Autopoiesis

Prof. Dr. Fábio Marques Simões de Souza

Vida Artificial

- O que é vida?
- Quais as características mínimas de um organismo vivo?
- A vida pode surgir espontaneamente da matéria inanimada?
- Existe Vida Artificial?
- É possível Construir uma Máquina Viva?
- Que características essa máquina deve ter para ser considerada viva?

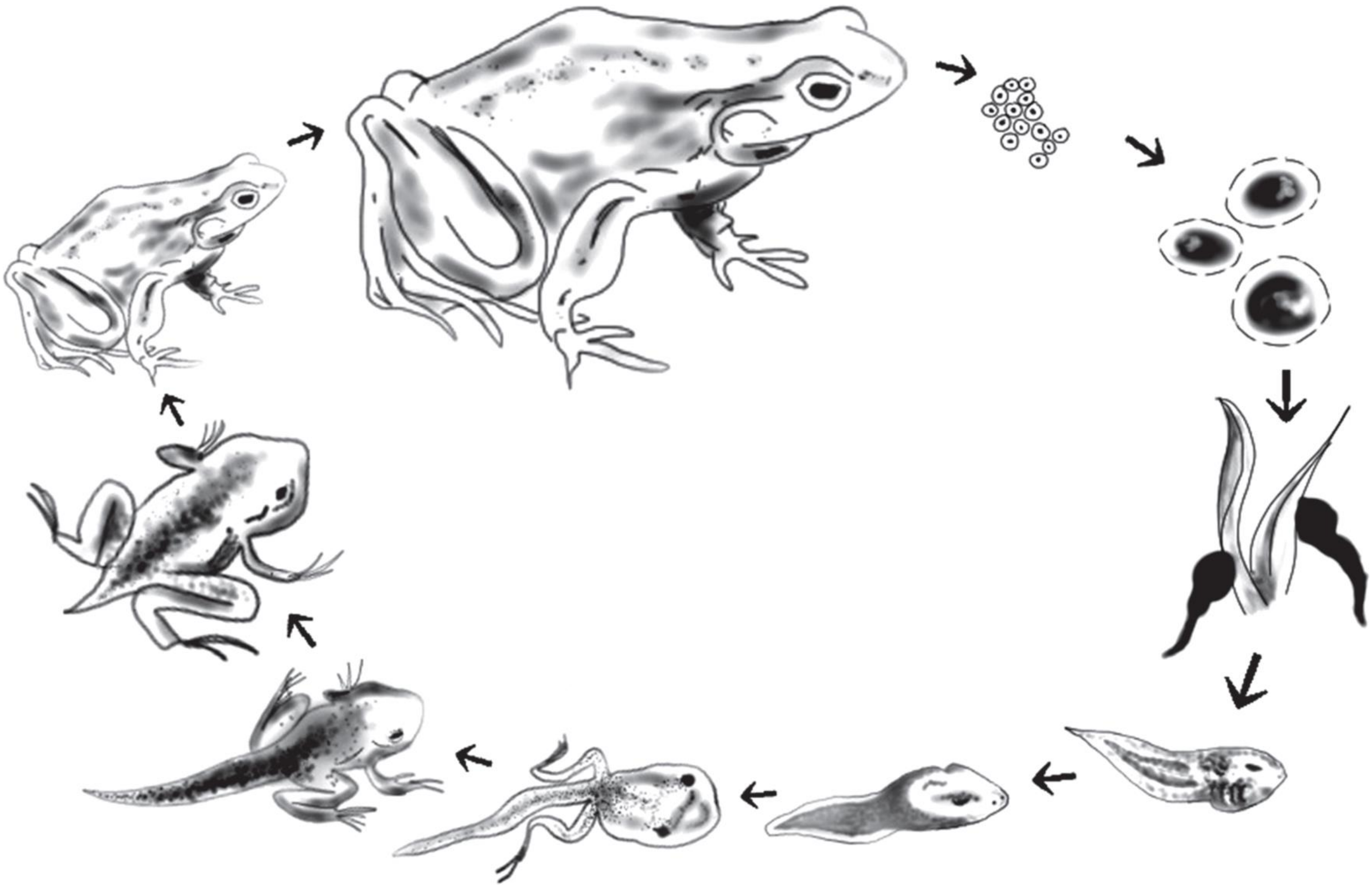
Vida

Table 1
Representative lists of characteristics of minimal living systems [Gánti's list is highlighted].

Author	Characteristics	Emphasis
Lamarck (1809)	1. Individuality; 2. Birth and development; 3. Special flux (electricity and caloric) dynamics; 4. Nutrition and controlled growth; 5. Manufacturing components of self; 6. Reproduction and multiplication; 7. Mortality	Self-organization, metabolism
Gánti (1971, 1987)	**1. Inherent unity; 2. Metabolism; 3. Inherent stability; 4. Information-carrying sub-system; 5. Program control; 6. Growth and multiplication; 7. Hereditary system enabling open-ended evolution; 8. Mortality**	**Self-organization; evolution**
Maturana and Varela (1973)	1. Individuality (closure); 2. Self-production; 3. Responsiveness; 4. Regulation and selectivity	Metabolism, autopoeisis
Orgel (1973)	1. Functionally complex organization; 2. Natural selection can occur; 3. Replication of a genetic material; 4. Information for specifying the living system stored in stable chemical molecules	Information, evolution
Mayr (1982)	1. Complexity and organization; 2. Chemical uniqueness (living organisms are composed of large polymers); 3. Quality (some relations between aspects of the living world can only be described qualitatively); 4. Uniqueness and variability; 5. Possession of a genetic program; 6. Historical nature; 7. Natural selection can occur; 8. Indeterminacy (biological systems have emergent properties)	Evolution
De Duve (1991)	1. Manufacturing its own constituents; 2. Extracting energy and converting it to work for the system; 3. Catalyzing system's reactions; 4. Having information systems enabling re-production; 5. Closure (individuality); 6. Regulation; 7. Multiplication	Metabolism
Boden (2009)	1. Self-organization; 2. Autonomy; 3. Emergence; 4. Development; 5. Adaptation; 6. Responsiveness; 7. Evolution; 8. Reproduction, growth; 9. Metabolism	Information, autopoiesis, evolution

S. Ginsburg, E. Jablonka / Journal of Theoretical Biology 381 (2015) 55–60

Ciclo de Vida



Everything Flows: Towards a Processual Philosophy of Biology. Oxford. Edited by D. J. Nicholson and J. Dupre

Ciclo de Vida Mínimo?

