COSC 594

Final Presentation

Membrane Systems/ P Systems

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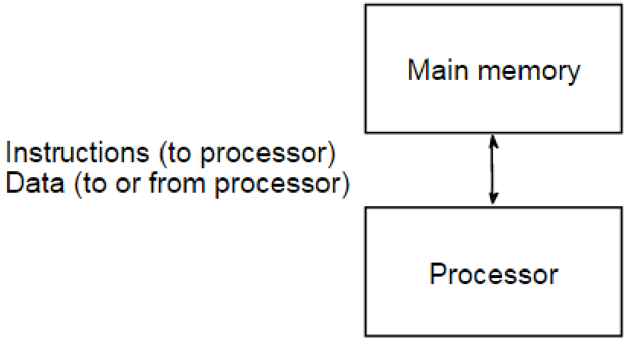
Motivation of Unconventional Computing

- Parallel computing-- restricted in conventional computers
- Deterministic conventional computing
- Exhaustive search exponential in classic computing
- Power and scaling--restraining element against better computing performance



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What is Membrane System/P System?

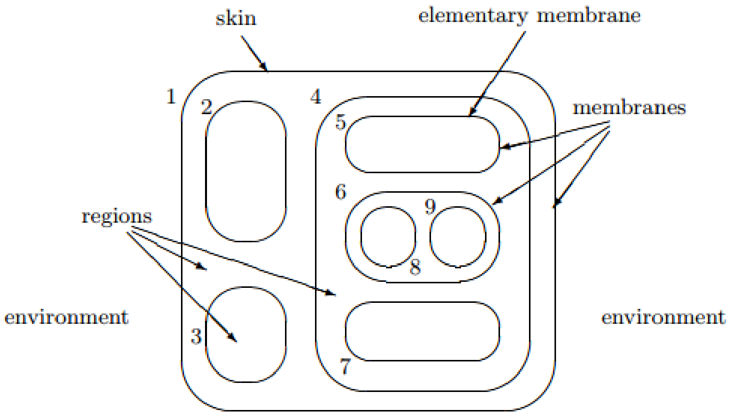
- Bio-inspired natural computing model
- Concept first introduced by Gheorghe Paun in 1998
- Structure based on biological cells
- Capable of parallel programming

History of P Systems

- Mechanically computable-- Turing Machine (1935)
- Neural Computing -- Anderson (1996)
- Genetic algorithms and evolutionary computing/programming -- Koza and Rice (1992)
- DNA computing -- Adleman (1994)

Elements of P System

- Basic Elements
  - Environment
  - Membranes
  - Symbols
  - Catalysts
  - Rules
- The Cell-like Membrane Structure



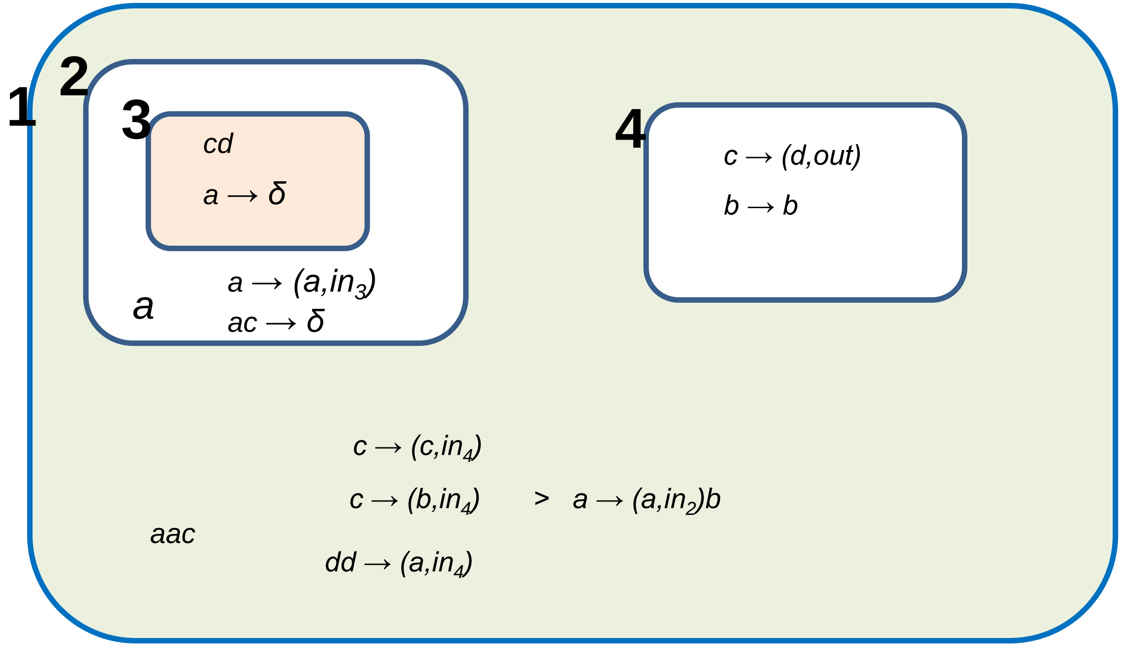
Păun, Gheorghe. "Introduction to membrane computing." *Applications of Membrane Computing*. Springer Berlin Heidelberg, 2006. 1-42.

Representation of a P system

$\Pi = (V, T, C, \mu, M_1,\ldots\ldots,M_m, R_1,\ldots\ldots,R_m\ R_m,i_0\ )$

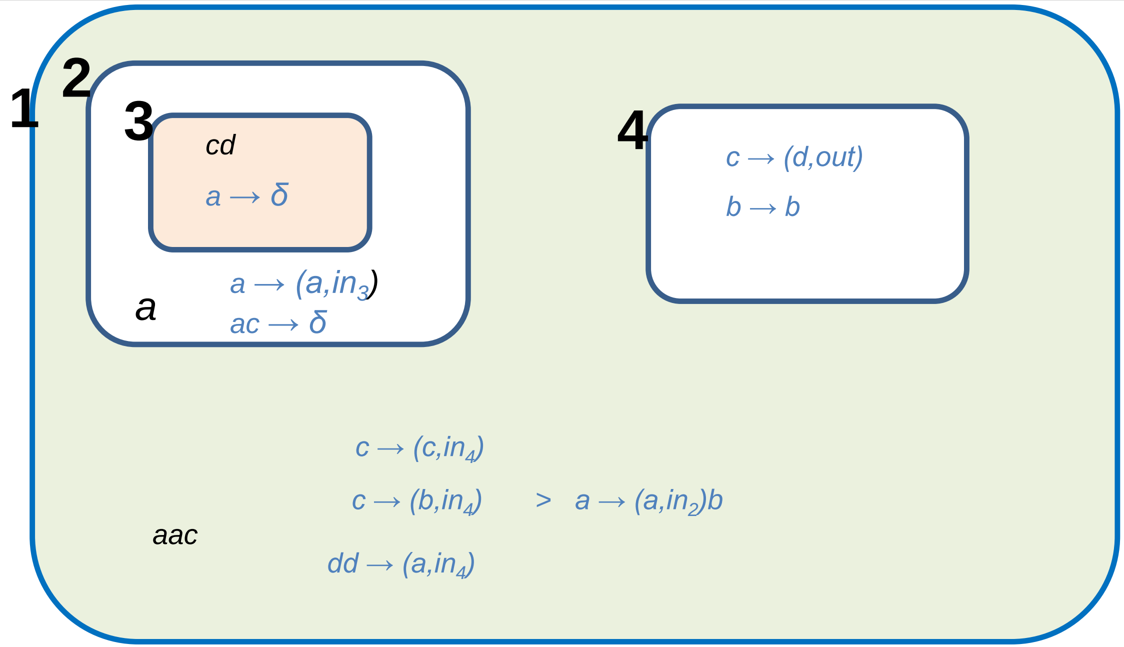
- V : the alphabet of the system
- $T \subseteq V$: the terminal alphabet
- C: set of catalysts
- μ : the membrane structure (of degree m here)
- $M_1,\ldots\ldots,M_m$: finite set of objects (strings/multisets) present in ‘m’ regions of the membrane structure, μ
- $R_1,\ldots\ldots,R_m$: finite rules associated with those ‘m’ regions of μ
- i_0 : Output membrane

