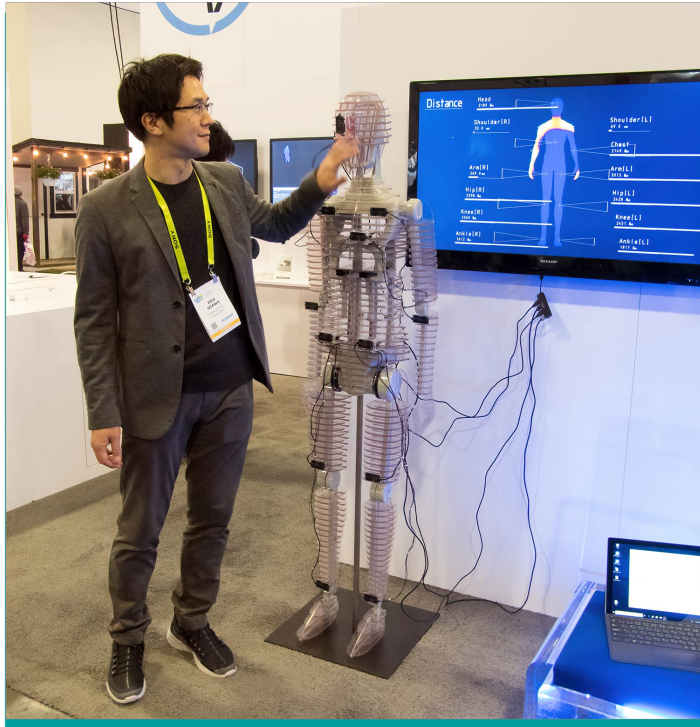

Respiri Wheezo

Wheeze detector that a user holds against their neck. Uses AI to detect early wheezing in patients with asthma and COPD, which lets them take action sooner.

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Next-Generation Wearable Sensors
Redefining 'Wearable'

Super Sensing Forum
Japanese consortium (Panasonic, Hitachi, THK, Omron, etc.) developing prototype body sensors. This model has proximity sensors.

Omron BP Wristband
FDA-approved oscillometric blood pressure cuff integrated into wristband is as accurate as gold standard sphygmomanometer.

Chronolife Smart Clothing
Smart clothing that collects real-time ECG, respiration, abdominal movement, temperature, pulmonary impedance, and activity level.

Pros & Cons
Some Considerations

Pros

- ✓ Objective real-world data
- ✓ More personalized patient experience, better targeted therapy
- ✓ Fewer hospital/clinic visits, lower costs
- ✓ Analytics may predict risk and behavior

Cons

- Require data science expertise
- Lack of standards for outputs
- FDA's new position on real-world data
- Lack of clear evidence for benefit
- Uncertain reimbursement

02
Medication
Adherence

Medication nonadherence is a national epidemic.

Millions of patients per year do not fill their medications or take their medications as prescribed, costing the U.S. healthcare system $100 billion to $290 billion annually.

Patients on average take only half their prescribed doses... Nearly one-quarter of new prescriptions are never filled.

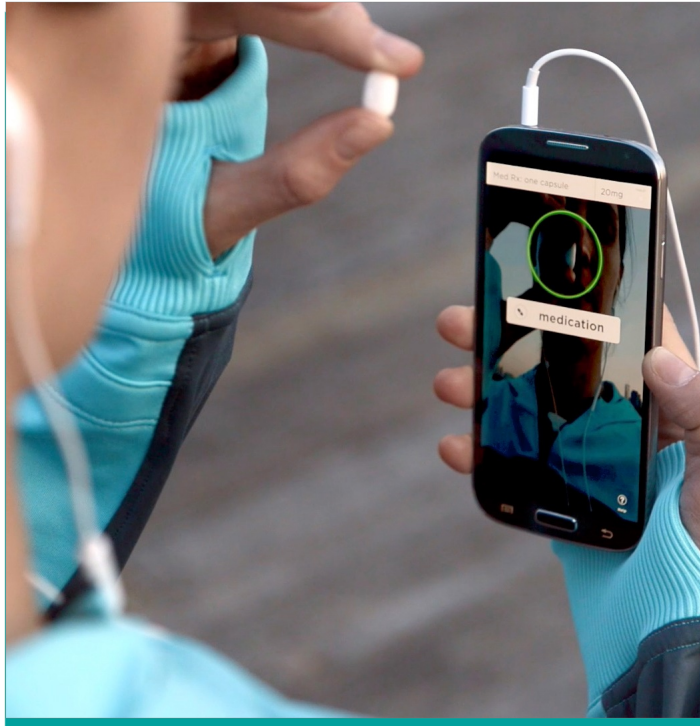This lack of adherence is estimated to cause approximately 125,000 deaths and more than 10 percent of hospitalizations per year.

