Chapter 1

Brain Style Computing: Origins and Issues

Neural Networks: A Classroom Approach
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Traces of History…

- Evolution of thought on the structure and function of the human brain has a history that spans almost 5,000 years.
- Theories of mind and brain have evolved with imprints of cultures and religious dogmas of each age.
- Today, we stand at the threshold of discovering how the human brain works…

Column IV of the Edwin Smith Surgical Papyrus script that dates to 1700 BC

Plato and Aristotle: Correlating Structure with Function

- Plato (427–347 BC)
- Rejected experiment and observation.
- Believed that true knowledge came only from pure reasoning and thought: empirical evidence adulterated true knowledge.
- Hypothesized that the brain was the seat of the soul and the center of all control.

- Aristotle (384–322 BC)
- Believed that the heart was the seat of sensation and intellect.
- Ascribed to the brain the task of merely cooling blood from the heart.
- Cooling capacity provided the basis for rational behaviour in humans.
- Questioned the value of speculation based on pure reason, and invented the scientific method of observation.

Epicureanism

- Psychological observations were a manifestation of the different structures of soul atoms.
- Consciousness was a natural outcome of their interaction.

Hippocrates (460–379 BC)

- Conducted anatomical studies
- Suggested " . . . that from the brain only, arise our pleasures, joys, laughter and jests, as well as our sorrows, pains, griefs and tears. Through it we think, see, hear . . . ."
- *De natura hominis* of the *Corpus Hippocraticum* proposed a scheme of correlations between four body fluids or *humours*, and character traits.
- "Humouralism" emphasized the dependence between mental states and bodily conditions.
- The brain was the seat of all intelligence.

The Poverty Of Anatomical Knowledge In Antiquity

- Epicureanism was suppressed.
- Platonic and Aristotelian theories of mind and brain were woven in with religious dogma.
- Evolved into an untenable "cognitive water-works" theory.
- Reconciled the brain-centred and heart-centred views of the mind.

From Galen (AD 130–200)

- Embraced the Hippocratic school of thought.
- Divided the brain into two major parts. He associated the cerebrum with sensations and cerebellum with control.
- Proposed that the action of the mind proceeds through a series of operations from sensation to memory, involving the movements of "humours" to or from the brain via the ventricles.

Vesalius (1514–1564)

- Galen's ventricular localization scheme persisted in written accounts and illustrations for about 1500 years.
- Some detail was added to the structure of the brain by Vesalius who is attributed with the rebirth of anatomy.
- These ideas were strengthened when French inventors hydraulically controlled mechanical automata during the Seventeenth century.

The Renaissance: Leonardo da Vinci

- Wrote, "…science comes by observation [and] not by authority…"
- Defied the Church by performing dissections in order to understand in more detail the nature of the body.
- Anatomical studies brought him into conflict with the Church.
- Was compelled to leave Rome in 1515.

Rene Descartes (1596-1650)

- French mathematician and philosopher.
- Defined animal as machine.
- Initiated the modern era of cybernetics.
- Distinguished between mind and body.
- Made explicit the principle of metaphysical dualism.
- Proposed that the bodily functions of the brain are entirely distinct from the domain of the soul: "*Cogito ergo sum*"—I think, therefore I am.

A Major Paradigm Shift

- 1748: La Mettrie's publication of *L'Homme Machine* suggested the possibility of building a mechanical man as a manifestation of an automaton.
- 1751: publication of *Experiments and Observations on Electricity* by Benjamin Franklin ushered in a new way to think about electrical phenomena.
- A major advance: Italian scientist Luigi Galvani's experiments on muscles and nerve stimulation.
- The fluid-mechanical metaphor was gradually replaced by the nerve-as-wire metaphor.

