Biochemical pathways

What is a “pathway”

Wikipedia (October 14th 2013): “In biochemistry, metabolic pathways are series of chemical reactions occurring within a cell. In each pathway, a principal chemical is modified by a series of chemical reactions. Enzymes catalyze these reactions [...]”

Different types: Signalling pathways, metabolic networks, gene regulatory networks ...

Many “pathway” databases:

Biocarta, Bio/MetaCyc, Ingenuity IPA, KEGG Pathway, Panther pathways, Reactome, STKE, Wikipathways etc.

➜ Detailed representation of reality based on observation

What is a “model”

Wikipedia (October 14th 2013): “A mathematical model is a description of a system using mathematical concepts and language.”

A model is made up of variables, functions and constraints

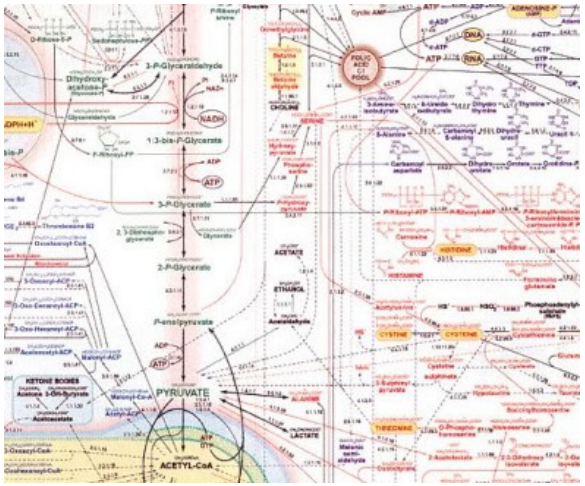
Different types: Dynamical models, logical models, rule-based models, multi-agent models, statistical models ...

Different levels of granularity for the variables and precision for the functions, based on the questions being asked and the data available

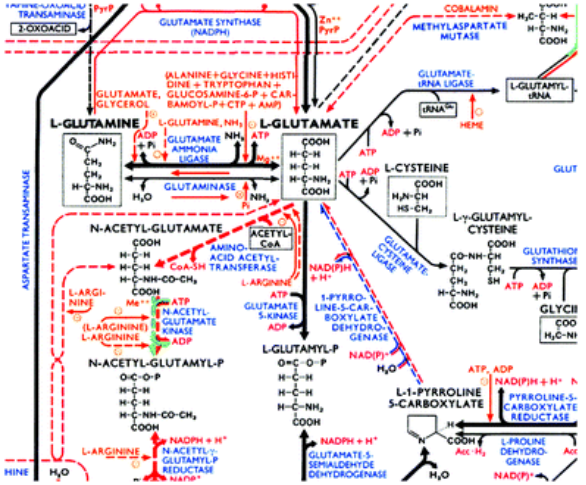
➜ Abstract representation of reality based on needs

Biochemical pathways are old … or not so much

- Gortner, R.A. *Outlines of Biochemistry* (Wiley, New York, 1949)
- Nicholson (1970)



Michal (1984)



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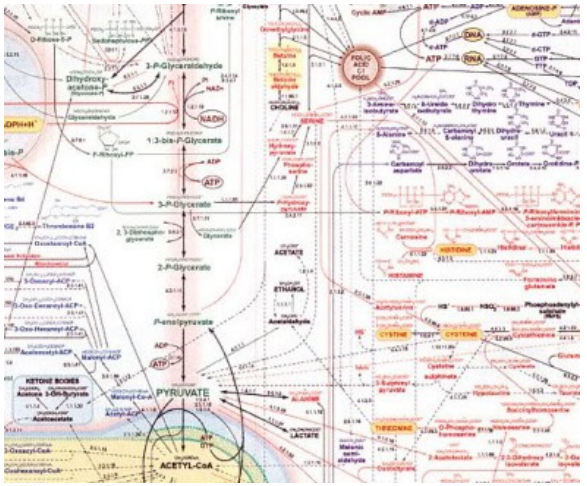
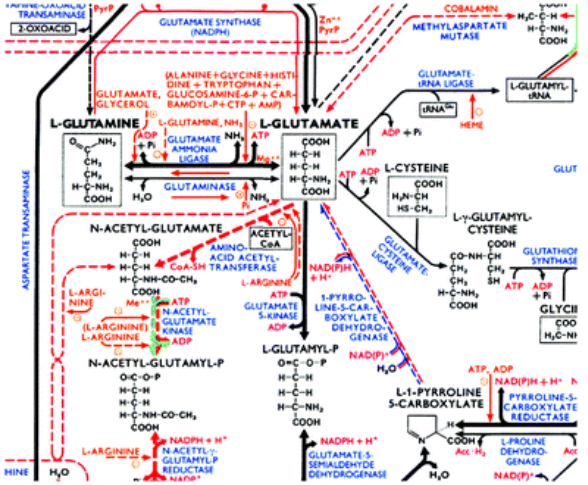


Michal (1984)