Representation of a P system



- $\Pi = (V, T, C, \mu, M_1, \ldots\ldots, M_m, R_1, \ldots\ldots, R_m, i_0)$

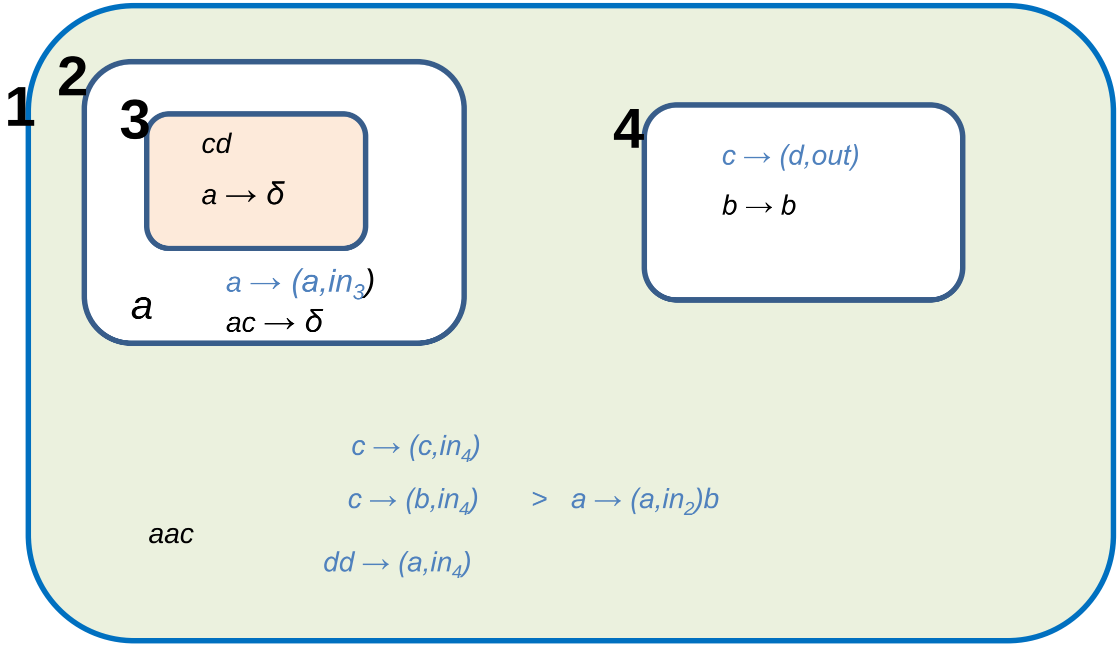
Rules of a P system



- Multiset rewriting rule
- Splicing rule
- Symport and antiport rule

- Rules are analogous to the chemical reaction rules working on objects present in that compartment

Rules of a P system



- Rules can indicate the flow of objects from one membrane to another membrane.
- Can be of forms like a→(a,in), a→(a,out) or a→(a,here)

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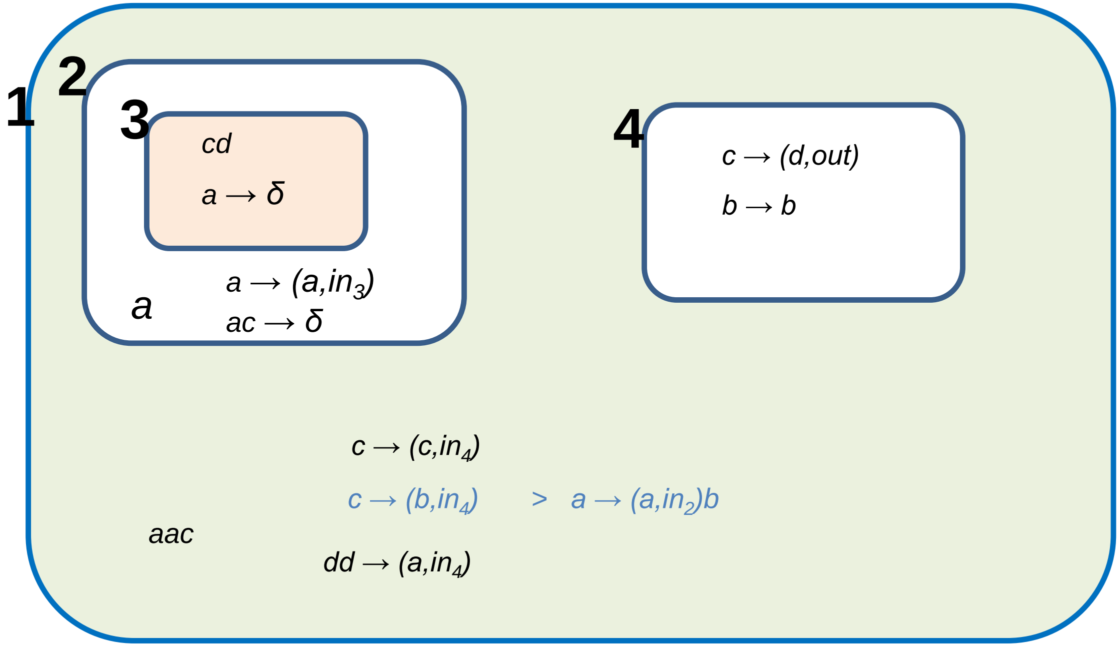
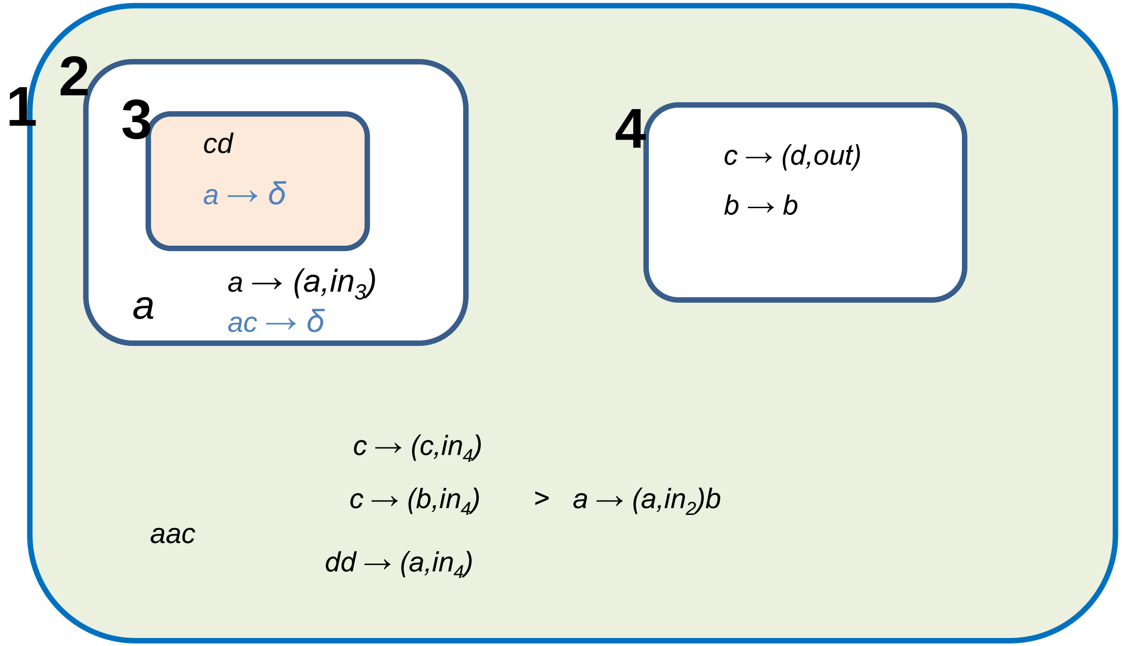
Rules of a P system



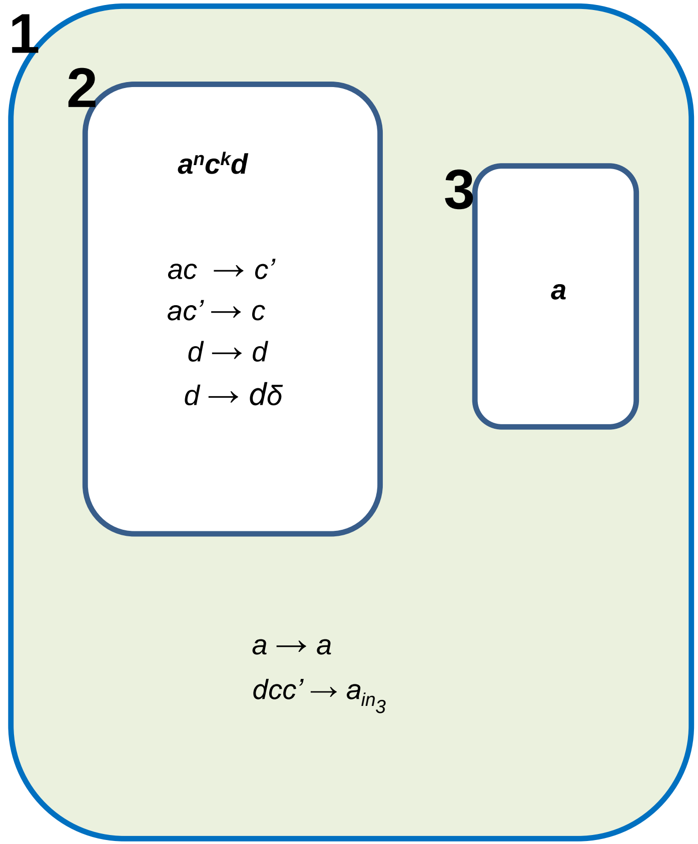
- Can have priority rules
- Can also have multiple sets of parallel rules that can't be applied simultaneously, chosen randomly