Advances During the 1800s

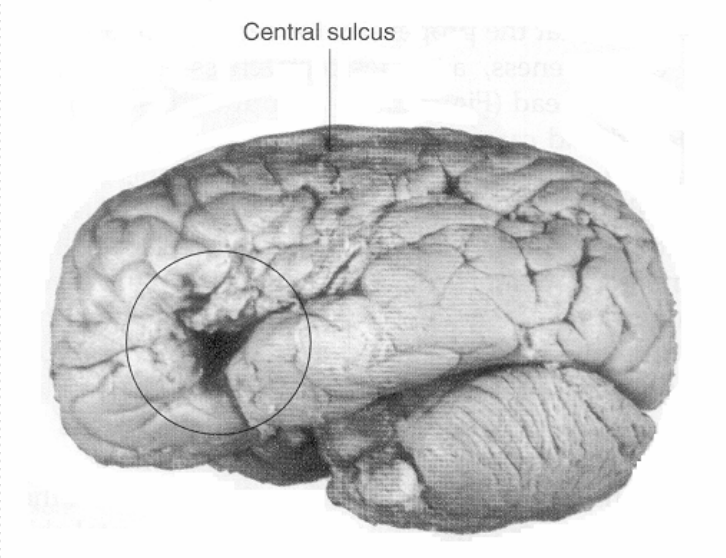
- 1810
  - Scottish physician Charles Bell and French physiologist Francois Magendie established strict one-way transmission along nerve fibres.
- 1823
  - French physiologist Marie-Jean-Pierre Flourens used the method of experimental ablation to establish a link between the cerebellum and coordination of movement, and the cerebrum and sensations.
- The pseudo-science of phrenology (Franz Joseph Gall, 1809) correlated the structure of the skull with personality traits, and died its natural death as scientific evidence on the brain accumulated over the years.

Advances During the 1800s

- 1848
  - Head injury of Phineas Gage and his accompanying personality change, created a radical change in man's understanding of the human brain.
- Neurologists observed the symptoms of human patients who suffered restricted damage to parts of the cerebral hemispheres.
- Suggested that the control of movement, sensations and speech were strictly **localized** within the brain.

Localization of Function (1)

- The study of *aphasia* led to significant advances in the theory of localization of function.
- In 1861 the French neurologist Pierre Paul Broca described the case of a patient who could understand language but who had lost the ability to speak.
- Post mortem examination revealed a lesion in the posterior portion of the frontal lobe of the brain, now called **Broca's area**.



The brain of Broca's patient showing the lesion in the posterior portion of the frontal lobe

Localization of Function (2)

- 1870
  - German physiologists Gustav Theodore Fritsch and Eduard Hitzig discovered that electrical stimulation of the *pre-central gyrus* in front of the *central sulcus* caused movements of the limbs in dogs.
  - Removal of the same region caused paralysis.
- 1876
  - Karl Wernicke discovered **Wernicke's aphasia**: speech is fluent, but does not make any sense.
  - Revealed a lesion in an area now referred to as Wernicke's area.
  - Suggested that fundamental mental functions are discretely localized.
  - Also suggested the philosophy of parallel distributed processing which forms the basis of modern neural networks.