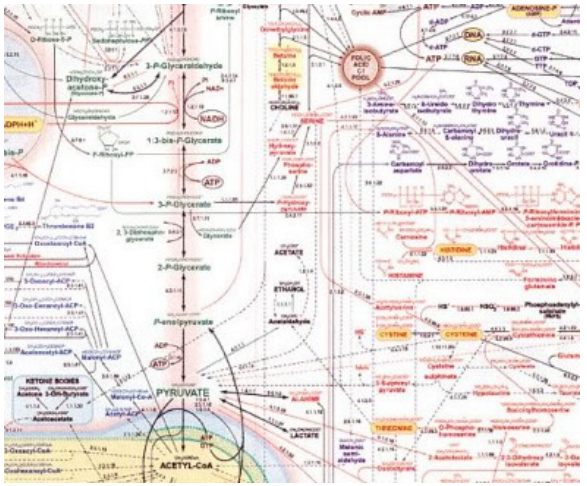


"Hand drawing" on paper

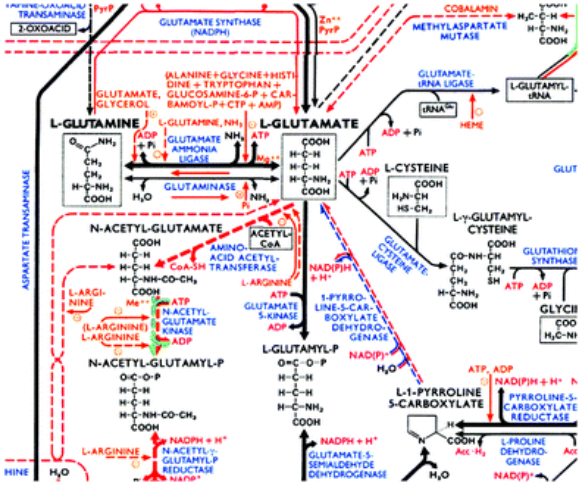
⟶ no software-based browsing, processing and analysis

Biochemical pathways are old … or not so much

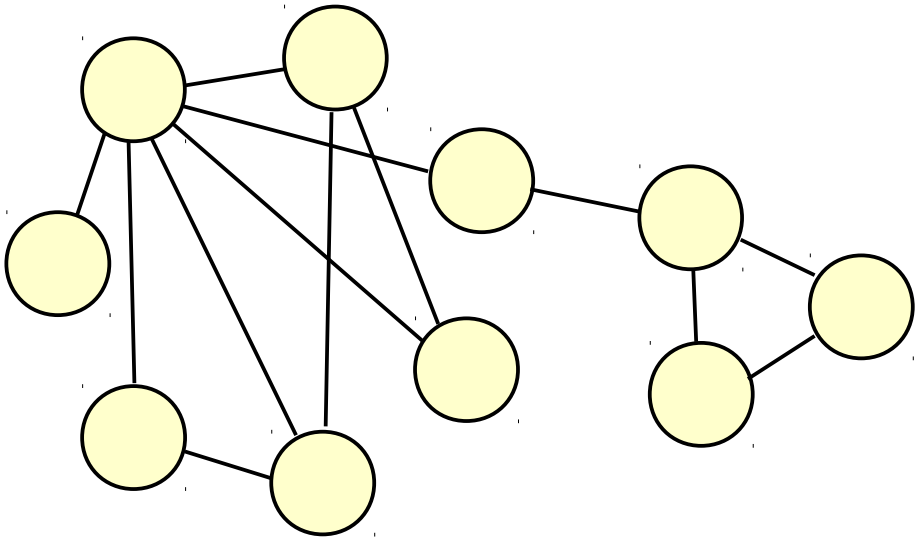
- Gortner, R.A. *Outlines of Biochemistry* (Wiley, New York, 1949)
- Nicholson (1970)

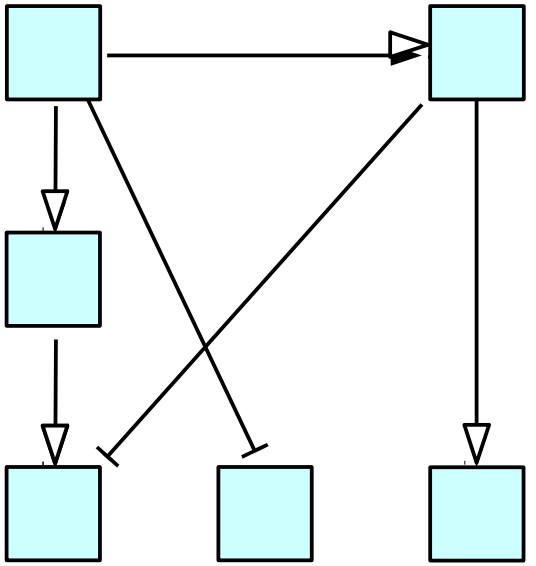


Michal (1984)