Rules of a P system



- Membrane dissolving rules: $a \to \delta$

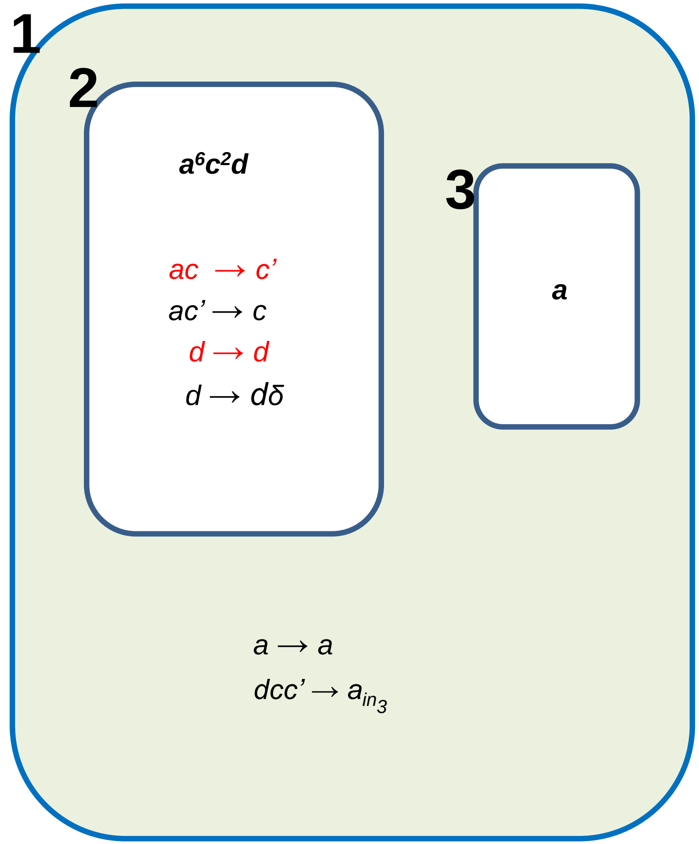
Find if n is divisible by k or not



- Find if n is divisible by k or not
- Membrane 3 is the resultant chamber

Find if n is divisible by k or not

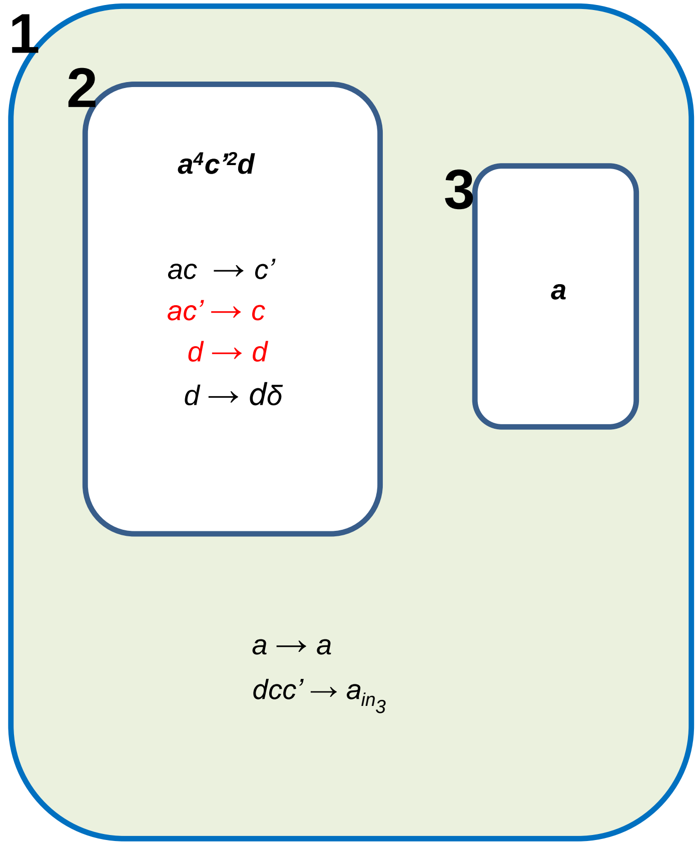
Step 1



Example:
n = 6
K = 2

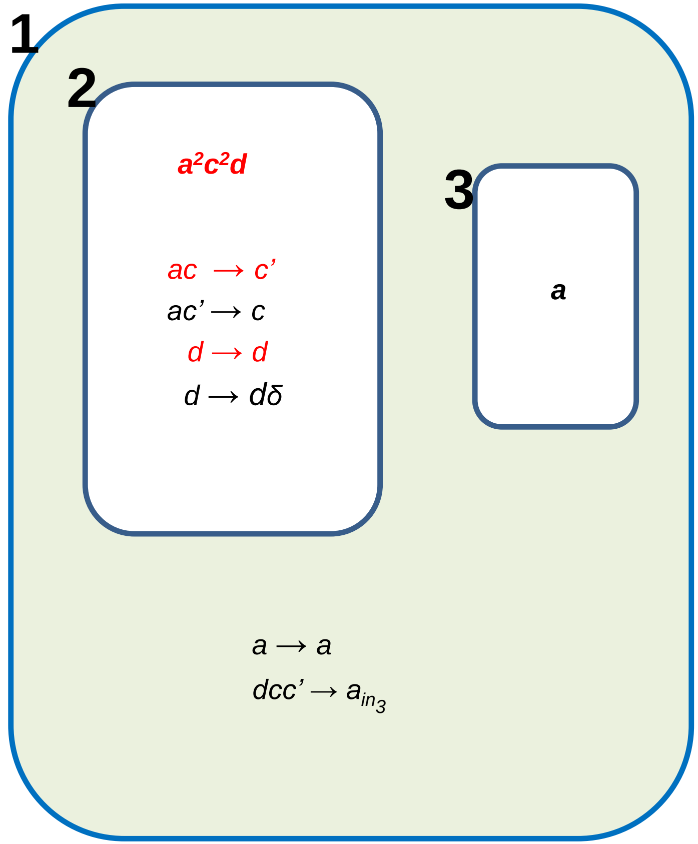
Find if n is divisible by k or not

Step 2



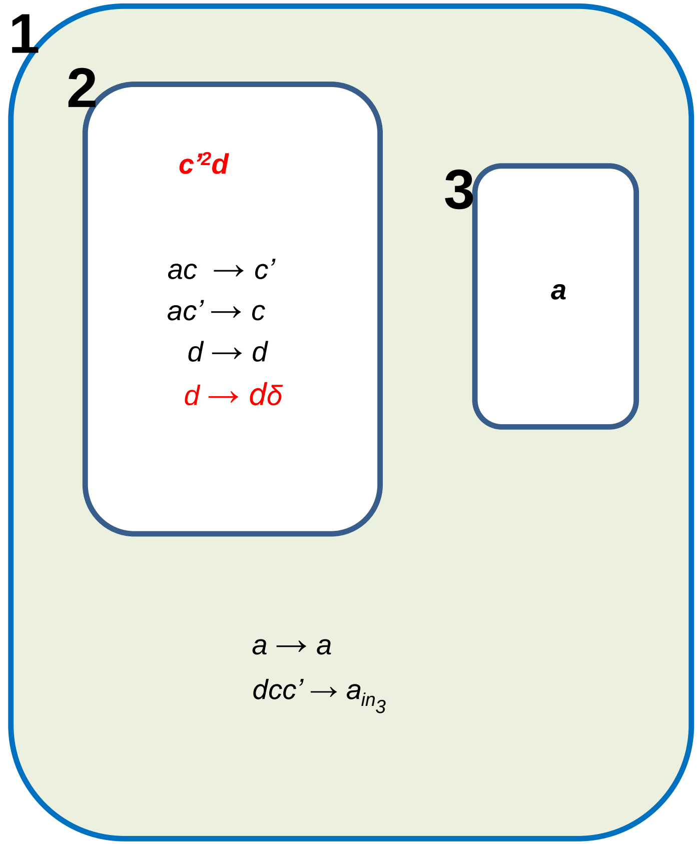
Find if n is divisible by k or not

Step 3



