

# Artificial Intelligence Techniques Using Structured Health Records

John Chelsom  
[john.chelsom@seveninformatics.com](mailto:john.chelsom@seveninformatics.com)

# Artificial Intelligence

We are currently at the start of the third wave of the discipline of Artificial Intelligence.

The *first wave*, and the birth of the discipline, started with the Dartmouth Conference in 1956, organised by John McCarthy and Claude Shannon, and attended by early pioneers such as Marvin Minsky, Allen Newell and Herb Simon.

The *second wave*, in the mid 1980's, saw the emergence of 'expert systems' and 'knowledge-based systems' as a paradigm for reasoning with declarative, rather than procedural knowledge.

Although the technology for pattern recognition and machine learning continued to develop throughout the two decades around the turn of the century, the widespread deployment of knowledge-based systems was hampered by a lack of robust, large-scale declarative knowledge bases and structured observational data.

The *third wave* of AI is driven by advances in speech recognition, natural language processing, speech synthesis, pattern matching and machine learning for mining unstructured or semi-structured Big Data sets.

# Artificial Intelligence Techniques Using Structured Health Records

In this seminar we are going to buck the trend of the Third Wave and look at AI techniques using structured health records and knowledge bases.

- Structured Health Records
- Knowledge and Reasoning
- Artificial Intelligence

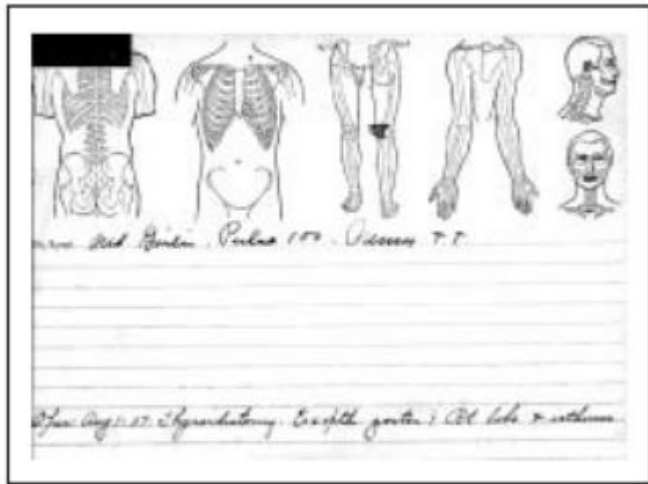
## Artificial Intelligence Techniques Using Structured Health Records

- Linking Health Records with Knowledge Sources
- Rules-based Reasoning
- Bayesian Inference

# Structured Health Records

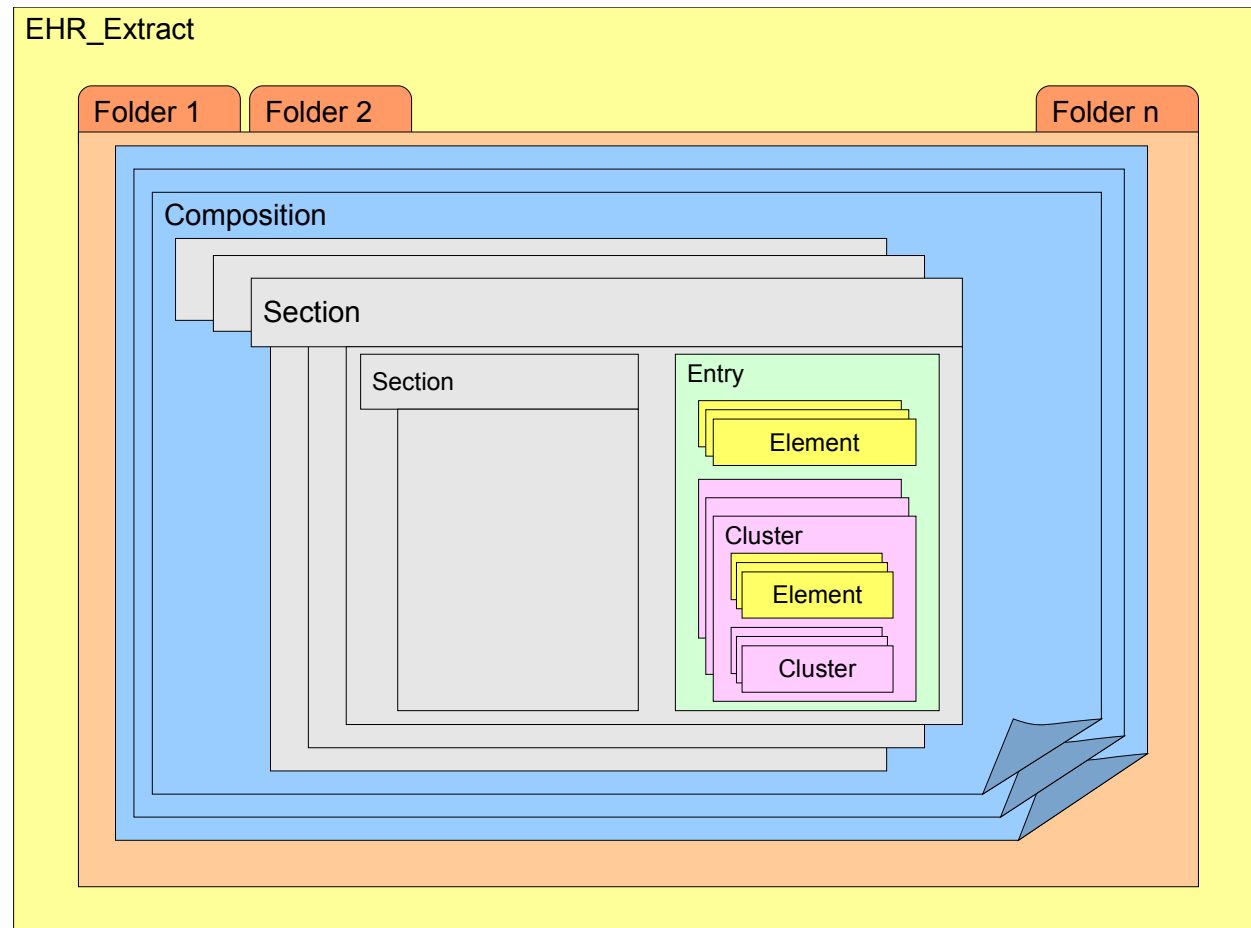
# Structure of a Health Record

- ISO-13606 standard
- Started as a European standards activity, adopted by ISO
- Defines the general structure of a health record (amongst other things)



The organisation of patient records as paper 'dossiers' was introduced by Henry S Plummer at the Mayo Clinic in 1907.

Camp et al, 2008.



# Structure of a Health Record

**Patient Information:** CHUMLEY-WARREN, Arthur (Mr) Born: 13-Feb-1947 (70 years) Gender: Male  
Patient Id 67676767 NHS Number 123456789

**Navigation:** Dashboard Patient Search Patient Cohor Care Setting: cityEHR Feature Demo

**Left Sidebar:** In Progress New Hide Events Summaries Letters Forms Pathways  
cityEHR Feature Demo (20)  
Current Observations  
Allergies and Warnings  
Bone Chemistry  
Laboratory Test Results  
Update Patient Demographics  
Feature Demonstration  
Hospital Anxiety and Depression Scale  
DAS 28  
Disease Activity Score (DAS 28)  
DAS 68  
Diagnosis  
Family History  
Fracture Record  
Medication

**Main Content:** 01-Aug-2017 - DAS 28 \*  
Effective Time: 01-8-2017 14:10:03.595

**Disease Activity Score (DAS 28) Figure:** A human silhouette with 'S' (Swollen) and 'T' (Tender) markers on joints. Legend: S Swollen, T Tender.

Count	Swollen Joints 3	Tender Joints 1
ESK	23	
Visual Analogue Scale	2	
DAS Score	3.52	

**Annotations:**  
- Folder: Care Setting dropdown  
- Cluster: DAS Score row  
- Element: DAS Score value  
- Entry: DAS Score row and value  
- Section: DAS 28 title  
- EHR\_Extract: DAS 28 section

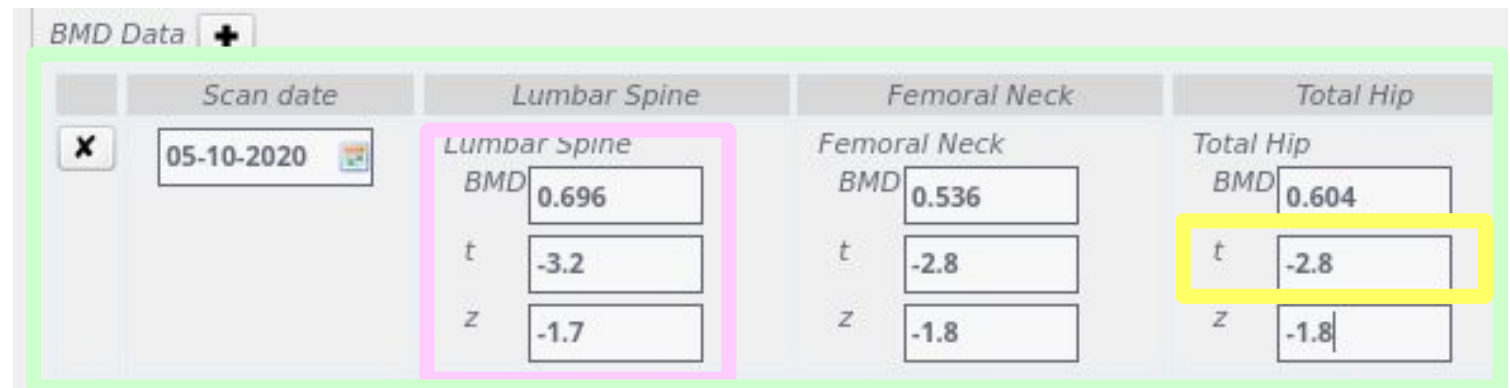
**Footer:** cityEHR Version Number - V1.5 User: cityEHR Administrator / cityEHR Feature Demo Logged on: 11:26:01 on Tuesday, 1st August 2017 Last logged on: 12:29:59 on Friday, 28th July 2017

# Clinical Statement

0.604 05-10-2020 These data carry no meaning.

-2.8

In ISO-13606, data items are modelled as Element, and grouped as Cluster



The screenshot shows a table titled 'BMD Data' with a '+' icon. The table has four columns: 'Scan date', 'Lumbar Spine', 'Femoral Neck', and 'Total Hip'. The 'Scan date' column contains '05-10-2020'. The 'Lumbar Spine' column contains 'Lumbar Spine', 'BMD 0.696', 't -3.2', and 'z -1.7'. The 'Femoral Neck' column contains 'Femoral Neck', 'BMD 0.536', 't -2.8', and 'z -1.8'. The 'Total Hip' column contains 'Total Hip', 'BMD 0.604', 't -2.8', and 'z -1.8'. The 't' value for 'Total Hip' is highlighted with a yellow box.

	Scan date	Lumbar Spine	Femoral Neck	Total Hip
X	05-10-2020	Lumbar Spine	Femoral Neck	Total Hip
		BMD	BMD	BMD
		0.696	0.536	0.604
		t	t	t
		-3.2	-2.8	-2.8
		z	z	z
		-1.7	-1.8	-1.8

The Clinical Statement is the lowest level of modelling that carries useful clinical context.

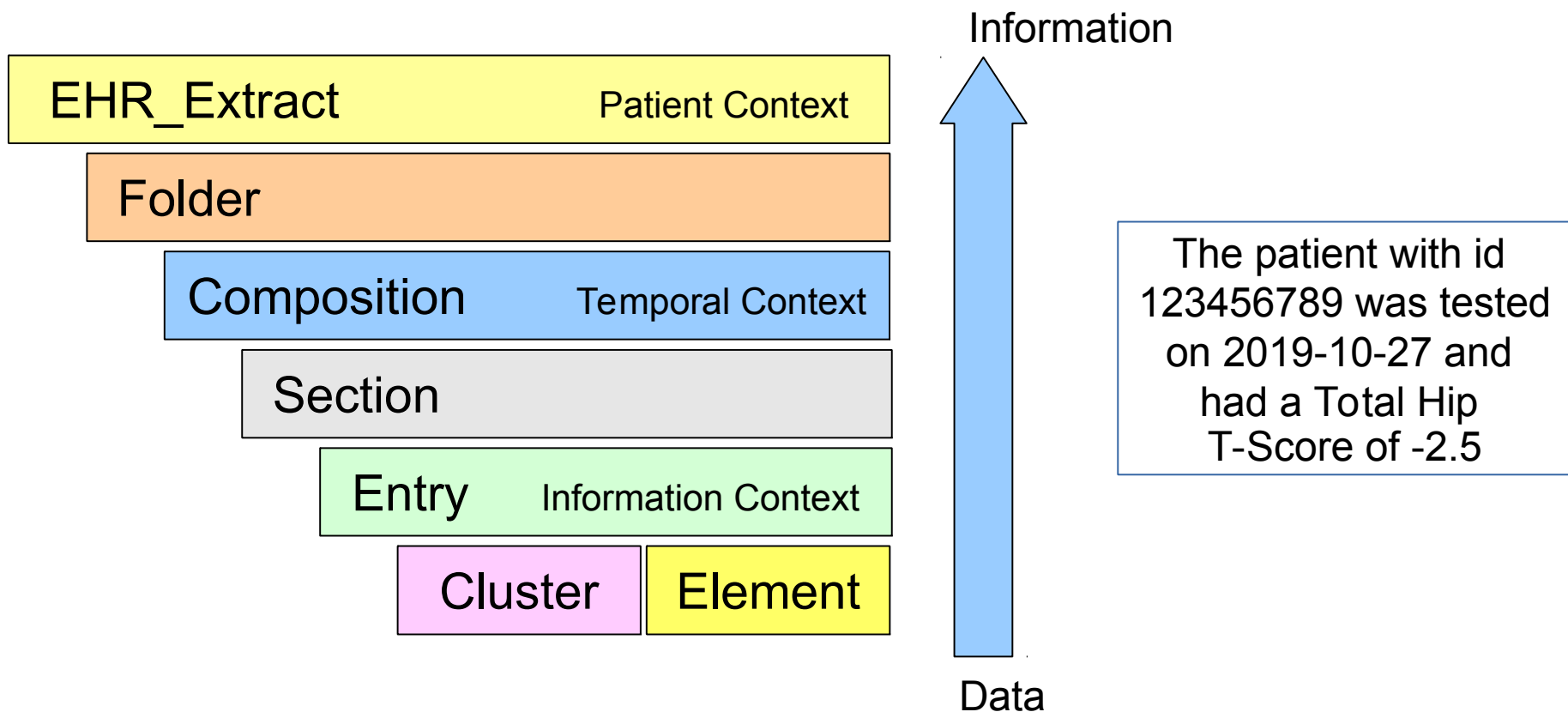
It is the point in the model at which data becomes information.

In ISO-13606 the Clinical Statement is modelled as Entry.

# Clinical Context

Different levels of the ISO-13606 model carry different aspects of clinical context.

