Immune System Modeling and Analysis using Bio-PEPA

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ICCP 2015 : IEEE 11th International Conference on Intelligent Computer Communication and Processing

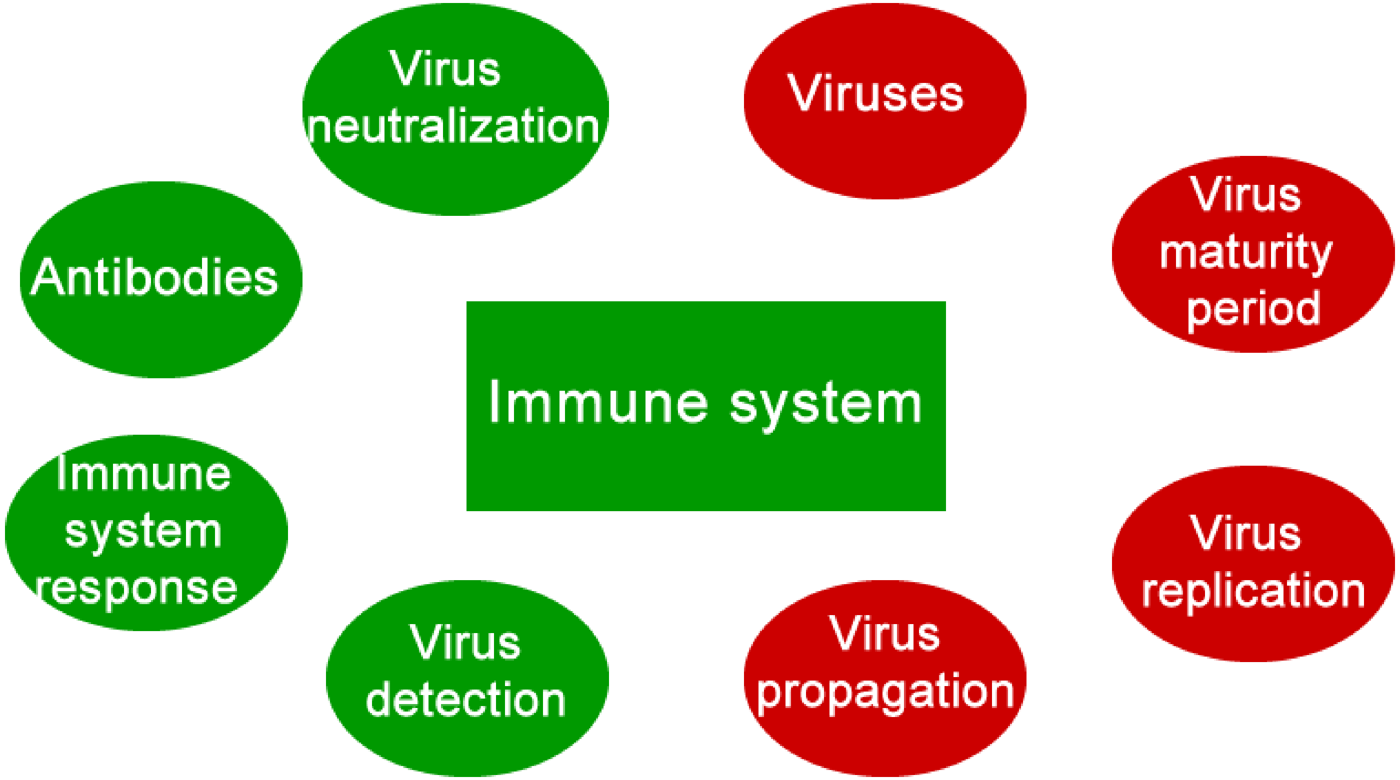
Cluj-Napoca, Romania, September 3-5, 2015

