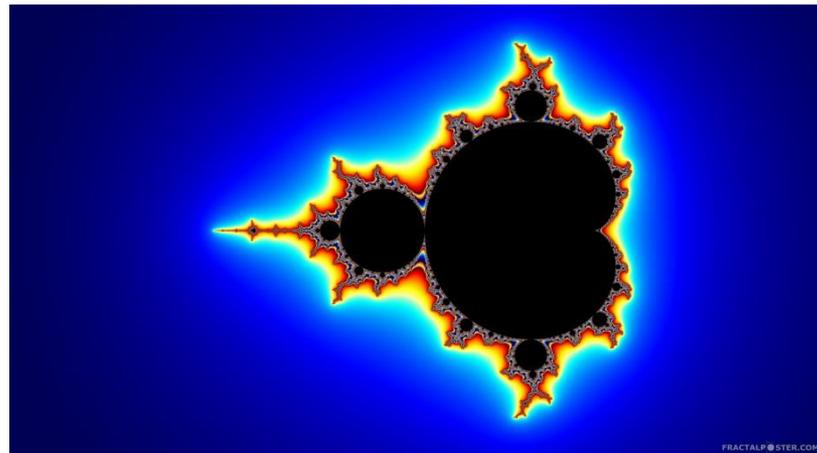


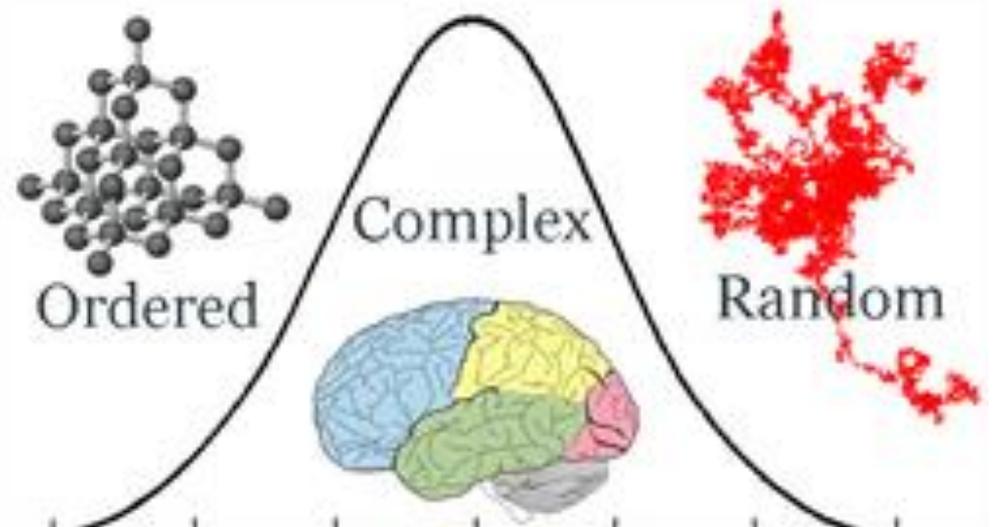
THE IMPLICATIONS OF COMPLEXITY SCIENCE TO MEDICINE AND HEALTH CARE

and its Integration with Health Outcomes in
the 21st Century



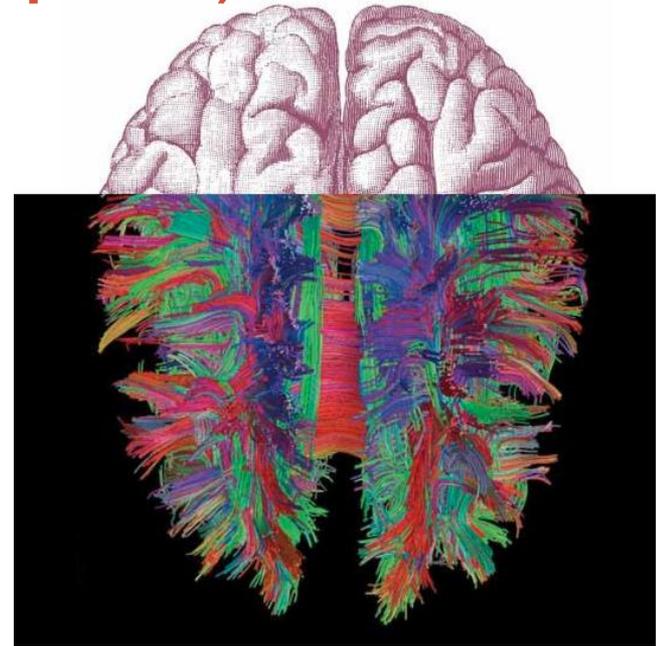
What is Complexity?

- Not easy to define. Intuitive approach is to look at some examples
 1. Ant colonies
 2. The Brain
 3. The Immune System
 4. Ecosystems and economies
 5. Internet (world wide web)



