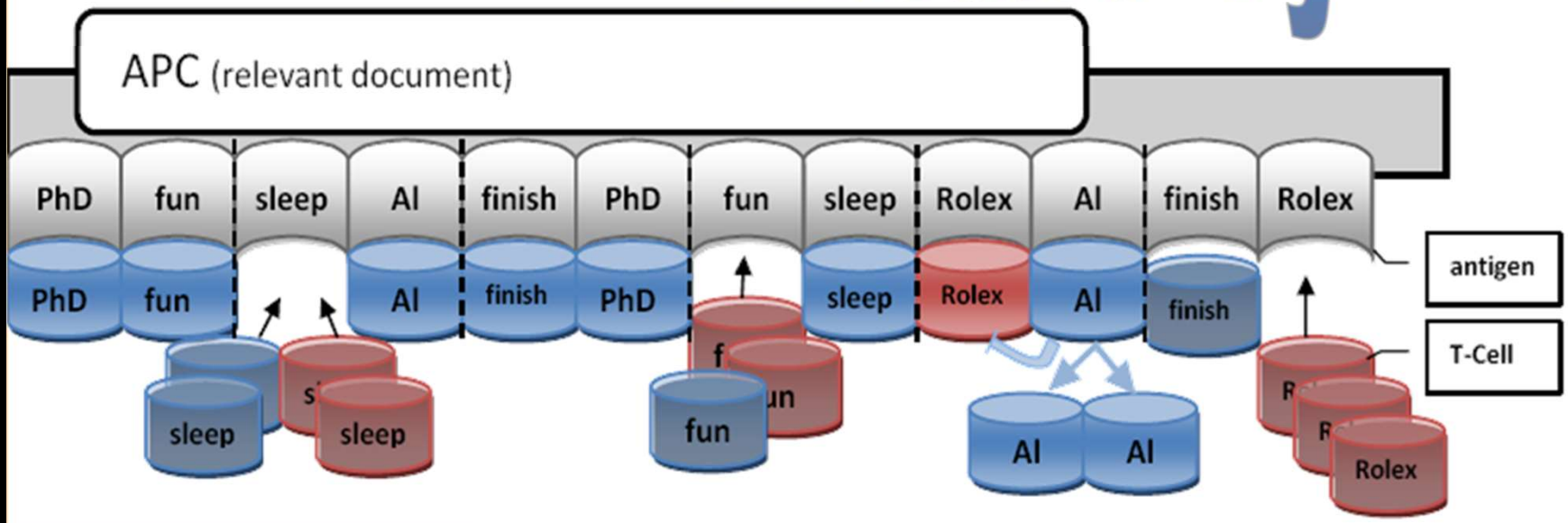
lecture 16

Artificial Immune Systems

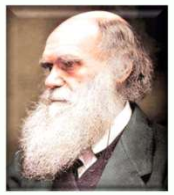


bit.ly/atBIC

rocha@binghamton.edu
casci.binghamton.edu/academics/i-bic

until now

- Class Book
  - Floreano, D. and C. Mattiussi [2008]. *Bio-Inspired Artificial Intelligence: Theories, Methods, and Technologies*. MIT Press.
    - Chapter 5
- Lecture notes
  - Chapter 1: What is Life?
  - Chapter 2: The logical Mechanisms of Life
  - Chapter 3: Formalizing and Modeling the World
  - Chapter 4: Self-Organization and Emergent Complex Behavior
  - Chapter 5: Reality is Stranger than Fiction
  - Chapter 6: Von Neumann and Natural Selection
  - Chapter 7: Modeling Evolutionary Systems
    - posted online @ http://informatics.indiana.edu/rocha/i-bic
- Papers and other materials
  - Optional
    - Nunes de Castro, Leandro [2006]. *Fundamentals of Natural Computing: Basic Concepts, Algorithms, and Applications*. Chapman & Hall.
      - Chapter 2, 7, 8
      - **Chapter 3, sections 3.1 to 3.5**



key events coming up

- Labs: 35% (ISE-483)
  - Complete 5 (best 4 graded) assignments based on algorit presented in class
    - Lab 5: April 28th
      - Ant Clustering Algorithm, (Assignment 5)
        - Delivered by Emad Abed and Kiet Ngo Tuan
        - Due **May 6th**
- SSIE – 583 -Presentation and Discussion: 25%
  - Present and lead the discussion of an article related to the class materials
    - Enginet students post/send video or join by Zoom

bit.ly/atBIC

BINGHAMTON UNIVERSITY
STATE UNIVERSITY OF NEW YORK
rocha@binghamton.edu
casci.binghamton.edu/academics/i-bic

- Projects
  - **Due by May ~~7th~~ 11th** in Brightspace, "Final Project 483/583" assignment
    - ALIFE 2025
      - Not necessarily to submit to actual conference due date
        - May 4 full paper, July 4, abstract
      - https://2025.alife.org/
      - Max 8 pages, author guidelines:
      - https://2025.alife.org/calls#paper-call
      - MS Word, PDF, and Latex/Overleaf templates.
  - Individual or group
    - With very definite tasks assigned per member of group

ALIFE 2025

Tackle a real problem using bio-inspired algorithms, such as those used in the labs.

bit.ly/atBIC

Reusing and expanding labs is highly encouraged.

