 p-ISSN: 2527-533X

Artificial Intelligence Inspired by Biological System: Techniques and Applications

Anton Satria Prabuwono
Email: aprabuwono@kau.edu.sa
Professor
Faculty of Computing and Information Technology in Rabigh
King Abdulaziz University, Jeddah, Saudi Arabia

Outline

- ❖ Introduction to AI
- ❖ Bio-Inspired AI
- ❖ Techniques & Applications
- ❖ Conclusions

2

Basic Knowledge

Classical AI →

- Electrical, Industrial Engineering
- Computer Science/Informatics
- Mathematics
- Statistics

Bio-inspired AI →

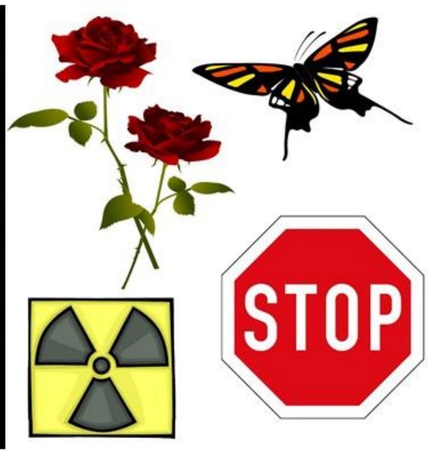
\+

- Biology

3

Aspects of Intelligence

Humans are good at recognizing patterns



4

Humans are good at understanding even difficult handwritings - thus human recognition capability is robust

SAMPLES OF HANDWRITING FROM 5 DIFFERENT PERSONS

5

Aspects of Biological Intelligence

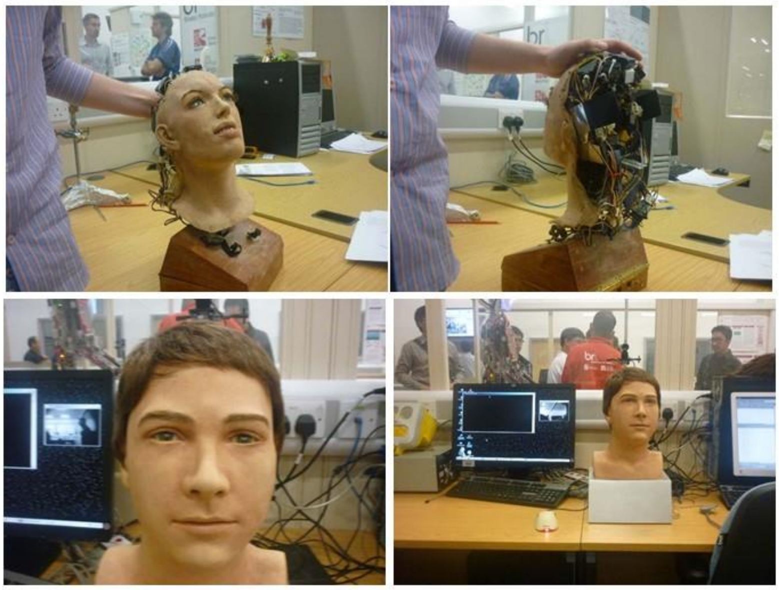
- Capability to Learn
- Capability to Generalize/Classify
- Capability to Survive
- Gathering of Information
- Recognizing Patterns
- Common Sense
- Logical Thinking
- Predicting/Forecasting
- Self-repair
- Self-guidance
- Reproduction
- Making Decisions
- Reasoning Capability
- Predicting/Forecasting
- Understanding Noisy
- Fuzzy Information

6

Natural Expression

7

Natural Expression Prototype



Bristol Robotics Lab, University of Bristol, UK

8

Humans Have Self-repair Mechanisms in Their Bodies

9

What is Artificial Intelligence?

AI is a "tool" that has been developed to imitate human intelligence and decision-making functions, providing basic reasoning and other human characteristics.

Can Machines be Developed to Have Intelligence?

Perhaps one way to do this is to develop algorithms based on human or animal intelligence.

11

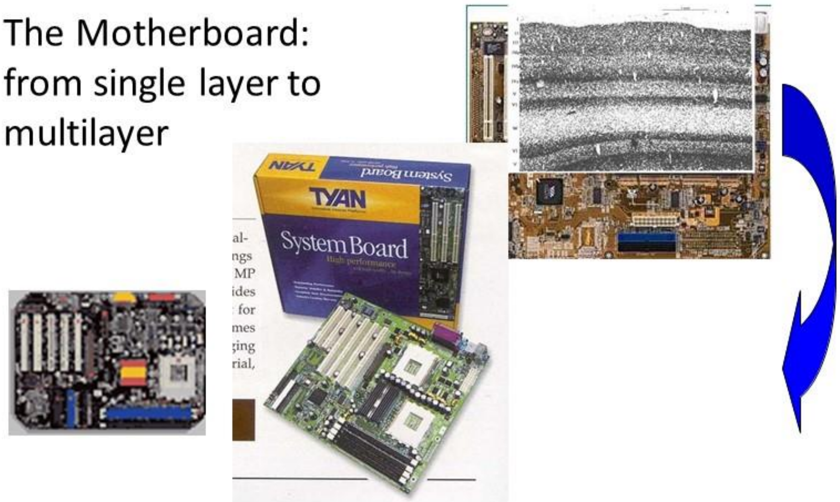
How Do We Design Intelligence?