Definition of a Complex (Adaptive) System

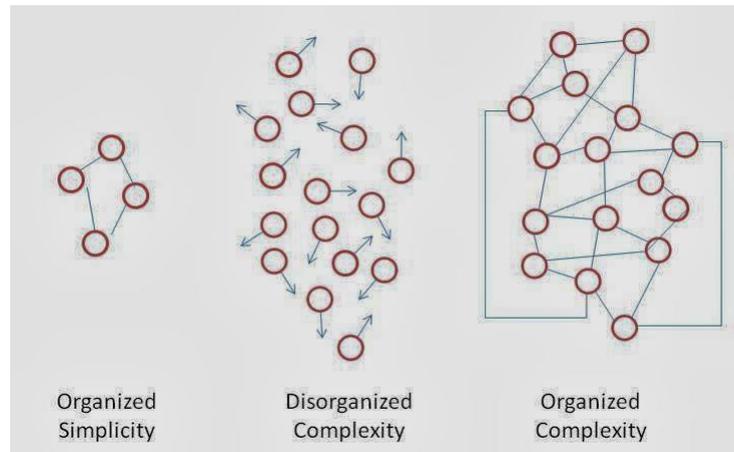
1. A large Network of Components
2. With No Central Control
3. Simple Rules of Operation
 - Gives rise to:
4. Non-trivial Emergent Behaviour
5. Sophisticated Information Processing and
6. Adaptation Including (Learning and Evolution)



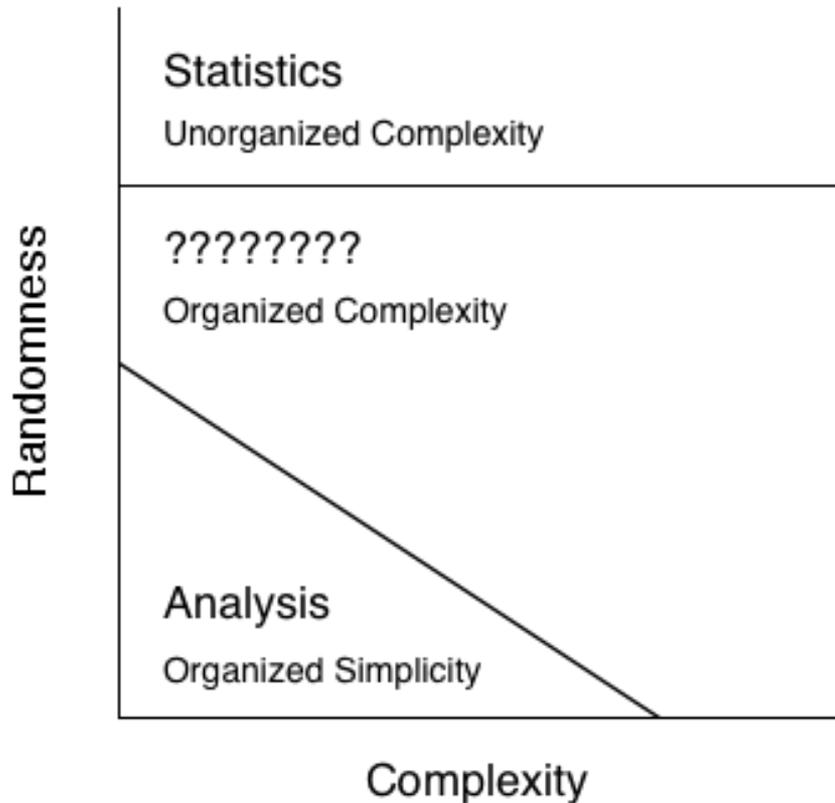
Warren Weaver's Prescient Prediction in 1948

Three types of problems in science

- Simplicity (Newton's laws – few variables)
- Disorganised Complexity (Thermodynamics or statistical mechanics – billions of variables are averaged e.g. Temperature, Pressure)
- Organised Complexity (Complexity Science - Moderate number of variables but interacting in non-linear ways, so they can't be averaged e.g. how the immune system functions as a whole)



