Cognitive Systems

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SYMBIOSIS INTERNATIONAL (DEEMED UNIVERSITY)
(Established under section 3 of the UGC Act, 1956)
Re-accredited by NAAC with 'A++' Grade | Awarded Category – I by UGC
Founder: Prof. Dr. S. B. Mujumdar, M. Sc., Ph. D. (Awarded Padma Bhushan and Padma Shri by President of India)

Course Name: Cognitive Systems
Course Code: TE7548
Faculty: Engineering
Course Credit: 3
Course Level: 4
Sub-Committee (Specialization): Artificial Intelligence and Machine Learning
Learning Objectives:

Students will be able to

Identify key concepts in cognitive systems and its relevance in AI field.
Explore and correlate different theories in cognitive science domain.
Identify knowledge representation and modelling techniques in cognitive science.
Illustrate real-time applications with respect to cognitive science.

Books Recommended:

Book	Author	Publisher
Cognitive linguistics: an introduction	Evans, Vyvyan and Melanie Green	Routledge, 2006
The MIT Encyclopedia of the Cognitive Sciences (MITECS)	Wilson, Robert A., & Keil, Frank C. (eds.)	MIT Press, 2001

Course Outline:

Sr. No.	Topic	Actual Teaching Hours	Contact Hours Equivalence
1	**Introduction to Cognitive Systems: Basics, introduction to computational theories of human cognition, drawing on formal models from classic and contemporary artificial intelligence approaches to cognition, philosophy of cognition, fundamental issues in human knowledge representation, inductive learning and reasoning, forms of knowledge, the inductive principles, computation of cognitive functioning in Machines, Human-robotics interaction, difference between AI and Cognitive systems, Computational intelligence techniques, cognitive linguistics.**	**15**	**15**
2	**Cognitive science :Concept Learning and Categorization, Reasoning about Natural Kinds, Learning Causal Relations, The Structure and Formation of Intuitive Theories of Physical, Biological and Social Systems, The Acquisition of Natural Language (syntax and semantics), Theory of Mind: How we Understand the Behavior and Mental States of Other People**	**12**	**12**
3	**Formal modeling: Bayesian Inference and Hierarchical Bayesian Models, Frameworks for Knowledge Representation: First-order Logic, Formal Grammars, Associative Networks, Taxonomic Hierarchies, Relational Schemas, Probabilistic and Causal Graphical Models, Relational Probabilistic Models, Controlling Complexity: Minimum Description Length, Bayesian Occam's Razor, Nonparametric Bayesian Models Inductive Logic Programming, Sampling Algorithms for Inference in Complex Probabilistic Models**	**10**	**10**
4	**Applications: Speech recognition, sentiment analysis, face detection, risk assessment, and fraud detection.**	**8**	**8**
	Total	**45**	**45**

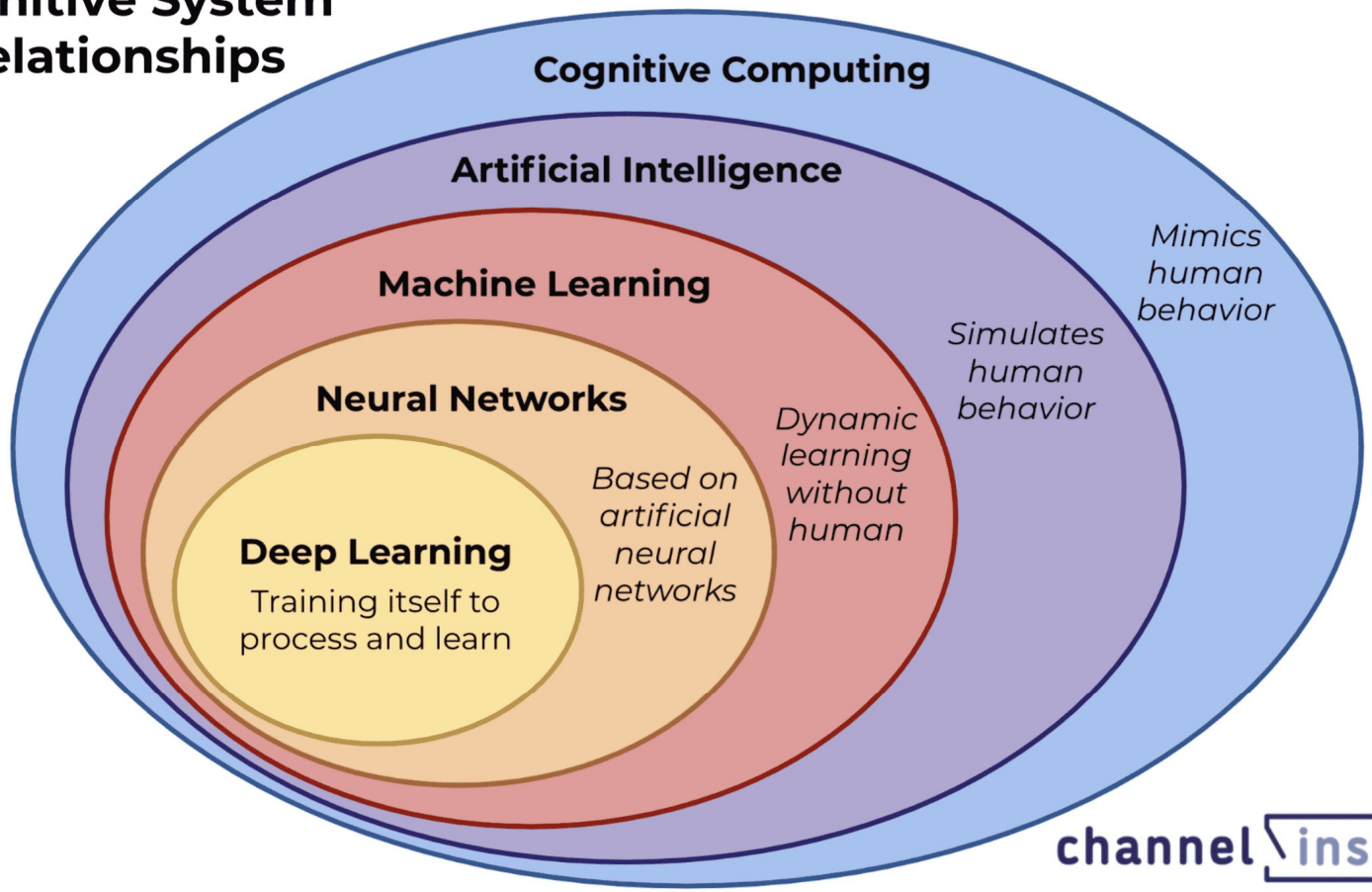
Evaluation Plan

Sr. No.	Component	Max marks	CO	Weight	Tentative date
1	Quiz	10	1	33.33%	July 2024
2	Modelling Assignment	10	2-3	33.33%	August 2024
3	Case Study (Group)	10	1-4	33.33%	October 2024

Unit 1: Introduction to Cognitive Systems

Basics, introduction to computational theories of human cognition, drawing on formal models from classic and contemporary artificial intelligence approaches to cognition, philosophy of cognition, fundamental issues in human knowledge representation, inductive learning and reasoning, forms of knowledge, the inductive principles, computation of cognitive functioning in Machines, Human-robotics interaction, difference between AI and Cognitive systems, Computational intelligence techniques, cognitive linguistics.

