2. Introduction to Computational Intelligence

Computational Intelligence for the Internet of Things (2019-20)

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Introduction to Computational Intelligence

- What is Computational Intelligence
- Origins and History
- Research Areas
- Neural Networks
- Evolutionary Algorithms and Swarm Intelligence
- Fuzzy Systems
- Hybrid systems
- Where can I find more about CI?

What is Computational Intelligence?

- WTF is Computational Intelligence???!?!?!?
- A bit of history…
  - 1983: IJCI – Int… Computational Intelligence
  - 1992: Jim Bezdek…
  - ...suggests to the IEEE Neural Networks Council, the use of the name "Computational Intelligence" for the forthcoming 1994 congress on Intelligent Systems
  - 2004: The de facto consensus in area name was reached when Computational Intelligence became a full Society of the IEEE (IEEE CIS)
- Note that CI (or its underlying techniques) has existed for several decades
  - P.K.A. (Previously Known As) Intelligent Systems, Soft Computing, Natural Computing, etc.

IEEE Computational Intelligence Society

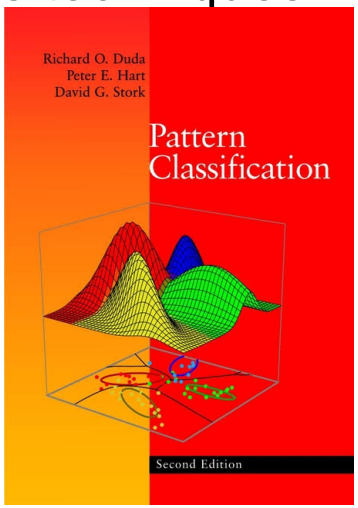
Origins

Thu Apr 9 12 :33 :11 1992
To: rsn@ece.wvu.wvnet.edu, rce@rti.rti.org, xm8@sdcc12.UCSD.EDU,
marks@blake.u.washington.edu, and d43131a@nucc.nagoya- u.ac.jp
From: jbezdek@trivia.coginst.uwf.edu
Subject: NEW name of council
Status: R
I suggest the COMPUTATIONAL INTELLIGENCE COUNCIL, later to become the COMPUTATIONAL INTELLIGENCE SOCIETY.

This suggestion was accepted by the NNC executive committee (Excom), and two months later the name *IEEE World Congress on Intelligent Systems* was changed to The *IEEE World Congress on Computational Intelligence* by the NNC administrative committee (Adcom) at its meeting in Baltimore on June 7, 1992. The first WCCI, held in Orlando in 1994, combined the two major conferences of the NNC (neural networks, fuzzy systems), with a new one on evolutionary computation (EC). The scope of the NNC was modified in 1991 to include both fuzzy systems and evolutionary computation. The revised scope, adopted in 1991 (visit the IEEE CIS history website for the source of this quote):

What is Computational Intelligence?

- "Mimicking nature for problem solving"
- Biologically or human inspired computing techniques
- Characterized by including a set of methodologies that are adaptive, tolerant in front of errors, inspired by biological or cognitive principles, parallel in nature, and operating in the numeric domain.
- Intersects Artificial Intelligence goals but not its techniques
- What about Machine Learning?
  - Also some intersection…
  - … but ML is mostly based on blackbox approaches for data manipulation
  - BTW, ML has also been around for ages…