Other levels in the model help clinical users to interact with and understand the information, but are of no clinical significance (i.e. do not contribute to the clinical context)





# HL7 Clinical Document Architecture

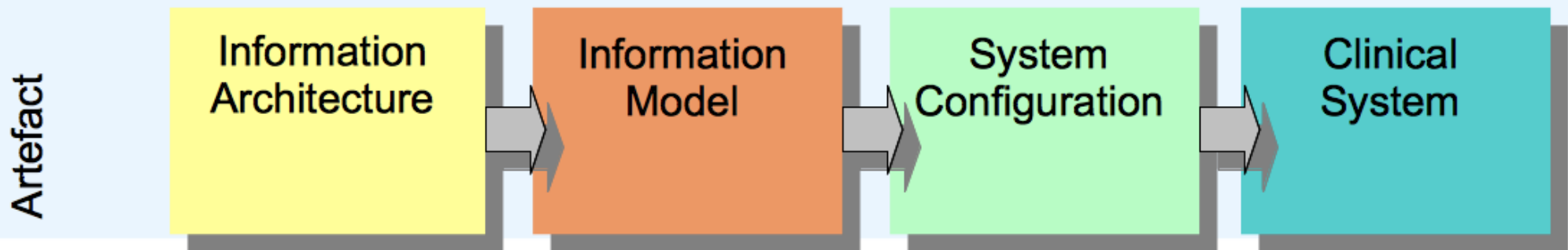
The screenshot displays a cityEHR interface for patient Timothy ABERNATHY (Mr), born 28-Mar-1939 (81 years). The patient ID is K1476889 and the NHS Number is 7563628274. The interface shows a navigation bar with 'In Progress' and 'New' tabs, and a main content area with 'Events' and 'Summaries' tabs. A table titled '05-Oct-2020 Bone Mineral Density' is visible, with a 'BMD Data' section containing a table with columns for 'Date of Scan' and 'BMD Data'. The 'Date of Scan' column has a value of '05-Oct-2020'. The 'BMD Data' column has a '+' icon. An 'XML Document Viewer' window is open, displaying XML code for an observation. The XML code includes elements for 'LumberSpine', 'FemoralNeck', and 'TotalHip' clusters, with sub-elements for 'BMDLumbar', 'TScoreLumbar', 'ZScoreLumbar', 'BMDFemoral', 'TScoreFemoral', 'ZScoreFemoral', 'BMDHip', 'TScoreHip', and 'ZScoreHip'. The XML code is as follows:

```
<observation>
  <typeId root="cityEHR" extension="#HL7-CDA:Observation"/>
  <id root="#ISO-13606:Entry:BMDData" extension="#ISO-13606:Entry:BMDData" cityEHR:origin="..."/>
  <code code="" codeSystem="cityEHR" displayName="BMD Data"/>
  <value root="#ISO-13606:Element:ScanDate" extension="#ISO-13606:Element:ScanDate" xsi:type="..."/>
  <value code="" codeSystem="" displayName="" root="#ISO-13606:Cluster:LumberSpine" extension="..."/>
  <value root="#ISO-13606:Element:BMDLumbar" extension="#ISO-13606:Element:BMDLumbar" xsi:type="..."/>
  <value root="#ISO-13606:Element:TScoreLumbar" extension="#ISO-13606:Element:TScoreLumbar" xsi:type="..."/>
  <value root="#ISO-13606:Element:ZScoreLumbar" extension="#ISO-13606:Element:ZScoreLumbar" xsi:type="..."/>
  </value>
  <value code="" codeSystem="" displayName="" root="#ISO-13606:Cluster:FemoralNeck" extension="..."/>
  <value root="#ISO-13606:Element:BMDFemoral" extension="#ISO-13606:Element:BMDFemoral" xsi:type="..."/>
  <value root="#ISO-13606:Element:TScoreFemoral" extension="#ISO-13606:Element:TScoreFemoral" xsi:type="..."/>
  <value root="#ISO-13606:Element:ZScoreFemoral" extension="#ISO-13606:Element:ZScoreFemoral" xsi:type="..."/>
  </value>
  <value code="" codeSystem="" displayName="" root="#ISO-13606:Cluster:TotalHip" extension="..."/>
  <value root="#ISO-13606:Element:BMDHip" extension="#ISO-13606:Element:BMDHip" xsi:type="..."/>
  <value root="#ISO-13606:Element:TScoreHip" extension="#ISO-13606:Element:TScoreHip" xsi:type="..."/>
  <value root="#ISO-13606:Element:ZScoreHip" extension="#ISO-13606:Element:ZScoreHip" xsi:type="..."/>
  </value>
  <value root="#ISO-13606:Element:Comments" extension="#ISO-13606:Element:Comments" xsi:type="..."/>
</observation>
</component>
</ganizer>
</ment>
->
```

Dolin, R.H., Alschuler, L., Boyer, S., Beebe, C., Behlen, F.M., Biron, P.V. and Shabo, A., 2006. HL7 clinical document architecture, release 2. Journal of the American Medical Informatics Association, 13(1), pp.30-39.

# Model-Driven EHR

- A base Information Architecture provides the building blocks
- Clinicians create clinical Information Models for their own systems
- The System Configuration is generated from the Information Model
- The runtime EHR system operates using the System Configuration
  - views of the patient record
  - search criteria
  - data collection forms
  - clinical messages
  - (pathways, orders, prescriptions)



Based on the concept of Archetypes introduced by Beale (2002) and included in ISO 13606

# EHR Ontology Model

```
<Declaration>
  <Class IRI="#ISO-13606:Entry"/>
</Declaration>
<Declaration>
  <NamedIndividual IRI="#ISO-13606:Entry:BMDDData"/>
</Declaration>
<ClassAssertion>
  <Class IRI="#ISO-13606:Entry"/>
  <NamedIndividual IRI="#ISO-13606:Entry:BMDDData"/>
</ClassAssertion>
<DataPropertyAssertion>
  <DataProperty IRI="#hasDisplayName"/>
  <NamedIndividual IRI="#ISO-13606:Entry:BMDDData"/>
  <Literal xml:lang="en-gb">DXA Scan Results</Literal>
</DataPropertyAssertion>
<ObjectPropertyAssertion>
  <ObjectProperty IRI="#hasContent"/>
  <NamedIndividual IRI="#ISO-13606:Entry:BMDDData"/>
  <NamedIndividual IRI="#ISO-3606:Element:BMDMeasurement"/>
</ObjectPropertyAssertion>
<ObjectPropertyAssertion>
  <ObjectProperty IRI="#hasContent"/>
  <NamedIndividual IRI="#ISO-13606:Entry:BMDDData"/>
  <NamedIndividual IRI="#ISO-13606:Element:TScore"/>
</ObjectPropertyAssertion>
<ObjectPropertyAssertion>
  <ObjectProperty IRI="#hasContent"/>
  <NamedIndividual IRI="#ISO-13606:Entry:BMDDData"/>
  <NamedIndividual IRI="#ISO-13606:Element:ZScore"/>
</ObjectPropertyAssertion>
```

Information model specified by assertions using the Web Ontology Language

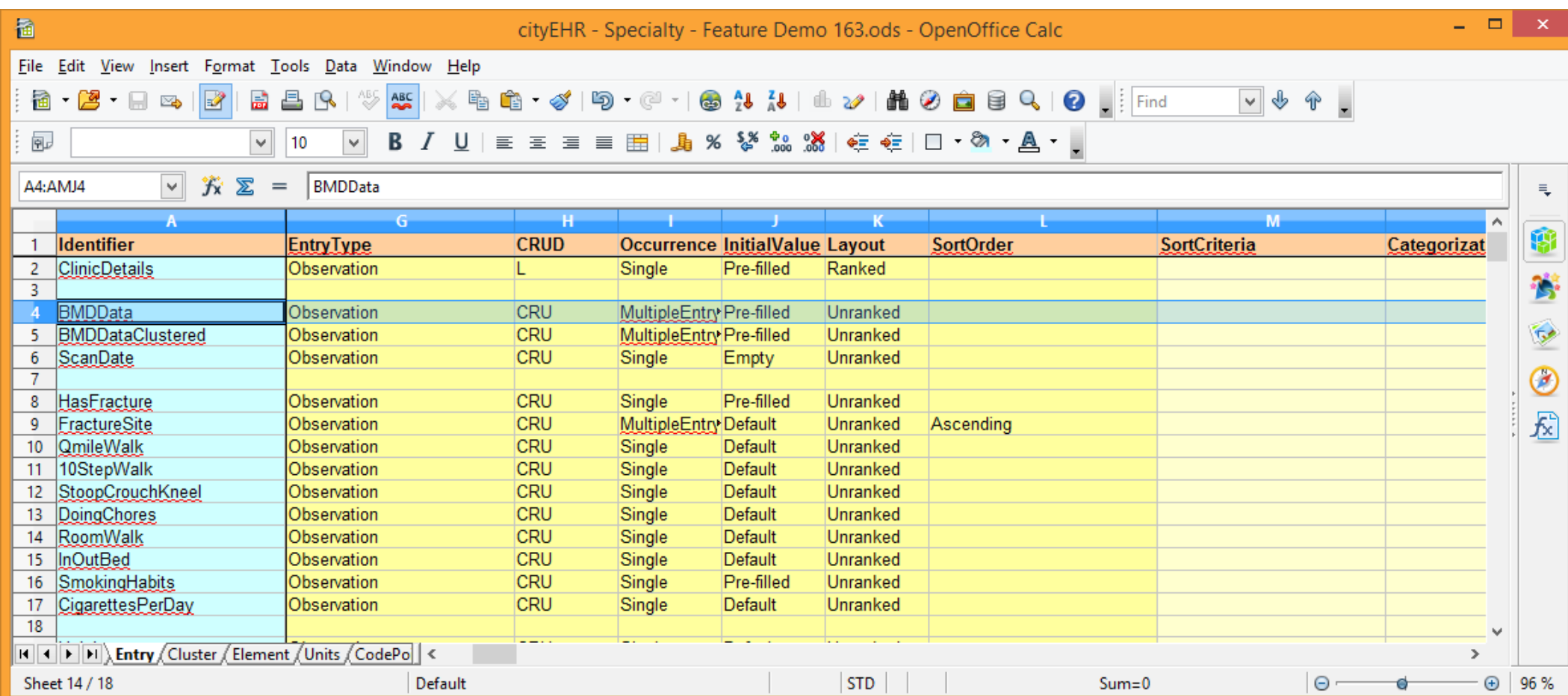
The OWL/XML format is one of several formats included in the standard

W3C Owl Working Group. 2012. OWL 2 Web Ontology Language. Document Overview (Second Edition) W3C Recommendation 11 December 2012.

# Information Model – Spreadsheet Input

Clinicians can create their own information models using a spreadsheet

Converted to an OWL/XML ontology when imported to cityEHR



The screenshot shows a spreadsheet titled "cityEHR - Specialty - Feature Demo 163.ods" in OpenOffice Calc. The spreadsheet contains a table with the following data:

Identifier	EntryType	CRUD	Occurrence	InitialValue	Layout	SortOrder	SortCriteria	Categorizat
ClinicDetails	Observation	L	Single	Pre-filled	Ranked			
BMDData	Observation	CRU	MultipleEntry	Pre-filled	Unranked			
BMDDataClustered	Observation	CRU	MultipleEntry	Pre-filled	Unranked			
ScanDate	Observation	CRU	Single	Empty	Unranked			
HasFracture	Observation	CRU	Single	Pre-filled	Unranked			
FractureSite	Observation	CRU	MultipleEntry	Default	Unranked	Ascending		
QmileWalk	Observation	CRU	Single	Default	Unranked			
10StepWalk	Observation	CRU	Single	Default	Unranked			
StoopCrouchKneel	Observation	CRU	Single	Default	Unranked			
DoingChores	Observation	CRU	Single	Default	Unranked			
RoomWalk	Observation	CRU	Single	Default	Unranked			
InOutBed	Observation	CRU	Single	Default	Unranked			
SmokingHabits	Observation	CRU	Single	Pre-filled	Unranked			
CigarettesPerDay	Observation	CRU	Single	Default	Unranked			

# Catching Up With the Mayo Clinic

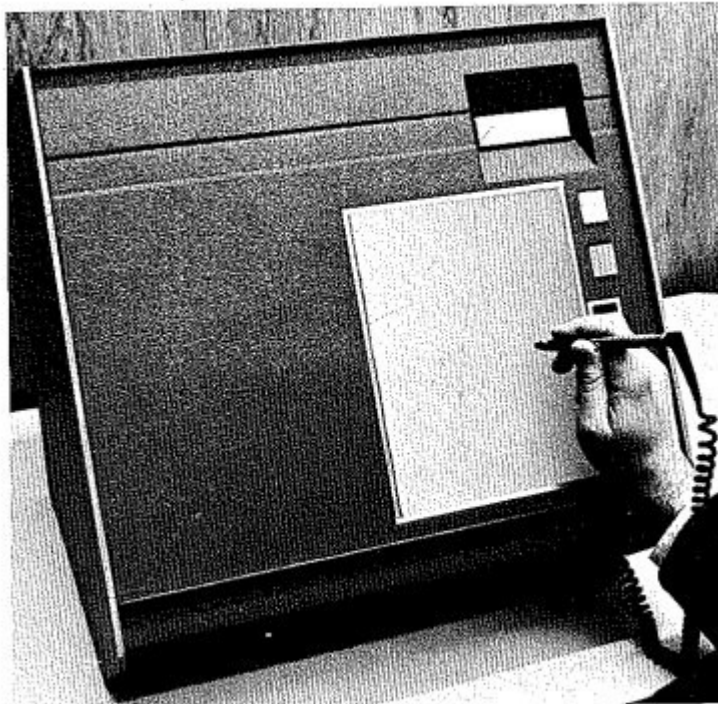


Fig. 1. Experimental graphic display terminal.

Mayne, J.G., Weksel, W. and Sholtz, P.N., 1968, January. Toward automating the medical history. In Mayo Clinic Proceedings (Vol. 43, No. 1, p. 1).

Which of the following phrases best describe the speed of your heartbeat?

- I am not usually aware of the speed of my heartbeat.
- My heartbeat is sometimes very fast.
- My heart seems to beat very fast all of the time.
- My heartbeat is sometimes very slow.
- I occasionally have attacks of very rapid heartbeat, which usually start suddenly and stop suddenly.
- None of the above describe it.