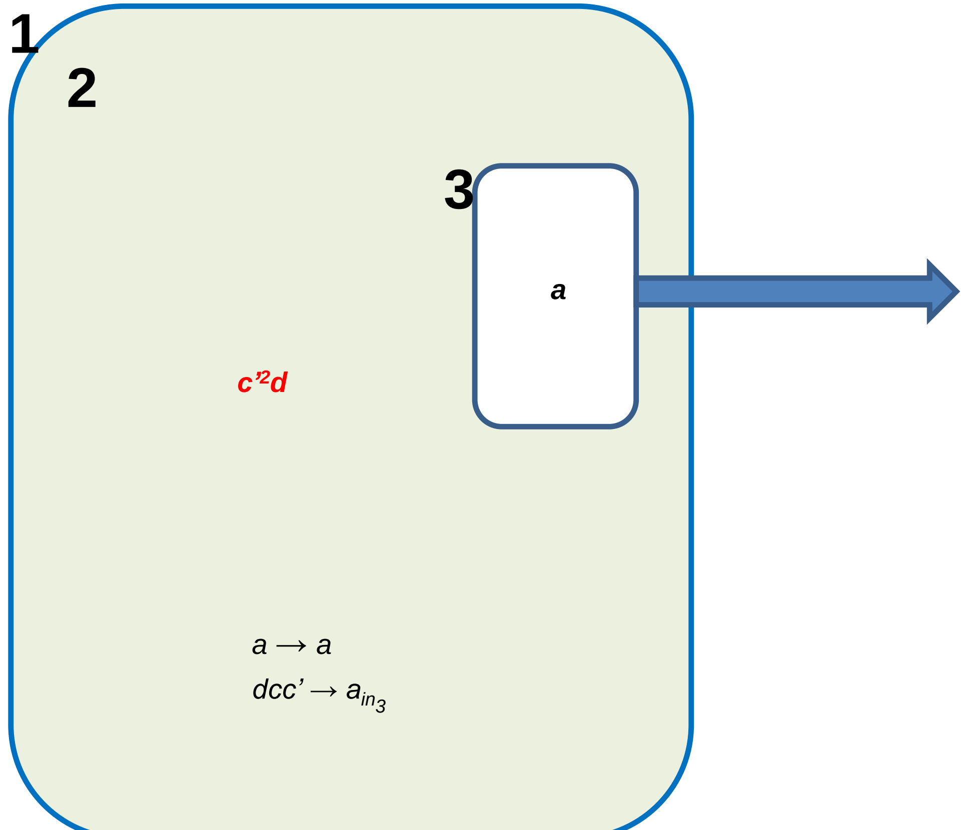
Find if n is divisible by k or not

Step 4



Find if n is divisible by k or not

Step 5

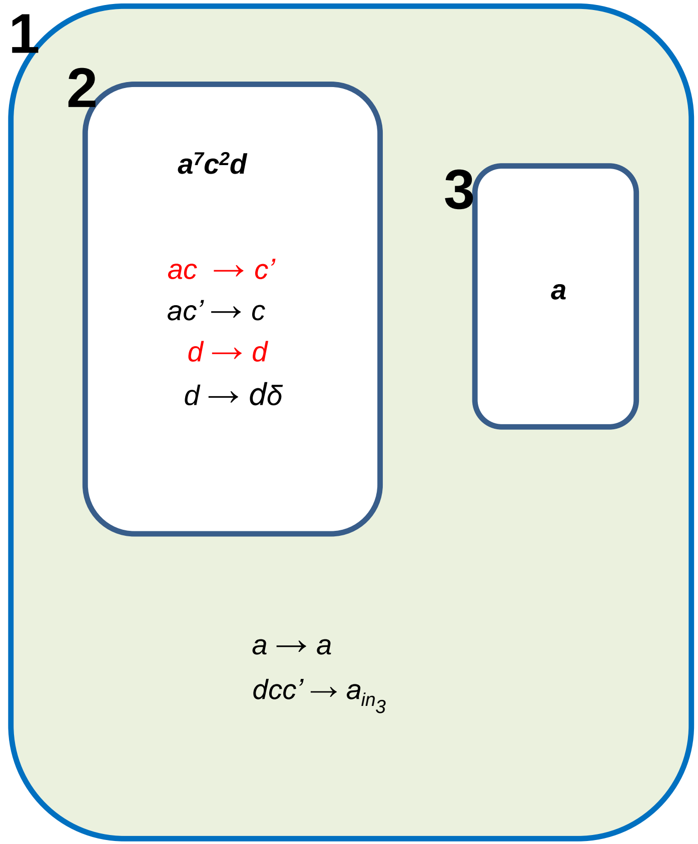


One copy of ‘a’, so in this example n is divisible by k

Computation halts

Find if n is divisible by k or not

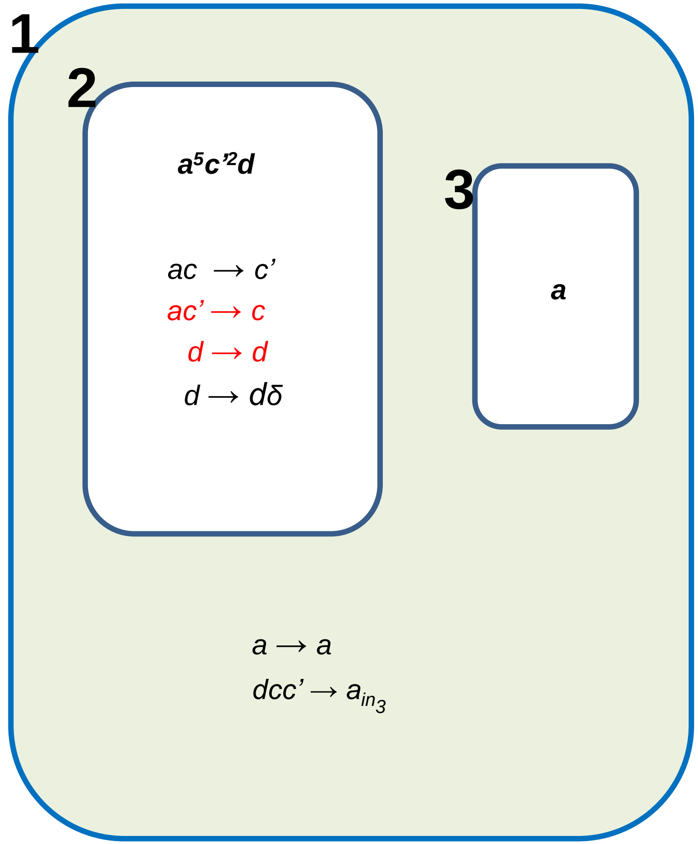
Step 1



Another example:
n = 7
k = 2

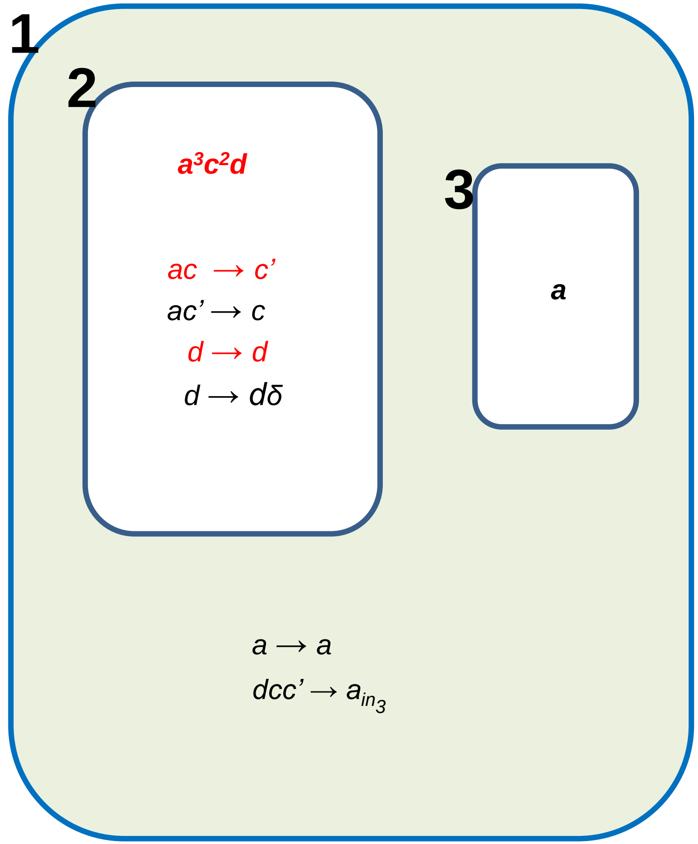
Find if n is divisible by k or not

Step 2



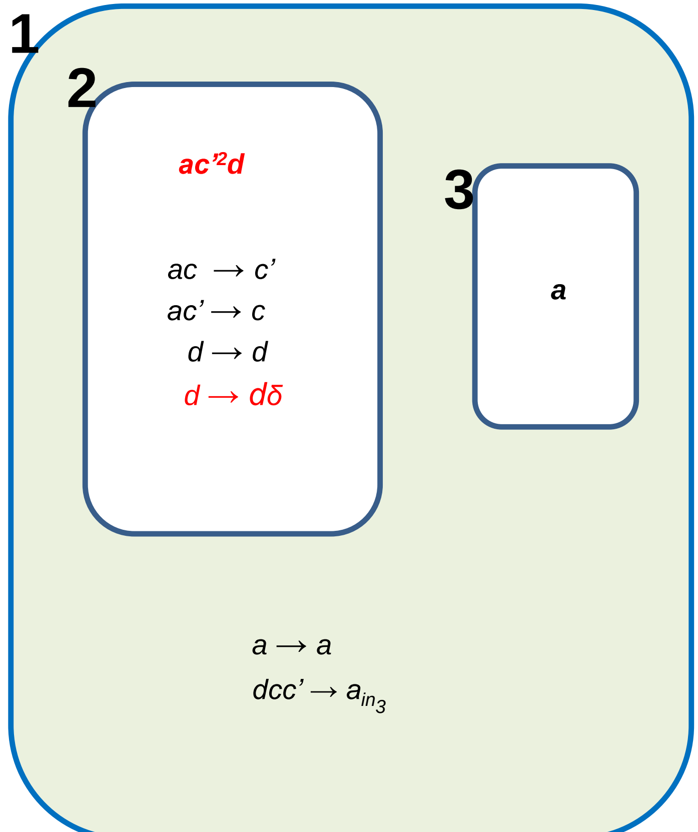
Find if n is divisible by k or not

