# Making Precision Medicine A Reality: Molecular Diagnostics, Remote Health Status Monitoring and the Big Data Challenge

**Dr. George Poste**
Chief Scientist, Complex Adaptive Systems Initiative
and Regents Professor of Health Innovation
Arizona State University
george.poste@asu.edu
www.casi.asu.edu

# Aspirations for the U.S. Healthcare System: National Academy of Medicine

**The Triple Aim**

- **improved outcomes**
- **reduced cost**
- **value-based care**

- **right information**
- **right decisions**
- **right culture**

**The Learning Healthcare System**

# Aspirations for the U.S. Healthcare System: National Academy of Medicine

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**VALUE**

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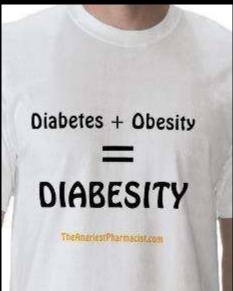
**The Learning Healthcare System**

# Aging Societies and the Chronic Disease Burden: Confronting the Largest Clinical and Economic Disruptions and Threats to Sustainable Healthcare



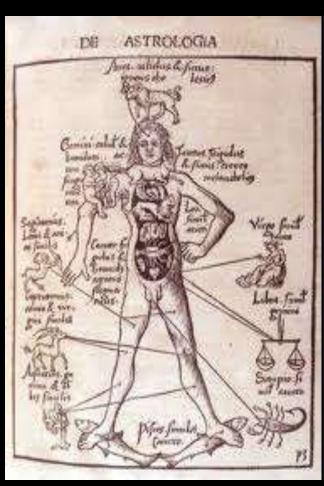| cancer | neurodegeneration | cardio-vascular/ metabolic disease | mental illness |

**Blurring the Boundaries of Biomedicine**

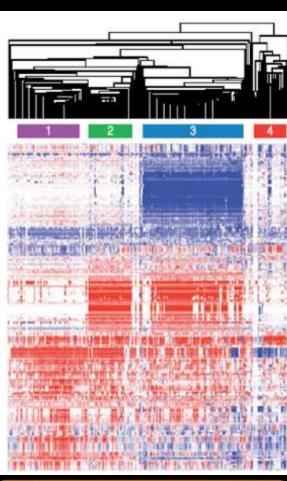**Technology Convergence and
New Cross-Sector Alliances**

**Convergence of Advances in Biomedicine,
Materials Science, Engineering, Telecommunications,
Robotics, Advanced Computing and Data Science**

# The Path to Precision Medicine:
# From Superstitions to Symptoms to (Molecular) Signatures
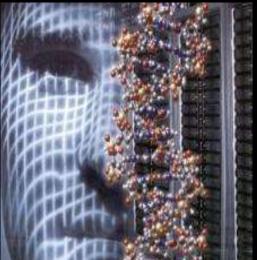


humors, astrology, shamanism, sin and divine fate
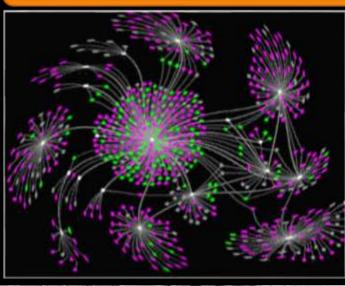
biochemistry and organ-based pathophysiology

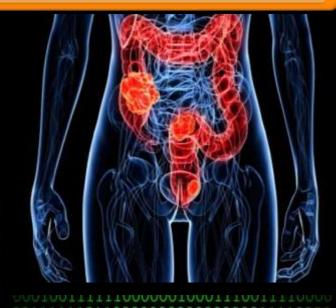molecular biology and multi-omics profiling

# Precision Medicine:

(Epi)Genomics

**Causal Relationships Between Disruption of Molecular Signaling Networks and Disease**
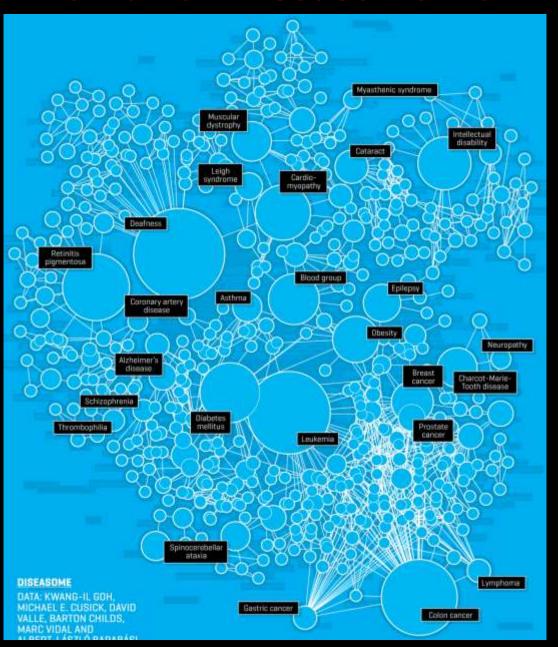


