Marks allocation

Project/EHIPASSIKO Presentation	Weekly interaction	End semester
25	25	50

Smart Product Design-2025

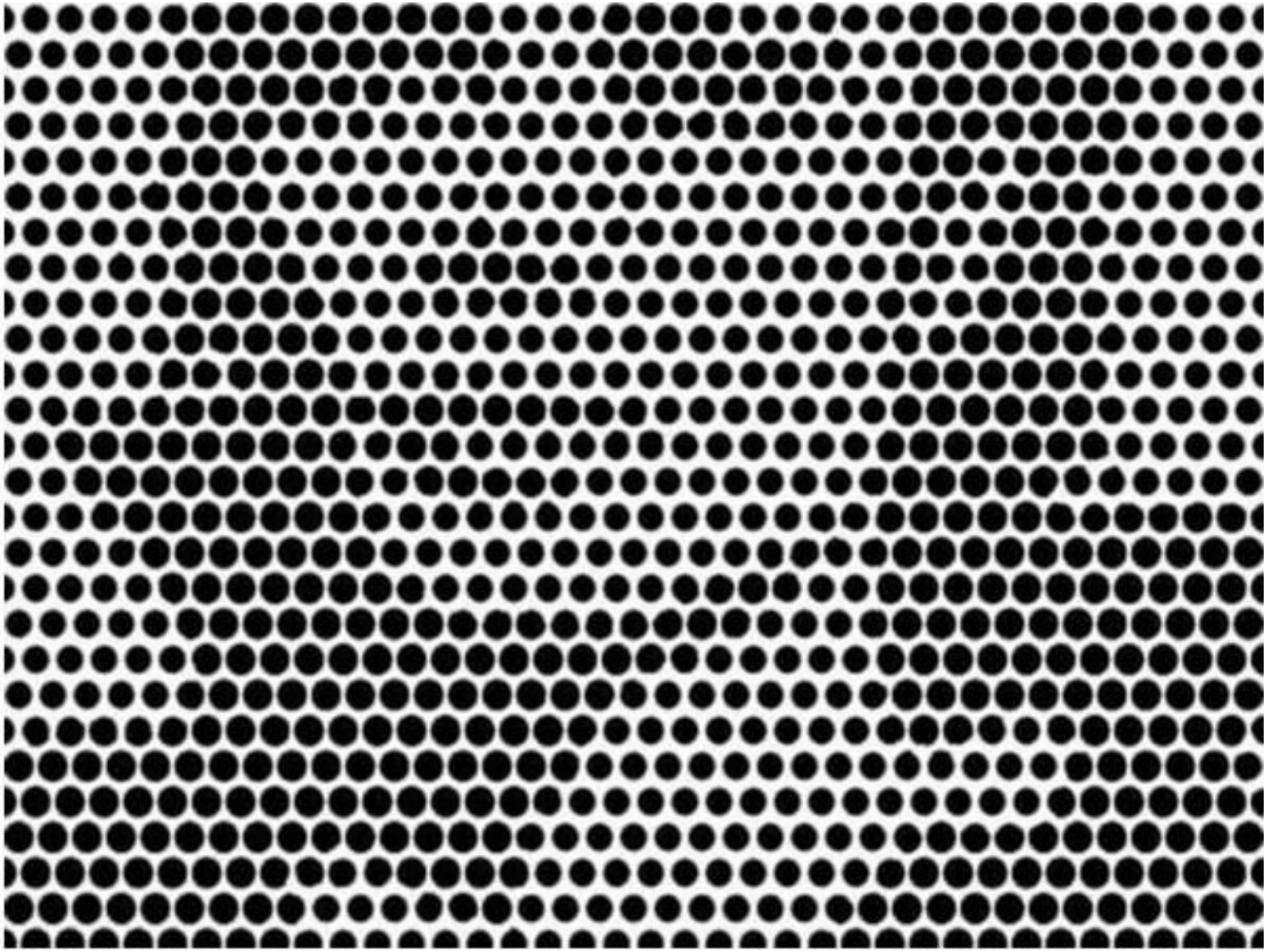
DS2001
Jan – May 2025

Dr . Jayachandra Bingi

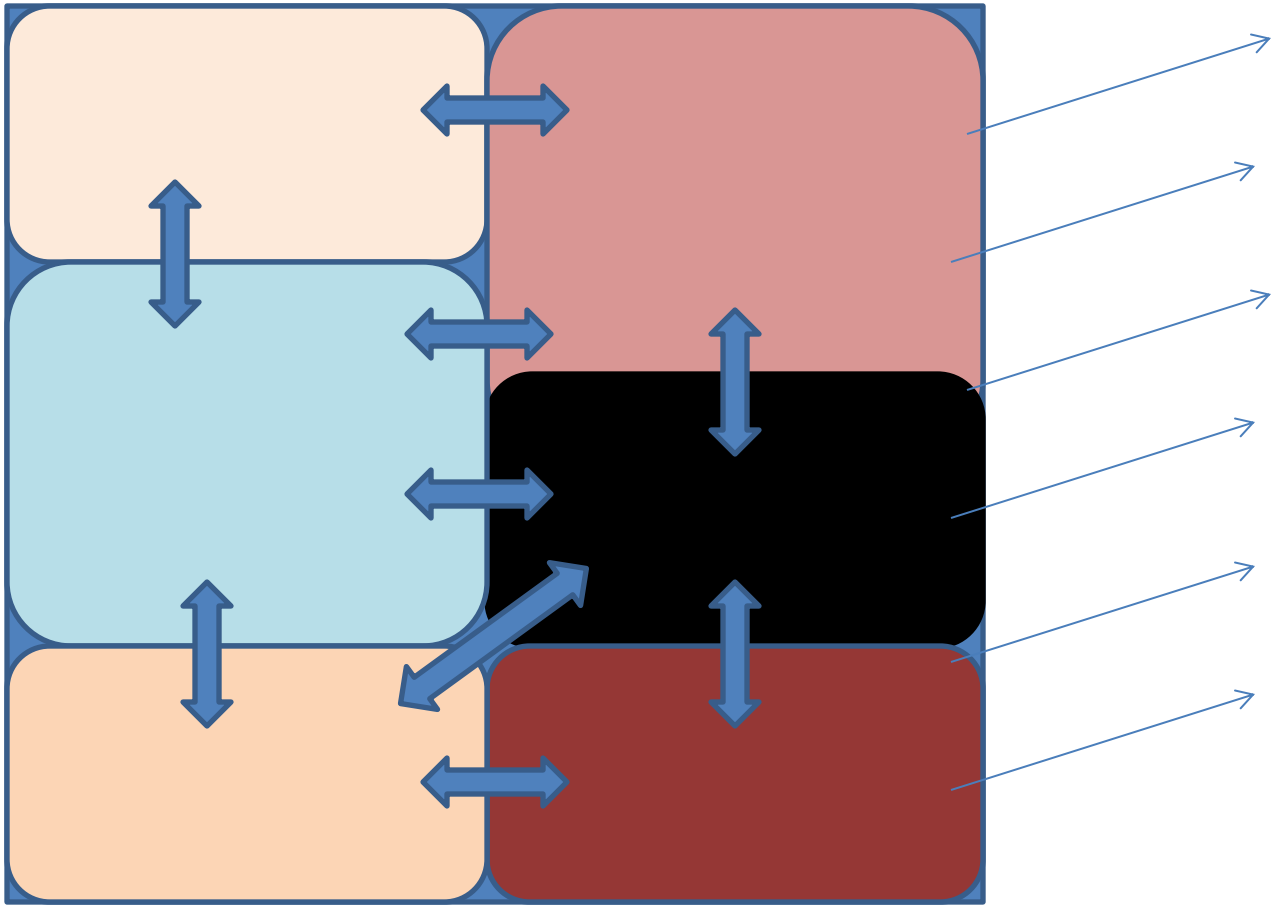
TOPICS

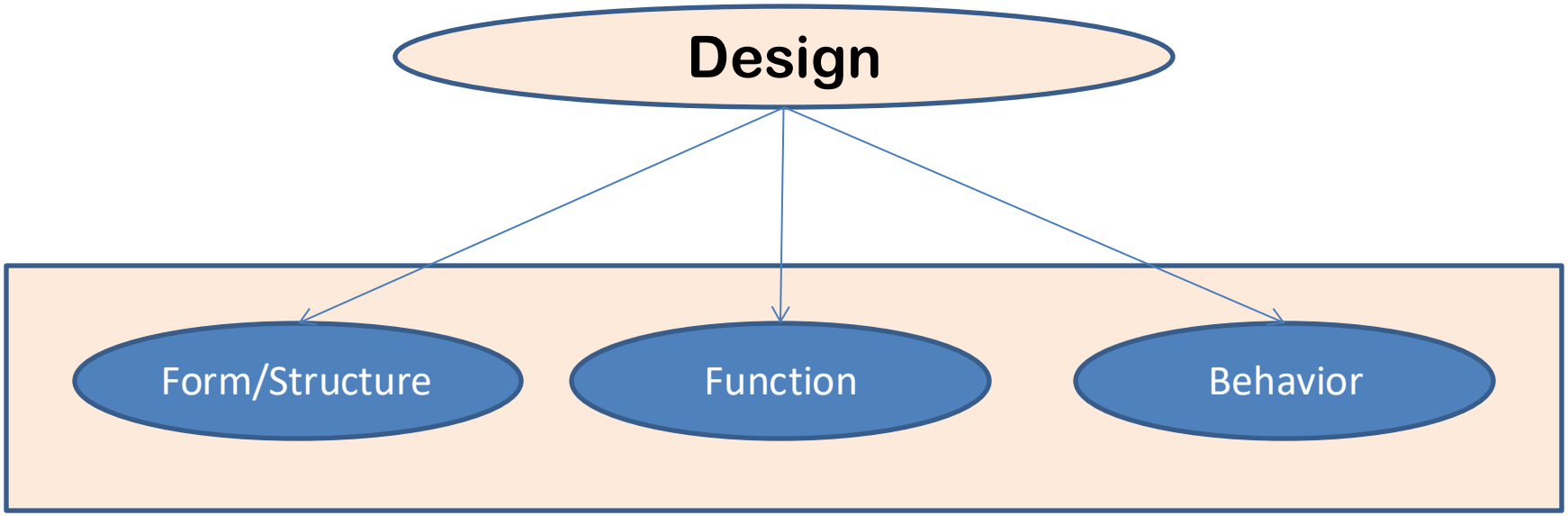
1. Definition of intelligence
2. Levels of intelligence
3. Dimensions of intelligence
4. Intelligence and information intensity relation (equilibrium, amplification)
5. Bio-inspired adaptive systems (Positive and negative feedback)
6. AI techniques
7. Theory of living systems
8. Theory of viable systems
9. Collective system model

Smart



Product / System





A plan or drawing produced to show the look and function or workings of a building, garment, or other object before it is made.

A design is **a plan or specification for the construction of an object or system or for the implementation of an activity or process**

A "context" driven creative process of developing the objects/systems/products::

"Context" (conditions/constraints) – User centric/ human centric / environment centric"

Definition of Intelligence

"The ability to use memory, knowledge, experience, understanding, reasoning, imagination and judgment in order to solve problems and adapt to new situations." AllWords Dictionary, 2006

"...ability to adapt effectively to the environment, either by making a change in oneself or by changing the environment or finding a new one ...intelligence is not a single mental process, but rather a combination of many mental processes directed toward effective adaptation to the environment." Encyclopedia Britannica, 2006