Step 3



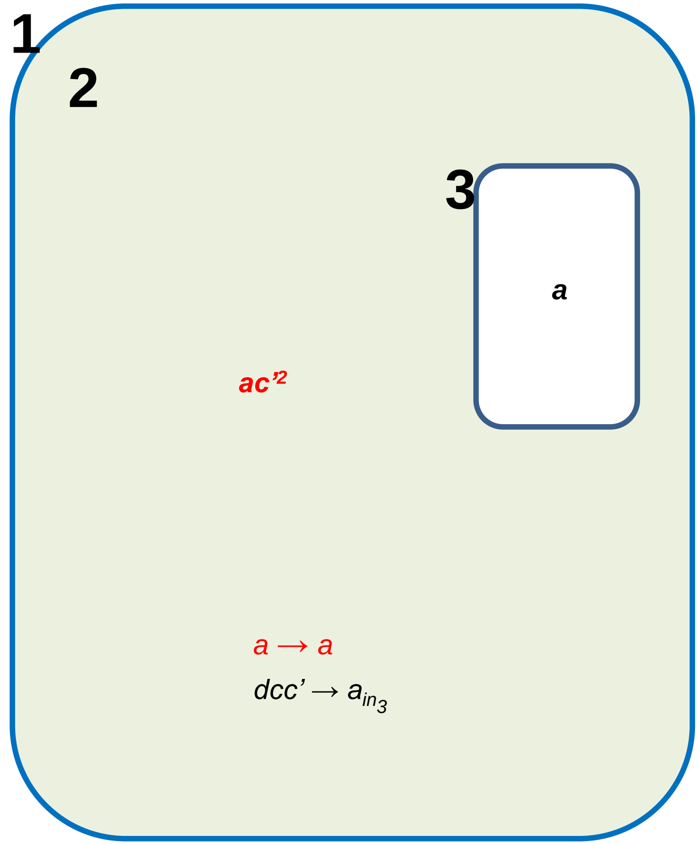
Find if n is divisible by k or not

Step 4



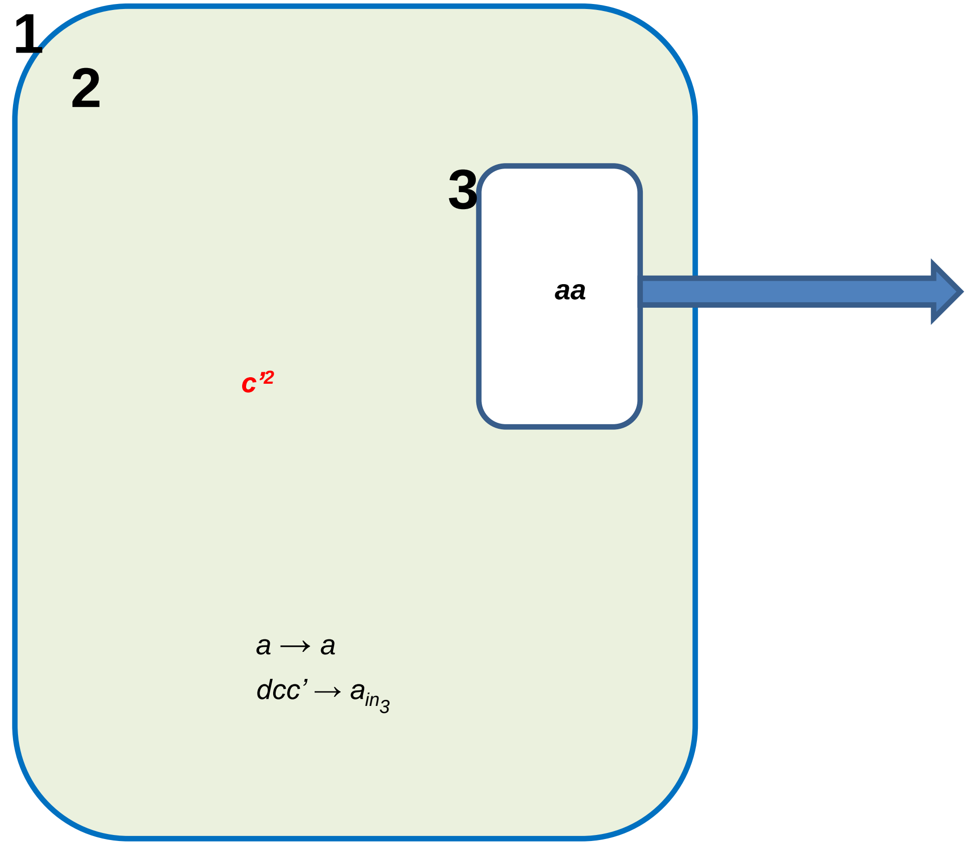
Find if n is divisible by k or not

Step 5



Find if n is divisible by k or not

Step 6



Computation halts

Two copies of ‘a’, so in this example n is not divisible by k

Another example: SAT(Boolean Satisfiability Problem)

NP-complete problem

Representation:

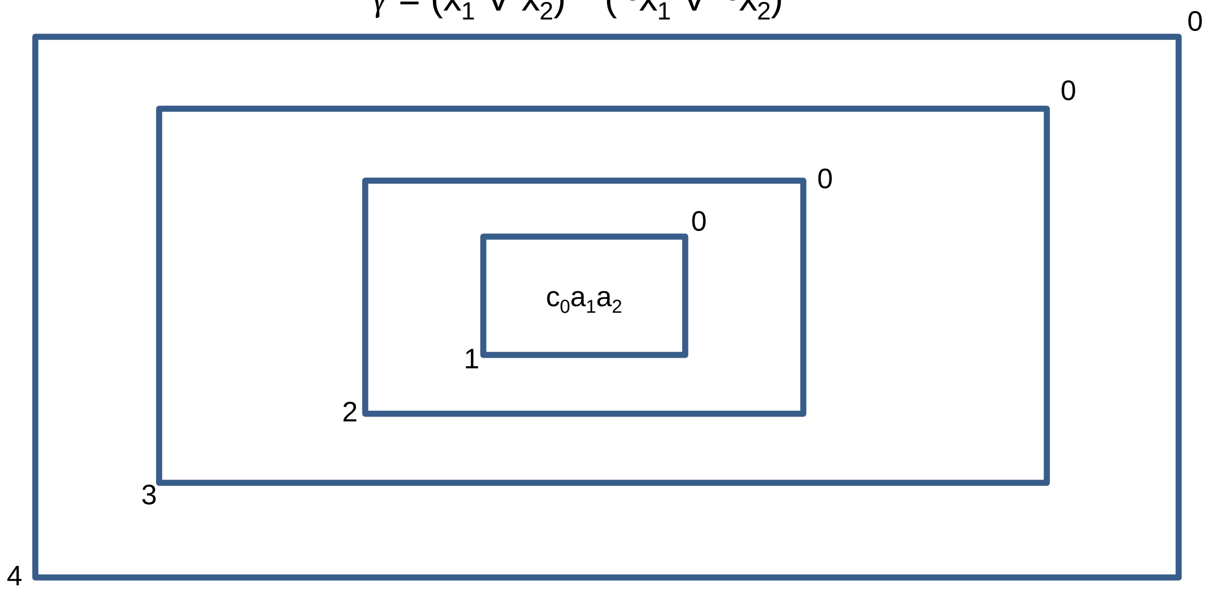
$\gamma = C_1 \wedge C_2 \wedge \ldots \wedge C_m$ with

