Leadership Challenges in Biomedical Innovation in an Era of Disruptive Change, Escalating Complexity and Pervasive Uncertainty
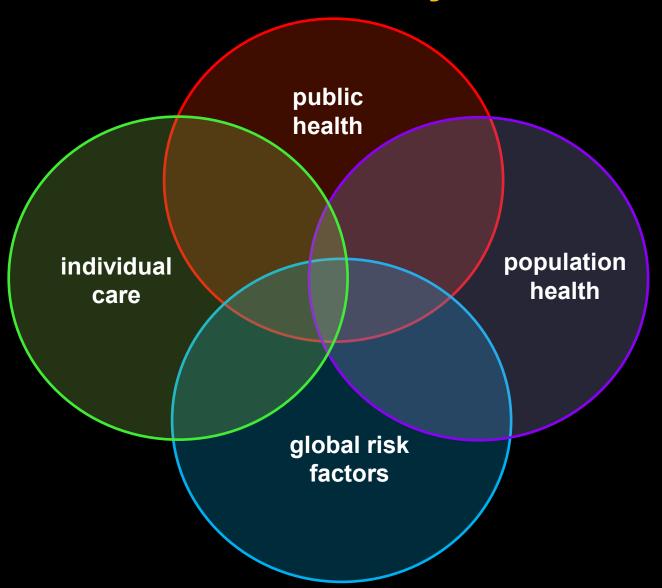
Dr. George Poste

Regents' Professor and Del E. Webb Chair in Health Innovation
Complex Adaptive Systems Initiative, Arizona State University
Co-Director, ASU-UA Institute for Future Health
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The US Healthcare Ecosystem

- **the $4.1 trillion US health system (c. 20% GDP) is unmatched in the scale and diversity of organizations and functions**

- **over 450,000 entities involved in the development and delivery of highly specialized services to heterogenous populations over their lifetimes**

- **health ranks highest in public and political expectations regarding access, availability, affordability and quality of care**

The US Health Ecosystem

- demographics of an aging society and increased chronic disease burden

    - 50% cost incurred in last six months of life

- disturbing increase in mental illness, SUD, suicide even before the COVID pandemic

- economically and clinically unsustainable

- imbalance between care-centric (sick care) versus health-centric (wellness) expenditures

- fee-for-service incentives for providers reward volume of care versus outcomes

- imbalance in investments in population focused health initiatives versus individual care

The US Health Ecosystem

- **protracted and varied diffusion of new technologies into clinical practice**

- **wide variation in clinical practice**

- **poor coordination and continuity of care across the health/health care system**

- **large disparities in access to care**

- **inefficient integration and analysis of data to drive evidence-based/best practice protocols**

The US Health Ecosystem

- **urgent societal imperative to increase access to care, reduce cost and improve clinical outcomes**

- **need for greater recognition of social determinants of health (SDoH) in disease risk and access/cost of care**

- **fragility in preparedness/resiliency for unanticipated large-scale disruption (pandemic, cyber, grid collapse, supply chains)**

The Health Ecosystem

- **facing a confluence of complex events that will radically alter all aspects of biomedical research and health care delivery**
  - **national and global**
- **cross-domain technology convergence**
  - **biomedicine, engineering and computing**
- **cross-sector industry convergence `**
  - **diagnostics, therapeutics, data analytics, social media**
- **public and political expectations**
  - **access, availability, affordability and outcomes**
  - **reduce disparities and inequities**

The Health Ecosystem

- facing a confluence of complex events that will radically alter all aspects of biomedical research and health care delivery
  - na
- cross
  - bio   g
- cross
  - diagnostics, therapeutics, data analytics, social media
- public and political expectations
  - access, availability, affordability and outcomes
  - reduce disparities and inequities

VALUE

Leaders as 'Design Architects'

'Design Thinking' in an Era of Disruptive Change, Escalating Complexity and Uncertainty

Navigating Change

**Complex Interactions Between Multiple Stakeholders
with Different Incentives**

Technical, Socio-Cultural, Economic and Political Change Drivers

Incremental Innovation Versus Disruptive (Radical) Innovation
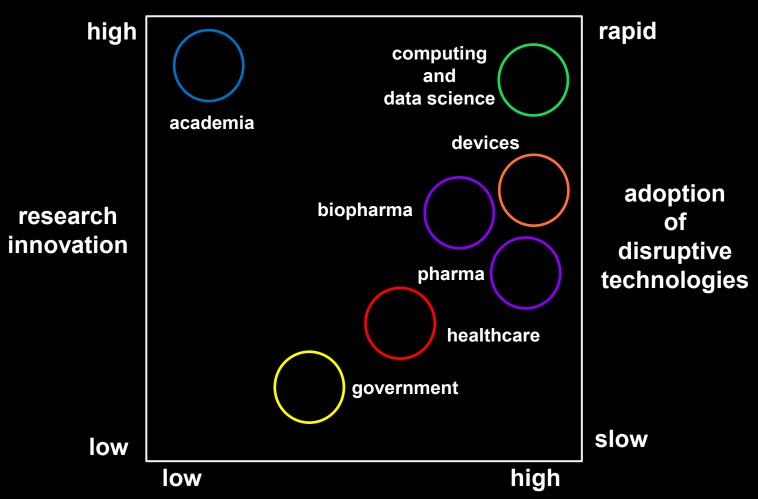
threats **opportunities**

Innovation

Disruptive Innovation

- new technical or commercial concepts that disrupts the status quo
- creation of entirely new markets for novel products/services
- competition on NEW VALUE PROPOSITIONS (intellectual/commercial/military)
- often unrecognized or dismissed by currently successful organizations (complacency)
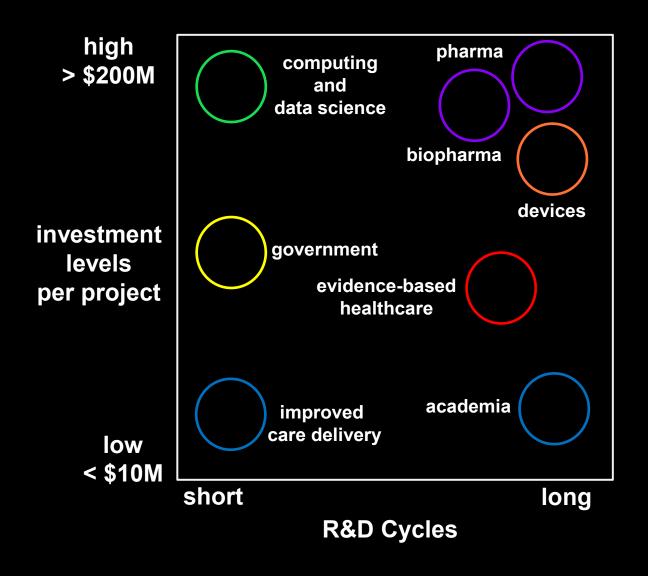
Incremental Innovation

- small conceptual refinements and/or design of additional features into existing products and services
- competition on VOLUME between minimally differentiated products/services (market share)