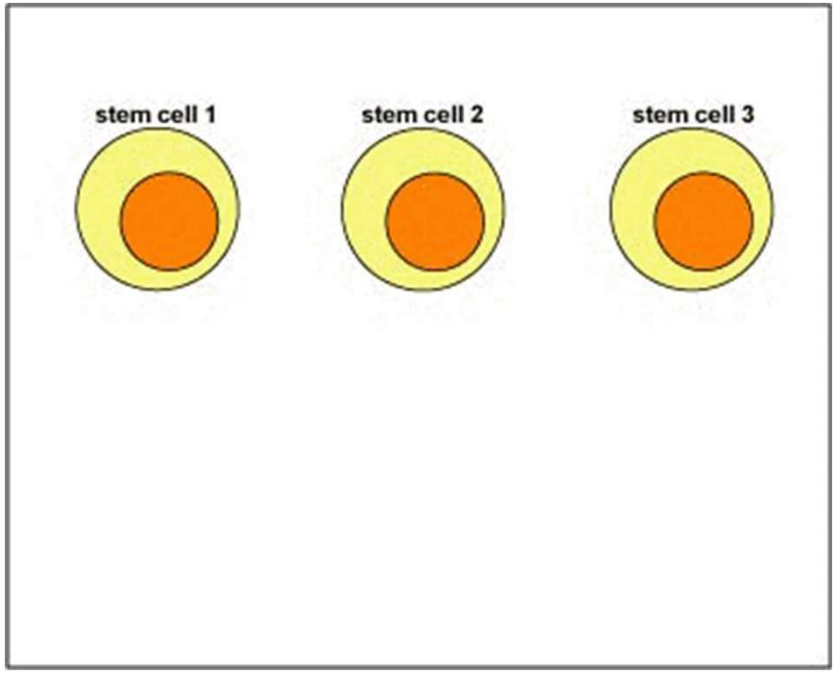
BINGHAMTON UNIVERSITY
STATE UNIVERSITY OF NEW YORK
rocha@binghamton.edu
casci.binghamton.edu/academics/i-bic

exploring similarities across nature

- self-similar structures
  - Trees, plants, clouds, mountains
    - morphogenesis
  - Mechanism
    - Iteration, recursion, feedback
- dynamical systems and unpredictability
  - From limited knowledge or inherent in nature?
  - Mechanism
    - Chaos, measurement
- self-organization, collective behavior, emergence
  - Complex behavior from collectives of many simple units or agents
    - cellular automata, dynamical networks, morphogenesis, swarms, brains, social systems
  - Mechanism
    - Parallelism, multiplicity, multi-solutions, redundancy
- evolution
  - Adaptation, learning, social evolution
  - Mechanism
    - Reproduction, transmission, variation, selection, Turing's tape
- Collective behavior derived from many inseparable sources
    - Multi-level selection, swarm intelligence, immune system, anticipatory systems, brain-body-environment-culture, embodiment, epigenetics, culture
  - Mechanism
    - Network causality, modularity, control, hierarchy, connectivity, stigmergy, redundancy

BINGHAMTON UNIVERSITY
STATE UNIVERSITY OF NEW YORK
rocha@binghamton.edu
casci.binghamton.edu/academics/i-bic