- **terabytes per individual**
- **zettabyte – yottabyte population databases**

**Patient-Specific Signatures of Disease or Predisposition to Disease**

**Big (Messy) Data**

# The Human Disease Network



From: DiBu et al. (2018)  Fortune 1 April 2018 p 53

# Molecular Diagnostics and Biomarkers as the Intellectual Drivers of Precision Medicine

- **disease predisposition risk**

- **increased accuracy of disease classification (molecular subtypes) and staging**

- **more rational treatment selection based on presence/absence of specific molecular targets for $R_x$ action**

- **pharmacogenetic profiling to avoid $R_x$ adverse events**

# Molecular Diagnostics and Biomarkers as the Intellectual Drivers of Precision Medicine

- monitoring $R_x$ efficacy

- detection of emergence of $R_x$ resistance (microbiology; oncology)

- early alert of pending relapse and/or minimal residual disease

# Precision Medicine and Digital Medicine: Obligate Inter-Dependencies

**Individual Data**

**Population Databanks**



integration and analysis of large scale, diverse data categories

"matching" individuals to 'best match' cohorts using data on similarities of molecular profiles and treatment outcomes

# Still Two Largely Separate Worlds

**precision medicine**

**routine healthcare delivery and SOC**

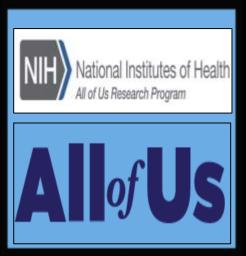**research and early clinical adopters**

**slow incremental adoption of technological advances**

**$100-125* billion (estimated)**

**$3.4 trillion (19% GDP)**

*includes investment in investigational $R_x$ candidates

# Large Scale Genome Sequencing Projects:
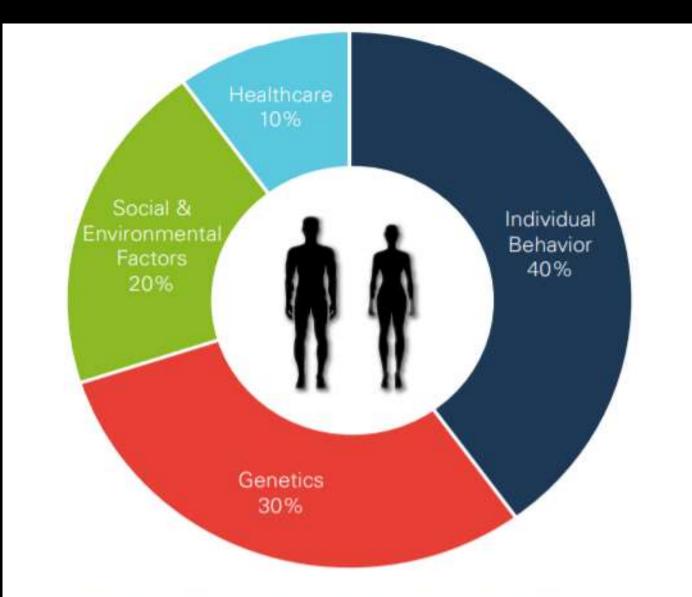# The Dangers of Reductionism and Ignoring Biological Complexity
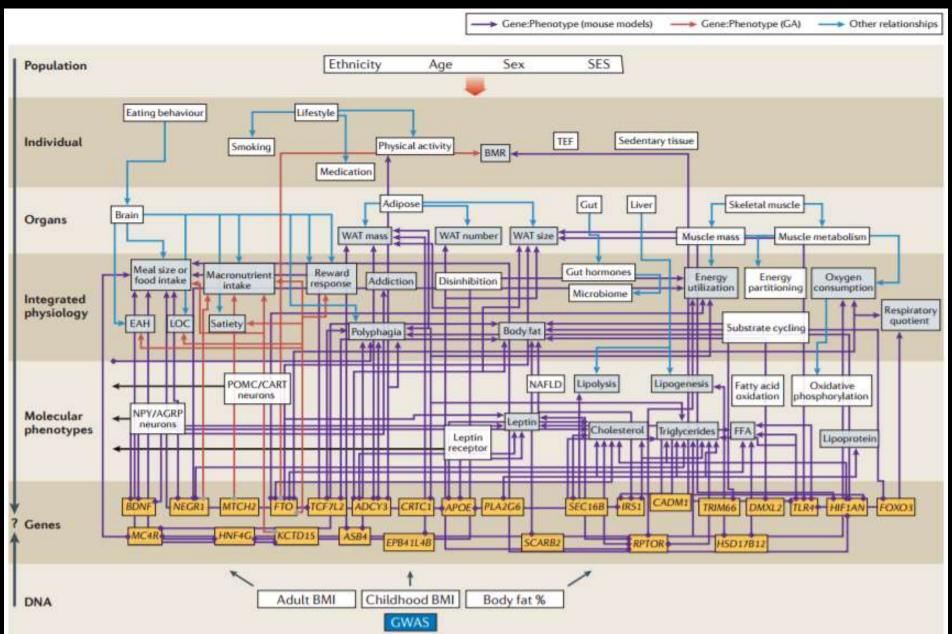
# Impact of Different Factors On The Risk of Premature Death



