Artificial Intelligence: main paradigms

Additional reading:

R.C. Arkin, *Behavior-Based Robotics*: Chapters 1, 2

R. Pfeifer & C. Scheier: *Understanding Intelligence*: Preface; Chapters 1, 3

The object of AI

- Engineering: designing, building "intelligent" machines (that are somehow "better")
- Science: investigating the nature of intelligence
  - > ***Understanding by building (synthesis)***

- What is "artificial"
  - Herbert A. Simon (1969, 1981), *The Sciences of the Artificial*. Cambridge, MA: The MIT Press.
- What is "intelligent"
- What is "constructive"?

Artificial?

- Artificial:
  - Artifice, fake (negative connotation)
  - "Artificial X" => functionally equivalent to X. Model.
- "Natural"?
  - Not the same as "biological" (forest vs farm)
- Four features of "artificial" vs "natural:
  - Artificial things are synthesized (although not always with full forethought) by humans; (but also synthetic vs artificial)
  - Artificial things might imitate "appearances"/ features in natural things while lacking, in one or more respects, the reality of the latter
  - Artificial things can be characterized in terms of functions, goals
  - Artificial things are often described (particularly from design point of view) in terms of imperatives (normative, how things ought to be) as well as descriptives (how things are)

Intelligence?

a) Symbolic (classical) AI:

- Functionally equivalent to "human intelligence" (rationality, thought)
- Symbolic representations, manipulating symbols by applying rules

b) Embodied "complete agent/creature" approaches:

- Intelligent behavior of creature adapted to particular environment => ***Embodied AI***
- Life-like behavior, properties of life => ***Artificial Life***

➢ Intelligence is not (only nor primarily) rationality:

- Situated cognition (symbolic, embodied)
- Embodied AI, Artificial Life
- Affective computing, ***Affective robotics*** (symbolic, ***embodied***)

Why Embodied AI?

"While symbolic approaches to cognition can give us good intuitions on how intelligence might work once it has already acquired symbols, they cannot tell us how to build those symbols nor help us to identify and manipulate non-symbolic aspects of our system" (Brooks & Stein, 1994)

- **The big problems of symbolic AI**:
  - The (symbol) grounding problem
  - The frame problem
  - How to capture tacit ("common sense") knowledge?

➢ *Embodied AI: alternative approach that attempts to overcome (avoid) those problems*

"New" vs "Classical" AI is misleading

- Both paradigms are rooted in the 1940s, 1950s
- Cybernetics
  - Embodied AI
- Dartmouth conference (Summer 1956)
  - Foundation and "labeling" of AI as discipline

Agent: general characterization

Agent => physical or virtual (software) entity …

a) Able to act on its environment
b) Able to "communicate" with other agents
c) Driven by a set of tendencies (individual goals, optimize fitness function, etc.)
d) Possessing its own resources
e) With (limited) capability to perceive its environment
f) Having a (at best) partial representation of its environment
g) Possesses competences and can "offer services"
h) Capable of reproduction (optional)
i) Its behavior tends to the satisfaction of own objectives, account taken of available resources and competences, and as a function of perceptions, representations, and communication

Software agent

Computational entity that …

a) Inhabits an open computational system (set of applications, networks and heterogeneous systems)
b) Is able to communicate *directly* with other agents
c) Driven by individual goals (often on behalf of humans)
d) Possesses its own resources
e) ---
f) Has a partial representation of other agents (its environment)
g) Possesses competences (services) that can offer to other agents
h) ---
i) Its behavior tends to the satisfaction of own objectives, account taken of available resources and competences, and as a function of perceptions, representations, and communication

Embodied (complete) agent (*creature*)