Contents

Objectives

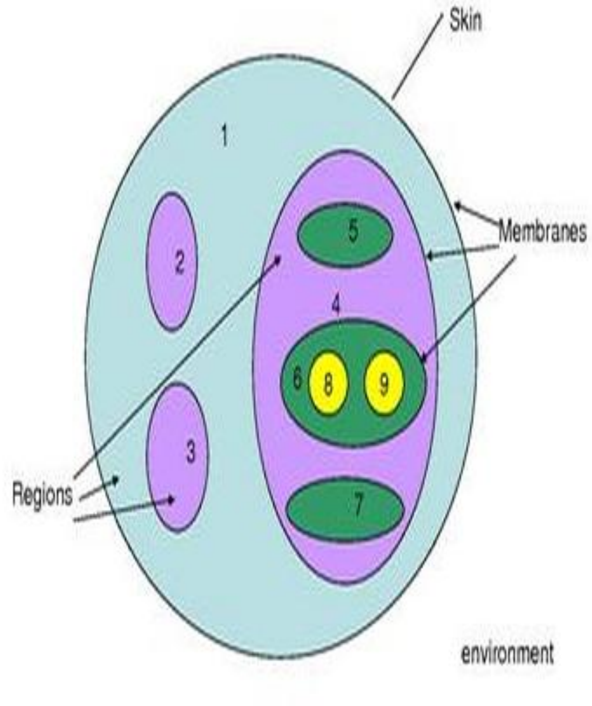
- Analyze the response of the immune system against virus attacks
  - Membrane computing patterns
  - Bio-PEPA
- Identify formal conditions for successful immune responses against virus attacks
  - identified and expressed based on Bio-PEPA functional rates

Immune system



Membrane computing

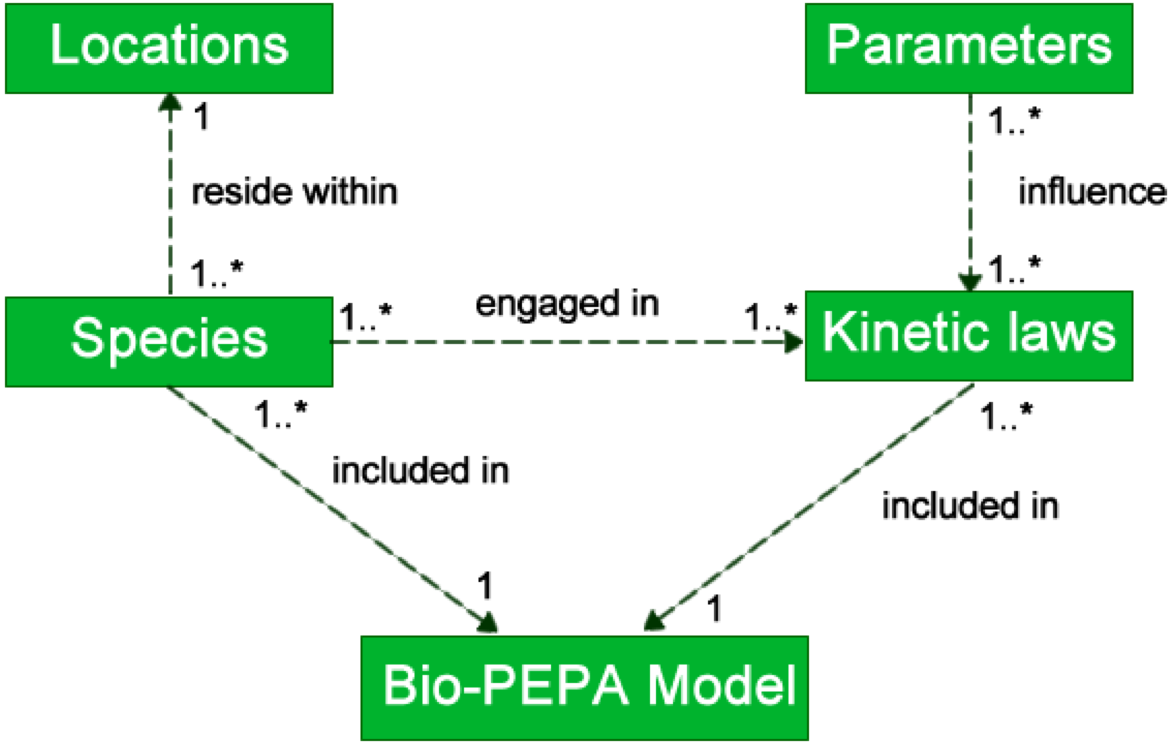
- Membrane structure



Bio-PEPA (1)

- Process algebra framework
- Model and analyze the biochemical networks
- Improvement of PEPA
  - Performance analysis of computer systems