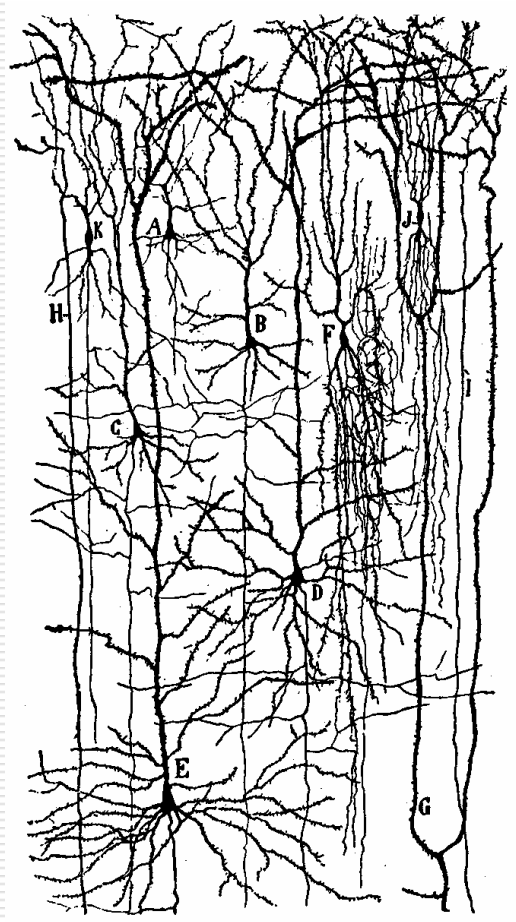
The Final Confirmation

- Towards the middle of the Twentieth century, Canadian neurosurgeon Wilder Penfield stimulated the cortex of conscious patients during brain surgery for epilepsy carried out under local anaesthesia.
- Tiny electrical stimulations at specific sites elicited diverse experiences: memories, smells, sounds and colours.
- Confirmed the theory of localization.
- Penfield mapped functions topographically on to specific cortical areas.

Father of Modern Brain Science : Ramón y Cajal

Cajal called neurons

"…the mysterious butterflies of the soul, the beating of whose wings may some day…clarify the secret of mental life."



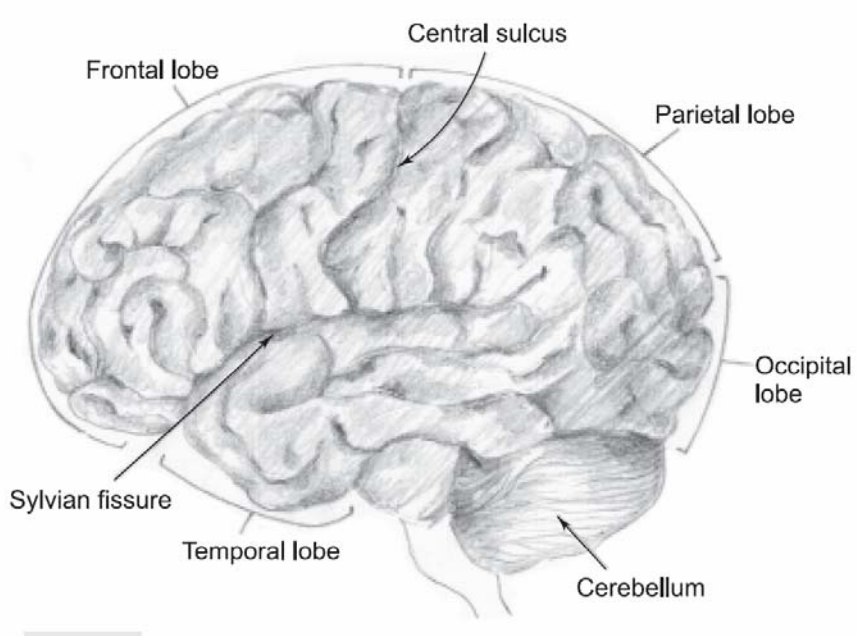
Modern Neuroscience: The Neuron Doctrine

- Camillo Golgi developed the histological silver impregnation method which allowed visualization of the neuron with all its processes.
- Santiago Ramon y Cajal suggested that the nervous system is made up of discrete signalling elements called neurons.
- Golgi and Cajal shared the sixth Nobel Prize for medicine in 1906.
- Physiological studies of Charles Sherrington on reflex behaviour led to an understanding of the inhibitory and excitatory nature of synapses.

Inspiration for Artificial Intelligence

AI has been inspired by two fundamental questions:

- How does the human brain work?
- How can we exploit the brain metaphor to build intelligent machines?



The Gift of Nature…

- Evolution has endowed the human brain with **phenomenological properties** not present in von Neumann or parallel computers.

Phenomenological Properties of the Human Brain

- massive parallelism
- distributed representation and computation
- the ability to self-organize
- the ability to generalize based on existing knowledge
- associative memory recall
- fault tolerance
- graceful degradation
- endurance of memories
- fast retrieval and quick alternation between concepts
- low energy consumption and very high capacity

On the Road to Artificial Intelligence: 1943

- McCulloch and Pitts published the first formal mathematical model of a neuron.
- One can say that the McCulloch-Pitts model represents the first neural network.
- Cybernetics pioneer Norbert Weiner's group suggested that feedback systems could provide the basis for explanation of the working of the brain.
- Craik contended that a basic feature of human thought is the formation of internal models which parallel the real world.

