

# Introduction to Computational Intelligence

CSCI/ENGR 8940

Cruise Director: Don Potter

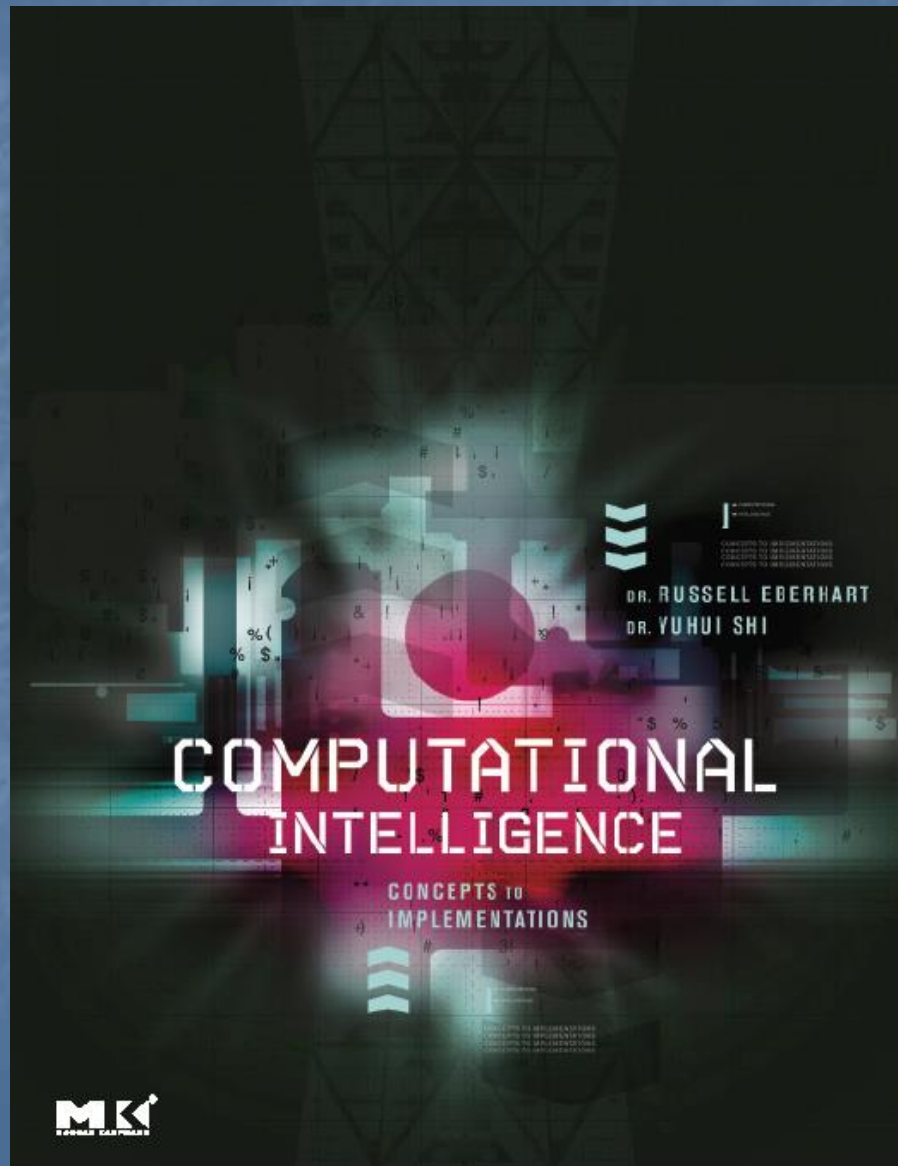
(Textbook slides by Eberhart were edited by Potter for use in CSCI/ENGR-8940)

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**Textbook: Computational Intelligence: Concepts to Implementations**  
**by Eberhart and Shi**



# Outline of class session

- Introduction
- Discuss handout
- Review course outline
- Individual introductions
- Resources in addition to textbook

# Intro. to CI: Course Outline (maybe)

- Introduction
- Foundations of CI
- Evolutionary Computation
- Neural Networks
- Fuzzy Logic
- Computational Intelligence
- Metrics and Analysis
- Case Studies



# Introduction

- Definition of computational intelligence
- Advantages of CI tools
  - \* Can be implemented by “domain” experts
  - \* Relatively short development time
- This course is applications-oriented
  - \* Can solve tough problems
- Book software assumes students have knowledge of:
  - \* C programming
- Applications selected based on:
  - \* Basic concepts,
  - \* Experience/practice,
  - \* Cool,
  - \* Impact factor

# Computational Intelligence Definition

**Computational intelligence** comprises practical **adaptation and self-organization** concepts, paradigms, algorithms and implementations that enable or facilitate appropriate actions (intelligent behavior) in complex and changing environments.

# **Outline of Book**

**Chapter 1 – Foundations**

**Chapter 2 – Computational Intelligence**

**Chapter 3 – Evolutionary Computation**

**Chapter 4 – Evolutionary Computation Implementations**

**Chapter 5 – Artificial Neural Networks**

**Chapter 6 – Neural Network Implementations**

**Chapter 7 – Fuzzy Systems**

**Chapter 8 – Fuzzy System Implementations**

**Chapter 9 – Computational Intelligence Implementations**

**Chapter 10 – Performance Metrics**

**Chapter 11 – Analysis and Explanation**

**Chapter 12 – Case Study Summaries**

**Appendix – Computational Intelligence Resources**

**Glossary**

**Note: Chapter 12 and glossary are on book's website.**



# Foundations Chapter

- Technical and historical discussion of component technologies
- *Foundations* reviews background of component technologies
- Defines terms; relates to biology and behavioral motivations; discusses “myths”; reviews applications

# Computational Intelligence

- Introduction to computational intelligence
- Adaptation
- Self-organization
- Computational intelligence systems
- How CI fits into the environment
- Soft computing

# Evolutionary Computation

- History: reviews development history of EC with focus on people
- Concepts, paradigms and implementations of evolutionary algorithms
- Evolutionary Computation Theory and Paradigms:* reviews genetic algorithms, evolutionary programming, evolution strategies, and genetic programming.
- Evolutionary Computation Implementations:* genetic algorithm and particle swarm optimization.

# Neural Networks

- Neural network concepts, paradigms, and implementations.
- *Neural Network Theory and Paradigms*: terminology, biological bases, survey of architectures and topologies, review of learning paradigms and recall procedures.
- *Neural Network Implementations*: back-propagation, self-organizing feature maps, and learning vector quantization.