Gebremedhin, D., and K. Werner, *MobiHealthNews*, August 2017

Over 250 Factors

Too Busy

Forgot

Too Expensive

Tastes Bad

Upsets My Stomach

NON-ADHERENCE

Doesn't Work

Too Many Meds

I Feel Fine

Don't Trust Doctor

Don't Want To Inject

Hard To Swallow
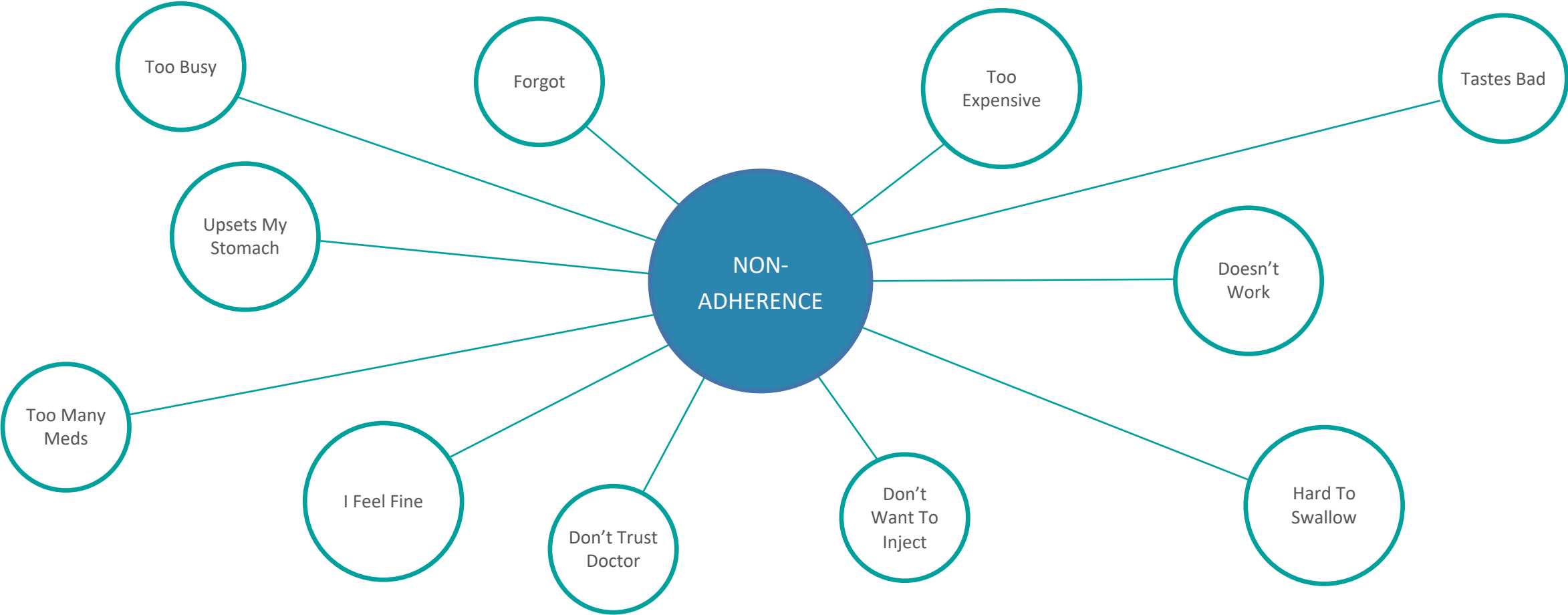
# Different Approaches

Complex Challenge, Crowded Market

AiCure

A.I.-powered app with face recognition, medication ID, ingestion verification. FDA 510(k) Class 1 Exempt status, registered December 2012.
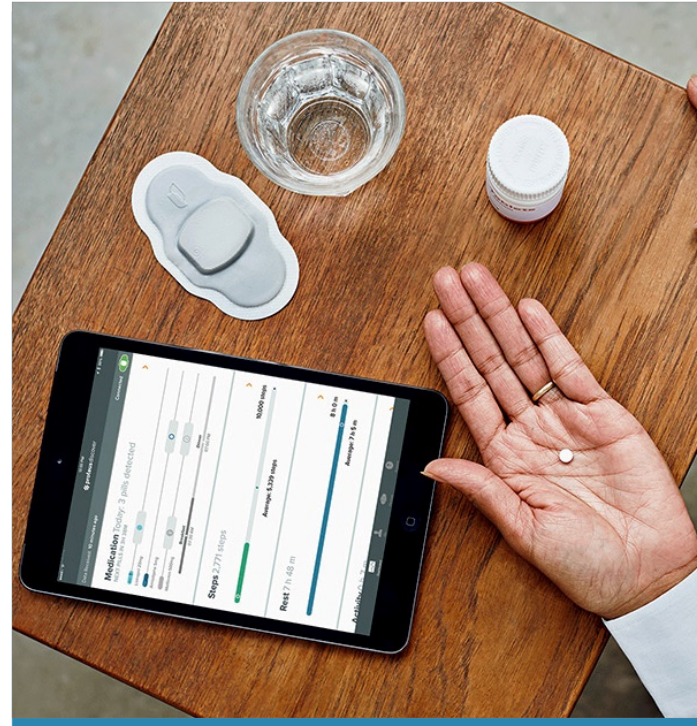
Proteus Smart Pill

Proteus Discover is a pill containing a biodigestible chip that sends a wireless signal once it hits the stomach to an adhesive patch worn by the patient. FDA 510(k) cleared February 2014.
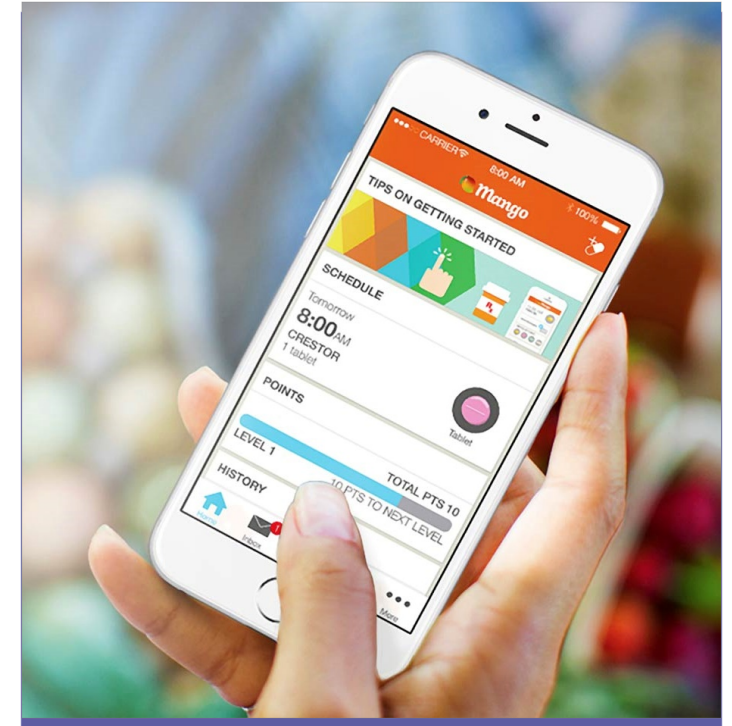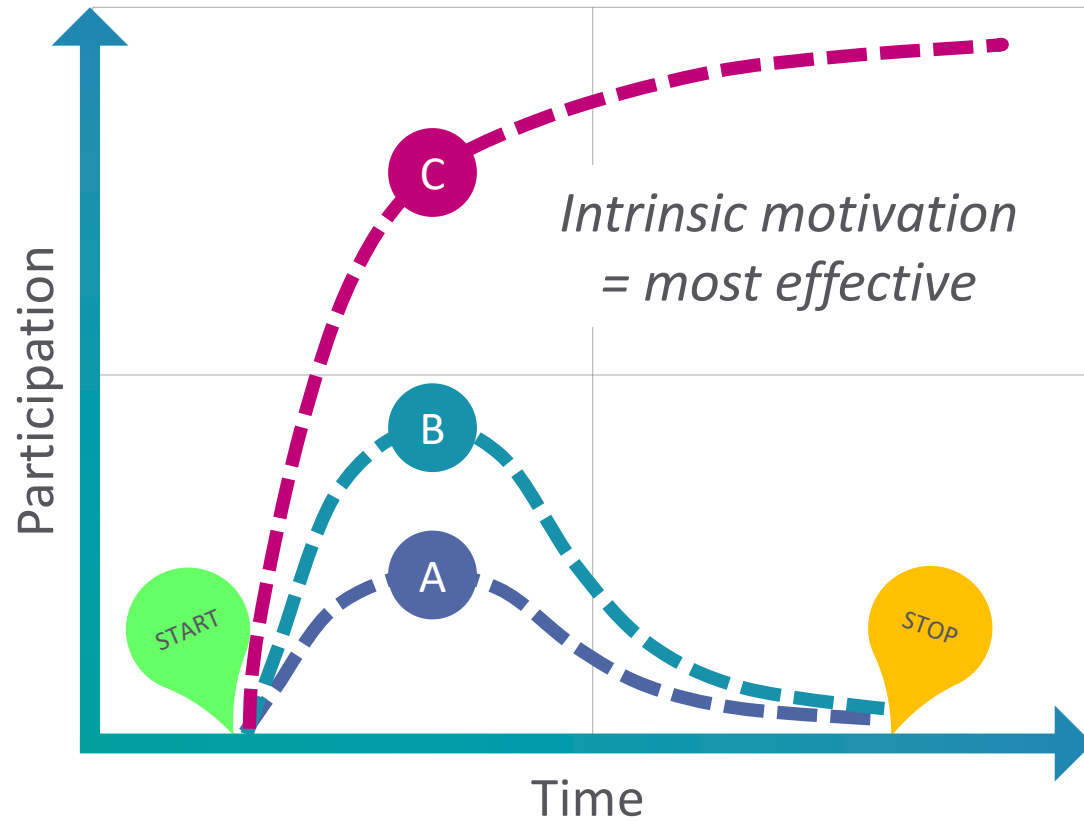