SELF-REPLICATING MICELLES — A CHEMICAL VERSION OF A MINIMAL AUTOPOIETIC SYSTEM

PIER LUIGI LUISI

Institut für Polymere der ETH, Zürich, Switzerland

and

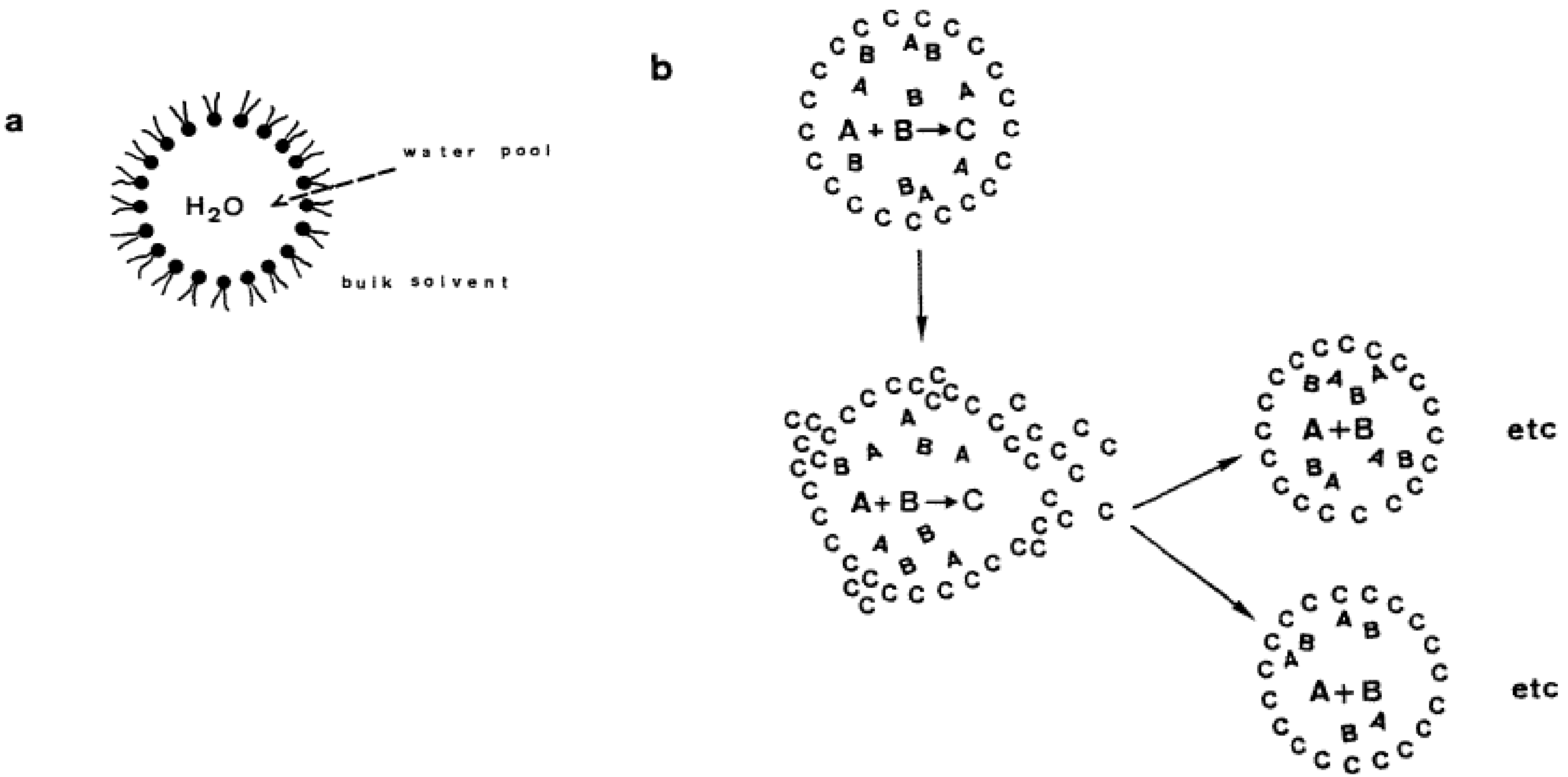
FRANCISCO J. VARELA

CREA, Ecole Polytechnique, Paris, France

(Received 5 December, 1988)

Abstract. Reverse micelles hosting the internal production of the surfactant are proposed as experimentally feasible models of simple (or 'minimal') autopoietic systems. We describe the conditions under which these may be formed and their possible biological implications. The micellar systems considered here turn out also to exhibit a capacity for self-reproduction through fragmentation under plausible conditions, thus constituting also a minimal experimental model for prebiotic self-reproduction.