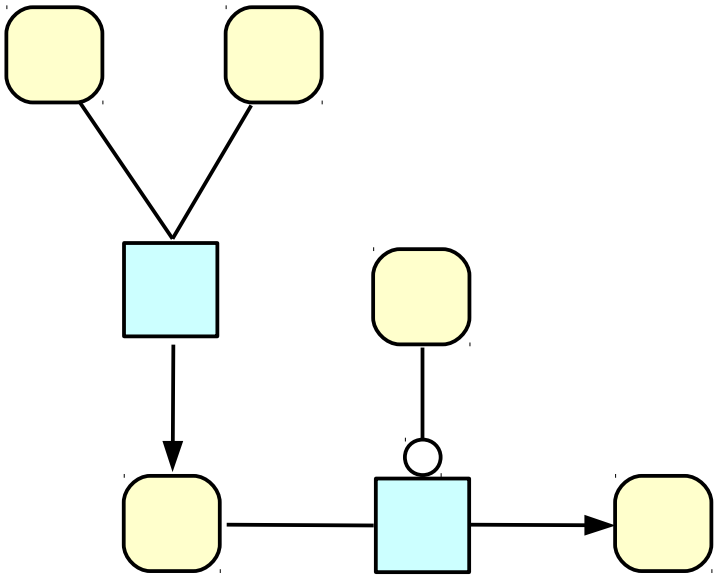


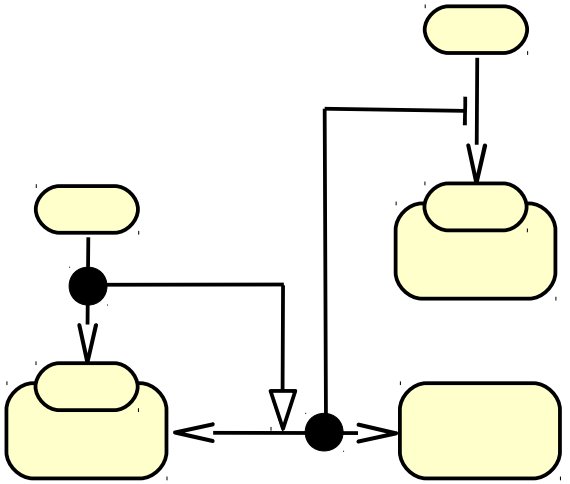
- 1990s: high-throughput data generation → Large amount of knowledge
  increase in computing power → automatic reconstruction, browsing and analysis
- Databases: KEGG (1995), EcoCyc (1994), Reactome (2000)
- Formats: BioPAX (2000), SBML (2000), PSI-MI (2002)



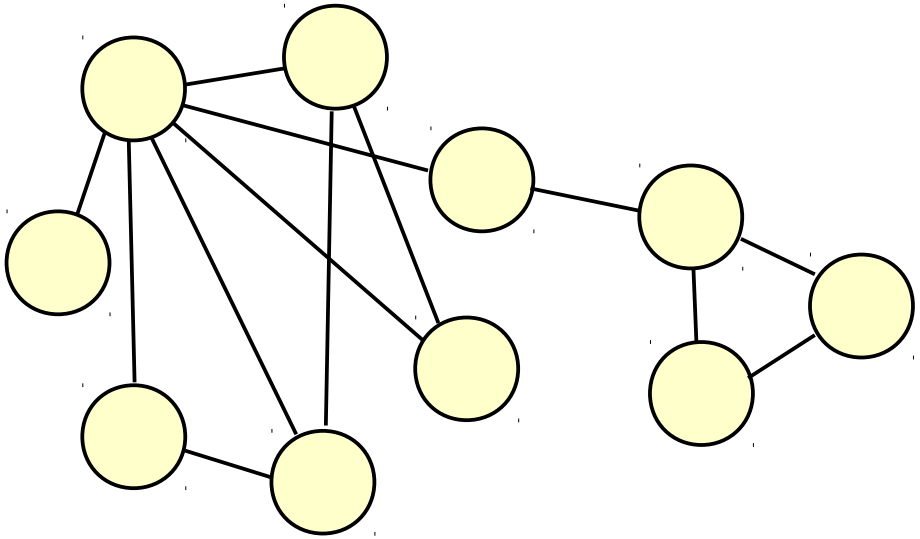


The four views of systems biology



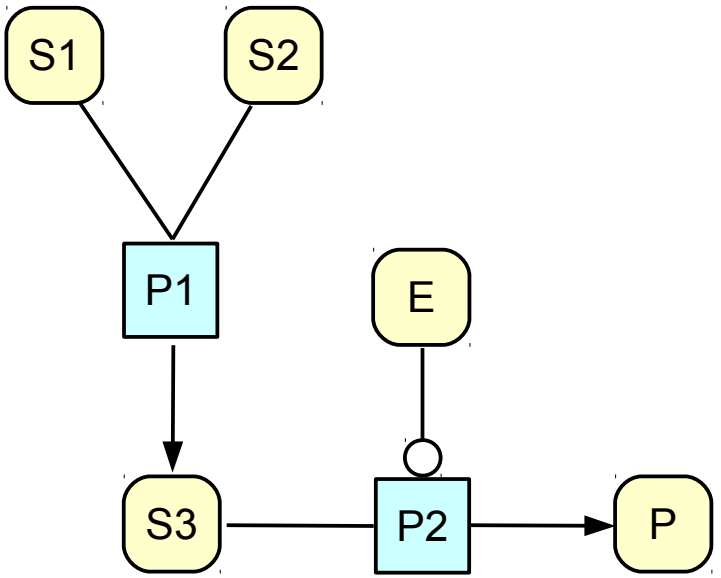


Interaction networks



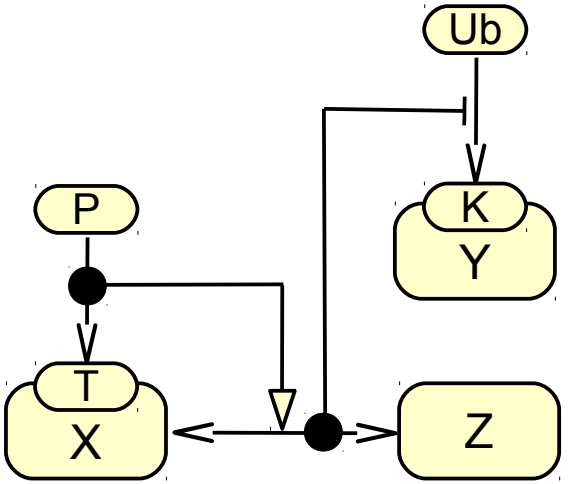
- Non-directional
- Non-sequential
- Non-mechanistic
- Statistical modelling
- Functional genomics