Bio-PEPA (2)



Locations
Parameters
1
reside within
1..*
1..*
influence
1..*
Species
1..*
engaged in
1..*
Kinetic laws
1..*
included in
1..*
included in
1
1
Bio-PEPA Model

Bio-PEPA (3)

- General form of an irreversible reaction j

$$\boxed{k_{1j}A_{1j}+\ldots+k_{nj}A_{njj} \xrightarrow{E_{1j},E_{2j},\ldots I_{1j},I_{2j}\ldots;\ f_j} k'_{1j}B_{1j}+\ldots+k'_{mj}B_{mjj}} \quad (1)$$

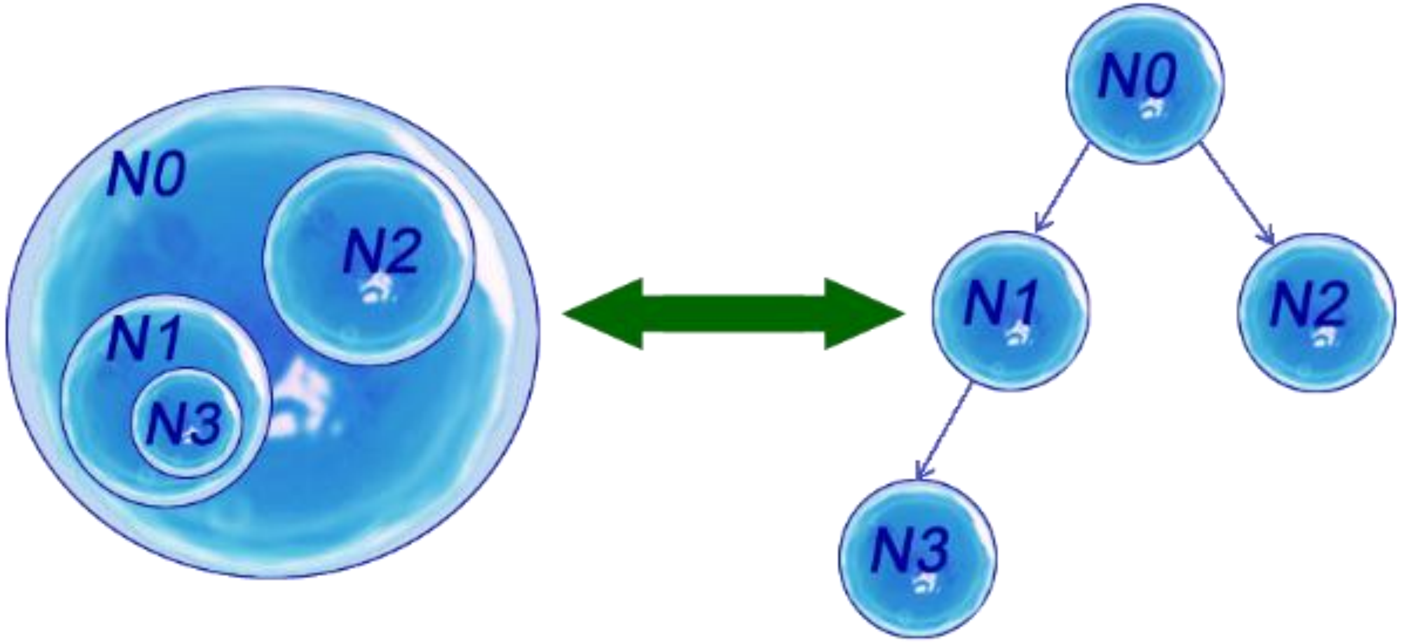
  - A_{hj} = reactants
  - B_{lj} = products
  - E_{vj} = enzymes
  - I_{uj} = the inhibitors of the reaction
  - k_{hj} and k'_{lj} = stoichiometric coefficients

Bio-PEPA (4)

- Bio-PEPA Model
  - formal and compositional representation of a biological system
  - allows the execution of a series of analyzes
- Bio-PEPA Eclipse Plug-in
  - ASCII representation of BIO-PEPA symbols