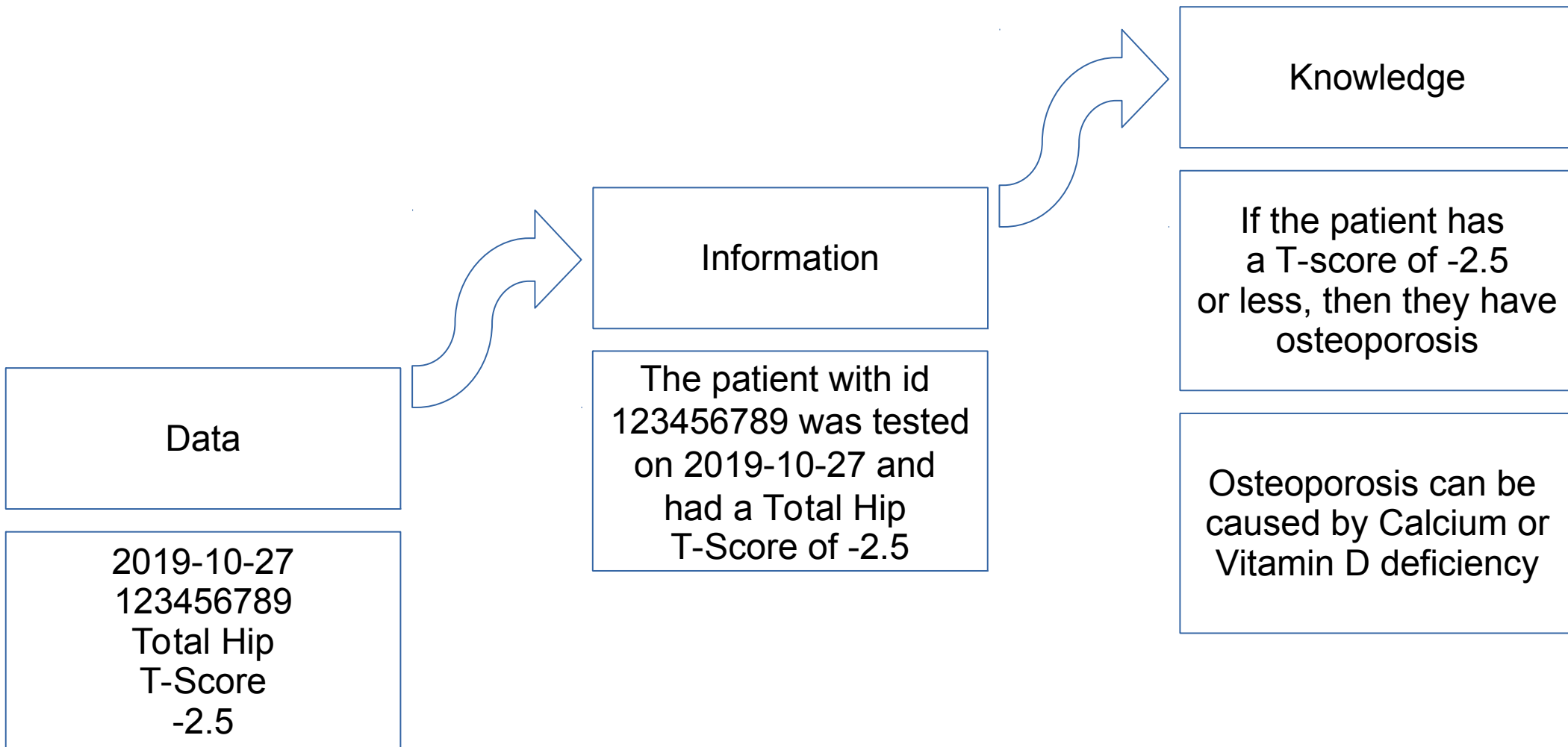
← Go back                       Erase                       Continue →

Fig. 2. Sample image, showing the three functional areas of each frame: question (top); response alternatives (middle); and instructions (bottom). In the actual projected image, each functional area is a different color.

# Knowledge and Reasoning

# Data – Information – Knowledge

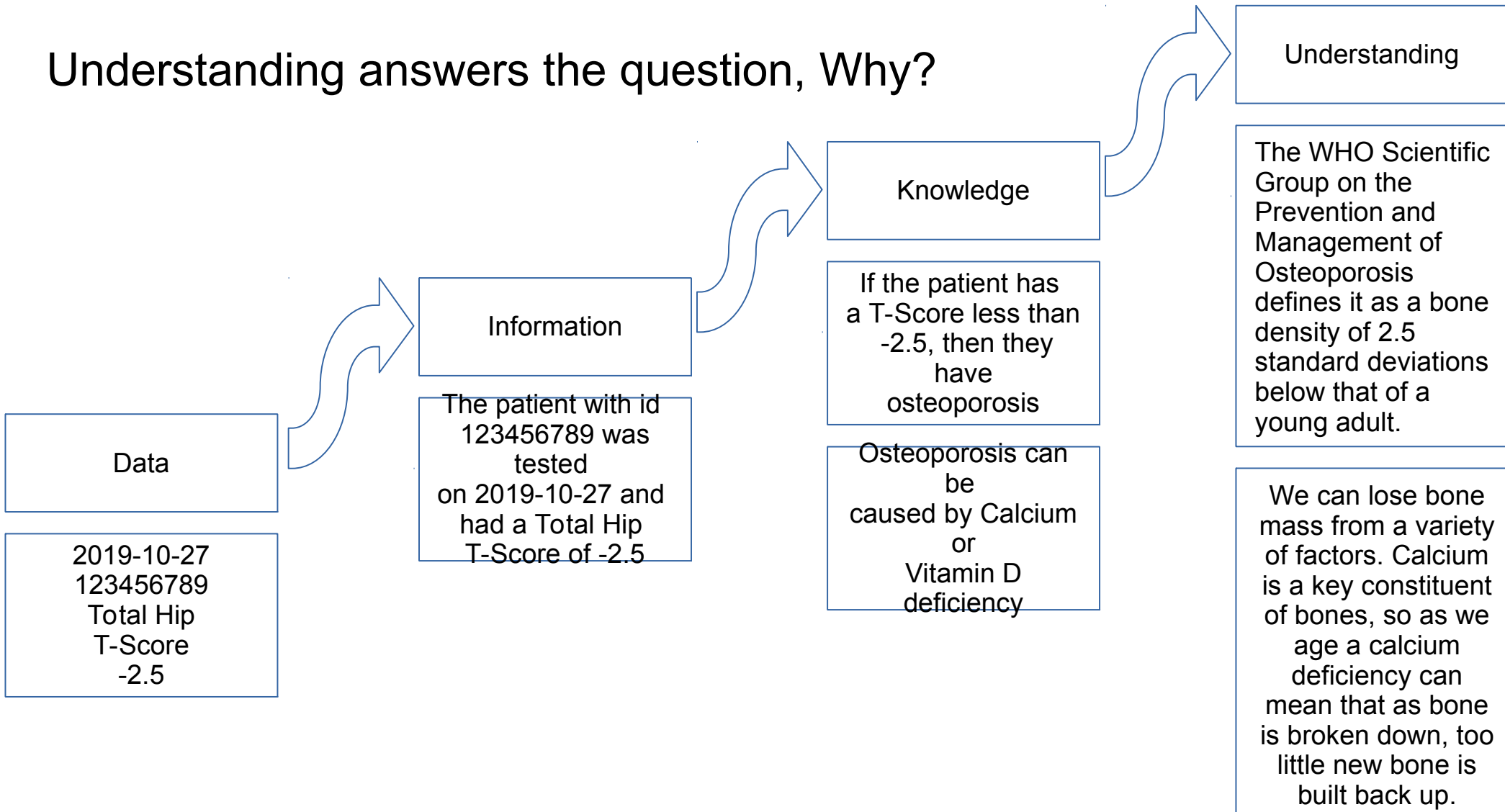
The progression had been well described by Russell Ackoff (1989).



# Understanding

Ackoff extends beyond Knowledge to Understanding and Wisdom

Understanding answers the question, Why?





# What is Ontology?

The concept of Ontology has been hijacked by Computer Scientists from the discipline of Philosophy, where it can be defined as

The branch of metaphysics dealing with the nature of being.

Oxford English Dictionary

Social Scientist, Anthony Giddens introduced the concept of Ontological Security

We begin from the premise that to be a human being is to know, virtually all of the time, in terms of some description or another, both what one is doing and why one is doing it [...] All individuals develop a framework of ontological security of some sort, based on routines of various forms.

Giddens (1991) *Modernity and Self-Identity: Self and Society in the Late Modern Age*

An ontologically insecure person does not accept at a fundamental level the reality or existence of things, themselves, and others.

Jackson II, R.L. and Hogg, M.A. eds., 2010. *Encyclopedia of Identity*

Or in Computer Science, we might say that

Ontological insecurity refers to a person who uses the word 'ontology' without really knowing what it means. Their insecurity arises from the fear that one day someone might ask them to define 'ontology' and they will be found lacking.

# Ontology

A body of formally represented knowledge is based on a conceptualization: the objects, concepts, and other entities that are assumed to exist in some area of interest and the relationships that hold among them.

A conceptualization is an abstract, simplified view of the world that we wish to represent for some purpose. Every knowledge base, knowledge-based system, or knowledge-level agent is committed to some conceptualization, explicitly or implicitly.

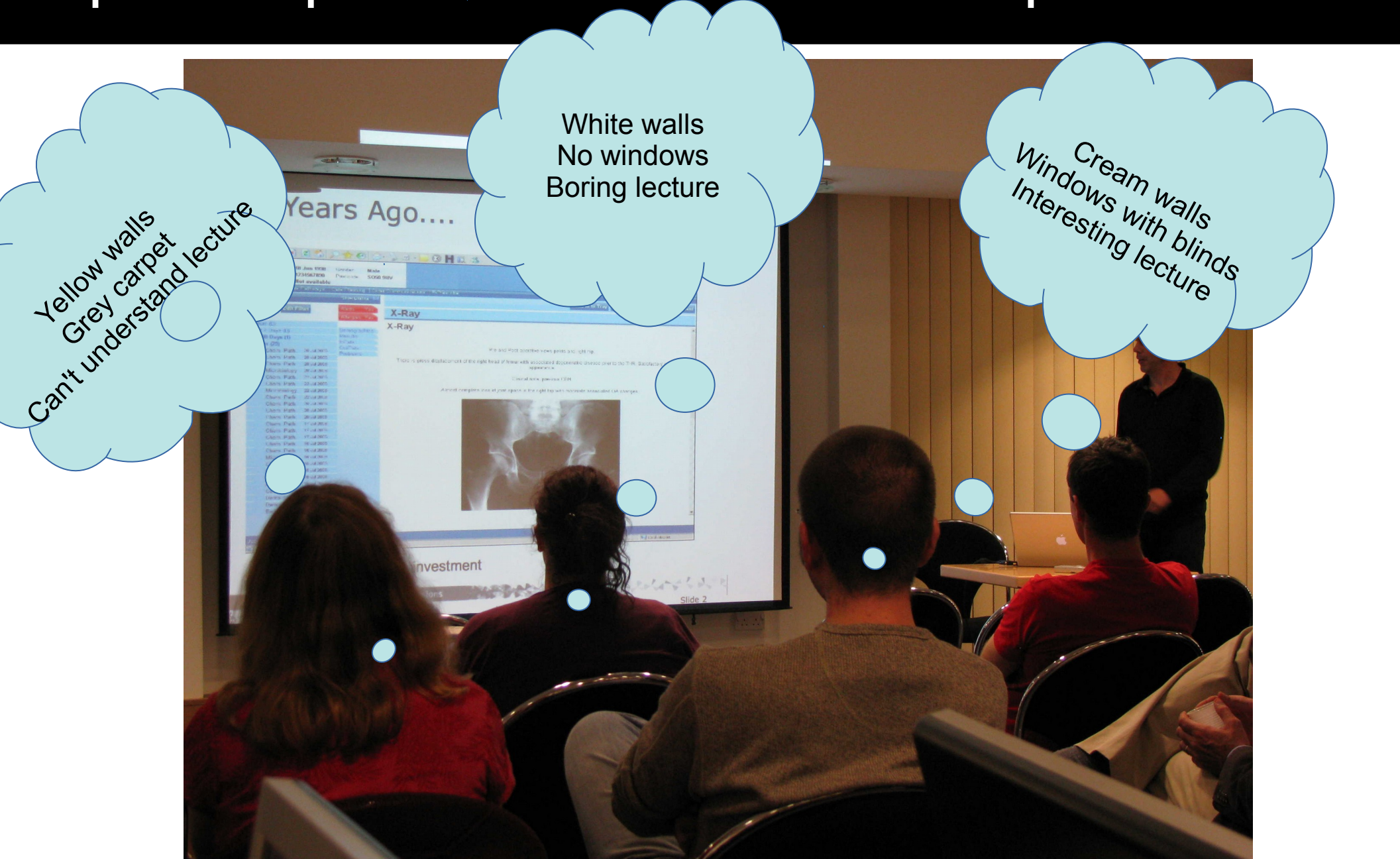
**An ontology is an explicit specification of a conceptualization.**

T. R. Gruber. A translation approach to portable ontologies. *Knowledge Acquisition*, 5(2):199-220, 1993



Tom Gruber, Stanford University, Knowledge Systems Lab

# Explicit Specification of a Conceptualization



# Knowledge

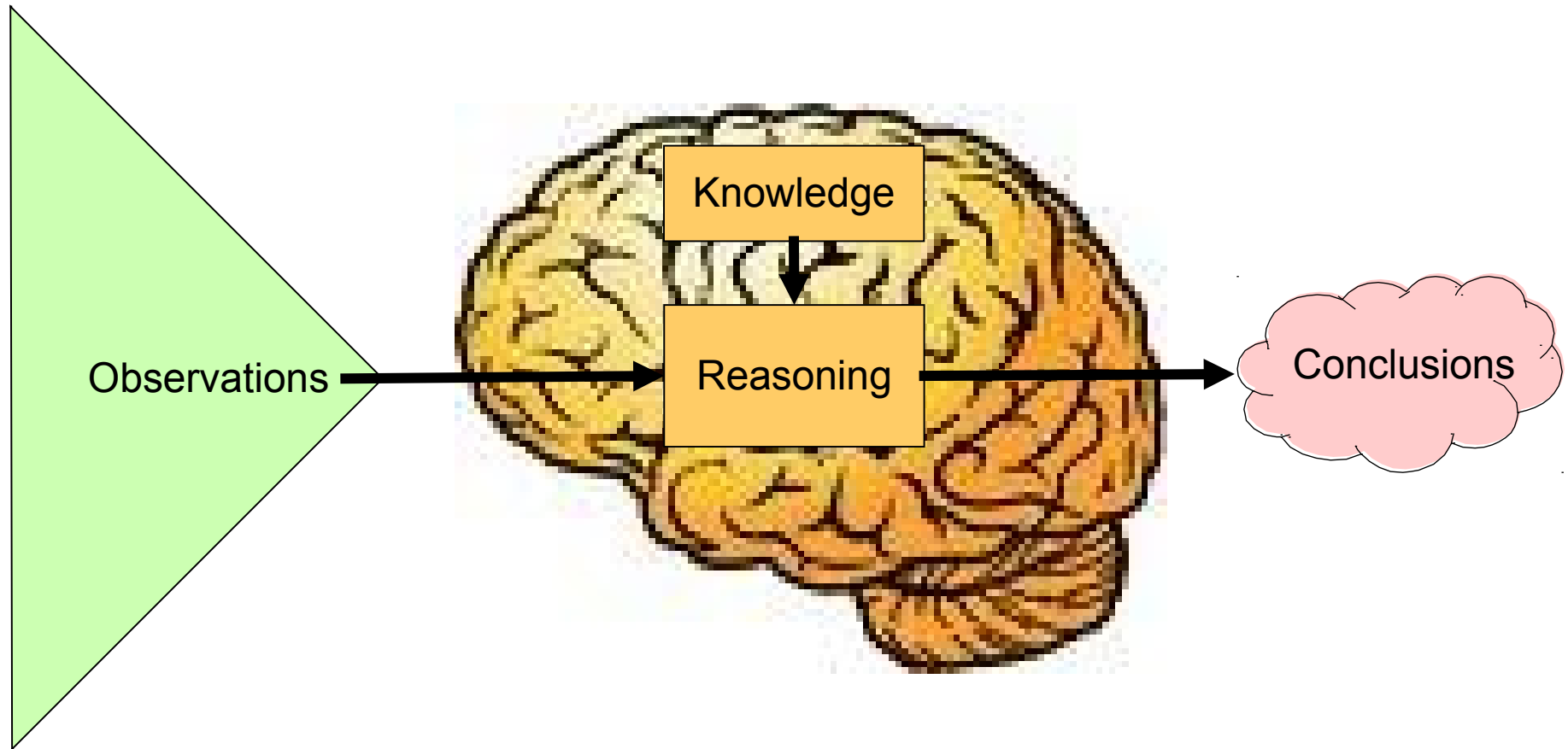
Knowledge is familiarity, awareness, or understanding gained through experience or study.

