Organic Computing

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Autonomic/Organic Computing Systems

Outline

- General Concepts
  - Autonomy
  - Intelligence
  - Modularity
  - Reconfiguration
- Introduction to Autonomous system
  - Autonomous systems
  - Artificial Intelligence
    - Knowledge-based control
    - Fuzzy control
    - Neural network control
    - Genetic control

General Concepts

Autonomy

- Different levels/degrees of autonomy
  - Energetic level
  - Sensory, motor, and computational level
  - Decisional level
- Needed degree of autonomy depends on task/environment in which the unit has to operate
- Environmental unpredictability is crucial: robot manipulator vs. mobile robot vs. sensor node

Intelligence

- What do we mean by intelligence?
  - Ability to ‘solve problems’in some abstract or real domain
  - Ability to produce behaviour appropriate to a situation
  - Ability to act in the environment so that a viability condition is always satisfied and the individual identity (in a broad sense) is maintained.
- What is it that has intelligence?
  - A natural system of one or more agents
  - An artificial system of one or more agents (computational entities or robots)
- At opposite ends of the scale:
  - Human intelligence vs. insect intelligence
- How useful is each of these as a model for intelligent artificial systems?

Intelligence

- Individual human intelligence
  - Highly capable, extremely flexible
  - Consciously reason about the problem, seeking new information where necessary, and generate and execute a plan.

- Individual artificial intelligence
  - Capable in niche areas, inflexible
  - Apply rules of logic and reason to an abstract representation of the problem situation, seeking new information where necessary, and generate and execute a plan.

Intelligence

- Individual insect intelligence
  - Extremely capable and flexible within niche (specialist) situations, generally incapable outside them. Cued to environment – incapable outside
  - Specialised behaviours triggered by specialised sensing; chaining of behaviours by internal or external cues; suppression of some behaviours by others.

- Insect level robots
  - “Insect lab”Rod Brooks AI lab at MIT, 1985
  - Excellent at low level tasks in particular environments, often flexible, easy to build, often robust to component failure.
  - Mimic individual insect intelligence -Specialised behaviours triggered by specialised sensing; chaining of behaviours by internal or external cues; suppression of some behaviours by others.

Collective Intelligence

- A team is provided with collective intelligence if the viability of the team is required in order to achieve the viability of the individual (Theraulaz, 1995).

- Can be applied to the Swarm Intelligence definition as well

Why Machine-Learning?

- Complementarity to a model-based approach: when low-level details matter and/or good solution do not exist!
- Design and optimization techniques robust to noise, nonlinearities
- Automatic design and optimization techniques
- Research issues: individual vs. group capabilities, homogeneous vs. Heterogeneous systems, off-line vs. on-line techniques, etc.
- Unsupervised, evaluative techniques such as Genetic Algorithms, Reinforcement Learning

Modularity – Individual Level

- Sensors, computation, actuation
- Array of sensors-> 1 sensor “module” for a given modality (e.g. camera, belt of proximity sensors)
- Computation: control/communication
- “Functional” blocks: (sensor-computation-actuation), (sensor-computation), etc.
- Interconnection via (wired) buses (e.g., SPI, I2C) and interfaces
- Predefined protocols for communication between modules (e.g., master-slave, addressing, …)

Modularity – Collective Level

- An additional dimension of modularity
- Basic component: 1 individual
- Fully functional – can in principle work as “stand-alone” machine
- Connectivity:
  - Explicit communication (e.g., peer-to-peer, broadcast; dedicated channel; temporally: short scale);
  - Implicit (through signs in the environment, e.g. stigmergy; temporally: long scale, including unlimited in time)
- Network of networks …

Reconfiguration

- Modification of the system structure
- Can be done at run-time while the system is running or not
- Modification of the structure can be done to the entire system or only on part of it
- System structure includes hardware as well as software
- Software reconfiguration is always possible
- However, hardware reconfiguration requires a viable hardware structure
  - Mechanical appropriate: configurable robots
  - Control hardware appropriate: FPGAs