Cognitive System Relationships



channel insider

Cognitive Science is a branch of Science, like a sister discipline Neuroscience.

Cognitive computing uses theories and models of the human mind to mimic the mind on computer systems.

We have a discipline called computational neuroscience, which uses studies of the human brain to create artificial learning systems.

What is Computational Cognitive Modeling?

Computational Cognitive Modeling is devoted to understanding the human mind and brain, in terms of their underlying computational processes.

Building computer simulations that mimic the intelligent behavior of humans, and using these simulations to predict and explain human behavior.

Key Questions

What is intelligence?

What kind of computer is the mind and brain?

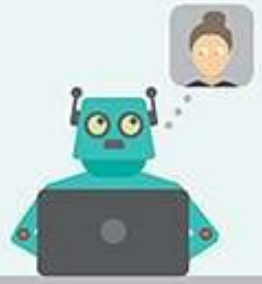
Can we better understand the mind/brain by building computational cognitive models?

Can we better understand behavioral data by building computational cognitive models?

Can we improve machine intelligence by incorporating insights from human intelligence?

Cognitive Computing vs. AI

COGNITIVE COMPUTING		ARTIFICIAL INTELLIGENCE
Machine learning, natural language processing, neural networks, deep learning, sentiment analysis	TECHNOLOGIES	Machine learning, natural language processing, neural networks, deep learning
Simulate human thought processes to assist humans in finding solutions to complex problems	CAPABILITIES	Find patterns in big data to learn and either reveal hidden information or deliver solutions to complex problems
Augment human capabilities	PURPOSE	Automate processes
Customer service, healthcare, industrial sector	INDUSTRIES	Finance, security, healthcare, retail, manufacturing, government



TechTarget

COGNITIVE COMPUTING

- Part of Artificial Intelligence
- Informed decisions
- Extracts information for decision-making
- Humans make the final decision

ARTIFICIAL INTELLIGENCE

- Broader concept
- Problem-solving tasks
- Suggests the best way to solve the problem
- Makes better decisions on behalf of humans

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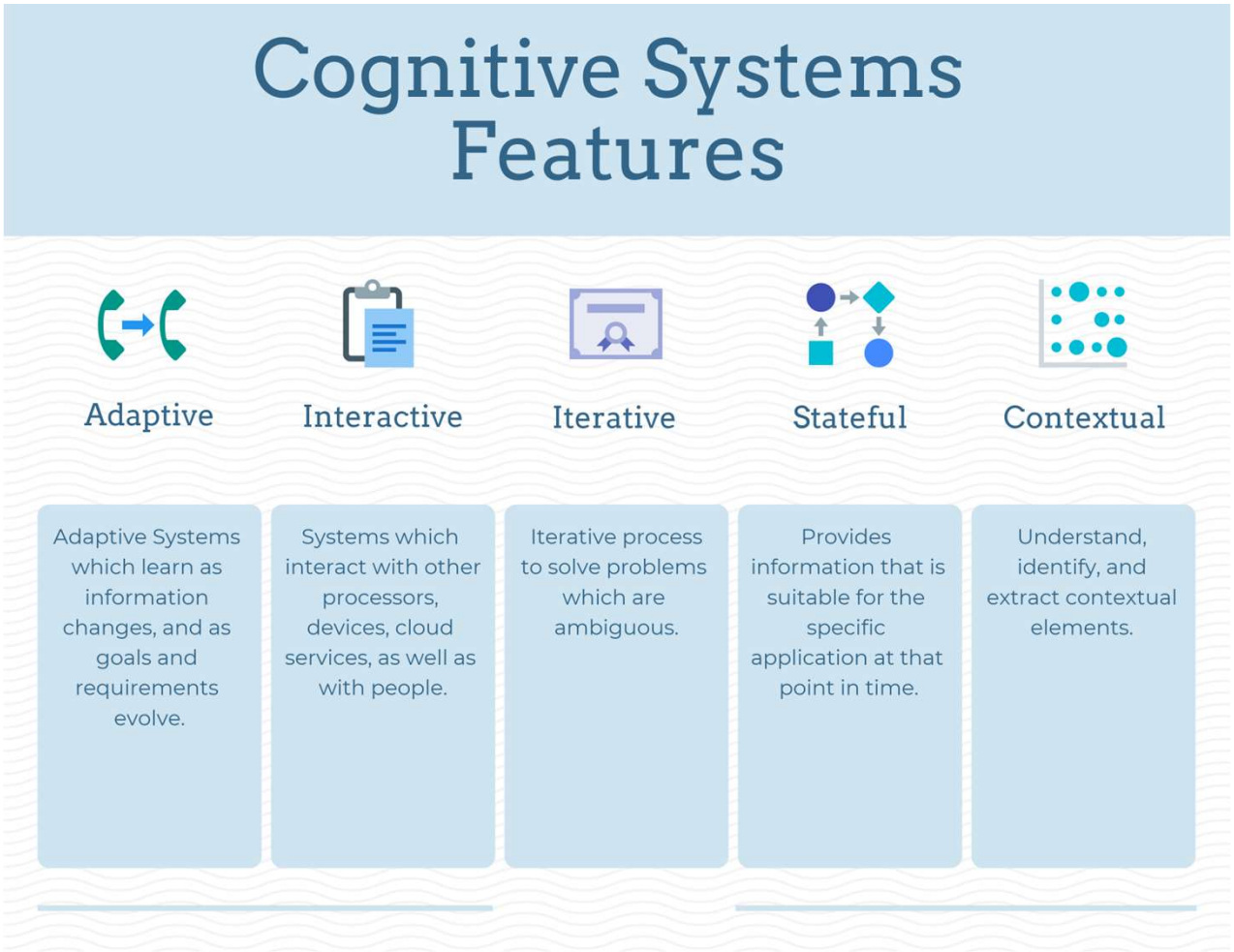
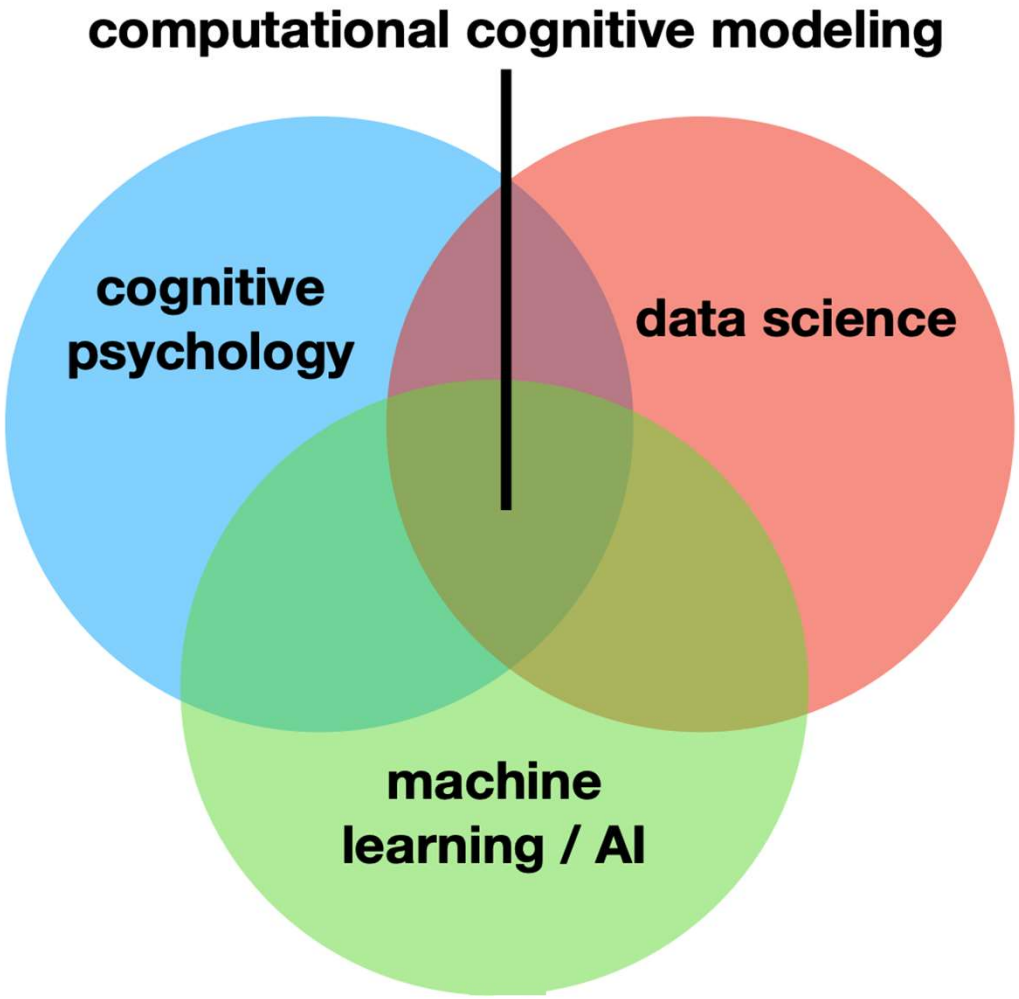
Q: Compare Cognitive computing with AI