Um sistema que se autoproduz?



$$A + B \longrightarrow C.$$

Luisi e Varela, 1988

Ganti´s Chemoton Model: Um Sistema Autoorganizado

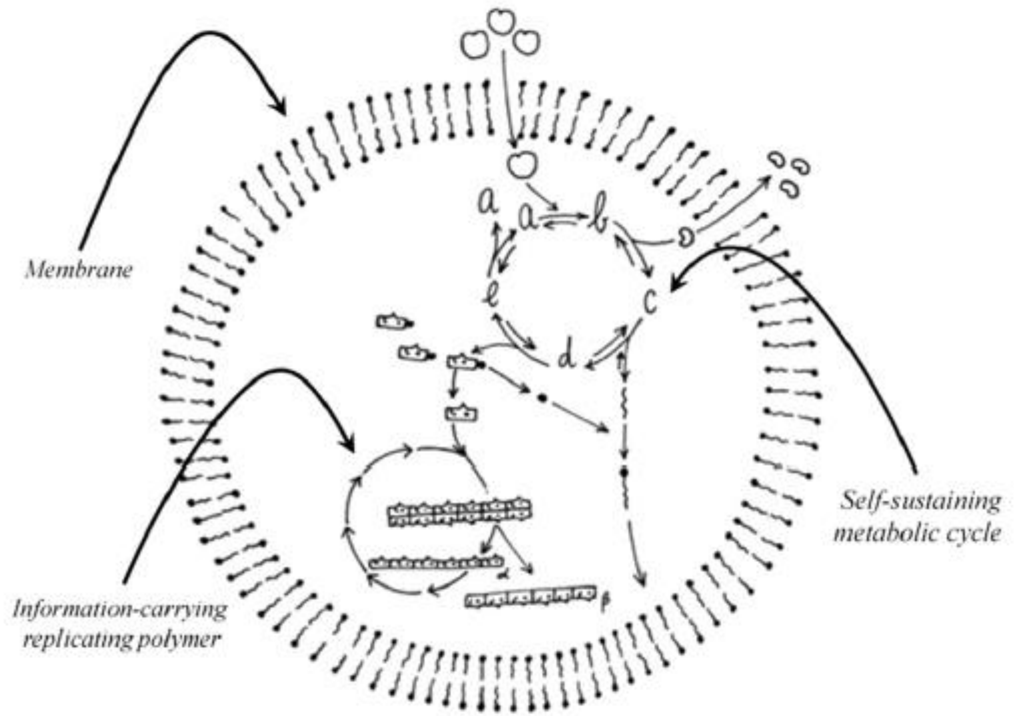


Fig. 1. Gánti's chemoton is made up of three tightly coupled subsystems: the autocatalytic metabolic cycle (abcde cycle), the informational cycle that generates the polymer, and the membrane-forming subsystems. [Based on Gánti, 2003, Fig. 1.1, p. 4), Maynard Smith and Szathmáry (1995, p. 20–23) and the modification of this figure in Jablonka and Lamb (2006, Fig 1, p. 237).]

S. Ginsburg, E. Jablonka / Journal of Theoretical Biology 381 (2015) 55–60

Ganti´s Chemoton Model

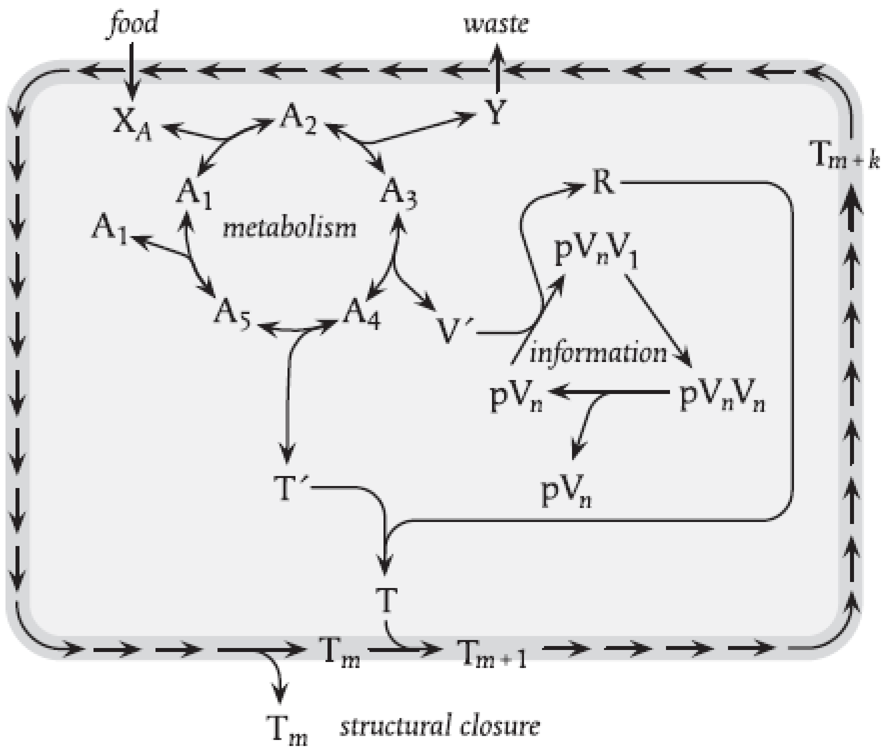


Fig. 1. The chemoton. All arrows represent chemical reactions, reversible in the case of double-headed arrows, irreversible otherwise. The diagram is based on Fig. 1.1 of Gánti (2003) redrawn to represent reactions involving multiple substrates in a more conventional way. The internal system shown against a grey background is separated from the external environment by a boundary formed from monomer units *T* that are fabricated by the system itself.