On the Road to Artificial Intelligence: 1949-1958

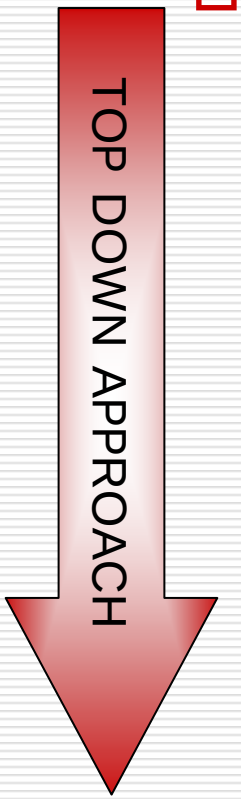
- 1949: Hebb published *The Organization of Behaviour*
  - Offered the first formal learning scheme.
  - Dealt with ways in which synapses can change their efficacies.
  - **Hebbian learning underlies diverse neural network learning schemes.**
- 1950: The Turing Test
  - A computer could be considered intelligent if a human communicating by teletype failed to distinguish the machine from a human being, on the basis of their response to arbitrary questioning.
- 1954: Ross Ashby published *The Design for a Brain*.

Artificial Intelligence

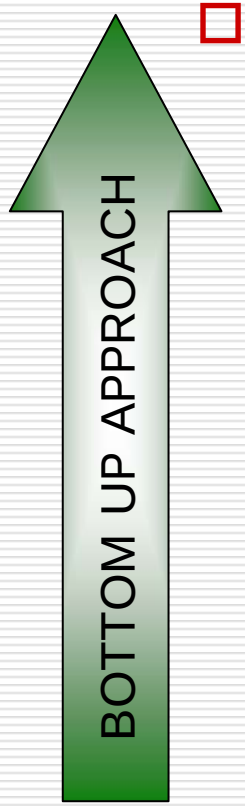
- 1956: Dartmouth College Conference the phrase "Artificial Intelligence" (AI) was coined.
- Stressed the importance of symbolic logic in the development of "intelligent" computer programs.

- 1958: Rosenblatt's *Perceptron* model
  - Demonstrated pattern recognition machine that could *learn.*
  - Proof of convergence of the Perceptron learning scheme.
  - Capability to classify linearly separable pattern classes.

Top Down vs Bottom Up



- Symbolic approach was born on the premise that "intelligence" in computational systems was achievable in its entirety through manipulation of symbolic language structures.



- Neural network approach: based on networks of relatively simple computing units whose prime design was motivated by the structure and working of neurons of the brain.

Symbolic AI Goes Ahead

- 1959 Newell-Simon-Shaw "General Problem Solver" (GPS)
- Minsky's 1961 review article "Steps Towards Artificial Intelligence"
  - set symbolic AI apart from neural networks and cybernetics, as a field in its own right.

Influential Criticism…1969

- Minsky and Papert's 1969 publication of *Perceptrons: An Essay in Computational Geometry*
  - pushed neural network research into the background and cleared the way for the serial symbolic AI paradigm.
- Praised its features—"its linearity, its intriguing learning theorem, its clear paradigmatic simplicity as a kind of parallel implementation".
- With devastating criticism— "There is no reason to suppose that any of these virtues carry over to the many-layered version. Nevertheless we consider it an important research problem to elucidate (or reject) our intuitive judgment that the extension to the multilayer case is sterile."