12

Copying from Biological Systems

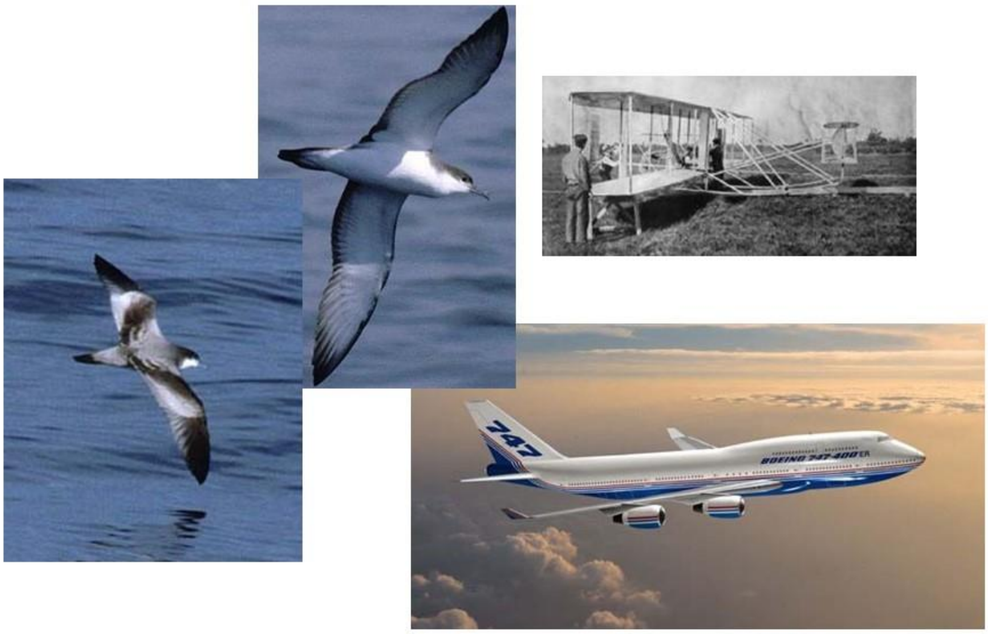
COMPUTER ARCHITECTURES

- The Motherboard: from single layer to multilayer



13

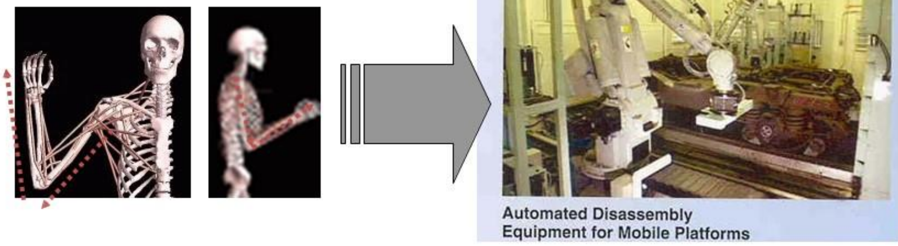
Copying from Biological Systems



14

Copying from Biological Systems

The design of the optimal length of robotic manipulators should follow the human arm (T. Yoshikawa, Kyoto University).



15

Copying from Biological Systems

wkxp ebSulqwb→EdubFrgh

Everyone, including identical twins, has a unique fingerprint. In other words, people's identities are coded at their fingertips. This coding system may also be compared to the barcode system that is used today.

16

Intelligence that Can Be Designed

- Self learning machines
- Self-organizing systems
- Self-optimization
- Path planning
- Pattern recognition
- Decision making
- Prediction
- ………………….

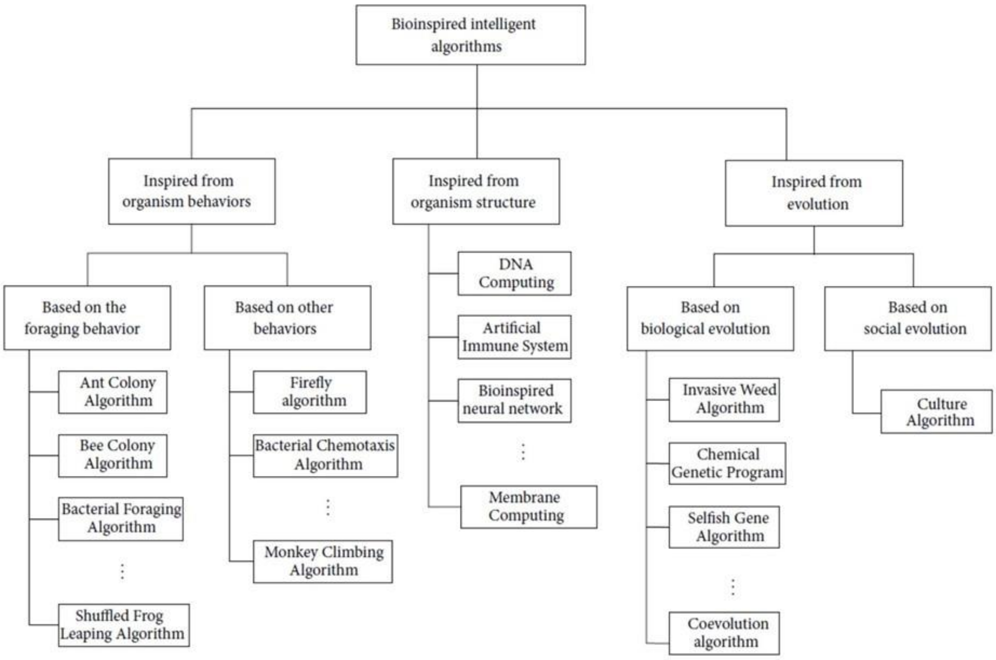
17

How Do We Design Intelligence?

- Study from biological models (brain, genetic, DNA, life, molecular biology, ….) → Neural Nets, Genetic Algorithm, Artificial Life, DNA Computing, etc.
- Study from human phenomena (common sense, reasoning, predicting, observing, inference, …) → Fuzzy Logic, Expert Systems, Search Techniques, etc.
- Need to develop mathematical/logical algorithms based on the above biological models or phenomena.