Source: Beyond Health Care: The Role of Social Determinants in Promoting Health and Health Equity. Kaiser Family Foundation, 2015.
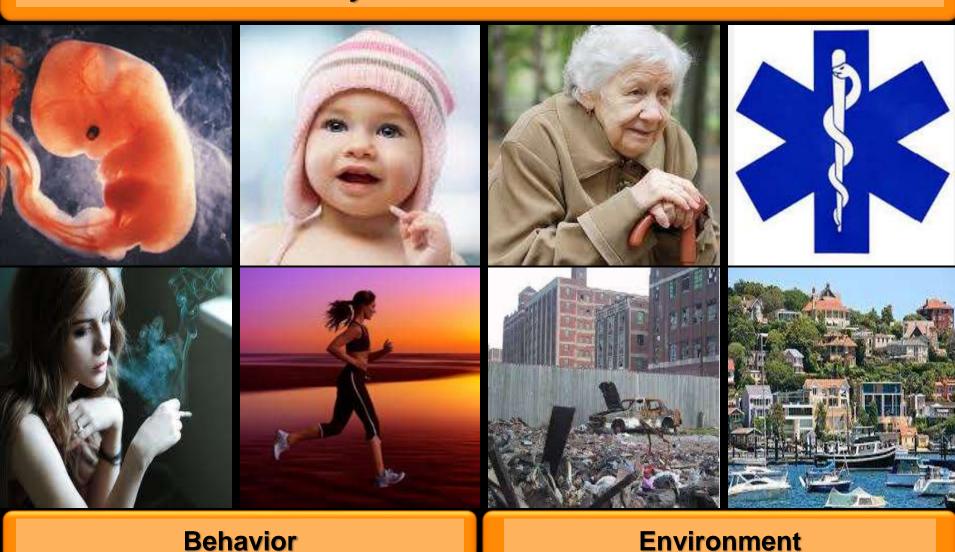
# Interaction Network of Genotypes and Phenotypes in Obesity



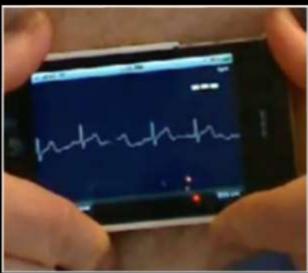From: S. Ghosh and C. Bouchard (2017) Nat. Rev. Genetics 18, 731

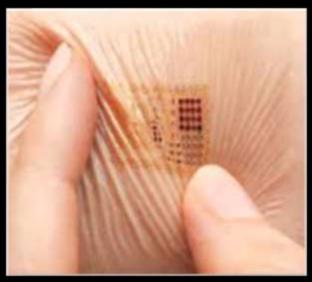# Most Events That Affect Our Health Occur Outside of the Healthcare System And Are Not Monitored

**Need for Continuity of Care Record: From Womb to Tomb**



**Behavior**

**Environment**

# Remote Monitoring of Health Status

# Building Value in Wellness Apps and Wearables

- legitimacy and clinical value still viewed as marginal by physicians/payers

- lack of robust data on improved outcomes

- regulation: accuracy, reliability, security and privacy

# Gray Technologies and Aging in Place:
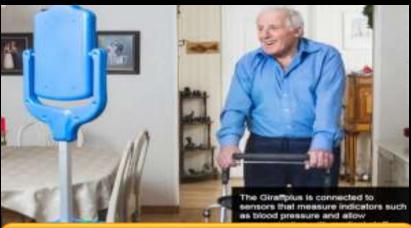# The Rapid Expansion of Telemedicine for Remote Health Monitoring