$C_i = y_{i1} \vee y_{i2} \vee \ldots \vee y_{ip}$

C: clause, y: literal

Example SAT problem:

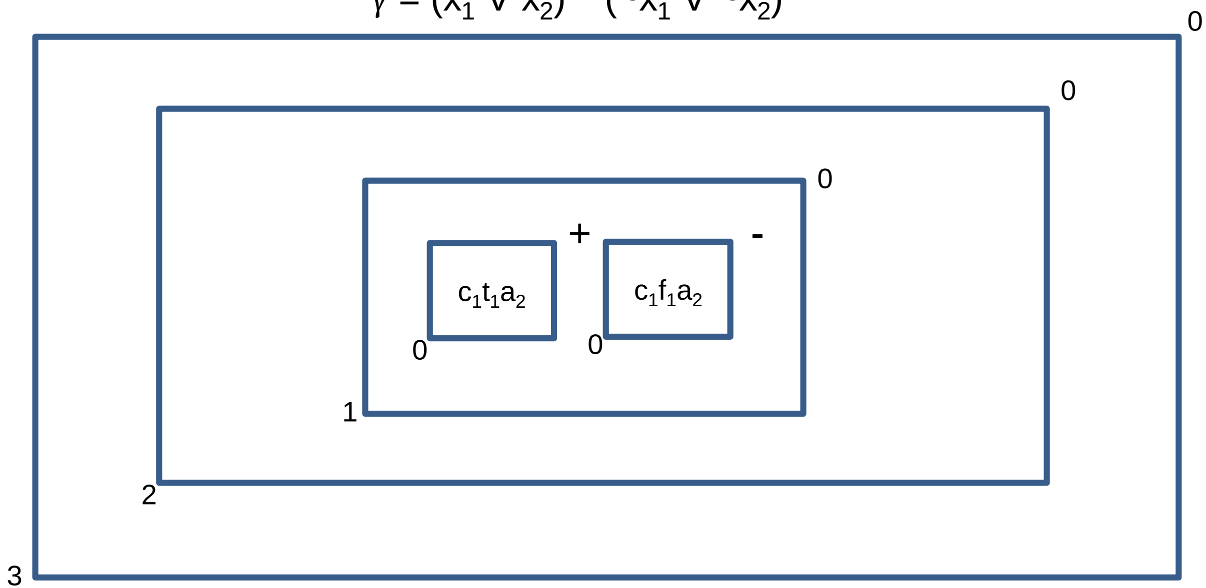
$\gamma = (x_1 \vee x_2) \wedge (\sim x_1 \vee \sim x_2)$



- Two variables a_1 and a_2
- C_0 is a object which increments in each time step

Solving SAT problem using P system:

$\gamma = (x_1 \vee x_2) \wedge (\sim x_1 \vee \sim x_2)$



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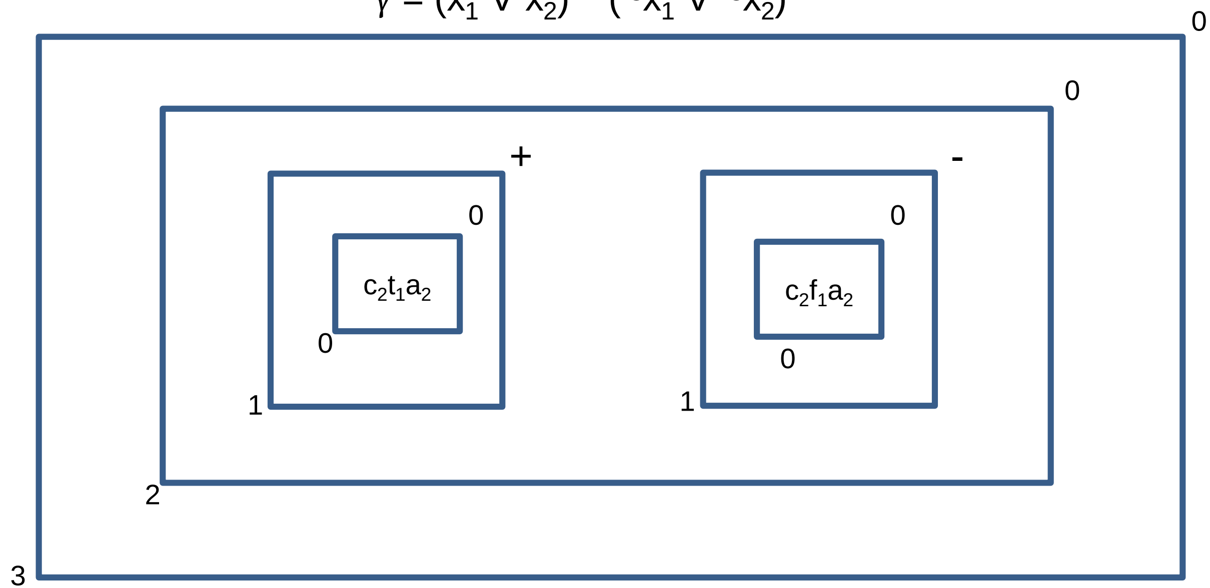

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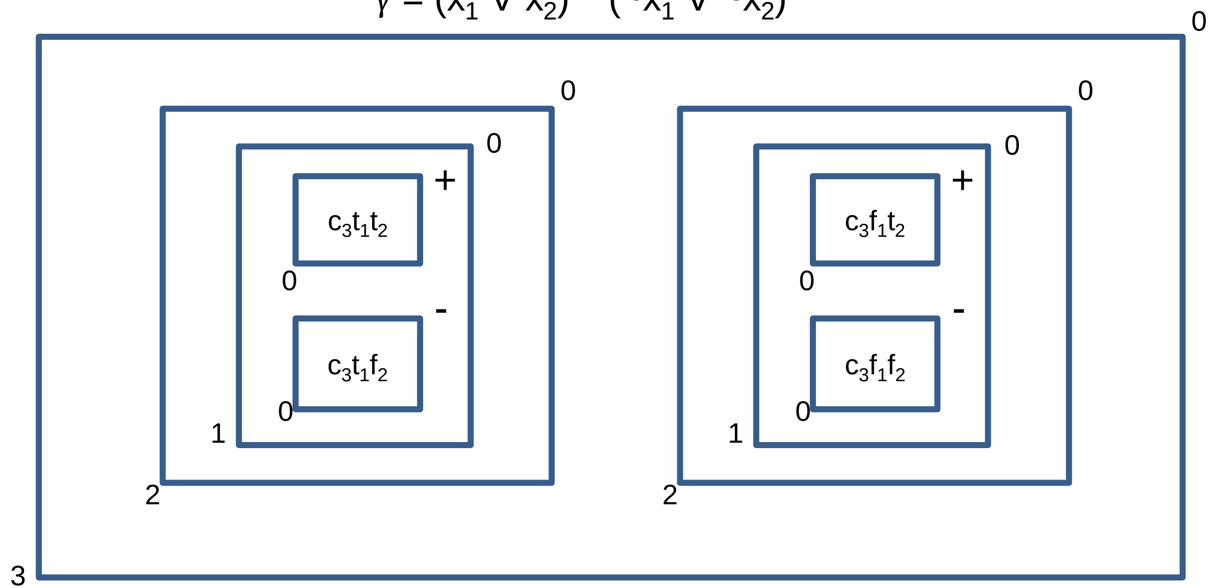