Mango Health

Leverages gamification, with real rewards for medication compliance, healthy habits, and self-reports on activity and vital signs. Supported by clinical studies.

Tenacity Study on Adherence*

MIT engineering graduate students, December 2012

3 Study Cohorts:

A — We'll pay you if you work out.

B — You have a group of friends. All of you will share workout results and collaborate to win prizes.

C — We won't pay you. But pick 2 friends who will follow your results. We'll pay *them* if you work out, and we won't pay them if you don't work out.

* Unpublished – personal communication

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03
Artificial Intelligence
(A.I.)

Artificial Intelligence Startups
Augmenting knowledge work using AI
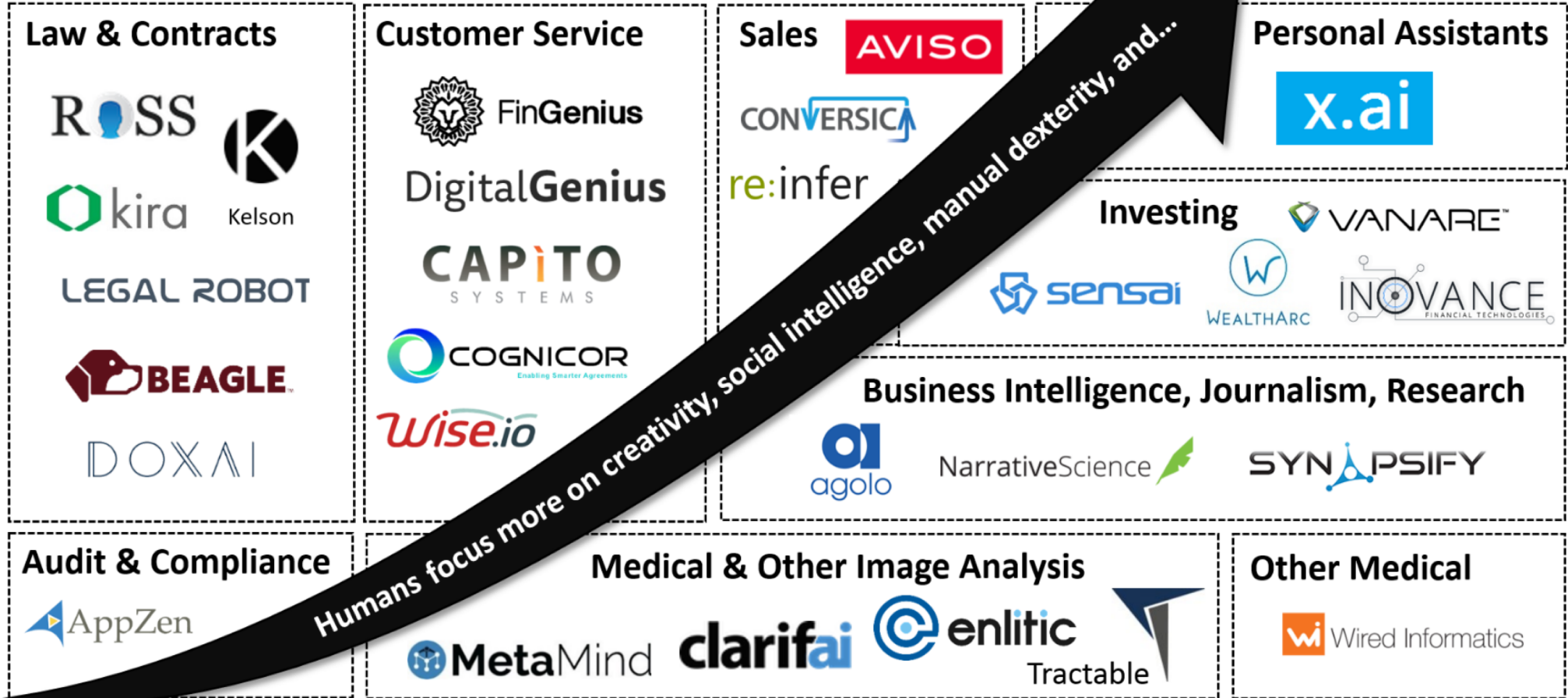
Venture Radar