A. Cornish-Bowden / Journal of Theoretical Biology 381 (2015) 6–10

Stochastic Simulation of Ganti´s Chemoton

(1) Nutrients

(2) Metabolites

(3) Waste Products

(4) Monomers

(5) Coupling Metabolic Cycle and Template Replication System

(6) Template Initiation Step

(7) Template Propagation Steps

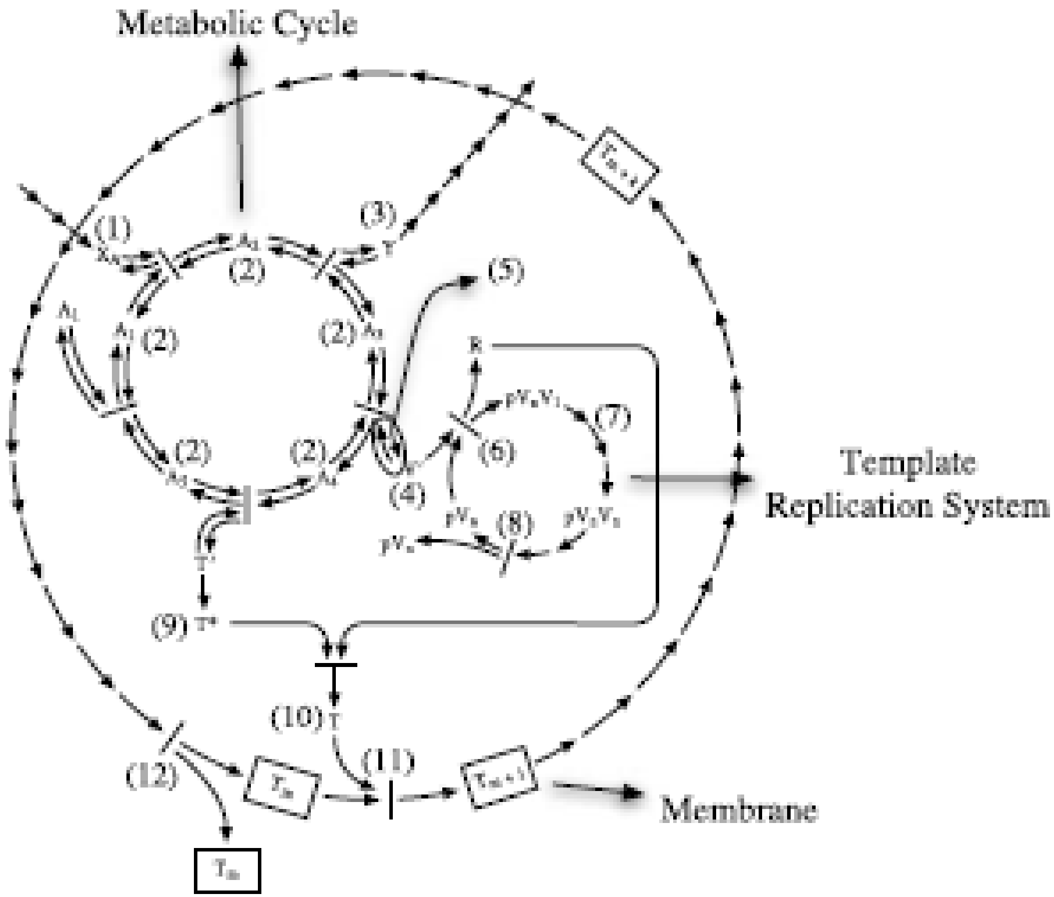
(8) Strand Separation

(9) Membrane Precursor Molecules

(10) Membrane Molecules

(11) Membrane Incorporation Reaction

(12) Cell Division



Artificial Life 15: 213–226 (2009)

Autopoiesis (Self-Making Systems)

Autopoiesis: The Organization of the Living was originally published in Chile under the title *De Maquinas y Seres Vivos*, © 1972 by Editorial Universitaria S.A.

HUMBERTO R. MATURANA and FRANCISCO J. VARELA

AUTOPOIESIS
AND
COGNITION

The Realization of the Living

With a preface to 'Autopoiesis'

by

Sir Stafford Beer

Vida Artificial com Autopoiesis

BioSystems 5 (1974) 187–196. NORTH-HOLLAND PUBLISHING COMPANY, AMSTERDAM

AUTOPOIESIS: THE ORGANIZATION OF LIVING SYSTEMS, ITS CHARACTERIZATION AND A MODEL

F.G. VARELA, H.R. MATURANA and R. URIBE

Facultad de Sciencias e Departamento de Electricidad,
University of Chile, Santiago, Chile

We formulate the organization of living organisms through the characterization of the class of autopoietic systems to which living things belong. This general characterization is seen at work in a computer simulated model of a minimal case satisfying the conditions for autopoietic organization.

Vida Artificial com Autopoiesis

SCHEMA I

[1] Composition: $* + 2\,\bigcirc \rightarrow * + \boxtimes$

[2] Concatenation: (Bonding) $\underbrace{\boxtimes - \boxtimes - \dots - \boxtimes}_{n} + \boxtimes \rightarrow \underbrace{\boxtimes - \boxtimes - \dots - \boxtimes}_{n+1}$