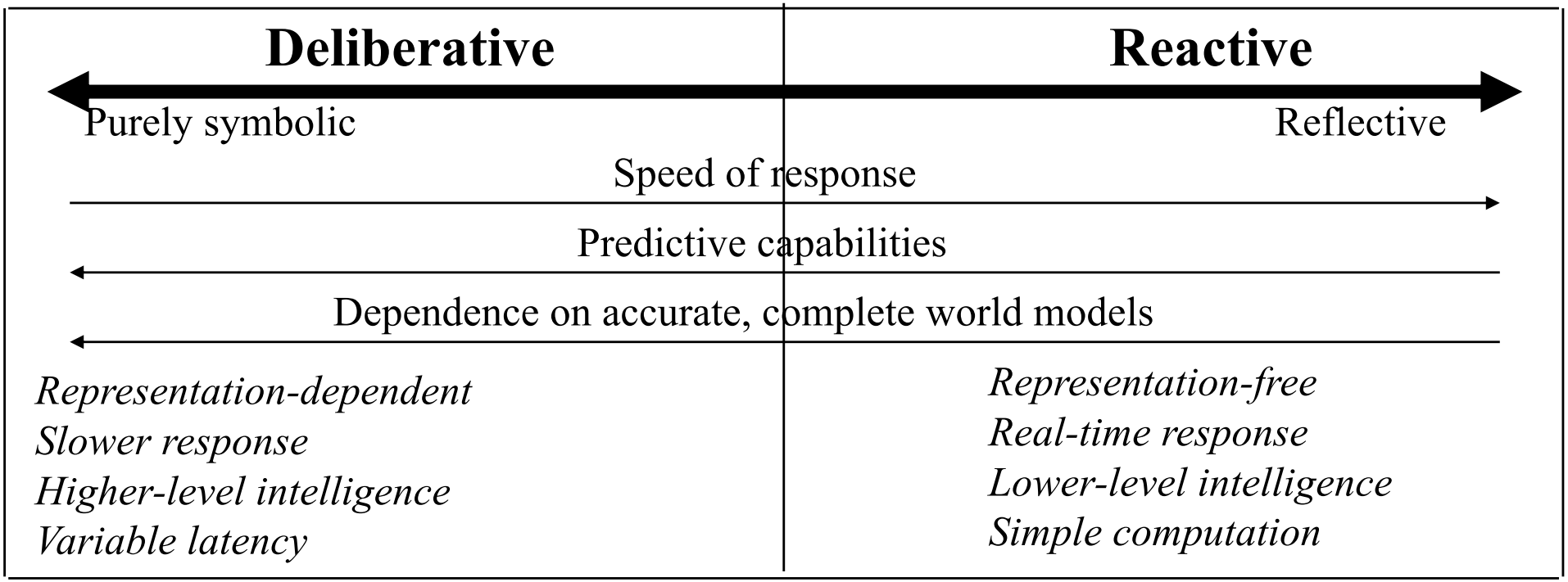
Physical (or simulation of physical) entity that …

a) Is *situated* in its environment and interacts through it
b) Able to "communicate" with other agents *through the environment*
c) Driven by *survival*-related goals
d) Possessing its own resources (energy, tools)
e) Has very limited capability to perceive its environment
f) Has no or very partial representation of its environment
g) Possesses competencies (behaviors)
h) Capable of reproduction (some times)
i) Its behavior tends to the satisfaction of its survival needs, account taken of available resources, perceptions, and competencies

What Creatures are NOT:

- An agent that can be viewed as perceiving its environment through sensors and acting upon it through effectors (input/output)
  - ***> Not enough, the perception-action loop must be closed***
- A rational agent that does the right thing. For each possible percept sequence, an ideal rational agent should do whatever action is expected to maximize its performance measure, on the basis of the evidence provided by the percept sequence and whatever built-in knowledge the agent has.
  - ***> What is "the right thing" in the real world?***
  - ***> Rationality is not needed for everything***
- A system is autonomous to the extent that its behavior is determined by its own experience
  - ***> How about its interactions with the environment??***
  - ***> Autonomy is a matter of degree***