Drivers of the Healthcare Innovation Ecosystem

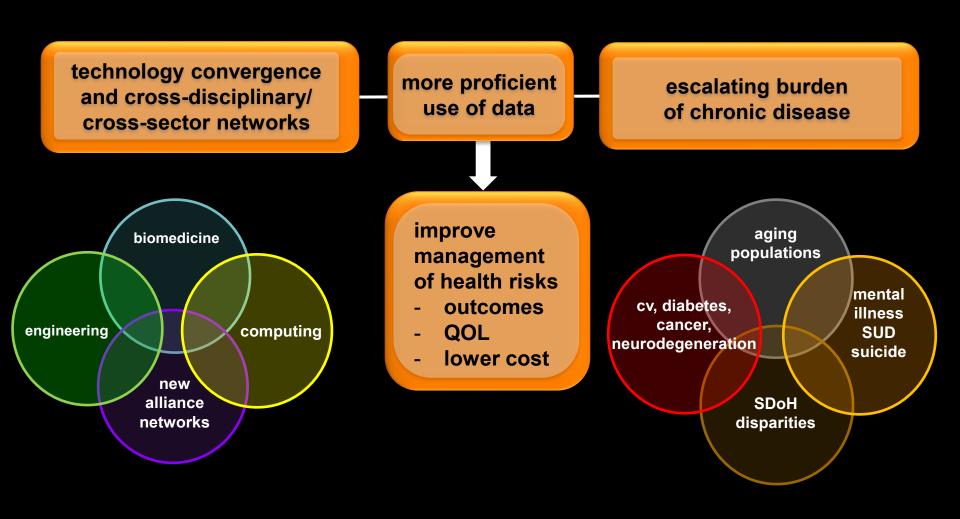# Drivers of the Healthcare Innovation Ecosystem

high
> $200M

investment
levels
per project

low
< $10M

computing
and
data science

pharma

biopharma

devices

government

evidence-based
healthcare

improved
care delivery

academia

short

long

R&D Cycles

Precision Health and Digital Health: Inter-dependent Strategic Drivers in the Evolution of Healthcare Policies and Priorities

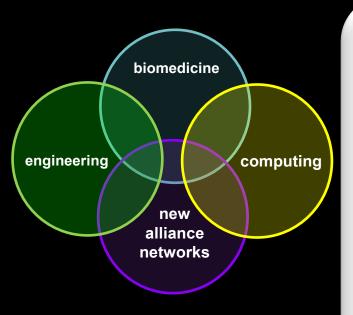# The Strategic Landscape for Biomedical Research and Health Services

technology convergence and cross-disciplinary/ cross-sector networks

more proficient use of data

escalating burden of chronic disease

improve management of health risks
- outcomes
- QOL
- lower cost

biomedicine

engineering

computing

new alliance networks

aging populations

cv, diabetes, cancer, neurodegeneration

mental illness SUD suicide

SDoH disparities

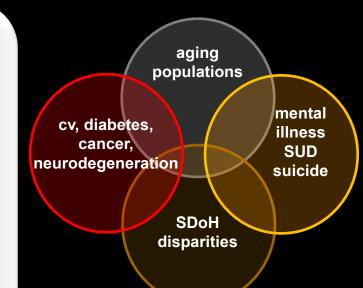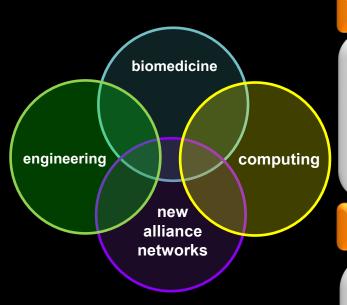# The Strategic Landscape for Biomedical Research and Health Services

technology convergence and cross-disciplinary/ cross-sector networks

more proficient use of data

escalating burden of chronic disease

- biomedicine
- engineering
- computing
- new alliance networks

- **remote health monitoring to identify/mitigate risk**
- **reduce (re)hospitalization**
- **the expanded care space and continuity of care**
- **SDoH and health disparities**
- **improve outcomes and QOL**

- aging populations
- cv, diabetes, cancer, neurodegeneration
- mental illness SUD suicide
- SDoH disparities

The Strategic Landscape for Biomedical Research and Health Services

technology convergence

escalating chronic disease burden

biomedicine

engineering

computing

new alliance networks

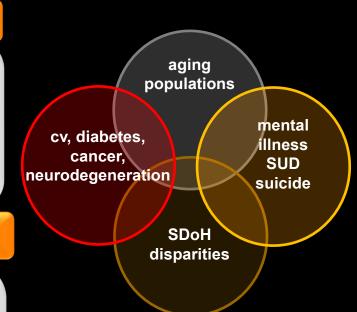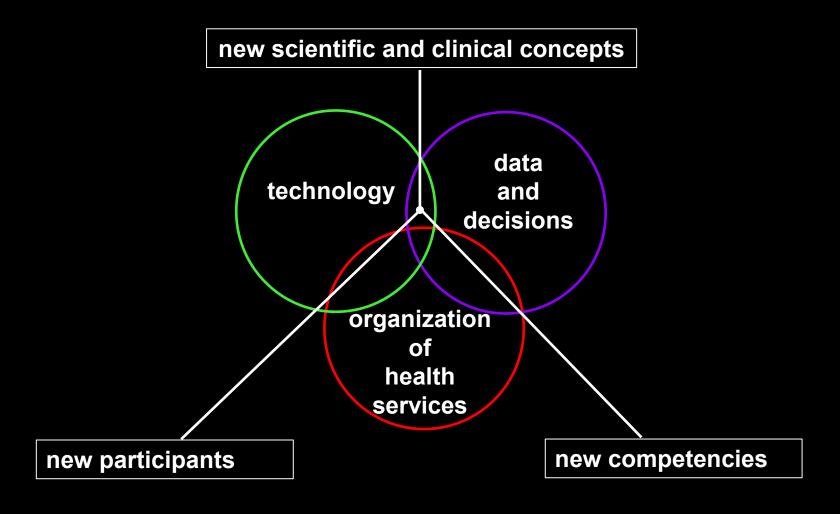**precision health**

- defining disease at the molecular level
- disease subtyping and optimum treatment selection
- identify predisposition risks

digital health
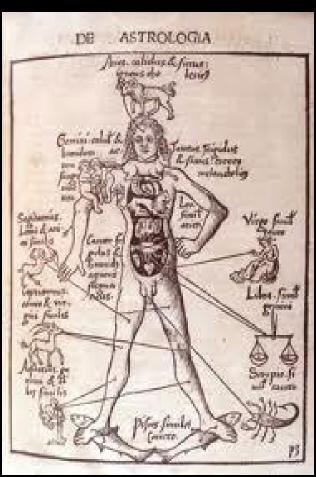
- telemedicine
- remote health monitoring
- ML/AI for large data analytics
- clinical decision support tools
- empowered patients

aging populations

mental illness SUD suicide

cv, diabetes, cancer, neurodegeneration

SDoH disparities
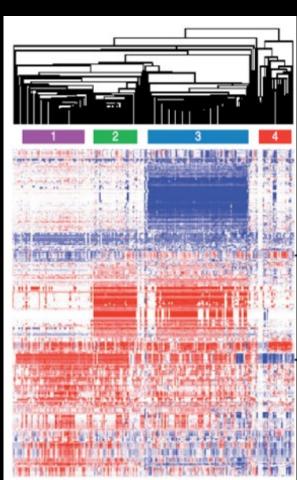
The Path to Precision Health:
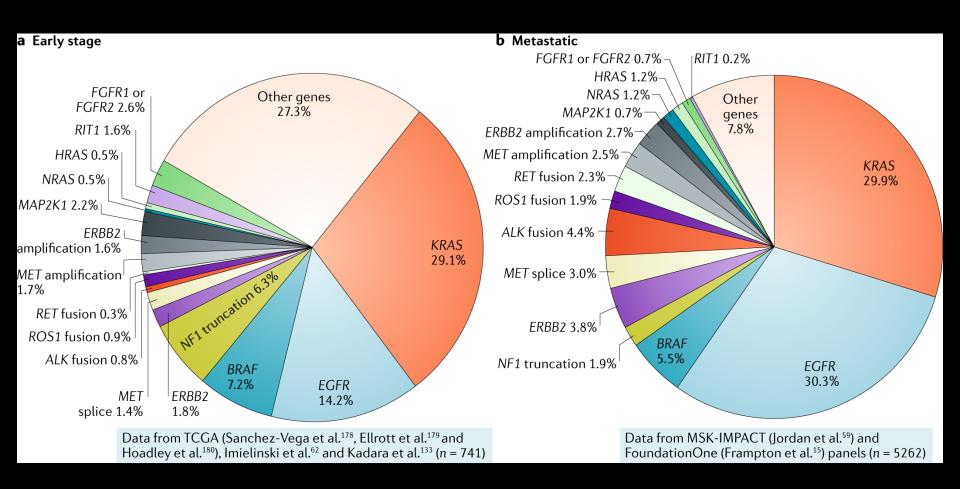# From Superstitions to Symptoms to (Molecular) Signatures