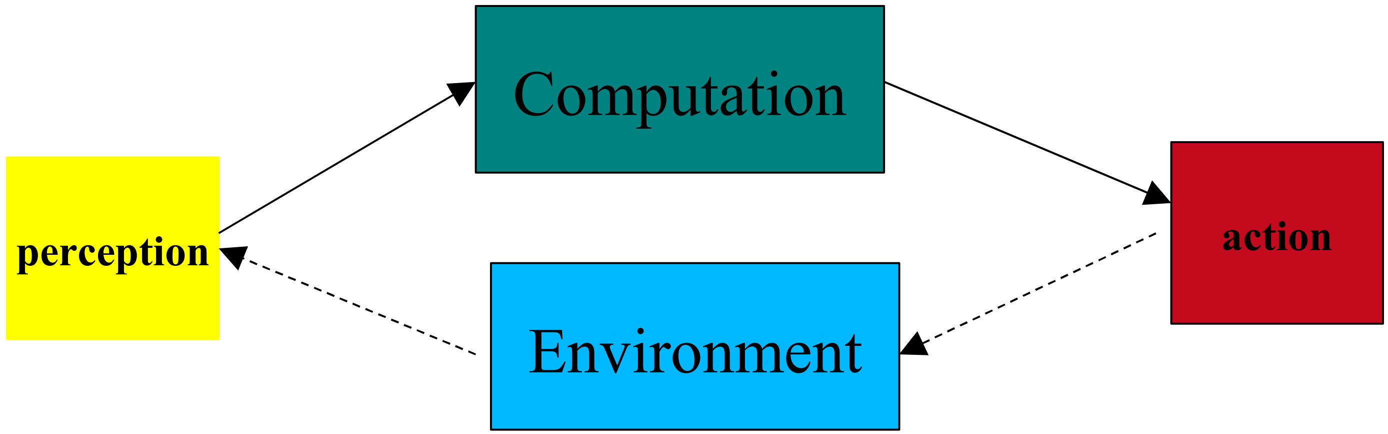
Introduction to Autonomous system

Autonomous Systems

- Autonomous systems belong to the class of feedback control systems
- Autonomous systems observe their environment Attempt to take actions when need
- Autonomous systems are particular type of control system in that they are able to reason before taking any action
- A control system is an arrangement of component connected or related in such a manner as to command, direct, or regulate itself or another system

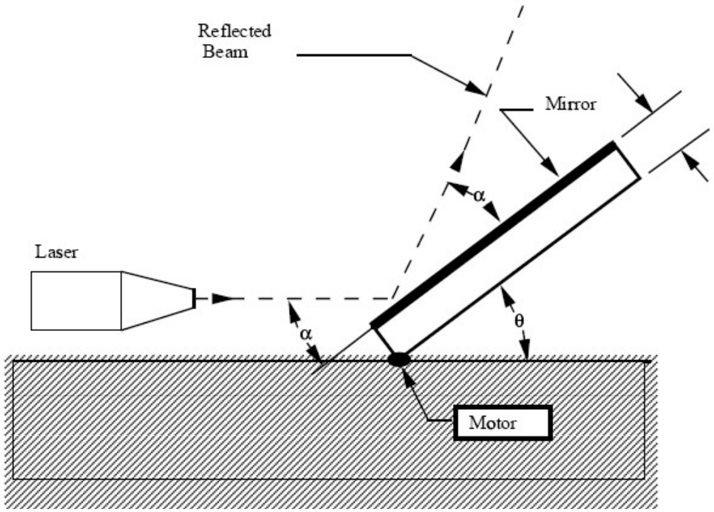
Autonomous Systems

- The input is the stimulus or excitation applied to a control system from an external energy source, usually in order to produce a specified response from the control system
- The output is the actual response obtained from the control system. It may or may not be equal the specified response
- Control system can be of three basic types: man-made, natural (including biological control system) or both



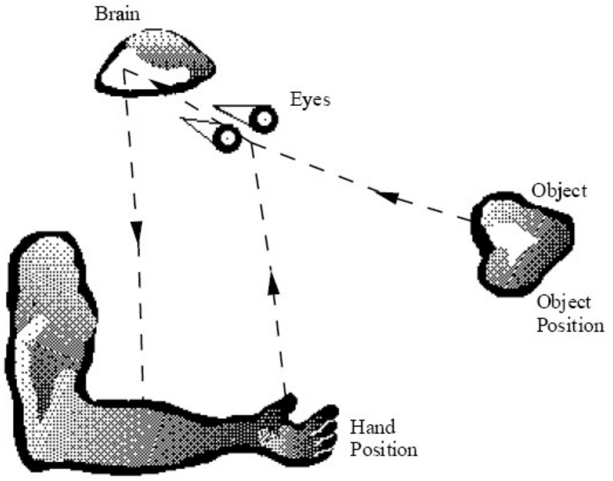
Autonomous Systems - Examples

- Mirror control by a stepping motor to regulate a laser beam to specific positions
  - The motor controls the combination of the laser beam and the mirror
  - The Input are the voltage applied to the motor and the position of the laser beam
  - The output is the movement of the laser beam to the actual position
  - Mirror + motor is the control system