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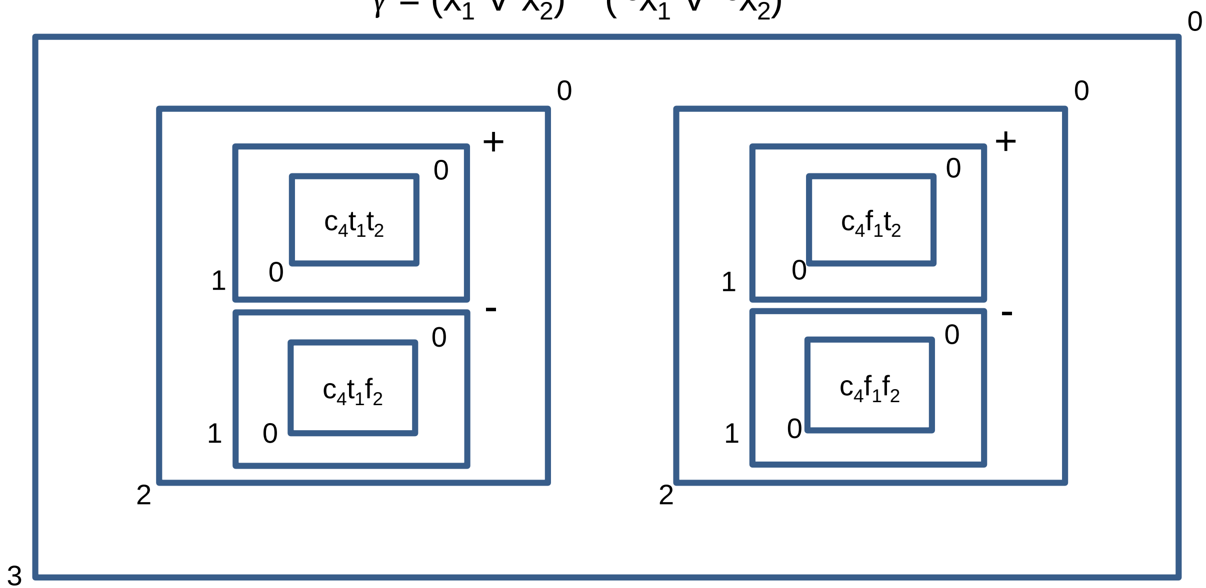

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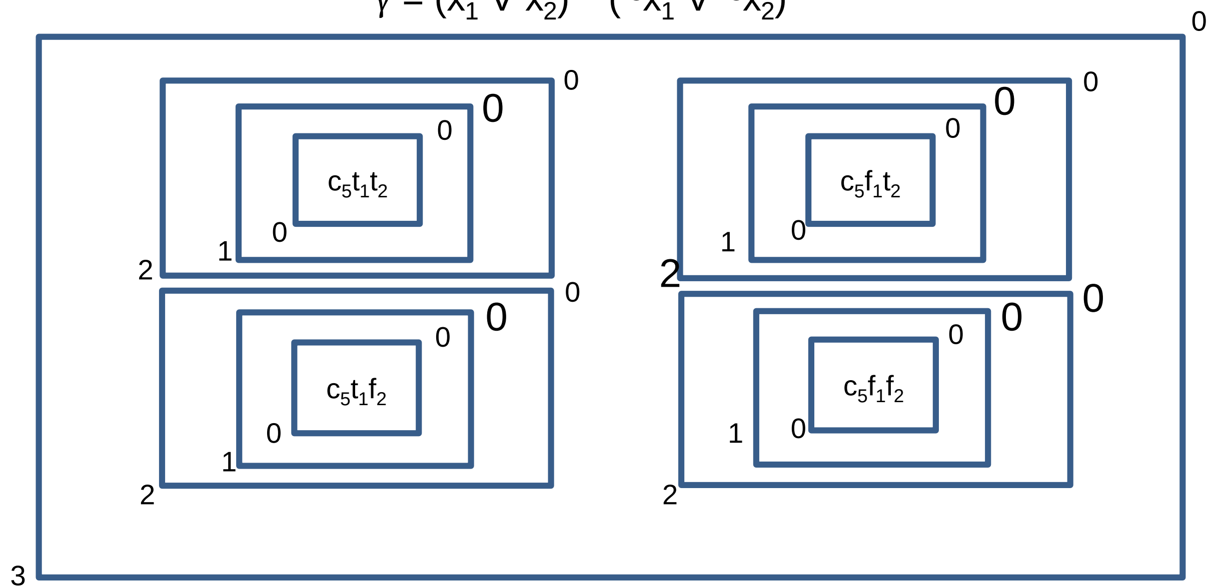

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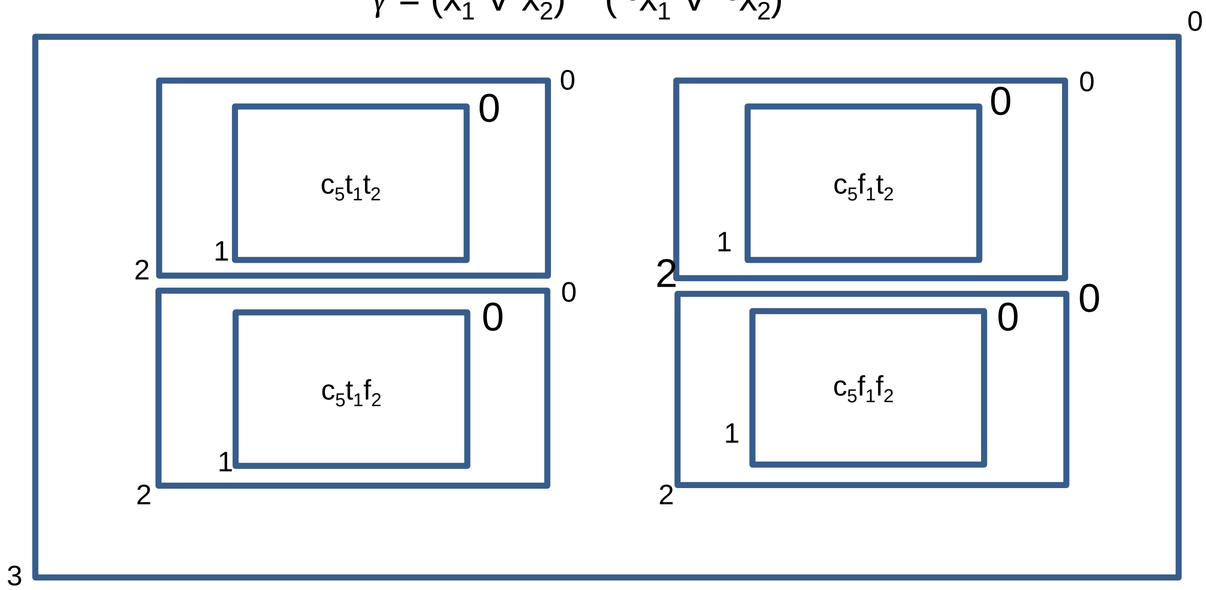

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Solving SAT problem using P system:

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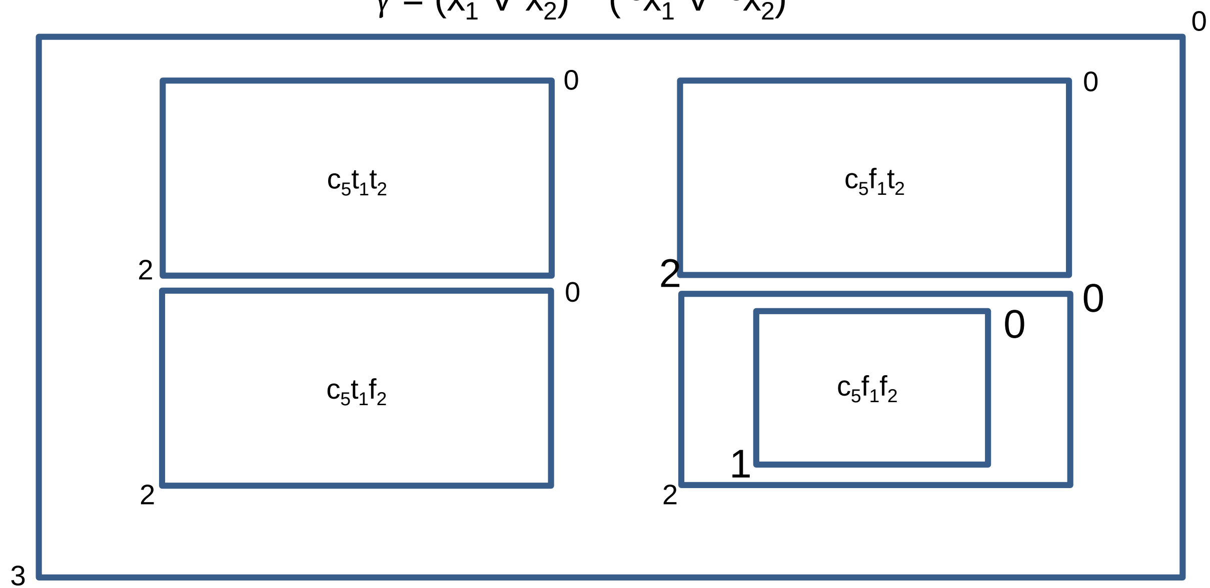