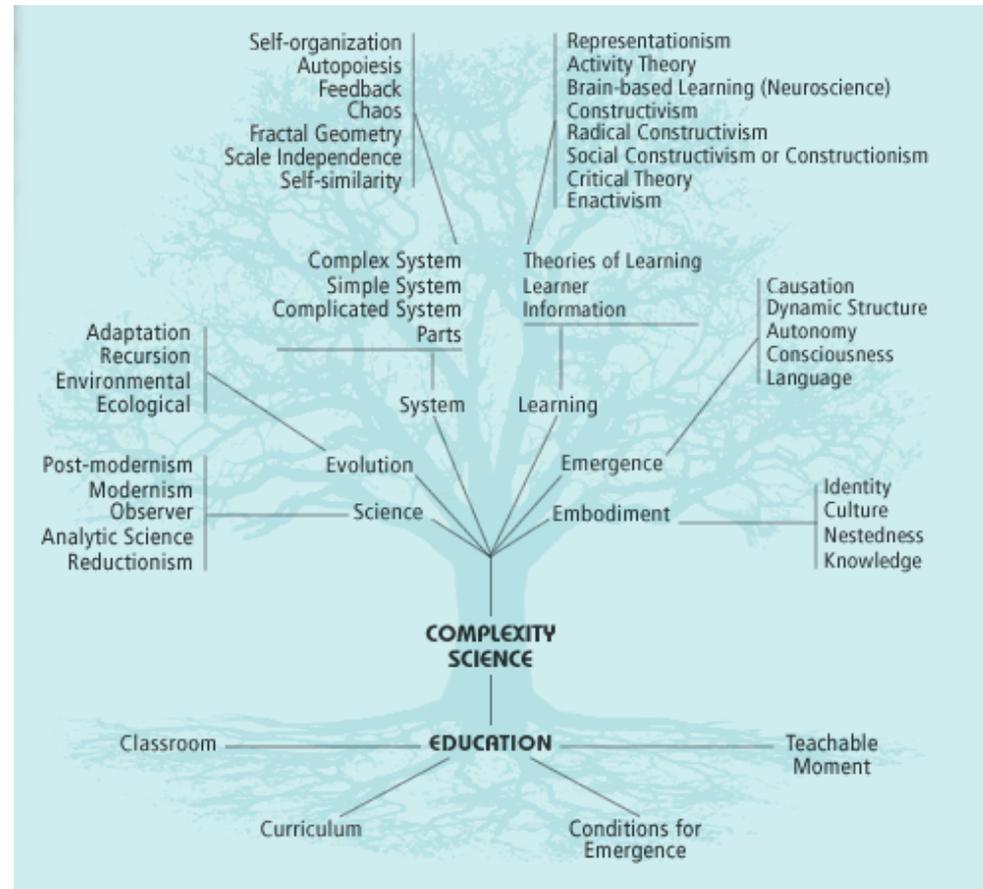
Weaver's Insights 1/2



“These problems... are just too complicated to yield to the old 19th century techniques which were so dramatically successful on two-, three-, or four-variable problems of simplicity. These new problems, moreover, cannot be handled with the statistical techniques so effective in describing average behavior in problems of disorganized complexity.”

Weaver's Insights 2/2

“These new problems, and the future of the world depends on many of them, requires science to make a third great advance, an advance that must be even greater than the 19th century conquest of problems of simplicity or the 20th –century victory over problems of disorganised complexity. Science must, over the next 50 years, learn to deal with these problems of organized complexity.”



The New Medical Paradigm

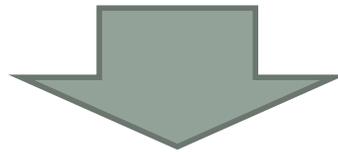
- Weaver's Organized Complexity is now known as Complexity Science
- Not yet complete
- However, can be widely applied. Our interest is how it can now be applied to the functioning of the human body and the health care system
- Both are examples of complex adaptive systems.

Paradigm Shift- The Human Body as a CAS

The earth was once thought of as flat

The spherical view led to many breakthroughs

The human body is viewed as solid (machine like)



Complexity Science has led me to the conclusion that
THE HUMAN BODY CAN ALSO BE VIEWED AS “PLASTIC” –
pliable, malleable – much more dependent on lifestyle
influences in

- causing disease
- overcoming disease

This talk presents some of the underlying mechanisms of this
plasticity based on the latest science

Plasticity Adaptation and Health

- It is my contention that this **plasticity** of the human body is the basis of adaptation and thus the basis of **health**.
- Measuring this plasticity may provide new **assessment tools** that **measure health**

The Science and Scientists Supporting the New Medical Model

Evolution

Theory of Relativity

Quantum Mechanics

Uncertainty Principle

Dissipative Structures

Chaos Theory

Complexity Theory

Phase Transition Theory

A New Kind of Science

Non-linear Dynamics

Information Theory

Santiago Theory of Cognition

Darwin

Einstein

Bohr/ Schrödinger

Heisenberg

Prigogine

Lorenz/ Mandelbrot

Santa Fe Institute

Langton/ Gell-Man

Wolfram

von Neuman

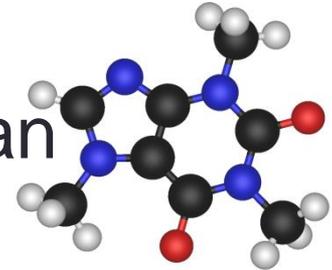
Shannon

Maturana/ Varela

In the next slide we explore insights of some of these scientists' discoveries that enable us to view the human body other than just a solid machine

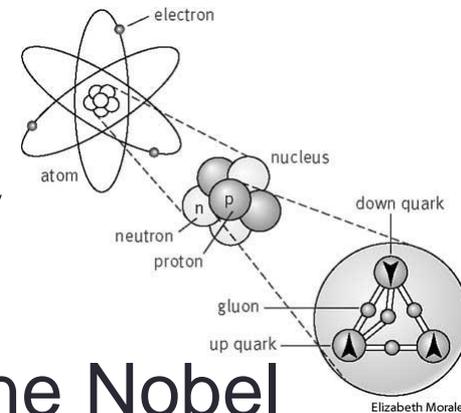
Viewing the Body from 3 Hierarchical Levels

1. The Molecular Level – Richard Feynman
Solid and Fluid (including Liquid and Gas)



2. The Subatomic Level – Quantum Mechanics – Bohr/Schrodinger

- ✓ Atom mainly empty space
- ✓ Electron particle/wave duality – simultaneously
- ✓ Heisenberg's Uncertainty Principle



3. Dissipative Structures – Ilya Prigogine Nobel Prize for Chemistry 1977

- Bifurcation Theory – Critically poised between solid and fluid

A Layman's Way of Approaching the Issue of Which 'Objective' Reality?

- Imagine you were born with X-ray vision – How solid would the person next to you appear?
- Imagine you also had (f)MRI vision and electron microscopy vision – What do you see? Movement Patterns! (Not structures)
- Which vision represents objective reality? Our normal vision or our enhanced vision?
- Complexity Science (and I) argue that both models are valid realities we can access and use to inform ourselves
- Crucially, different scientific laws apply to each model