Types of agents



Types of behaviors / Relation to world	**Cognitive relation**	**Reactive relation**
Teleonomic	*Intentional agents*	*Motivated agents*
Reflex	*"Modules"*	*Tropic, reactive agents*

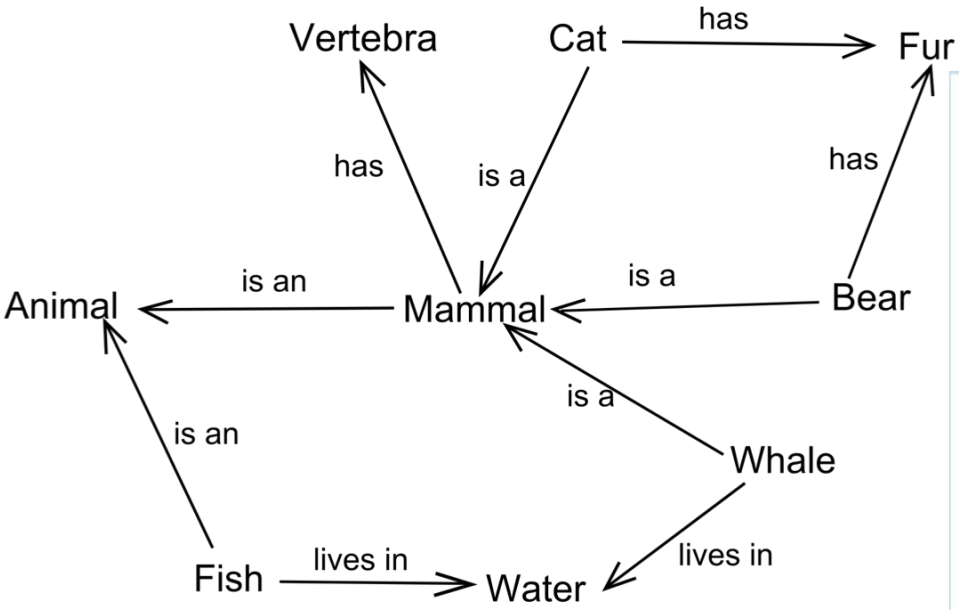
Representations

Purely cognitive agents — **Purely reactive agents**

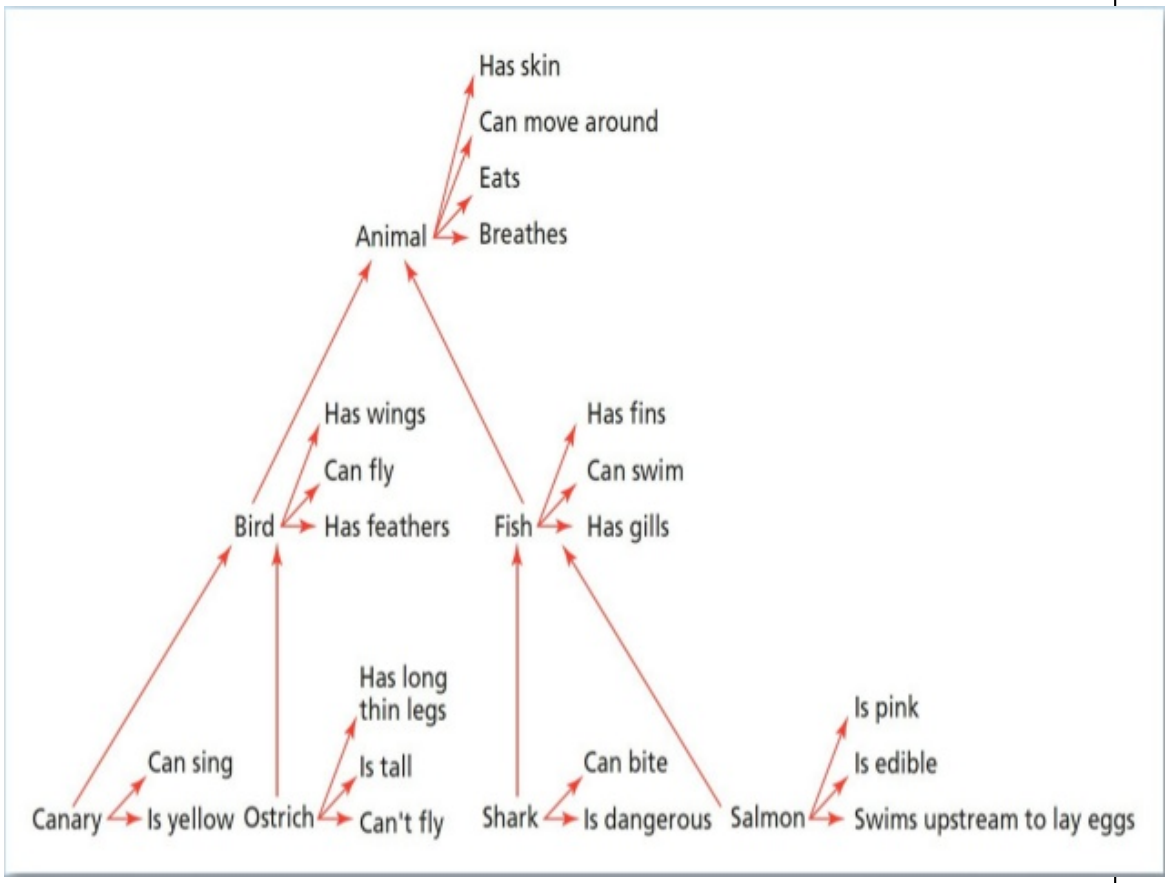
symbolic representations only	Mixed symbolic-numeric representations	Non-symbolic representations	Absence of representations (real world)

⇨ *Influence the ability to solve complex tasks individually and the ability to anticipate outcomes, behaviors, etc.*

Examples of Symbolic AI representation



Semantic network



Memory

Intelligence in symbolic AI

Newell (1990) -> unified theory of cognition

("same set of mechanisms underlying all cognitive behavior")

Cognitive psychology
Cognitive sciences
Symbolic processing
von Neumann computer

Human(-like) intelligence

performance

1. Flexible behavior as a function of the environment
2. Adaptive behavior (rational, intentional)
3. Real-time operation
4. Deal with rich and complex environment:
    - 4.1 perceive richness of changes
    - 4.2 intensive use of knowledge
    - 4.3 control motor system with many DoF
5. Use symbols and abstractions
6. Use of language (natural and artificial)
7. Learning from the environment
8. Develop new capabilities
9. Live autonomously in social environment
10. Consciousness and notion of identity

embodiment

11. Implemented as a nervous system