Autonomous Systems - Examples

- A hand is controlled by the brain which activates the muscles
  - The brain controls the movement of the hand according to the values read by the eyes
  - The Input is the position of an object to be hold
  - The output is the position of the hand which is observed and measure by the eyes
  - The observed position is compared to the desired position and the difference is used by the brain to direct the hand
  - Brain + Hand + Eyes build the biological control system



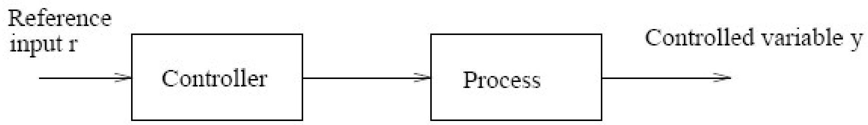
Autonomous Systems - Types

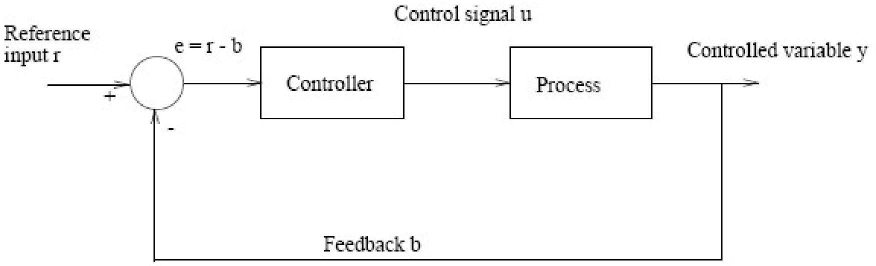
- Open-loop
  - The control action is independent of the output
  - Example: The mirror control system.
    - The position of the mirror is reached only based on the reference voltage of the motor
- Close-loop
  - The control action depends somehow on the output
  - Example: The Brain Hand Eye control system
    - The eyes observes the position of the hand and produce a feedback signal to the brain
    - The brain combined the feedback signal to the input value to control the muscles.
  - Example: Heating system in an oven
    - The heater is switched on or off according to the measured temperature in the oven
  - Close-loop control system are llso called feedback control systems
    - Will be considered in this course

Autonomous Systems - Feedback

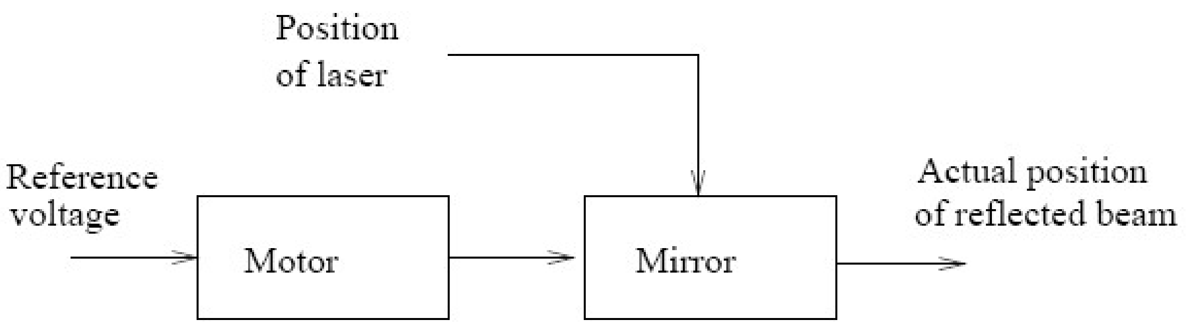
- Feedback:
  - The property of feedback in close-loop systems permits the output or some other controlled variable of the system to be compared with the input to the system so that the appropriate action may be taken as a function of input and output
  - In a open-loop control system, the input to the controller is the reference value
  - In a close-loop control system, the input of the controller is the difference (error) e between reference value r and the feedback b
    - $e = r - b$