25% of all job-based tasks will be automated by 2019 - *Forrester Research*
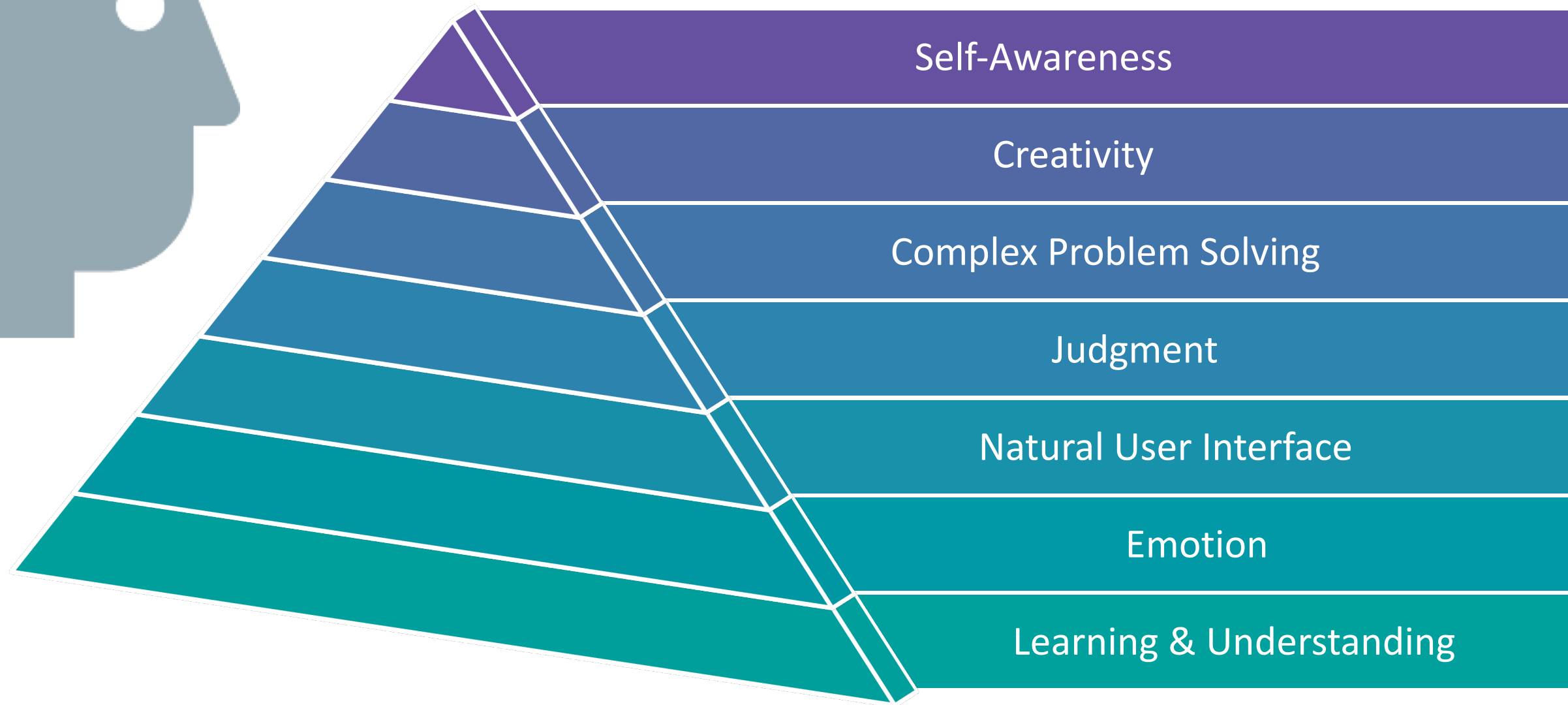
Many experts believe that by 2050 machines will have reached human level intelligence

Hundreds of startups are already using AI to augment knowledge work

Law & Contracts
ROSS K Okira Kelson LEGAL ROBOT BEAGLE DOXAI

Customer Service
FinGenius DigitalGenius CAPiTO SYSTEMS COGNICOR Enabling Smarter Agreements Wise.io

Sales
AVISO CONVERSICA re:infer

Personal Assistants
x.ai

Investing
SENSAI VANARE WEALTHARC INOVANCE FINANCIAL TECHNOLOGIES

Business Intelligence, Journalism, Research
agolo NarrativeScience SYNAPSIFY

Audit & Compliance
AppZen

Medical & Other Image Analysis
MetaMind clarifai enlitic Tractable

Other Medical
Wired Informatics

Humans focus more on creativity, social intelligence, manual dexterity, and...

More: https://www.ventureradar.com/

What is Intelligence?

- Self-Awareness
- Creativity
- Complex Problem Solving
- Judgment
- Natural User Interface
- Emotion
- Learning & Understanding

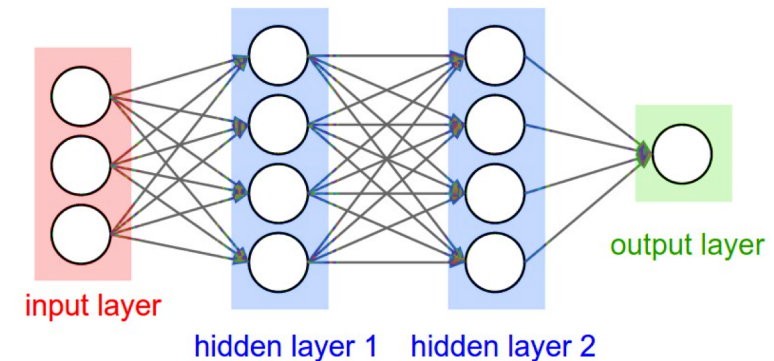AI: Learning & Understanding

Learning & Understanding

First-generation AI systems

- Well-defined rules and hard-coded algorithms

  - Cardiac ECG waveform interpretation (*e.g.*, atrial fibrillation)

  - Breast cancer screening mammography interpretation – rules-based pattern recognition of lesions

    - 2007 study: screenings produced more biopsies, but *worse* early detection results