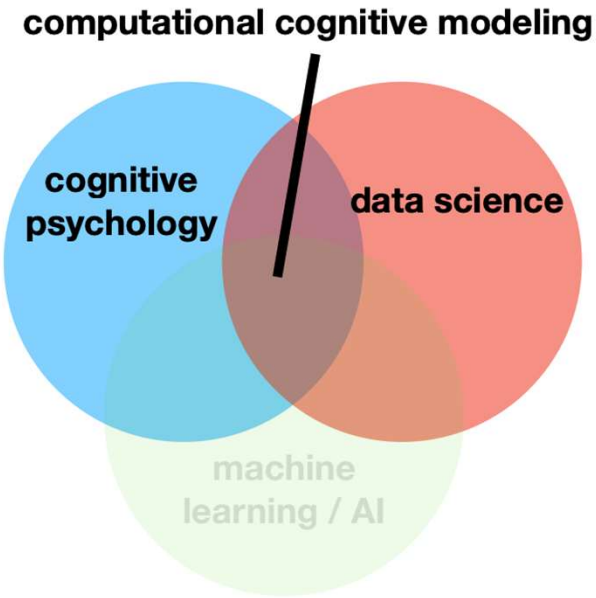


Q: What are are features of cognitive systems

Cognitive computing is a superset of artificial intelligence (AI) that aims to create systems capable of mimicking human-like cognitive functions. The term “cognitive” refers to processes related to perception, learning, reasoning, and problem-solving – functions traditionally associated with human intelligence. The goal of **cognitive computing** is to develop systems that can understand, interpret, and respond to complex information like the way humans do.


computational cognitive modeling
cognitive psychology
data science
machine learning / AI

Connections between computational cognitive modeling and data science



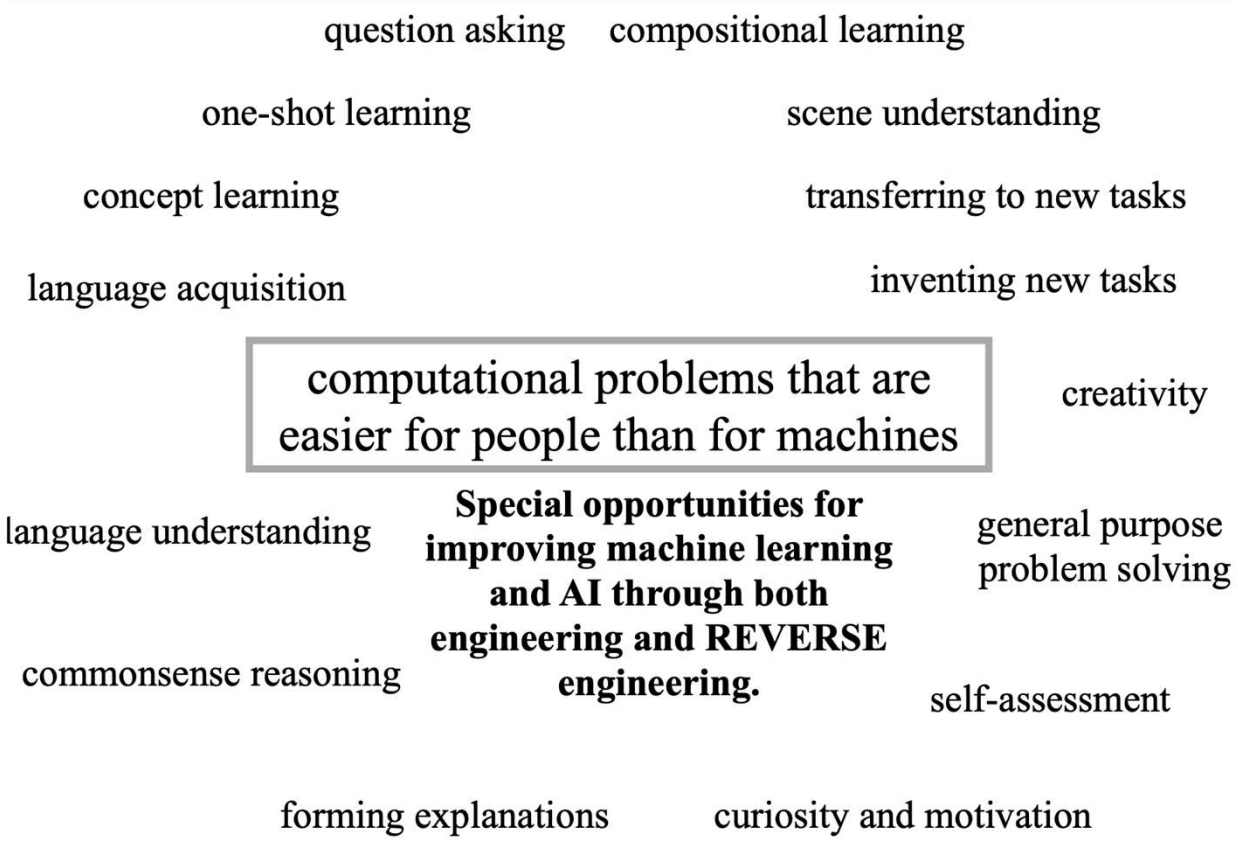
- **Similar goals**: build computational models to explain or predict behavioral data
- **Similar computational paradigms and techniques**: neural networks / deep learning, reinforcement learning, Bayesian modeling, probabilistic graphical models, program induction
- Data science is about **extracting knowledge from data**. The human mind is the best (known) system for extracting knowledge from data.
- There is ripe potential for even deeper connections. We hope that, by bringing together students from a variety of backgrounds, this class can help realize this potential.