$n = 1, 2, 3, \dots$

[3] Disintegration: $\boxtimes \rightarrow 2\,\bigcirc$

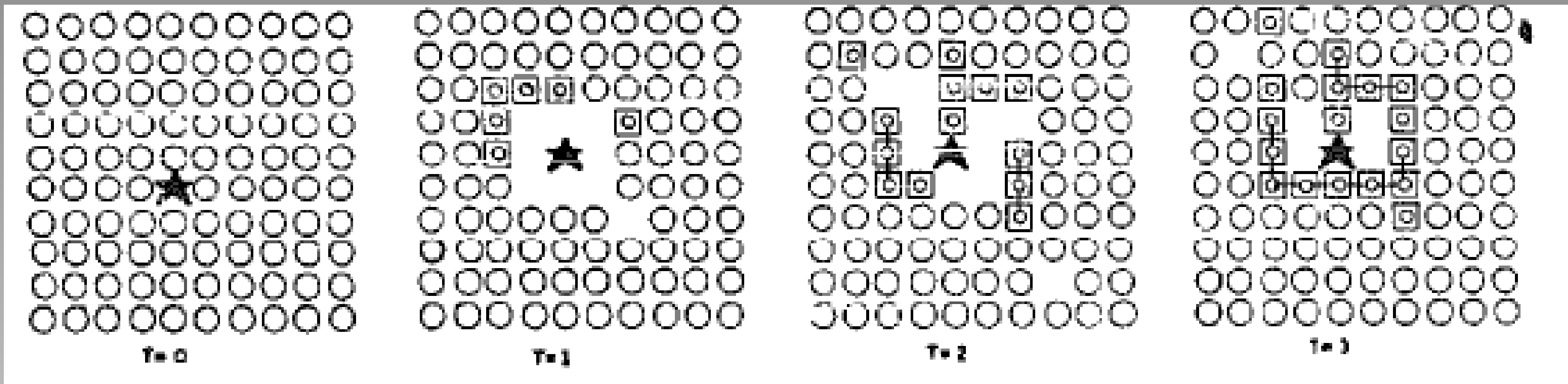
Conventions

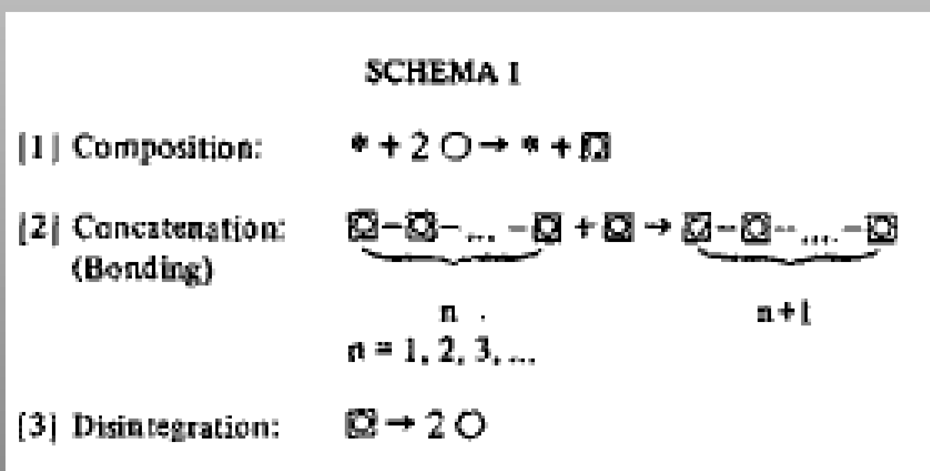
We shall use the following alphanumeric symbols to designate the elements referred to earlier:

Substrate:	$\bigcirc$	$\rightarrow$ S
Catalyst:	$*$	$\rightarrow$ K
Link:	$\boxtimes$	$\rightarrow$ L
Bonded link:	$-\boxtimes-$	$\rightarrow$ BL

BioSystems 5 (1974) 187–196. E

Vida Artificial com Autopoiesis





BioSystems 5 (1974) 187–196.

Vida Artificial com Autopoiesis

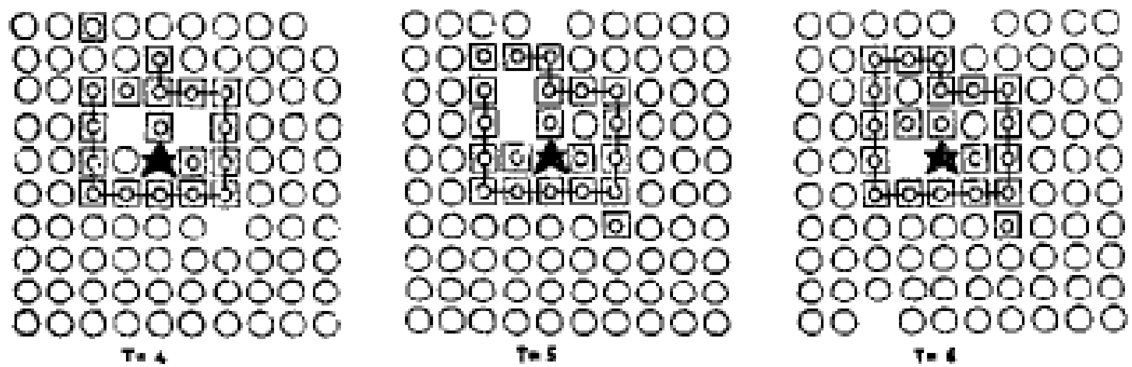


Fig. 1. The first seven instants (0→6) of one computer run, showing the spontaneous generation of an autopoietic unity. Interactions between substrate ○ and catalyst * produce chains of bonded links ⊡, which eventually enclose the catalyst, thus closing a network of interactions which constitutes an autopoietic unity within this universe.

SCHEMA I

[1] Composition: * + 2 ○ → * + ⊡

[2] Concatenation: (Bonding) $\underbrace{⊡-⊡- \ldots -⊡}_{n}$ + ⊡ → $\underbrace{⊡-⊡- \ldots -⊡}_{n+1}$

n = 1, 2, 3, ...

[3] Disintegration: ⊡ → 2 ○

BioSystems 5 (1974) 187–196.