\- The controlled variable is the physical quantity to be controlled

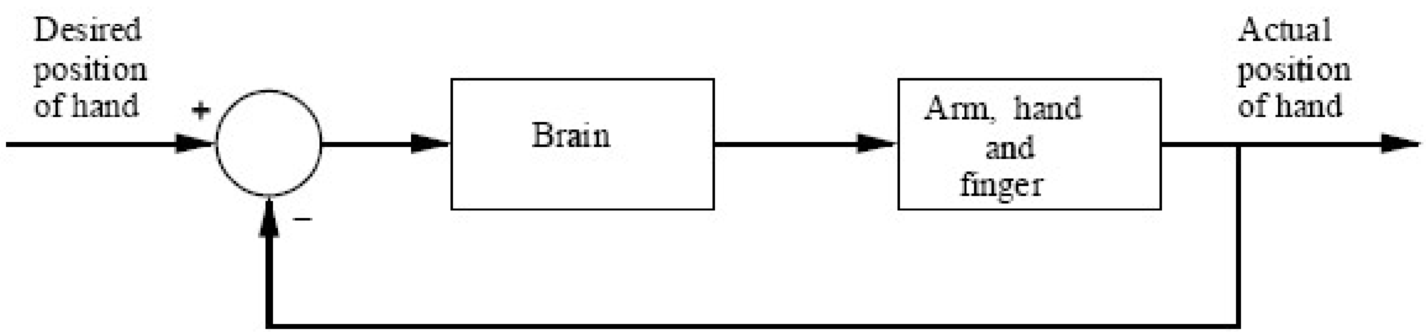




Autonomous Systems - Feedback - examples

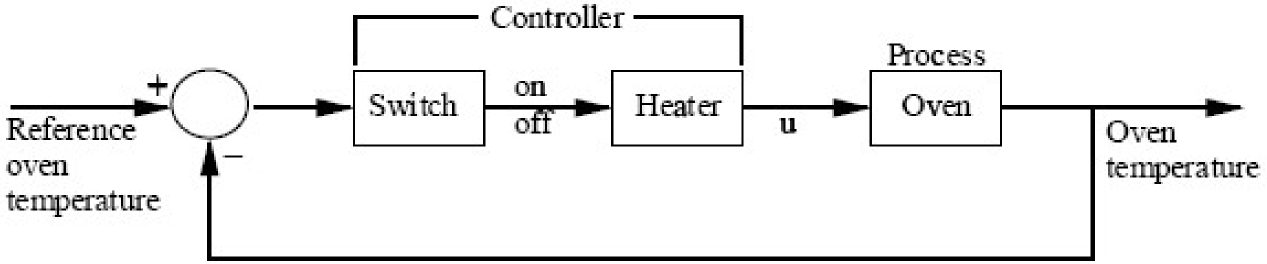


Bloc diagram representing motor control of the mirror

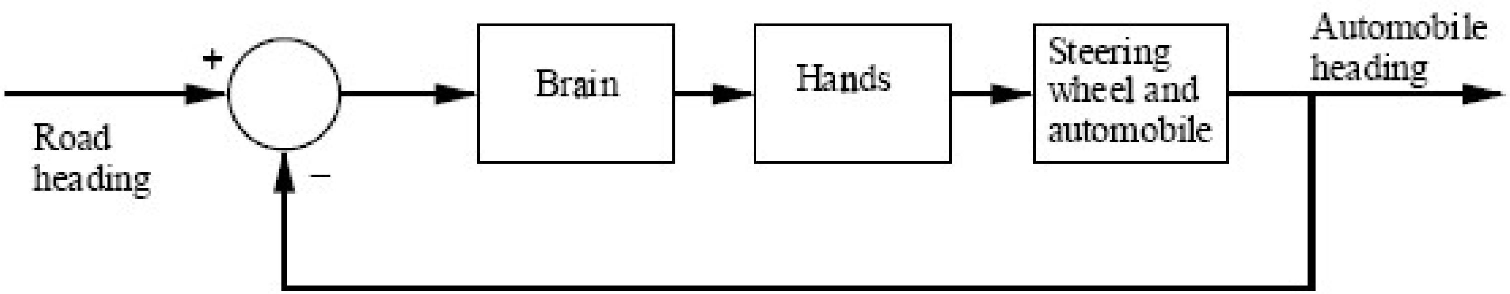


Bloc diagram representing the brain/hand/eye control system

Autonomous Systems - Feedback - examples



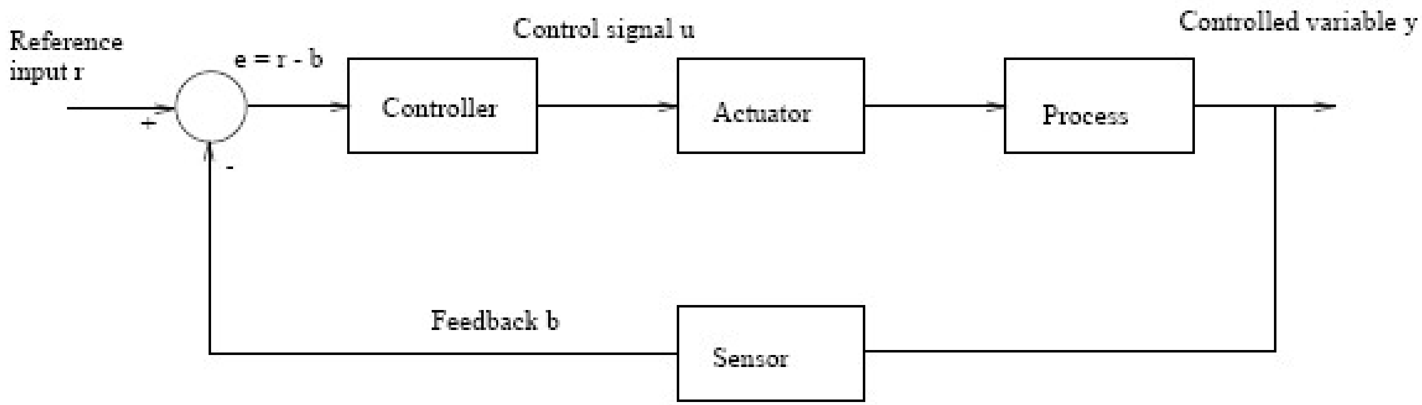
Bloc diagram representing oven control system



Human as a controller who drives car

Autonomous Systems - Transducer

- A transducer is a device that convert one form of energy into another
- Sensors belong to a specific class of transducer, which produce an input signal to the control system
- Actuators are transducers used to realize changes into the environment
- examples: potentiometers, photo diode



Autonomous Systems – In practice