**Rx adherence**

**cognitive stimulation**

**in home support and reduced readmissions**

**reduced office visits**

# Chatbots and Support Robots in Healthcare
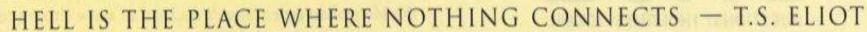
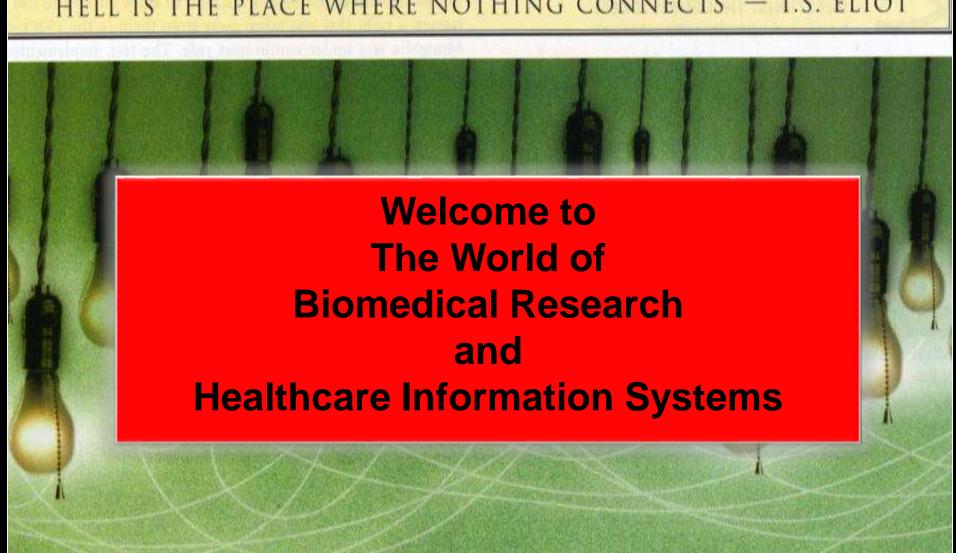# VR/AR and Neuromodulation



- **promote behavior change via altered sensory inputs and feedback**

- **mental illness: PTSD, physical rehabilitation, substance abuse and pain control**
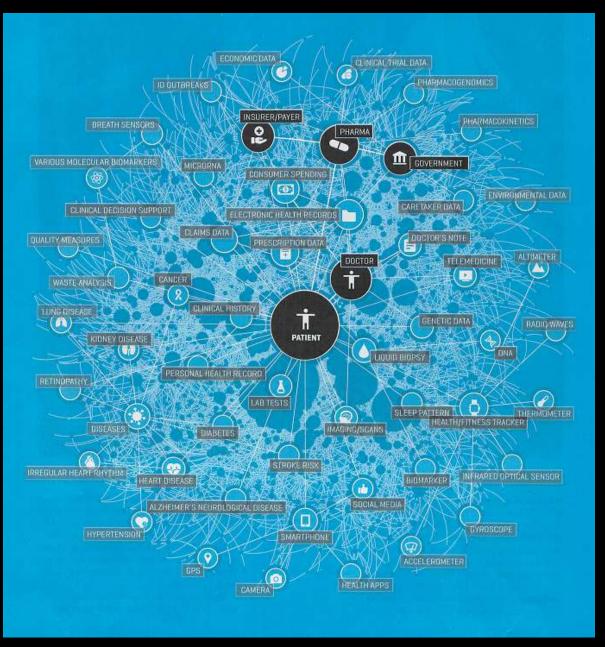
# Now Comes the Hard Part!