Research Areas

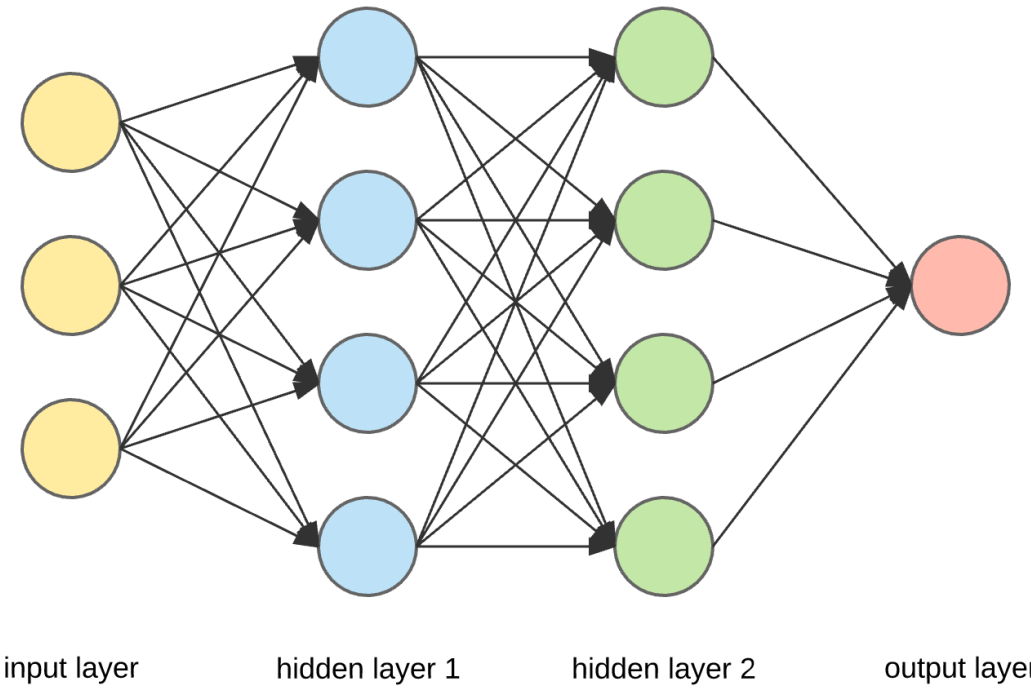
- Three main research areas:
  - Artificial Neural Networks (Rosenblatt 50's-60's)
  - Fuzzy Systems (Zadeh 60's)
  - Evolutionary Computation (Holland 60's-70's)
- …and several acknowledged areas including systems that abide to CI principles and are more or less close to at least one of the main areas. E.g:
  - Swarm Intelligence (Ants, Particle Swarm, Bees, Fish School, etc.)
  - Simulated Annealing
- When mixing more than one area, we have the so called "Hybrid systems": Neural-Fuzzy systems (ANFIS, etc.), Genetic-Fuzzy systems; Genetic-Neural systems; Fuzzy Cognitive Maps; etc.)

NN, FL, EA…

- All three areas have one common characteristic:
  - The techniques they propose (NN, FL, EA) are universal approximators that essentially perform as high order polynomials when approximating a given function!
  - However, they accomplish that behavior using completely different approaches
  - …and that's how things become interesting! ☺

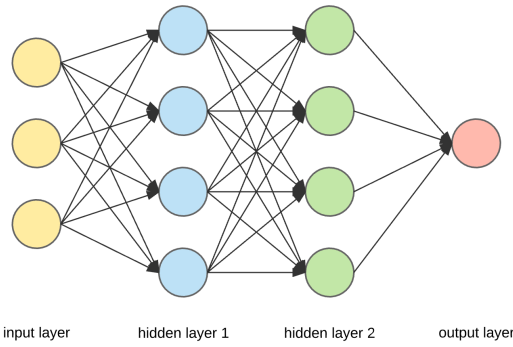
Neural Networks

- Neural Networks can learn!
  - Learning is achieved by examples:
    - The NN must be told the expected output for a given set of input values
- Given enough examples, the NN is able to learn and generalize the outputs for unforeseen inputs



Neural Networks (II)

- With their ability to derive meaning from complicated or imprecise data, NN can be used to extract patterns and detect trends that are too complex to be noticed by either humans or traditional computer techniques
- They are also able to perform tasks that are trivial to humans but very difficult using other computational techniques, such as, e.g., handwritten character recognition
- Since neural networks are best at identifying patterns or trends in data, they are well suited for classification, prediction or forecasting needs