12. Generable through embryonic processes
13. Generated through evolution

Intelligence in Embodied AI

Brooks (1986) -> intelligent (adaptive) behavior in complete creatures

Ethology
Cybernetics
Biology
Evolution
Neurosciences
Ecological psychology

⇓

Behavioral Competencies
(ethograms)

6. Reason about behavior of objects in the world and modify "plans" accordingly

5. Reason about world in terms of identifiable relevant objects and perform tasks related to given (relevant) objects

4. Notice changes in ("static") environment

3. Build (partial) maps of the environment and navigate from one place to another

2. "Explore" the world

1. Wander endlessly *and* avoiding obstacles

0. Avoid contact with other objects (static or dynamic)

Ethology

➢ *Study of animal behavior in its natural environment*

- **Four perspectives on behavior (Tinbergen)**:
  - *Causality*
    - Internal and external factors that determine that a behavior appears at a given moment and in a given context
  - *Adaptive value*
    - Benefits of a behavior for an organism and its offspring
  - *Evolution*
    - Evolution of a behavior in phylogenetic history
  - *Development*
    - Ontogenesis of a behavior (as result of individual history)
- **Key notions**:
  - Behavior (reflexes, taxis, kinesis, action patterns and tendencies) and ethograms
  - Ecological niche

Ethogram

Table 3-5. List of rodent behaviors utilizing both empirical and functional terms (from Eisenberg 1967).