<https://en.wikipedia.org/wiki/Knowledge>

- Western philosophers for centuries have distinguished between two kinds of knowledge
- A priori knowledge is gained or justified by reason alone, without the direct or indirect influence of any particular experience (e.g. the truths of logic and mathematics)
- A posteriori knowledge is attained or justified by reference to experience (i.e. observation or measurement)  
This is also called empirical knowledge.



# Knowledge Fuels Reasoning



- Observations provide information on the current (problem) context
- Knowledge base and observations are inputs to a reasoning engine
- Reasoning generates conclusions (solutions) relevant to the current context, based on observations and knowledge

# Reasoning

Reasoning. The act of using reason, to derive a conclusion from certain premises, using a given methodology.

Reason is the ability to form and operate on concepts in abstraction, using rationality and logic

<https://en.wikipedia.org/wiki/Reason>



- logic deals principally with provable facts and demonstrably valid relations between them

Mr Spock



- rationality is a much broader term than logic, as it includes "uncertain but sensible" arguments based on probability, expectation and personal experience

Captain Kirk

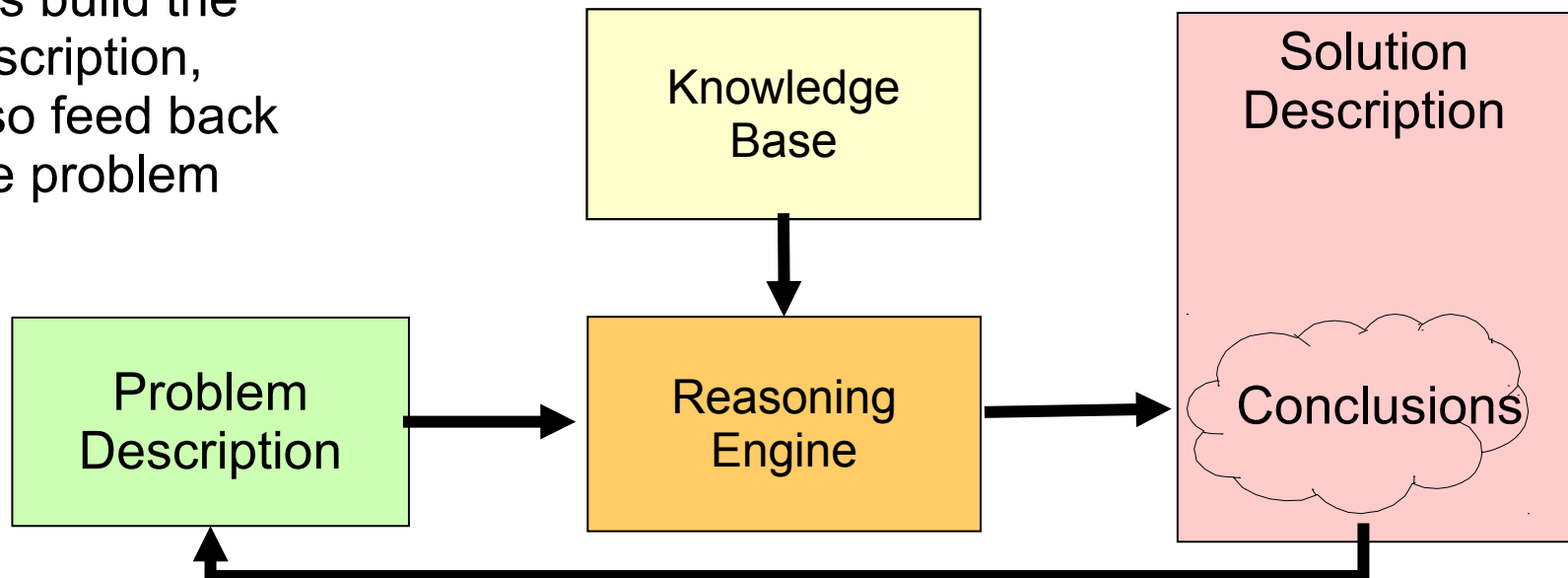


# Reasoning Engine

A reasoning engine is a computer program that tries to derive answers from a knowledge base.

It is the “brain” that knowledge based systems use to reason about the information in the knowledge base, for the ultimate purpose of formulating new conclusions.

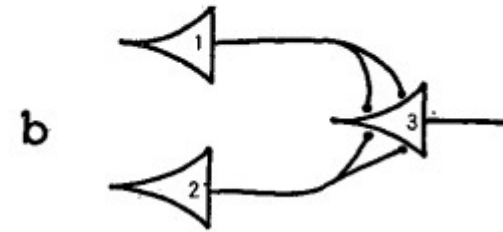
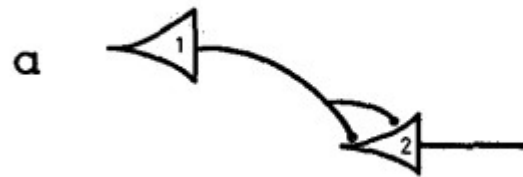
Conclusions build the solution description, but may also feed back to refine the problem description



# Models of Human Thought Processes

130

LOGICAL CALCULUS FOR NERVOUS ACTIVITY



In 1943, McCulloch and Pitts proposed a mathematical model of nervous activity.

In 1958, Rosenblatt introduced the theory of the perceptron.

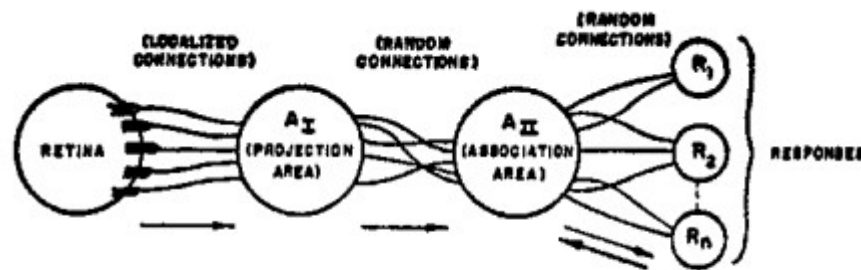


FIG. 1. Organization of a perceptron.

The theory has been developed for a hypothetical nervous system, or machine, called a perceptron. The perceptron is designed to illustrate some of the fundamental properties of intelligent systems in general, without becoming too deeply enmeshed in the special, and frequently unknown, conditions which hold for particular biological organisms. The analogy between the perceptron and biological systems should be readily apparent to the reader.

These two papers laid the foundations for the simulation of human thought processes using computers, leading to the field of Artificial Neural Networks (ANNs).

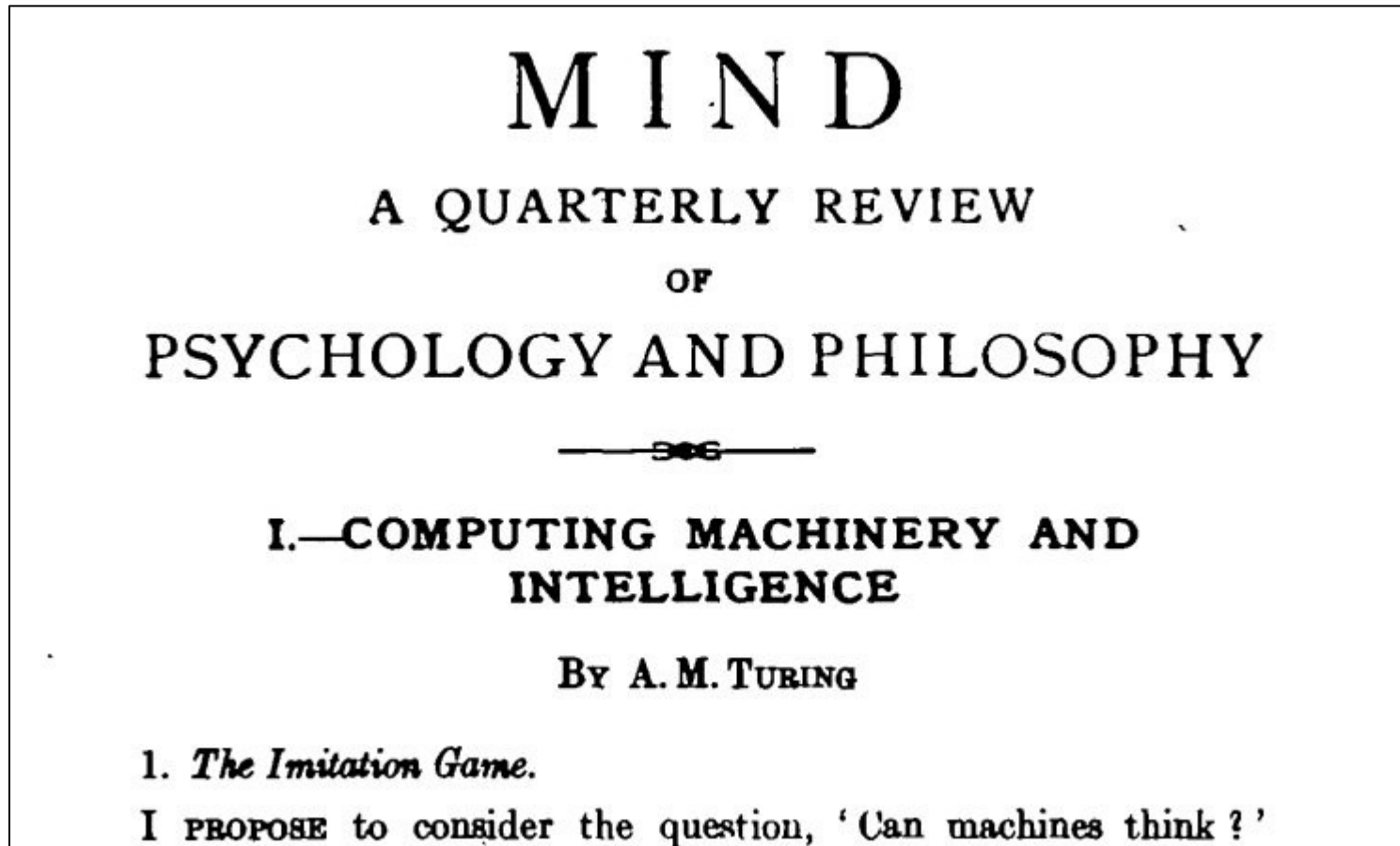


# Artificial Intelligence

# Artificial Intelligence – Beginnings

The academic discipline of Artificial Intelligence can be said to have begun in 1950 when Alan Turing posed the question "Can Machines Think?"

Turing answered the question by introducing "The Imitation Game" – which has since become known as "The Turing Test".



# The Imitation Game

The essence of the Imitation Game is that a human and a computer are interrogated by a second human, who must decide which of the entities under interrogation is the computer and which is the human, based solely on their answers to the questions posed; if the interrogator is unable to say, definitively, which is the human and which is the computer, then the computer is deemed to be a 'thinking machine'.



Some important questions follow:

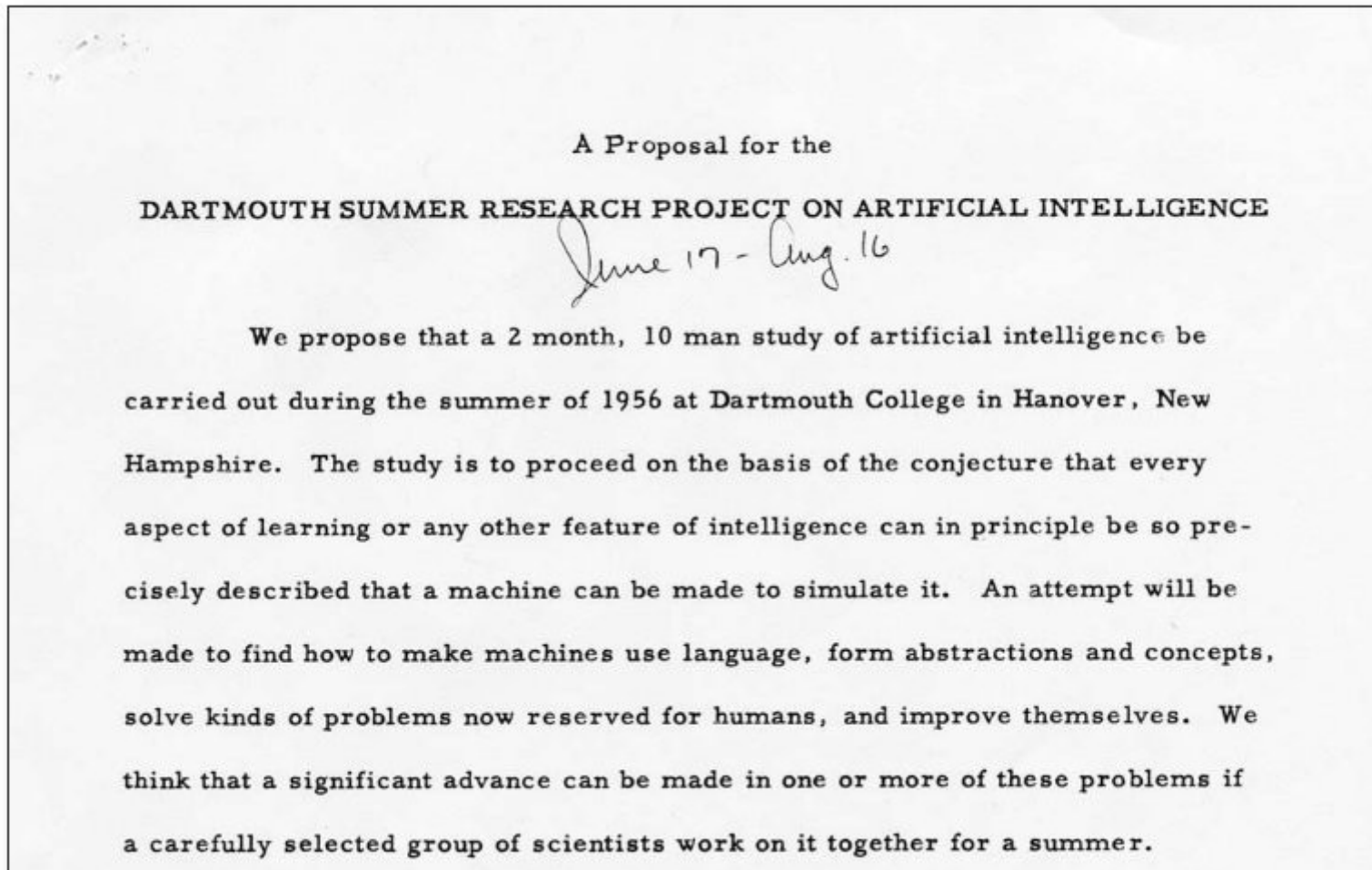
Does the 'thinking machine' display artificial intelligence or artificial stupidity?