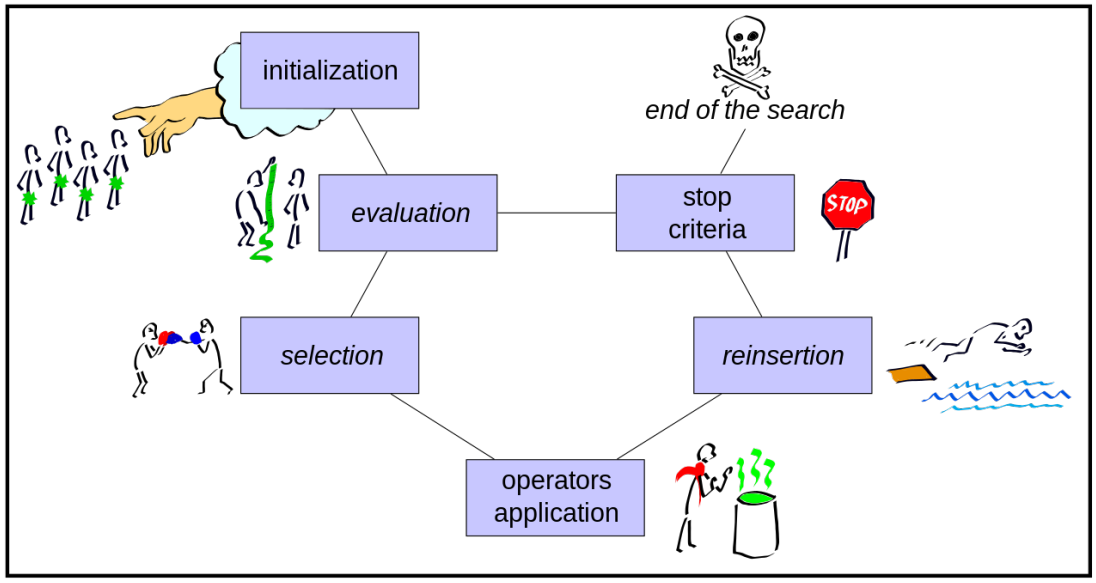


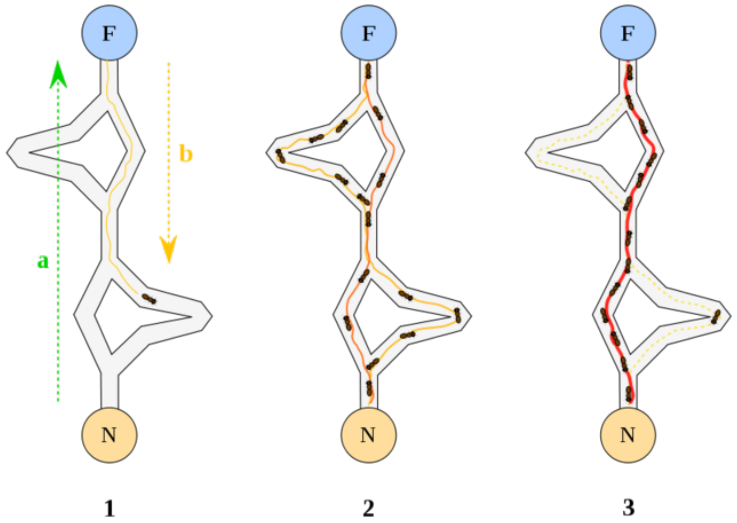
Neural Networks (III)

- Some application examples:
  - Object detection; Speech recognition; Network load forecast; Channel allocation in cellular mobile systems; Image Compression; SPAM detection; Bot detection; Anomaly detection; Network intrusion detection; etc.
- When should a NN be used?
  - When one cannot formulate an algorithmic solution, and a large annotated dataset is available (i.e., large amount of examples – input/output quantitative data – is available);
  - When continuous learning from previous results is important;
  - ☹ Only if there is no need to extract knowledge from the resulting NN, i.e., understand “why the NN produces a certain result”.