"the general mental ability involved in calculating, reasoning, perceiving relationships and analogies, learning quickly, storing and retrieving information, using language fluently, classifying, generalizing, and adjusting to new situations." Columbia Encyclopedia, sixth edition, 2006

"The ability to acquire and apply knowledge and skills." Compact Oxford English Dictionary, 2006

"...the ability to adapt to the environment." World Book Encyclopedia, 2006

"The ability to learn and understand or to deal with problems." Word Central Student Dictionary, 2006

Intelligence definition

"Intelligence is not a single, unitary ability, but rather a composite of several functions. The term denotes that combination of abilities required for survival and advancement within a particular culture." A. Anastasi [2]

"We shall use the term 'intelligence' to mean the ability of an organism to solve new problems ..." W. V. Bingham [6]

"A person possesses intelligence insofar as he has learned, or can learn, to adjust himself to his environment." S. S. Colvin quoted in [35]

"Sensory capacity, capacity for perceptual recognition, quickness, range or flexibility or association, facility and imagination, span of attention, quickness or alertness in response." F. N. Freeman quoted in [35]

"...performing an operation on a specific type of content to produce a particular product." J. P. Guilford

"Ability to adapt oneself adequately to relatively new situations in life." R. Pinter quoted in [35]

There's a cluster of cognitive abilities that lead to successful adaptation to a wide range of environments." D. K. Simonton [33]