Bi-directional exchanges of computational methods and paradigms

machine learning / AI / data science -> <- cognitive science / psychology

- Artificial neural networks
- Temporal difference learning
- Factor analysis
- Multi-dimensional scaling
- Probabilistic graphical models
- Structured Bayesian models
- Bayesian non-parametric models
- Probabilistic programming
- Recurrent neural networks

Data science is about extracting knowledge from data. The human mind is the best general system we know of for extracting knowledge from data.



Can we better understand behavioral data by building computational cognitive models?

Computational Models of Cognition

- Brain + Minds + Machines
- What kind of computer is the brain/mind
- How can we characterize intelligence in computational terms
  - Pattern recognition engine? – AI side – Neuroscience based- CNN / RNN and variants

    Deeper and more layers – deep neural networks
  - Prediction Engine? – Bayesian networks, causal modes, predictive coding, causal reasoning, Causal inference

    Directed graphical models
  - Symbol Processing/Manipulation Engine? – logic, calculus, Symbolic expressions (Plato is a man, all men are mortal, therefore Plato is a mortal. This app lies to not only Plato but anyone who is a man)

  - Mathematics-> Symbolic languages-> computer science/AI - > today's deep elarning or probabilistic inference
  - direction of arrows – from sensory inputs to decision outputs (Feed forward in NN or bottom up in graphs) or from eggect to causes (feedback in NN or top to down)
  - How to combine them together

- Intelligence is not just about *pattern recognition*.
- It is about *modeling the world*…
  - *explaining* and *understanding* what we see.
  - *imagining* things we could see but haven't yet.
  - *problem solving* and *planning* actions to make these things real.
  - *building new models* as we learn more about the world.

Knowledge Representation

- The fundamental goal of knowledge Representation is to facilitate inference (conclusions) from knowledge.
- Knowledge representation and reasoning (KR, KRR) is the part of Artificial intelligence which concerned with AI agents thinking and how thinking contributes to intelligent behavior of agents.
- It is responsible for representing information about the real world so that a computer can understand and can utilize this knowledge to solve the complex real world problems such as diagnosis a medical condition or communicating with humans in natural language.
- It is also a way which describes how we can represent knowledge in artificial intelligence. Knowledge representation is not just storing data into some database, but it also enables an intelligent machine to learn from that knowledge and experiences so that it can behave intelligently like a human.

What to Represent

Following are the kind of knowledge that needs to be represented in AI systems:

- **Object:** All the facts about objects in our world domain. E.g., Cars have breaks, Dog has two ears etc.
- **Events:** Events are the actions that occur in our world.
- **Performance:** It describes behaviour that involves knowledge about how to do things.
- **Meta-knowledge:** It is knowledge about what we know.
- **Facts:** Facts are the truths about the real world and what we represent.
- **Knowledge-Base:** The central component of the knowledge-based agents is the knowledge base. It is represented as KB. The Knowledgebase is a group of the Sentences (Here, sentences are used as a technical term and not identical with the English language).
- **Knowledge:** Knowledge is awareness or familiarity gained by experiences of facts, data, and situations.

Types of Knowledge

Q : What are the different types of knowledge?

1. Declarative Knowledge

- Declarative knowledge is to know about something.
- It includes concepts, facts, and objects.
- It is also called descriptive knowledge and expressed in declarative sentences.
- It is simpler than procedural language.

2. Procedural Knowledge

- It is also known as imperative knowledge.
- Procedural knowledge is a type of knowledge which is responsible for knowing how to do something.
- It can be directly applied to any task.
- It includes rules, strategies, procedures, agendas, etc.
- Procedural knowledge depends on the task on which it can be applied.

Q : Explain in brief any one type of knowledge?

3. Meta-knowledge:

•Knowledge about the other types of knowledge is called Meta-knowledge.

4. Heuristic knowledge:

•Heuristic knowledge is representing knowledge of some experts in a field or subject.

•Heuristic knowledge is rules of thumb based on previous experiences, awareness of approaches, and which are good to work but not guaranteed.

5. Structural knowledge:

•Structural knowledge is basic knowledge to problem-solving.

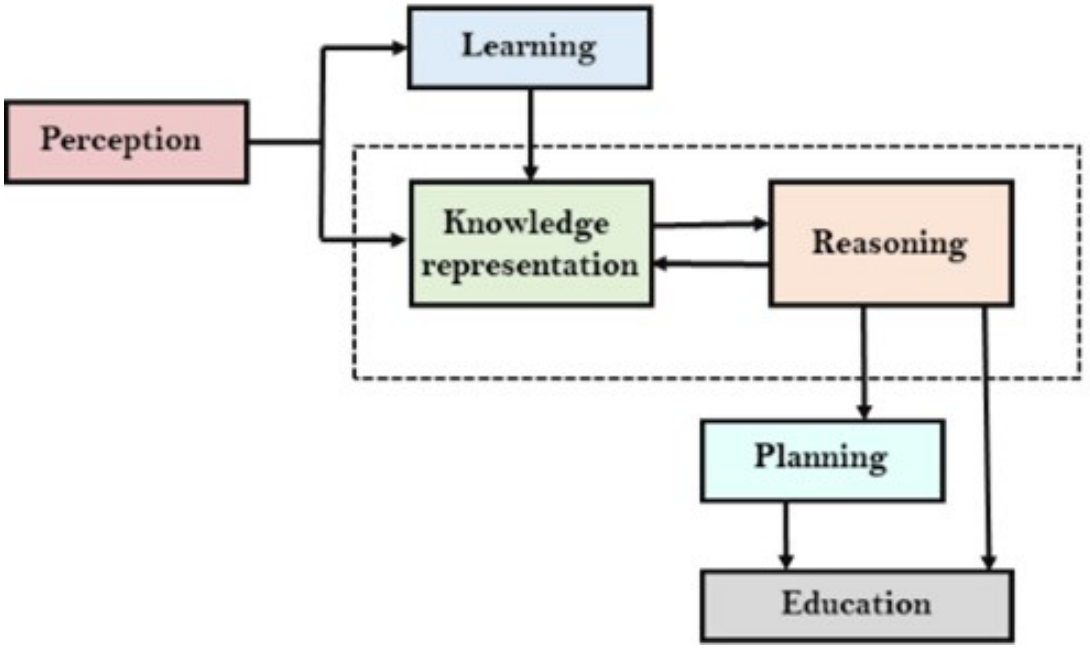
•It describes relationships between various concepts such as kind of, part of, and grouping of something.

•It describes the relationship that exists between concepts or objects.

AI knowledge cycle:

An Artificial intelligence system has the following components for displaying intelligent behavior:

- Perception
- Learning
- Knowledge Representation and Reasoning
- Execution
- Planning



Q: What are the components of AI knowledge cycle ?