humors; astrology, shamanism, sin and divine fate

biochemistry and organ-based pathophysiology

molecular biology and multi-omics profiling

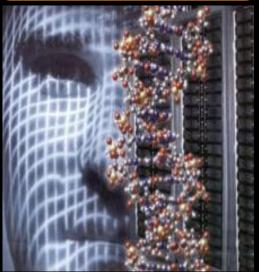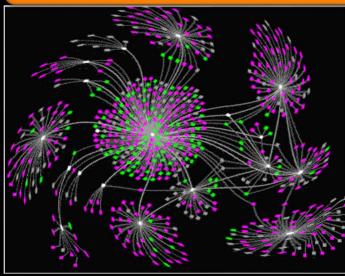# Molecular Classification of NSCLC and Identification of Single, Largely Non-Overlapping Oncogenic Alterations

a Early stage

- FGFR1 or FGFR2 2.6%
- RIT1 1.6%
- HRAS 0.5%
- NRAS 0.5%
- MAP2K1 2.2%
- ERBB2 amplification 1.6%
- MET amplification 1.7%
- RET fusion 0.3%
- ROS1 fusion 0.9%
- ALK fusion 0.8%
- MET splice 1.4%
- ERBB2 1.8%
- BRAF 7.2%
- NF1 truncation 6.3%
- EGFR 14.2%
- KRAS 29.1%
- Other genes 27.3%

Data from TCGA (Sanchez-Vega et al.[178], Ellrott et al.[179] and Hoadley et al.[180]), Imielinski et al.[62] and Kadara et al.[133] (n = 741)

b Metastatic

- FGFR1 or FGFR2 0.7%
- RIT1 0.2%
- HRAS 1.2%
- NRAS 1.2%
- MAP2K1 0.7%
- ERBB2 amplification 2.7%
- MET amplification 2.5%
- RET fusion 2.3%
- ROS1 fusion 1.9%
- ALK fusion 4.4%
- MET splice 3.0%
- ERBB2 3.8%
- NF1 truncation 1.9%
- BRAF 5.5%
- EGFR 30.3%
- KRAS 29.9%
- Other genes 7.8%

Data from MSK-IMPACT (Jordan et al.[59]) and FoundationOne (Frampton et al.[15]) panels (n = 5262)

From: F. S. Koulidis and J. V. Heymach (2019) Nature Rev. Cancer 19, 495

Precision Health

Deep Phenotyping: "Much More Than Omics"

From Womb to Tomb: Systematic Integration of Diverse Health Data

SDoH, Lifestyle, Environment, Health Disparities

- the majority of events that influence wellness/disease risk and treatment adherence occur outside of formal interactions with the healthcare system

- daily decisions by individuals have greater effects on their health than decisions controlled by the healthcare system

Expanding the "Care Space" in Healthcare

Healthcare Beyond The Clinic
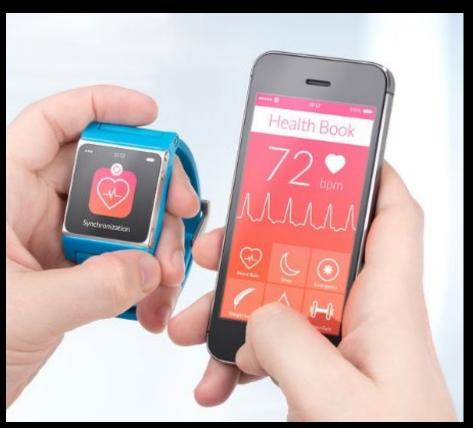
Remote Health Status Monitoring

Smartphones, Wearables, Devices and Digital Services

M4: Making Medicine More Mobile

AORTA: Always On, Real Time Access

Wearables and Mobile Devices:
Key Drivers in Remote Health Monitoring and Care Delivery

Wellness Apps for Fitness, Diet and Exercise
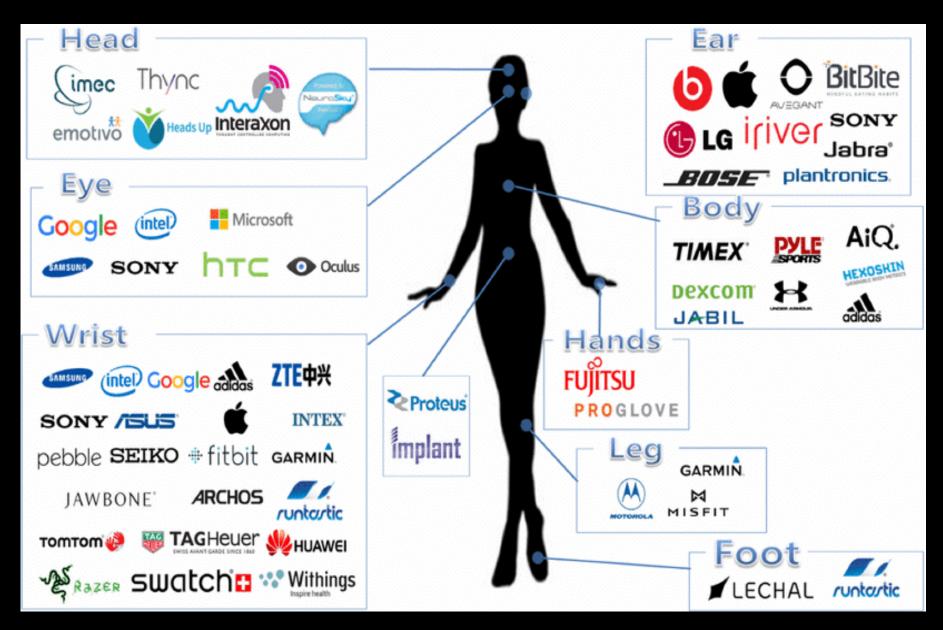
Wearables and Remote Health Status Monitoring

Smart Devices for Automated Drug Delivery and Improved Therapeutic Adherence

Propeller Health

Gecko (now Teva)

CapMedic

Biocorp Inspair

Aterica Veta EpiPen

Rapid Growth in Wearables, Sensors and Devices for In-Home Remote Health Status Monitoring

The Eldercare Gap

10,000 ● **boomers turn 65 every day**

79% ● **increase in boomers age 80 or older from 2010 to 2030**

1% ● **projected increase in number of caregivers aged 45 to 64 from 2010 to 2030**

348,000 ● **projected number of home health aides needed in next decade**

Digital Technologies and Aging in Place: Independent But Monitored Living for Aging Populations

Rx adherence

cognitive stimulation

in-home support and reduced readmissions

reduced office visits

Empowered Patients:
Social Networking Sites and Their Role in Clinical Care

- logical extension to healthcare of rapid rise of web/apps in mainstream culture

- increasingly proactive and engaged consumers/patients/families

- greater access to information on treatment options, cost and provider performance

- new clinical practice tools to optimize physician-patient relationships

- Ux and formation of senior executive level Chief Patient Experience Officer posts in large provider organizations