# Fuzzy Systems

- Theory, concepts and implementations of fuzzy logic and fuzzy systems.
- *Fuzzy Systems Theory and Paradigms*: Fuzzy logic terminology and symbology, fuzzy logic theorems, differences with probability, steps in applying fuzzy logic.
- *Fuzzy Systems Implementation*: fuzzy expert system.



# Computational Intelligence Implementations

- Implementation issues including GA and fuzzy adaptation
- The fuzzy evolutionary fuzzy rule system implementation
- Packages: EnCog, Neuroph, Neuroshell, Weka,
  - Matlab, Roll-Your-Own, etc.
- Choosing/using the best methods

# Metrics and Analysis

- Tools needed for CI system development.
- *Performance Metrics*: methods for measuring and representing the performance of computational intelligence tools.
- *Analysis and Explanation Facilities*: graphical representation of neural network weights, development of explanation facilities for CI systems, example of explanation facility for a neural network.

# Case Studies From Book

- Detection of epileptiform spikes
- Battery state of charge
- Schedule optimization
- Human tremor analysis
- Control system
- Neural network approach
- Fuzzy logic approach

# Our Case Studies

- Multiple Fault Diagnosis
- Network Configuration
- Harvest Scheduling
- Multiple Recursive Generators
- Snake in the Box
- Solar Radiation Prediction
- Temperature Prediction
- Others

## **This course is about:**

- Computational tools for uses in practical applications
- Self-organization
- Complex adaptive systems

## **This course is not about:**

- Everything there is to know about CI and its components
- Lots of mathematical derivations and proofs
- Agents
- Life (whatever that is)



# Foundations - Outline

- Introduction
- Definitions
- Biological/behavioral bases
- Myths
- Application areas

# Introduction

- Focus on practical applications
- Emphasize the PC platform
- Implementation is up to you

# Definition of Intelligence

*Webster's New Collegiate Dictionary* defines intelligence as “**1a**(1) : The ability to learn or understand or to deal with new or trying situations : REASON; *also* : the skilled use of reason (2) : the ability to apply knowledge to manipulate one's environment or to think abstractly as measured by objective criteria (as tests).”

# Another Definition of Intelligence

The capability of a system to adapt its behavior\* to meet its goals in a range of environments. It is a property of all purpose-driven decision makers.

- David Fogel

\* implement decisions

# Definition: Evolutionary Computation

Machine learning optimization and classification paradigms roughly based on mechanisms of evolution such as natural selection and biological genetics. Includes genetic algorithms, evolutionary programming, evolution strategies and genetic programming.



# Definition: Artificial Neural Network

- An analysis paradigm very roughly modeled after the massively parallel structure of the brain.
- Simulates a highly interconnected, parallel computational structure with numerous relatively simple individual *processing elements*.

# Definition: Fuzziness

*Fuzziness:* Non-statistical imprecision and vagueness in information and data.

*Fuzzy Sets* model the properties of properties of imprecision, approximation or vagueness.

*Fuzzy Membership Values* reflect the membership grades in a set.

*Fuzzy Logic* is the logic of approximate reasoning. It is a generalization of conventional logic.

# More Definitions

*Paradigm:* A particular choice of attributes for a concept. An example is the back-propagation paradigm that is included in the neural network concept. In other words, it is a specific example of a concept.

*Implementation:* A computer program written and compiled for a specific computer or class of computers that implements a paradigm.

# Soft Computing

Soft computing is not a single methodology. Rather, it is a consortium of computing methodologies which collectively provide a foundation for the conception, design and deployment of intelligent systems. At this juncture, the principal members of soft computing are fuzzy logic, neurocomputing, genetic computing, and probabilistic computing, with the last subsuming evidential reasoning, belief networks, chaotic systems, and parts of machine learning theory. In contrast to traditional hard computing, soft computing is tolerant of imprecision, uncertainty and partial truth. The guiding principle of soft computing is: exploit the tolerance for imprecision, uncertainty and partial truth to achieve tractability, robustness, low solution cost and better rapport with reality.

- L. Zadeh



# Definition of Computational Intelligence

A methodology involving computing that exhibits an ability to learn and/or to deal with new situations, such that the system is perceived to possess one or more attributes of *reason*, such as generalization, discovery, association and abstraction.

Silicon-based computational intelligence systems usually comprise hybrids of paradigms such as artificial neural networks, fuzzy systems, and evolutionary algorithms, augmented with knowledge elements, and are often designed to mimic one or more aspects of carbon-based biological intelligence.



# Computational Intelligence Definition

**Computational intelligence** comprises practical **adaptation and self-organization** concepts, paradigms, algorithms, and implementations that enable or facilitate appropriate actions (intelligent behavior) in complex and changing environments.