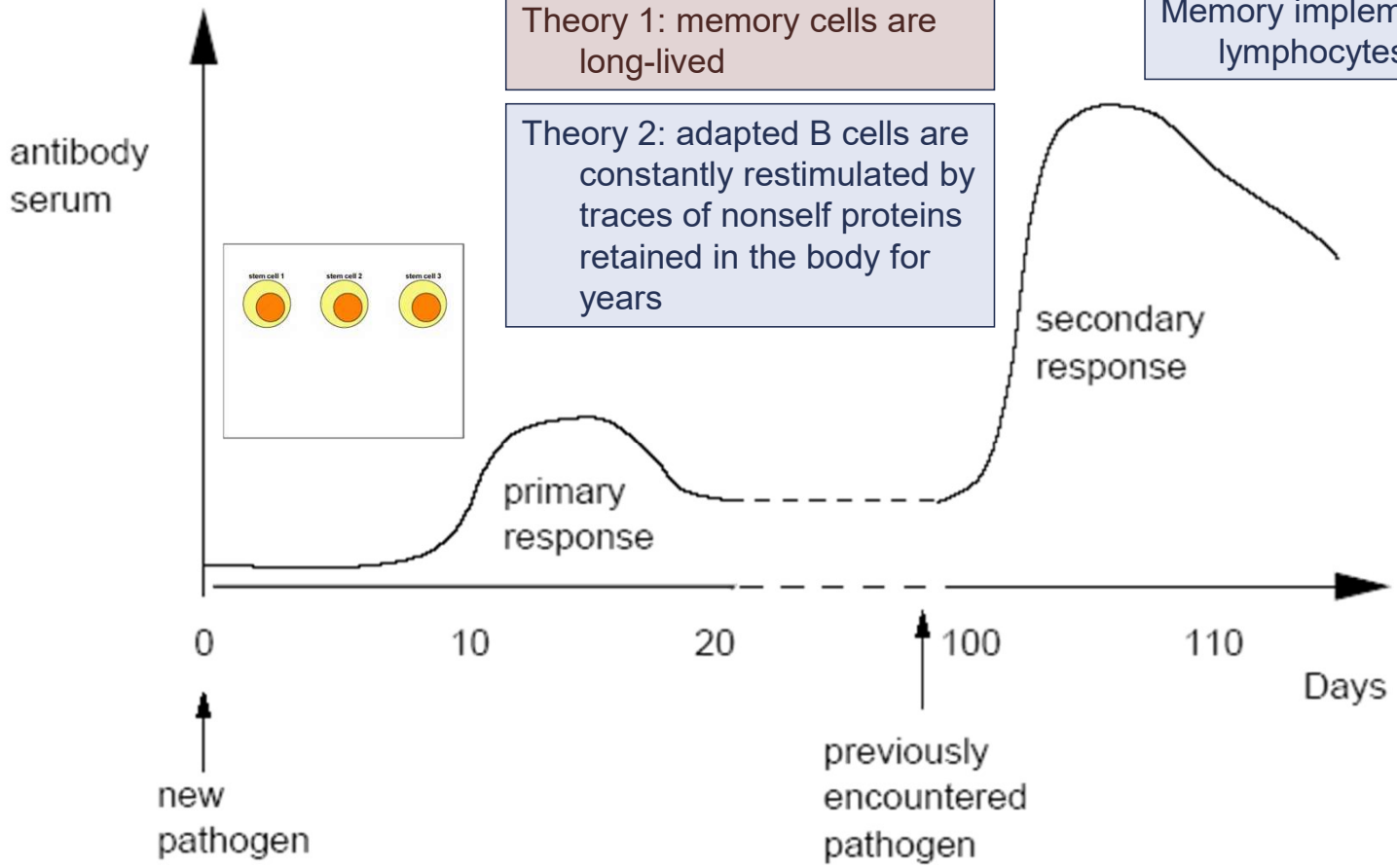
Of B-Cells



From: Doc Kaiser's Microbiology Home Page

rocha@binghamton.edu
casci.binghamton.edu/academics/i-bic

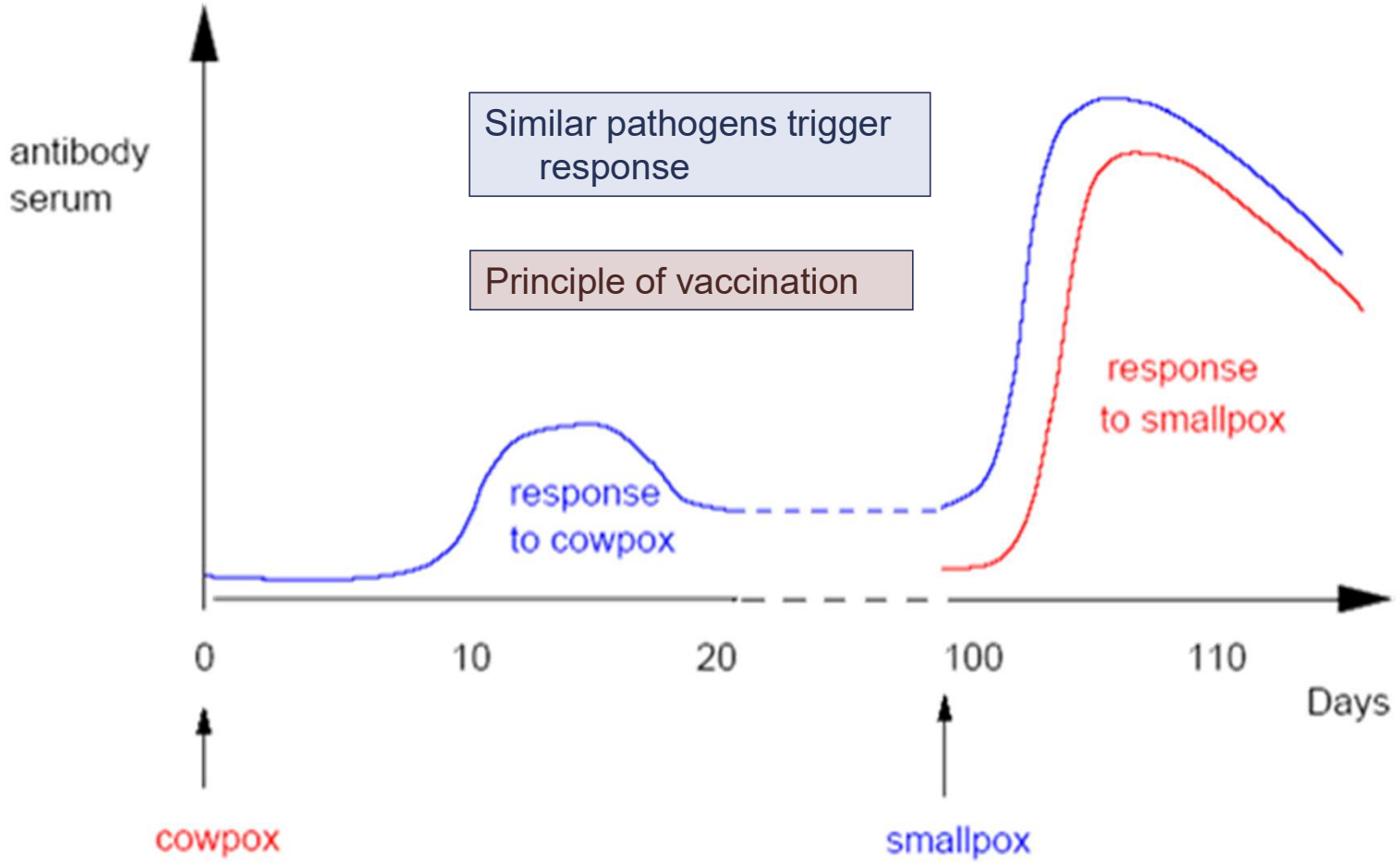
remembering specific learned pathogens



rocha@binghamton.edu
casci.binghamton.edu/academics/i-bic

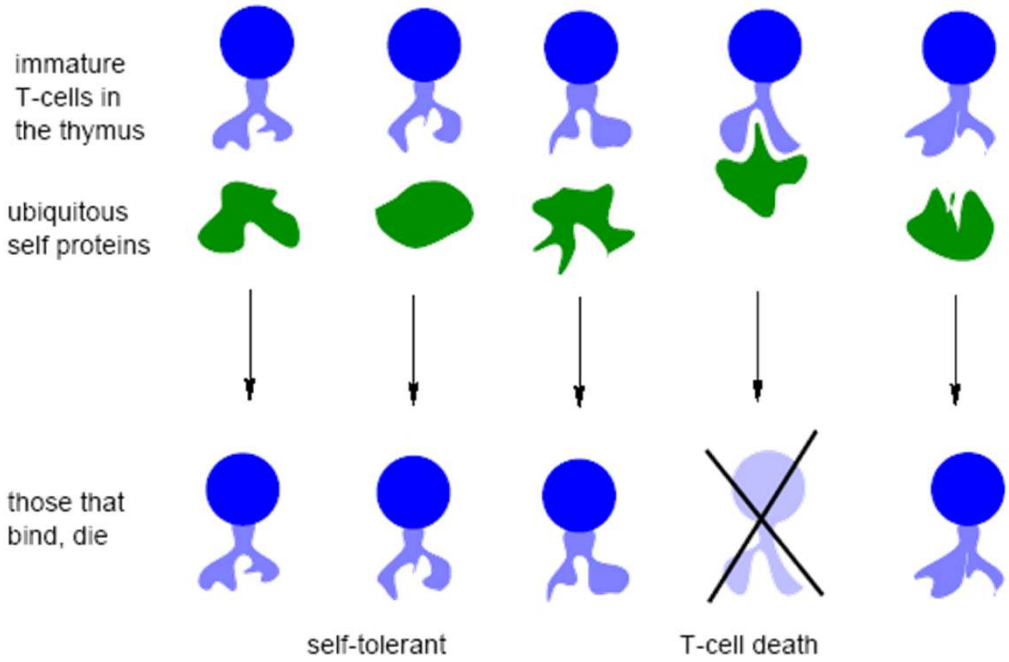
An interpretative introduction to the Immune System. Steven A Hofmeyr