The Dark Age: 1970-1982

- For more than fifteen years after that, neural networks research receded to the background.
- A few persistent groups (or "stubborn souls" as Margaret Boden puts it):
  - Steve Grossberg (Boston)
  - Teuvo Kohonen (Helsinki)
  - Shun Amari (Tokyo)
  - MIT PDP Group

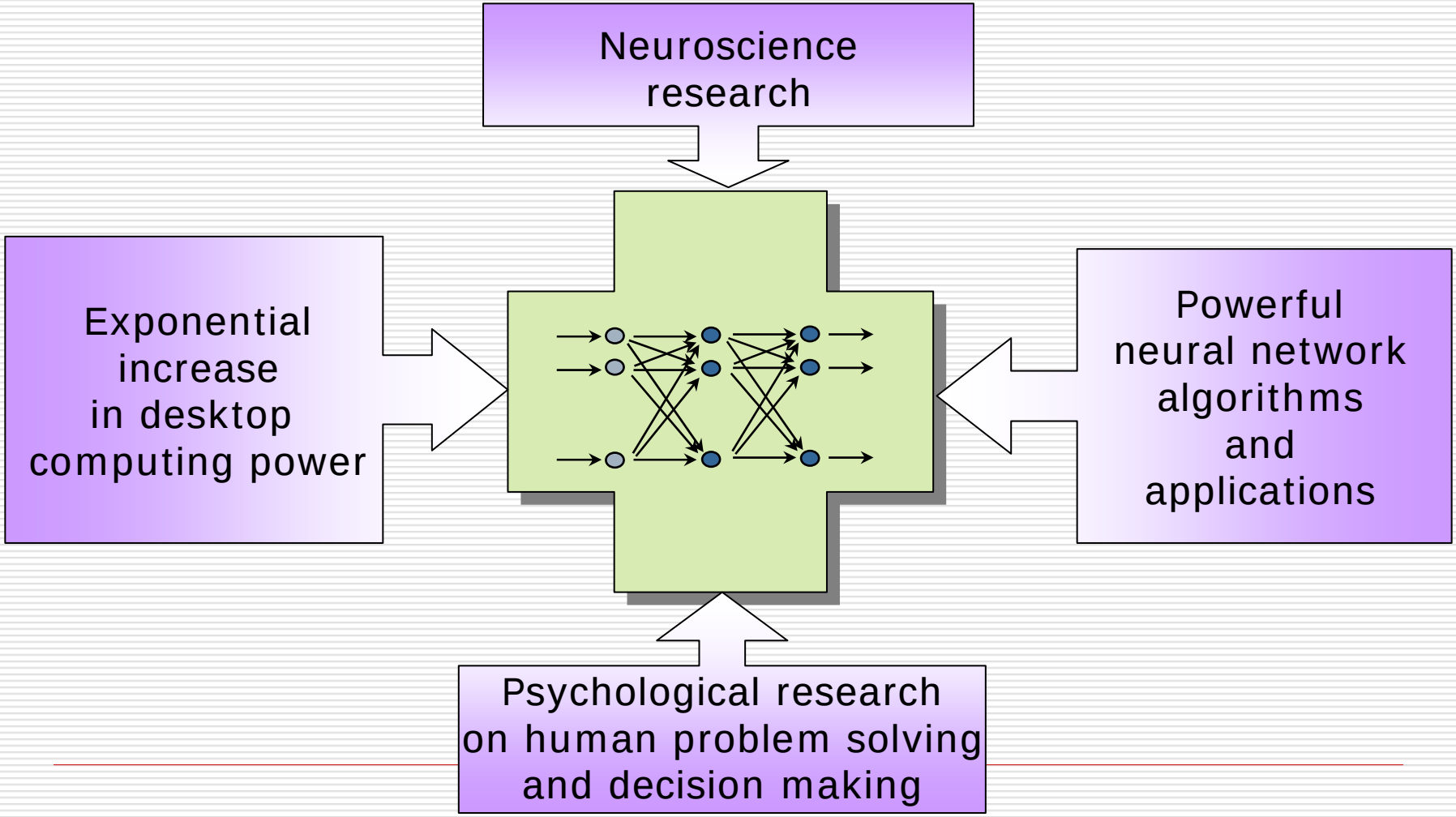
Revival and Rebirth: 1982-
A Salient Metaphor

- Popularized by Nobel Laureate John Hopfield of Caltech.
- 1982 publication interpreted the dynamics of complex neural networks in terms of an energy landscape metaphor.
- Hopfield neural network formalism based on Ising spin glass models.
- Showed that recurrent neural network architectures possess interesting dynamics and can be applied to solve complex optimization problems and implement associative memory.