Techniques of knowledge representation

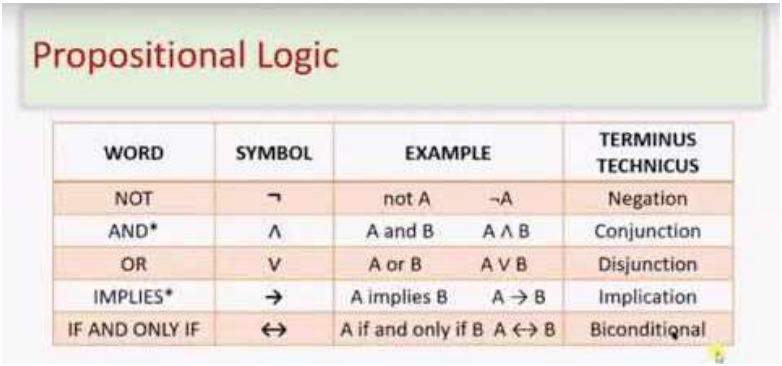
1. Logical Representation
2. Semantic Network Representation
3. Frame Representation
4. Production Rules

Logical Representation

- Logical representation is a language with some concrete rules which deals with propositions and has no ambiguity in representation. Logical representation means drawing a conclusion based on various conditions. This representation lays down some important communication rules. It consists of precisely defined syntax and semantics which supports the sound inference. Each sentence can be translated into logics using syntax and semantics.
- Logical representation can be categorised into mainly two logics:

  1.Propositional Logics

  2.Predicate logics



1. Logical representation enables us to do logical reasoning.
2. Logical representation is the basis for the programming languages.

- Disadvantages of logical Representation:

1. Logical representations have some restrictions and are challenging to work with.
2. Logical representation technique may not be very natural, and inference may not be so efficient.

Semantic Network Representation

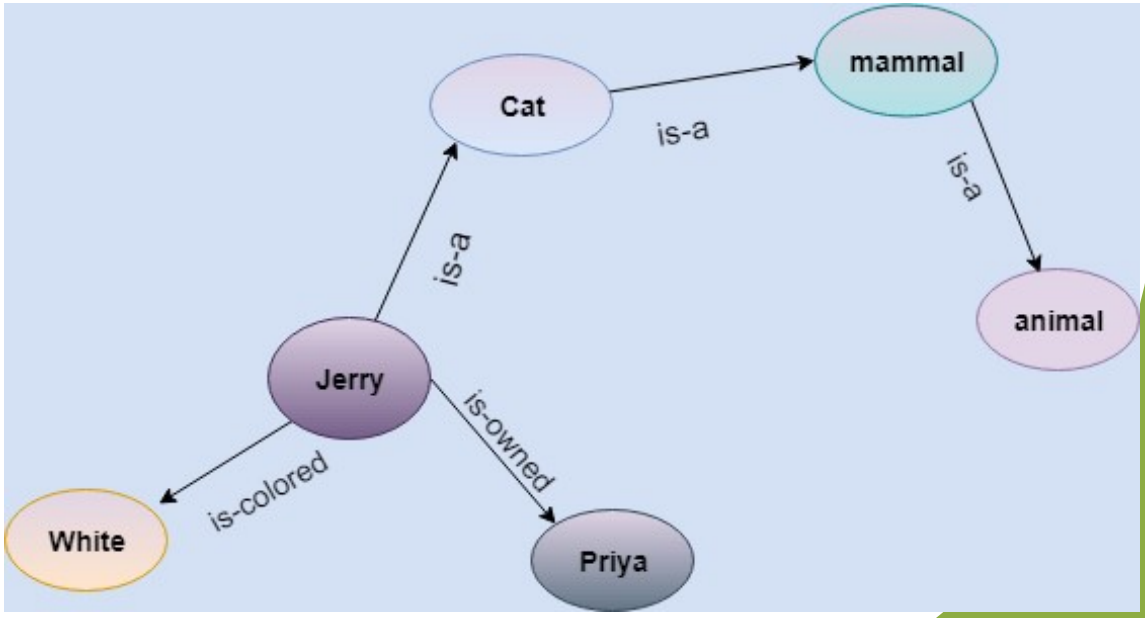
Semantic networks are alternative of predicate logic for knowledge representation. In Semantic networks, we can represent our knowledge in the form of graphical networks. This network consists of nodes representing objects and arcs which describe the relationship between those objects. Semantic networks can categorize the object in different forms and can also link those objects. Semantic networks are easy to understand and can be easily extended.

- This representation consist of mainly two types of relations:

1. IS-A relation (Inheritance)
2. Kind-of-relation

- **Example:** Following are some statements which we need to represent in the form of nodes and arcs.
- Statements:

Jerry is a cat. Jerry is a mammal. Jerry is owned by Priya. Jerry is white colored. All Mammals are animal.



In the above diagram, the different type of information is represented in the form of nodes and arcs. Each object is connected with another object by some relation.

Advantages and Disadvantages of Semantic Representation

Drawbacks in Semantic representation:

1. Semantic networks take more computational time at runtime as we need to traverse the complete network tree to answer some questions. It might be possible in the worst case scenario that after traversing the entire tree, we find that the solution does not exist in this network.
2. Semantic networks try to model human-like memory to store the information, but in practice, it is not possible to build such a vast semantic network.
3. These types of representations are inadequate as they do not have any equivalent quantifier, e.g., for all, for some, none, etc.
4. Semantic networks do not have any standard definition for the link names.
5. These networks are not intelligent and depend on the creator of the system.

Advantages of Semantic network:

1. Semantic networks are a natural representation of knowledge.
2. Semantic networks convey meaning in a transparent manner.
3. These networks are simple and easily understandable.

Frame Representation

- A frame is a record like structure which consists of a collection of attributes and its values to describe an entity in the world. Frames are the AI data structure which divides knowledge into substructures by representing stereotypes situations. It consists of a collection of slots and slot values. These slots may be of any type and sizes. Slots have names and values which are called facets.

- **Facets:** The various aspects of a slot is known as **Facets**. Facets are features of frames which enable us to put constraints on the frames. Example: IF-NEEDED facts are called when data of any particular slot is needed. A frame may consist of any number of slots, and a slot may include any number of facets and facets may have any number of values. A frame is also known as **slot-filter knowledge representation** in artificial intelligence.

Let's suppose we are taking an entity, Peter. Peter is an engineer as a profession, and his age is 25, he lives in city London, and the country is England. So following is the frame representation for this:

Slots	Filter
Name	Peter
Profession	Doctor
Age	25
Marital status	Single
Weight	78

Frames are derived from semantic networks and later evolved into our modern-day classes and objects. A single frame is not much useful. Frames system consist of a collection of frames which are connected. In the frame, knowledge about an object or event can be stored together in the knowledge base. The frame is a type of technology which is widely used in various applications including Natural language processing and machine visions.

- **Advantages of frame representation:**

1. The frame knowledge representation makes the programming easier by grouping the related data.
2. The frame representation is comparably flexible and used by many applications in AI.
3. It is very easy to add slots for new attribute and relations.
4. It is easy to include default data and to search for missing values.
5. Frame representation is easy to understand and visualize.

- **Disadvantages of frame representation:**

1. In frame system inference mechanism is not be easily processed.
2. Inference mechanism cannot be smoothly proceeded by frame representation.
3. Frame representation has a much generalized approach.