Evolutionary Algorithms and Swarm Intelligence

- Primary (single?) goal: optimization!
- Metaheuristic optimization algorithms
- Inspired by biological evolution and or biological systems
- Population based: individuals are used to achieve/find the best possible solution (optimal or near optimal)





Evolutionary Algorithms and Swarm Intelligence (II)

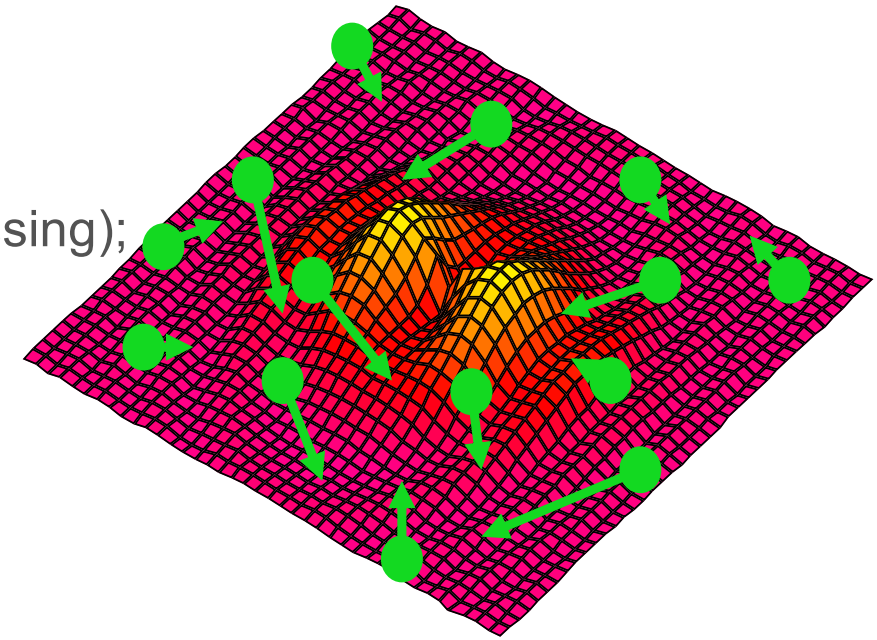
- Evolutionary Algorithms
  - Genetic Algorithms (GA, 60's-70's)
    - Seek the solution of a problem in the form of strings of numbers, by applying operators such as recombination, or mutation
  - Genetic Programming; Evolutionary programming; Differential evolution…
- Swarm Intelligence
  - Particle swarm optimization (PSO, 90's)
    - Based on the ideas of animal flocking behaviour; Useful for problems in which a best solution can be represented as a point or surface in an n-dimensional space
  - Ant Colony Optimization (ACO, 90's)
    - A probabilistic technique; Useful in problems that deal with finding better paths through graphs
  - Artificial Bee Colony (ABC, 00's); Bees (00's); Artificial Immune systems (AIS)…

Genetic Algorithms vs. Grid search or Random search

- A *genetic algorithm (GA)* is a probabilistic search algorithm that iteratively transforms a *population* of mathematical objects (typically fixed-length binary character strings), each associated with a fitness value, into a new population of offspring objects
- GA are are useful in very large search spaces. E.g:
  - 81-bit problems are considered very small for GA
  - Number of possible combinations using 81 bits: $2^{81} = 10^{27}$
  - Even if we could test a possible solution every nanosecond, it would take us 10^{27} nanoseconds to test every possible solution
  - But 10^{27} nanoseconds = 15 billion years, which is the estimated age of our universe!

Evolutionary Algorithms and Swarm Intelligence (III)

- Example applications:
  - Load balancing of nodes in the cloud;
  - Routing vehicles;
  - Routing packets;
  - Routing in sensor networks;
  - Scheduling;
  - Frequency assignment;
  - Edge detection (image processing);
  - Finding maximum in multi dimensional problems
  - Etc.



Fuzzy Logic

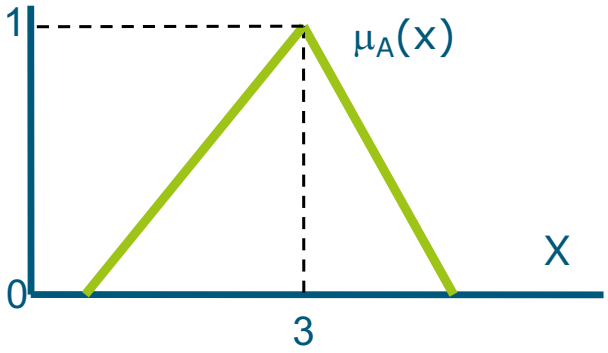
- Fuzzy Logic is basically a multivalued logic that allows intermediate values to be defined between conventional evaluations like *yes/no, true/false, black/white,* etc.
- Notions like *rather warm* or *pretty cold* can be formulated mathematically and processed by computers
- In Fuzzy systems, an attempt is made to apply a more human-like way of thinking in the programming of computers

- The term *Fuzzy Logic* is a misnomer:
  - It implies that in some way the methodology is vague or ill-defined. This is far from true!
  - Fuzzy logic just evolved from the need to model the type of vague or ill-defined systems that are difficult to handle using conventional binary valued logic. The methodology itself is based on mathematical theory.