Rediscovery of Backpropagation

- 1986 MIT PDP Groups' seminal volumes on *Parallel Distributed Processing*
- Re-discovered the backpropagation learning algorithm
- Most popular neural network algorithm
- Hundreds of spinoff applications
- Quick resurgence of interest in neural computing.

Other Factors that Promoted Interest



The Brain Metaphor Spawns Numerous Domains of Research

Biological Control Theory	Control theoretic techniques such as linear approximation, feedback, and stability are applied to the analysis of diverse physiological systems.
Computational Neuroscience	Micro-electrode *in vitro* studies, advanced imaging, pharmacological and other experimental techniques with mathematical modelling to perform advanced computer simulations of biological neurons and their networks.
Artificial Intelligence	A branch of computer science that has evolved to study the techniques of construction of computer programs capable of displaying intelligent behaviour.

The Brain Metaphor Spawns Numerous Domains of Research

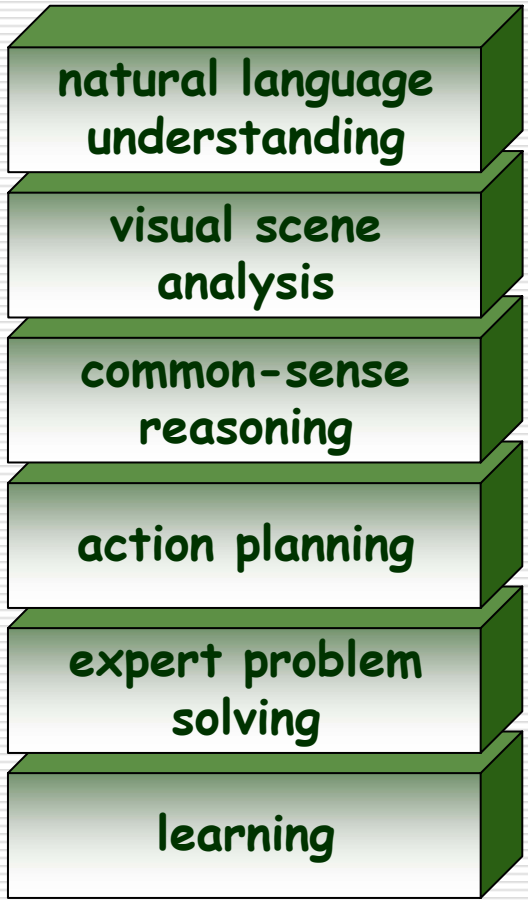
Cognitive Psychology	Explains human perception and problem solving with the help of information processing constructs.
Brain Theory	Adopts an approach to the study of the brain based on computational neuroscience, seeking to bridge the gap between behavioural function and neurobiological structure.
Neural Networks	Studies the collective behaviour of structured ensembles of simple computational units (artificial neurons), applied to solving difficult problems such as function approximation, control, pattern recognition and optimization.