Associative memory



rocha@binghamton.edu
casci.binghamton.edu/academics/i-bic

Tolerance to self (negative selection)



Somatic hypermutation could lead to autoimmunity

Tolerance is implemented by another type of lymphocyte: ***T-helper Cells*** (matured in the Thymus)

Most self epitopes are expressed in the thymus where Th cells mature

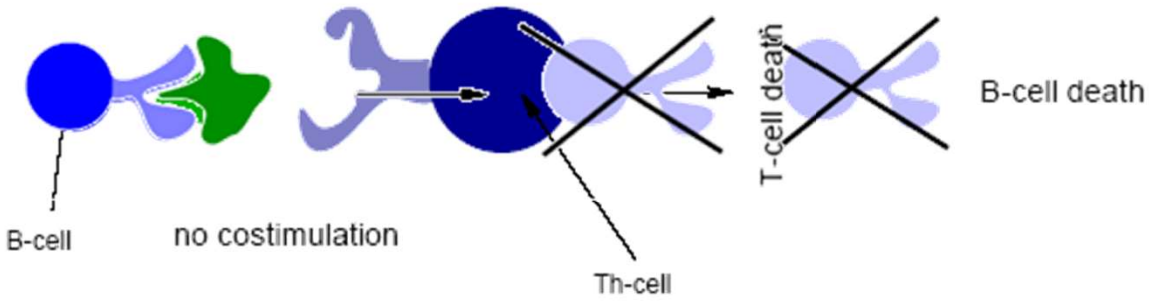
Clonal selection or ***negative selection*** kills T-cells that bind to self

B-Cells are also tolerized in the bone marrow, but via clonal selection could still become **autoreactive**

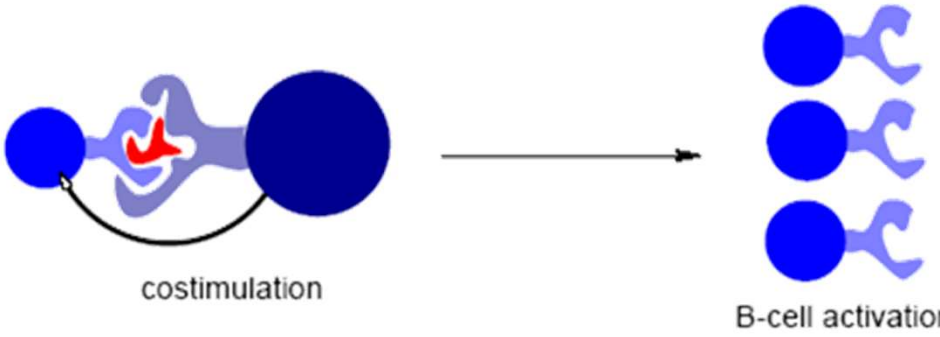
Central tolerance: T-cells tolerized in one single location (the thymus)

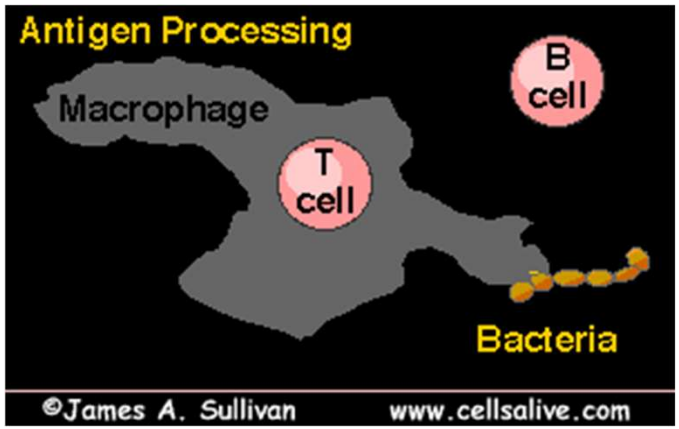
rocha@binghamton.edu
casci.binghamton.edu/academics/i-bic

Tolerance to self: costimulation



Helper T-Cells **verifiy** the epitopes that bind to B-cells for autoreaction





B-cells need to be ***co-stimulated*** by receptor binding and T-Cells

rocha@binghamton.edu
casci.binghamton.edu/academics/i-bic

Biological complexity afforded by the Turing tape for self-other recognition

- Much is unknown
- Other theories
  - Immune Network Theory
  - Danger theory
- Intracellular pathogens
- Collective symbiosis
- Etc,etc,etc,etc

BINGHAMTON UNIVERSITY
STATE UNIVERSITY OF NEW YORK
rocha@binghamton.edu
casci.binghamton.edu/academics/i-bic

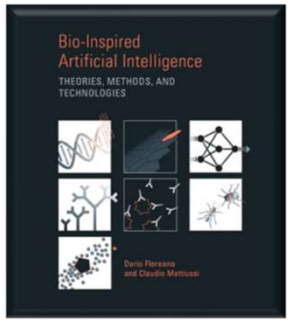
modeling the immune system

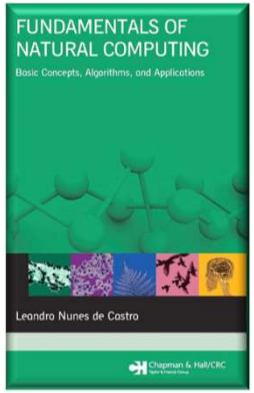
from a bio-inspired computing perspective

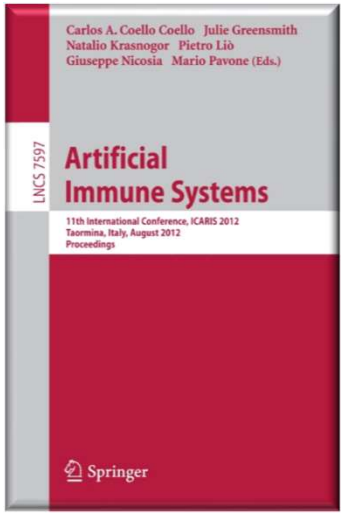
- Objective
  - explore collective dynamics of t-cell cross-regulation
    - *computational intelligence* : build a novel bio-inspired machine learning solution for document classification
    - *computational biology* : understand how well collections of t-cells engaged in crossregulation perform as a classifier.