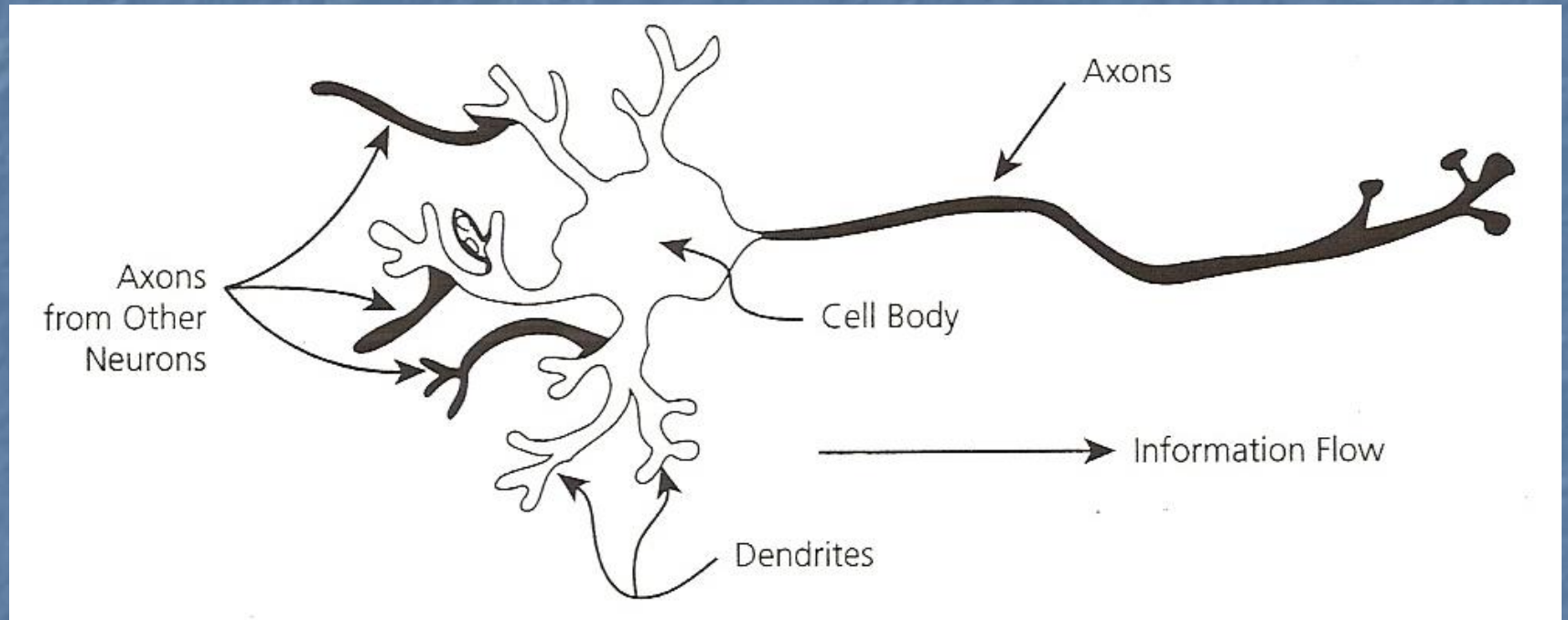
# Biological Basis: Neural Networks

Neurons: nerve cells; consist of dendrites, body and an axon; signals flow through *synapses*.

Some differences between biological and artificial neurons (processing elements):

- \* Signs of weights (+ or -)
- \* Signals are AC in neurons, DC in PEs
- \* Many types of neurons in a system; usually only a few at most in neural networks
- \* Basic cycle time for PC (~100 ns) faster than brain (10-100ms) {as far as we know!}

# Biological Neuron



# Biological Basis: Evolutionary Computation

- Ties with *genetics*, “a branch of biology that deals with the heredity and variation of organisms”
- Chromosomes*: structures in cell bodies that transmit genetic information; humans have 46, in 23 pairs
- Individual patterns in EC correspond to chromosomes in biological systems
- The *genotype* completely specifies an organism; in EC a *structure* specifies a system; in most EC tools, one string specifies a structure, so structure is interchangeable with chromosome. A solution.



# Chromosomes



Drawing by Mark Eberhart



# Biological-EC Chromosome Differences

- Artificial (EC) chromosomes all same length
- Biological: DNA...EC: bits or real numbers
- In reproduction, biological cells divide, while EC cells copy
- Synthesis of new chromosomes: 50 percent from each biological parent, any percentage from EC parents. Mutation not intrinsic to biological system as it is in EC.

# Fuzzy Logic Behavioral Motivations

- FL analogous to uncertainty in human experiences  
("Stop the car *pretty soon*.")
- Fuzziness is associated with *nonstatistical uncertainty*
- FL thus is reflected at the behavioral level of the organism
- Fuzziness is not resolved by observation or measurement

# CI Myths

- The supercomputer/Nobel laureate myth
- CI implementations are faster, cheaper and better than anything else
- CI will eliminate need for programming
- CI is more important than preprocessing
- Only biology experts can use CI
- Fuzzy logic is fuzzy
- Fuzzy logic is a substitute for probability
- Optimization is possible

# Application Areas: Neural Networks

- Classification/Prediction
- Associative memory
- Clustering or compression
- Simulation or composition
- Control systems

# Application Areas: Evolutionary Computation

- Optimization
  - \* Route Finding
  - \* Scheduling
- Classification
  - \* Diagnosis (OK, minimal set covering)
- Configuration (aka, design)



# Application Areas: Fuzzy Logic

- Control systems
  - \* Vehicles
  - \* Home appliances
- Expert systems
  - \* Industrial processes
  - \* Diagnostics
  - \* Finance
  - \* Robotics and manufacturing

# Chapter 1 Final Thoughts

- Hardware/software distinctions are blurred
- Emphasis on applicability, not plausibility
- Not looking for route to intelligent behavior
- Developer (you) must do active design, develop, test and debug (traditional), plus observation and analytical thinking (not so traditional).

# Chapter 2:

# Computational Intelligence

# Computational Intelligence: Introduction

- *Adaptation* and *learning* are discussed and compared
- Self-organization and evolution are discussed
- Historical views of CI are reviewed
- Concepts of CI are reviewed, as is how it fits into larger picture
- Definitions of CI are presented and discussed
- Work reported here is extension of that done by Marks and Bezdek



# Adaptation versus Learning

- **Adaptation 1:** the act or process of adapting : the state of being adapted **2:** adjustment to environmental conditions: as **a:** adjustment of a sense organ to the intensity or quality of stimulation **b:** modification of an organism or its parts that makes it more fit for existence under the conditions of its environment.
- **Adapt:** to make fit (as for a specific or new use or situation) often by modification
- **Fit:** suitable, adapted so as to be capable of surviving, acceptable from a particular viewpoint



# Adaptation versus Learning

**Learning:** knowledge or skill acquired by instruction or study *syn:* knowledge

**Learn:** to gain knowledge or understanding of or skill in by study, instruction or experience *syn:* discover

Learning is what an entire intelligent system does.

# Definition of Adaptation

Adaptation is any process whereby a structure is progressively modified to give better performance in its environment.

*Holland 1992*

Adaptive processes are improvement (amelioration) processes. They are usually not really optimization processes.

# Adaptation

- Adaptation overcomes the barriers of nonlinearity and local optima.
- It involves a progressive modification of some structure or structures, and uses a set of operators acting on the structure(s) that evolve over time.
- Adaptation is "...a fundamental process, appearing in a variety of guises but subject to unified study."

- *J. Holland*

# Barriers to Adaptation

- Large problem spaces
- Large numbers of variables
- Complex and nonlinear fitness functions
- Fitness functions that change over time and over the problem space
- Complex and changing environments

# The Law of Sufficiency

If a solution to a problem is:

- Good enough (it meets specs)
- Fast enough
- Cheap enough

Then it is Sufficient.