18

Bio-inspired Intelligent Algorithms (BIAs)

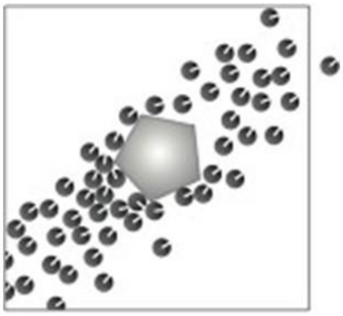


BIAs Applications

Category	Name	Advantages	Applications
Inspired from organism behavior	Bacterial Foraging Algorithm	Parameter insensitivity; strong robustness; easy implementation	Image segmentation; robot path planning; optimum scheduling; optimal power flow
	Monkey Climbing Algorithm	A few parameters to adjust; low calculation cost; fast convergence rate	Optimal sensor placement; feature selection and extraction; numerical optimization
Inspired from organism structure	DNA Computing	High parallelism; massive storage ability; low energy consumption	Information security; robotic control; task assignment problem; clustering problem
	Membrane Computing	Inherent parallelism; distributed feature; nondeterminism	Numerical optimization; broadcasting problem; computer graphics; traveling salesman problem
	Artificial Immune System	Noise patience; learning without teacher; self-organization and identity	Community detection; anomaly detection; fault diagnosis; web page classification
Inspired from evolution	Selfish Gene Algorithm	High convergent reliability and convergent velocity	Optimization design problem; traveling salesman problem; scheduling problem
	Invasive Weed Algorithm	Easy to understand; good adaptability; strong robustness	Image clustering problem; parameter estimation problem; numerical optimization
	Culture Algorithm	With a double evolution structure; high search efficiency; with a certain universality	Pattern recognition; multirobot coordination; fault classification; engineering design problem

20

Inspired by Organism Behavior: **Swarm Intelligence**



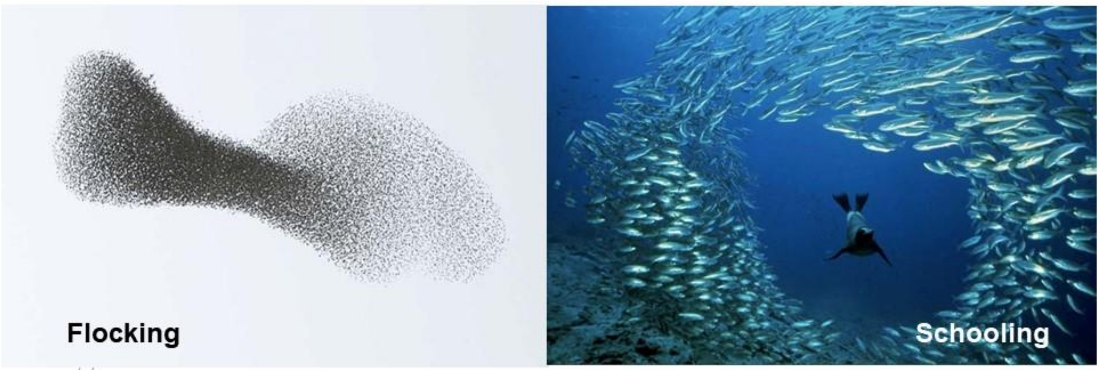
21

Emergent Collective Behavior

Some animal societies display coordinated and purposeful navigation of several individuals (from tens to thousands).

Each individual uses only local information about the presence of other individuals and of the environment.

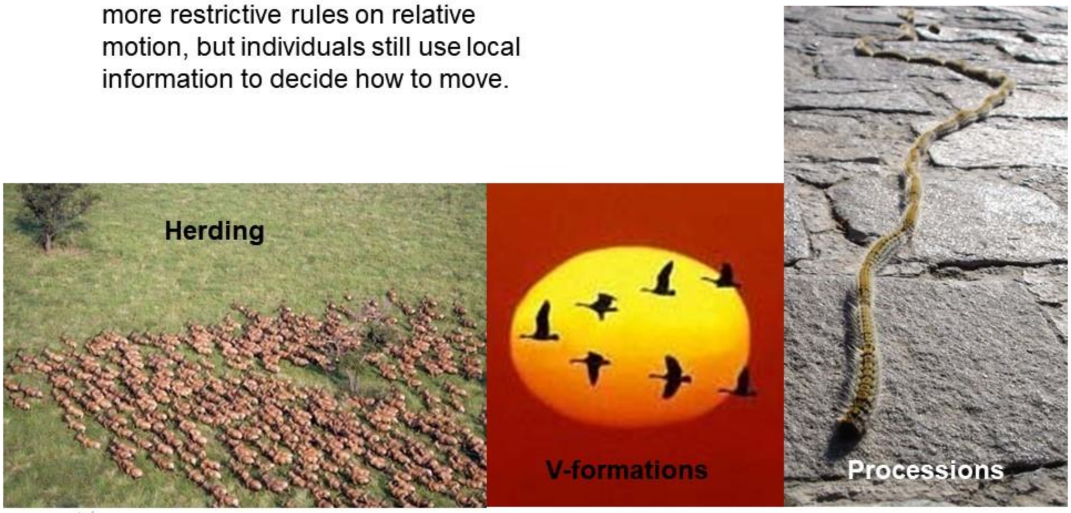
There is no predefined group leader.



22

Emergent Collective Behavior

In some cases there is a leader and more restrictive rules on relative motion, but individuals still use local information to decide how to move.



23

Swarm Intelligence

Swarm Intelligence is the emergent collective intelligence of groups of simple individuals.

Main principles:

1) The swarm can solve complex problems that a single individual with simple abilities (computational or physical) could not solve.