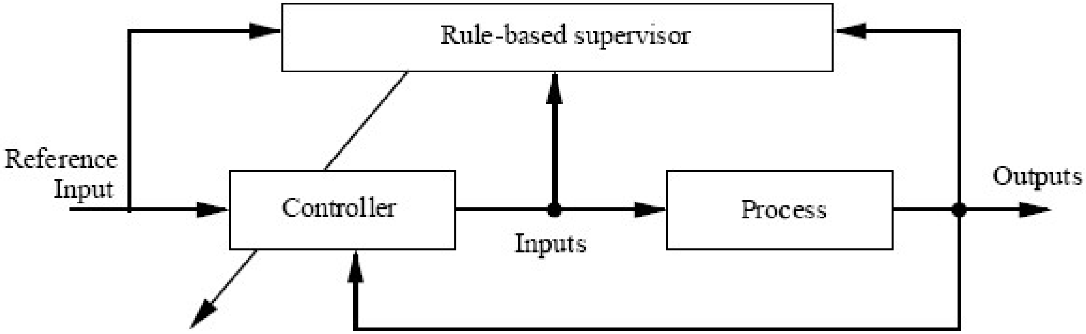
- Oldest man-made control system was pure mechanical
  - Mechanical weight controlling the pressure valve of a steam engine, invented by James Watt, preventing other pressure engine
  - Analogue to analogue signal processing with the appearance of electricity
    - Analogue signal as reference input, processing and analogue signal as reference output
    - Ex: servo system is a power system amplifier in which the output is a mechanical position or a time derivative such as velocity or acceleration
- Today, the computation is mostly digital based
  - ADCs convert analogue value to digital value for computation. After computation the digital values are converted back to analogue values using DACs
- The computation often requires real-time processing, where the result must be provided in a given time frame.
- Real-time computers are useful in this case