Vida Artificial com Autopoiesis

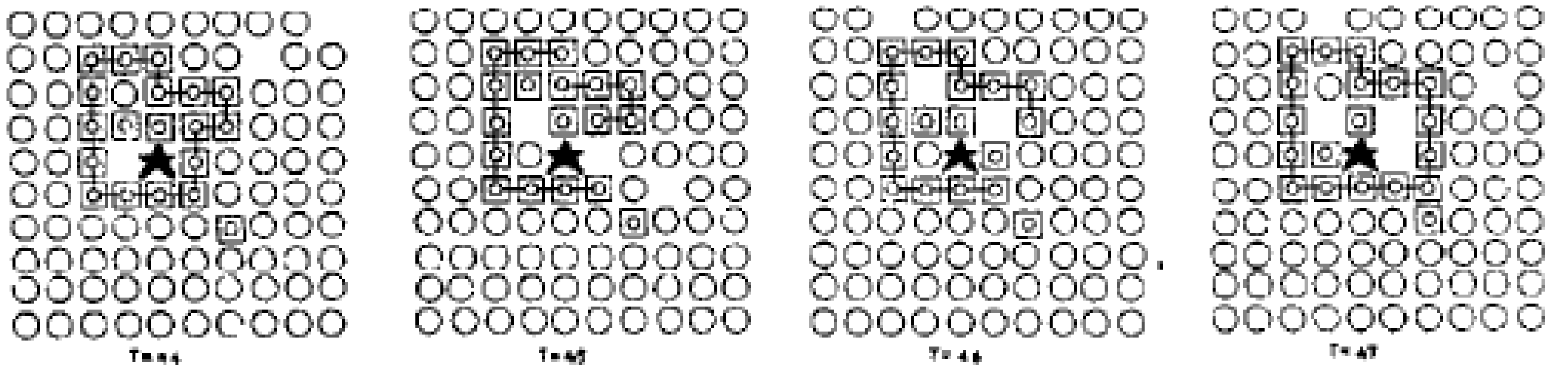
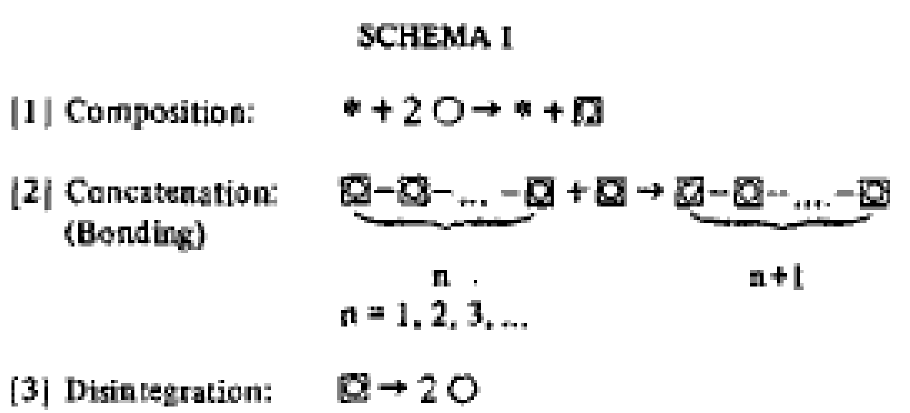


Fig. 2. Four successive instants (44–47) along the same computer run (Fig. 1), showing compensation in the boundary broken by spontaneous decay of links. Ongoing production of links re-establishes the unity under changes of form and turnover of components.



BioSystems 5 (1974) 187–196.

Algorítmo da Autopoiesis

Algorithm

1. **Motion, first step**
   - 1.1. Form a list of the coordinates of all holes h_i.
   - 1.2. For each h_i, make a random selection, n_i, in the range 1 through 4, specifying a neighboring location.
   - 1.3. For each h_i in turn, where possible, move occupant of selected neighboring location in h_i.
   - 1.31. If the neighbor is a hole or lies outside the space, take no action.
   - 1.32. If the neighbor n_i contains a bonded L, examine the location n'_i. If n'_i contains an S, move this S to h_i.
   - 1.4. Bond any moved L, if possible (Rules, 6).

BioSystems 5 (1974) 187–196.

Vida Artificial com Autopoiesis

2. Motion, second step

2.1. Form a list of the coordinates of free L's, m_i.

2.2. For each m_i, make a random selection, n_i, in the range 1 through 4, specifying a neighboring location.

2.3. Where possible, move the L occupying the location m_i into the specified neighboring location.

2.31. If location specified by n_i contains another L, or a K, then take no action.

2.32. If location specified by n_i contains an S, the S will be displaced.

2.321. If there is a hole adjacent to the S, it will move into it. If more than one such hole, select randomly.

2.322. If the S can be moved into a hole by passing through bonded links, as in step 1, then it will do so.

2.323. If the S cannot be moved into a hole, it will exchange locations with the moving L.

2.33. If the location specified by n_i is a hole, then L simply moves into it.

2.4. Bond each moved L, if possible.

4.

BioSystems 5 (1974) 187–196.

Vida Artificial com Autopoiesis

3. Motion, third step

3.1. Form a list of the coordinates of all K's, c_i.

3.2. For each c_i, make a random selection n_i, in the range 1 through 4, specifying a neighboring location.

3.3. Where possible, move the K into the selected neighboring location.

3.31. If the location specified by n_i contains a BL or another K, take no action.

3.32. If the location specified by n_i contains a free L, which may be displaced according to the rules of 2.3, then the L will be moved, and the K moved into its place. (Bond the moved L, if possible).

3.33. If the location specified by n_i contains an S, then move the S by the rules of 2.32.

3.34. If the location specified by n_i contains a free L, not movable by rules 2.3, exchange the positions of the K and the L. (Bond L if possible).

3.35. If the location specified by n_i is a hole, the K moves into it.

BioSystems 5 (1974) 187–196.

Vida Artificial com Autopoiesis

4. Production

4.1. For each catalyst c_i, form a list of the neighboring positions n_{ij}, which are occupied by S's.

4.11. Delete from the list of n_{ij} all positions for which neither adjacent neighbor position appears in the list (i.e., "1" must be deleted from the list of n_{ij}'s, if neither 5 nor 6 appears, and a "6" must be deleted if neither 1 nor 2 appears).

4.2. For each c_i with a non-null list of n_{ij}, choose randomly one of the n_{ij}, let its value be p_i, and at the corresponding location, replace the S by a free L.

4.21; If the list of n_{ij} contains only one which is adjacent to p_i, then remove the corrsponding S.

4.22. If the list of n_{ij} includes both locations adjacent to p_i, randomly select the S to be removed.

4.3. Bond each produced L, if possible.

BioSystems 5 (1974) 187–196.

Vida Artificial com Autopoiesis

5. Disintegration

5.1. For each L, bonded or unbonded, select a random real number, d, in the range (0,1).

5.11. If d ≤ Pd (Pd an adjustable parameter of the algorithm), then remove the corresponding L, attempt to re-bond (Rules, 7).

5.12. Otherwise proceed to next L.

BioSystems 5 (1974) 187–196.

Vida Artificial com Autopoiesis

6. Bonding

This step must be given the coordinates of a free L.

6.1. Form a list of the neighboring positions n_i, which contain free L's, and the neighboring positions m_i, which contain singly bonded L's.

6.2. Drop from the m_i any which would result in a bond angle less than 90°. (Bond angle is determined as in Figure 4).

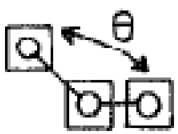


Fig. 4. Definition of "Bond-Angle" θ.