Intelligence definition

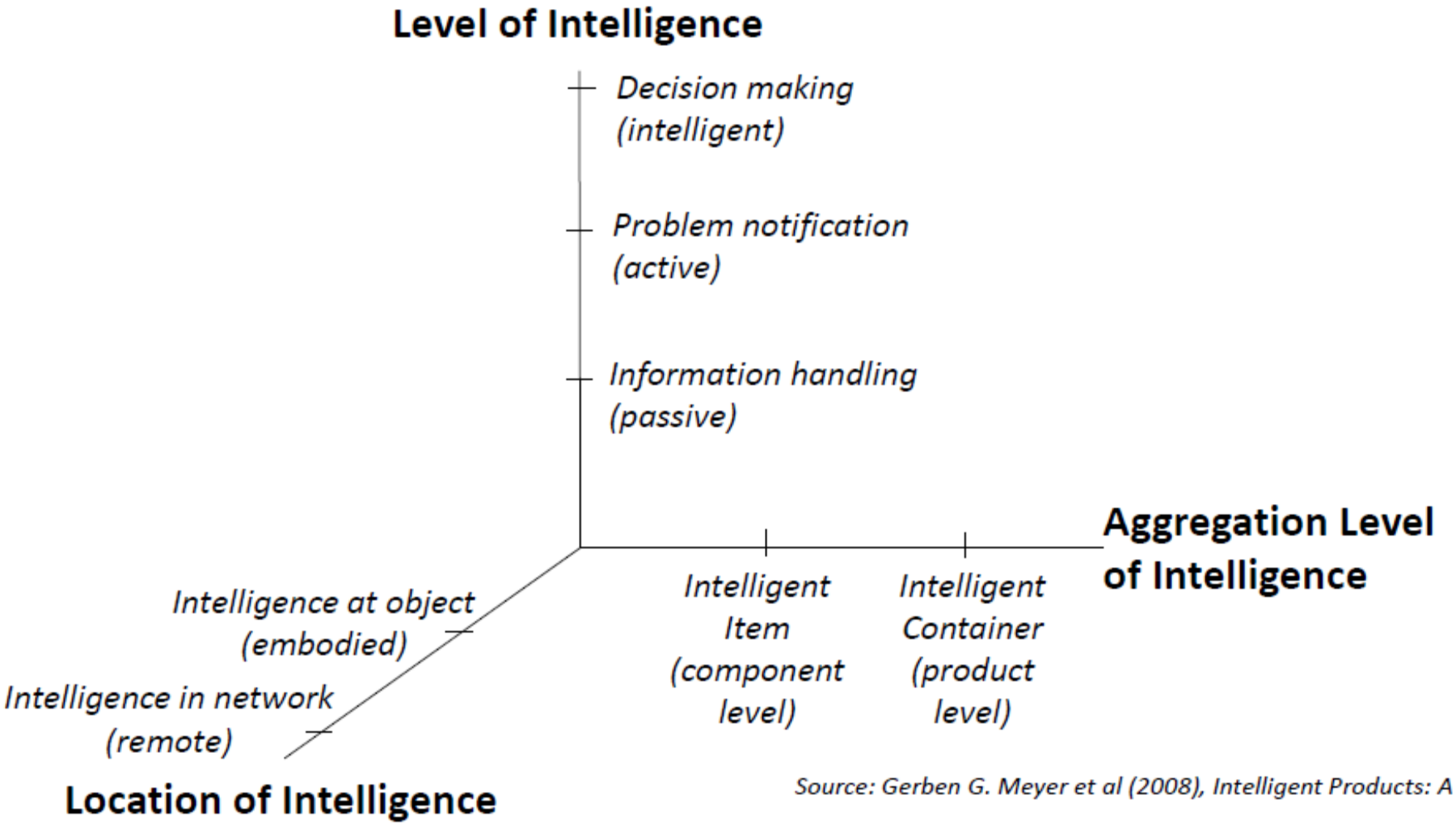
"...the ability of a system to act appropriately in an uncertain environment, where appropriate action is that which increases the probability of success, and success is the achievement of behavioral subtotals that support the system's ultimate goal." J. S. Albus [1]

"Any system ...that generates adaptive behviour to meet goals in a range of environments can be said to be intelligent." D. Fogel [10]

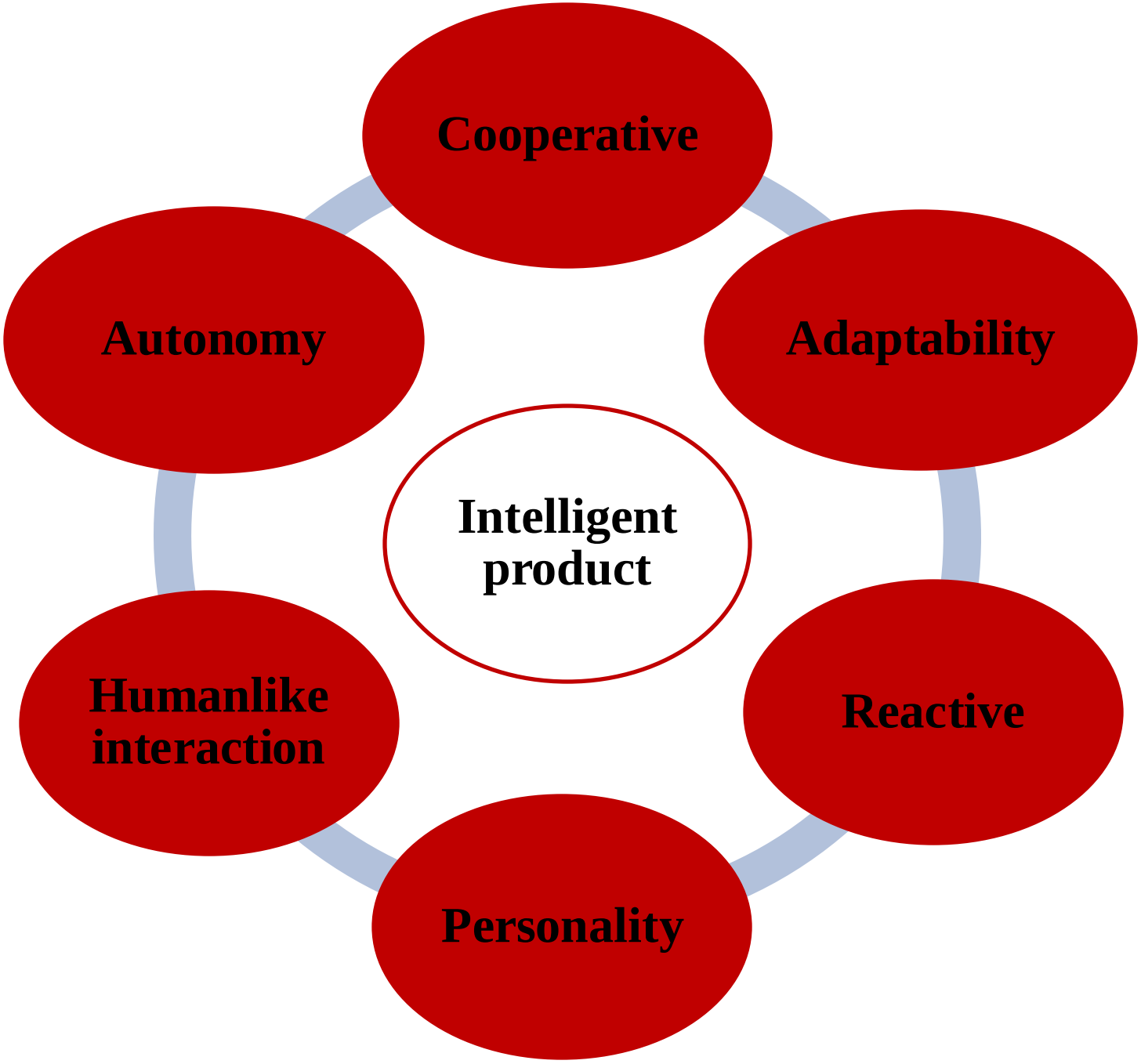
- Is a property that an individual agent has as it interacts with its environment or environments.
- Is related to the agent's ability to succeed or profit with respect to some goal or objective.
- Depends on how able the agent is to adapt to different objectives and environments.