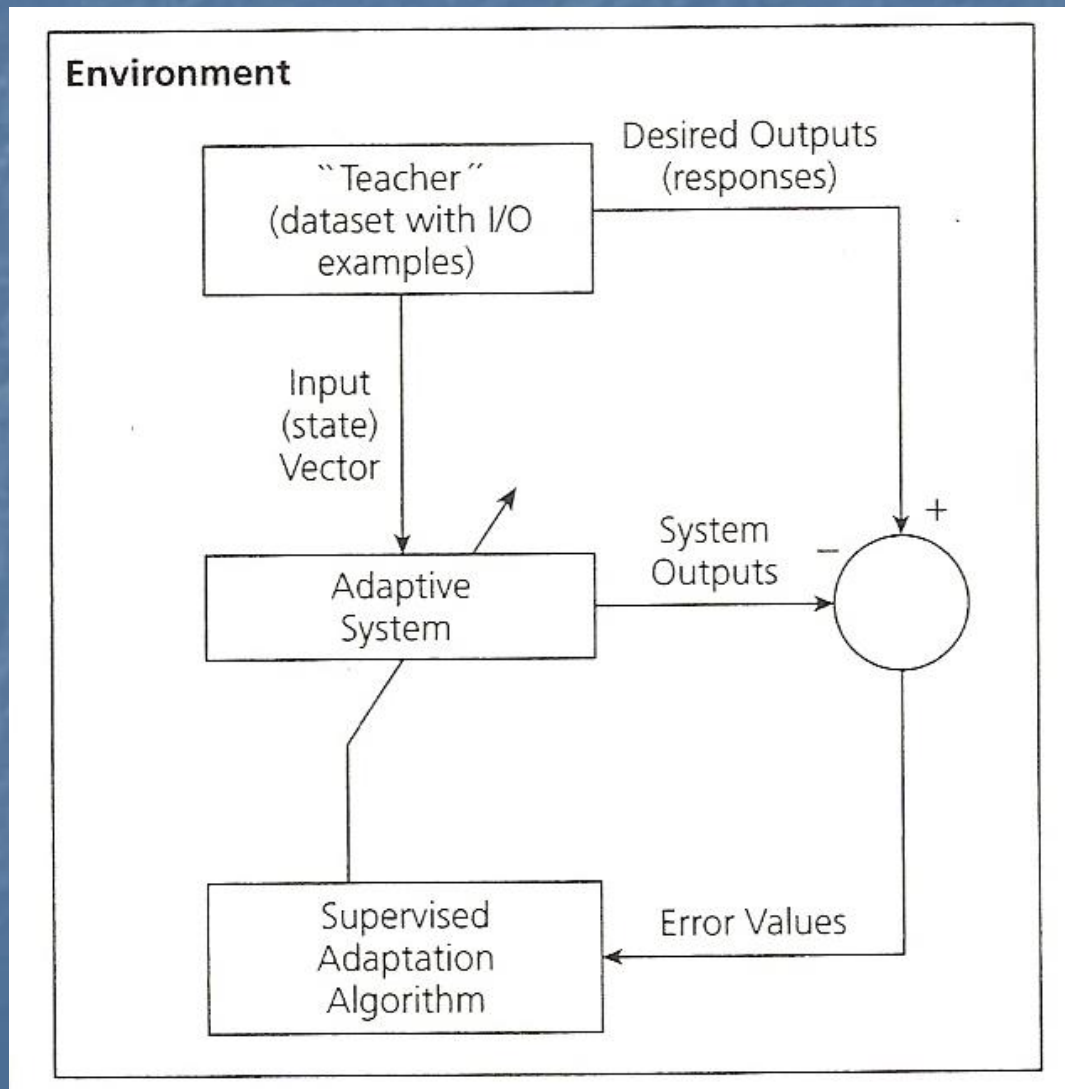
# System Adaptation Methodologies

- Supervised adaptation (training, learning)
- Unsupervised adaptation (training, learning)
- Reinforcement adaptation (training, learning)

# Definition of Supervised Adaptation:

"The process of adjusting (adapting) a system so it produces specified outputs in response to specified inputs." "Supervised" means that the output is known for all inputs and the system training algorithm uses the error to guide the training. (Reed and Marks 1999)

# Supervised Adaptation



# Supervised Adaptation

- A “teacher” provides input-output examples (the “gold standard”)
- Adaptation is carried out one iteration at a time
- Fitness is often inversely proportional to a function of the sum of errors
- Good for function approximation: mapping input vectors to output vectors
- Example: Back-propagation algorithm used to train neural networks