6.3. If there are two or more of the m_i, select two, form the corresponding bonds, and exit.

6.4. If there is exactly one m_i, form the corresponding bond.

6.41. Remove from the n_i any which would now result in a bond angle of less that 90°.

6.42. If there are no n_i, exit.

6.43. Select one of the n_i, form the bond, and exit.

6.5. If there are no n_i, exit.

6.6. Select one of the n_i, form the corresponding bond, and drop it from the list.

6.61. If the n_i list is non-null, execute steps 6.41 through 6.43.

6.62. Exit.

7. Rebond

7.1. Form a list of all neigbor positions m_i occupied by singly bonded L's.

7.2. Form a second list, p_{ij}, of pairs of the m_i which can be bonded.

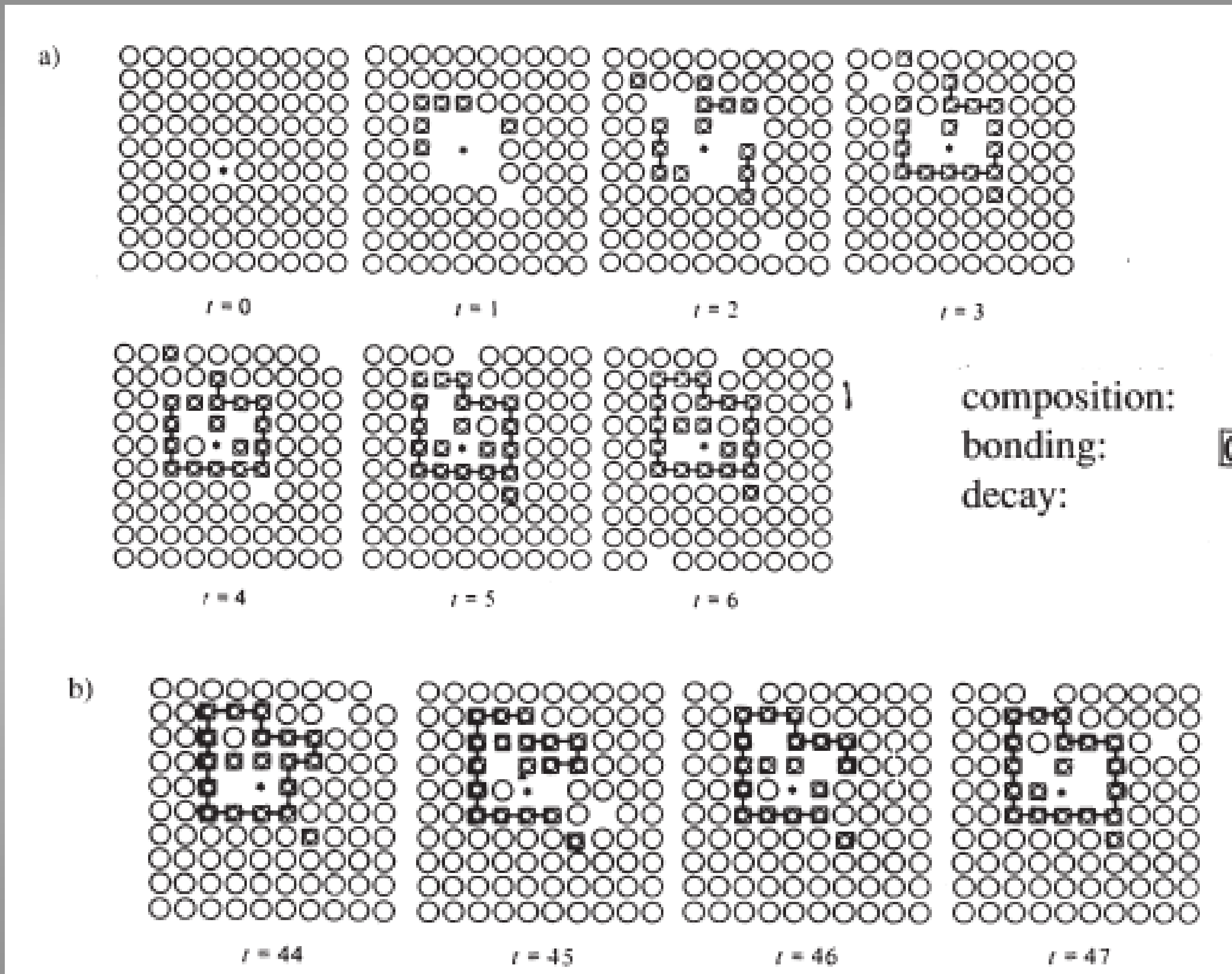
7.3. If there are any p_{ij}, choose a maximal subset and form the bonds. Remove the L's involved from the list m_i.

7.4. Add to the bond m_i any neighbor locations occupied by free L's.

7.5. Execute steps 7.1 through 7.3, then exit.

BioSystems 5 (1974) 187–196.

Sistema Autopoiético Mínimo



composition: $* + 2\,\mathrm{O} \rightarrow * + \boxed{\mathrm{O}}$

bonding: $\boxed{\mathrm{O}}\text{-}\boxed{\mathrm{O}}\text{-}\boxed{\mathrm{O}}\text{-}\ldots + \boxed{\mathrm{O}} \rightarrow \boxed{\mathrm{O}}\text{-}\boxed{\mathrm{O}}\text{-}\boxed{\mathrm{O}}\text{-}\boxed{\mathrm{O}}\text{-}\ldots$