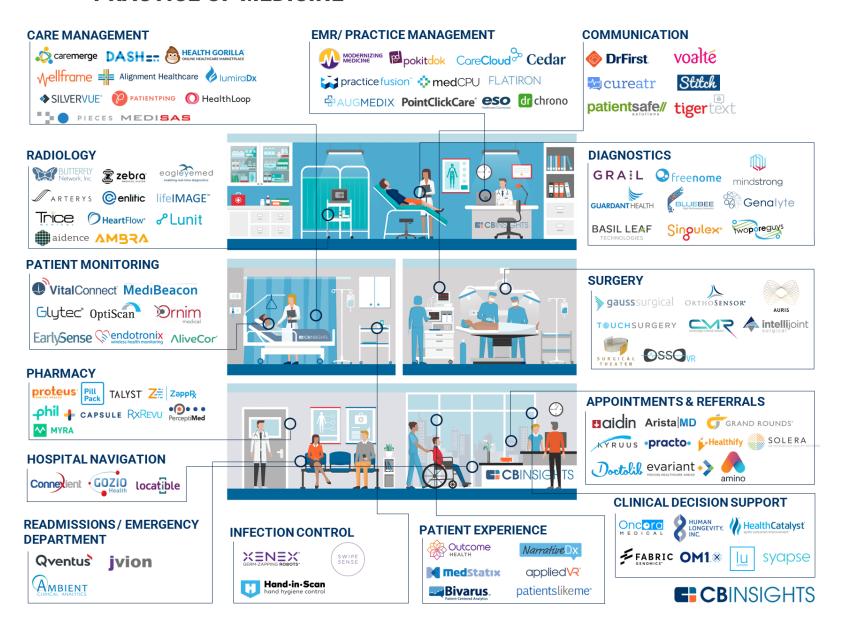# Economies of Scale and Consumer Convenience

Networked Telehealth Between Provider Organizations: Centralized 24/7 Monitoring of Critical Care and Expert Consultations

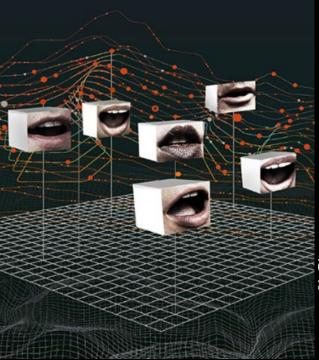# THE DIGITAL HOSPITAL: 100+ COMPANIES REINVENTING THE PRACTICE OF MEDICINE

CARE MANAGEMENT

caremerge · DASHer · HEALTH GORILLA ONLINE HEALTHCARE MARKETPLACE
Wellframe · Alignment Healthcare · lumiraDx
SILVERVUE · PATIENTPING · HealthLoop
PIECES · MEDISAS

EMR/ PRACTICE MANAGEMENT

MODERNIZING MEDICINE · pokitdok · CareCloud · Cedar
practice fusion · medCPU · FLATIRON
AUGMEDIX · PointClickCare · eso Healthcare Connected · dr chrono

COMMUNICATION

DrFirst · Voalté
cureatr · Stitch
patientsafe solutions · tigertext

RADIOLOGY

BUTTERFLY Network, Inc. · zebra Medical Vision · eagleyemed enabling real-time diagnostics
ARTERYS · enlitic · lifeIMAGE
Trice Medical · HeartFlow · Lunit
aidence · AMBRA

DIAGNOSTICS

GRAIL · freenome · mindstrong
GUARDANT HEALTH · BLUEBEE High Performance Analysis · Genalyte
BASIL LEAF TECHNOLOGIES · Singulex · twoporeguys

PATIENT MONITORING

VitalConnect · MediBeacon
Glytec · OptiScan · Ornim medical
EarlySense · endotronix wireless health monitoring · AliveCor

SURGERY

gauss surgical · ORTHOSENSOR · AURIS
TOUCHSURGERY · CMR cambridge medical robotics · intellijoint surgical
SURGICAL THEATER · OSSO VR

PHARMACY

proteus DIGITAL HEALTH · Pill Pack · TALYST · ZappRx
phil · CAPSULE · RxRevu · PerceptiMed
MYRA

APPOINTMENTS & REFERRALS

aidin · Arista MD · GRAND ROUNDS
KYRUUS · practo · Healthify · SOLERA AN INTEGRATED HEALTH NETWORK
Doctolib · evariant MOVING HEALTHCARE AHEAD · amino

HOSPITAL NAVIGATION

Connexient · GOZIO Health · locatible

CLINICAL DECISION SUPPORT

Oncora MEDICAL · HUMAN LONGEVITY, INC. · HealthCatalyst ignite outcomes improvement
FABRIC GENOMICS · OM1 · lumiata syapse

READMISSIONS / EMERGENCY DEPARTMENT

Qventus · jvion
AMBIENT CLINICAL ANALYTICS

INFECTION CONTROL

XENEX GERM-ZAPPING ROBOTS · SWIPE SENSE
Hand-in-Scan hand hygiene control

PATIENT EXPERIENCE

Outcome HEALTH · NarrativeDx
medStatix · appliedVR
Bivarus Patient-Centered Analytics · patientslikeme

CB INSIGHTS

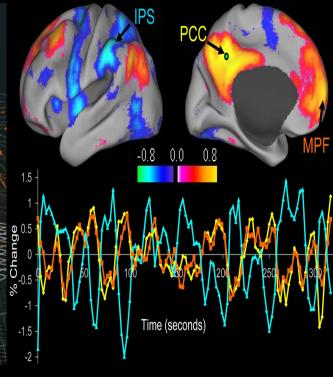# Telemedicine and Behavioral Health: Digital Psychiatry and Non-Pharmacologic Digital Therapeutics

Increased ED Behavioral Health Emergencies

- reported range of 8-25% of ED volume
- 70% of behavioral health patients also have one or more co-morbidities
- opioid-related visits tripled between 2005-19
- approx. 1 in 4 individuals with serious mental illness also have substance abuse disorder
- 60% of adolescents in community-based SUD treatment programs also meet diagnostic criteria for mental illness
- dramatic increase in mental health needs in COVID-19 pandemic

Computer Vision, Facial Recognition and New Digital Psychometrics in the Evaluation of Mental Illness

- eye movements
- facial dynamics
- stimulus response reaction and interaction speeds

- speech patterns (rhythm, tone, volume)
- semantic construction

- 256 lead EEG
- brain imaging functional MRI
- altered signal pathways

ML/AI analysis of individual multiparameter responses matched to large-scale analysis of video data banks of patients with clinically validated mental disorders

"Digiceuticals": Software as Therapy

"We envision empowering individuals with digital therapeutic solutions that address underlying motivational and technical deficits by deciphering neural pathways that support motivation, decision-making and reinforcement to prompt health."

Dr. Ben Wiegand
Global Head, Janssen R&D
World Without Disease Accelerator
PharmaVoice 2017

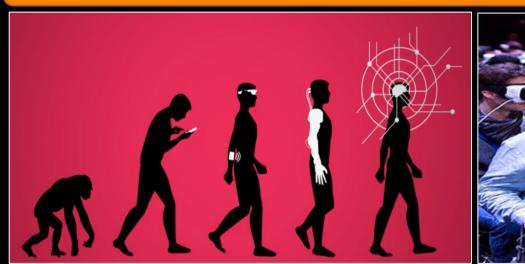# Digital Therapeutics Alliance

Robot–Human Directed Interactions

Co-evolution of Human-Machine Interactions, Robotics and Augmented Cognition

VR/AR/MR and Preparation for Complex Procedures

AR/VR/MR Neuromodulation in Clinical Care

- **injury rehabilitation**
- **reduce apprehension/distraction in painful procedures**
- **anxiety, depression, PTSD, phobias**

The Internet, Social Media and the Road to the Metaverse

- **who knows why people do what they do?**
  - **the fact is that they do!**
- **the confessional of social media**
- **these actions can now be traced and measured with unprecedented precision**
- **with sufficient data the numbers reveal increasingly predicable behavior and individual risk patterns**
- **blurring of private and public spaces**
- **blurring of the real and the imaginary**
- **complex ethical and legal issues**
  - **consent, privacy, security, surveillance**
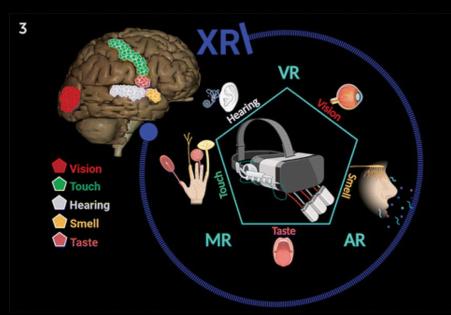
Welcome to Avatar World: Metaverse V. 1