Hart, Emma, and Jon Timmis. "Application areas of AIS: The past, the present and the future." *Applied soft computing* 8.1 (2008): 191-201.

Nunes de Castro, Leandro [2006]. *Fundamentals of Natural Computing: Basic Concepts, Algorithms, and Applications*. Chapman & Hall.







Bersini, Hugues, and Francisco J. Varela. "Hints for adaptive problem solving gleaned from immune networks." *Parallel Problem Solving from Nature: 1st Workshop, PPSN I Dortmund, FRG, October 1–3, 1990 Proceedings 1*. Springer Berlin Heidelberg, 1991.

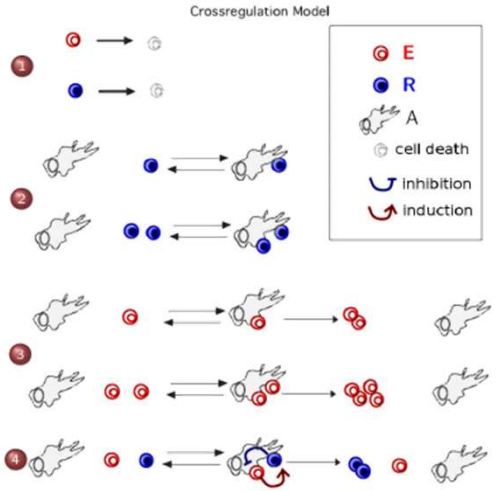
Forrest, Stephanie, et al. "Self-nonself discrimination in a computer." Proceedings of 1994 IEEE computer society symposium on research in security and privacy.

BINGHAMTON UNIVERSITY
STATE UNIVERSITY OF NEW YORK

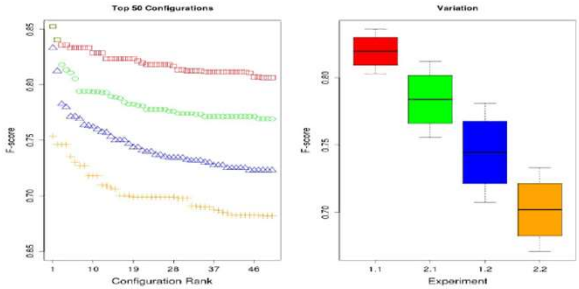
rocha@binghamton.edu
casci.binghamton.edu/academics/i-bic

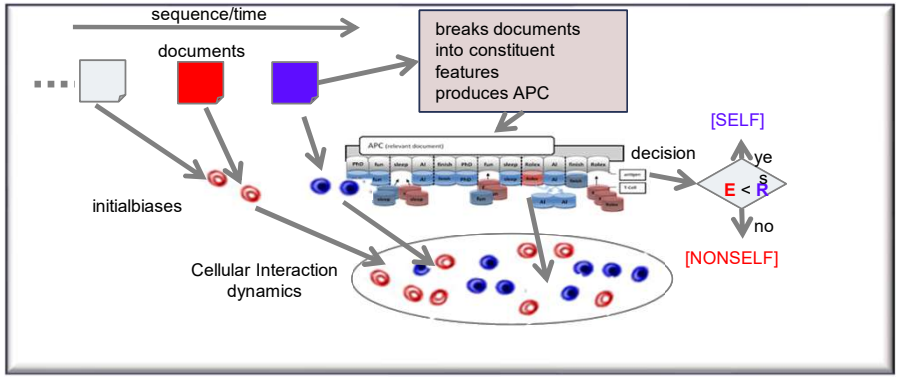
agent-based model of immune cross-regulation dynamics

Applied for binary classification of text (spam and biomedical articles)



- inspired by the cross-regulation model.
  - Carneiro et al. (2007).
  - Purely dynamical model of t-cell regulation leading to bistable states
    - Harmful non-self detection
  - Studying concept drift



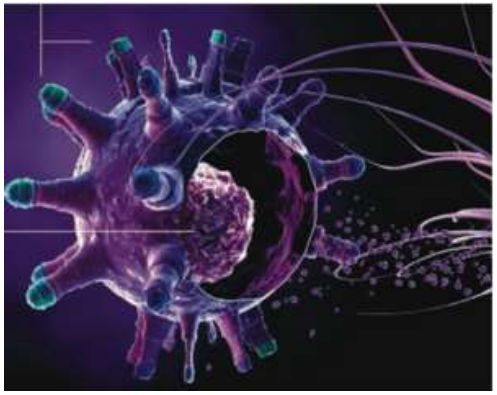


A. Abi-Haidar and L.M. Rocha [2011]. *Evolutionary Intelligence*. **4**(2):69-80.

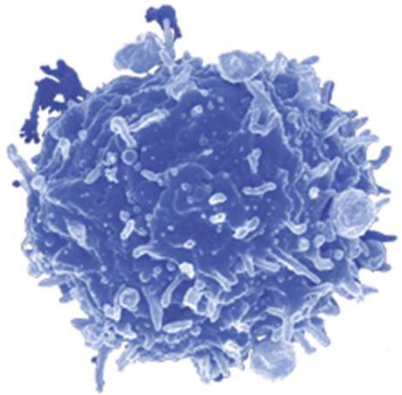
BINGHAMTON UNIVERSITY STATE UNIVERSITY OF NEW YORK
rocha@binghamton.edu
casci.binghamton.edu/academics/i-bic

regulating self-organizing dynamics for self/nonself discrimination

- regulatory t-cells
  - help prevent autoimmunity by down-regulating other t-cells that might bind to and kill self antigens
- Analytical model of Carneiro et al (2007)
  - model self/nonself discrimination
  - Three cell-types or components