"Intelligence measures an agent's ability to achieve goals in a wide range of environments." S. Legg and M. Hutter [22]

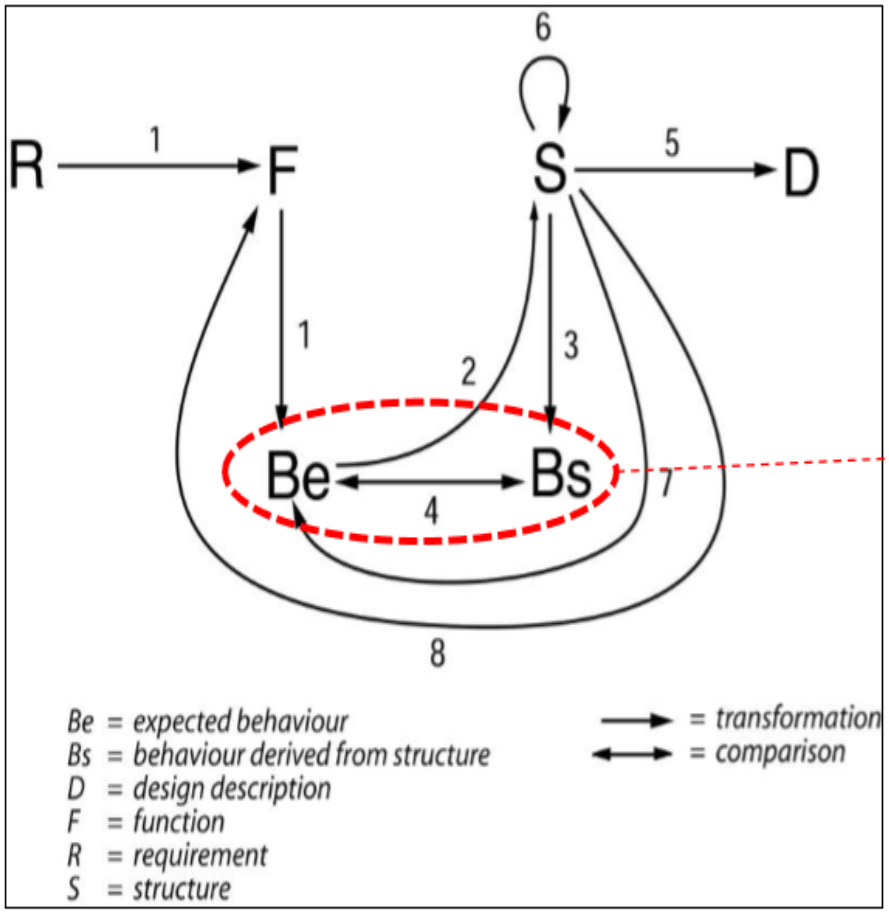
Classification of intelligent Products



Source: Gerben G. Meyer et al (2008), Intelligent Products: A survey


Cooperative
Adaptability
Reactive
Personality
Humanlike interaction
Autonomy
Intelligent product

Designing for Intelligent Behavior



Intelligent behavior like any other behavior depends on function and structure

The definitions of intelligence guide us to use metaphors / analogies of human / living / natural systems for designing intelligent systems ... But, what do we hope to extract from the metaphors / analogies and how do we do it? Can they say something about F/S?

And, what is the connection between information intensity and intelligence?

Metaphor based intelligent system design

• It is unique in the way that Ashby used rather sophisticated mechanical concepts, such as equilibrium and amplification, which were not particularly favored by other researchers
• And moreover, he used these concepts not merely metaphorically, but also imported their associated mathematical formulations as a basis for quantifying intelligent behavior.

•Equilibrium

•Amplification

• It is unique in the way that Ashby used rather sophisticated mechanical concepts, such as equilibrium and amplification, which were not particularly favored by other researchers
• And moreover, he used these concepts not merely metaphorically, but also imported their associated mathematical formulations as a basis for quantifying intelligent behavior

Exploiting the mathematical formulations of “equilibrium”
• Animal and human behavior shows many features. Among them is the peculiar phenomenon of “adaptiveness.” Although this fact is easily recognized in any given case, yet it is difficult to define with precision
• It is suggested here that adaptive behavior may be identical with the behavior of a system in stable equilibrium, and that this latter concept may, with advantage, be substituted for the former
• Stable equilibrium is necessary for existence, and that systems in unstable equilibrium inevitably destroy themselves… all dynamic systems change their internal organizations spontaneously until they arrive at some state of equilibrium

A scientific approach to using metaphors in design: Ashby on mechanisms of mind (1951)

• Intelligence is understood as a combination of the abilities to produce a great many meaningless alternatives, and to eliminate by appropriate selection the incorrect choices among those—a two stage process.

• All forms of intelligence depend necessarily on receiving information in order to achieve any appropriate selection that they make. And the greater the set of possibilities and complexity of the partitioning of alternatives, the more information will be required for the selection to be appropriate. … Increase in information intensity is a pre-requisite for intelligent behavior

How to increase/amplify/manage the information intensity

Bio-inspired intelligence behavior and system
Living system theory

Adaptive systems are composed of deferent heterogeneous parts or entities that interact and perform actions favoring the emergence of global desired behavior.

Further more, entities must **self-evolve and self-improve** by learning from their interactions with the environment. The main challenge for engineering these systems is to design and develop distributed and adaptive algorithms that allow system entities to select the best suitable strategy/action and drive the system to the best suitable behavior according to the current state of the system and environment changes.

During the past few years, research in artificial intelligence, agent-based systems, mobile and autonomous robots, distributed systems, and autonomic systems, has focused on the development of adaptive approaches and systems that modify their own behavior at run-time to address constantly changing environments. Some of these approaches are inspired by features and capabilities seen in natural and biological systems, e.g., human brain, immune systems, ant colony, flocks of birds.