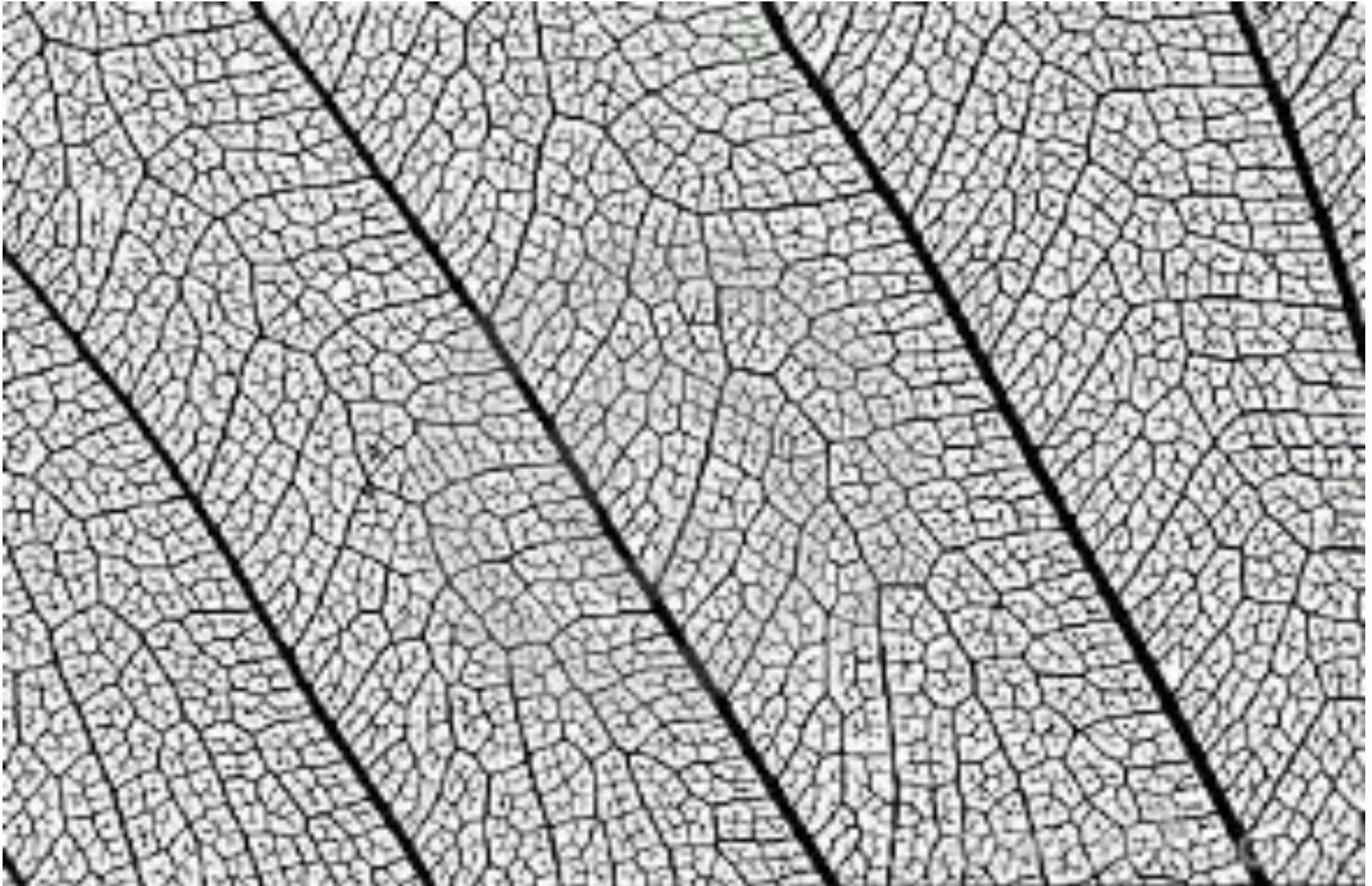
A Crucial Element of Complexity Science is the role played by what are now called “Fractals”

- So what are Fractals?
- Fractals are infinitely complex patterns that are self-similar across different scales
- Can be both physical objects or movement patterns that are described by Mandelbrot’s pioneering mathematics as set out in detail in 1977

Broccoli is Fractal



Leaf veins are Fractal



Galaxy Clusters are Fractal



Fractals and Complexity Science

- When Mandelbrot published his pioneering book in 1977 “The Fractal Geometry of Nature” he was not aware of the connections between fractal geometry and chaos theory
- The “SOPHTID” or “Strange Attractor” movement patterns are an essential part of any dissipative structure or CAS – were seen to be trajectories that exhibit “fractal geometry” (fractals in time)
- It is these very ‘movement patterns’ that enable bifurcations to occur and complex behaviors to emerge

Let Us Concentrate on a Single Cell

Bacterium

- Looking at a cell with this in mind enables us to see the relationship between structure in the biomedical model and function within the CAS or dissipative model
- Despite the biomedical model being built on the idea that solids are molecules moving slowly and tightly bound to each other, in practice the model does not reinforce the idea as it plays no integrative role to the model's application
- The CAS model reinforces this underlying movement activity (reality) because it is integral to how dissipative structures function and evolve over time
- When water turns to ice, it does so at one precise temperature/pressure point - this is called a “**First Order Phase Transition**”
- There are substances (or systems) that stay in an in-between Phase state for a broader range of the varying attribute (temperature/pressure in the above case) – this is called a “**Second Order Phase Transition**”

The SOPHTID State

- SOPHTID - **S**econd **O**rders **P**hase **T**ransition **ID**entity (or Extended Criticality of Longo and Montevil)
- Analysis of this continuous in-between state of matter shows the movement patterns of molecules:
 - ❑ Are TURBULENT or CHAOTIC (not quite random)
 - ❑ Have a very small amount of NEGENTROPY (qualitative energy) available to couple with its environment
- This enables it to COUPLE with another substance in its environment (e.g. lactose)
- This coupling happens by INCREASING THE ORDER of that substance (lactose).
- This results in the previous movement pattern being “form”-alised in a physical form that now sits on the substance

Complexity Science

- This latest science encourages and supports the view that the human body like the single cell is made up of components which are

- SOLID
- FLUID – a minimum of 70% of the human body's mass is fluid (water)

And a constant state between the two -

- SOPHTID (now better known as 'Extended Criticality')
- With a fourth element:
 - A permanent connection to the environment

IN
ENERGY MATTER
+ NEGENTROPY



OUT
ENERGY MATTER
+ ENTROPY

What is Information?