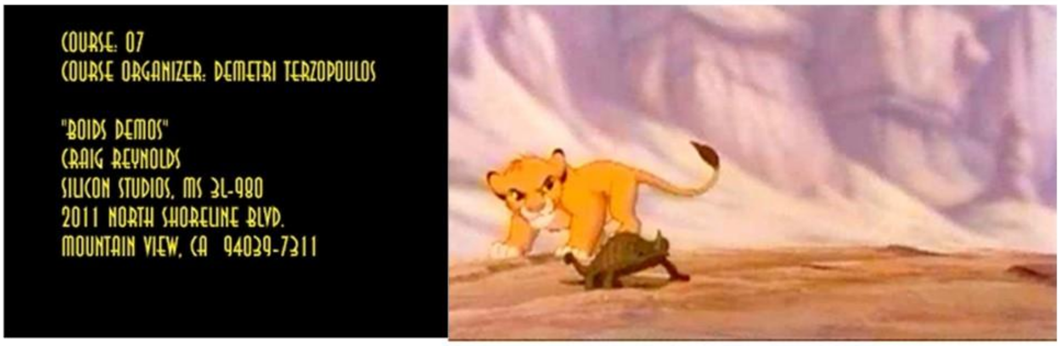
2) The swarm is composed of several individuals, some of which may be lost or make mistake, but its performance is not affected.

3) Individuals in a swarm have local sensory information, perform simple actions, have little/no memory; they do not know the global state of the swarm or its goal.

24

Application of Character Animation

Emergent coordinated behavior. The approach is applicable to any type of animated characters in groups where behavior coordination is used.



The Lion King, 1994 (Walt Disney)

25

Particle Swarm Optimization

Particle Swarm Optimization is an optimization algorithm inspired upon birds flocking to find the best food area.

A caricature scenario:
The flock wants to find the area with the highest concentration of food (insects). Birds do not know where that area is, but each bird can shout to their neighbors how many insects are at its location. Birds also remember their own location where they found the highest concentration of food so far.

The flock is most likely to succeed when birds combine **three strategies**:

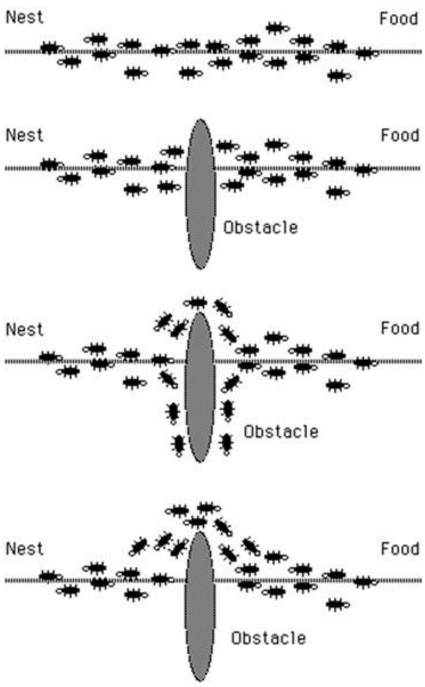
1) **Brave**: keep flying in the same direction
2) **Conservative**: fly back towards its own best previous position
3) **Swarm**: move towards its best neighbor

26

Ant Trails

27

Stigmergy



The term indicates communication among individuals through modification of the environment.

For example, some ants leave a chemical (pheromone) trail behind to trace the path. *The chemical decays over time.*

This allows other ants to find the path between the food and the nest. It also allows ants to find the shortest path among alternative paths.

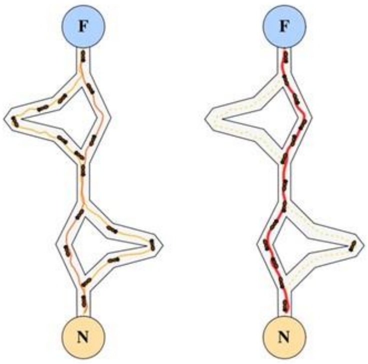
28

Finding the Shortest Path

1) As they move, ants deposit pheromone
2) Pheromone decays in time
3) Ants follow path with highest pheromone concentration
4) Without pheromone, equal probability of choosing short or long path

Shorter path allows higher number of passages and therefore pheromone level will be higher on shorter path.

Ants will increasingly tend to choose shorter path.



Goss et al. 1989, Deneubourg et al. 1990

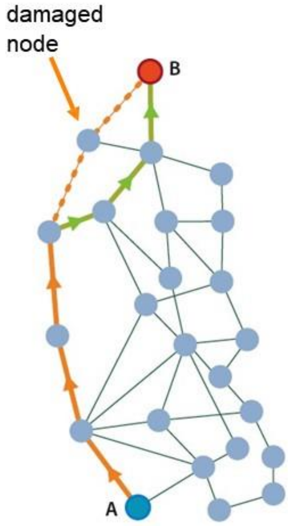
29

Ant Colony Optimization (ACO)

Ant Colony Optimization is an algorithm developed by Dorigo et al. in 1994 inspired upon stigmergic communication to find the shortest path in a network.

Typical examples are telephone, internet, and any problem that can be described as Travel Salesman Problem. Used/adopted by British Telecom, MCI Worldcom, Barilla, etc.