Autonomous Systems – Artificial Intelligence

- Due to sophistication in embedded systems, controller are becoming more and more complex. Adaptive at run-time is needed (Self-* characteristics)
- Processing the feedback loop requires the human intervention in several system (unmanned mission, autonomous vehicle in critical environment)
  - Requires some level of symbolic computation
- Adaptive control or autonomous control combines AI techniques with traditional controller techniques.
- Example of adaptive control system: collision avoidance
  - Non adaptive navigation control system with a path planning may produce a collision between two vehicles
    - The system acts within foreseen limits
  - Adaptive navigation control system will adapt the path according to the dynamic situation created by other vehicles moving around

Autonomous Systems – Intelligent control

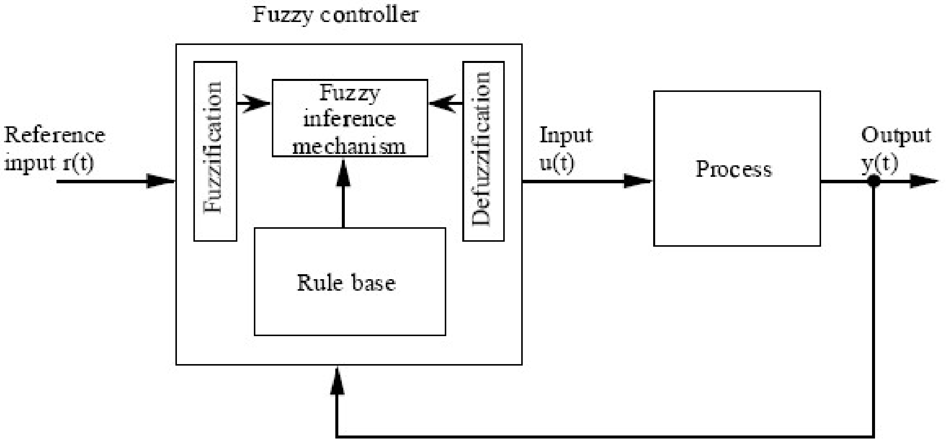
- Knowledge-based control
  - Applied to several industrial applications
  - A rule-based supervisor switch from controller to controller in order to apply the optimal controller for a given task
  - Also applied in robotic for complex path planning
    - The planner generates that appropriate parameter settings to robot controller



Knowledge-based control
Diagonal arrow -> the controller is being tune

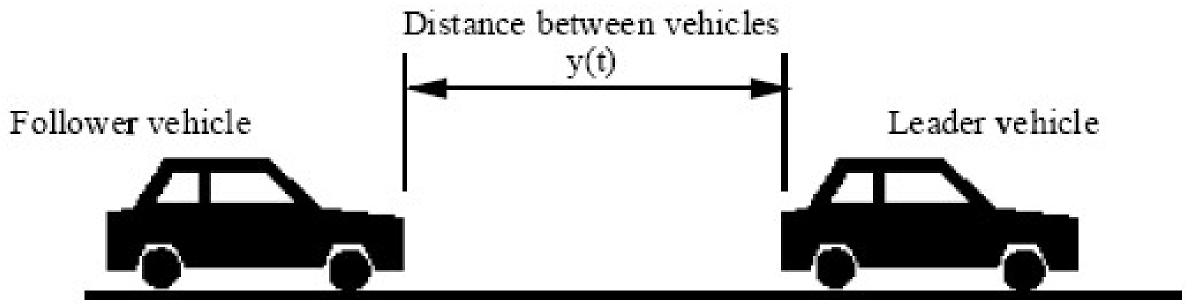
Autonomous Systems – Intelligent control

- Fuzzy control
  - Most widely use technique for embodying human-like thinking ino control systems
  - A fuzzy controller is designed to emulate the human deductive process, the process used to infer conclusions from what they know
  - Four main components:
    - a rule base holds the set of if-then else rules that quantify the knowledge human experts
    - a fuzzy inference mechanism makes successive decision about rules most relevant to the current state
    - Input/output fuzzification interface transform numeric into symbolic and vice versa