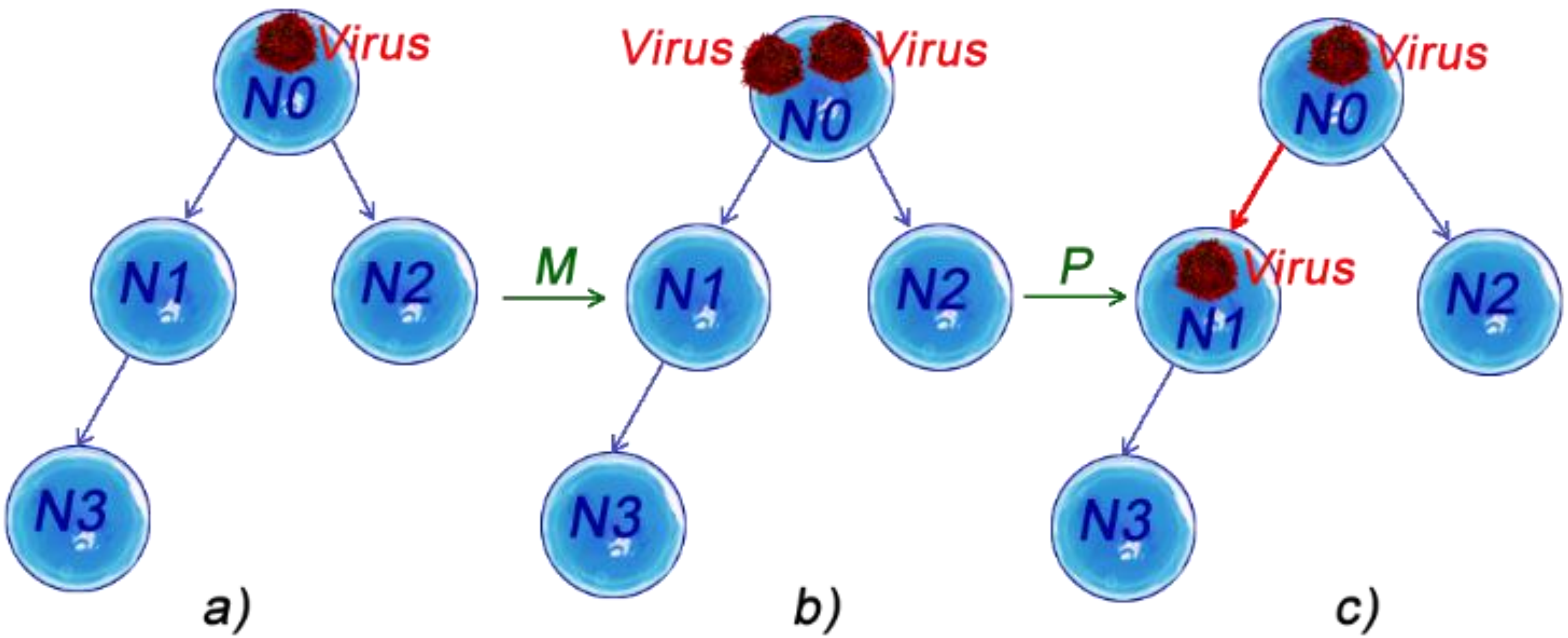
Immune System Modeling (1)