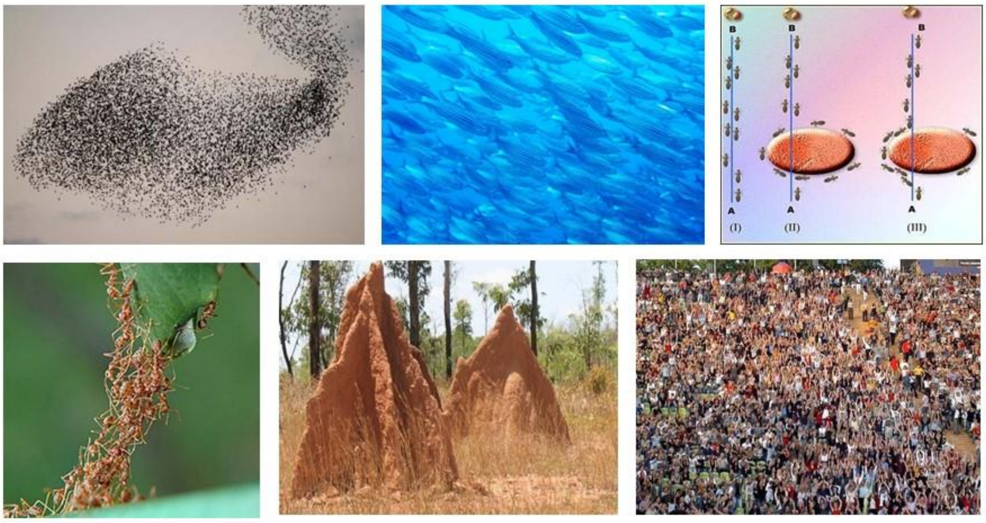
Advantage of algorithm is that, as ants do, it allows dynamic rerouting through shortest path if one node is broken. Most other algorithms instead assume that the network is static.



30

Swarm Robotics

Sources of Inspiration



31

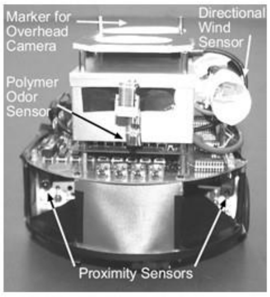
Key Properties

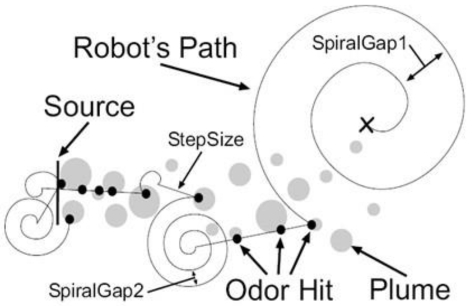
- Composed of many individuals
- The individuals are relatively homogeneous.
- The individuals are relatively incapable.
- The interactions among the individuals are based on simple behavioral rules that exploit only local information.
- The overall behavior results from a self-organized process.

32

Application (1): Environmental Monitoring

- Swarm of mobile robots for localizing an odor source
- Simple behaviors based on odor and wind detection
- Communication can help to increase the efficiency.

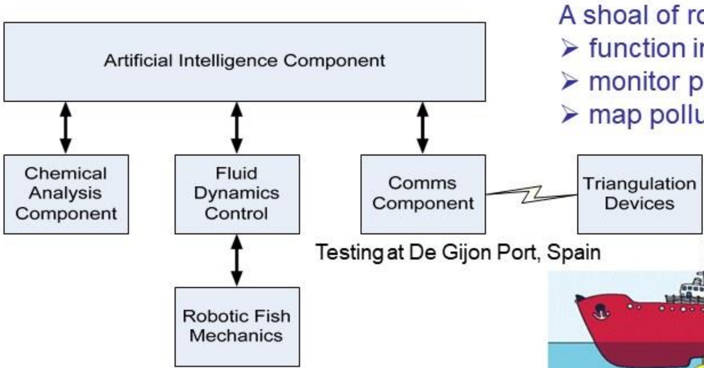




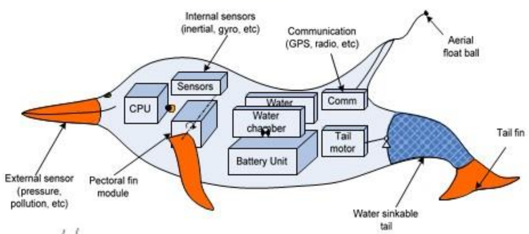
Hayes et al., 2002

33

EU FP7 ICT Project – SHOAL

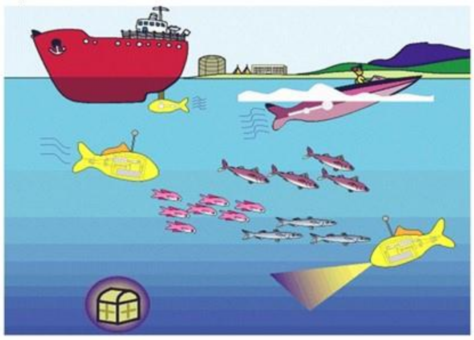


A shoal of robotic fish will:
- function in collaboration,
- monitor pollution in a port, and
- map pollution levels & its position.



Testing at De Gijon Port, Spain

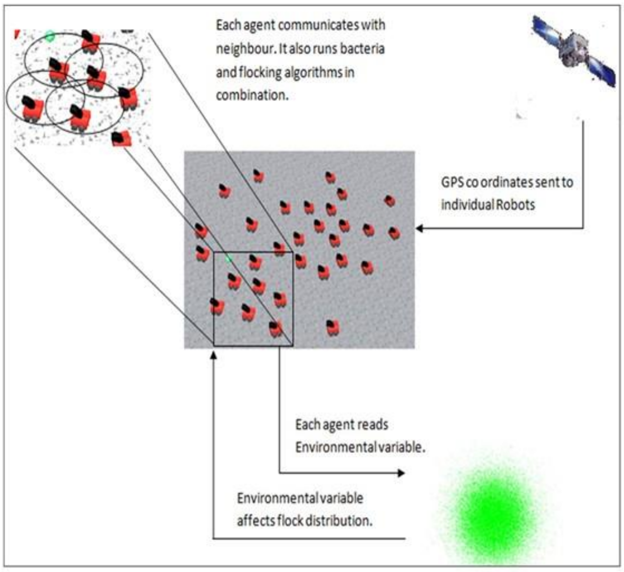
Referred from NMRI, Japan



34

Environmental Monitoring

- For optimal coverage of an environmental variable for pollution monitoring.
- Control of real and simulated agents using a combination of bacteria controller and flocking controller.
- Architecture and system design for the System.