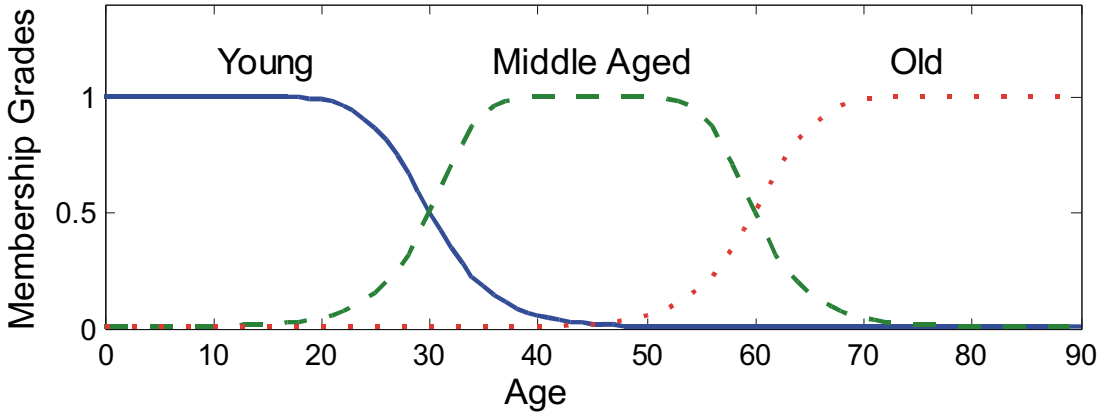
Fuzzy Sets

- Sets with fuzzy, gradual boundaries (Zadeh 1965)
- A fuzzy set A in X is characterized by its membership function $\mu_A: X \rightarrow [0,1]$

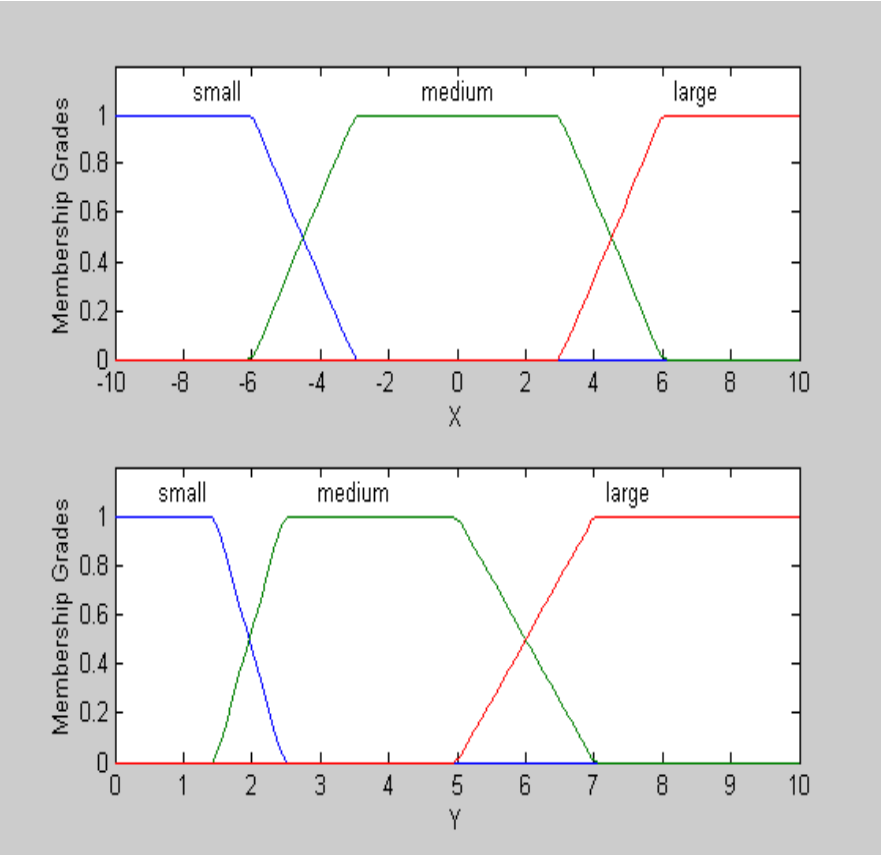
Real numbers about 3:



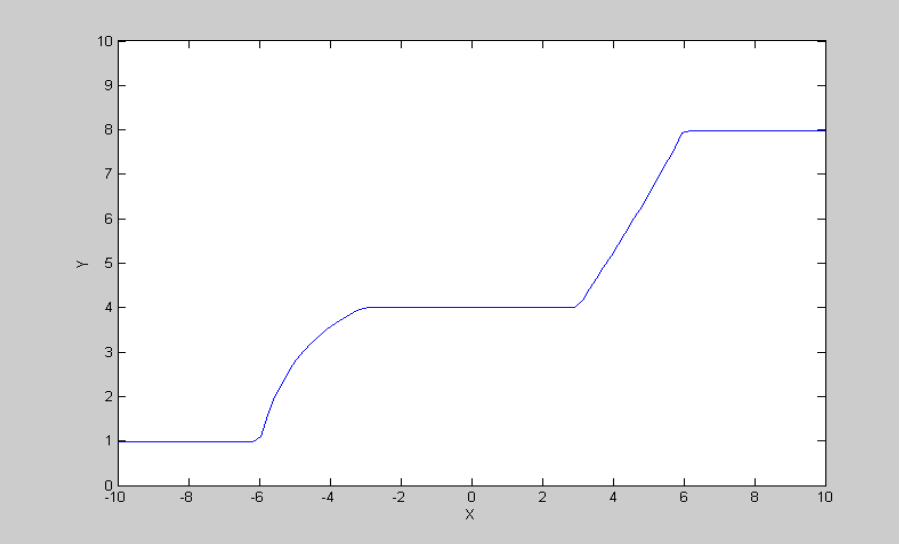
Fuzzy partition of Age:



Fuzzy Rule Based System – single input (x), single output (y)



Rules:
If x is Small then y is Small
If x is Medium then y is Medium
If x is Large then y is Large



Fuzzy Systems

- Application examples:
  - Subway systems in Japan, Taiwan, Canada
  - VAG automatic gearbox
  - Canon Auto-focus
  - Microwaves, washing machines
  - Medical diagnosis - mathematical meaning to linguistic symptoms such as intensity of headaches
  - MASSIVE (Multiple Agent Simulation System in Virtual Environment) generate crowd-related visual effects (Avatar, Lord of the Rings, ...)
  - Risk prediction/analysis

Fuzzy Systems

- ☺ Advantages of fuzzy systems
  - Considerable skill for little investment
    - Fuzzy logic systems piggy bank on human analysis
      - Humans encode rules after intelligent analysis of lots of data
      - Verbal rules generated by humans are robust
    - Simple to create
      - Not much need for data or ground truth
      - Logic tends to be easy to program
  - Fuzzy rules are human understandable
- ☹ Avoid the use of fuzzy systems if:
  - Humans do not understand the system
  - Different experts disagree (although some systems can conciliate different opinions)
  - Knowledge cannot be expressed with verbal rules

Hybrid systems

- ANN: have the ability to learn
- EA: are great for performing optimization
- FSS: can take advantage of human expert knowledge to model nonlinear functions of arbitrary complexity
- Hybrid systems try to combine and take advantage of each technique strong points:
  - Use NN to introduce learning in FS;
  - Use GA to optimize NN (GANN) or FS parameters;
  - Use FS to try to understand NN behaviour (e.g. FBN);
  - Etc.

Where should I go to see what's happening in CI?