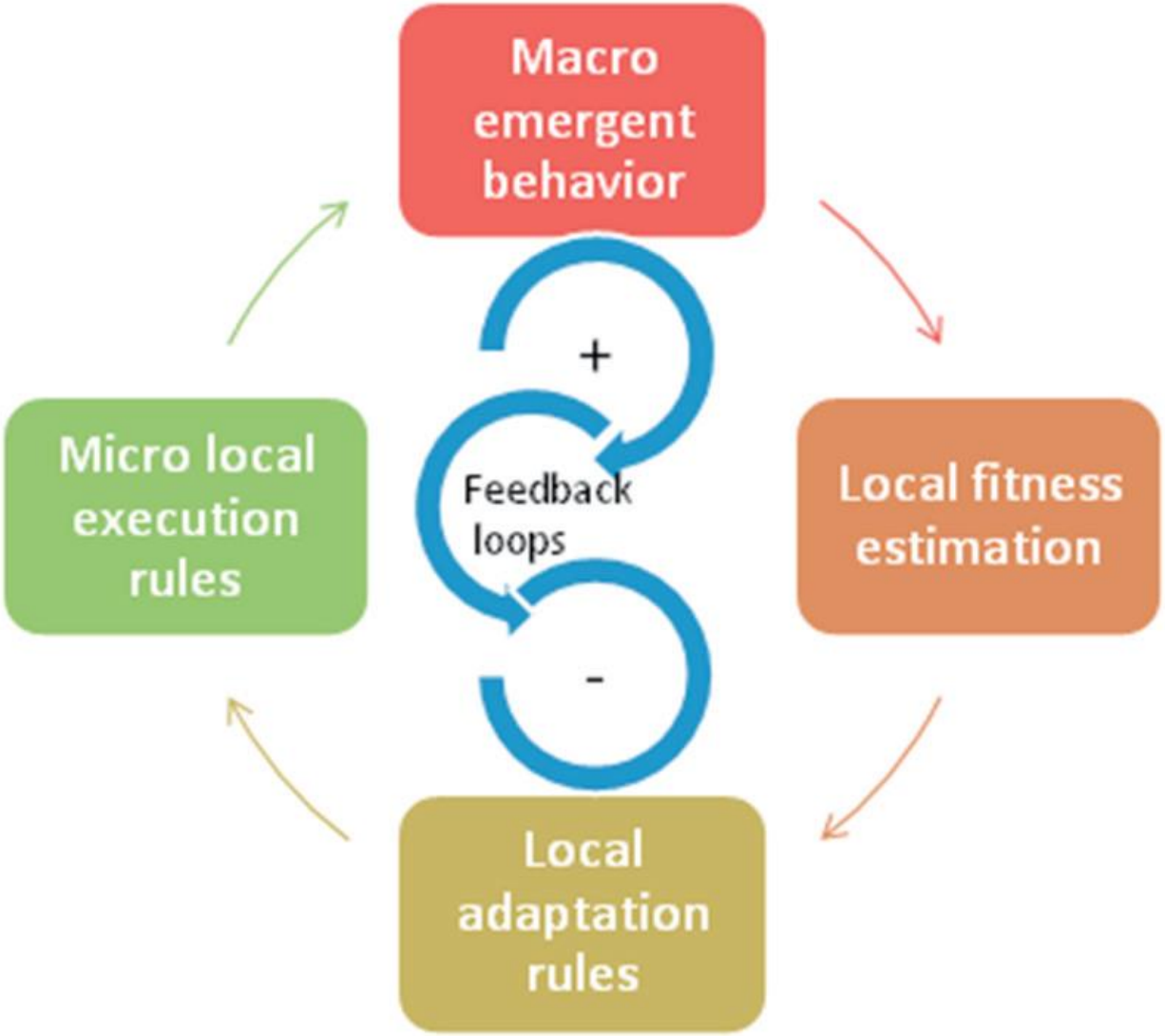
self-aware (e.g., self-configuration, -organization, -optimization) properties

Recent studies have emphasized that designing adaptive systems requires a shift from the current top-down design approach to a bottom-up design approach

1) how to design basic system components in which decisions are distributed and not fully controlled by a single component?,
2) how to design strategies (at micro level) that allow the system to adapt to environment changes (at macro level) by selecting the best suitable actions/strategies?,
3) what are the dynamic rules that drive the system to the expected behavior (i.e., reliable, performance and energy efficient)?,
4) What are techniques and tools for studying the electiveness of these mechanisms and evaluating the expected functionalities and performance metrics?.

feedback loops are core design elements and should be made explicit in modeling, design, implementation, and validation approaches

MAPE-K (monitor, analyze, plan, execute over a knowledge base) can be also seen as a feedback loop17



positive and negative feedback loops also seen in natural and biological systems

Positive or self-reinforcing feedback amplifies the current change in the system.

Negative or self-correcting feedback seeks balance and provides equilibrium by opposing the changes taking place in the system.

The two types of feedback should be combined to insure the stability of the system.

The most common techniques use *if/switch statements to evaluate the* local function or expression to select a suitable action

honey bees, the waggle dance could be seen as a positive feedback to attract the attention of other entities about foraging at a specific location

The biological immune system can be seen as a *massively distributed architecture* with a diverse set of cells distributed throughout the body but *communicating using chemical signals.*

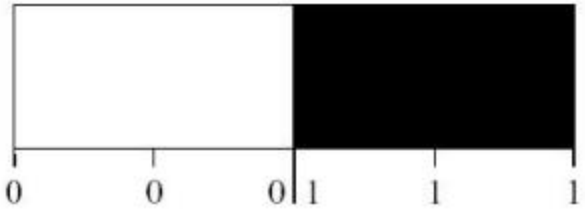
There is *no central control (i.e. distributed); the multitude of independent cells work together resulting in the emergent behavior* of the immune system.

The immune system *evolves to adapt and improve the overall system performance (e.g.* organizational memory).

Other swarm based distributed broadcasting approaches inspired by Ants and Bees direct and indirect communication principles for VANETs are proposed in 39. For example, when an abnormal environmental event is noticed on the road surface, a safety message is created to inform other vehicles and roadside units along its way. This is similar to Ant/Bee behaviour, i.e. when an Ant/Bee observes a food source it creates pheromone/dance to convey indirectly to other Ants/Bees about route information of that food source. Similarly, when a vehicle *vi observes an event pj that* needs to be disseminated to other vehicles, it will generate a safety message *mpj and will report to RSU (Road Side* Unit). This message includes a timestamp *t0*, *the location information*, *and an initial relevance value R0v i ,pj (t0) and is* disseminated periodically up to a time *T, which represents the maximum timespan required to handle the event*

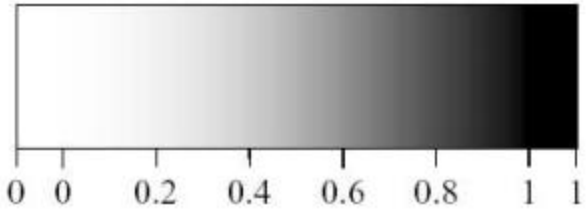
AI techniques

Rule based expert systems



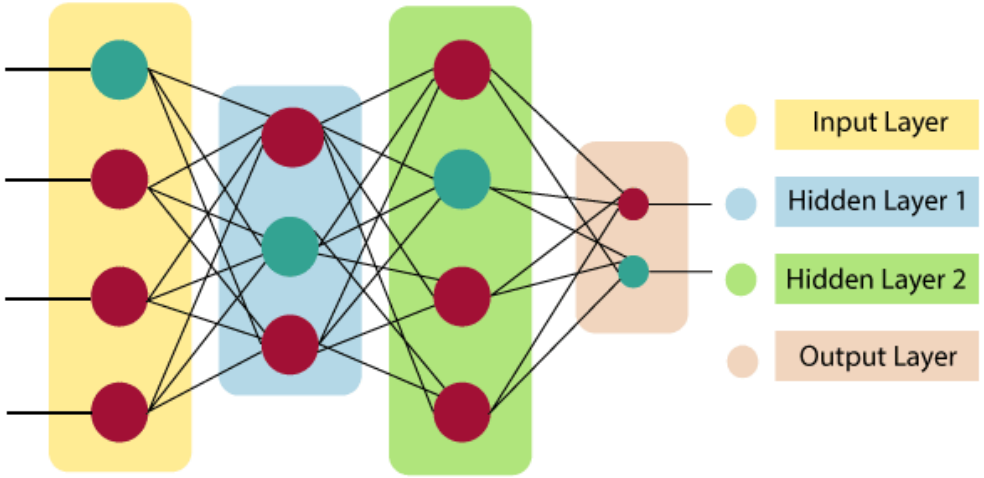
(*a*) Boolean Logic.