- Machine no smarter on the 1000th reading than on the first

Second-generation AI systems

- Discovery without rules or explicit programming; may be supervised

  - Neural networks are modeled on neuronal layers in the human brain

  - Iterative weighting & reinforcement = deep learning

input layer

hidden layer 1   hidden layer 2

output layer

- Machine learns from new data and becomes smarter over time

Learning & Understanding

Riding a bicycle

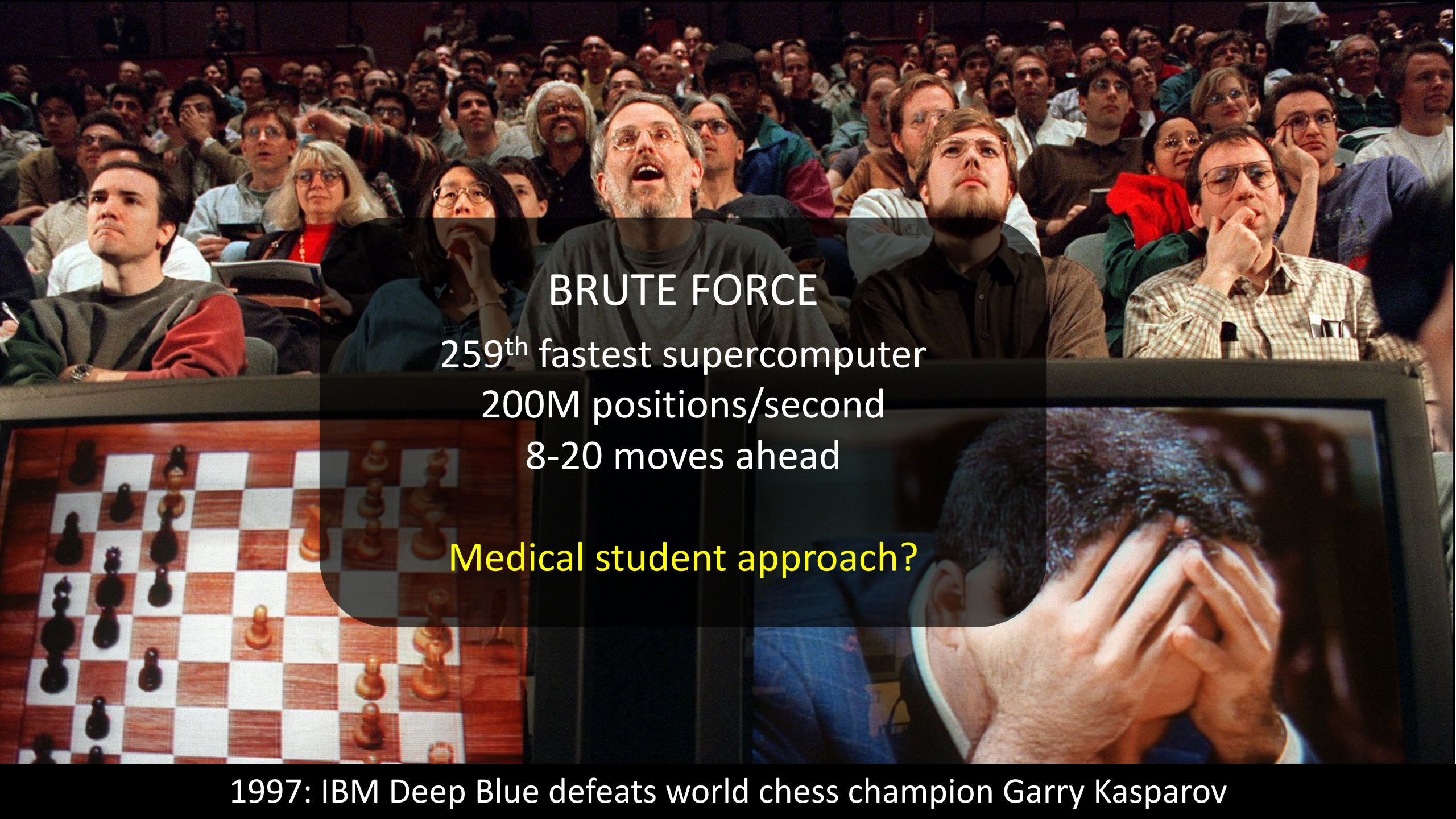**Learning to be a good physician** — DIDAC-TIC · PRACT-ICE · EXPER-IENCE · CAPAB-ILITY — **Unconscious Competence**

Learning to be a good AI — RULES · DATA · FEED-BACK · PREDICT-ION — **Automatic Competence**
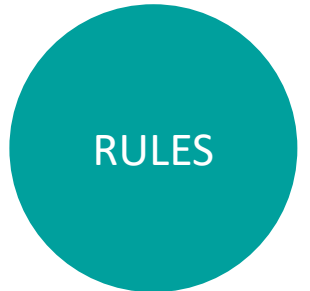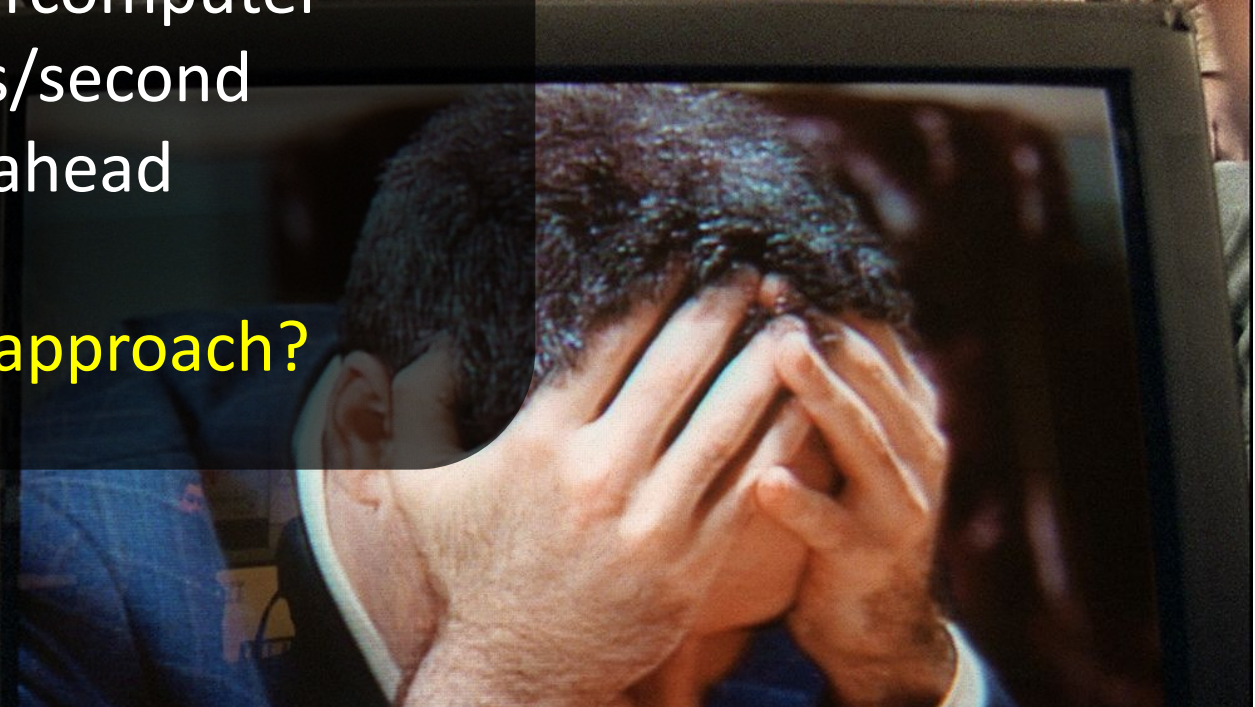
BRUTE FORCE

259th fastest supercomputer

200M positions/second

8-20 moves ahead

Medical student approach?