Metaverse Market Map

Experience · Discovery · Creator Economy · Spatial Computing · Decentralize · Human Interface · Infrastructure
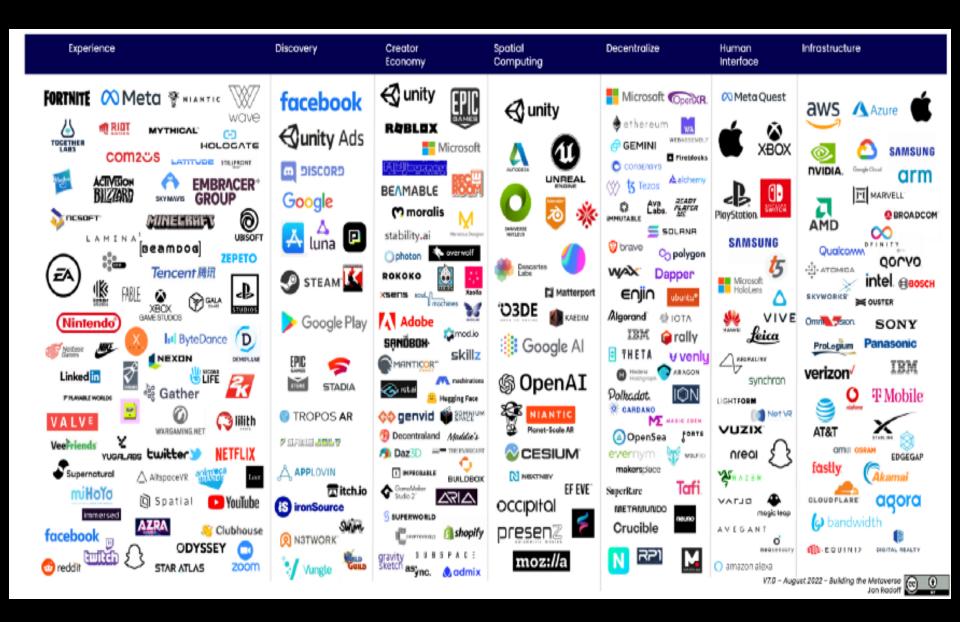
Welcome to Metaverse World:

extended reality (XR): building the virtual sensorium

new virtual experiences: Tamagotchi babies

The Neurobiology of Instant, Superficial, Repeated Gratification

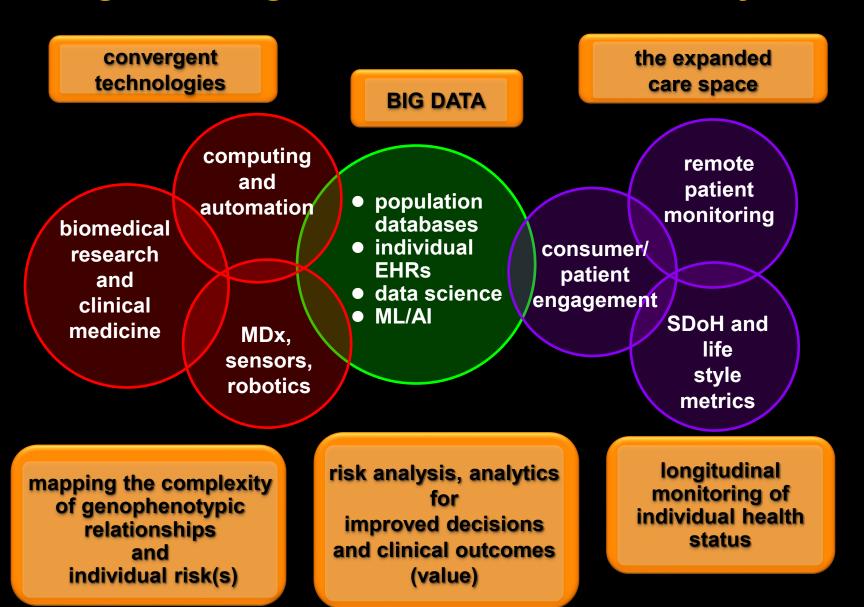interactive multiplayer gaming and modulation of reward neurocircuitry

virtual immersion and education in the most plastic phase in the development of human analytical skills and socialization

Health Effects of Ubiquitous Immersion and Dependencies in Digital Environments

- **unknown long term socio-cultural implications of new sensory, cognitive and behavior patterns positively reinforced in digital ecosystems**
  - **individuals, institutions, society**
  - **the new evolutionary selection pressure? (digital Darwinian fitness)**

Now Comes the Hard Part!

**Driving Precision Health and Large Scale
Data Analytics into Routine Clinical Practice**

New Incentives and New Delivery Models

New Participants and New Business Models

More Than Just Technology

Clinical-Centric Needs

Patient (Caregiver)-Centric Needs

Payor Needs

- integration of new work processes
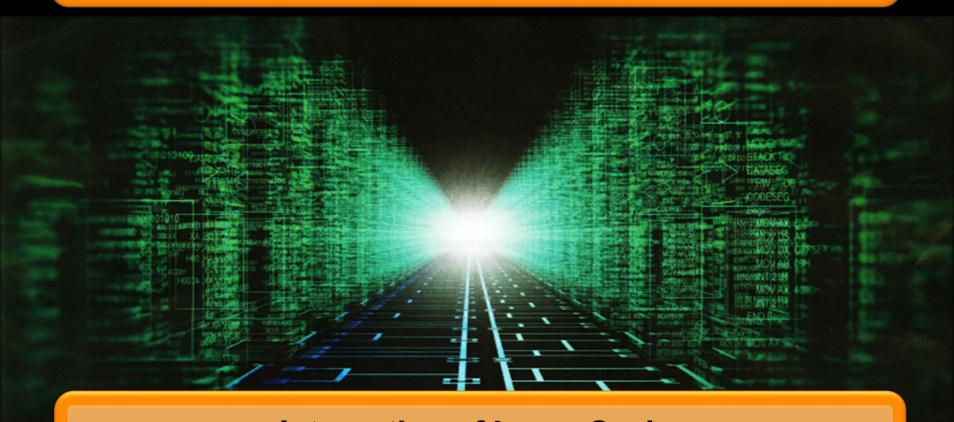- no risk to income(HCPs), profitability(private sector)
- continuing training curricula and CME

- increased convenience, acceptance and adherence treatment
- telemedicine and interactive systems
- empowerment

- the bottom line and margins
- reduce direct care costs
- optimize use of finite and expensive resources (Facilities, Equipment, Personnel, Training)

Big Biology and Biomedicine Meets Big Data

The Pending Zettabyte Era
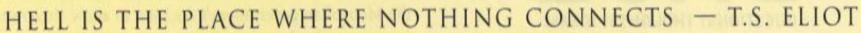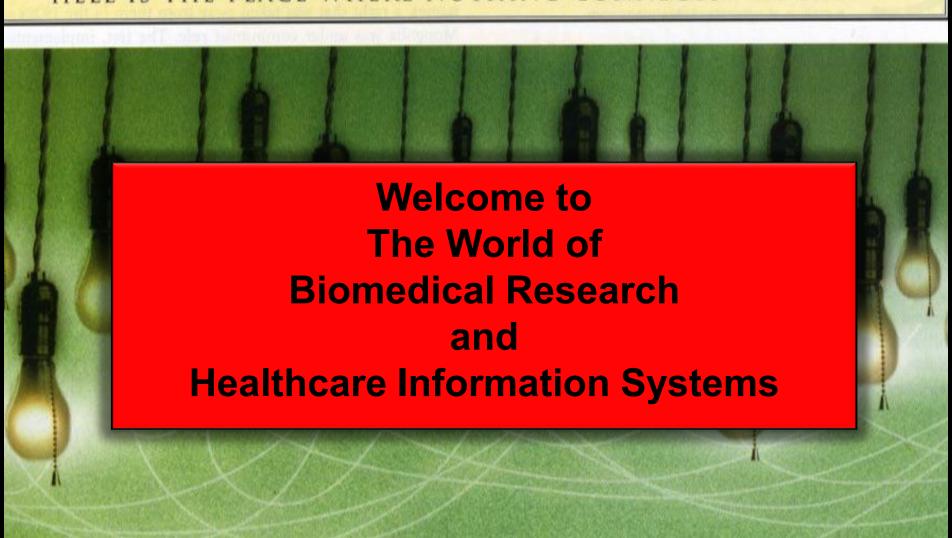**1,000,000,000,000,000,000,000**