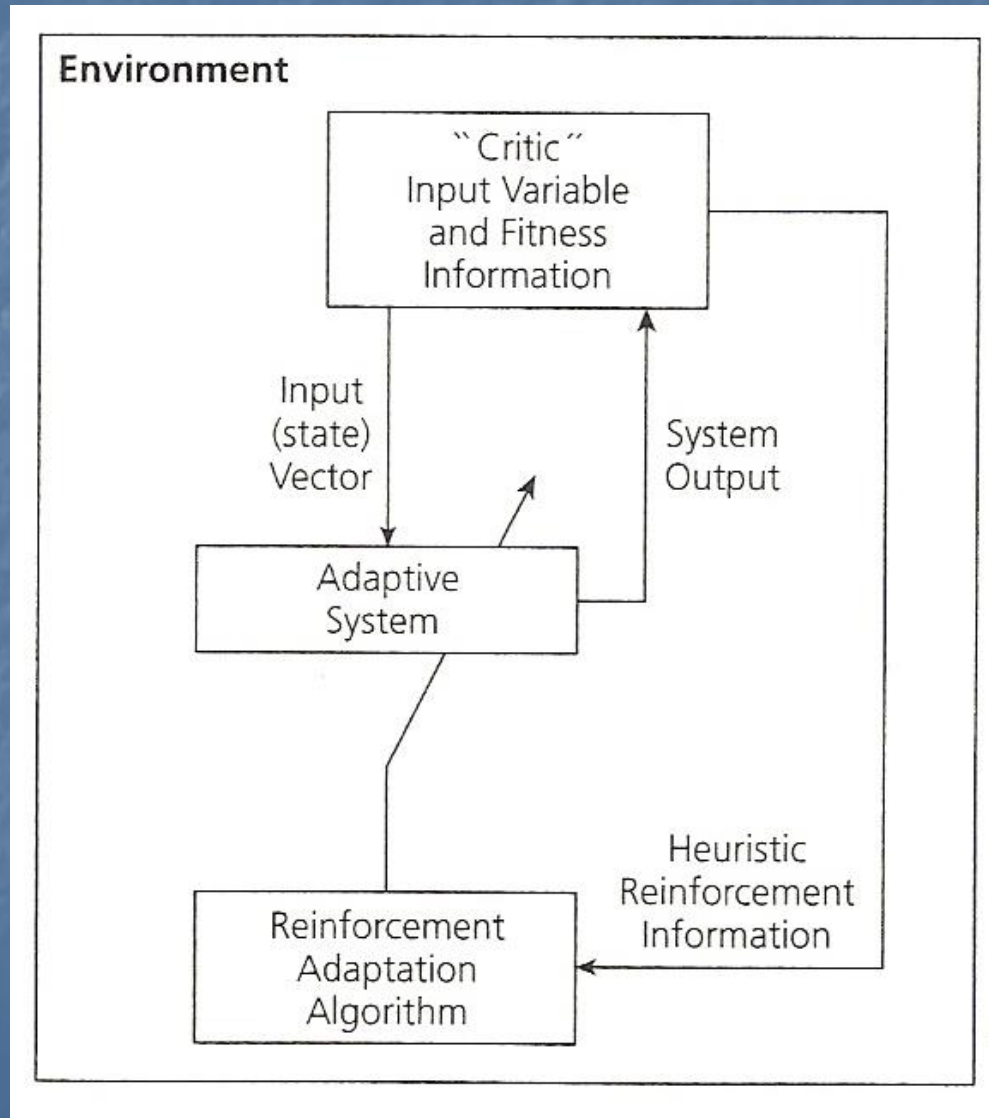
# Definition of Reinforcement Adaptation:

A "sparse reinforcement signal" grades the system response as good or bad. A "critic" provides heuristic reinforcement information.

Example: game playing.



# Reinforcement Adaptation



# Reinforcement Adaptation

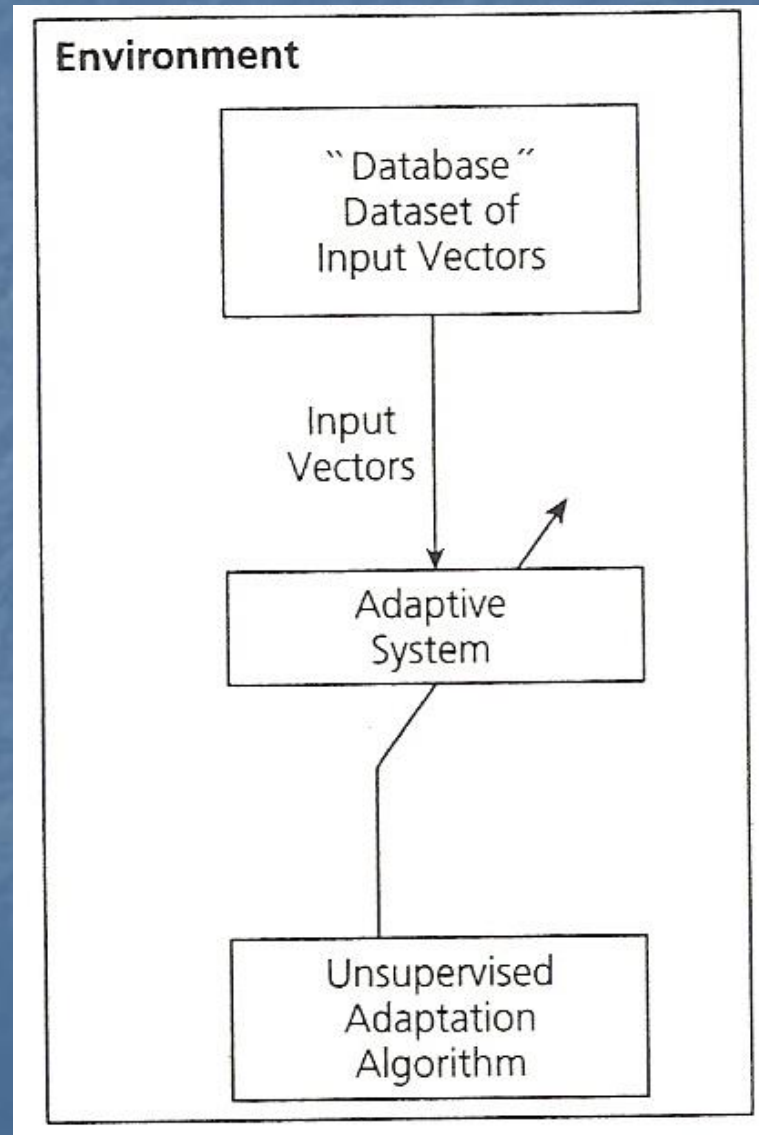
- Most closely related to biological systems
- Has roots in dynamic programming
- Often waits until the time series of inputs is complete to judge the fitness
- The system “critic” only looks at outcomes, not individual error measures

Example: Particle swarm optimization

# Definition of Unsupervised Adaptation:

- The system adapts to regularities in the data according to rules implicit in its design. The 'design' is a substitute teacher. Targets don't exist. (Reed and Marks 1999)
- No indication of fitness exists whatsoever
- Offline evaluation occurs after the algorithm stops running
- Examples: SOFM and LVQ networks (clustering)

# Unsupervised Adaptation



# The Three Spaces of Adaptation

- Input parameter (problem) space  
Defined by dynamic ranges of input variables
- System output (function) space  
Defined by dynamic ranges of output variables
- Fitness space  
Defines “goodness” of solutions; often scaled from 0 to 1

*Remember that, in general, system output and fitness values aren't the same.*



# Behavior of Adapted System

- Converges to stable point
- Exhibits cyclical behavior
- Exhibits chaotic behavior
- Exhibits complex behavior (the edge of chaos)

Note: These behaviors are also exhibited by system adaptation processes!