1997: IBM Deep Blue defeats world chess champion Garry Kasparov

QUESTION ANSWERING

"Ophthalmologists put a plus sign before your prescription number to denote this condition"

100s of parallel algorithms
Calculates chance of being correct

Understanding humans

2011: IBM Watson defeats top *Jeopardy!* champions Ken Jennings & Brad Rutter

NEURAL NET

Policy & Value neural nets
Trained 1 yr with historical & sim
games, experts, self-play

Learning from experience

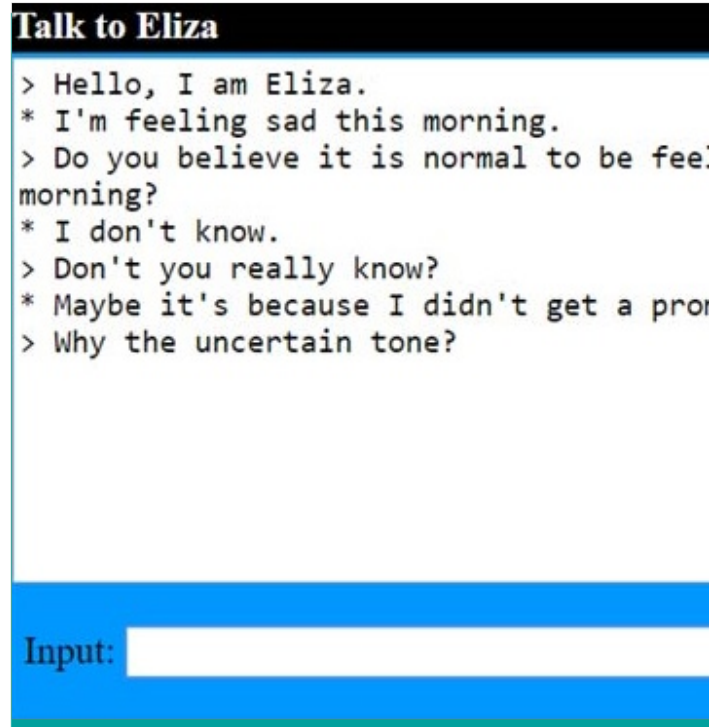2016: Google AlphaGo defeats 18-time world Go champion Lee Sedol

Is a General-Purpose A.I. Possible?

AlphaGo Zero   OCT 2017

Alpha Zero   DEC 2017

RESULTS

- Trained on Go in 3 d with 4.9M self games
Beat $AlphaGo_{2016}$ 100:0 using only 4 TPUs vs 48

- Learned chess in 4 h
Beat top chess program Stockfish 28W:72D:0L while using a computer that was 900X slower

A 'human' approach

Is a General-Purpose A.I. Possible?

AlphaGo Zero OCT 2017

Alpha Zero DEC 2017

CONCERNS

- Outperforms humans in certain situations, but thinking process is not visible / intelligible
- How does it adapt to new rules or scenarios?
- What safeguards need to be put in place?

Alpha Zero will tackle protein folding next

Learning & Understanding
Some Experiments

ELIZA
Natural language processing program developed at MIT 1964-66. It emulated a Rogerian therapist using rules. Some people mistook ELIZA for a real human.
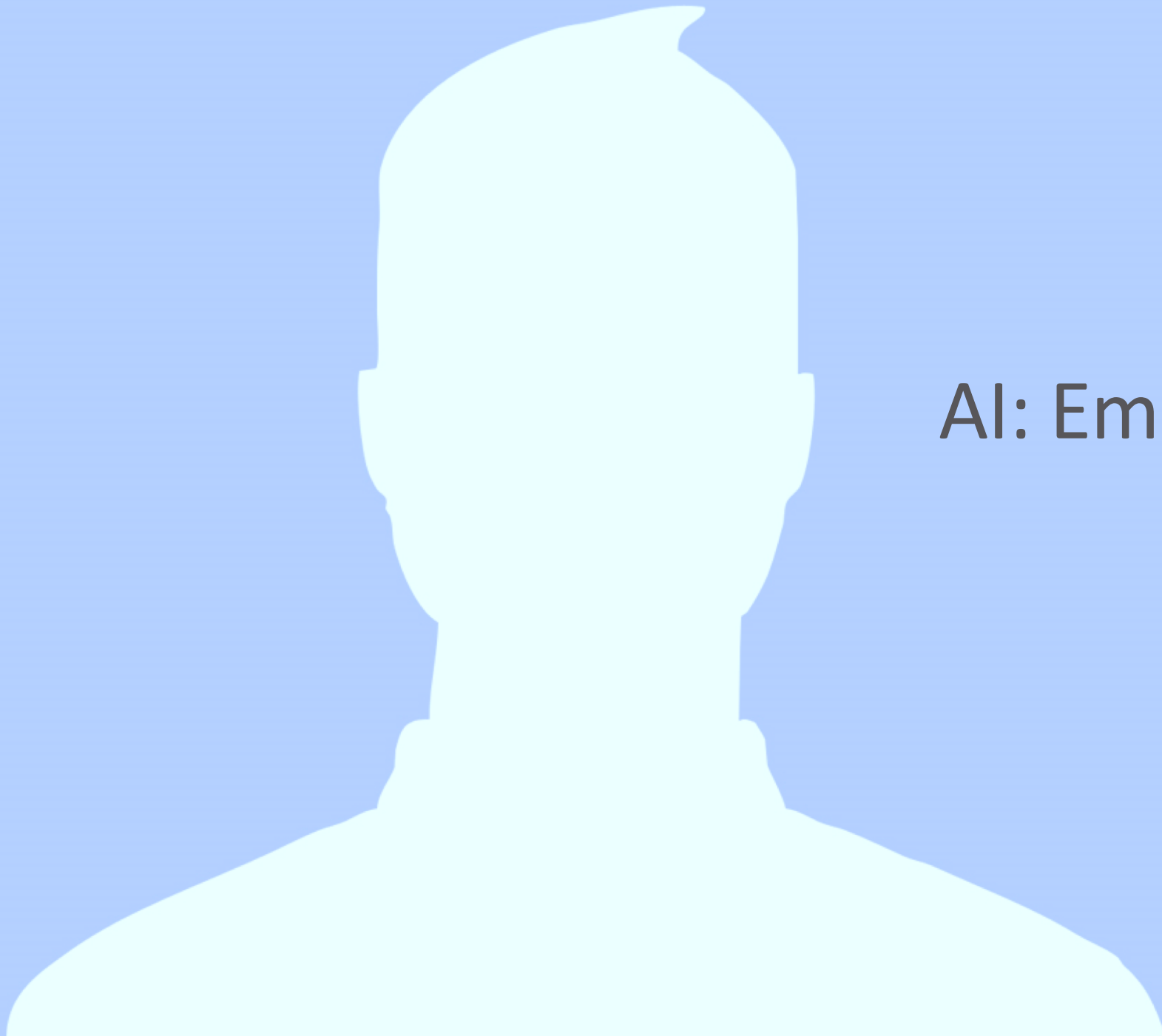
Google Flu Trends
In 2009 Google tried to predict global flu epidemics by analyzing Google searches. It then missed the Swine Flu pandemic. Reason? The data was bad.