Integration of Large Scale,
Multi-Disciplinary Datasets

Managing Big Data in Biomedicine Will Not Be a Simple Extrapolation from Current Practices

Co-Evolution of Professional Competencies With Advanced Computing and Automated Clinical Decision Systems

HELL IS THE PLACE WHERE NOTHING CONNECTS — T.S. ELIOT

**Welcome to
The World of
Biomedical Research
and
Healthcare Information Systems**

Biomedical Data: Vast, Growing Rapidly but Poorly Used

- **inadequate standardization**

- **fragmented, incomplete, inaccurate data and uncertain provenance**

- **incompatible data formats as barrier to data integration and sharing**

- **static, episodic snap shots of individual health status versus integrated longitudinal health history**

- **obstacles to EHR integration of new data classes multi-Omics; wearables; IoMT; RHM**

- **legislative barriers to data transfer based on well intentioned privacy protections (HIPAA)**

- **organizational, economic and cultural barriers to open data sharing**

- **major impediments to research productivity, optimum clinical decisions and continuity-of-care for patients**

The Pending Era of Cognitive Computing and Decision-Support Systems: Overcoming the "Bandwidth" Limits of Human Cognition
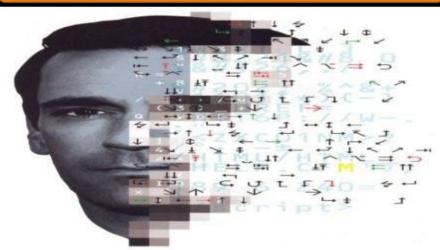

- **limits to individual expertise**
- **limits to our multi-dimensionality**
- **limits to our sensory systems**
- **limits to our cognitive experiences and perceptions**
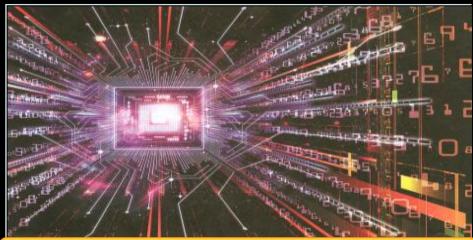- **limits to our objective decision-making**

Technology Acceleration and Convergence:
The Escalating Challenge for Professional Competency, Decision-Support and Future Medical Education
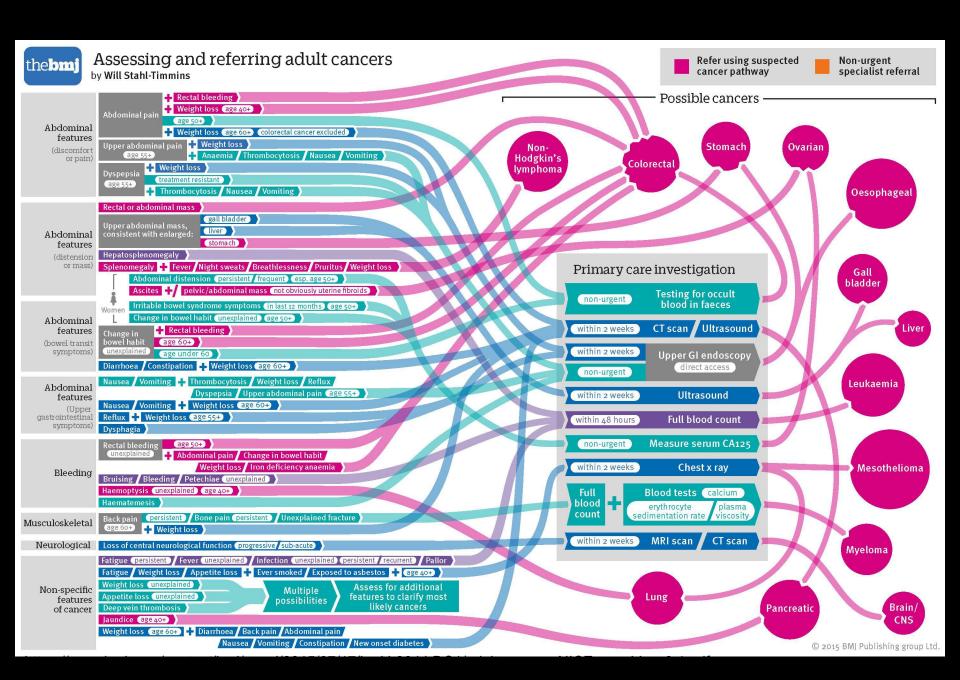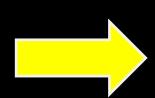
Data Deluge

Cognitive Bandwidth Limits

Automated Analytics and Decision Support

Facile Formats for Actionable Decisions

Assessing and referring adult cancers

by Will Stahl-Timmins

the bmj

Legend:
- ■ Refer using suspected cancer pathway
- ■ Non-urgent specialist referral

Possible cancers

Abdominal features (discomfort or pain)

Abdominal pain
- **+** Rectal bleeding
- **+** Weight loss (age 40+)
- (age 50+)
- **+** Weight loss (age 60+) (colorectal cancer excluded)

Upper abdominal pain (age 55+)
- **+** Weight loss
- **+** Anaemia / Thrombocytosis / Nausea / Vomiting

Dyspepsia (age 55+)
- **+** Weight loss
- treatment resistant
- **+** Thrombocytosis / Nausea / Vomiting

Abdominal features (distension or mass)

- Rectal or abdominal mass
- **Upper abdominal mass, consistent with enlarged:** gall bladder / liver / stomach
- Hepatosplenomegaly
- Splenomegaly **+** Fever / Night sweats / Breathlessness / Pruritus / Weight loss
- Abdominal distension (persistent / frequent) (esp. age 50+)
- Ascites **+/** pelvic/abdominal mass (not obviously uterine fibroids)

Women
- Irritable bowel syndrome symptoms (in last 12 months) (age 50+)
- Change in bowel habit (unexplained) (age 50+)

Abdominal features (bowel transit symptoms)

Change in bowel habit (unexplained)
- **+** Rectal bleeding
- (age 60+)
- (age under 60)
- Diarrhoea / Constipation **+** Weight loss (age 60+)

Abdominal features (Upper gastrointestinal symptoms)

- Nausea / Vomiting **+** Thrombocytosis / Weight loss / Reflux
- Dyspepsia / Upper abdominal pain (age 55+)
- Nausea / Vomiting **+** Weight loss (age 60+)
- Reflux **+** Weight loss (age 55+)
- Dysphagia

Bleeding

- **Rectal bleeding** (unexplained) (age 50+)
- **+** Abdominal pain / Change in bowel habit / Weight loss / Iron deficiency anaemia
- Bruising / Bleeding / Petechiae (unexplained)
- Haemoptysis (unexplained) (age 40+)
- Haematemesis

Musculoskeletal

- Back pain (age 60+) persistent / Bone pain (persistent) / Unexplained fracture
- **+** Weight loss

Neurological

- Loss of central neurological function (progressive / sub-acute)