Production Rules

Production rules system consist of (**condition, action**) pairs which mean, "If condition then action". It has mainly three parts:

- The set of production rules
- Working Memory
- The recognize-act-cycle
- In production rules agent checks for the condition and if the condition exists then production rule is activated and corresponding action is carried out. The condition part of the rule determines which rule may be applied to a problem. And the action part carries out the associated problem-solving steps. This complete process is called a recognize-act cycle.
- The working memory contains the description of the current state of problems-solving and rule can write knowledge to the working memory. This knowledge matches and may fire other rules.
- If a new situation (state) is generated, then multiple production rules are fired together, this is called conflict set. In this situation, the agent needs to select a rule from these sets, and it is called a conflict resolution.

Example:

•IF (at bus stop AND bus arrives) THEN action (get into the bus)
•IF (on the bus AND paid AND empty seat) THEN action (sit down).
•IF (on bus AND unpaid) THEN action (pay charges).
•IF (bus arrives at destination) THEN action (get down from the bus).

- **Advantages of Production rule:**

1. The production rules are expressed in natural language.
2. The production rules are highly modular, so we can easily remove, add or modify an individual rule.

- **Disadvantages of Production rule:**

1. Production rule system does not exhibit any learning capabilities, as it does not store the result of the problem for the future uses.
2. During the execution of the program, many rules may be active hence rule-based production systems are inefficient.

Requirements for knowledge Representation system:

- A good knowledge representation system must possess the following properties.

1.1. Representational Accuracy:

KR system should have the ability to represent all kind of required knowledge.

2.2. Inferential Adequacy:

KR system should have ability to manipulate the representational structures to produce new knowledge corresponding to existing structure.

3.3. Inferential Efficiency:

The ability to direct the inferential knowledge mechanism into the most productive directions by storing appropriate guides.

4.4. Acquisitional efficiency- The ability to acquire the new knowledge easily using automatic methods.

AI Knowledge Cycle

The AI knowledge cycle is a process that involves the acquisition, representation, and utilization of knowledge by AI systems. It consists of several stages, including:

- **Data collection:** This stage involves gathering relevant data from various sources such as sensors, databases, or the internet.
- **Data preprocessing:** The collected data is then cleaned, filtered, and transformed into a suitable format for analysis.
- **Knowledge representation:** This stage involves encoding the data into a format that an AI system can use. This can include symbolic representations, such as knowledge graphs or ontologies, or numerical representations, such as feature vectors.
- **Knowledge inference:** Once the data has been represented, an AI system can use this knowledge to make predictions or decisions. This involves applying machine learning algorithms or other inference techniques to the data.
- **Knowledge evaluation:** This stage involves evaluating the accuracy and effectiveness of the knowledge that has been inferred. This can involve testing the AI system on known examples or other evaluation metrics.
- **Knowledge refinement:** Based on the evaluation results, the knowledge representation and inference algorithms can be refined or updated to improve the accuracy and effectiveness of the AI system.
- **Knowledge utilization:** Finally, the knowledge acquired and inferred can be used to perform various tasks, such as natural language processing, image recognition, or decision-making.

The AI knowledge cycle is a continuous process, as new data is constantly being generated, and the AI system can learn and adapt based on this new information. By following this cycle, AI systems can continuously improve their performance and perform a wide range of tasks more effectively.

Problem with Knowledge Representation

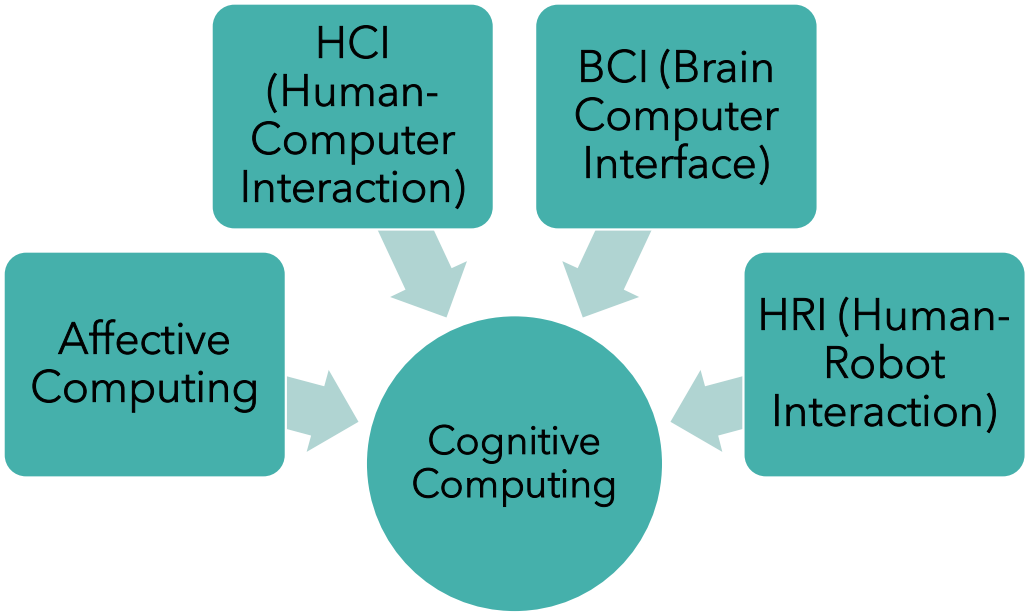
- **Scalability:** Scalability becomes a significant difficulty as knowledge's volume and complexity rise. Large knowledge bases must be efficiently represented and processed using sophisticated methods and distributed computing concepts.
- **Information that is Uncertain or Incomplete:** AI systems frequently work with information that is uncertain or incomplete. A major research area is improving knowledge representation approaches to manage uncertainty and reason with inadequate data.
- **Knowledge Fusion and Integration:** Combining and integrating knowledge from various sources and modalities is a difficult task. The goal of future research is to create methods that make it possible for heterogeneous knowledge to be seamlessly integrated for better AI performance.
- **Explainability & Interpretability:** AI systems should be able to justify their decisions with explanations. Building trust, assuring ethical AI, and satisfying legal standards all depend on the development of clear and understandable knowledge representation approaches.