Process Descriptions



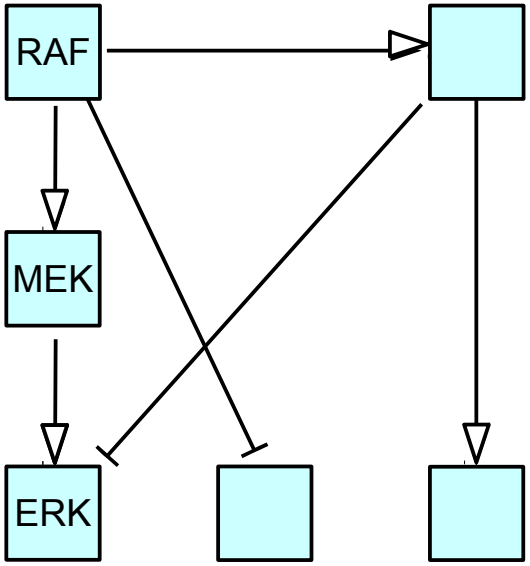
- Directional
- Sequential
- Mechanistic
- Process modelling
- Biochemistry, Metabolic networks
- Generally within “closed world”
- Subjected to combinatorial explosion

Entity Relationships

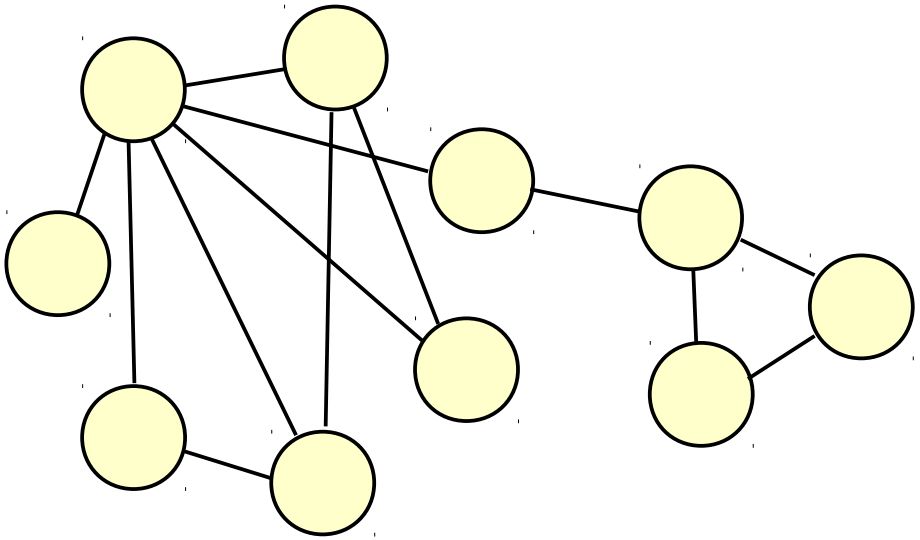


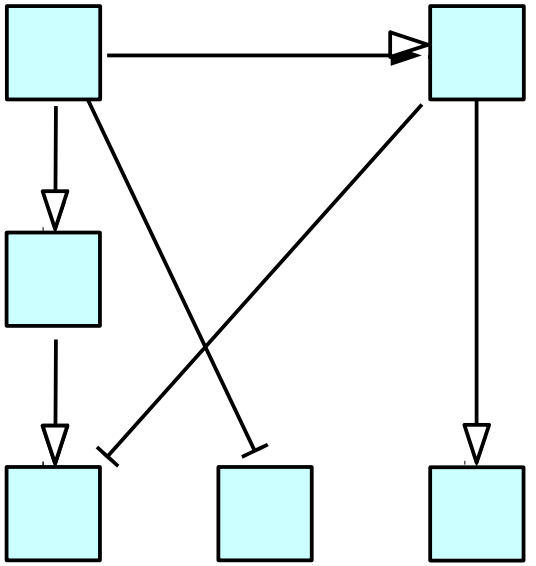
- Directional
- Non-sequential
- Mechanistic
- Rule-based modelling
- Molecular Biology
- “Open world”
- Independent rules: no explosion

Activity-Flows (influence diagrams)