Non-specific features of cancer

- Fatigue (persistent) / Fever (unexplained) / Infection (unexplained) (persistent / recurrent) / Pallor
- Fatigue / Weight loss / Appetite loss **+** Ever smoked / Exposed to asbestos **+** (age 40+)
- Weight loss (unexplained)
- Appetite loss (unexplained)
- Deep vein thrombosis
- Jaundice (age 40+)
- Weight loss (age 60+) **+** Diarrhoea / Back pain / Abdominal pain / Nausea / Vomiting / Constipation / New onset diabetes

Multiple possibilities → Assess for additional features to clarify most likely cancers

Primary care investigation

- **non-urgent** — Testing for occult blood in faeces
- **within 2 weeks** — CT scan / Ultrasound
- **within 2 weeks / non-urgent** — Upper GI endoscopy (direct access)
- **within 2 weeks** — Ultrasound
- **within 48 hours** — Full blood count
- **non-urgent** — Measure serum CA125
- **within 2 weeks** — Chest x ray
- **Full blood count** **+** Blood tests (calcium) / erythrocyte sedimentation rate / plasma viscosity
- **within 2 weeks** — MRI scan / CT scan

Possible cancers (circles)

- Non-Hodgkin's lymphoma
- Colorectal
- Stomach
- Ovarian
- Oesophageal
- Gall bladder
- Liver
- Leukaemia
- Mesothelioma
- Myeloma
- Lung
- Pancreatic
- Brain/CNS

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Precision Health and Digital Health: Building a Learning Health System

qualitative, descriptive information of variable quality and provenance

→

quantitative data of known provenance and validated quality

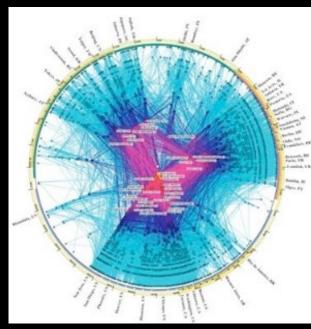**complex ecosystem of largely unconnected data sources**

→

evolving, inter-connected networks of data sources for robust decisions and improved care

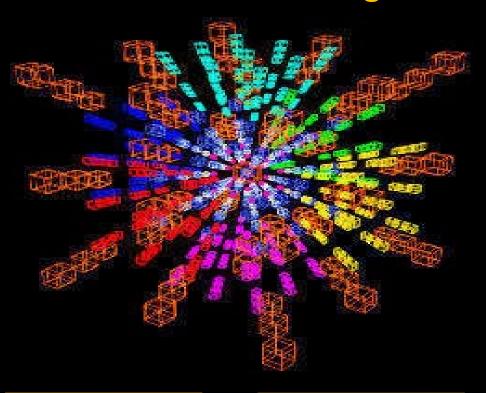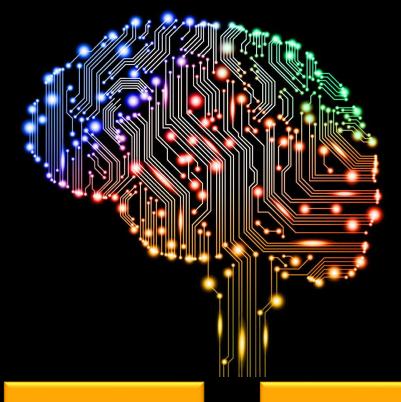# The Emergence of Big Data Changes the Questions That Can Be Asked

Isolated Data

Complex Networked Data

Complex Computational Data

Automated Context: Data Finding Data
"Intelligence at Ingestion"

Feature Extraction and Classification	→	Context Analysis ⇕ Persistent Context	→	• Relevance Mapping • Learning Systems	→	• Situational Awareness • Rapid, Robust Decisions

Machine Learning (ML) and Artificial Intelligence (AI) and the Analysis of Large Scale Heterogenous Health Data

The Future of 'Automated Search' and 'Retrieval'

Deep Understanding of Content and Context
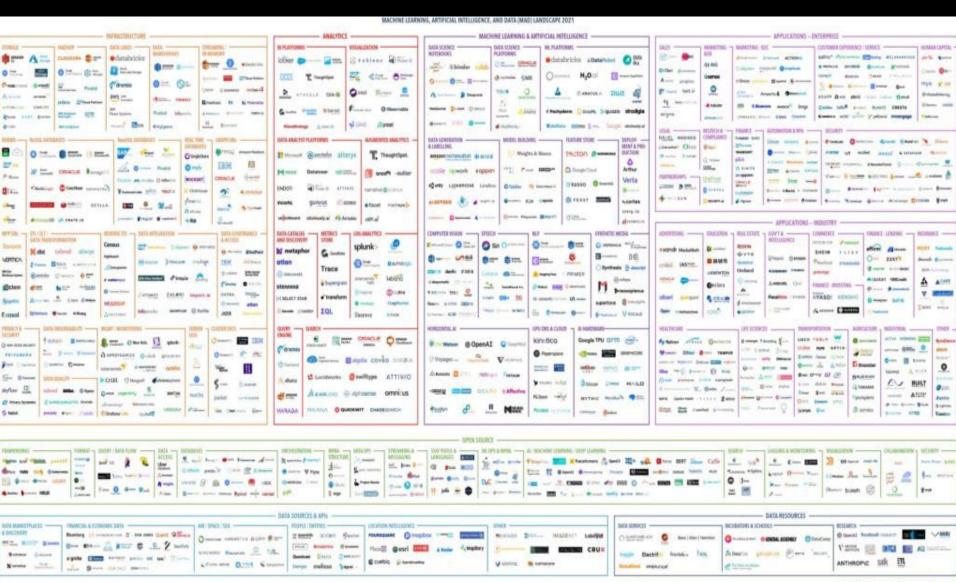
Collapse Time to Decision: Intelligence at Ingestion

Automated and Proactive Analytics:
Why Wait for the Slow Brain to Catch Up to the Fast Machine

Machine Learning (ML) and Artificial Intelligence (AI):
Massive Infusion of Private-Sector Funding and Entrepreneurial Activities

https://mattturck.com/data2021/

MACHINE LEARNING, ARTIFICIAL INTELLIGENCE, AND DATA (MAD) LANDSCAPE 2021

Just What the Data Ordered

Machine Intelligence and Algorithms for Clinical Diagnosis and Treatment Decisions

Black Box Medicine?

The ML Adoption of AI Platforms in Clinical Medicine

- **from current applications in image analysis to comprehensive assembly and interpretation of multifactorial "deep phenotyping" data to build 'signatures' of individual health status and risk**

Precision Health and Digital Health: Evolving Inter-Dependencies

Individual Data

Population Data

integration and analysis of large-scale diverse data

exabyte and zettabyte data tsunami

Deep Phenotyping:

- multiOmics
- clinical history- EHR/PHR
- remote health monitoring
- socio-behavioral data
- environmental exposures

Building Personalized 'Digital Twins':
Matching Individual Deep Phenotypes to 'Best Fit' Cohorts

Individual Data

Population Databanks
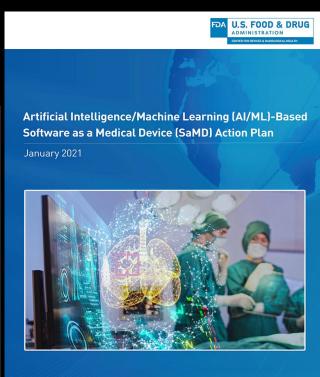
- 'digital twins and siblings' and imputed phenotypes
- risk predisposition and disease prevention
- selection of optimum treatment regimen for overt disease
- improved outcomes and QOL

How Will Healthcare ML-AI Algorithms/Decision Analytics Be Validated and Regulated?