- WCCI – World Congress on Computational Intelligence
  - A good starting point to check "what is happening in CI"
  - IEEE Computational Intelligence Society main conference
  - From 2008, every 2 year
  - Joins the following annual conferences:
    - IJCNN – International Joint Conference on Neural Networks;
    - CEC – IEEE Congress on Evolutionary Computation
    - FUZZ-IEEE – IEEE International Conference on Fuzzy Systems
  - Focused both on engineering applications and theoretical developments
  - WCCI2018, Rio de Janeiro: more than 2000 submissions…
  - WCCI2020, Glasgow, Scotland

CI Area comparison

WCCI	1994 Orlando	1998 Anchorage	2002 Honolulu	2006 Vancouver	2008 HK	2010 Barcelona	2012 Brisbane	2014 Beijing	2016 Vancouver	2018 Rio
#Papers		907	1155	1687	1622	1962	1281	1427	1781	1359
IJCNN		51%	45%	49%	40%	44%	39%	43%	41%	56%
CEC		16%	30%	29%	37%	32%	38%	31%	39%	26%
FUZZ-IEEE		33%	25%	21%	23%	24%	24%	26%	20%	18%

Where should I go to see what's happening in CI? (II)

- Other conferences:
  - SSCSI; NIPS; IFSA; EUSFLAT; NAFIPS; IPMU; CIG; CIBCB; GECCO; Evostar...
- Some top journals:
  - IEEE Transactions on Fuzzy Systems (TFS), IF:8.75
  - IEEE Transactions on Pattern Analysis and Machine Intelligence, IF:4.9
  - International Journal of Neural Systems, IF:4.28
  - Fuzzy Sets and Systems, IF: 2.78
  - IEEE Transactions on Neural Networks and Learning Systems, IF:2.92
  - IEEE Transactions on Evolutionary Computation (TEVC), IF:3.65
  - IEEE Transactions on Systems, Man and Cybernetics (TSMC)
  - IEEE CI Magazine, IF:2.57
  - Applied Soft Computing (ASC), IF:2.73
  - Expert Systems with Applications (ESWA), IF:2.53
  - International Journal of Approximate Reasoning (IJAR), IF:1.95
  - IEEE Transactions on CI and AI in Games (TCIAIG), IF:1.48

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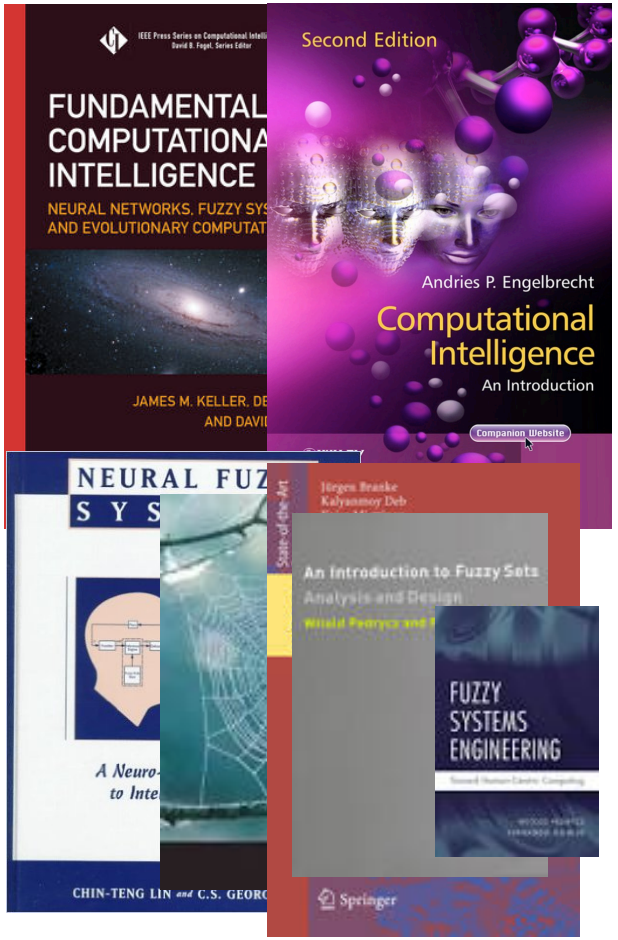