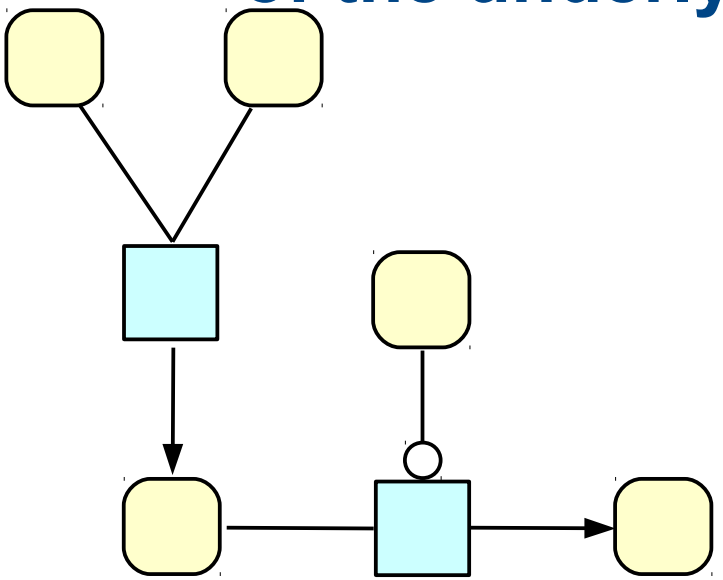


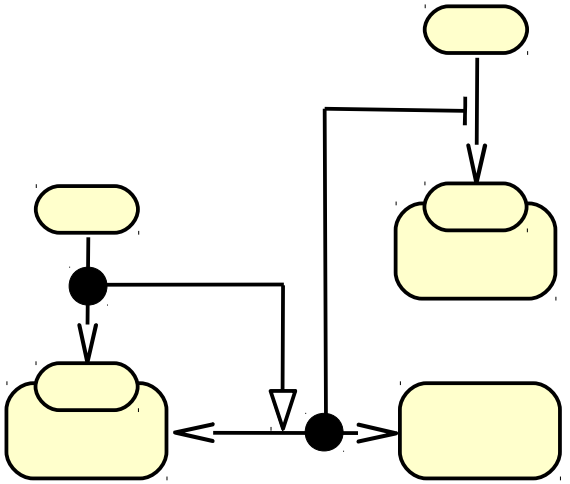
- Directional
- Sequential
- Non-mechanistic
- Logical modelling
- Signalling pathways, gene regulatory networks

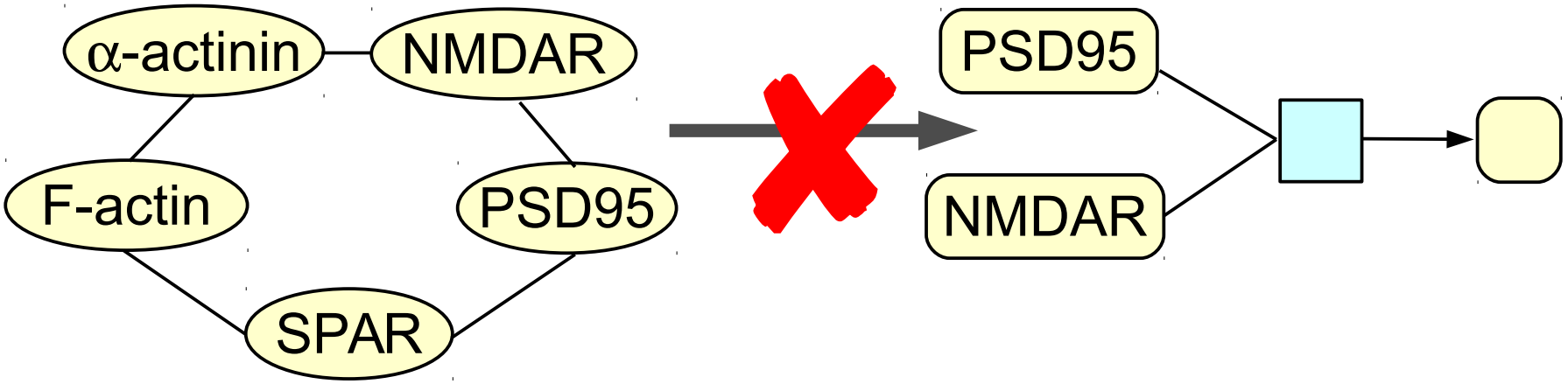




The four views are orthogonal projections of the underlying biological phenomena



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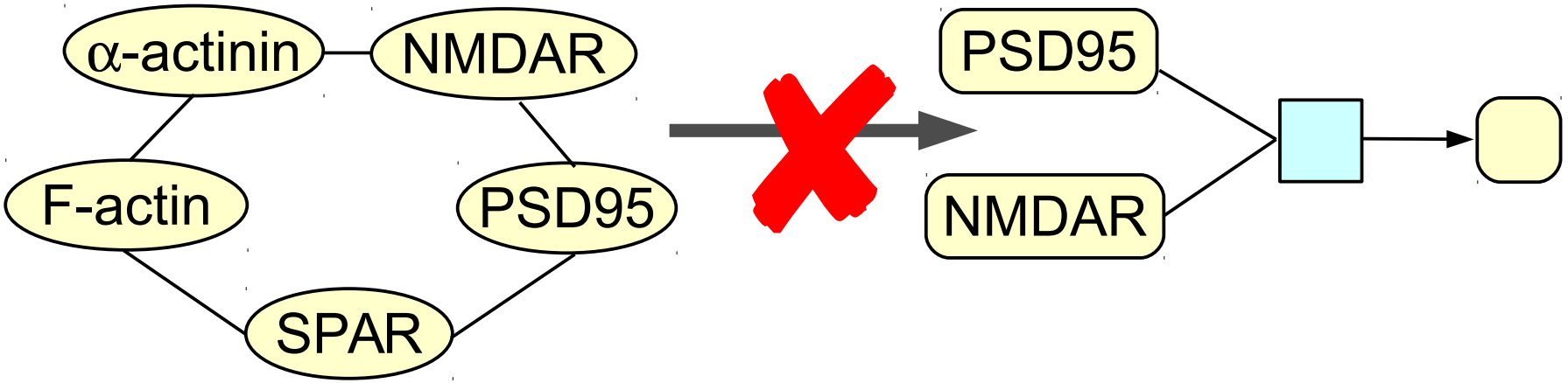
NMDAR
F-actin
PSD95
SPAR
PSD95
NMDAR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NMDAR
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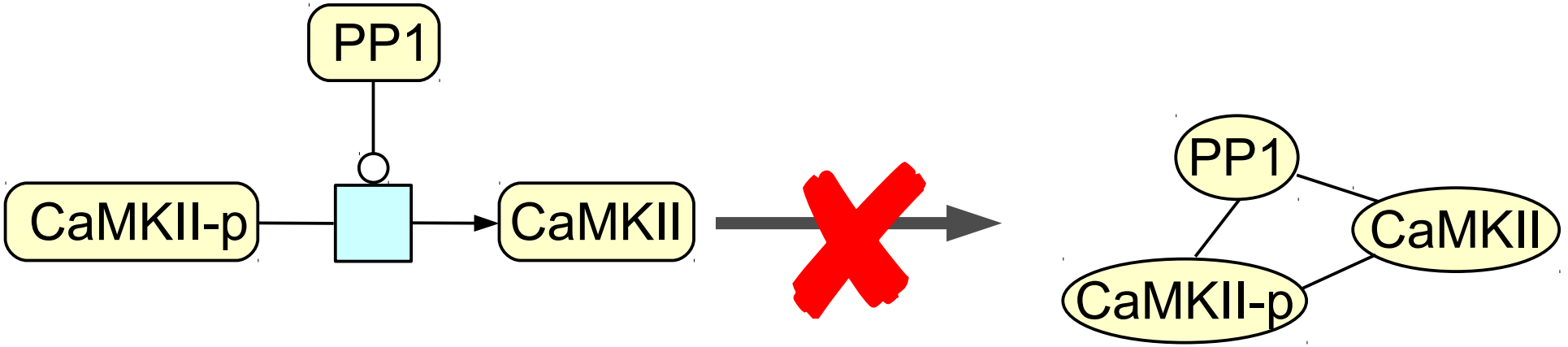