Defining AI

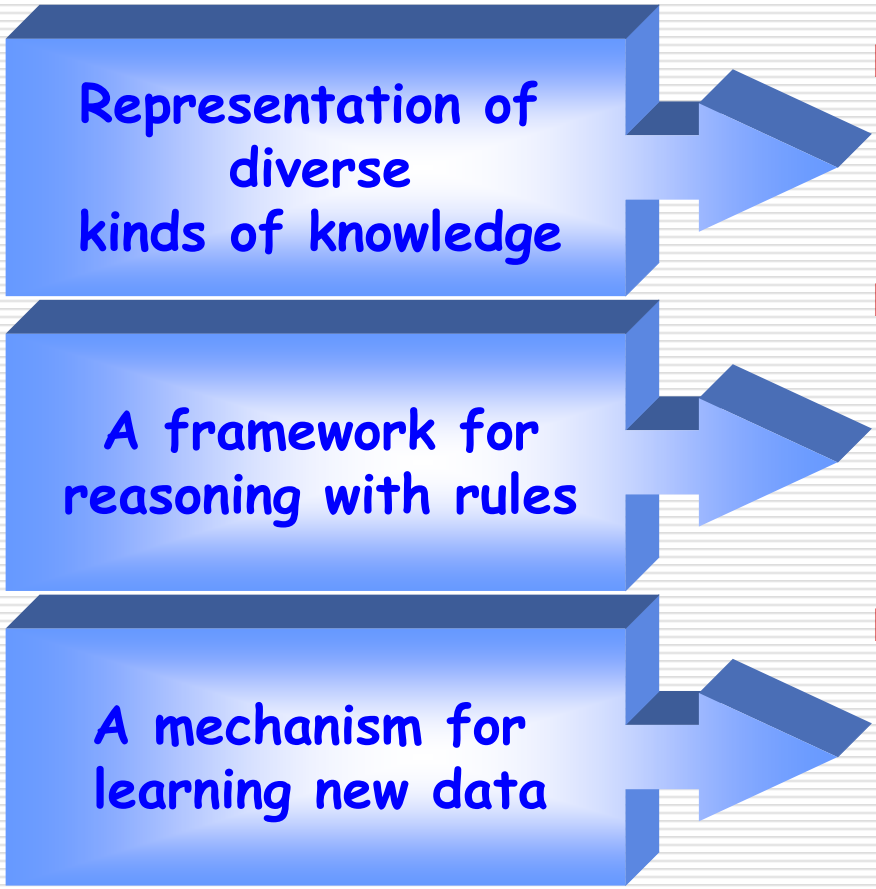
- "We call a program for a computer artificially intelligent if it does something which, when done by a human being, will be thought to require human intelligence."
- "Artificial intelligence is the study of computations that make it possible to perceive, reason, and act."

Applications of AI

The aim of AI is the development of paradigms or algorithms that cause machines to perform tasks that apparently require cognition or perception when performed by humans.



Three Essential Components of AI Systems



- Should be able to handle knowledge that is both general and domain specific, implicit and explicit, and at different levels of abstraction.
- Involves having suitable control mechanisms to constrain the search through the knowledge base, and a means of arriving at conclusions from premises and available evidence.
- This should be designed such that it modifies the existing internal representational structure to incorporate the new information, with minimal disturbance to existing information.

Symbolic and Sub-symbolic: Level of Explanation

- Classical AI
  - Emphasizes symbolic representations of discrete concepts.
  - Assumes the *existence* of symbolic mental representations.
  - Models cognition based on the manipulation of these symbolic representations.
  - Employs a set of formal rules programmed using a computer language such as LISP or PROLOG.
- Neural networks
  - compute with units that are not recognizable as equivalents of everyday concepts.
  - They do not code words, or phrases of familiar words, or concepts.
  - Each unit represents a *micro-feature* of a global pattern.
  - Typically compute using differential or difference equations.
  - Can place emphasis on neurobiological primitives.

Symbolic and Sub-symbolic: Processing Style

- Classical AI
  - Processing is performed in a sequential fashion.
  - Inspired by the sequential nature of natural language and logical inference, and the sequential execution of computer programs on von Neumann architectures.
- Neural Networks
  - Parallel and distributed processing is a ubiquitous and essential feature of neural networks.
  - Often involves a large number of artificial neurons.
  - Makes the system computation robust: network states can deviate from desired values.
  - Computation proceeds properly even in the presence of noisy or incomplete inputs.

Symbolic and Sub-symbolic: Representation of Knowledge

- Knowledge in symbolic systems
  - *declarative* (a collection of facts)
  - *procedural* (specifying an algorithmic code to process information)
- Neural networks
  - store global patterns or function information using a distributed encoding.
  - Global information superimposed over many connections of the network.
  - Single concept represented by a pattern of unit activations.
  - Patterns for different concepts can therefore overlap in the units they use.
  - Knowledge is distributed over connections in the entire network: *coarse* or *distributed* coding.

Integrated Paradigms

- All available technologies have their own strengths and weaknesses; no one is better than other.
- Hybridization: The whole offsets the weaknesses of parts.
- Hybrid systems combine more than one intelligence paradigm in a synergistic framework.
- Soft Computing/Computational Intelligence