Fuzzy Logic/expert systems

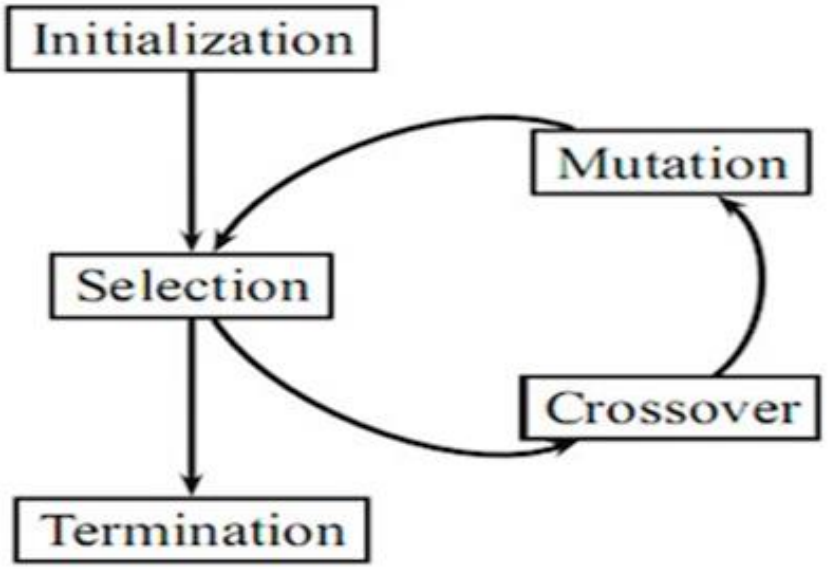


(*b*) Multi-valued Logic.