Diagnosing Skin Cancer
Neural net trained on 2,000 gold standard biopsy-confirmed images was both more sensitive and more specific than dermatologists (Thrun, 2015ff).

AI: Emotion

Emotional Intelligence

- **Affective computing – we don't need to feel emotion in order to understand it**
  - In humans, high Emotional Quotient (EQ) is associated with low emotionality
- **Computers can recognize many clues to emotion**
  - Facial demeanor, posture, gestures, speech, cognition
  - Sensor data – VS, activity, sleep, stress, environment
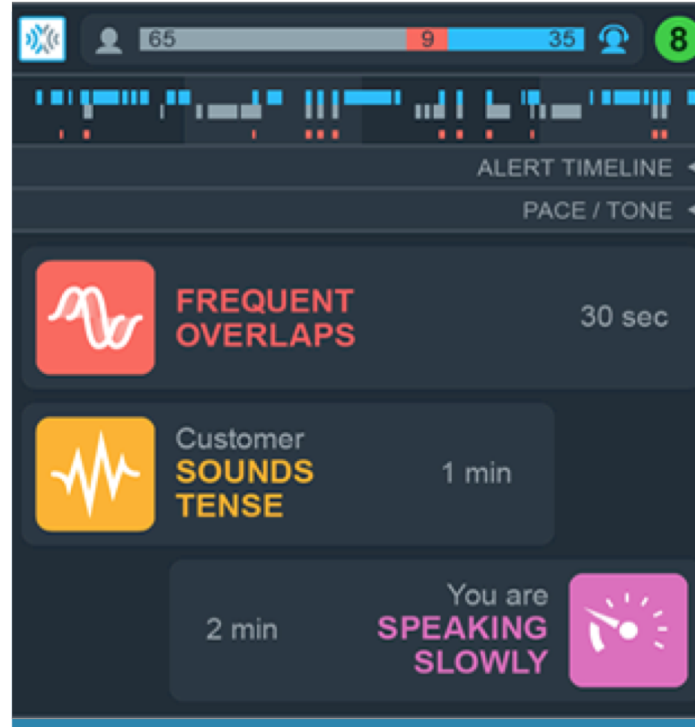- **In some cases, computers may show a *higher* EQ than humans**

Emotional Intelligence

Recognizing mood, attitude, and engagement

Nuralogix

Reads invisible facial blood flow changes and uses ML algorithms to identify emotional state. Substitute for traditional polygraph lie detector.

Cogito

Real-time voicestream analysis to detect emotion in speech, such as tone, energy, empathy, distraction, frustration, lying, and other characteristics. Used by call centers.
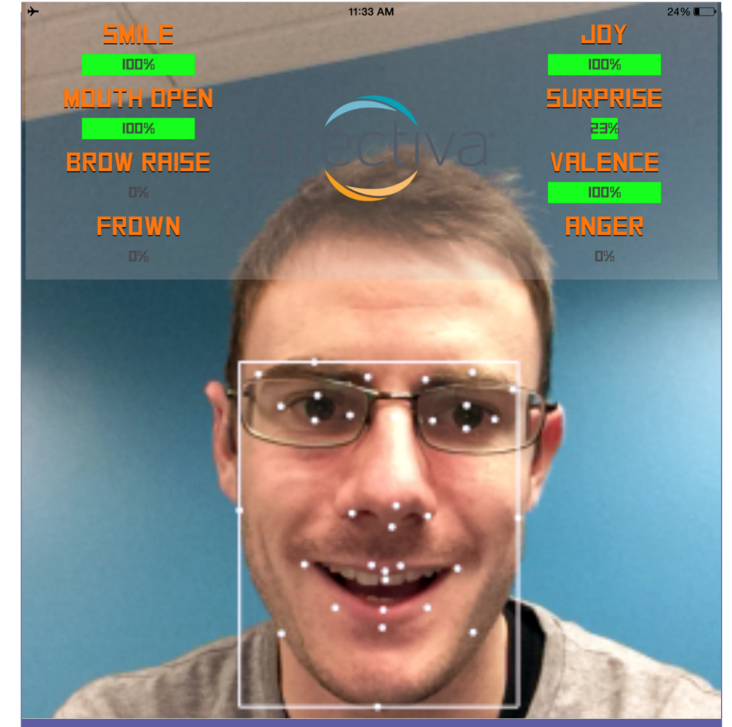
Affectiva Emotion AI

AI tools to accurately identify emotion based on facial expression, voice, and machine learning. Accuracy in high 90s. Non-medical.
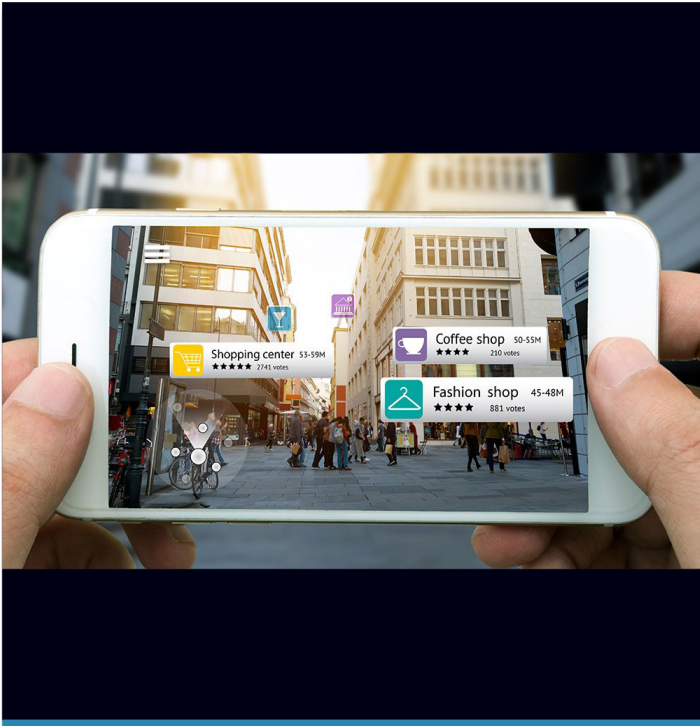
AI: Natural User Interface

Natural User Interface
Sophisticated user-friendliness

Conversational Interface
Products like the Amazon Echo and Google Home have become extremely popular due to technological advances in speech recognition and analytics.