- Immune system model architecture



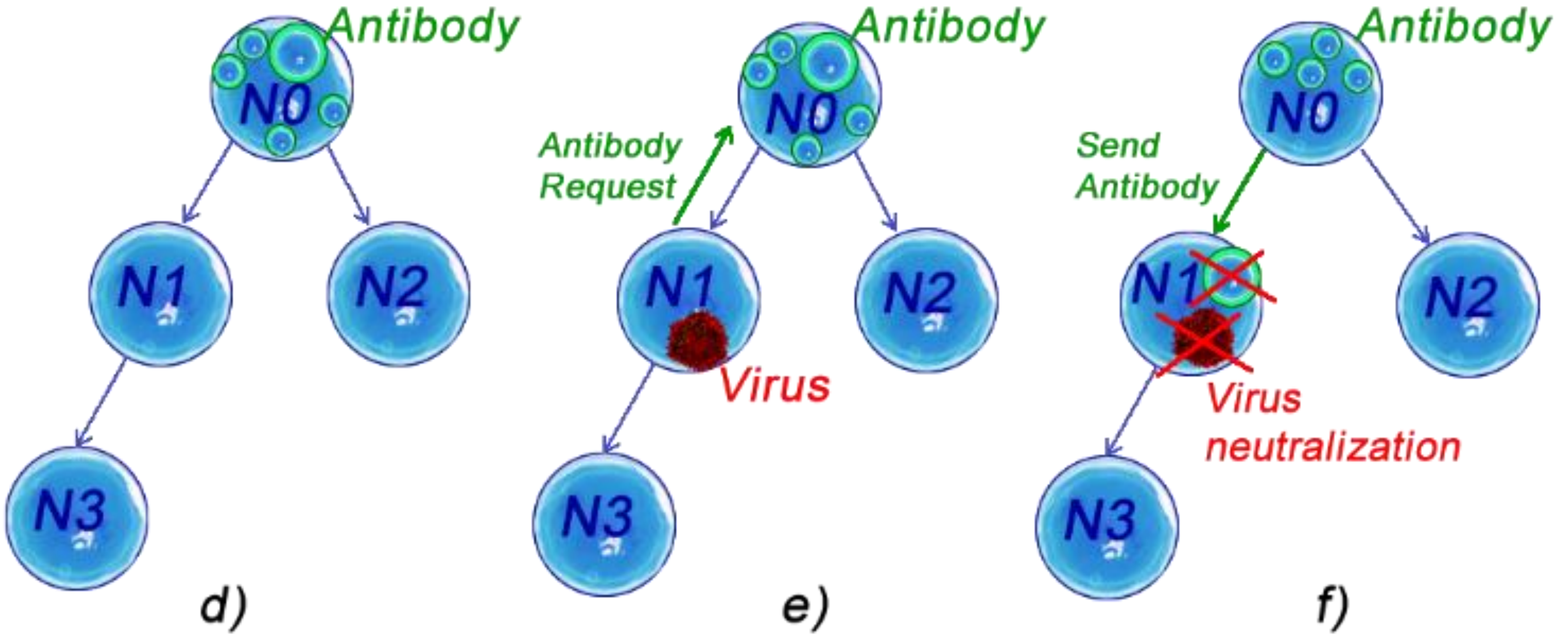
Immune System Modeling (2)

- Virus replication and propagation processes



Immune System Modeling (3)

- Virus neutralization process

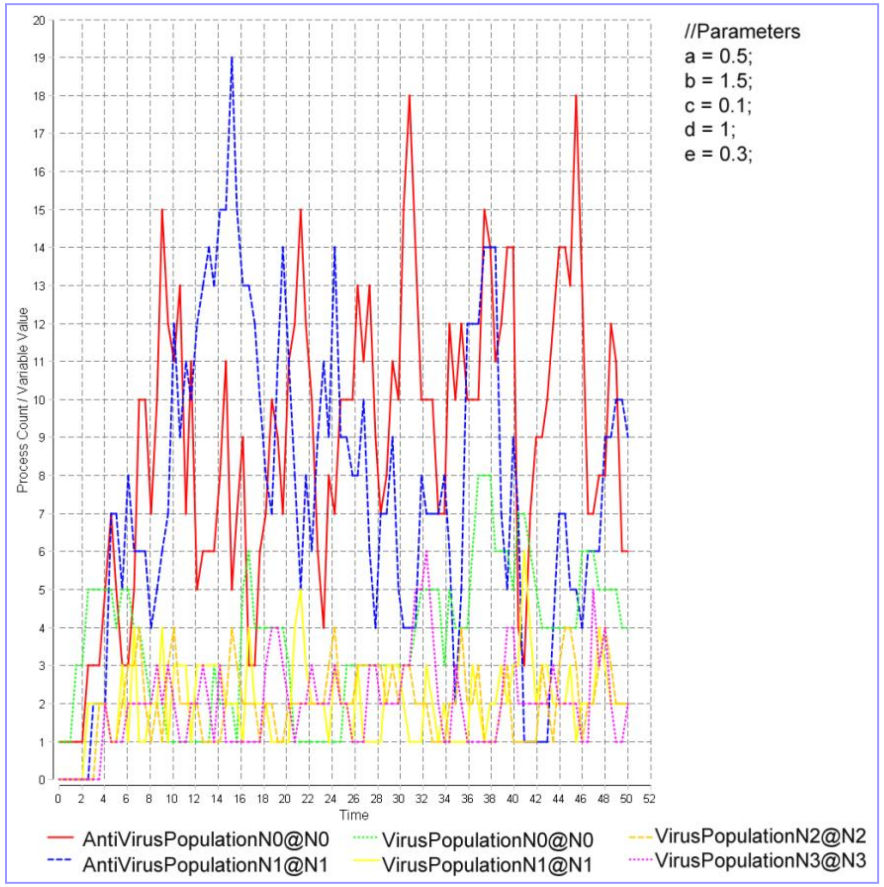


Experimental results (1)