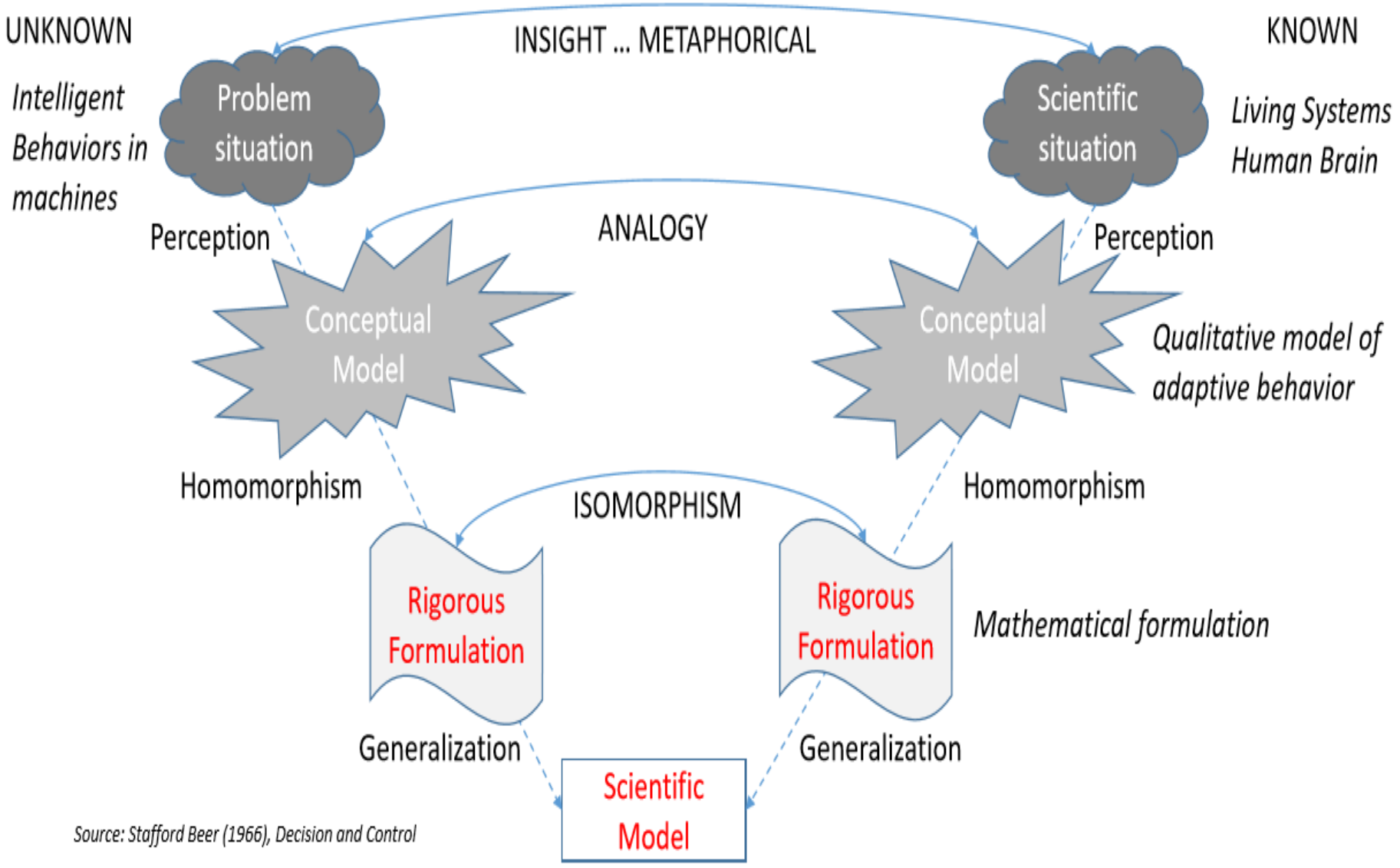
Artificial neural networks



Evolutionary computation



An approach to using analogies for intelligent systems design



Source: Stafford Beer (1966), Decision and Control

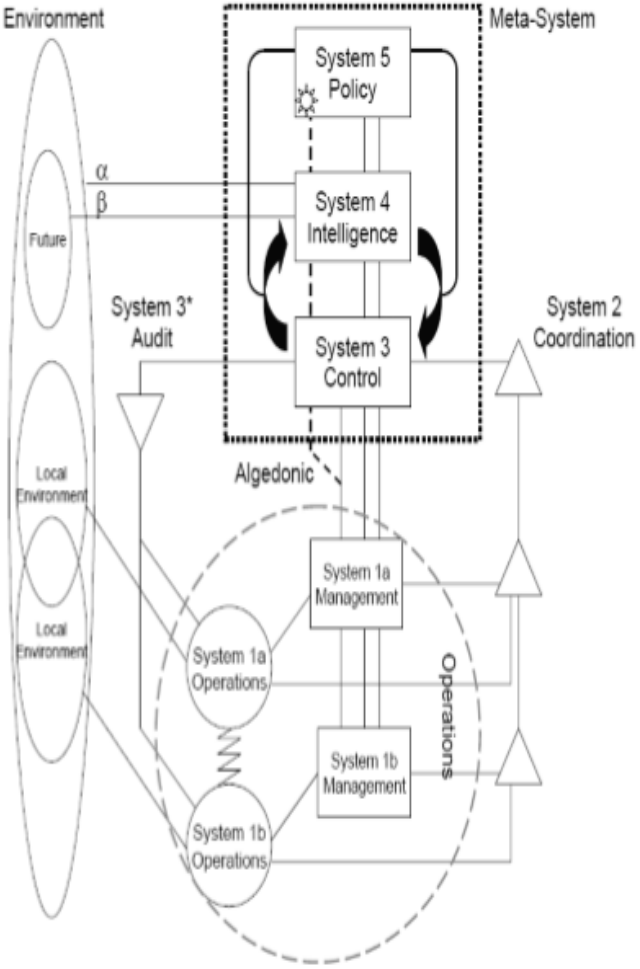
Architecture for Intelligent Behavior based on principles of viability

Developed by Stafford Beer (1979) – based on Ashby's Design for Brain

Viability is the ability to maintain an independent existence

Based on principles of requisite variety, self-regulation and recursion

Viable systems comprise five key functions at every level of recursion



Policy (System 5)
Provides closure

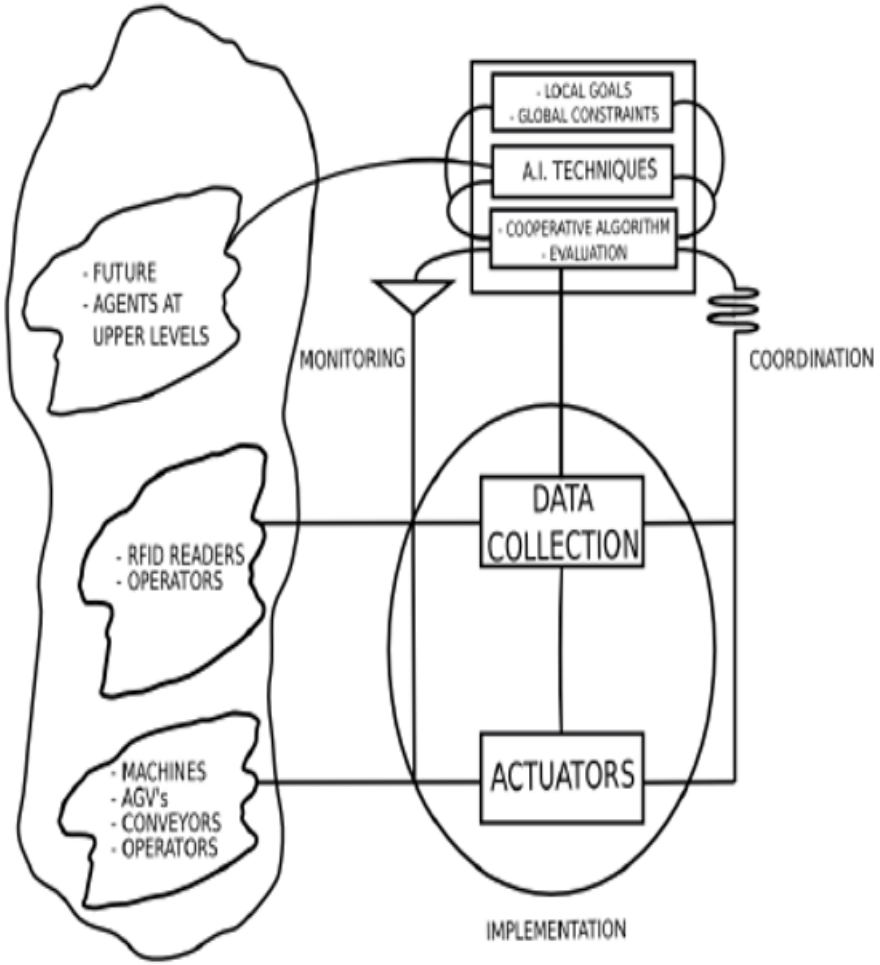
Intelligence (System 4)
Identifies external opportunities and threats

Monitoring and Control (System 3)
Monitors internal strengths and weaknesses

Co-ordination (System 2)
Reduces instability across system 1s

Operations (System 1)
Directly interacts with the environment Equivalent to the core functions of the product. But, may also include those processes that have extensive interaction with the environment Indicates the actual purpose of the system

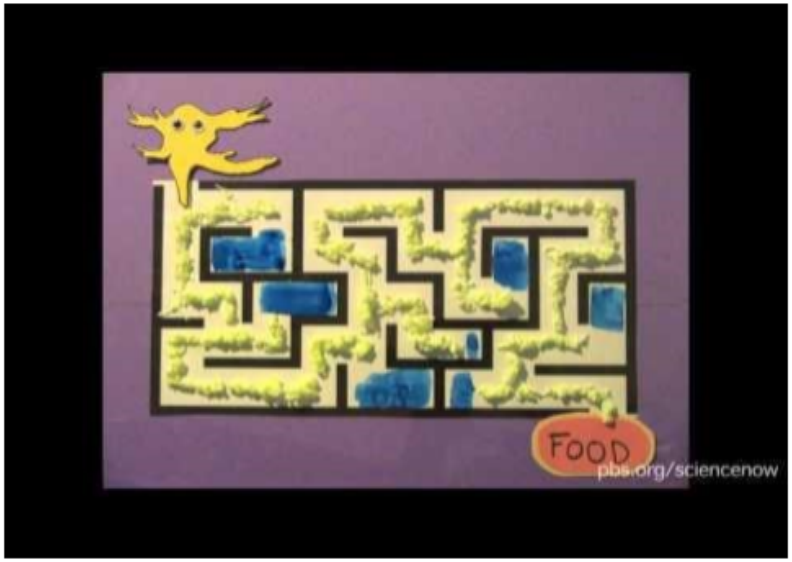
Intelligent Product as a Viable System



Function	Description
Primary Activities	Input / Output data (data collection) Environment interaction activities (actuators)
Coordination	Communication between data collection and interaction activities
Control	Internal activity regulation by coordinating and monitoring Auto-organization and evaluation Cooperative algorithm (interaction with other products)
Monitoring	Sporadic audit of the primary activities
Intelligence	External knowledge, future anticipation, response actions
Policy	Local goals and global constraints