**Driving Precision Medicine and Data-Driven Healthcare Into Routine Clinical Practice**

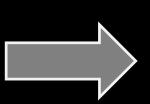**The Problem with Real World Data is the Real World**

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

**Welcome to
The World of
Biomedical Research
and
Healthcare Information Systems**
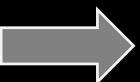
# The Digital Health Ecosystem

# Precision Medicine and Digital Health: Building a Learning Healthcare System

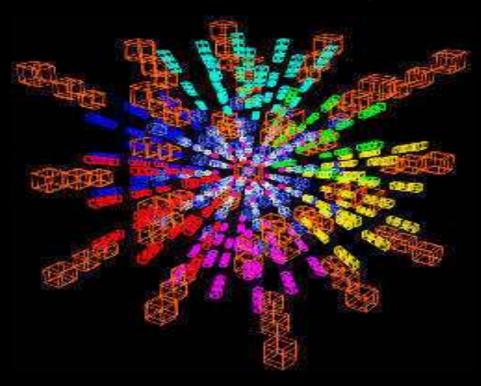**qualitative, descriptive information of uncertain quality and provenance** ➡ **quantitative data of known provenance and validated quality**

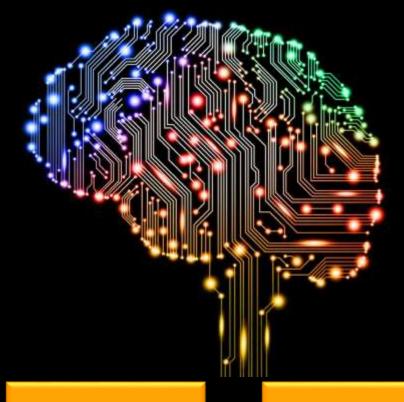**complex ecosystem of largely unconnected data sources** ➡ **evolving, inter-connected networks of data sources for robust decisions and improved care**

# Automated Context: Data Finding Data "Intelligence at Ingestion"



| Feature Extraction and Classification | Context Analysis ⇕ Persistent Context | • Relevance Detection<br>• Learning Systems | • Situational Awareness<br>• Rapid, Robust Decisions |

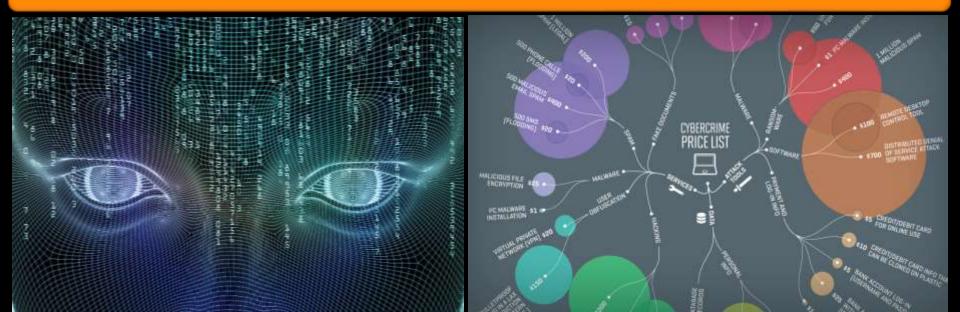# Major Investments in Digital Health by Major Corporations Within and Outside of Traditional Healthcare

# "People Analytics"
## Social Activities and Behavior Become Quantifiable

- **who knows why people do what they do?**
  - **the fact is that they do!**

- **these actions can now be traced and measured with unprecedented precision**

- **with sufficient data, the numbers reveal increasingly predictable behavior and individual risk patterns**

- **the confessional of social media**

- **the blurring of private and public spaces**

- **complex ethical and legal issues**
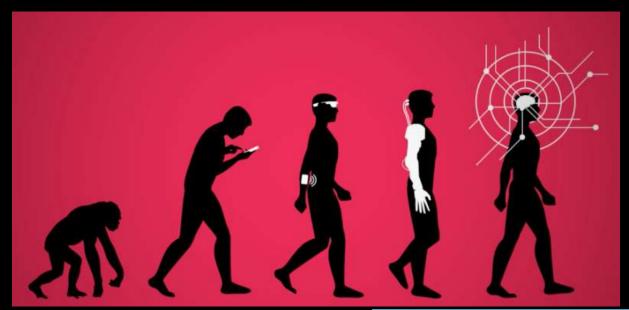  - **consent, privacy, security, surveillance**