If the machine gets the same questions 'wrong' as the human, is this useful to us?

Should we try to make machines which think like humans (i.e. use similar processes) or just appear to think like humans?

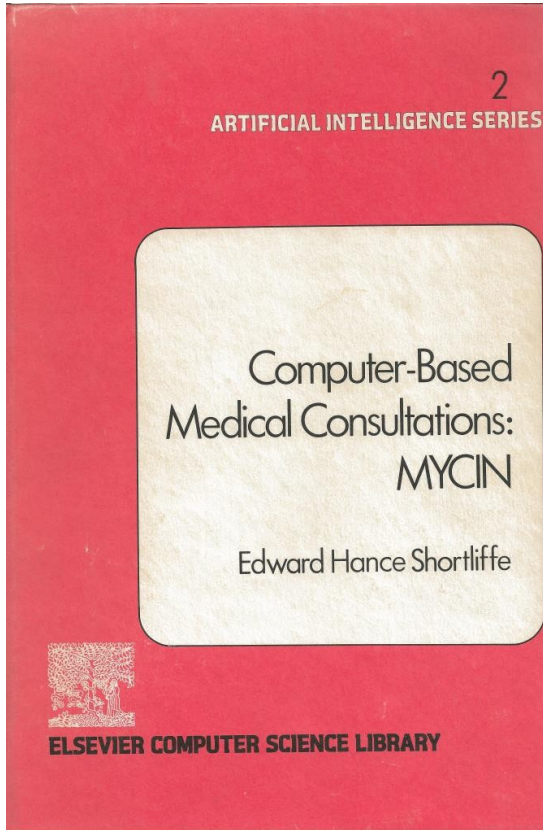
# Artificial Intelligence – Dartmouth Summer Project

The term "Artificial Intelligence" appeared in John McCarthy's proposal for a summer research project at Dartmouth College in 1956, which brought together many of the early pioneers and really kicked off the study of AI.



# Artificial Intelligence in Medicine

The MYCIN rule-based expert system, for the identification and treatment of bacterial infections, became the most widely known AI system in the medical arena.



## RULE037

IF: 1) THE IDENTITY OF THE ORGANISM IS NOT KNOWN WITH CERTAINTY, AND  
2) THE STAIN OF THE ORGANISM IS GRAMNEG, AND  
3) THE MORPHOLOGY OF THE ORGANISM IS ROD, AND  
4) THE AEROBICITY OF THE ORGANISM IS AEROBIC  
THEN: THERE IS STRONGLY SUGGESTIVE EVIDENCE (.8) THAT THE CLASS OF THE ORGANISM IS ENTEROBACTERIACEAE

## RULE145

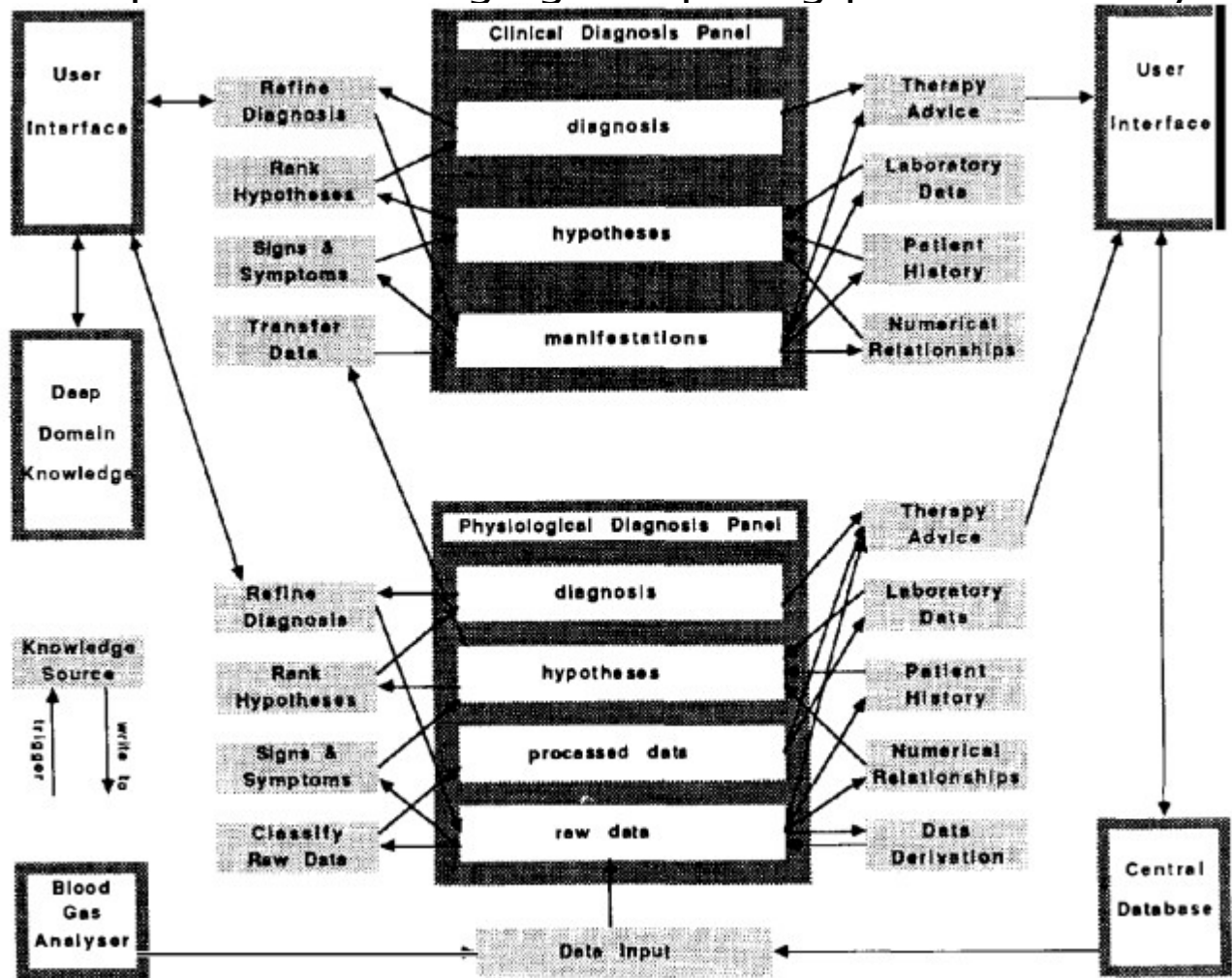
IF: 1) THE THERAPY UNDER CONSIDERATION IS ONE OF: CEPHALOTHIN CLINDAMYCIN ERYTHROMYCIN LINCOMYCIN VANCOMYCIN, AND  
2) MENINGITIS IS AN INFECTIOUS DISEASE DIAGNOSIS FOR THE PATIENT  
THEN: IT IS DEFINITE (1) THE THE THERAPY UNDER CONSIDERATION IS NOT A POTENTIAL THERAPY FOR USE AGAINST THE ORGANISM

Shortliffe, E.H., 1974. MYCIN: a rule-based computer program for advising physicians regarding antimicrobial therapy selection. STANFORD UNIV CALIF DEPT OF COMPUTER SCIENCE.

Available at: <http://people.dbmi.columbia.edu/~ehs7001/Shortliffe-1976/MYCIN%20thesis%20Book.htm>

# Knowledge-Based Expert Systems

The second wave, in the mid-1980s, arrived just when the (IBM) Personal Computer was bringing computing power to every desktop.



Blackboard paradigm for developing hypotheses.

Physiological diagnosis based on data from critical care unit

Clinical diagnosis of acid-base Disorders

Used statistical models of uncertainty, including a Bayesian Belief Network

Chelsom, J.J. et al 1988. Blood gas analysis: a knowledge-based adviser for the interpretation of results.

Pearl, J., 1986. Fusion, propagation, and structuring in belief networks.

# Artificial Neural Networks

The third wave, from 2010, when cloud computing, big data and personal assistants caught up with various theories that started in the earlier waves.

Artificial Neural Networks (ANN) are a network of nodes where the signal pattern presented at the inputs is propagated through the connected (and weighted) nodes to produce an output.

The network is 'trained' by presenting a series of known test patterns, and the weights (and node architecture) are adjusted until the desired outputs are obtained.

One key training algorithm is that of 'back propagation', first described by Paul Werbos in 1974, which started to gain attention in the 1980s.

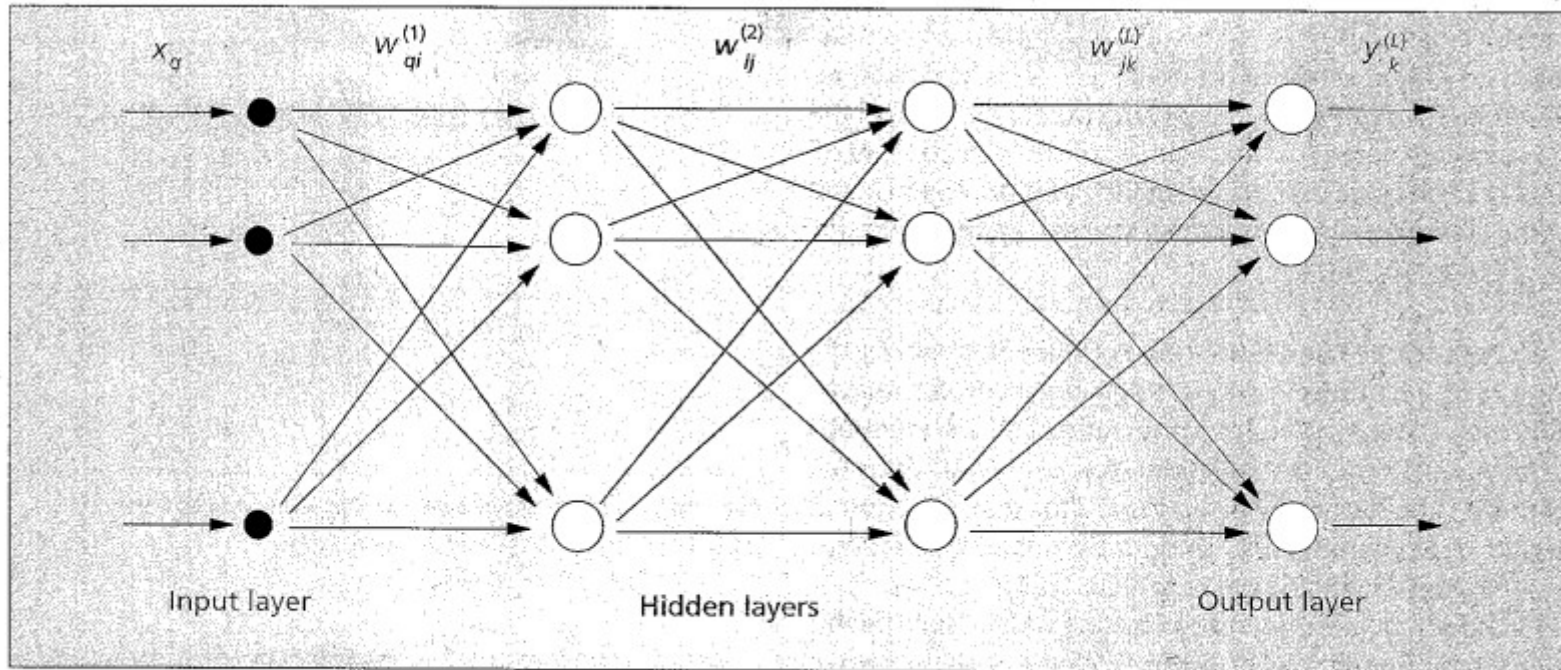


Figure 7. A typical three-layer feed-forward network architecture.

Jain, A.K., Mao, J. and Mohiuddin, K.M., 1996. Artificial neural networks: A tutorial. Computer, 29(3), pp.31-44.

# Artificial Intelligence Techniques Using Structured Health Records

## **Linking Health Records with Knowledge Sources**

Rules-based Reasoning

Bayesian Inference



# Clinical Coding



**SNOMED CT  
Browser**

UK SNOMED CT  
Clinical Edition  
NHS Data Migration  
April 2020

[Concept Search](#)

[About SNOMED-CT](#)

You have searched for: osteoporosis

[Go back to search results](#)

[Disorder of bone \(disorder\)](#)

**Name:** Osteoporosis (disorder) See more descriptions.

**Concept ID:** 64859006

**Read Codes:** N330. N3300 N330z NyuB1 NyuB2

**ICD-10 Codes:** M819 M818

- + [Disuse osteoporosis \(disorder\)](#)
- + [Drug-induced osteoporosis \(disorder\)](#)
- [Gorham's disease](#)
- + [Idiopathic osteoporosis \(disorder\)](#)
- [Osteoporosis co-occurrent and due to mu](#)
- [Osteoporosis due to cystic fibrosis](#)
- + [Osteoporosis due to malabsorption \(dis](#)
- [Osteoporosis in endocrine disorders](#)
- [Osteoporosis localised to spine](#)
- [Osteoporotic bone marrow defect](#)
- [Osteoporotic kyphosis \(disorder\)](#)
- + [Pathological fracture due to osteoporos](#)
- + [Postoophorectomy osteoporosis \(disord](#)
- + [Post-surgical malabsorption osteoporos](#)
- [Posttraumatic osteoporosis](#)
- + [Primary osteoporosis](#)

SNOMED CT consists of over a million medical Concepts.

For example 64859006 means Osteoporosis.