Validation of 'Black Box' ML/AI Algorithms

- **regulatory frameworks for ML/AI platforms used for clinical decisions for patient care**
  - **'software as medical device'**
- **"interpretable AI"**
  - **uncoupling of learned intermediary from comprehension of how the output(s) for decision opinion(s) were derived**
- **getting ready for "primetime"?**
  - **generative adversarial networks and transformer platforms**
- **general artificial intelligence (GAI)**
  - **ChatGPT, RYTR, and DALL-E**

ChatGPT Generative AI Passed All Three Parts of the US Medical Licensing Examination (Dec. 2022) Without Prior Training on Medical Dataset

medRxiv
THE PREPRINT SERVER FOR HEALTH SCIENCES

CSH Cold Spring Harbor Laboratory   BMJ   Yale

Performance of ChatGPT on USMLE: Potential for AI-Assisted Medical Education Using Large Language Models

Tiffany H. Kung, Morgan Cheatham, ChatGPT, Arielle Medenilla, Czarina Sillos, Lorie De Leon, Camille Elepaño, Maria Madriaga, Rimel Aggabao, Giezel Diaz-Candido, James Maningo, Victor Tseng

Axios
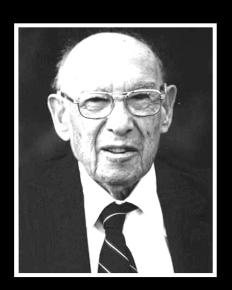
Machine Learning (ML), Artificial Intelligence (AI) and Healthcare

- which clinical specialties/processes will be at risk of replacement by ML-AI and when?

- how will professional competencies in using ML-AI decision-support tools be developed and sustained?

  - MD curriculum, CME

  - non-medical data science professionals

- how will ML-AI platforms alter payment schemes ?

- what new malpractice liabilities will emerge by failure to use/interpret ML-AI platforms?
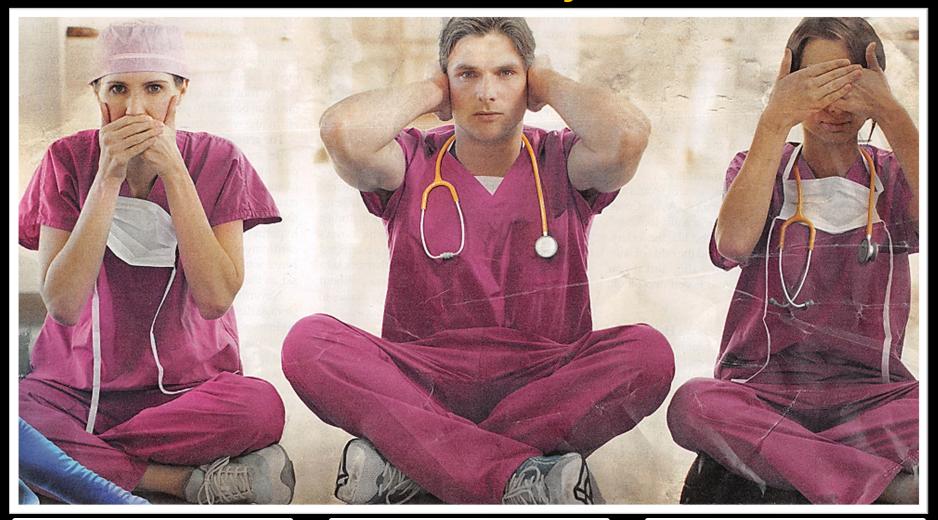
Unidimensional "Quick Fixes"

"The greatest danger in times of turbulence,
is not the turbulence,
it is to act with yesterday's logic."

- Peter Drucker

DNR:
Is the Current Healthcare System Terminal?

Denial **Negativity** **Resistance**
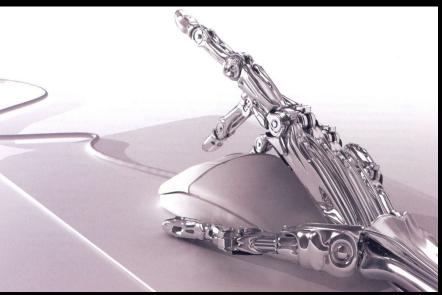
Living In The Infocosm

Burgeoning Information and An Expanding Metaverse
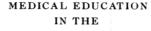
- boundaries between traditional expertise domains increasingly blurred
- entirely new domains emerge, dissolve and re-emerge in reconfigured form at ever faster rates
- escalating complexity of mapping, multi-dimensional strategic spaces
- ML/AI platforms embedded in all aspects of healthcare

"Digital Darwinism": A Looming Digital Divide

- understanding data structure and its productive application/customization for improved decisions and clinical outcomes will become a critical institutional competency

- major skill gaps and personnel shortages in biomedicine

- training of a new cadre of data scientists (medical and non-medical)

- institutions lacking adequate computational infrastructure and critical mass in data analytics will suffer 'cognitive starvation' and relegation to competitive irrelevance

Major Transitions in Medical Education and Healthcare
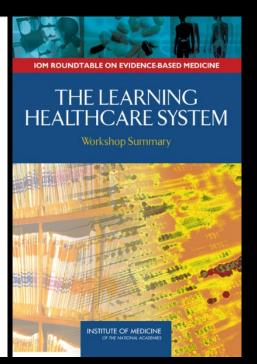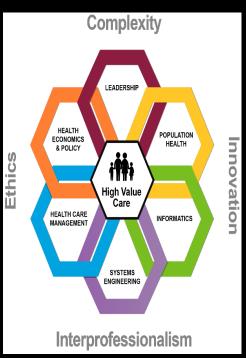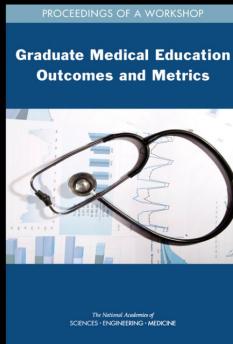
1910 - present

2000 - present

2015 - ?

(science-centric)

healthcare as a
learning system
(data-centric)

mastery of escalating complexity
and massive data (network-centric)

New Patterns of Learning

Asleep at the Wheel: Ignoring Healthcare Challenges of Increasing Complexity and Urgency

- dysfunctional national governance, lack of bipartisanship and legislative paralysis

- ideological extremism

- the rise of anti-science, anti-expert populism

- legislative technical illiteracy and the retreat from complexity

- the corrosive role of social media in fueling social and political division

- the myopia of short-term, cosmetic quick fixes and kicking the problem down the road

Asleep at the Wheel: Ignoring Healthcare Challenges of Increasing Complexity and Urgency
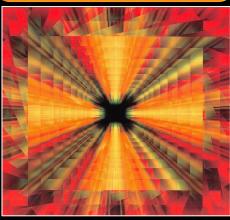
- aging demographics and the chronic disease burden cost access, availability and affordability

- mental health

- SUD and lack of border security

- cybersecurity and data protection

- preparedness for highly disruptive biosecurity events (pandemics) or other major disasters

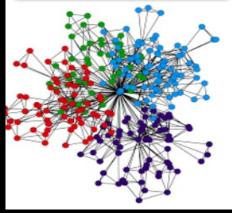- novel threats from dual-use technologies and complex ethical and legal issues

The Evolution of Data-Intensive Precision Medicine

Technology Convergence and Acceleration

Mapping Geno-Phenotype Complexity

Topology of Biological Information Networks

Big Data

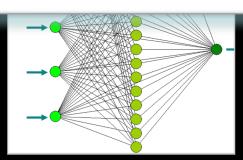## Slides Available @ http://casi.asu.edu/presentations
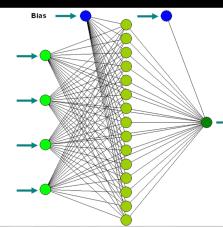
Data Security and Privacy

Robotics and Human Machine Interactions
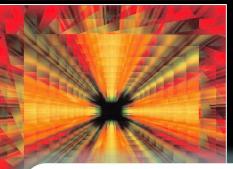
Artificial Intelligence and Decision Support

Public Policy: Ethics, Risk and Regulation