1. Antigen Presenting Cells (A)
2. T Effector Cells **(E)**
3. T Regulatory Cells **(R)**



BINGHAMTON UNIVERSITY
STATE UNIVERSITY OF NEW YORK
rocha@binghamton.edu
casci.binghamton.edu/academics/i-bic

regulating self-organizing dynamics for self/nonself discrimination

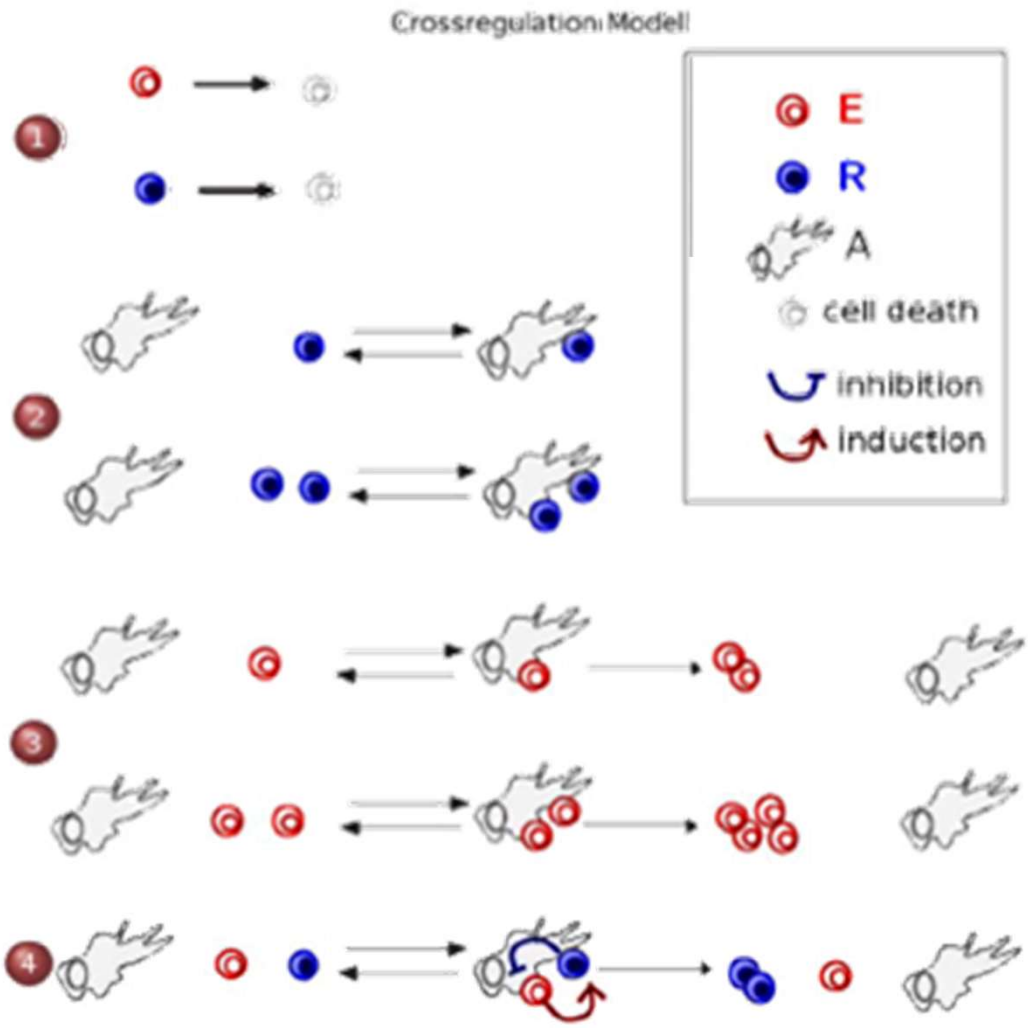
- Analytical model of Carneiro et al (2007)
  - model self/nonself discrimination
  - Three cell-types or components
  - Four interaction rules

1. Antigen Presenting Cells (A)
2. T Effector Cells **(E)**
3. T Regulatory Cells **(R)**

1. $E \xrightarrow[d_E]{} \{\}$ and $R \xrightarrow[d_R]{} \{\}$
2. $A + R \rightarrow A + R$
3. $A + E \rightarrow A + 2E$
4. $A + E + R \rightarrow A + E + 2R$

BINGHAMTON UNIVERSITY STATE UNIVERSITY OF NEW YORK
rocha@binghamton.edu
casci.binghamton.edu/academics/i-bic

1. $E \xrightarrow[d_E]{} \{\}$ and $R \xrightarrow[d_R]{} \{\}$
2. $A + R \rightarrow A + R$
3. $A + E \rightarrow A + 2E$
4. $A + E + R \rightarrow A + E + 2R$



BINGHAMTON UNIVERSITY
STATE UNIVERSITY OF NEW YORK
rocha@binghamton.edu
casci.binghamton.edu/academics/i-bic

dynamical behavior

- Dynamical system
  - Three cell-types or components
  - Four interaction rules
- Carneiro et al modeled a single antigen system
  - One population of monospecific t-cells
    - Sepulveda (2009) extended analytical model to deal 2 antigens
  - Leads to a bistable system
    - Two population attractors

1. [SELF] Co-existence of both **E** and **R** (**E** < **R**)
2. [NONSELF] Prevalence of **E** (**E** >> **R**)

BINGHAMTON UNIVERSITY STATE UNIVERSITY OF NEW YORK
rocha@binghamton.edu
casci.binghamton.edu/academics/i-bic

agent-based t-cell crossregulation model

computational extension to model large numbers of antigens

- Multi-agent dynamical system
  - Three cell-types or components
  - Four interaction rules
  - (very) **polyspecific** APC
  - hundreds of **distinct antigens** and respective (monospecific) t-cell populations: $\mathbf{E_f}$ and $\mathbf{R_f}$