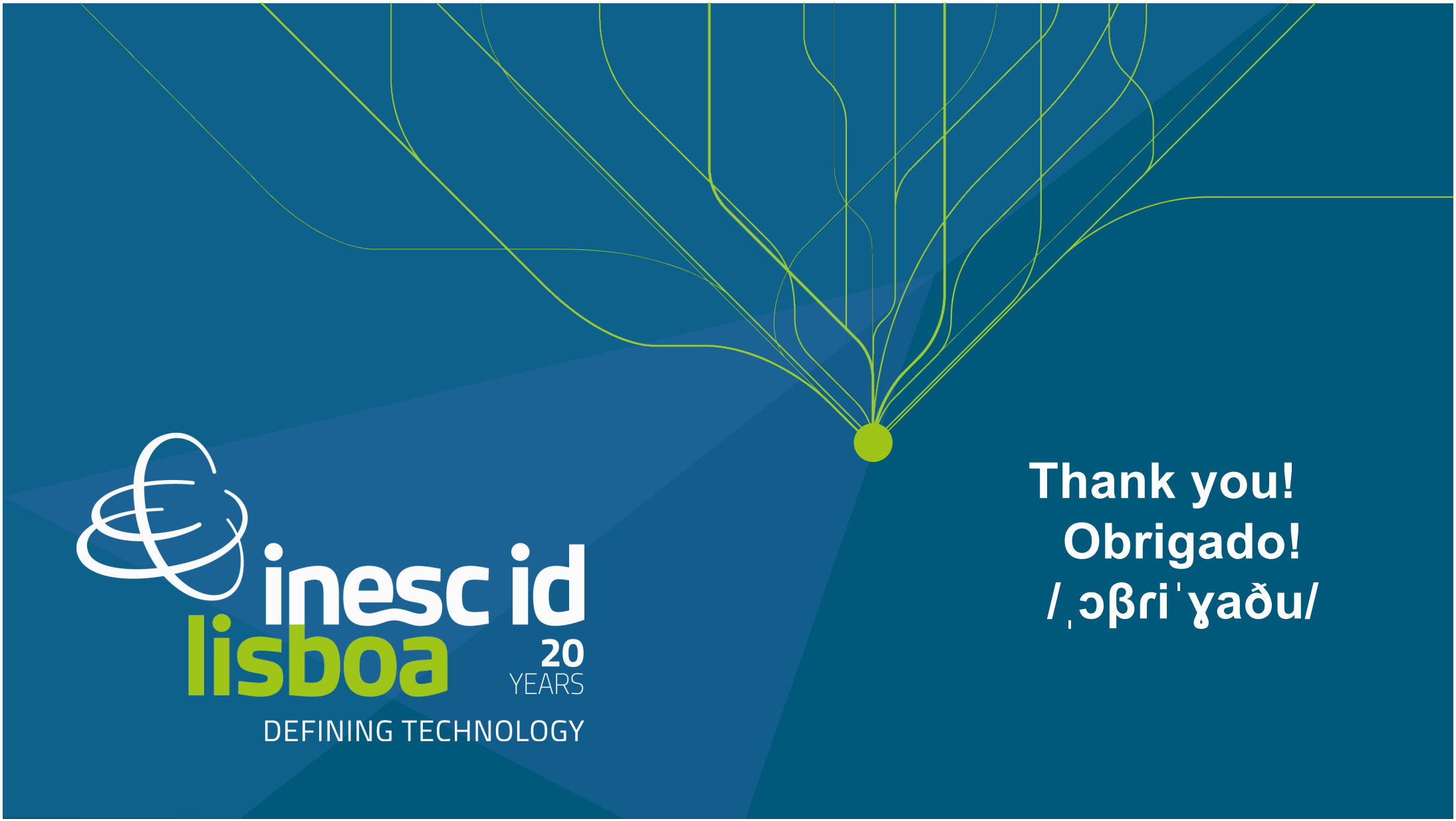
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20
YEARS
DEFINING TECHNOLOGY
Thank you!
Obrigado!
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