decay: $\boxed{\mathrm{O}} \rightarrow 2\,\mathrm{O}$

FRANCISCO J. VARELA

ORGANISM: A MESHWORK OF SELFLESS SELVES

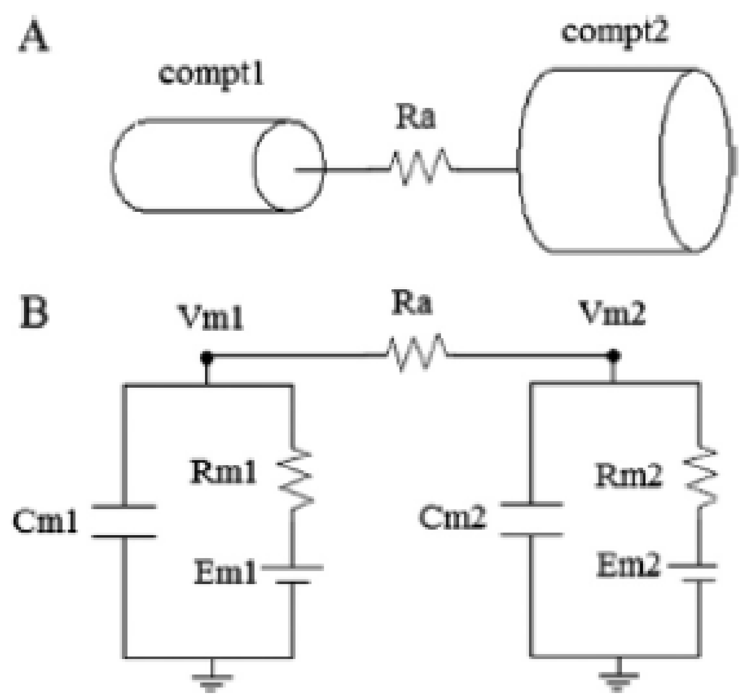
Algoritmo da Autopoiesis

- Se vocês fosse implementar um algoritmo autopoiético, como vocês faria? Você modificaria o código do Maturana e Varela? Como?

- É possível fazer um código mínimo que cria a si mesmo em um ciclo autopoiético? Como você faria isso na prática?

Lista Exercícios Modelagem Biofísica

a) Descreva e explique o modelo abaixo:



$$Cm_2 \frac{dVm_2}{dt} = \frac{-(Vm_2 - Em_2)}{Rm_1} - \frac{(Vm_2 - Vm_1)}{Ra}$$

$$Cm_1 \frac{dVm_1}{dt} = \frac{-(Vm_1 - Em_1)}{Rm_1} - \frac{(Vm_1 - Vm_2)}{Ra}$$

Lista Exercícios Modelagem Biofísica

b) Dadas as dimensões espaciais abaixo e as propriedades passivas relativas, calcule os valores absolutos de Cm1, Rm1 e Ra para o modelo descrito em b.

Dimensões espaciais dos compartimentos:

L_1 = 10 μm (comprimento)

D_1= 1 μm (diâmetro)

L_2 = 10 μm (comprimento)

D_2= 2 μm (diâmetro)

A = Área superfície do cilindro = $\pi.D.L$

S= Área secção transversal do cilindro = $\pi.(D/2)^2$

Conversão μm para cm: 1 μm = 10^{-4} cm

Parâmetros Elétricos:

RA = 0.115 KΩ.cm

RM = 2 KΩ.cm^2

CM = 1 μF/cm^2

Cm = ? (μF)

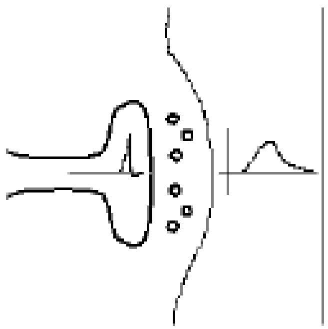
Rm = ? (KΩ)

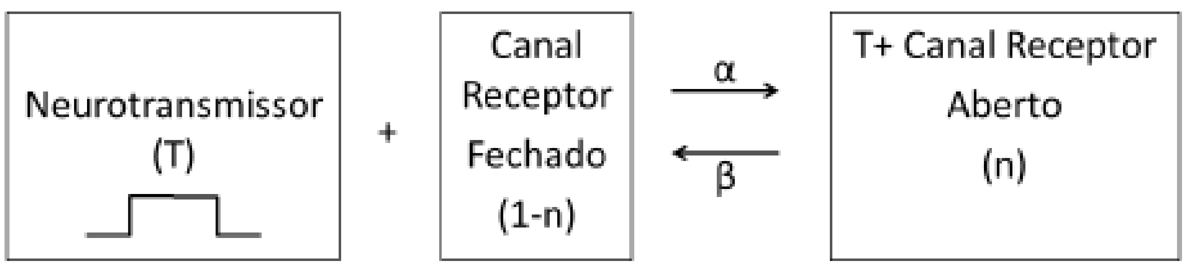
Ra = ? (KΩ)

Lista Exercícios Modelagem Biofísica

2. Modelos de Sinapses

a) Descreva e explique o modelo abaixo:





$$\frac{dn}{dt} = \alpha T(1-n) - \beta n$$

$$I_{sinapse} = n(t).g\,s_{inapse}.(Vm - E_{sinapse})$$

Lista Exercícios Modelagem Biofísica

b) Qual parâmetro da equação deve ser alterado para modelar uma sinapse inibitória e uma sinapse excitatória?

c) Descreva a diferença entre o modelo descrito em a e o modelo abaixo:

$$I_{sinapse} = n(t).g\,s_{inapse}.(Vm - E_{sinapse}) / (1 + \exp(-0.63Vm)(([Mg / 3.57]))$$

Lista Exercícios Modelagem Biofísica

3) Modelos de Plasticidade Sináptica
   a) Explique o postulado de Hebb. Como você modelaria computacionalmente esse postulado? Aponte duas vantagens e duas desvantagens desse modelo.
   b) Mostre como você modificaria a lei de Hebb para superar essas limitações?
   c) O que é STDP? Descreva e explique um modelo computacional capaz de simular esse fenômeno.

Lista Exercícios Modelagem Biofísica

4) Redes Neurais Simples
   a) Descreva e explique o funcionamento de um modelo de CPG.
   b) O que é uma máquina de estado líquido? Para quê ela serve? Exemplifique.
   c) Descreva uma rede recorrente com capacidade de memória associativa. Como você modificaria essa rede para operar como uma memória de trabalho?