PP1
CaMKII-p
CaMKII
PP1
CaMKII
CaMKII-p

Open world

Anything not explicitly stated is unknown

Failure to observe does not imply inexistence

New pieces of knowledge do not affect prior pieces

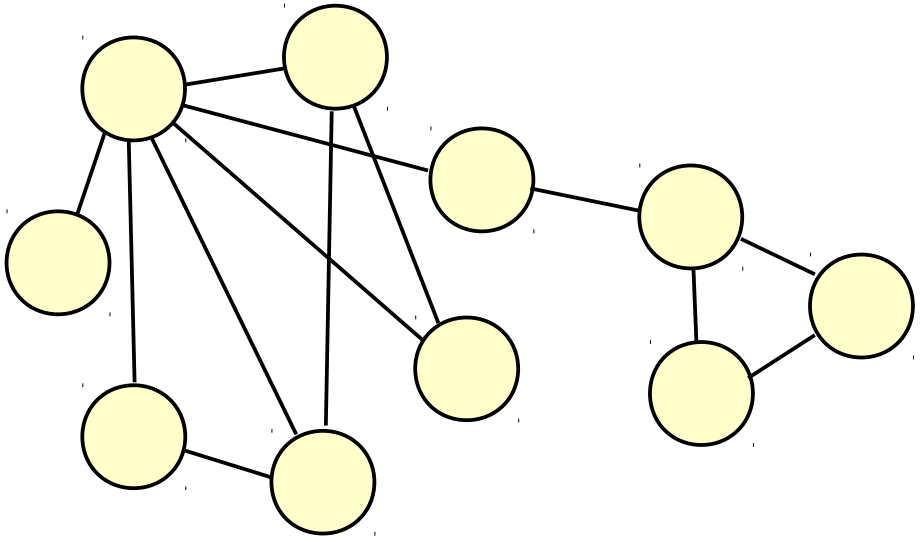
Closed world

Anything not explicitly stated does not exist

Failure to observe implies inexistence

New pieces of knowledge might change the meaning of prior pieces

Interaction networks



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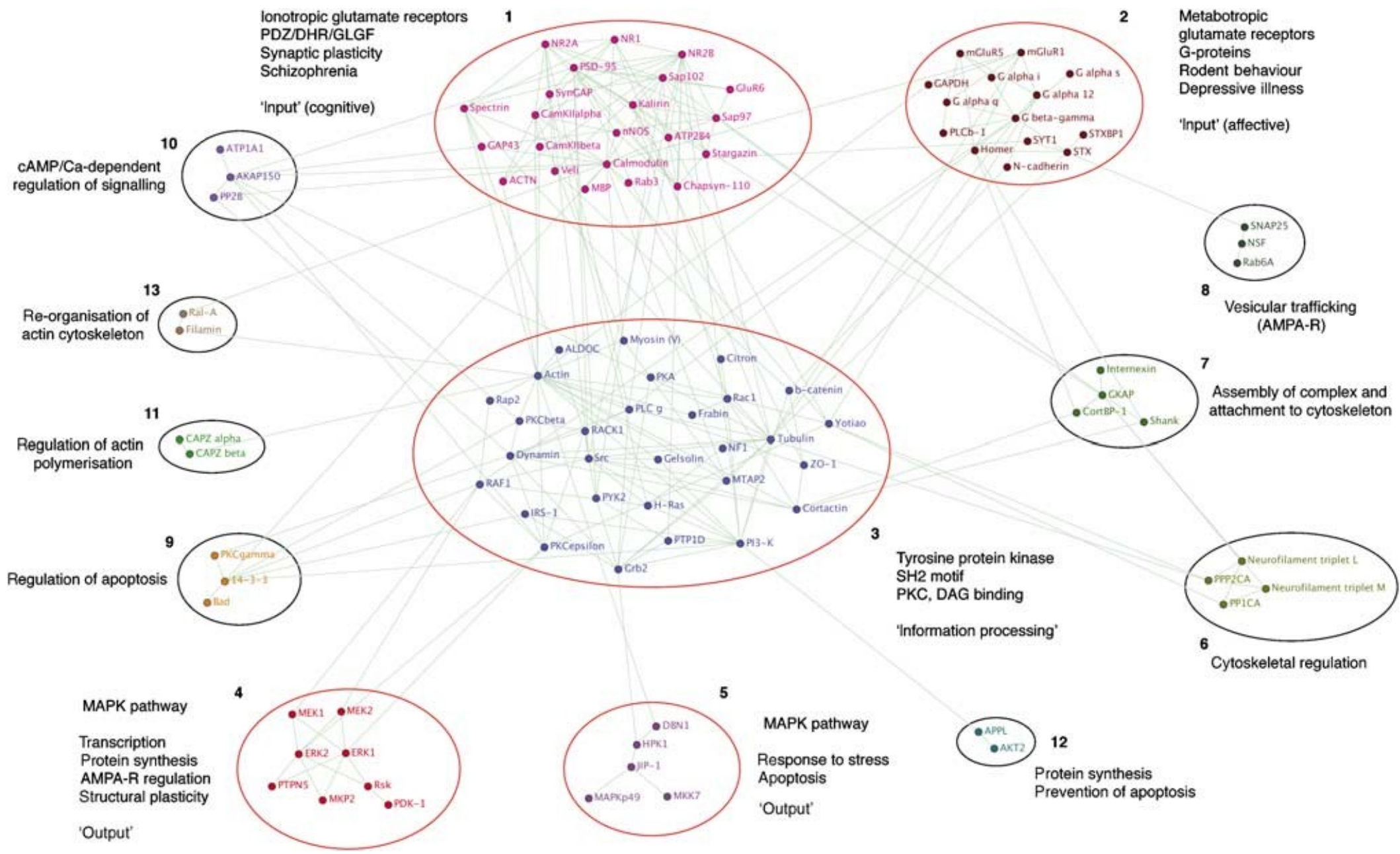

Pocklington AJ, Cumiskey M, Armstrong JD, Grant SG. Mol Syst Biol. 2006;2:2006.0023.

http://www/ebi.ac.uk/IntAct

Search: Q01097 Search Clear Show Advanced Fields » MIQL syntax reference