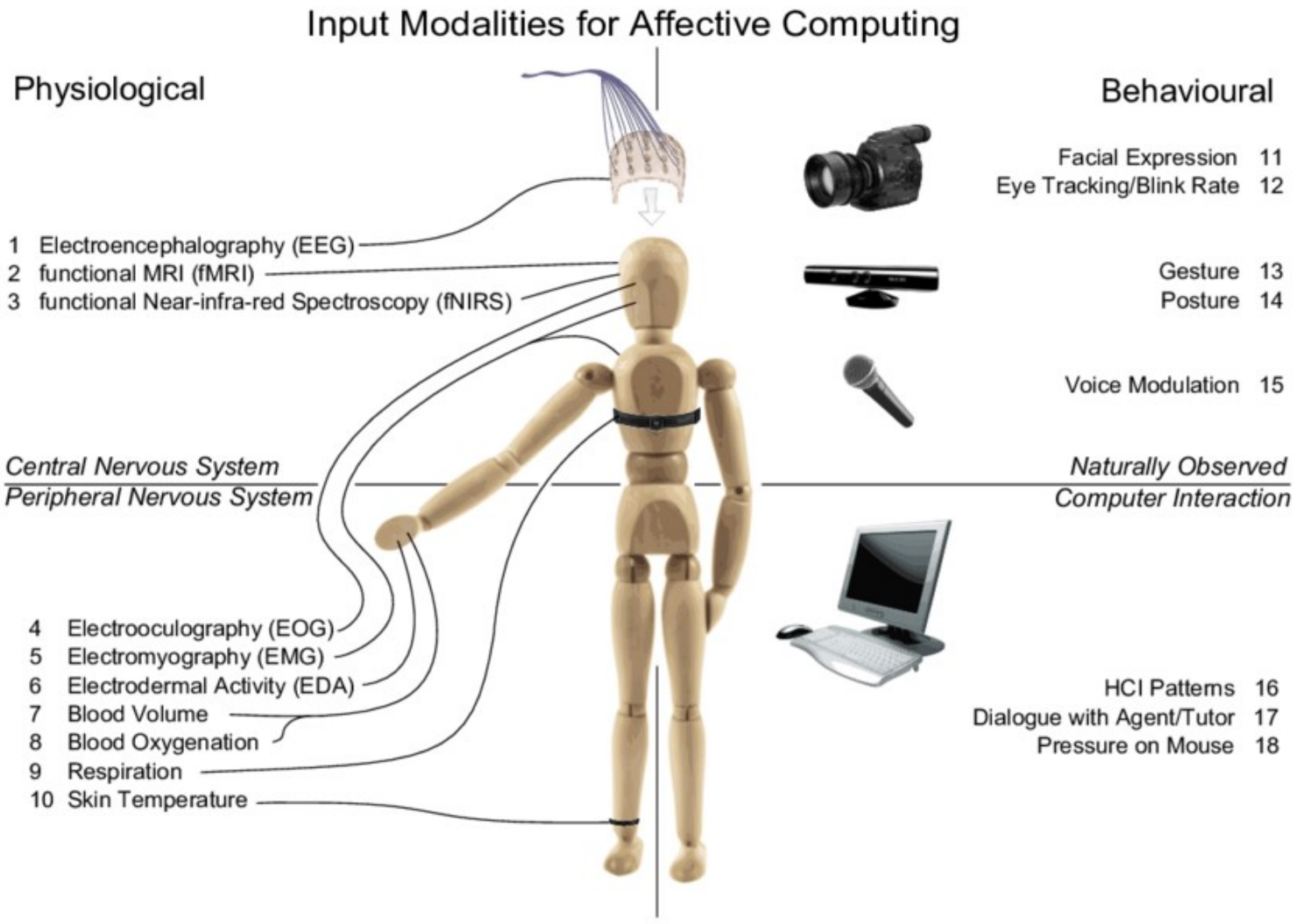
Difference between AI and cognitive systems

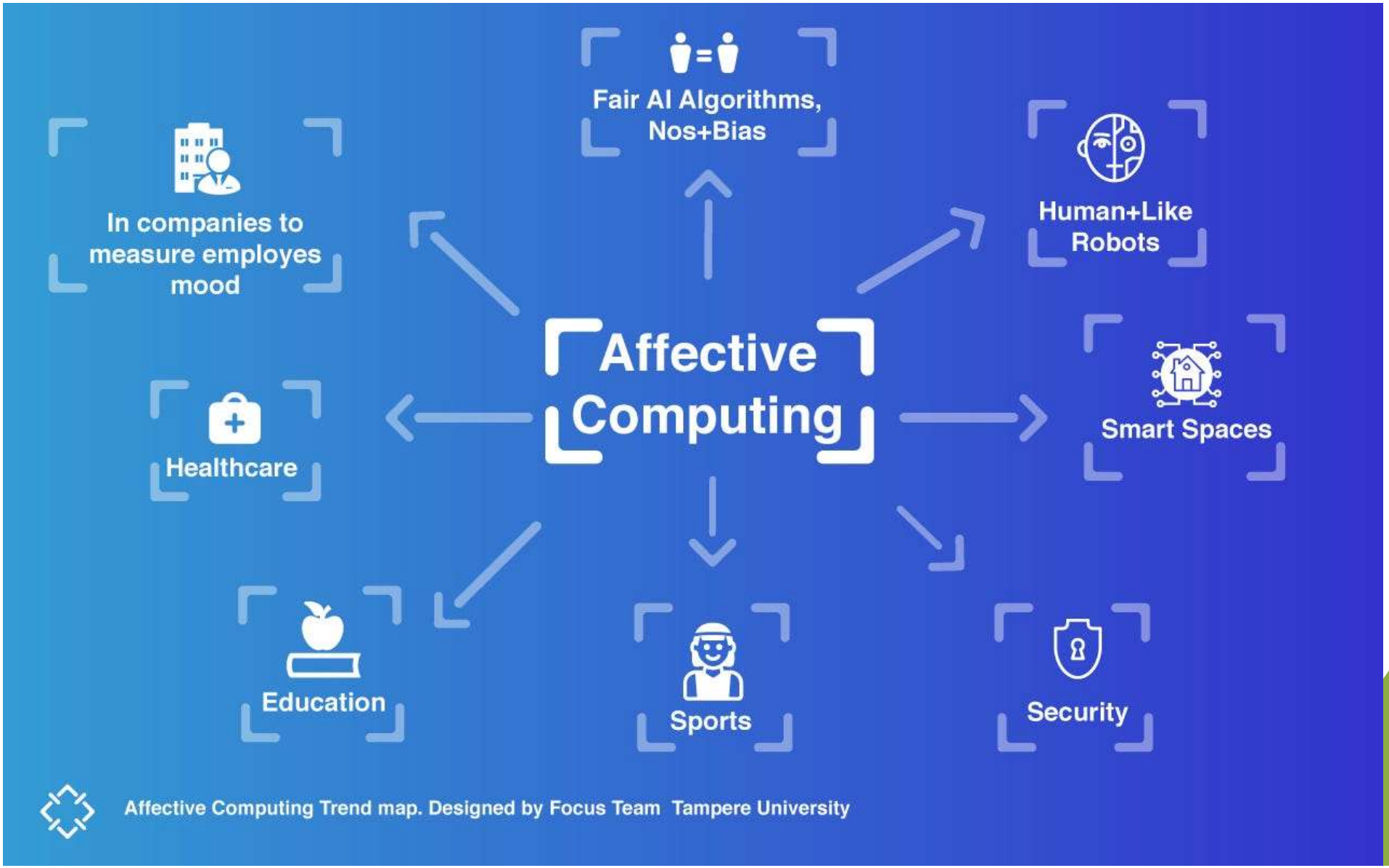
- They may utilise some of the same technologies, but the difference lies in their respective applications and aims.
- The purpose of AI is to think on its own and make decisions independently, whereas the purpose of Cognitive Computing is to simulate how the human mind reasons
- **Artificial Intelligence is automation, Cognitive Computing is augmentation.** They both use very similar technologies such as Machine Learning, neural networks, deep learning and more. They also both aim to streamline the process of making a decision.