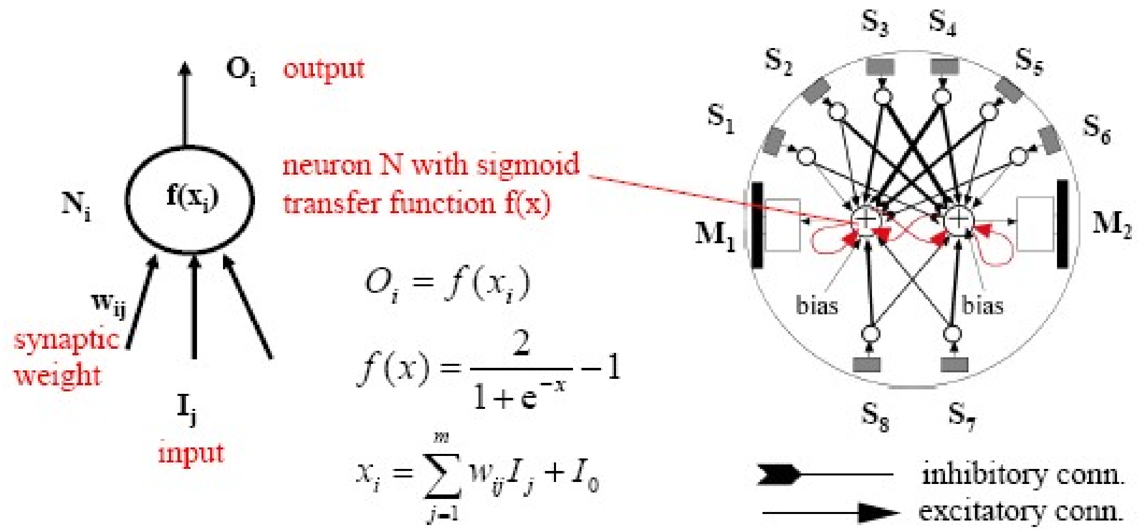
Autonomous Systems – Intelligent control

- Fuzzy control – example: cart distance control system
  - Emulate the human behaviour to regulate the inter-vehicle and keep it constant
  - e(t) = r(t) – y(t) error between the desired and actual inter-vehicle distance spacing and u(t) beeing the throttle input. If then else rule would be:
    - IF e(t) is positive-small and de(t)/d(t) is positive-medium THEN u(t) is positive-medium
      - Error is neglectable: continue with the medium throttle input
    - IF e(t) is positive-small and de(t)/d(t) is negative-medium THEN u(t) is positive-small
      - Error is small but decreasing at medium rate. A smaller throttle input should be applied



Autonomous Systems – Intelligent control

- Neural network
  - Emulate the biological function of the brain to solve difficult control problems
  - Requires a training phase to provide the neurons with sufficient knowledge on problem solution



Autonomous Systems – Intelligent control

- Genetic control
  - Embody the principles of evolution, natural selection and genetics from the biology
  - Perform a parallel stochastic but directed search to evolve the most fit population
  - Off-line proven that genetic algorithm can artificially evolve an appropriate controller. The steps requires are
    - Maintain a populated strings each representing a different candidate controller
    - The genetic algorithm operates on string with genetic operators like crossover and mutation coupled with a fitness measure to spawn successive controller generations

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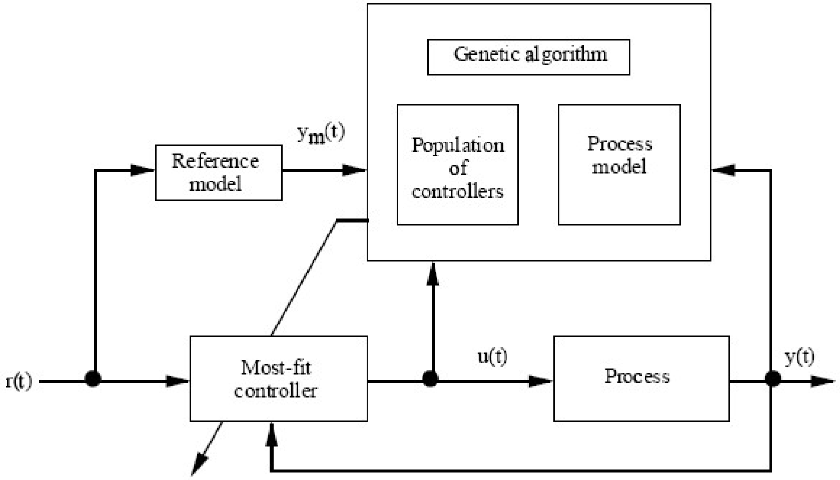

Autonomous Systems – Design

- Abstraction hierarchies in the the architecture model in order to solve complex system design problems

- Next: Organization and design of autonomous systems
  - Concepts
  - Functional architecture
  - Operational architecture
  - Implementation architecture