General Maintenance Behavior

- Sleeping and resting
  - Curled
  - Stretched
    - On ventrum
    - On back
  - Sitting
- Locomotion
  - On plane surface
    - Diagonal
    - Quadrupedal saltation
    - Bipedal walk
    - Bipedal saltation
    - Jumping
  - Climbing
    - Diagonal coordination
    - Fore and hind limb alteration
  - Swimming
- Care of the body surface and comfort movements
  - Washing
    - Mouthing the fur
      - Licking
      - Nibble
    - Wiping with the forepaws
    - Nibbling the toenails
  - Scratching
  - Sneezing
  - Cough
  - Sandbathing
    - Ventrum rub
    - Side rub
    - Rolling over the back
    - Writhing
  - Stretch
  - Yawn
  - Shake
  - Defecation
  - Urination
  - Marking
    - Perineal drag
    - Ventral rub
    - Side rub
- Ingestion
  - Manipulation with forepaws
  - Drinking (lapping)
  - Gnawing (with incisors)
  - Chewing (with molars)
  - Swallowing
  - Holding with the forepaws
- Gathering foodstuffs and caching
  - Sifting
  - Dragging, carrying
  - Picking up
    - Forepaws
    - Mouth
  - Hauling in
  - Chopping with incisors
  - Digging
  - Placing
  - Pushing with forepaws
  - Pushing with nose
  - Covering
    - Push
    - Pat
- Digging
  - Forepaw movements
  - Kick back
  - Turn and push (forepaws and breast)
  - Turn and push (nose)
- Nest Building
  - Gathering
  - Stripping
    - Biting
    - Jerking
    - Holding
  - Pushing and patting
  - Combing
  - Molding
  - Depositing
- Isolated animal exploring
  - Elongate, investigatory
  - Upright
  - Testing the air
  - Rigid upright
  - Freeze (on all fours)
  - Escape leap
  - Sniffing the substrate
  - Whiskering

Continued on next page

total behavioral patterns, the greater the probability of misinterpreting results.

Table 3-5. Rodent behaviors (continued)

Social Behavior

- Initial contact and contact promoting
  - Naso-nasal
  - Naso-anal
  - Grooming
  - Head over-head under
  - Crawling under and over
  - Circling (mutual naso-anal)
- Sexual
  - Follow and driving
  - Male patterns
    - Mount
    - Gripping with forelimbs
    - Attempted mount
  - Copulation
    - Thrust
    - Intromission
    - Ejaculate
  - Female patterns
    - Raising tail
    - Lordosis
  - Neck grip
  - Postcopulatory wash
- Approach
  - Slow approach
  - Turn toward
  - Elongate
- Agonistic
  - Threat (proper) (remains on all four legs)
  - Rush
  - Flight
  - Chase
  - Turn away
  - Move away
  - Bite
- Agonistic (continued)
  - Locked fighting (mutual)
  - Fight (single)
  - Defense (on back)
  - Side display
    - Shouldering
    - Sidling
    - Rumping
  - Uprights
    - Class I (upright threat)
    - Class II
    - Locked upright
  - Striking, warding
  - Sparring
  - Tail flagging
  - Kicking
  - Attack leap
  - Escape leap
  - Submission posture
  - Defeat posture
  - Tooth chatter
  - Drumming
  - Pattering (with forepaws)
  - Tail rattle
- Miscellaneous patterns seen in a social context
  - Sandbathing
  - Digging and kick back
  - Marking
    - Ventral rub
    - Side rub
    - Perineal drag
  - Pilo-erection
  - Trembling