  However, the difference lies in how these technologies are utilised. **With AI, the focus is on finding an effective algorithm to generate the best overall solution to a problem. With Cognitive Computing, the focus is on making the best decision based on circumstances** and on top of that, providing information for the best decision instead of actually making it.
- From the fundamental differences between AI and Cognitive computing, they also vary in application. **Often in situations where you need a quick response, AI is the most suited.** This could be, for example, in more service-heavy industries where a set amount of information is needed. Alternatively, **in situations where the best option will vary, Cognitive Computing will work best.** Making specific suggestions that can vary depending on context is currently best left to a human, **so Cognitive Computing works best when a human needs to make an informed decision.**
- **To give an example of the difference between Cognitive Computing and AI**, think of a situation where you want to order a pizza. If you put the task to AI, it would analyse all of the past times you've ordered pizza and form an algorithm to make a prediction based on the patterns from previous orders. Further than that, it would likely also order the pizza for you. If you assigned this task to Cognitive Computing, it would use the same information to try and think in the same way you would when ordering. For example, if you're in a different location than usual or if you're ordering for multiple people. Using information from your ordering habits and context, it would suggest a few top options to you instead, leaving the end decision to you.
- Both of these technologies are constantly undergoing advancements, so their applications will increase in both diversity and efficiency as time goes on

Various Tasks under Cognitive Computing



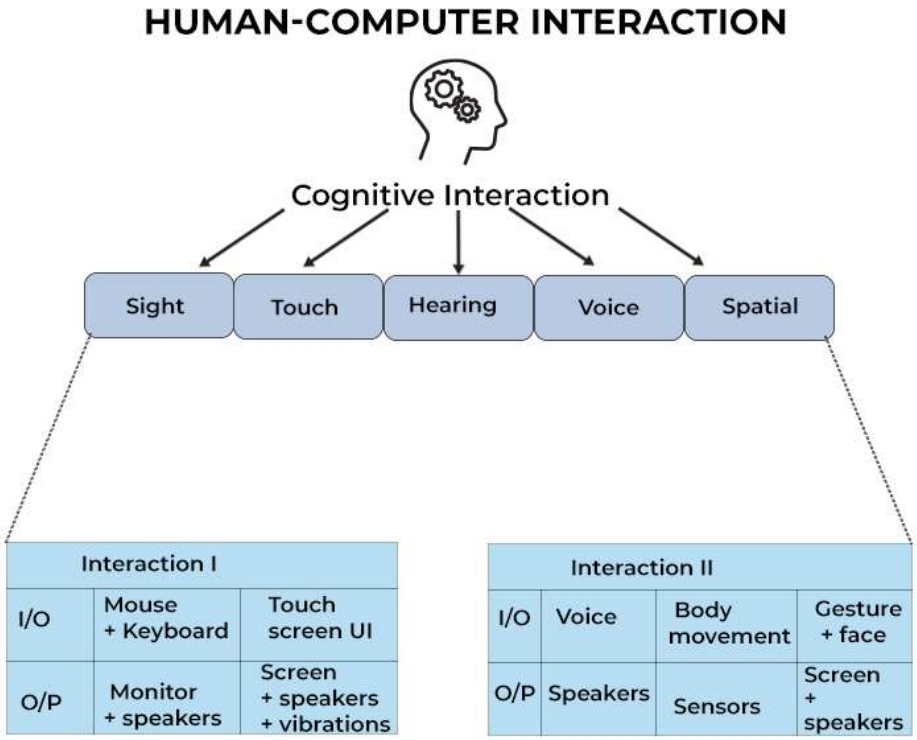

Input Modalities for Affective Computing
Physiological
Behavioural
1 Electroencephalography (EEG)
2 functional MRI (fMRI)
3 functional Near-infra-red Spectroscopy (fNIRS)
Facial Expression 11
Eye Tracking/Blink Rate 12
Gesture 13
Posture 14
Voice Modulation 15
Central Nervous System
Peripheral Nervous System
Naturally Observed
Computer Interaction
4 Electrooculography (EOG)
5 Electromyography (EMG)
6 Electrodermal Activity (EDA)
7 Blood Volume
8 Blood Oxygenation
9 Respiration
10 Skin Temperature
HCI Patterns 16
Dialogue with Agent/Tutor 17
Pressure on Mouse 18

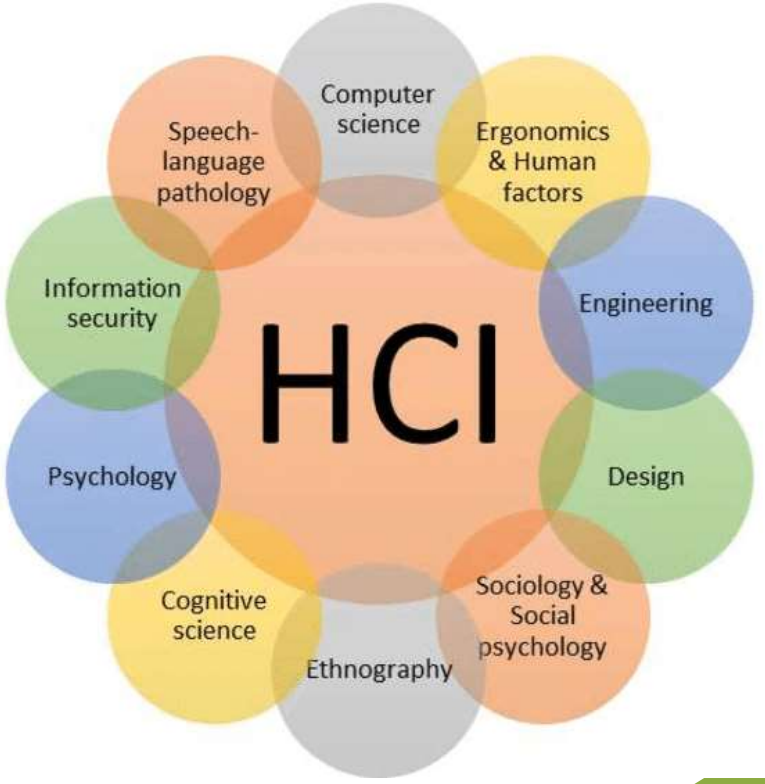

Fair AI Algorithms, Nos+Bias
In companies to measure employes mood
Human+Like Robots
Affective Computing
Healthcare
Smart Spaces
Education
Sports
Security
Affective Computing Trend map. Designed by Focus Team Tampere University

Affective Computing

HCI

Human-computer interaction (HCI) is the field of study that focuses on optimizing how users and computers interact by designing interactive computer interfaces that satisfy users' needs.





BCI

- A **brain–computer interface** (**BCI**), is sometime also called as a **brain–machine interface** (**BMI**)
- It is a direct communication link between the brain's electrical activity and an external device, most commonly a computer or robotic limb.
- BCIs are often directed at researching, mapping, assisting, augmenting, or repairing human cognitive or sensory-motor functions
- They are often conceptualized as a human–machine interface that skips the intermediary of moving body parts (hands…)
- BCI implementations range from non-invasive (EEG, MEG, MRI) and partially invasive (ECoG and endovascular) to invasive (microelectrode array), based on how physically close electrodes are to brain tissue.[2]
- Due to the cortical plasticity of the brain, signals from implanted prostheses can, after adaptation, be handled by the brain like natural sensor or effector channels.

HRI

Human–robot interaction (HRI) is the study of interactions between humans and robots. Human–robot interaction is a multidisciplinary field with contributions from human–computer interaction, artificial intelligence, robotics, natural language processing, design, psychology and philosophy.