- Or - why is this information?
- Definitions of Information
- INFORMATION
 - Is the DISTINCTION of DIFFERENCES – Bateson
 - Is Physical - Vedral
- As the SOPHTID activity is chaotic and infinite, it generates differences from an infinite number of options, and if one of these DIFFERENCES ARE **STABILISED** in a physical form, it generates information
- I propose that this is what enabled the earliest protocell's or any organism's future behaviour to be determined by internal information processing rather than external forces

Information Generation

- It is the not “locked in” very small amount of negentropy that enables the movement pattern to **Structurally Couple** with an ENVIRONMENT SUBSTANCE (e.g. lactose)
- It is theorised it takes on a FRACTAL SHAPE like its preceding movement pattern – a fractal activity
- The “FORMATION” sits on the environmental substance and uniquely codes it similar to a barcode from an infinite number of choices, as most fractals are unique.
- This new “IN-FORM-ATION” advises the rest of the cell as to the nature of this environmental substance (e.g. lactose).
- This process thereby has
 1. Simultaneously generated information
 2. Increased neg-entropy from that substance when combining with the environmental substance (lactose) – it is evidenced by having created ORDER (lower level of entropy) from CHAOS (higher level of entropy)

Information Processing

- The solid part of the cell – the cell membrane – ensures the newly “barcoded” fractal substance (see next slide) does not escape – the information is **STORED**.
- The fluid part of the cell enables the newly generated information (encoded lactose) to be **TRANSFERRED** across distances within the cell.
- The combination of these processes, namely:
 - Information **GENERATION** of encoded information that has a physical form,
 - + Information **STORAGE**
 - + Information **TRANSFER**
 - = **INFORMATION PROCESSING**.
- Hence it enables **KNOWING** which leads to **COGNITION**

The Downside of Structural Coupling

- Incorporating encoded information as a PERMANENT RECORD of an EXPERIENCE – good or bad – has converted our flexible, full-of-movement potential into a stabilised, but also more rigid, **single**, physical record
- All the possible outcomes (in generating new information) have been restricted by more rigid fractal form or pattern, the result of previous structural coupling
- Once a pattern has taken form it is likely to act as a TEMPLATE or guide future structural coupling, through the circular self referring process of cognition
- This has resulted in the human body becoming MORE RIGID (solid) and LESS AVAILABLE to combining with the MOST BENEFICIAL elements of substances or activities in its environment
- Increasing solidification  decreasing adaptability

Measuring the Human Body's Rigidity or Plasticity*

- Today, in psychometrics (which deals with measurements of mental traits and physical capacities and processes, e.g. DASS, SF-36 or Oswestry Back Index) there is widespread use of advanced statistical methods that measure a host of human levels of “activity” (dynamism) and/or “functions” of individuals as a whole
- As they measure “activity” of humans, it can be argued, that by proxy, they are measuring the plasticity or rigidity at the micro-scales of the human body
- <http://www.petercsermely.linkgroup.hu/docs/Csermely-inauguration-lecture-Hungarian-Academy-2014.pdf>

New Diagnostic Tests

- I maintain that the Dynamic SF-36 questionnaire - or similar multi-dimensional functional health status measures - are currently our best proxy for measuring the subtle internal forces (hybrid movement patterns) that underpin the functionality and dynamism of healthy individuals
- They reflect the body's plasticity, adaptability and thus, its health
- I am suggesting that these represent a possible new set of health assessments that are measuring a person's health based on their specific adaptability
- With the introduction of wearable devices to collect psychometric data and the Quantified-self movement (e.g. PatientsLikeMe.com) there is the potential for the emergence of new objective tools to practice Complexity Science Medicine

Integration of Health Outcomes

- Recent moves towards health outcomes measurement suggest growing acceptance of its utility and inherent benefit
 - ❑ PROMS (Patient Reported Outcome Measures – UK)
 - ❑ ICHOM (International Collaboration of Health Outcome Measurements - US)
 - ❑ The Global Life Sciences Report by Ernst & Young 2012 (Global)
 - ❑ New Website Companies (e.g. MyClinicalOutcomes.com and Outcomes Based Healthcare UK)
 - ❑ Insurance Companies increasingly using gamification techniques to engage clients and collect ‘big’ data
 - ❑ WHO ICF, “WHODAS” and another 1400 Measures

Health Outcomes and Management

- Management Theory demands that we first determine what “The Objectives” are for Medicine and Health Services



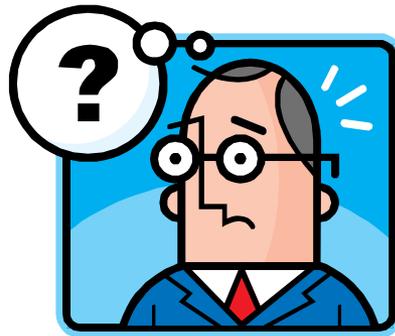
- Lembke 1952 – Determined there were 4 objectives
 1. Prolonging Life
 2. Improving Function
 3. Relieving Distress
 4. Preventing Disability/Disease

Measure and Quantify Objectives

- Management Theory then insists these should be MEASURABLE i.e. Quantified in amount and time (when)



- How do we Measure these 4 Objectives?