Cybernetics

- **Norbert Wiener** (1948): *Cybernetics*
  - ➢ Theory of control and communication in humans and animals
  - – Combines control theory, information science and biology (homeostasis)
- **W. Ross Ashby** (1952): *Design for a Brain*
  - – Organism designed like machine, using mathematical theory (feedback, control systems) to describe natural behavior
  - – Organism as dynamic system
  - – Survival as viability
  - – Adaptation as internal stability
- **W. Gray Walter** (1953): *Machina Speculatrix*, turtle
  - – Predecessor of behavior-based robots

G. Walter's tortoises 1

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

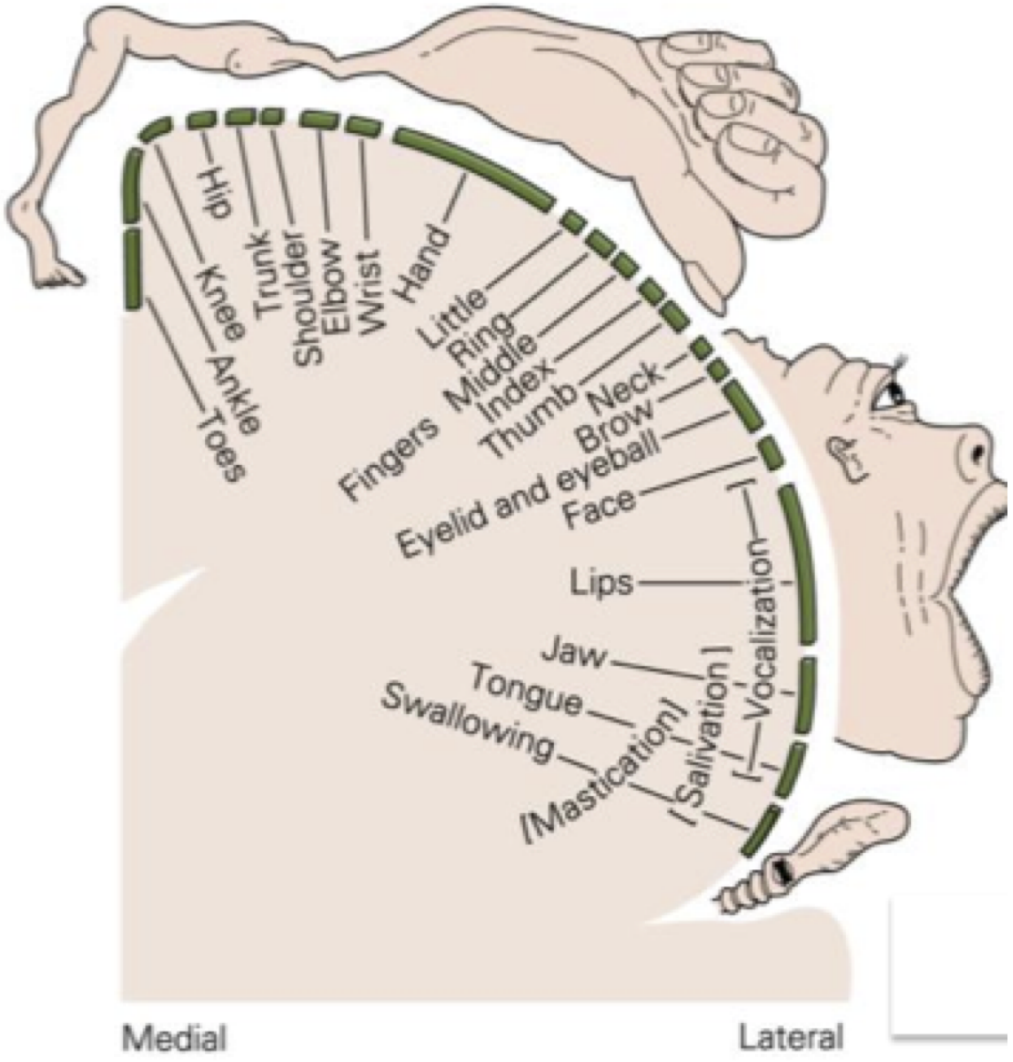
G. Walter's tortoises 2

https://www.youtube.com/watch?v=wQE82derooc

Biology

- **Evolution**:
  - Natural evolution as model to guide the design of artificial creatures
  - Approach to design: incrementally add behavioral layers of increasing complexity, without modifying lower-level ones.
- **Animals**:
  - Living examples of adaptive systems
  - Morphology is important for behavior/intelligence
  - Intelligent behavior at many levels, not necessarily "cognitive"
- **Neurosciences**:
  - Inspiration from the brain and its evolution
  - Study of underlying mechanisms that give rise to behavior => use this as source of inspiration for design

Somatotopic cortical map



"Ecological" Psychology

- **Gibson** (1979):
  - Thorough understanding of the environment in which an organism is situated and of how evolution affected its development
- **Notion of *affordance*** to explain the perceptual roots of behavior:
  - Things are perceived in terms of the opportunities that they afford for action (particular agent and environment)
  - Action is a direct consequence of perception
  - This results from an organism's evolutionary adaptation to the stimuli available in the environment where it is situated
- **Environment** is what the organism *perceives*
  - Different from physical world
- Observer and environment *complement each other*

Intelligence revisited

Symbolic AI

- Human cognitive capabilities
- Isolated cognitive competences (functions)
- Golden standard = rationality
- Focus on (measurable) results
- Centralization, unified view
- Internal rationality
- Knowledge, representation
- Evaluation: Turing test