<http://www.snomedbrowser.com/>

# Ontology Model of Clinical Coding

```
<Declaration>
  <Class IRI="#CodingSystem:SNOMED"/>
</Declaration>
<Declaration>
  <NamedIndividual IRI="#Code:SNOMED:64859006"/>
</Declaration>
<ClassAssertion>
  <Class IRI="#CodingSystem:SNOMED"/>
  <NamedIndividual IRI="#Code:SNOMED:64859006"/>
</ClassAssertion>
<DataPropertyAssertion>
  <DataProperty IRI="#hasDisplayName"/>
  <NamedIndividual IRI="#Code:SNOMED:64859006"/>
  <Literal xml:lang="en-gb">Osteoporosis</Literal>
</DataPropertyAssertion>
<DataPropertyAssertion>
  <DataProperty IRI="#hasCode"/>
  <NamedIndividual IRI="#Code:SNOMED:64859006"/>
  <Literal>64859006</Literal>
</DataPropertyAssertion>
```

```
<Declaration>
  <Class IRI="#CodePoint"/>
</Declaration>
<Declaration>
  <NamedIndividual IRI="#CodePoint:BDMDData:64859006"/>
</Declaration>
<ClassAssertion>
  <Class IRI="#CodePoint"/>
  <NamedIndividual IRI="#CodePoint:BDMDData:64859006"/>
</ClassAssertion>
<DataPropertyAssertion>
  <DataProperty IRI="#hasCondition"/>
  <NamedIndividual IRI="#CodePoint:BDMDData:64859006"/>
  <Literal>BMDDData/TScore lt -2.5</Literal>
</DataPropertyAssertion>
<ObjectPropertyAssertion>
  <ObjectProperty IRI="#hasCode"/>
  <NamedIndividual IRI="#CodePoint:BDMDData:64859006"/>
  <NamedIndividual IRI="#Code:SNOMED:64859006"/>
</ObjectPropertyAssertion>
<ObjectPropertyAssertion>
  <ObjectProperty IRI="#hasCodePoint"/>
  <NamedIndividual IRI="#ISO-13606:Entry:BMDDData"/>
  <NamedIndividual IRI="#CodePoint:BDMDData:64859006"/>
</ObjectPropertyAssertion>
```

# Code Points – Spreadsheet Entry

Code Points can be created in the Information Model (using the spreadsheet)

The screenshot shows an OpenOffice Calc spreadsheet titled "cityEHR - Specialty - Feature Demo 163.ods". The spreadsheet contains a table with the following data:

Identifier	Code	Code System	Context	Conditions
BMIObese	414915002	SNOMED	- Entry: BMI	BMI/CalculatedBMI gt 30
BMIOverweight	238131007	SNOMED	- Entry: BMI	BMI/CalculatedBMI le 30 and BMI/CalculatedBMI gt 25
BMIHealthy	43664005	SNOMED	- Entry: BMI	BMI/CalculatedBMI le 25 and BMI/CalculatedBMI gt 18
BMI	301331008	SNOMED	- Entry: BMI	
BMIUnderweight	248342006	SNOMED	- Entry: BMI	BMI/CalculatedBMI le 18
Osteoporosis	64859006	SNOMED	- Entry: BMDData	BMDData/TScoreHip le -2.5
Osteopenia	312894000	SNOMED	- Entry: BMDData	BMDData/TScoreHip gt -2.5 and BMDData/TScoreHip le -1.0

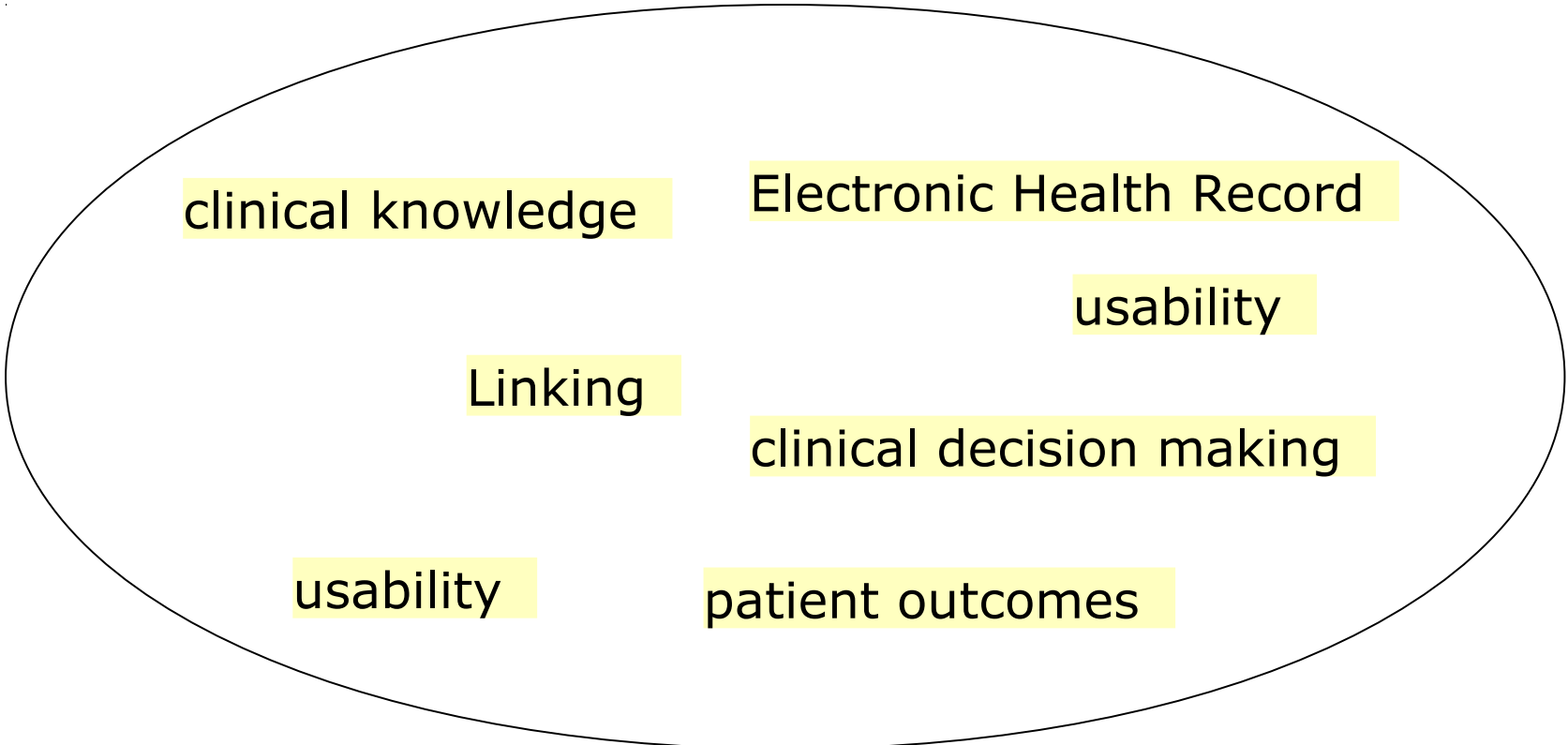
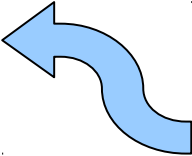
The spreadsheet interface includes a menu bar (File, Edit, View, Insert, Format, Tools, Data, Window, Help), a toolbar with various icons, and a status bar at the bottom showing "Sheet 18 / 18", "Default", "STD", "Sum=0", and "96 %".

# Linking Health Records with Knowledge Sources

Linking sources of clinical knowledge with the Electronic Health Record, is a relatively 'quick win' for improving the usability of the EHR and supporting clinical decision making, with associated benefits for clinical safety and patient outcomes.

# Linking Health Records with Knowledge Sources

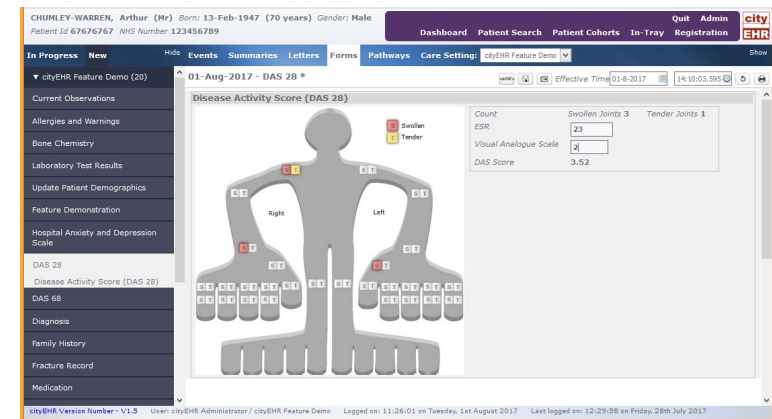
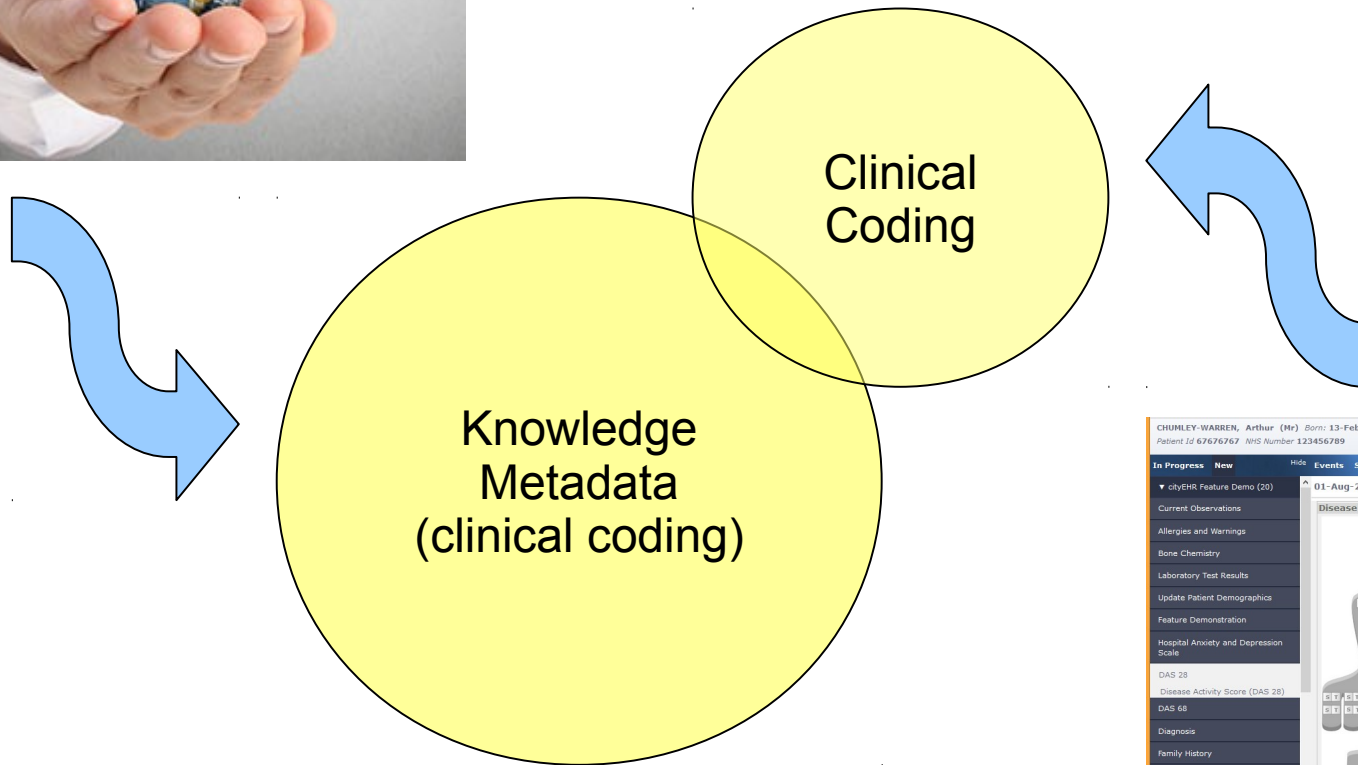
Linking sources of clinical knowledge with the Electronic Health Record, is a relatively 'quick win' for improving the usability of the EHR and supporting clinical decision making, with associated benefits for clinical safety and patient outcomes.



# World Of Knowledge



Knowledge available on the Internet – the Semantic Web.



Clinical Information in a structured health record.

# A World Of Knowledge

Here's some of the knowledge about osteoporosis, available on youtube



## 3011 - Osteoporosis / From Sickness to Health - Barbara O'Neill

Amazing Discoveries • 100K views • 1 year ago

In this lecture with Barbara O'Neill we will look at what causes the deterioration of our bones and learn what we can do to ...



## HOW TO REVERSE OSTEOPOROSIS IN 6 MONTHS - Increase bone density by Amitabh Pandit

Amitabh Pandit • 198K views • 3 years ago

This has been a long awaited video I personally wanted to upload. First I wanted to see the results myself whether these foods did ...



## 5 Signs of Osteoporosis

Cure Diseases Naturally • 3.5K views • 7 months ago

Hey Everyone, Aqila here.. In this video I will talk about "5 Signs of Osteoporosis" Knowing the early 5 Common Signs of ...

Subtitles



## Osteoporosis: Prevention and Treatment

Stanford Health Care • 10K views • 2 years ago

Over 50% of women and 25% of men over the age of 50 will sustain a fragility fracture due to osteoporosis. This talk addresses ...

# Resource Description Framework (RDF)

Resource Description Framework (RDF)

Part of the Semantic Web activity from the World Wide Web Consortium

Suppose that I find a video on youtube about the disorder Osteoporosis

Meta data about the video (i.e. a resource on the web) can be represented as 'triples' of **Subject** - **Predicate** - **Object**

Video disorder is Osteoporosis

Disorder in the Video is Osteoporosis

```
<rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
  xmlns:medicalTerms="http://medicalTerms.org/disorders"/>
  <rdf:Description rdf:about="https://www.youtube.com/embed/wAK1-2sOTaY">
    - <medicalTerms:Disorder>Osteoporosis</medicalTerms:Disorder>
  </rdf:Description>
</rdf:RDF>
```



# RDF Knowledge Map

```
<?xml version="1.0" encoding="UTF-8"?>
<rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
  xmlns:dc="http://purl.org/dc/elements/1.1/" dc:title="Knowledge Map">

  <rdf:Description rdf:about="http://pathways.nice.org.uk/pathways/osteoporosis">
    <dc:subject rdf:datatype="http://www.snomed.org">391068001</dc:subject>
    <dc:description rdf:datatype="http://www.snomed.org">
      Hip dual energy X-ray photon absorptiometry scan T score
    </dc:description>
  </rdf:Description>

  <rdf:Description rdf:about="http://pathways.nice.org.uk/pathways/osteoporosis">
    <dc:subject rdf:datatype="http://www.snomed.org">64859006</dc:subject>
    <dc:description rdf:datatype="http://www.snomed.org">Osteoporosis</dc:description>
  </rdf:Description>

  <rdf:Description rdf:about="http://pathways.nice.org.uk/pathways/osteoporosis">
    <dc:subject rdf:datatype="http://www.snomed.org">312894000</dc:subject>
    <dc:description rdf:datatype="http://www.snomed.org">Osteopenia</dc:description>
  </rdf:Description>

</rdf:RDF>
```

# Coding Knowledge Sources

cityEHR / ISO-13606-Folder-FeatureDemo - Administration - Code Knowledge Sources

Coding System:  Osteoporosis Causes

Code System	Clinical Code	Description	Knowledge Source (URL)
http://www.snomed.org	64859006	Osteoporosis	http://pathways.nice.org.uk/pathways/osteoporosis
http://www.snomed.org	312894000	Osteopenia	http://pathways.nice.org.uk/pathways/osteoporosis
http://www.snomed.org	391068001	Hip dual energy X-ray photon absorptiometry scan T score	http://pathways.nice.org.uk/pathways/osteoporosis
http://www.snomed.org	64859006	Osteoporosis Causes	https://www.youtube.com/embed/wAKI-2sOTaY

cityEHR Version Number - V1.7-2019-02-13-v1    User: cityEHR Administrator / No specialty loaded.    Logged on: 19:37:32 on Friday, 15th February 2019    Last logged on: 17:40:48 on Friday, 15th February 2019

# Addressable Knowledge can be Coded

<https://www.youtube.com/embed/wAKI-2sOTaY>



5 Signs of Osteoporosis

5 COMMON SIGNS OF OSTEOPOROSIS

Watch later Share

Embed Video

```
<iframe width="560" height="315" src="https://www.youtube.com/embed/wAKI-2sOTaY" frameborder="0" allow="accelerometer; autoplay; encrypted-media; gyroscope; picture-in-picture" allowfullscreen></iframe>
```


Start at 0:00


EMBED OPTIONS

Show player controls.