# Mishandling of Patient Information Shows How Governments and Companies Must Become More Worthy of Trust



# The Dark Web and Healthcare Data Theft and Fraud

# The Co-evolution of Augmented Humans, Robotics and Human-Machine Interactions

# Human-Computer Interactions



# VR/AR and Training for Complex Tasks
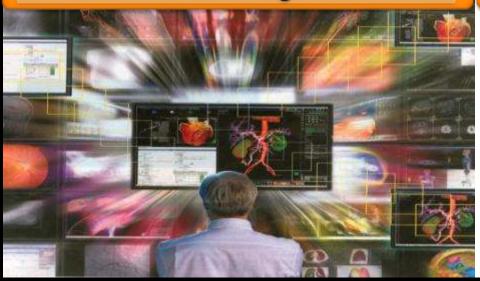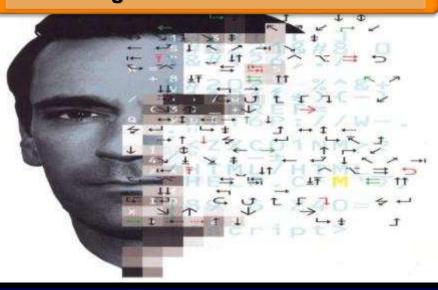
# Technology Acceleration and Convergence: The Escalating Challenge for Professional Competency, Decision-Support and Future Medical Education
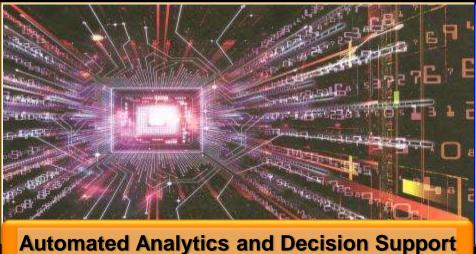


**Data Deluge**

**Cognitive Bandwidth Limits**

**Automated Analytics and Decision Support**

**Facile Formats for Actionable Decisions**

# Machine Learning and Image Analysis in Clinical Medicine

| pathology | radiology | dermatology | ophthalmology |



- large scale training sets and classification parameters

- standardized, reproducible and scalable

- 260 million images/day for $1000 GPU

# Living in a World Where the Data Analytics and Interpretation Algorithms Are Obscure to the End User

- ● ceding decision authority to computerized support systems

- ● culturally alien to professionals in their claimed expertise domain but they accept in all other aspects of their lives

- ● who will have the responsibility for validation and oversight of critical assumptions used in decision tree analytics for big data?

    - regulatory agencies and professional societies?

    - humans?

    - machines?

# Artificial Intelligence (AI) and Healthcare

- how will AI algorithms/decision analytics be validated/regulated?

- how will AI be integrated into current work flow or will radical reorganization/re-training be required?

- how will AI platforms alter payment schemes?

- what new malpractice liabilities will emerge by failure to use/interpret AI platforms

- legal liability for AI-based clinical decision software

# The Future of Healthcare: Precision Medicine and Digital Medicine

new technology platforms

the expanded care space

Big Data

automation and advanced computing

multiplex profiling of molecular network topologies

- PHR/EHR
- population health
- precision medicine
- digital medicine
- AI

wearables, sensors, telemedicine
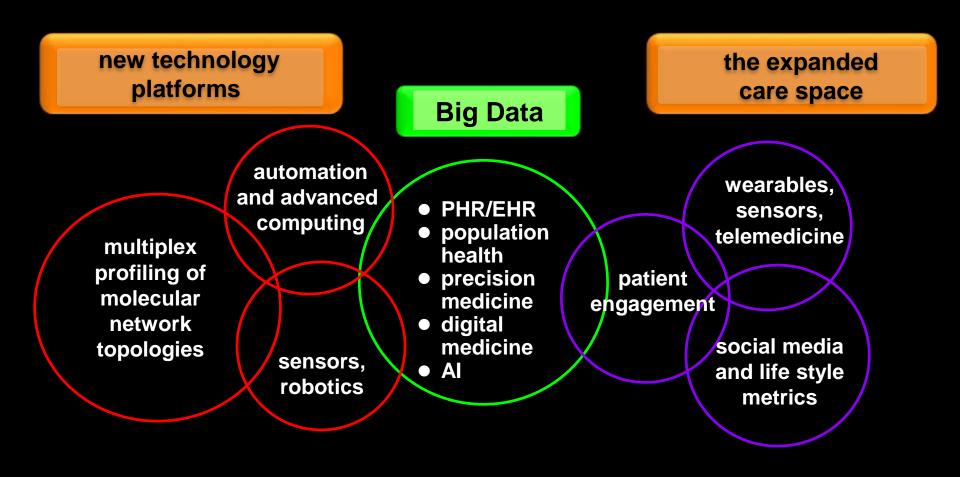
patient engagement

sensors, robotics

social media and life style metrics

molecular classification of disease

analytics for improved decisions and clinical outcomes at lower cost (value)

remote monitoring of health status

# Precision Medicine and Digital Medicine:
## Obligate Inter-Dependencies



**Slides Available @ http://casi.asu.edu/presentations**