Mixed Reality
Virtual, augmented, and mixed reality systems are starting to make inroads into gaming (*e.g.*, Pokemon Go), retail shopping, staff training, and medicine (*e.g.*, surgical simulation and phobia therapy).

Brain-Computer Interface
BCI is the fastest, most direct (one-way) path between the brain and the machine. Mapping thoughts could be accelerated by machine learning.
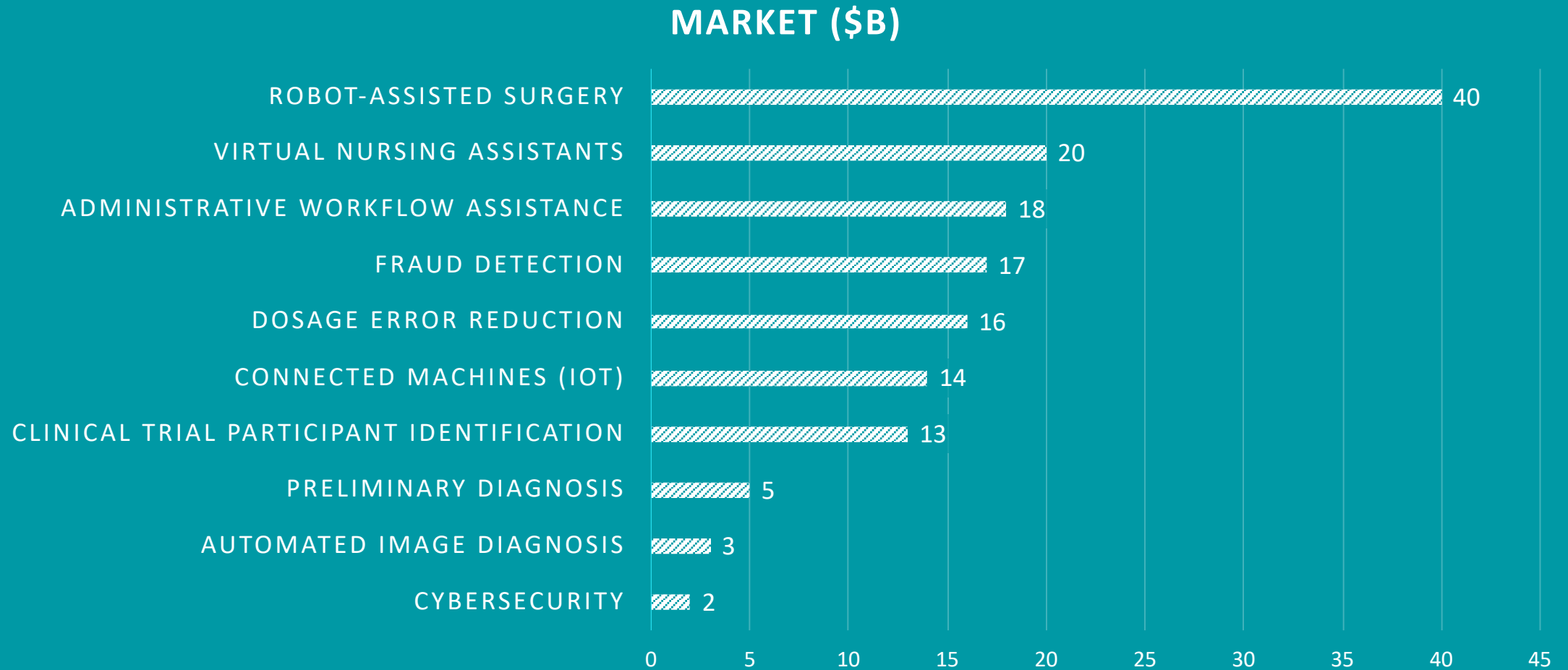
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Some A.I. Applications in Health Care Today*

- Diagnostics
  - Medical imaging
    - Radiologic interpretation
    - Diabetic retinopathy screening
    - Dermatologic classification of skin cancer
  - Computational diagnostics
    - FFR in coronary CT angiography
  - Genomic variant analysis
- Software
  - SaMD (Software As a Medical Device), SiMD
  - Using A.I. to diagnose will require higher validation than using A.I. to provide decision support
- Remote data collection
  - Personal ECG (fingerpad, mobile app)
  - Parkinson's tremors (mobile app)
  - Asthma tracking & management (flow meter)

- Decision support
  - Medical
    - ICU patient risk score
    - Prediction of 30-day readmission
    - Compliance prediction
  - Financial
    - NLP-based risk adjustment
    - Value-based payment
- Patient voice
  - Patient engagement & empowerment
  - Personalized behavioral incentives
  - Real-world value assessment
- Clinical research
  - Recruitment, prediction, big data analysis
  - Drug discovery, endpoints, polypharmacology

* HealthIT.gov, January 2018

106 STARTUPS TRANSFORMING HEALTHCARE WITH AI

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Top 10 Healthcare A.I. Applications in 2026*

MARKET ($B)

Application	Market ($B)
ROBOT-ASSISTED SURGERY	40
VIRTUAL NURSING ASSISTANTS	20
ADMINISTRATIVE WORKFLOW ASSISTANCE	18
FRAUD DETECTION	17
DOSAGE ERROR REDUCTION	16
CONNECTED MACHINES (IOT)	14
CLINICAL TRIAL PARTICIPANT IDENTIFICATION	13
PRELIMINARY DIAGNOSIS	5
AUTOMATED IMAGE DIAGNOSIS	3
CYBERSECURITY	2

* Accenture study, 2017

Final Thoughts

The Future of Health Care

TECHNOLOGY & INDUSTRY

REAL-WORLD VALUE
FOR PATIENTS, EMPLOYERS,
& PAYERS

INNOVATION & AGILITY

RESEARCH & EDUCATION

VISION & STRATEGY

CHANGING ROLES OF
PATIENTS, PROVIDERS, &
OTHER PARTICIPANTS

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