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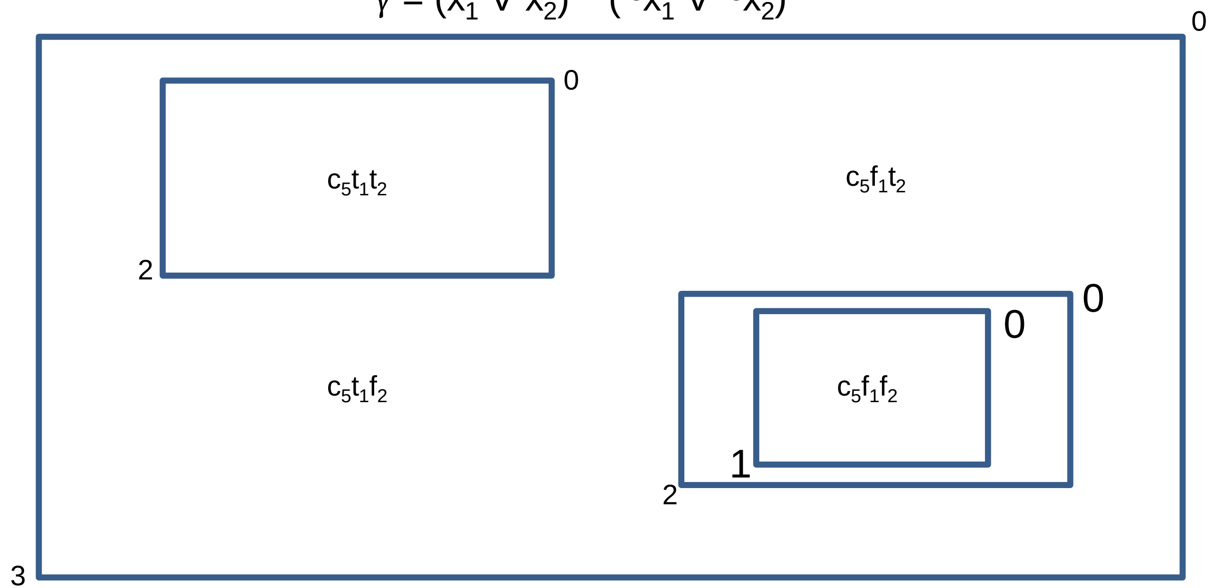
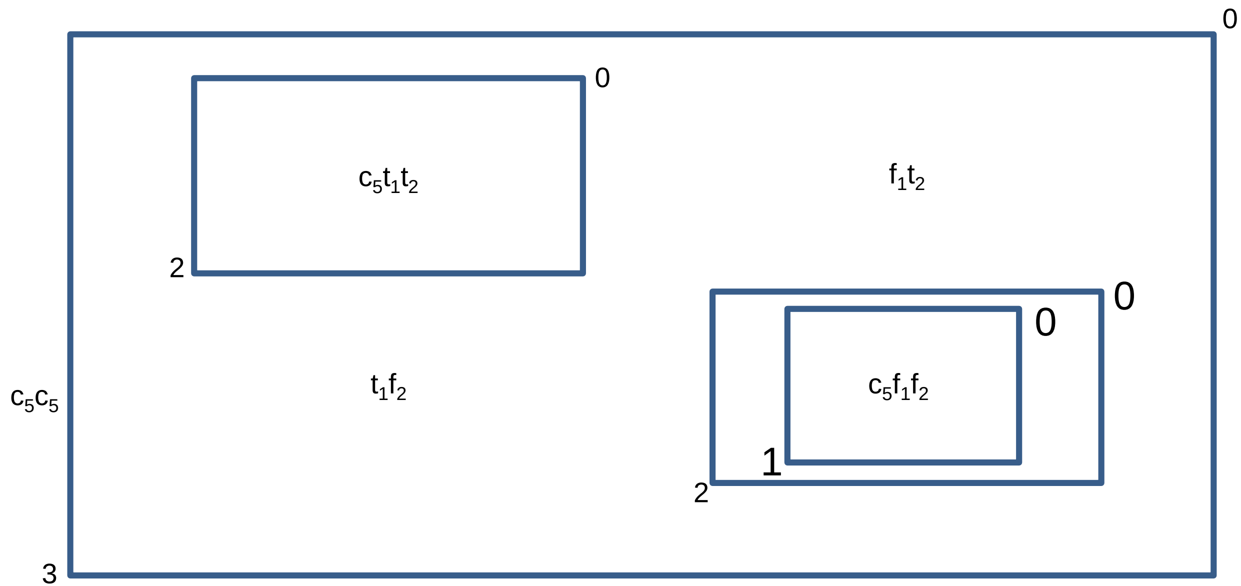


Solving SAT problem using P system:



- Membranes which satisfy the conditions dissolve
- NP-complete problem thus can be solved in linear time using P system

Types of P Systems

- Three main types of P system
  - Cell-like P systems
  - Tissue-like P systems
  - Neural-like P systems

Types of P Systems

- Cell-like P systems
  - Imitates the cell and basic membrane structure
  - Objects described by symbols or strings and multisets of objects places in compartments
  - Rules maintained-- Rewriting rules, transport rules, transition rule and string processing rule

Types of P Systems

- Tissue-like P systems
  - One membrane cells evolving in a common environment
  - Both cells and environment contain objects
  - Cells communicate directly or through the environment
  - Channels are given in advance or dynamically established (*population P-systems*)

Types of P Systems

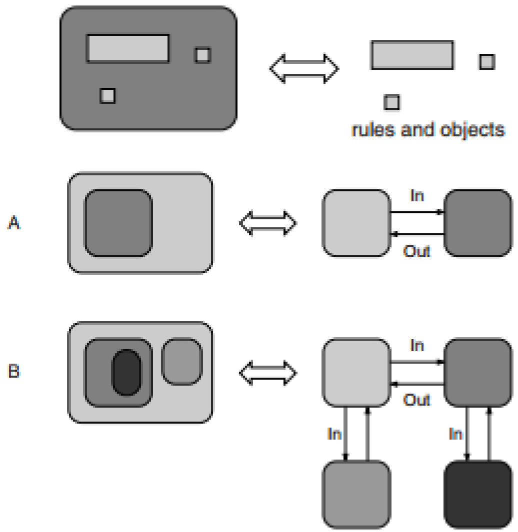
- Neural-like P systems
  - Basically two types.
    - Tissue like neural P systems
    - Spiking neural P systems
  - Tissue like neural P systems inspired by neurons and have a state which controls evolution
  - Spiking neural P system uses only one object, *“spike”* and main information to work with is distance between consecutive spikes

Efficiency of P System Computation

- P systems are powerful (most classes are Turing complete) and efficient (contains enhanced parallelism)
- Speed-up obtained by trading space for time
- Exponential workspace--Membrane creation, separation and string replication
- Investigations with complexity of time and space

Research and Future of P Systems

- Hardware Implementation:
  - Petreska and Teuscher's hardware implementation
    - Fundamental features of P systems
    - Reaction rules applied sequentially in region
    - One level of parallelism



"it is important to underline the fact that "implementing" a membrane system on an existing electronic computer cannot be a real implementation, it is merely a simulation. As long as we do not have genuinely parallel hardware on which the parallelism [...] of membrane systems could be realized, what we obtain cannot be more than simulations, thus losing the main, good features of membrane systems"

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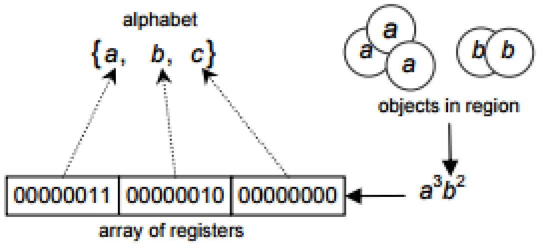
Research and Future of P Systems

- Hardware Implementation:
  - Reconfigurable Hardware (Reconfig-P)
    - V. Nguyen *et al*. implemented on ASIC design
    - Better performance than software based microprocessors
    - Source code generator and an FPGA



Major Application of a P System

- Biology
  - Modeling of cells, tissues, neurons
  - Modeling biological dynamics
- Computer science
  - As another computing system
  - Cryptography, Computer graphics, Optimization problem etc.

Concluding Thoughts

- Compartmentalization
- Non-deterministic and maximally parallel application
- Polynomial or linear solutions to NP-complete problems