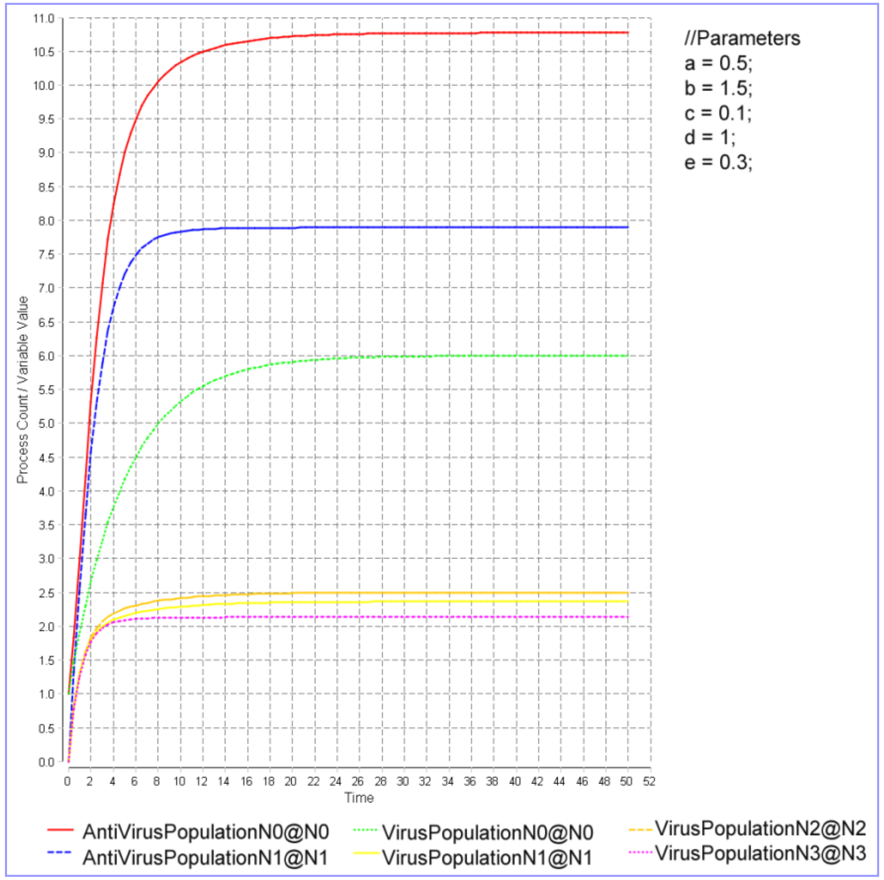
- Immune System Analysis using Bio-PEPA
  - Stochastic
  - ODE

Experimental results (2)

Stochastic simulation of the successful Bio-PEPA immune response model



ODE simulation of the successful Bio-PEPA immune response model



Experimental results (3)

- Formal conditions for successful immune responses against virus attacks

- Sufficient condition for the system state to be “clean”

  $$M > 2D$$

- Necessary condition for the system state to be “clean”

  $$n(t) = n(t-P) + n(t-M) \qquad (2)$$

Future work

- Java parallel implementation of the immune system model
  - Map each membrane on a core of a multicore computer
  - Validate the stochastic and ODE simulations

- Investigate the semantics of Bio-PEPA
  - operational and denotational semantics
  - continuations semantics for concurrency

Conclusions (1)

- Strategy of modeling and analyzing the behavior of the immune system against virus attacks
- Membrane computing patterns
- Bio-PEPA process algebra

Conclusions (2)

- The effectiveness of modeling biochemical networks can be significantly improved by providing an intermediate, formal compositional representation of the model on which different kinds of analysis can be carried out