(Source: Prof. H. Hu, School of CSEE, University of Essex, U.K.)

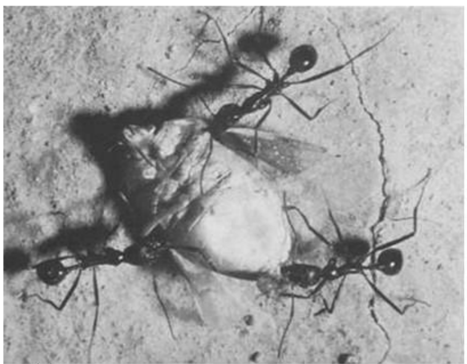
35

Application (2): Coordinated Task

- Task requires cooperation
- No explicit communication
- Behavior-based approach
- Ant-inspired stagnation recovery mechanism

Kube and Zhang, 1993;
Kube and Bonabeau, 2000

Hoelldobler et al., 1978

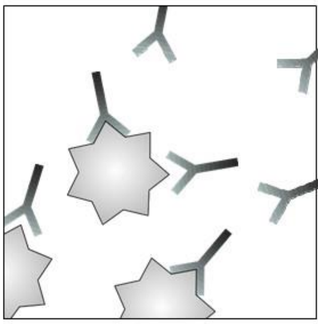


36

Coordinated Transportation

37

Inspired by Organism Structure: **Artificial Immune Systems**



38

Biological Immune Systems

- Living organism must protect themselves from the attempt of other organisms to exploit their resources
- Some would-be exploiter (*pathogen*) is much smaller than its target (the *host*)
  - The organs that the host uses to interact with the environment are poorly suited to the detection and elimination of potential pathogens
  - The pathogen can reproduce much faster than the typical host and can rapidly evolve new strategies of attack
- Physical barriers, alteration of physiological conditions, and avoidance of dangerous environments are only a partial solution
- The host needs a set of countermeasures which operate at the same scale and which can keep the evolutionary pace of the pathogens.
- This collection of countermeasures constitutes the *immune system* of the host.

39

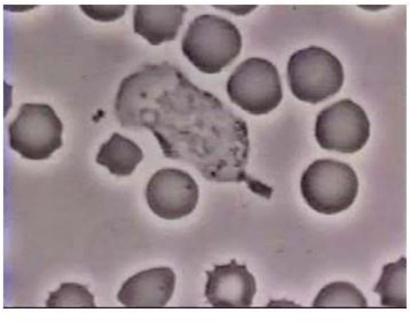
Functions of the Immune Systems

The immune system must:

- *Detect* the pathogens once they have entered the host body
- *Eliminate* the pathogens with *minimal cost* in terms of resources employed and damage done to the host
- Initiate the repair of the damages done by the pathogen

Additionally, the immune system can be asked to:

- Detect and repair the malfunctioning and failures of individual host cells (e.g., damaged, mutated, and cancerous cells)



40

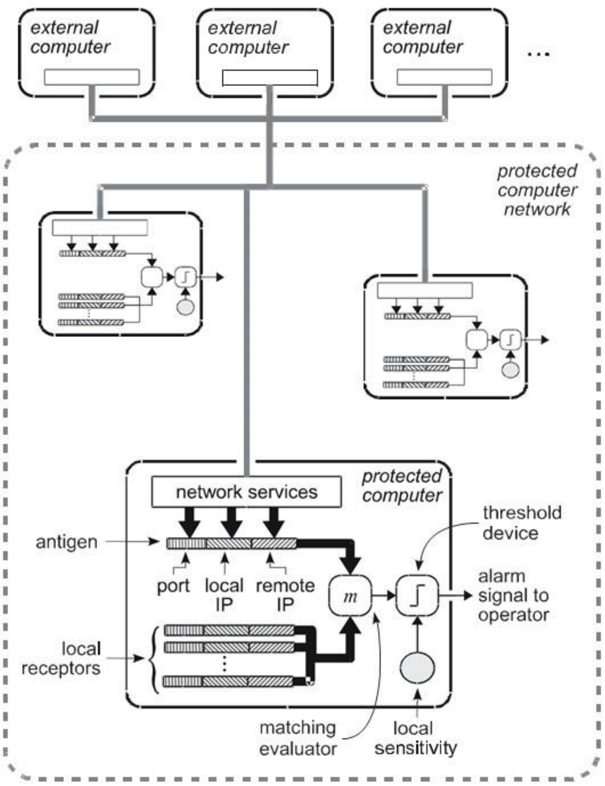
Artificial Immune Systems (AIS)

- Human-built systems (e.g., networked computers) must also be protected from the attempt of exploitation of their resources (computational power, data, identity…)
- Some non-authorized operations are executed at a low level in the hierarchy of software levels of the computer system
  - Their effect is not immediately apparent at the scale of the computer user or network administrator interface
  - The strategies of attack can change rapidly
- Isolation of the computing system is seldom an option
- The current solution is the use of antivirus and intrusion detection programs designed and updated by specialized software firms
- A better solution would be a protection system capable of autonomously detecting and opposing the attempts to intrusion and exploitation, that is, an *artificial immune system* (AIS).
- An AIS might also detect and correct (sub)system malfunctioning

41

Application

- LISYS (Lightweight Intrusion detection SYStem) is a network intrusion detection system based on AIS.
- The strings that are monitored summarize the information about the connections that concern the nodes. Each string contains the identity (IP addresses) of the connected nodes and the specification of the kind of service requested.
- The system was tested with data collected from real computer networks which contained known intrusions and was able to detect all the intrusion attempts, apart from very short ones