# Self-Organization

## Definitions:

- apparently spontaneous order
- matter's incessant attempts to organize itself into ever more complex structures, even in the face of the incessant forces of dissolution described by the second law of thermodynamics
- overall system state is emergent property of the system  
interconnected system components become organized in a productive or meaningful way based on local information

Complex systems can self-organize

The self-organization process works near the "edge of chaos"

# Self-organization, cont'd.

Bonabeau's definition of self-organization: "A set of dynamical mechanisms whereby structures appear at the global level of a system from interactions among its lower-level components. The rules specifying the interactions among the system's constituent units are executed on the basis of purely local information, without reference to the global pattern, which is an emergent property of the system rather than a property imposed on the system by an external ordering influence."

Examples: Formation of ice crystals, salt crystals. Cellular automata. The human brain.

# Evolution beyond Darwin

- Darwinian view of evolution
- Shortcomings of Darwinian theory
- Self-organization
- New view of evolution
- Implications for CI & system adaptation

# Darwinian View of Evolution

- Actually Darwin and Mendel
- Chromosome composition determined by parents (animals and humans)
- Mutation expands “search space” (WHAT?)
- Survival of the fittest (or the most skillful)



# Shortcomings of Darwinian Theory

- Origin of life by "chance" or mutation is highly improbable in time frame of earth, well maybe
- Evolution of complex life forms by mutation alone also highly improbable, seems reasonable

# New View of Evolution

- Complex systems can “appear” over relatively short time (compared with Darwinian evolution)
- It appears that natural selection and self-organization work “hand-in-hand,” *i.e.*, that  
***evolution = natural selection + self organization***

# Implications for Computational Intelligence and System Adaptation

- CI has been based roughly on Darwinian theory and biological analogies
- We need to incorporate more self-organization (emergent behavior) into CI *by design* rather than by accident (focus on the edge of chaos)
- The CI chapter goes into this in more detail

# History of Computational Intelligence

- Arranged by methodology
- Focus is on people (somewhat arbitrarily chosen)
- Discussed roughly in chronological order



# The Age of Computational Intelligence

- First use of the term (in its current context) by James Bezdek in 1992
- First IEEE World Congress on Computational Intelligence in Orlando in 1994
- First CI text in 1996
- Second IEEE World Congress on CI in Anchorage in 1998
- Subsequent World Congresses in Hawaii (2002), Vancouver (2006)...next in Hong Kong (2008)



# Historical View of Computational Intelligence

- “Computational Intelligence” was used in the title of a journal in Canada starting in 1980s, but not meaning what we now mean by the term
- First paper using term published by Bezdek in 1992 in *Int. Jour. Approximate Reasoning*.
  - Dealt with pattern recognition only
  - Evolutionary computing included in CI only by reference

# History of Computational Intelligence, Cont'd.

Marks published editorial in IEEE Trans. Neural Networks in 1993 focused on the World Congress on Computational Intelligence to be held in 1994.

He identified “Neural networks, genetic algorithms, fuzzy systems, evolutionary programming, and artificial life” as the “building blocks of CI.”

He also said, “Although seeking similar goals, CI has emerged as a sovereign field whose research community is virtually distinct from AI.”

# Bezdek's 1994 Definition of CI

A system is *computationally intelligent* when it: deals only with numerical (low-level) data, has a pattern recognition component, does not use knowledge in the AI sense; and additionally, when it (begins to) exhibit (i) computational adaptivity; (ii) computational fault tolerance; (iii) speed approaching human-like turnaround, and (iv) error rates that approximate human performance.

# Pattern Recognition

*Definition:* The identification of objects and images by their shapes, forms, outlines, color, surface texture, temperature, or other attribute, usually by automatic means. [Weik '89, ATIS Committee T1A1]

Pattern recognition, like intuition, has a vague definition. We know what it means to recognize a face, but we cannot explain how we do it.