COPY

# Record Bone Mineral Density

COLLYMORE, Corey (Mr) Born: 13-Jan-1989 (30 years) Gender: Male  
 Patient Id 15437052 NHS Number 7237373 


Dashboard Patient Search Patient Cohorts In-Tray Registration 

In Progress New Hide Events Summaries Letters Forms Pathways Show

15-Feb-2019 - Bone Mineral Density \* Page load time: PT2.063S Highlight Entries -- None --   

**BMD Data**


Date of Scan  Age at scan 30 years


BMD Data 

	Scan date	Lumbar Spine	Femoral Neck	Total Hip	Comments
<input checked="" type="checkbox"/>	<input type="text" value="15-2-2019"/>	Lumbar Spine BMD <input type="text" value="0.696"/> t <input type="text" value="-3.2"/> z <input type="text" value="-1.7"/>	Femoral Neck BMD <input type="text" value="0.356"/> t <input type="text" value="-2.6"/> z <input type="text" value="1.1"/>	Total Hip BMD <input type="text" value="0.604"/> t <input type="text" value="-2.6"/> z <input type="text" value="-3.2"/>	<input type="text"/>

cityEHR Version Number - V1.7-2019-02-13-v1 User: cityEHR Administrator / cityEHR Feature Demo Logged on: 19:37:32 on Friday, 15th February 2019 Last logged on: 17:40:48 on Friday, 15th February 2019





# Knowledge Linked Using Clinical Codes


COLLYMORE, Corey (Mr) Born: 13-Jan-1989 (30 years) Gender: Male  
 Patient Id 15437052 NHS Number 7237373 

Dashboard Patient Search Patient Cohorts In-Tray Registration 

Show Events Summaries Letters Forms Pathways More Less Hide

15-Feb-2019 - Bone Mineral Density \* Page load time: FT2.0035

Highlight Entries -- None --    

**BMD Data**  
 Date of Scan: 15-2-2019 Age at scan: 30 years  
 BMD Data 

Scan date	Lumbar Spine	Femoral Neck	Total Hip	Comments
15-2-2019	Lumbar Spine BMD 0.696 T: -3.2 Z: -1.7	Femoral Neck BMD 0.356 T: -2.6 Z: 1.1	Total Hip BMD 0.604 T: -2.6 Z: -3.2	

**Knowledge Links:**

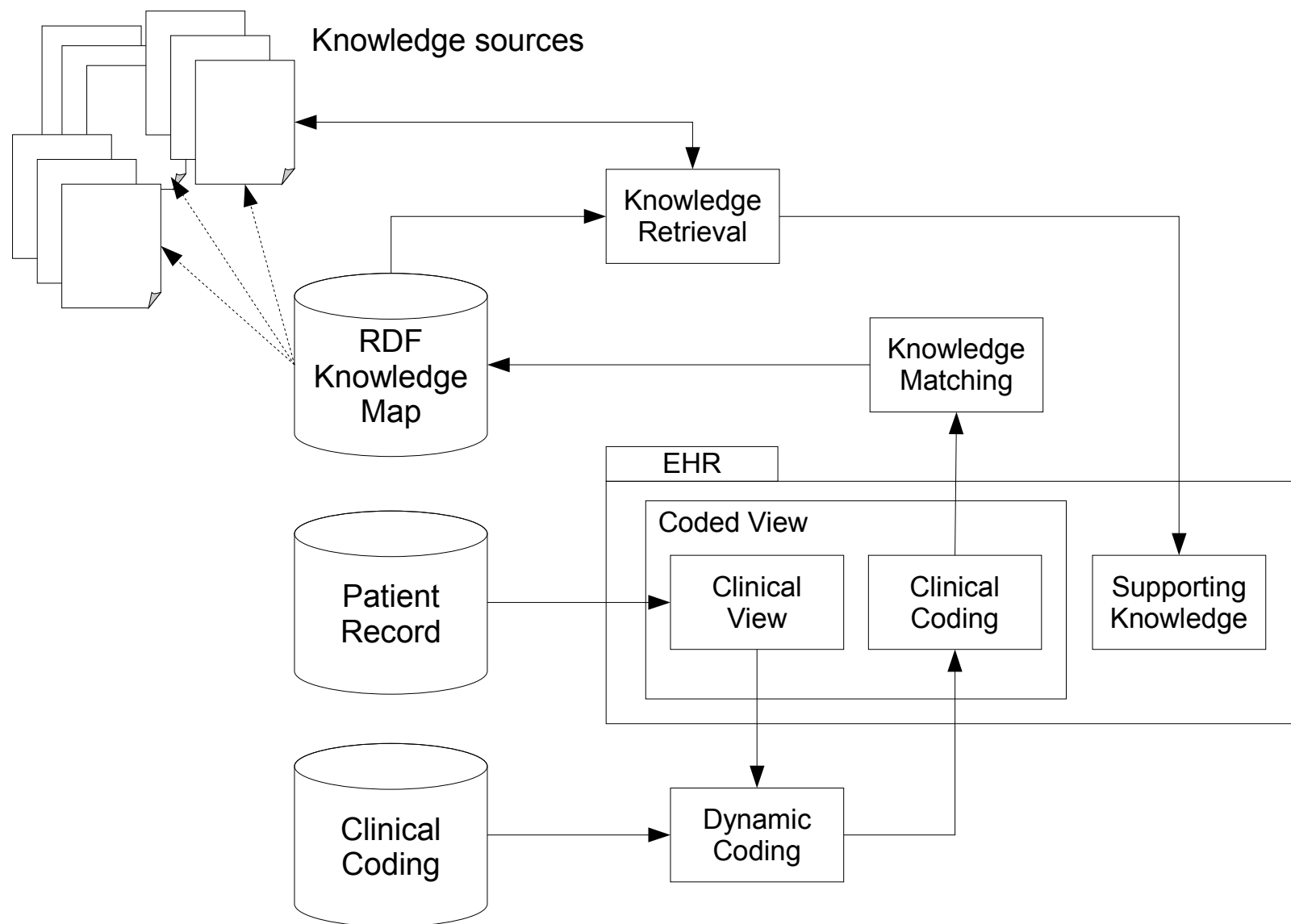
- Person aged 18 or over presenting in any healthcare setting
- Assessing the risk of fragility fracture
- See what NICE says on patient experience in adult NHS services
- Treating vertebral compression fractures
- Alternative secondary prevention treatments for postmenopausal women

**5 COMMON SIGNS OF OSTEOPOROSIS**

<https://www.youtube.com/embed/wAKI-2s0TbY>

cityEHR Version Number - V1.7-2019-02-13-v1 User: cityEHR Administrator / cityEHR Feature Demo Logged on: 19:37:32 on Friday, 15th February 2019 Last logged on: 17:40:48 on Friday, 15th February 2019

# Linking Health Records with Knowledge



# Artificial Intelligence Techniques Using Structured Health Records

Linking Health Records with Knowledge Sources  
**Rules-based Reasoning**  
Bayesian Inference

# Deduction

If a patient has a T-Score (measure of their bone mineral density) less than -2.5 then they have Osteoporosis.

Deduction is generally defined as "the deriving of a conclusion by reasoning". In deduction the truth of the conclusion is guaranteed by the truth of the statements or facts considered.

*Merriam-Webster Dictionary*



"You know my methods, Watson"

(Actually, Watson doesn't really know, since deduction isn't usually one of Sherlock Holmes' methods.)



# Syllogism

A syllogism is a deductive scheme of a formal argument consisting of a major and a minor premise and a conclusion

*Merriam-Webster Dictionary*

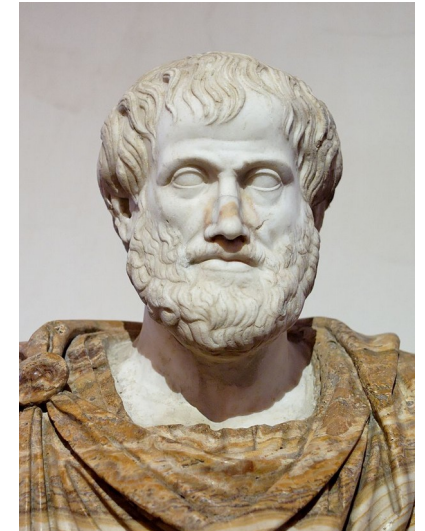
As introduced by the Greek philosopher, Aristotle

The major premise is a general statement of truth

The minor premise is a specific statement

A common term links the major and minor premises

The common term is eliminated in the conclusion



Deduction as a syllogism

Major premise: Osteoporosis is defined by a T-Score less than -2.5

Minor premise: Doris has a T-Score of -3

Conclusion: Doris has Osteoporosis

# Induction

A Fragility Fracture is any fall from a standing height or less, that results in a fracture. Our bodies should be able to sustain a fall from this height without a fracture unless there is an underlying cause that makes the bones fragile.

*University of Michigan, Fragility Fracture Clinic*

Bone is living tissue that is constantly being broken down and replaced. Osteoporosis occurs when the creation of new bone doesn't keep up with the loss of old bone. Osteoporosis causes bones to become weak and brittle.

*Mayo Clinic*

Major premise: Weak bones cause fragility fractures

Minor premise: Osteoporosis causes bones to become weak

Conclusion: Osteoporosis may cause a fragility fracture

Induction is a method of reasoning involving an element of probability. In logic, induction refers specifically to "inference of a generalized conclusion from particular instances." In other words, it means forming a generalization based on what is known or observed.

*Merriam-Webster Dictionary*

# Abduction

There is a *causal link* between Osteoporosis and fragility fractures; these types of fracture are caused by weakening of the bones. Osteoporosis weakens the bones.

But if a patient has Osteoporosis then they won't definitely suffer a fragility fracture.

And if a patient does suffer a fragility fracture, this may be caused by Osteoporosis, but there are other possible causes (bone cyst, cancer, Osteomyelitis, ...)

We can explain a fragility fracture by saying that the person may be suffering from Osteoporosis

Abduction provides an explanation for the fragility fracture – a hypothesis

We traverse the inductive rule in the opposite direction

Abduction is defined as "a syllogism in which the major premise is evident but the minor premise and therefore the conclusion only probable." *Merriam-Webster Dictionary*

Major premise: Doris has a fragility fracture

Minor premise: Osteoporosis may cause a fragility fracture

Conclusion: Doris may have Osteoporosis

# Chain of Reasoning

Major premise: Osteoporosis is defined by a T-Score less than -2.5

Minor premise: Doris has a T-Score of -3

Conclusion: Doris has Osteoporosis

Major premise: Weak bones cause fragility fractures

Minor premise: Osteoporosis causes bones to become weak

Conclusion: Osteoporosis may cause a fragility fracture

Major premise: Doris has Osteoporosis

Minor premise: Osteoporosis may cause a fragility fracture

Conclusion: Doris may suffer a fragility fracture

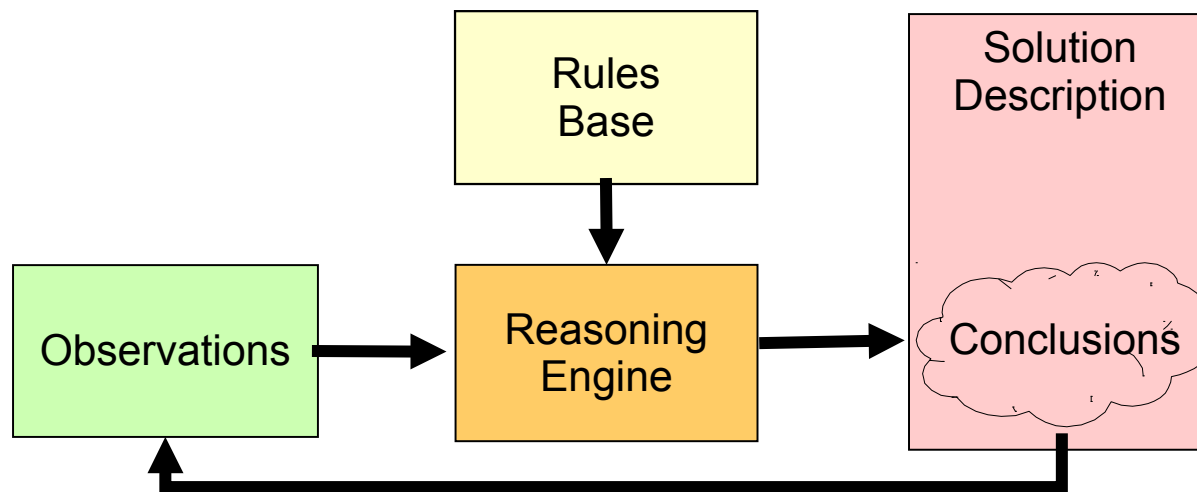
Major premise: Alendronate reduces the risk of suffering a fragility fracture

Minor premise: Doris may suffer a fragility fracture

Conclusion: Doris should be prescribed Alendronate

# Production Systems

Rules-based production systems as described by Davis and King in 1975.



IF T-Score < -2.5 THEN  
Osteoporosis

IF Osteoporosis THEN  
risk of fragility fracture

Forward-chaining system

The Reasoning Engine matches observations with the Left Hand Side of the rules, to make new assertions (Induction)

Backward-chaining system

The Reasoning Engine matches observations with the Right Hand Side of the rules, to make new hypotheses (Abduction)

# Ontology-based Rules

```
<DataPropertyAssertion>
  <DataProperty IRI="#hasCalculatedValue"/>
  <NamedIndividual IRI="#ISO-13606:Element:CalculatedBMI"/>
  <Literal>
    Round-half-to-even(
      10000*BMI/WeightInKg div (BMI/HeightInCm * BMI/HeightInCm)
      ,2)
  </Literal>
</DataPropertyAssertion>
```

```
<DataPropertyAssertion>
  <DataProperty IRI="#hasCalculatedValue"/>
  <NamedIndividual IRI="#ISO-13606:Element:BMIRange"/>
  <Literal>
    if (BMI/CalculatedBMI lt 18.5) then 'Underweight'
    else if (BMI/CalculatedBMI ge 18.5 and BMI/CalculatedBMI lt 25)
      then 'Healthy'
    else if (BMI/CalculatedBMI ge 25 and BMI/CalculatedBMI lt 30)
      then 'Overweight'
    else 'Obese'
  </Literal>
</DataPropertyAssertion>
```

# Using X-Forms as a Rules-Based Inference Engine

The screenshot displays the cityEHR patient record for Michael JEEVES (Mr), born 10-Jun-1981 (38 years), Male. The patient's ID is K8928573 and NHS Number is 7563628274. The interface includes a navigation menu with options like Dashboard, Patient Search, and Registration. The main content area shows a summary for '25-Sep-2019 - Body Mass Index' with a page load time of PT2.047S. A table lists three BMI measurements:

	Measurement date	Height (cm)	Weight (kg)	BMI (kg/m <sup>2</sup> )	Interpretation
X	09-May-205	173	70	23.39	Healthy
X	08-May-205	173	80	26.73	Overweight
X	17-Apr-205	173	90	30.07	Obese

Summary statistics for Height and Weight are provided below the table:

Height	Minimum 173 (cm)	Maximum 173 (cm)	Average 173 (cm)
Weight	Minimum 70 (kg)	Maximum 90 (kg)	Average 80 (kg)

The footer of the page shows the cityEHR Version Number - V1.7-2019-08-28, User: cityEHR Administrator / cityEHR Feature Demo, and login information for Wednesday, 25th September 2019 and Thursday, 19th September 2019.