- Free text search will look by default for interactor identifier, species, interaction id, detection method, interaction type, publication identifier or author
- For a more specific search, use MIQL syntax or advanced search
- Search based on exact word matches eg. BRCA2 will not match BRCA2B
- Search for isoforms of 'P12345' by using 'P12345*'

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about 8 days ago IntAct release 158/159! 302465 binary interactions from 5787 manually curated publications ftp://ftp.ebi.ac.uk/pub/databases/intact/current

about 13 days ago IntAct is now available for download in PSI MITAB2.7 in addition to PSI-MI XML, MITAB2.5 and MITAB2.6.

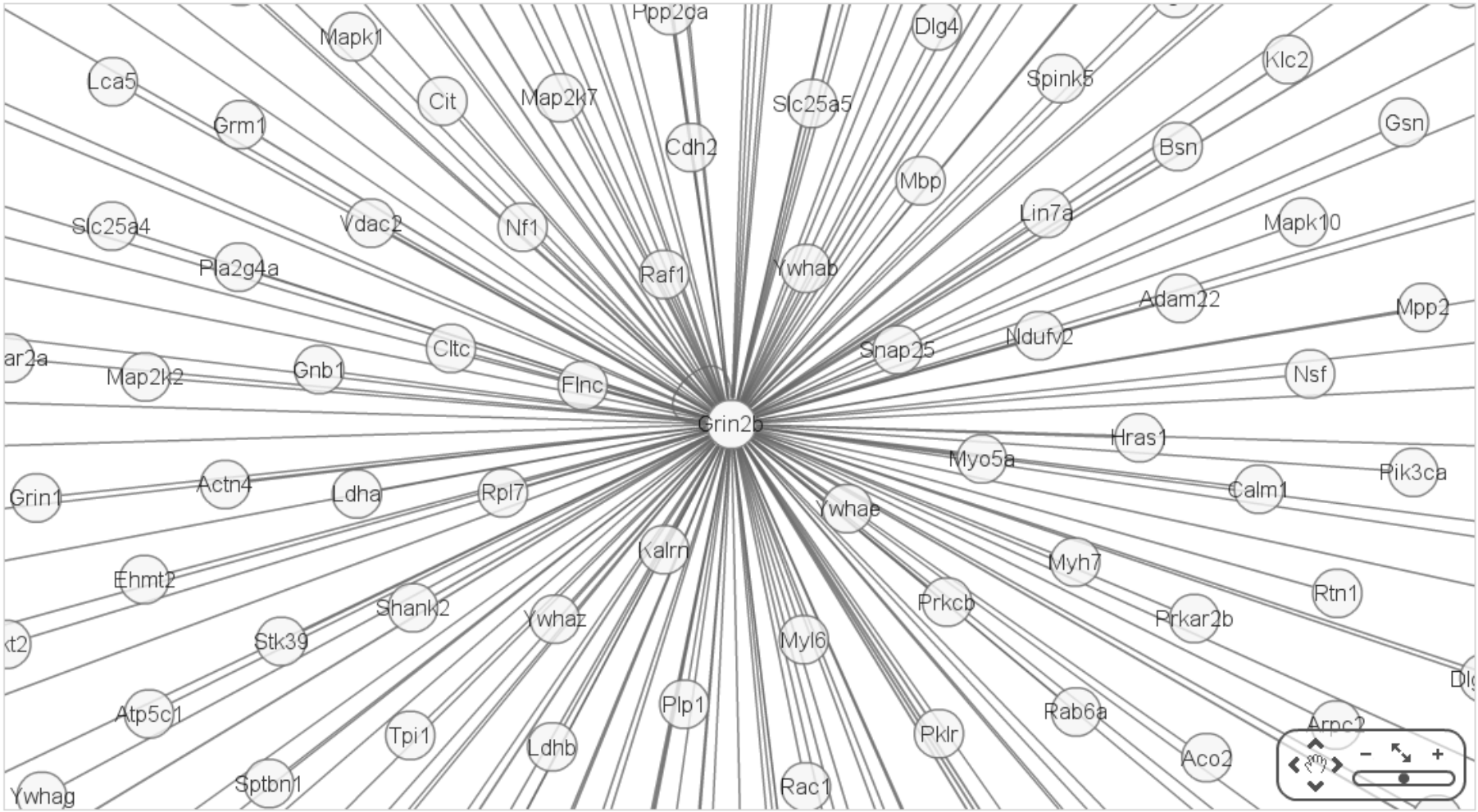
about 13 days ago Tarassov et al (PMID:18467557) low confidence interactors withdrawn in consultation with the authors