# From Bezdek:

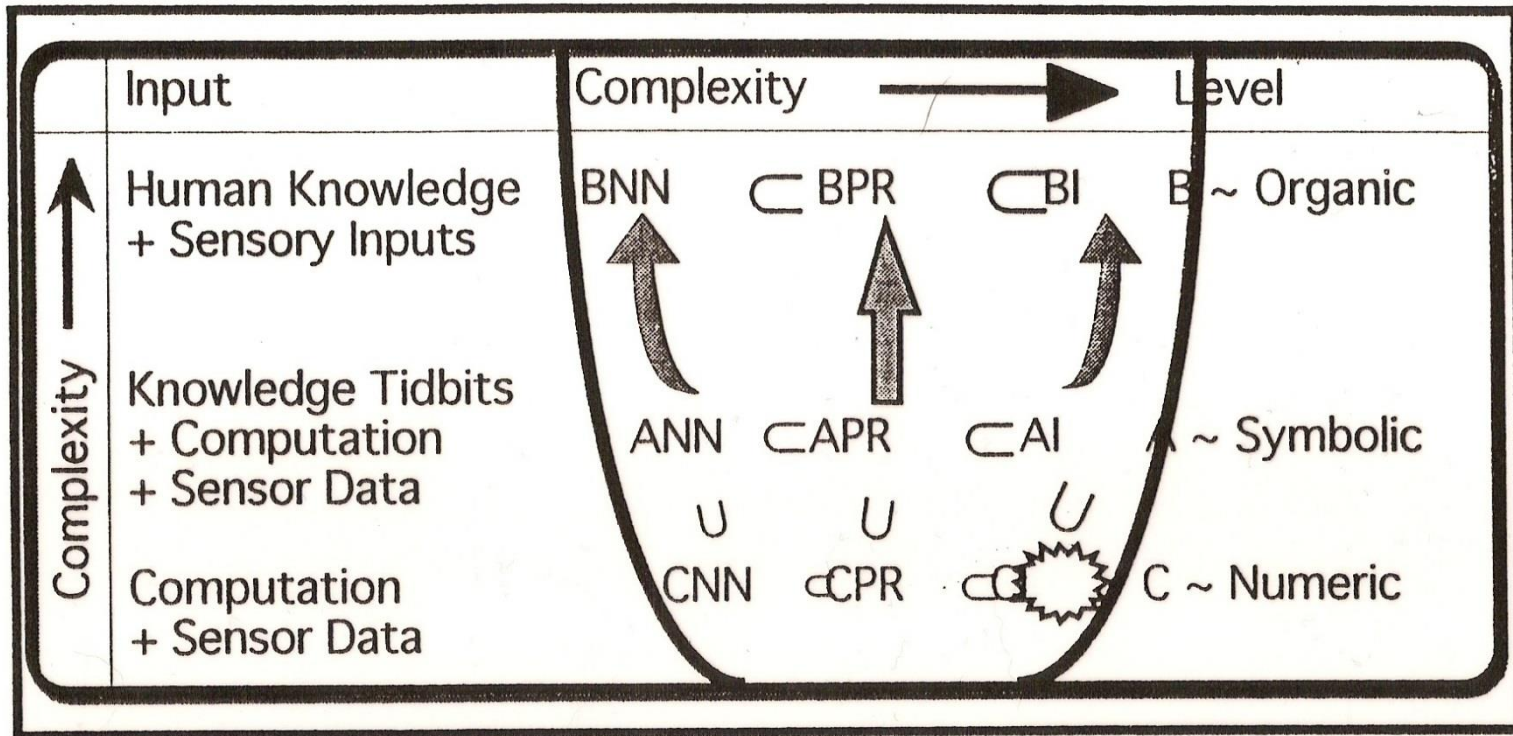


Fig. 2.1. Commuting through the ABCs [1, 5]: my *new* view

$\subset$ : Is subset of  
 $\Rightarrow$ : "helps enable"  
 "leads to"



# From Bezdek:

**Table 1. Defining the ABC's**

<b>BNN</b>	Your hardware : the <i>brain</i>	Processing of your sensory inputs
<b>ANN</b>	Mid-level models : CNN (+) Knowledge Tidbits	Mid-level processing in the <i>style of the brain</i>
<b>CNN</b>	Low-level, biologically inspired models	Sensor data processing in the <i>style of the brain</i>
<b>BPR</b>	Your search for structure in sensory data	Recognition of structure in your perceptual environment
<b>APR</b>	Mid-level models : CPR (+) Knowledge Tidbits	Mid-level numeric and syntactic processing
<b>CPR</b>	The search for structure in sensor data	All CNNs + fuzzy, statistical, and deterministic models
<b>BI</b>	Your software : the <i>mind</i>	Cognition, memory and action : you have them !
<b>AI</b>	Mid-level models : CI (+) Knowledge Tidbits	Mid-level cognition in the <i>style of the mind</i>
<b>CI</b>	Low-level algorithms that reason computationally	Low-level cognition in the <i>style of the mind</i>

# Pedrycz's Definition of Computational Intelligence

Computational intelligence (CI) is a recently emerging area of fundamental and applied research exploiting a number of advanced information processing technologies. The main components of CI encompass neural networks, fuzzy set technology and evolutionary computation. In this triumvirate, each of them plays an important, well-defined, and unique role.

(Pedrycz 1998)

# Another View of Computational Intelligence

A different viewpoint exists with respect to aspects of Bezdek's model:

- \* the dichotomy of functions along carbon vs. silicon lines
- \* statement that some computational models don't have biological equivalents
- \* characterization of nodes as subsets of subsequent nodes
- \* requirement that pathways from low complexity nodes to high complexity nodes pass through intermediate nodes



# The Authors' Viewpoint

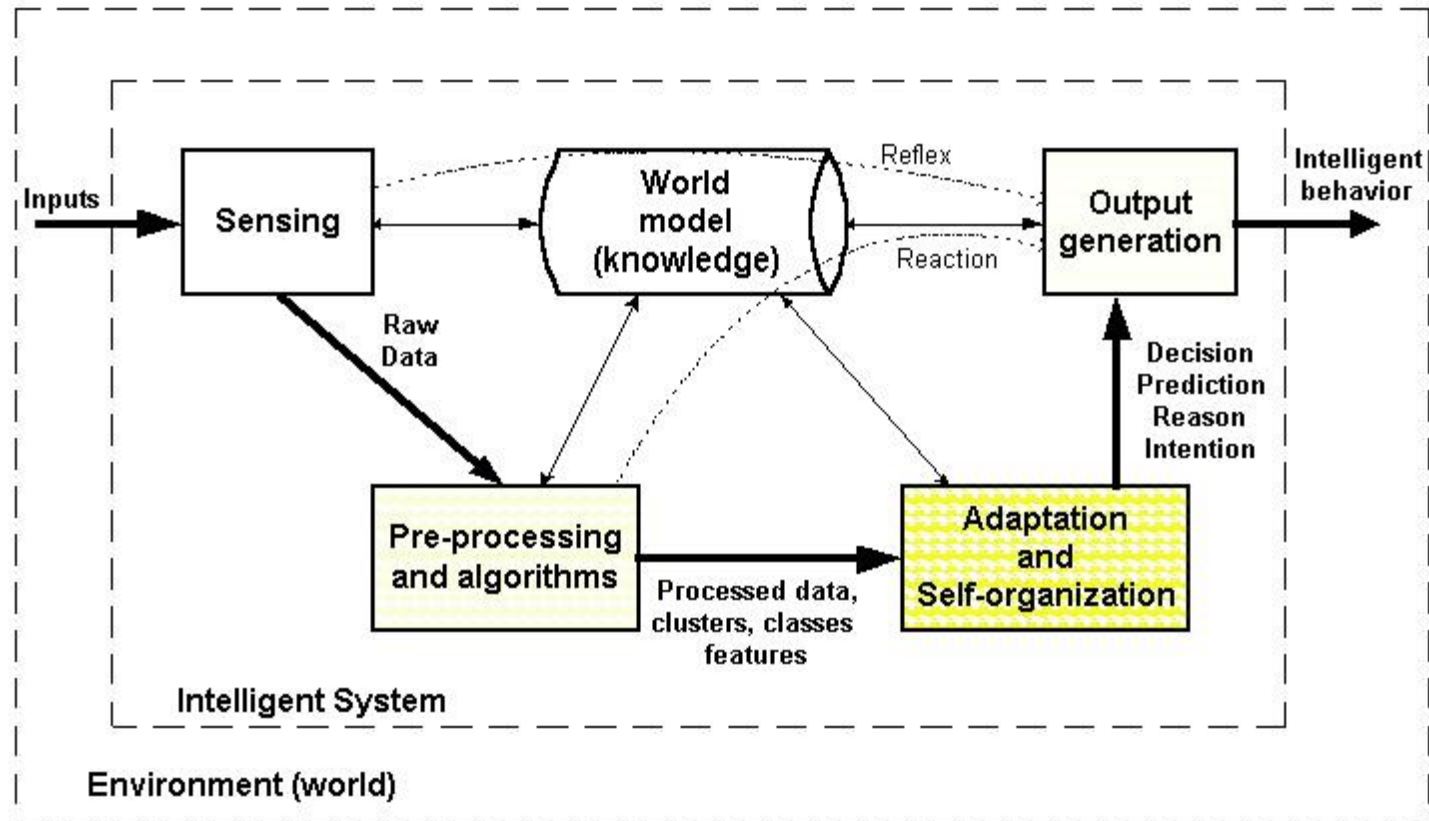
- \* Intelligence exists in many kinds of systems; it does not matter what kind of system produces the intelligence
- \* All computational models were designed and implemented by humans; therefore, they must have biological analogies
- \* Nodes are not always subsets of more complex nodes... two-way communication occurs
- \* Direct pathways exist from nodes of low complexity to those of high complexity