# Artificial Intelligence Techniques Using Structured Health Records

Linking Health Records with Knowledge Sources  
Rules-based Reasoning  
**Bayesian Inference**



# Diseases and Symptoms

A patient suffering a particular disease may display certain signs or symptoms of that disease.



For a specific observation,  $o$  and disease  $d$  it is quite easy to measure:

**These observations are modelled in**

– the probability of  $o$  in the general population,  $P(o)$

**ISO-15606 as an Entry.**

– the probability of  $o$  for a patient with disease  $d$ ,  $P(o|d)$

– and the probability of  $d$  in the general population  $P(d)$

# Bayes' Theorem

For diagnosis, we are interested in deducing the disease, given a set of observations for a patient,  $P(d|o)$ , which is not so easy to measure.

$$P(d|o) = \frac{P(d).P(o|d)}{P(o)}$$

So if one in a hundred people are currently testing positive for Covid-19

And half of people diagnosed with Covid have a persistent cough

And 5% of people generally have a persistent cough at the moment

Then the probability that someone with a persistent cough has Covid is

$$P(d|o) = (0.01 * 0.5) / 0.05 = 0.1$$

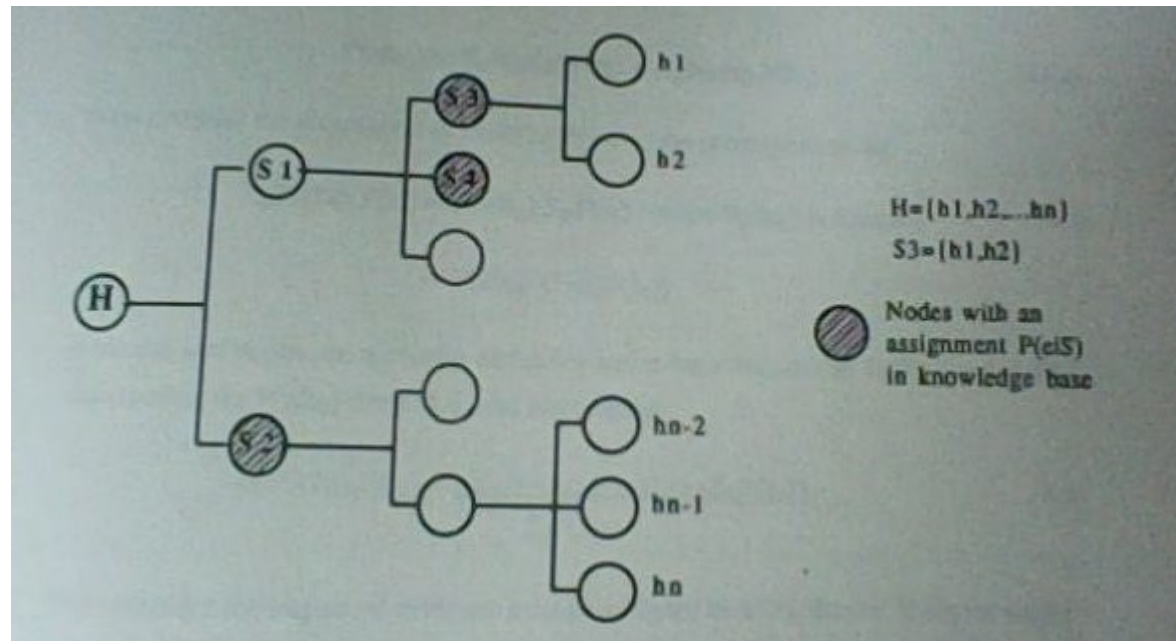
LII. *An Essay towards solving a Problem in the Doctrine of Chances. By the late Rev. Mr. Bayes, F. R. S. communicated by Mr. Price, in a Letter to John Canton, A. M. F. R. S.*

Dear Sir,

Read Dec. 23, 1763. **I** Now send you an essay which I have found among the papers of our deceased friend Mr. Bayes, and which, in my opinion, has great merit, and well deserves to be preserved. Experimental philosophy, you will find, is nearly interested in the subject of it; and on this account there seems to be particular reason for thinking that a communication of it to the Royal Society cannot be improper.

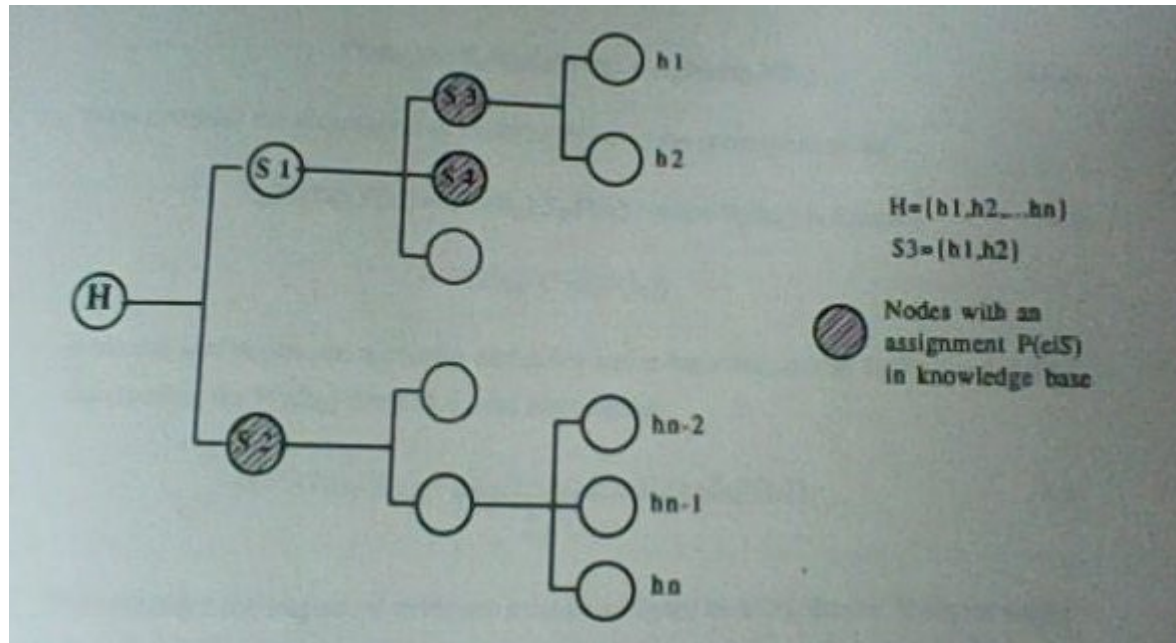
# Bayesian Belief Network

Hypotheses organised as a hierarchy, in which the root node describes the class of diagnoses and the leaf nodes form a mutually exclusive and exhaustive set of hypotheses,  $H$ , for that class.



The apriori probabilities of each hypothesis sum to 1.

# Bayesian Belief Network



Observations provide evidence for each node in the hierarchy and we can assign the apriori probabilities of each hypothesis  $h$ , given evidence  $e$ .

So  $P(h|e)$

As each new observation is made, a method described by Judea Pearl (1986) allows the belief in each node of the hierarchy to be updated using the prior probabilities (and Bayes' Theorem).

# Assign Prior Probabilities of Disease

Create classifications of disease

And Observation sets which define characteristics of the disease

Assign apriori probabilities to each disease class, observation and observation|class

Can then use Bayes' theorem to suggest diseases, given a set of observations

The image shows a screenshot of a medical classification tree on the left and a list of observations for a specific disease on the right. The tree is a hierarchical list of diseases with expandable/collapsible icons. The right side shows a list of clinical observations for 'Rheumatoid arthritis - seropositive' with a 'yes / no / not known' response format.

**Auto immune disease**

- + Connective Tissue Disease
  - Rheumatoid arthritis
    - Rheumatoid arthritis NOS
    - Rheumatoid arthritis - seronegative
    - Rheumatoid arthritis - seropositive
  - Inflammatory arthritis
    - + Crystal arthritis
    - Post viral arthritis
    - Reactive arthritis
      - Reactive arthritis NOS
      - + Reactive arthritis - post-dysenteric
      - + Reactive arthritis - post-genitourinary infection
      - Reactive arthritis - post-streptococcal
    - Rheumatoid arthritis
      - Rheumatoid arthritis NOS
      - Rheumatoid arthritis - seronegative
      - Rheumatoid arthritis - seropositive**
  - + Spondyloarthropathy

**Rheumatoid arthritis - seropositive**  
SNOMED: 239791005  
ICD-10: M05.9  
RA core data

Rheumatoid factor positive	yes / no / not known
ANA positive	yes / no / not known
Nodule	yes / no / not known
Vasculitis	yes / no / not known
Lung involvement	yes / no / not known
Inflammatory eye disease	yes / no / not known
Dry eyes / mouth	yes / no / not known
Felty's syndrome	yes / no / not known
ACPA	yes / no / not known
Smoker	yes / no / not known
Erosions	yes / no / not known
Family H of RA	yes / no / not known
Palindromic onset	yes / no / not known

# Suggest Diagnosis, Based on Evidence

The screenshot shows a software interface for medical diagnosis. It is divided into two main sections: "Diagnosis" and "Comorbidities".

**Diagnosis Section:**

- Header: "Diagnosis" with a green plus icon.
- Left side: A list of suggested diagnoses. One entry is "Rheumatoid arthritis NOS" with "CDS" next to it. A red 'X' icon is visible to the left of this entry.
- Right side: A list of evidence points, each followed by "yes":
  - Rheumatoid factor positive
  - Inflammatory eye disease
  - Dry eyes / mouth

**Comorbidities Section:**

- Header: "Comorbidities" with a green plus icon.
- Left side: A list of suggested comorbidities. One entry is "Chronic Liver Disease" with "CDS" next to it. A red 'X' icon is visible to the left of this entry.

As evidence is entered, suggestion(s) of the most likely diagnosis can be made, based on all relevant observations recorded to date.



John Chelsom  
Seven Informatics  
[john.chelsom@seveninformatics.com](mailto:john.chelsom@seveninformatics.com)



**FORDHAM UNIVERSITY**

THE JESUIT UNIVERSITY OF NEW YORK



12<sup>th</sup> – 17<sup>th</sup> September 2021  
[xmlsummerschool.com](http://xmlsummerschool.com)



summer school

# References

## Structured Health Records

Beale, T., 2002, November. Archetypes: Constraint-based domain models for future-proof information systems. In OOPSLA 2002 workshop on behavioural semantics (Vol. 105, pp. 1-69).

Camp, C.L., Smoot, R.L., Kolettis, T.N., Groenewald, C.B., Greenlee, S.M. and Farley, D.R., 2008, December. Patient records at Mayo Clinic: lessons learned from the first 100 patients in Dr Henry S. Plummer's dossier model. In Mayo Clinic Proceedings (Vol. 83, No. 12, pp. 1396-1399). Elsevier.

Chelsom, J.J., Summers, R., Pande, I. and Gaywood, I., 2011, June. Ontology-driven development of a clinical research information system. In 2011 24th International Symposium on Computer-Based Medical Systems (CBMS) (pp. 1-4). IEEE.

Dolin, R.H., Alschuler, L., Boyer, S., Beebe, C., Behlen, F.M., Biron, P.V. and Shabo, A., 2006. HL7 clinical document architecture, release 2. Journal of the American Medical Informatics Association, 13(1), pp.30-39.

ISO 13606-1:2008 Health informatics - Electronic health record communication - Part 1: Reference model. [http://www.iso.org/iso/iso\\_catalogue/catalogue\\_tc/catalogue\\_detail.htm?csnumber=40784](http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=40784)

Mayne, J.G., Weksel, W. and Sholtz, P.N., 1968, January. Toward automating the medical history. In Mayo Clinic Proceedings (Vol. 43, No. 1, p. 1).



# References

## Knowledge and Reasoning

Ackoff, R.L., 1989. From data to wisdom. *Journal of applied systems analysis*, 16(1), pp.3-9.

Berners-Lee, T., Hendler, J. and Lassila, O., 2001. The semantic web. *Scientific American*, 284(5), pp.34-43.

Chomsky, N., 1956. Three models for the description of language. *IRE Transactions on information theory*, 2(3), pp.113-124.

Gruber, T.R., 1993. A translation approach to portable ontology specifications. *Knowledge acquisition*, 5(2), pp.199-220.

McCulloch, W.S. and Pitts, W., 1943. A logical calculus of the ideas immanent in nervous activity. *The bulletin of mathematical biophysics*, 5(4), pp.115-133.

Rosenblatt, F., 1958. The perceptron: a probabilistic model for information storage and organization in the brain. *Psychological review*, 65(6), p.386.

Shannon, C.E., 1948. A mathematical theory of communication. *The Bell System Technical Journal*, 27(3), pp.379-423.

W3C Owl Working Group. 2012. OWL 2 Web Ontology Language. Document Overview (Second Edition) W3C Recommendation 11 December 2012.

# References

## Artificial Intelligence

- Chelsom, J.J., Ellis, T.J., Carson, E.R. and Cramp, D.G., 1988, November. Blood gas analysis: a knowledge-based adviser for the interpretation of results. In Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society (pp. 1360-1361). IEEE.
- Jain, A.K., Mao, J. and Mohiuddin, K.M., 1996. Artificial neural networks: A tutorial. *Computer*, 29(3), pp.31-44.
- McCarthy, J., Minsky, M.L., Rochester, N. and Shannon, C.E., 2006. A proposal for the dartmouth summer research project on artificial intelligence, august 31, 1955. *AI magazine*, 27(4), pp.12-12.
- McCarthy, J., 1960. Recursive functions of symbolic expressions and their computation by machine, Part I. *Communications of the ACM*, 3(4), pp.184-195.
- McCarthy, J., 1989. Artificial intelligence, logic and formalizing common sense. In *Philosophical logic and artificial intelligence* (pp. 161-190). Springer, Dordrecht.
- Shortliffe, E.H., 1974. MYCIN: a rule-based computer program for advising physicians regarding antimicrobial therapy selection. STANFORD UNIV CALIF DEPT OF COMPUTER SCIENCE. Available from: <http://people.dbmi.columbia.edu/~ehs7001/Shortliffe-1976/MYCIN%20thesis%20Book.htm>
- Turing, A.M., 1950. Computing machinery and intelligence. *Mind*, 59(236), pp.433-460.
- Werbos, P.J., 1990. Backpropagation through time: what it does and how to do it. *Proceedings of the IEEE*, 78(10), pp.1550-1560.

# References

## **Artificial Intelligence Techniques Using Structured Health Records**

Bayes, T., 1763. LII. An essay towards solving a problem in the doctrine of chances. By the late Rev. Mr. Bayes, FRS communicated by Mr. Price, in a letter to John Canton, AMFR S. Philosophical transactions of the Royal Society of London, (53), pp.370-418.

Buchanan, B.G. and Shortliffe, E.H., 1984. Rule-based expert systems: the MYCIN experiments of the Stanford Heuristic Programming Project.

Davis, R. and King, J., 1975. An overview of production systems. Stanford Univ Ca Dept of Computer Science.

Lassila, O. and Swick, R.R., 1998. Resource description framework (RDF) model and syntax specification.

Pearl, J., 1986. Fusion, propagation, and structuring in belief networks. Artificial intelligence, 29(3), pp.241-288.

Post, E.L., 1943. Formal Reductions of the General Combinatorial Decision Problem. American Journal of Mathematics, 65(2), pp.197-215.