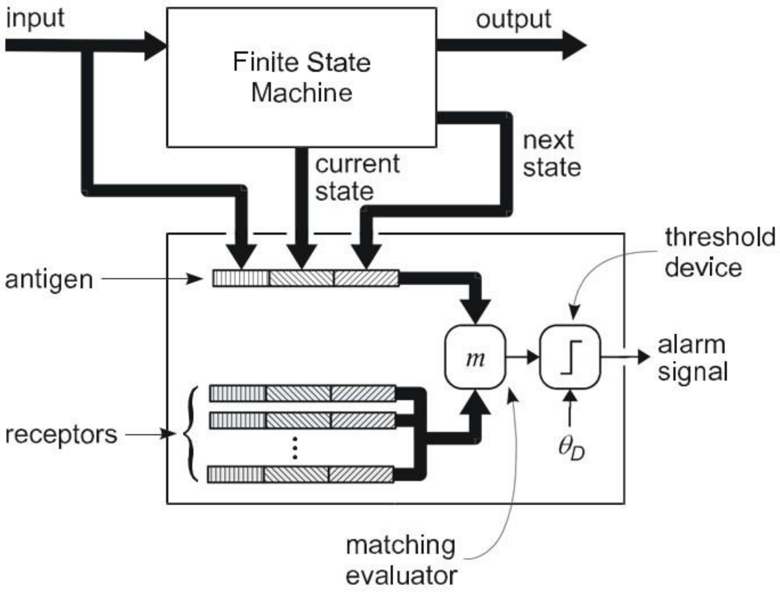


Immunotronics

- Immunotronics is an application of AIS concepts to the detection and recovery of faults in digital electronic systems.
- The classical approaches to fault detection and recovery in digital systems are redundancy and the addition of protection systems that check and possibly corrects the validity of the system state
- The immunotronics applies the immune system concept of self/nonself discrimination to automate the generation of the verification criteria used by the protection system.
- The immunotronics approach applies to finite state machines (FSM), a class of systems where the operation is modeled in terms of states and transitions between them. The self can be defined as the collection of strings that represent the legal transitions between the states of the machine
  - The self can be generated by observing the operation of the system in its fault-free condition.

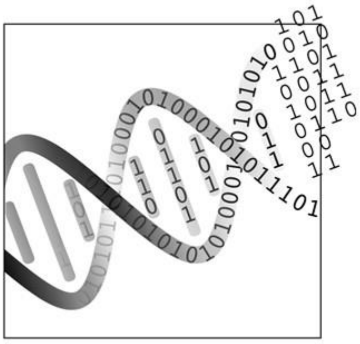
43

Immunotronics



44

Inspired by Evolution: **Evolutionary Electronics**

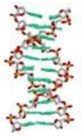


45

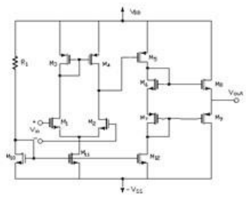
Introduction

Evolutionary Electronics (EE) is defined as the application of evolutionary techniques to the design (synthesis) of electronic circuits

Evolutionary algorithm



(schematic)



Electronic Circuit

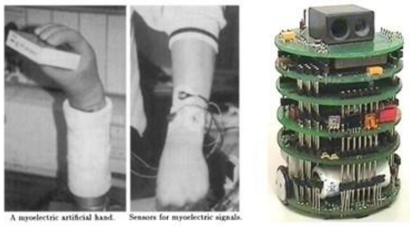
(physical layout)

- Evolution of the parameters (sizing) given a fixed circuit topology
- Evolution of both parameters and circuit topology
- Placement and routing of the devices that compose the circuit

46

Motivation: why Evolutionary Electronics?

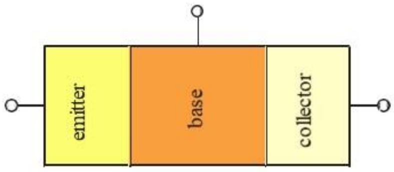
- Complex and performing electronic circuits are required with which the traditional design techniques cannot cope efficiently and thus produce a waste of resources
- Some design problems are poorly specified in the sense that the functionality is not defined in terms of a precise input/output relationship but still a global performance can be measured easily



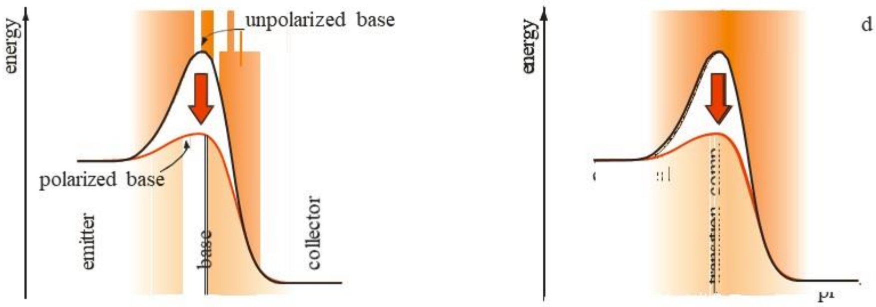
- The state of advancement of electronic technology permits the exploitation of the virtues of evolutionary methods (waiting for the coming of age of nanotechnologies…)
- Evolutionary electronics provides an illustration of many aspects that are relevant in the real-world application of evolutionary methods

47

Electronic and Biological "Devices"

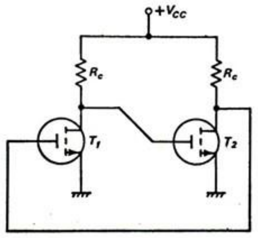


"… the fundamental elements of information processing in electronic and genetic systems are strikingly similar…"
[Simpson *et al.*, Proc. IEEE, May 2004]



48

Electronic and Biological Networks



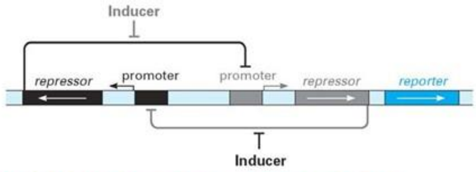


FIGURE 8.3 • Theoretical two-gene bistable toggle switch.