# Computational Intelligence Definition

**Computational intelligence** comprises practical **adaptation and self-organization** concepts, paradigms, algorithms and implementations that enable or facilitate appropriate actions (intelligent behavior) in complex and changing environments.



# Relationships Among Components of Intelligent Systems



Relationships among components of intelligent systems

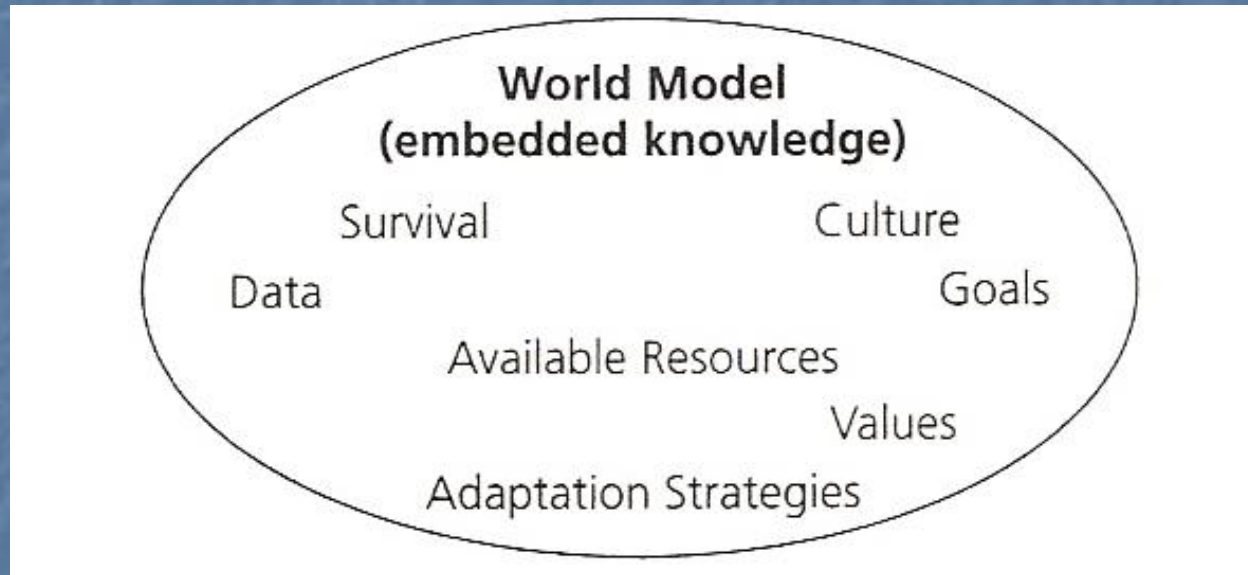
# Attributes of Intelligence

Some attributes of intelligence are not explicitly represented on the diagram:

- \* Complexity - generally increases from left to right on diagram
- \* Stochasticity/chaos - probably present in each element of diagram

Diagram emphasizes pattern recognition; other elements are *very important (and are missing)*

# World Model Details



# Simplified View of Computational Intelligence



# Chaos or Stochasticity

CI paradigms are replete with “stochasticity” or “randomness.”

- NN weight initialization
- NN asynchronous updating
- NN and EC simulated annealing
- EC crossover (ES recombination)
- EC mutation
- EC selection (usually)



# Randomness Does Not Exist

- Randomness is only *simulated* in computers with deterministic programs
- We therefore are really dealing with *pseudorandomness*
- As for nature, “God does not play dice.” – A. Einstein
- What we observe as “random” or “stochastic” in nature are actually nonlinear dynamics systems

# Generalization

Assume a function  $y = f(x)$  maps each input to an output in the problem space, and that our data set represents only a small part of the problem space. We want to build a model  $f^*(x)$  such that other values of  $x$  will be mapped into  $Y$  such that  $f^*(x) \approx f(x)$  for  $x^*$  not in the data set. *This is generalization.*

*We usually assume that  $f^*(x) = f(x)$  for a perfect system.*

*Note that we usually split our data set into training and test sets, and we thus usually measure the generalization capability on the test set. Note also that the size of the dataset must be sufficiently large.*

# What About Artificial Intelligence?

Where does AI fit in? At the shell of the Adaptation and Self-organization node, and in the World Model, mainly.

CI attributes that do not hold for AI and hard computing:

- The ability to generalize
- The ability to deal with partial truths and uncertainty
- Graceful degradation of system performance
- The ability to perform well in complex and changing environments

Hard computing attributes that do not hold for CI systems:

- Precision
- Certainty

# AI Definition

In the 1992 Dictionary of Science and Technology published by Academic Press (Christopher Morris, Ed., San Diego, CA: Academic Press, page 160), Gordon S. Novak (then at the University of Texas) defines artificial intelligence as:

“the study of the computation required for intelligent behavior and the attempt to duplicate such computation using computers. Intelligent behavior connects perception of the environment to action appropriate for the goals of the actor. Intelligence, biologically costly in energy, pays for itself by enhancing survival. It isn’t necessary to understand perfectly, but only to understand well enough to act appropriately in real time.”

Might substitute the word “processing” for “computation,” and say “using computers and other systems,” but generally the definition is reasonable.



# Computational Intelligence Implementations

- CI systems usually comprise hybrids of paradigms such as neural nets, fuzzy logic, and evolutionary algorithms.
- Component paradigm tools become inseparable and indistinguishable, i.e., each tool loses its individual identity.



# Conclusion

*Computational Intelligence provides success stories that are often hard to justify with formal mathematical models (which are but a subset of all computational models, some of which are based on mathematics, and some of which are not).*

*- Jim Bezdek*