Prolonging Life – Quantity of Life

- This is easy
 - ✓ Life Expectancy and Mortality Rates



The Other 3 were less easy

- In the 1980s, the only way to measure:
 2. Health Related Quality of Life (Improving Function)
 3. A Patient's Confidence that Care and Comfort were available in times of illness (Relieving Distress)
 4. Preventing Disability – Positive Health

was by Quantified Questionnaires to the individual

What is the Relative Importance of Each of These Objectives?

- Some Management Theories suggest one way to determine this is to look at the time and resources actually devoted to each of these aims as a proxy for their relative importance
- This can be looked at from the individual physician or from the whole of the health services behaviour/activities
- I found the proportions of my time and resources devoted as follows:

1.	Quantity of Life	10%
2.	Health Related Quality of Life	40%
3.	Health “CARE” Status	30%
4.	Positive Health	20%

Enter Psychometrics

- The field of psychometrics had grown in the 1980s and accurate, reliable, valid quantified questionnaires, were developed that met robust statistical standards. These could be adapted to measure the above objectives
- The advent of IT make these readily implementable today
- The outcome measures for health related quality of life can be divided up into two major groups
 1. **GENERIC**
e.g. Dyna SF-36/ SF-12/ E-5D/ WHODAS
 2. **Body Part or System Specific Measures**
e.g. Oxford Knee Index, *Quick* DASH, Seattle Angina questionnaire

Sources

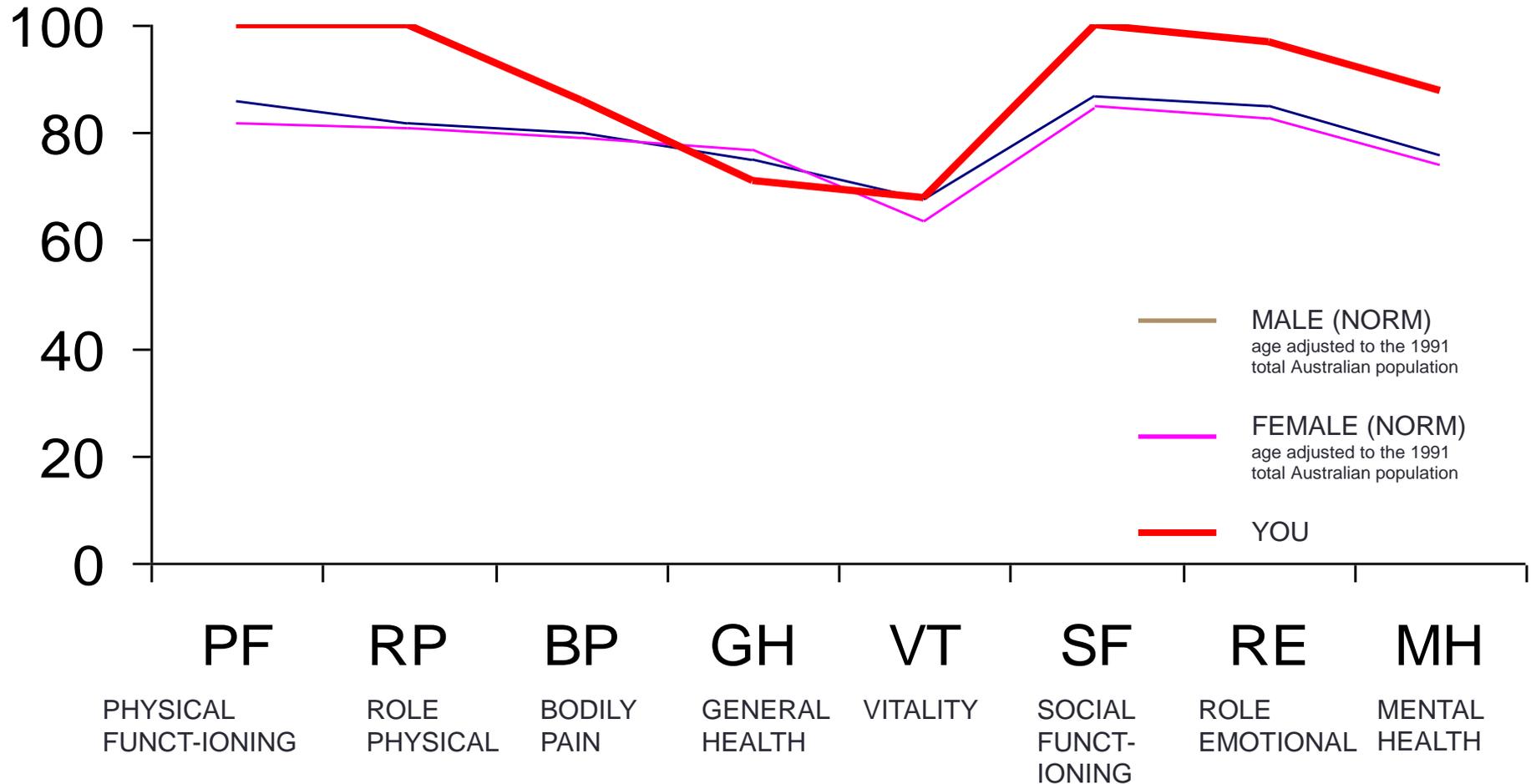
- Major Sources of these Measures are now
 1. MAPI – PROQOLID <http://proqolid.org>
 2. Australian Centre on Quality of Life
<http://www.deakin.edu.au/research/acqol/instruments/instrument.php>
 3. Qualitymetric – <http://www.qualitymetric.com/>
 4. Orthopaedic Scores - <http://www.orthopaedicscore.com/>
 5. ICF http://www.who.int/classifications/icf/icf_more/en/