Embodied AI

- *Ability to adapt to given environment*
- *Multiple (behavioral) competencies and control of their interactions*
- *Intelligence as continuum*
- *Focus on process, development*
- *Decentralization, diversity*
- *External intentionality*
- *Emergent behavior*
- *Evaluation: survival in the environment*

Genghis: foundational embodied AI robot

How does an embodied AI robot go from A to B?

https://www.youtube.com/watch?v=BUxFfv9JimU

Shakey: foundational symbolic AI robot

How does a symbolic AI robot go from A to B?

https://www.youtube.com/watch?v=qXdn6ynwpiI

Topics of AI: Symbolic AI

Division is specialized areas => human cognitive functions

Areas of U.T.C

- Problem solving, decision making
- Memory, learning
- Perception, motor actions
- Language
- Motivation, emotion
- Imagination, dreams
- Consciousness …

(Newell 1990)

Areas of AI:

- Natural language processing
- Knowledge representation
- Automated reasoning
- Learning
- Vision
- Robotics

(Russell & Norvig 1995)

… Turing test:

partial

total

Traditionally –> independent study of each function

New trend (since 90s) –>

- *"Agent" paradigm*
- *Integration of functions in "agents" (e.g., SOAR)*

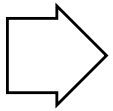
Topics of AI: Embodied AI

No division in areas => mechanisms that generate behaviors

Problem of AI:

Mechanisms and principles giving rise to complete creatures

Focus on building systems able to interact in and adapt to the real world and to learn from this interaction



- Embodiment
- Architectures
- Autonomy, self-sufficiency
- Adaptation
- Situatedness
- Emergent behavior
- Development, evolution
- Social behavior

EAI double (theoretical) objective

- **Short term**:
  - Contribute to the development of disciplines that study adaptive behavior in humans and other animals
  - Implementation of these models in complete creatures (software and robots)

- **Long term**:
  - Contribute to the development of cognitive sciences
  - Study to what extent it is possible to understand (animal, human) intelligence from an evolutionary perspective
  - How can intelligence be explained in terms of simpler adaptive behaviors inherited from other animals?

=> Understanding by building, synthesis

+ engineering objective => better adapted and more efficient robots