Collective Systems

- There are several natural phenomena where simple agents appear to produce complex collective behaviors
- They do not require a global plan or a central coordinator, and are robust to malfunction or deviations of some individual
- Different terms used to refer to these: Complexity Theory, Complex Adaptive Systems, Multi-agent Systems
- Example: Ant Colonies, Honey Bees, Flock of Birds, Slime Mold Smarts…

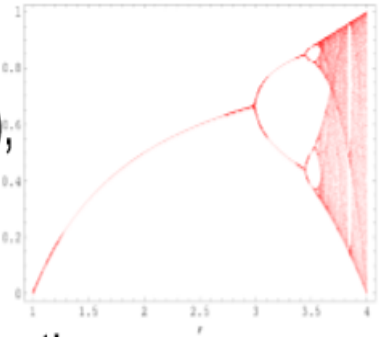


https://www.youtube.com/watch?v=lls27hu03yw

Principles of Collective Systems

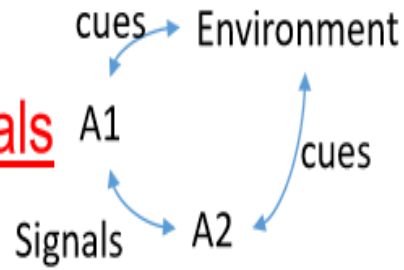
- Self-organization in biological systems is based on two types of interactions
- Attraction or follow (Positive Feedback)
- Repulsion or avoid (Negative Feedback)

- Such systems exhibit multiple states of equilibrium and trajectories
  - For example, the logistic equation $N_{t+1} = rN_t\,(1 - N_t/K)$, which describes the evolution of the population size N, produces
    - a gradual extinction when the parameter r is smaller than 1 ($0 < r < 1$),
    - a growth to a constant value for $1 \leq r < 3$,
    - the oscillation between two different sizes for $3 < r \leq 3.4$, and
    - multiple states for $r > 3.4$ that quickly display chaotic trajectories where the population can transit between several unpredictable, but not random, sizes



- Parameter r is partly or entirely determined by genetically dependent factors. Evolution may favor parameter values that generate stable behaviors, such as in the regulation of the nest temperature

- Interaction between animals occurs by means of cues and signals



- A cue is an unintentional index that be picked up by an animal, such as a trail in the snow. The perceiving animal can decide whether to follow (positive feedback) or avoid (negative feedback) the cue
  - *Stigmergy* is a specific type of cue based communication through modification of the environment. The result of work by an individual affects the action of another individual … foraging strategy of ants that deposit pheromones
- A signal is an intentional index emitted by an animal that is intended to affect the behavior of other receiving animals.
  - For example, the alarm cry of some birds when a predator approaches, human language

Aggregation: This behavior can be produced using models of positive & negative feedback loops - by assuming that fish displays four behavioral reactions that depend on the position and orientation of other fish:

a) if there is another fish in its immediate neighborhood, the focal individual will move away to avoid collision (negative feedback)
b) if there is another fish at an intermediate distance, the focal individual will tend to align along its orientation
c) if there is another fish at a greater distance, the focal individual will tend to swim toward it (positive feedback)
d) if there is no fish in sight, the focal individual will perform random search movements

- **Clustering & Sorting**

• Several ant species engage in clustering and sorting of objects. For example,

• Eggs are organized in regular patterns where neighboring eggs have similar maturation times for more efficient feeding

• Corpses of dead ants are organized in large clusters at the periphery, or near walls, of the nest for better circulation

Clustering & Sorting: These types of clustering and sorting behaviors can be explained by variations of a simple behavioral model that combines positive and negative feedback. Example,

• The probability that an ant picks up an object is inversely proportional to the number of objects that it has experienced within a short time window. Therefore, the ant will tend to pick up isolated objects, but won't remove objects that occur in clusters

• The probability that an ant deposits an object is directly proportional to the number of perceived objects in a short time window. Therefore, the ant will be more likely to deposit an object near larger clusters of objects

• Sorting behaviors may be explained by adding different response probabilities for different types of objects in the environment

- **Nest Construction**

• Termites and wasps collectively build nests whose architectural complexities exceed the perceptual and cognitive abilities of single individuals

• A number of models based on positive and negative feedback have been advocated to explain how such engineering feats can be realized without a plan or a master architect

• All models rely on stigmergic communication whereby the perception of the result of previous work triggers specific construction behaviors genetically encoded as stimulus response associations

Foraging

• Some ant species lay a pheromone trail (stigmergy) that is used to select a path, find the shortest one, and establish a link between the food area and the nest – increasing efficiency of collective foraging

• If the ants are presented with two paths of different length, they will tend to choose the shorter one because ants on the short path return earlier to the nest and thus leave more pheromones on that path

Learning outcomes

- Identify and define the right type of intelligent behavior for a chosen product concept

- Design high-level functional and component (structural) architecture for intelligent behavior using appropriate metaphor and analogy

- Evaluate and select the right AI technique for the proposed functional and component architecture and vice versa

TASK 1

Derive 15 features / functionalities you can define in the “system of your project”

A “**context**” driven “**creative process**” of developing the **objects/systems/products**::

“Context” (conditions/constraints) – User centric/ human centric / environment centric”

TASK 2

Understand one simple system in your surroundings (follow PCP)

TASK 1

Design a symbol for class room and realize the outcome with a white paper

A "**context**" driven "**creative process**" of developing the **objects/systems/products**::

"Context" (conditions/constraints) – User centric/ human centric / environment centric"

Task - 3

Know and write about the 4 smart systems you know about

Task 4: Apply intelligence definition

Assignment 1

1. Observe the event

2. Analyze which acts and processes you consider as intelligence and why

3. Put it down on paper

Computer with Anti-virus and performance monitoring code

Develop the smart dining table concept using different levels of intelligence

Consider (table + chairs) as a system

You can start by applying definition of intelligence

You can apply multiple levels of intelligence, no restriction

Upload the concept in the shared assignment

Intelligent products

Technical foundations of intelligent products

1. Automatic identification
2. Embedded processing
3. Distributed information storage and processing
4. Agent based system
5. Technologies for fault detection
6. Remote maintenance


Cooperative
Adaptability
Reactive
Personality
Humanlike interaction
Autonomy
Intelligent product

Task 3

Develop the smart dining table concept applying different intelligence dimensions

- Analyze the concepts of equilibrium and amplification in the event ?

Relation between information intensity and intelligence

Where this event (Analyzed behavior/conceptual model) can be used as metaphor?

Recall what we discussed so far

- Definition of intelligence
- Levels of intelligence
- Dimensions of intelligence
- Intelligence and information intensity relation (equilibrium, amplification)
- Bio-inspired adaptive systems (Positive and negative feedback)
- AI techniques
- Theory of living systems
- Theory of viable systems
- Collective system model