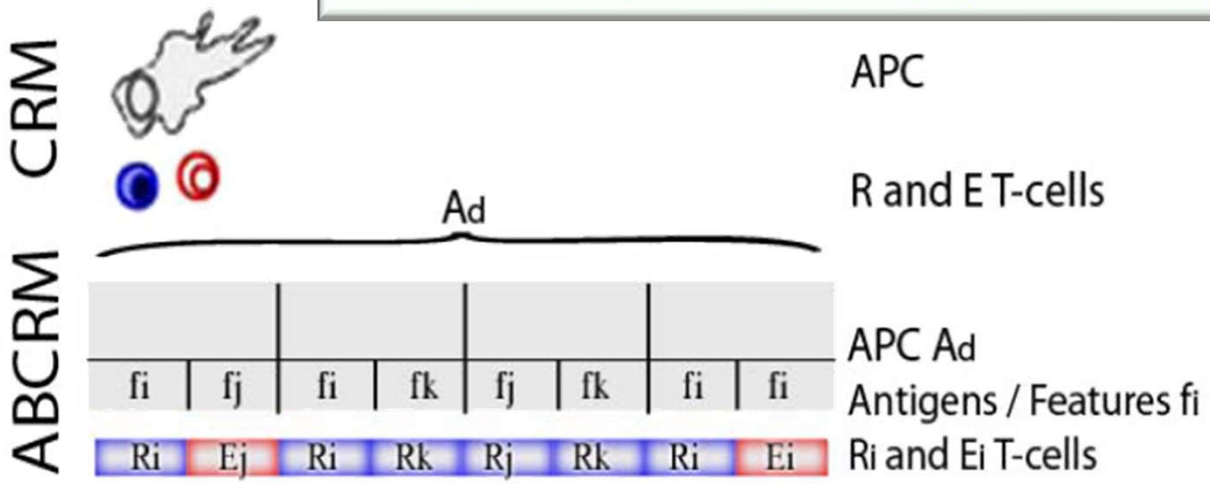


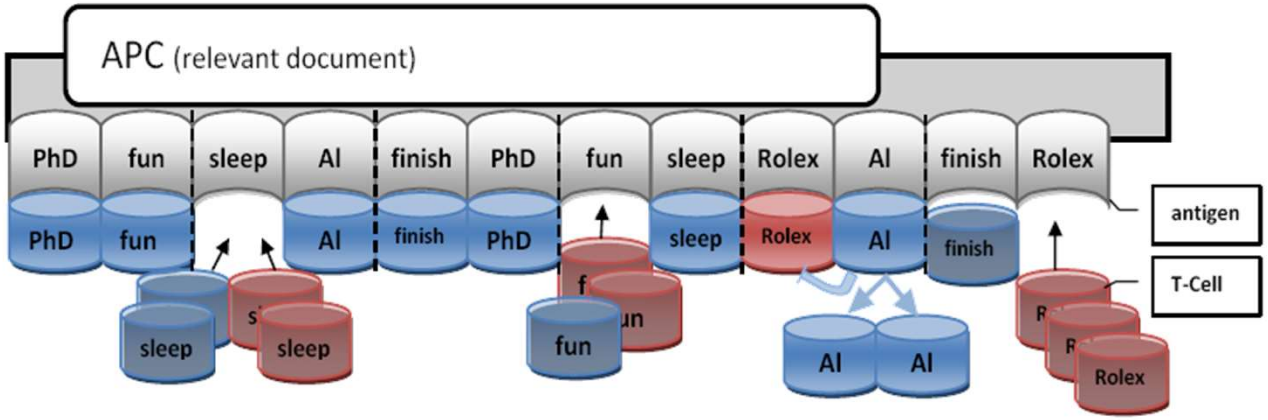
Figure: e.g. $R_i + E_j \rightarrow 2R_i + E_j$ (Rule 4)

A. Abi-Haidar and L.M. Rocha [2011]. *Evolutionary Intelligence*. **4**(2):69-80.

BINGHAMTON UNIVERSITY STATE UNIVERSITY OF NEW YORK
rocha@binghamton.edu
casci.binghamton.edu/academics/i-bic

for textual documents

- Bio-inspired classification algorithm
  - Antigens are textual patterns (features)
  - **polyspecific** APC present textual fragments (features) of specific documents (broken into pieces)
  - hundreds of **distinct antigens/features** represented by (monospecific) t-cell populations: E_f and R_f