"…the analysis, modeling, and simulation of natural and synthetic genetic circuits, often proceed in a manner similar to that used for electronic systems"

".. the expertise and skills contained within electrical and computer engineering disciplines apply not only to design within biological systems , but also to the development of a deeper understanding of biological functionality."

"It is possible that new strategies for engineered system design may emerge from this examination of natural gene circuit architectures."

[Simpson et al., Proc. IEEE, May 2004]

49

How Evolutionary Electronics Works

1. A genetic representation is defined for the electronic circuits of interest
2. A set of objectives is defined in terms of functionality and performances of the desired circuit
3. An initial population (collection of individuals) is generated
4. The genome of each individual in the population is decoded into a circuit
5. The functionality and performances of the circuit are evaluated and the result is used to enforce a selection policy
6. The selected individuals are reproduced and the genetic operators are applied to obtain a new population

Until the objectives are met or some stopping criterion (time, computational resources…) is fulfilled

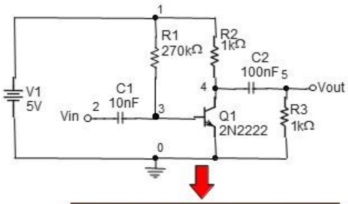
50

Extrinsic vs. Intrinsic Evolution

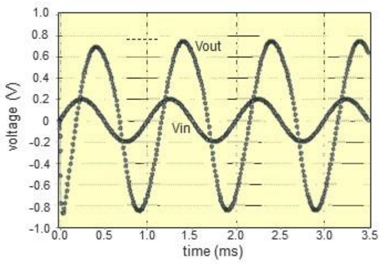
The behavior of an electronic circuit can be estimated using a circuit simulator

In extrinsic evolutionary design: each circuit is simulated to assess its performance

- The structure of the circuit can be almost arbitrary
- The circuit is virtual and cannot be damaged
- The simulated models are only approximations




```
* SPICE simulation example

* circuit description:
C1   2 3     10n
C2   4 5     100n
R1   3 1     270k
R2   4 1     1k
R3   0 5     1k
Q1   4 3 0   Q2N2222
V1   1 0     5Vdc

* input signal:
Vin  2 0 SIN 0 0.2 1k 0 0 0

* simulator directives:
.TRAN  0 3.5ms 0 0.01ms
.OPTIONS TEMP=25

* device models:
.MODEL Q2N2222  NPN
+ IS 14.3E-15 BF 256 NF 1
+ VAF 74 IKF 0.28 ISE 14.3E-15
+ NE 1.3 BR 6.1 NR 1 RB 10 RC 1
+ CJE 22.0E-12 MJE 0.377
+ CJC 7.3E-12 MJC 0.3416
+ TF 411E-12 XTF 3 VTF 1.7
+ ITF 0.6 TR 46.9E-09 XTB 1.5

.END
```



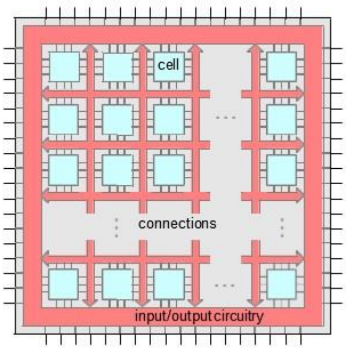
51

Extrinsic vs. Intrinsic Evolution

The existence of reconfigurable devices opens the way to the possibility of performing evolution directly in hardware

In intrinsic evolutionary design: each circuit is physically implemented and tested

- The evaluation is done using real devices (no approximations)
- There are some constraints on the circuit structure
- The results can depend on the physical device used for the evolution



- The evolutionary setting can be defined so as to produce an adaptation during the operating life of the circuit (e.g., to obtain fault tolerance)

52

Conclusions

- The approaches and examples described show that biology is a bewildering source of inspiration for the design of intelligent artifacts capable of efficient and autonomous operation in unknown and changing environments.
- The first caveat is that copying a mechanism from biology does not necessarily bring an advantage either because the technology may not match the biology or because the desired functionality may be different from that of the biological mechanisms.
- Proper practice of bio-inspired artificial intelligence requires a *scientific effort* to extract the principles of biological intelligence from the data and theories provided by biologists, and an *engineering effort* to translate those principles into functional artifacts and technologies.

53

References

- Fan, X., Sayers, W., Zhang, S., Han, Z., Ren, L., and Chizari, H. 2020. Review and classification of bio-inspired algorithms and their applications. Journal of Bionic Engineering, Vol. 17, pp. 611-631.
- Floreano, D., and Mattiussi, C. 2008. Bio-Inspired Artificial Intelligence, Theories, Methods, and Technologies. MIT Press, Cambridge.
- Negoita, M. Gh., and Hintea, S. 2009. Bio-Inspired Technologies for the Hardware of Adaptive Systems, Real-world Implementations and Applications. Springer-Verlag, Berlin.
- Ni, J., Wu, L., Fan, X., and Yang, S. X. 2016. Bioinspired intelligent algorithm and its applications for mobile robot control: a survey. Computational Intelligence and Neuroscience, Vol. 2016, Article ID 3810903, 16 pages.
- Omar, K., Nordin, M.J., Vadakkepat, P., Prabuwono, A.S., Abdullah, S.N.H.S., Baltes, J., Amin, S.M., Wan Hassan, W.Z., and Nasrudin, M.F. 2013. Intelligent Robotics Systems: Inspiring the Next. Springer, Berlin.

54