Some Examples of Health Outcome Measurements in Histogram format

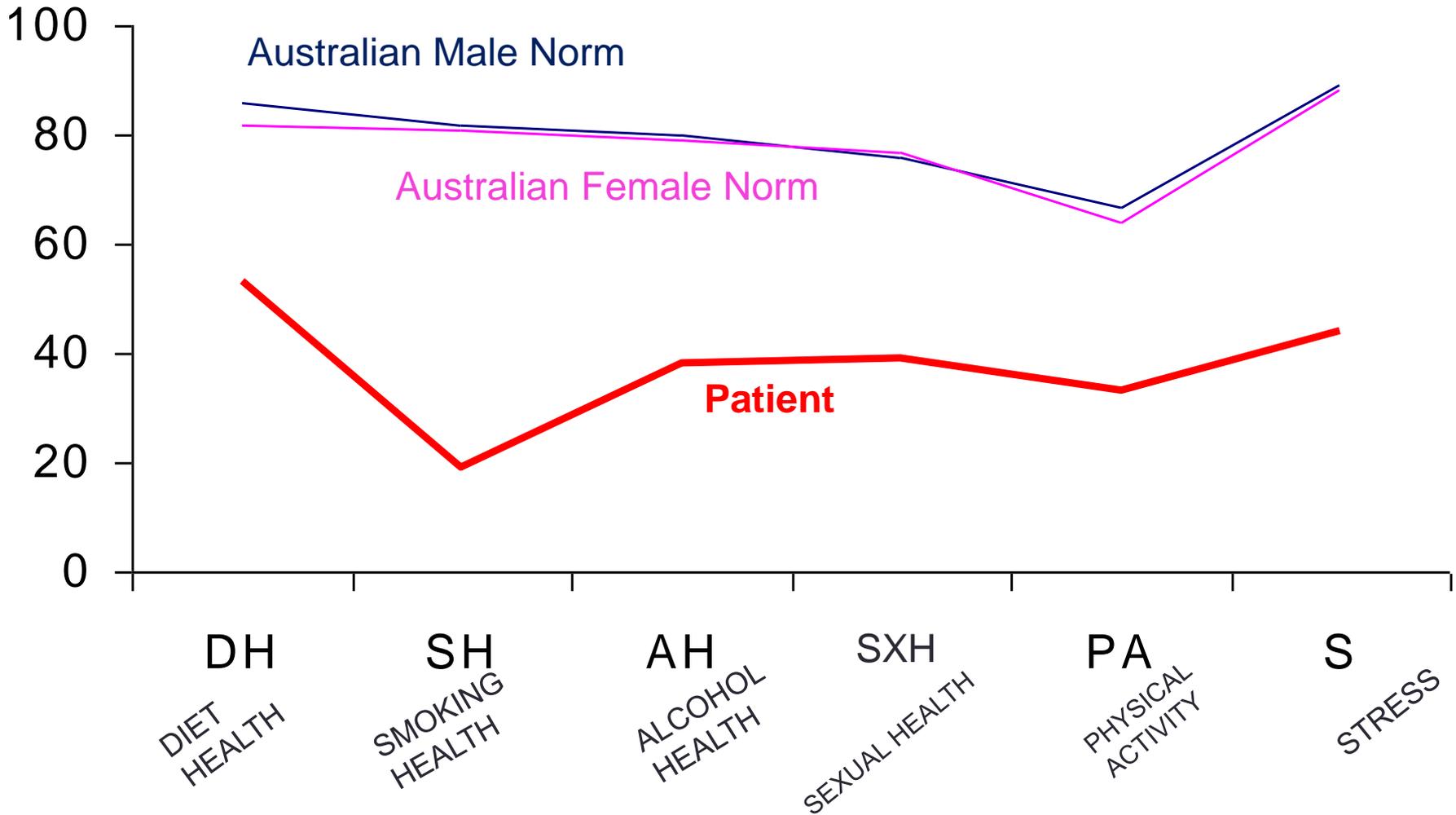
The following slides show histograms using standard scoring of the health parameters for:

- SF-36 Functional Health Status
- Behavioural Health Index (proposed based on technology underlying SF-36)
- Environmental Health Index