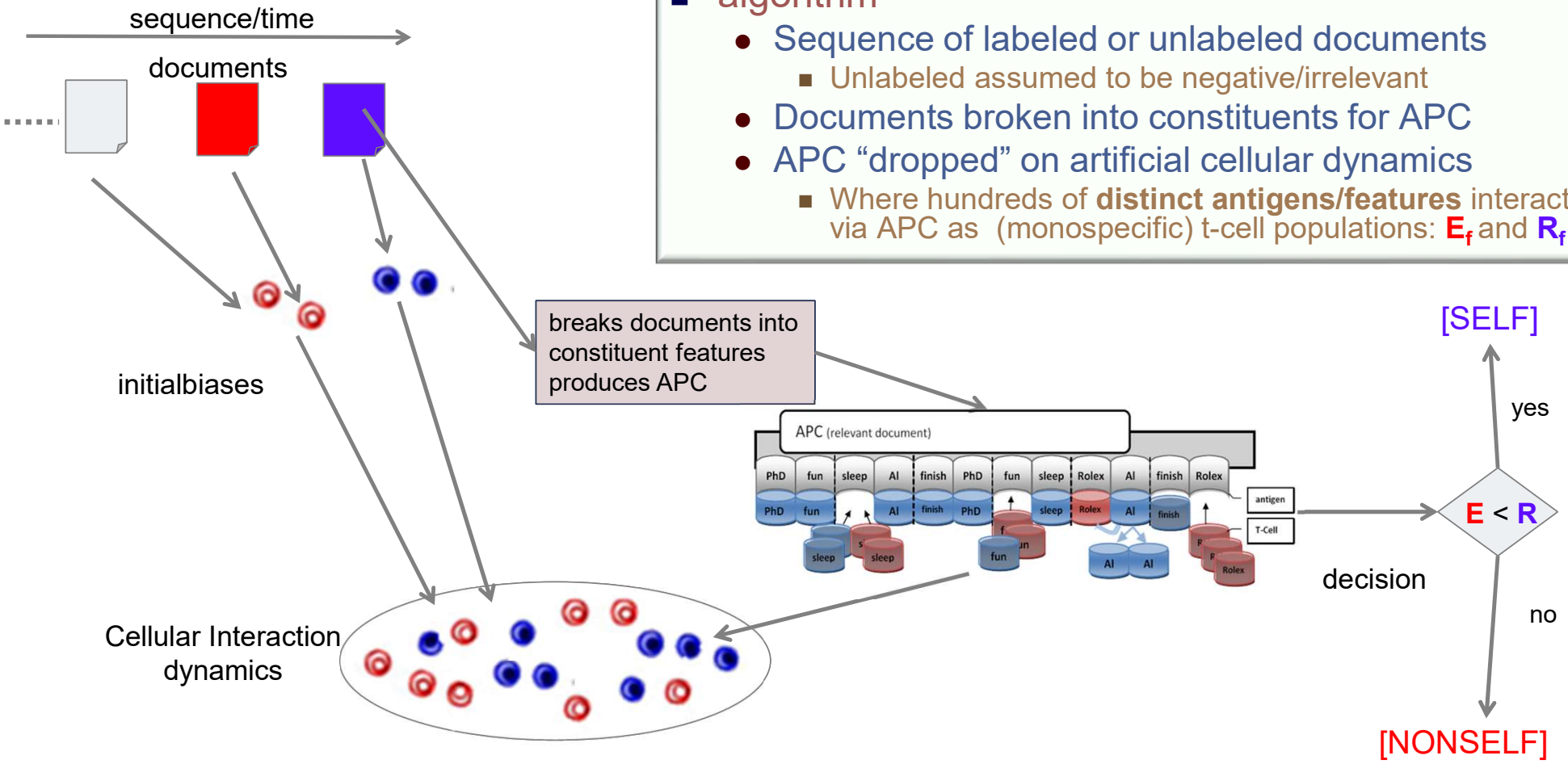


BINGHAMTON UNIVERSITY
STATE UNIVERSITY OF NEW YORK
rocha@binghamton.edu
casci.binghamton.edu/academics/i-bic

agent-based t-cell crossregulation model

for textual documents

- algorithm
  - Sequence of labeled or unlabeled documents
    - Unlabeled assumed to be negative/irrelevant
  - Documents broken into constituents for APC
  - APC "dropped" on artificial cellular dynamics
    - Where hundreds of **distinct antigens/features** interact via APC as (monospecific) t-cell populations: $\mathbf{E_f}$ and $\mathbf{R_f}$

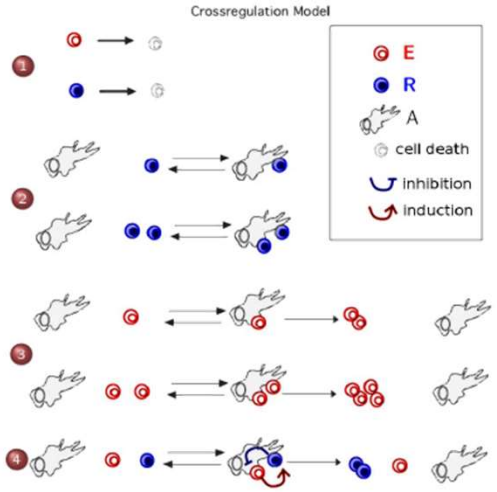


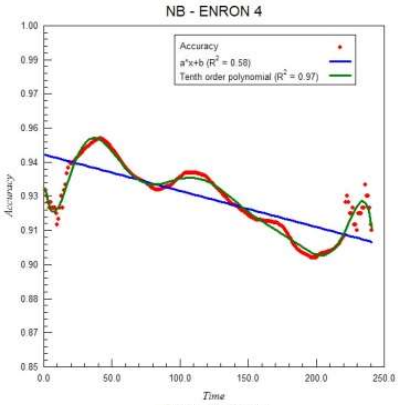
A. Abi-Haidar and L.M. Rocha [2011]. *Evolutionary Intelligence*. **4**(2):69-80.

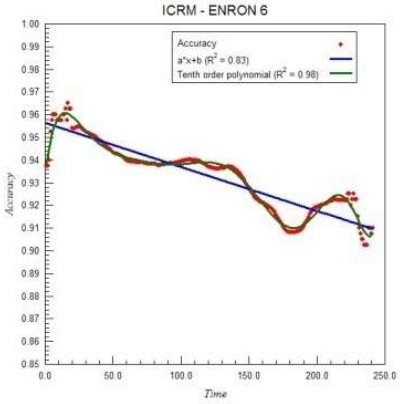
BINGHAMTON UNIVERSITY
STATE UNIVERSITY OF NEW YORK
rocha@binghamton.edu
casci.binghamton.edu/academics/i-bic

agent-based model of immune cross-regulation dynamics

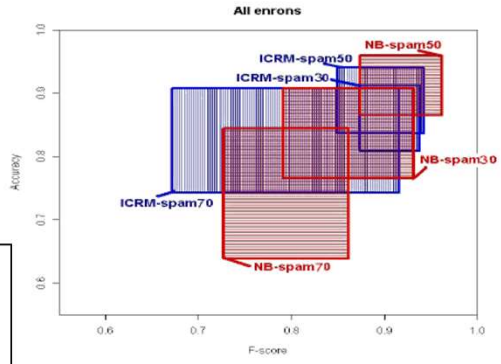
for adaptive (e-mail) spam detection

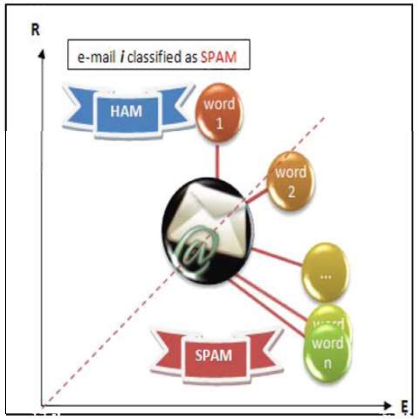






- inspired by the cross-regulation model.
  - Carneiro et al. (2007).
  - Purely dynamical model of t-cell regulation leading to bistable states
    - Harmful non-self detection
  - Studying concept drift





Abi-Haidar & Rocha [2008]. *Alife11*.

Abi-Haidar & Rocha [2008]. *ICARIS 2008*. LNCS, **5132**: 36-47. .

BINGHAMTON UNIVERSITY
STATE UNIVERSITY OF NEW YORK

rocha@binghamton.edu
casci.binghamton.edu/academics/i-bic