QUALITY OF LIFE FUNCTIONAL HEALTH STATUS

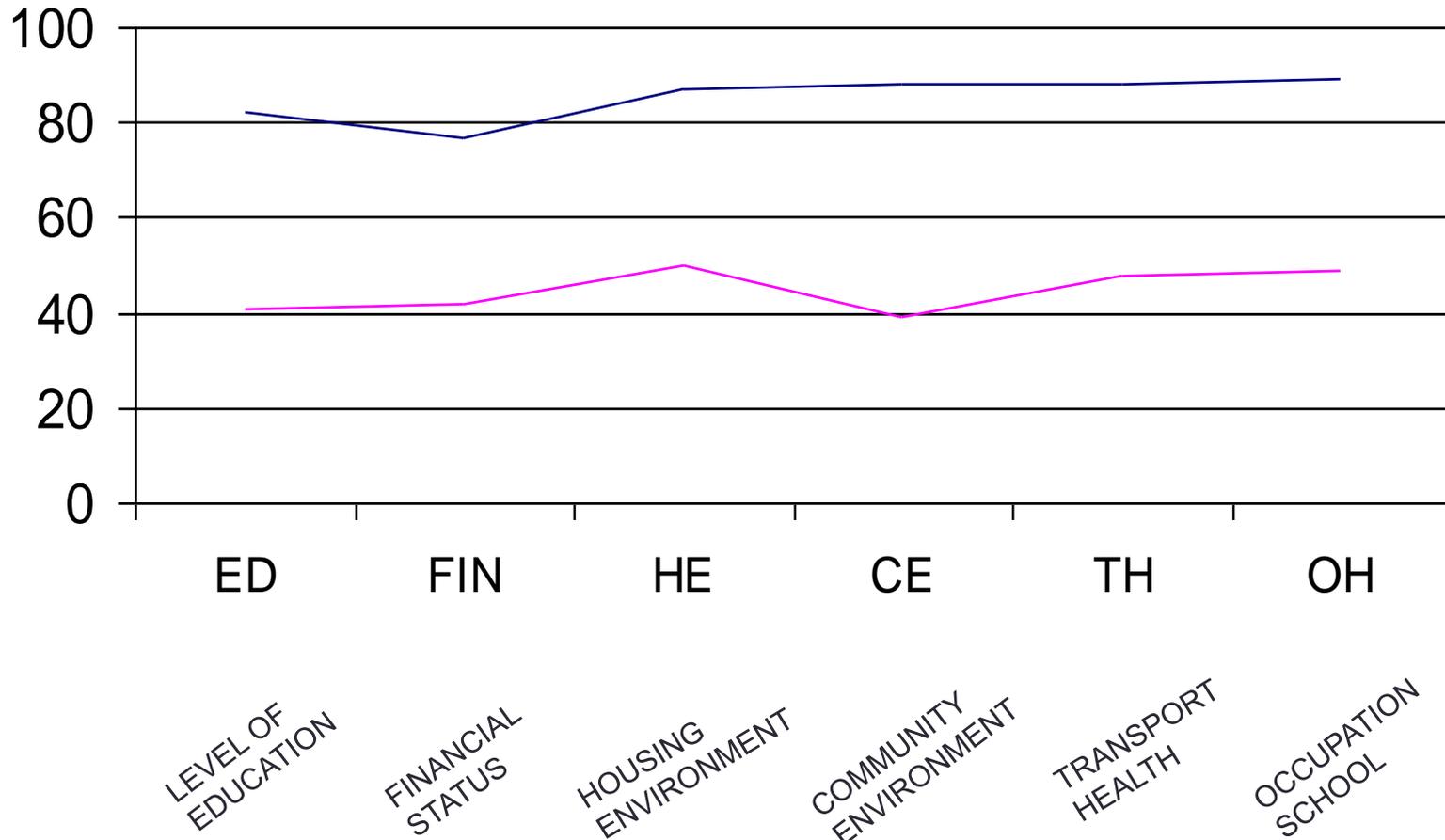


■ FAT EATING, SMOKER, DRINKER, STRESSED, NON-EXERCISER



PREDISPOSING FACTORS Socio-economically Disadvantaged Patient

— NORMAL — PATIENT



Possible Role of Health Outcomes in Hospital Quality Care Evaluation

- As currently utilised in the NHS PROMS project every patient could complete
 1. Generic Health Outcome Measure (Patient Reported Outcome) and
 2. A Body Part Specific or DRG (Diagnostic Related Group) Specific Measure
 - I. On admission
 - II. On Discharge
 - III. 90 days Post Discharge

Injury Claimants Quality Care Evaluations

- A similar but perhaps more frequent quality evaluation regime could be implemented for injury claimants from the commencement of their claim
- Improved transparency of outcome delivery in dealing with industrial injuries should lower costs and drive efficiencies
- Patients, payers and service providers all stand to benefit
- American Medical Assn. Guides to Permanent Impairment 6th Edition 2008 incorporated Functional Health Status measurements 20 US States utilizing the 6th Ed. Guidelines enjoyed a 20% reduction in claims cost for Permanent Impairment Assessments

Maximising the Potential of Patient Reported Outcome Utilisation in Clinical Practice

- ICHOM ask patients to complete these outcome measures as a baseline prior to treatment
- If they are completing these prior to any treatment activity they are not really outcome measures but better described as
 - ❑ Functional Health Status Measurements
or
 - ❑ Functional Health Status Assessments
- As an assessment tool, they have become close to being a 'Diagnostic tool'

My Own Experience

- Surveyed 100 employees of 1 client company using SF-36 in 1994
- 2 employees scored poorly on physical functioning parameter
- If it was a valid tool, both should have had a physical ailment
- On investigation one employee had diagnosed arthritis which was as expected
- The other employee had no known diagnosis but further questioning on her functional habits allowed me to diagnose IBS (her frequency of a need for a toilet dominated where she sat at work and had curtailed any social life)

IT The Essential Enabler

- The emergence of Complexity Science would not have been possible without the phenomenal advances in Information Technology (IT)
- It is the same IT that has enabled Patient Reported or with wearable devices - Patient Measured functioning over time to be practical
- This has opened up the ability to measure – “functioning”, “caring” and “environmental” influences at the individual patient level that enables additional measures of Quality Care as well as heralding a new age of Digitized Medicine
- Could be implemented sooner if it is supported by physicians
- Its widespread adoption may have the potential to improve Health Outcomes while at the same time Lowering Costs?