about 21 days ago Dataset of the month (November). Blandin et al. A Human Skeletal Muscle Interactome Centered on Proteins involved in Muscular Dystrophies.

about 34 days ago Now IntAct can

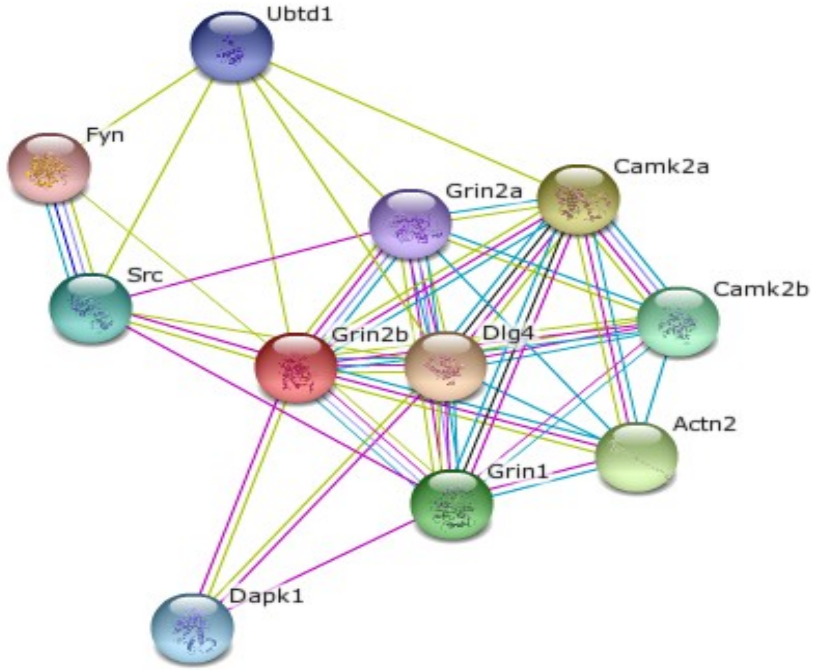
Home | Search | Interactions (254) | Browse | Lists | Interaction Details | Molecule View | Graph

Network visualisation



http://string-db.org/

Home · Download · Help/Info STRING 9.0



This is the **evidence view**. Different line colors represent the types of evidence for the association.

confidence evidence actions interactive advanced more less save

(requires Flash player 10 or better)

Your Input:

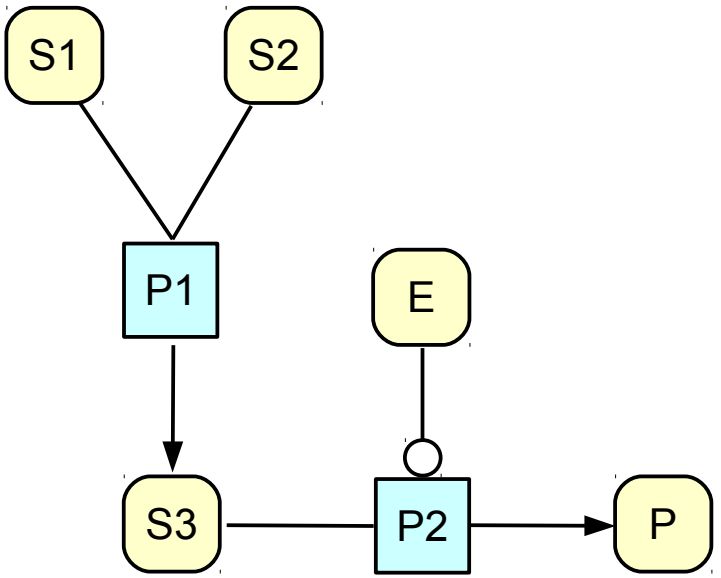
Grin2b glutamate receptor, ionotropic, NMDA2B (epsilon 2) Gene; NMDA receptor subtype of glutamate-gated ion channels with high calcium permeability and voltage-dependent sensitivity to magnesium. Mediated by glycine (1482 aa)
(Mus musculus)

Predicted Functional Partners:

Neighborhood Gene Fusion Cooccurrence Coexpression Experiments Databases Textmining [Homology] Score

Babraham Institute

Process Descriptions



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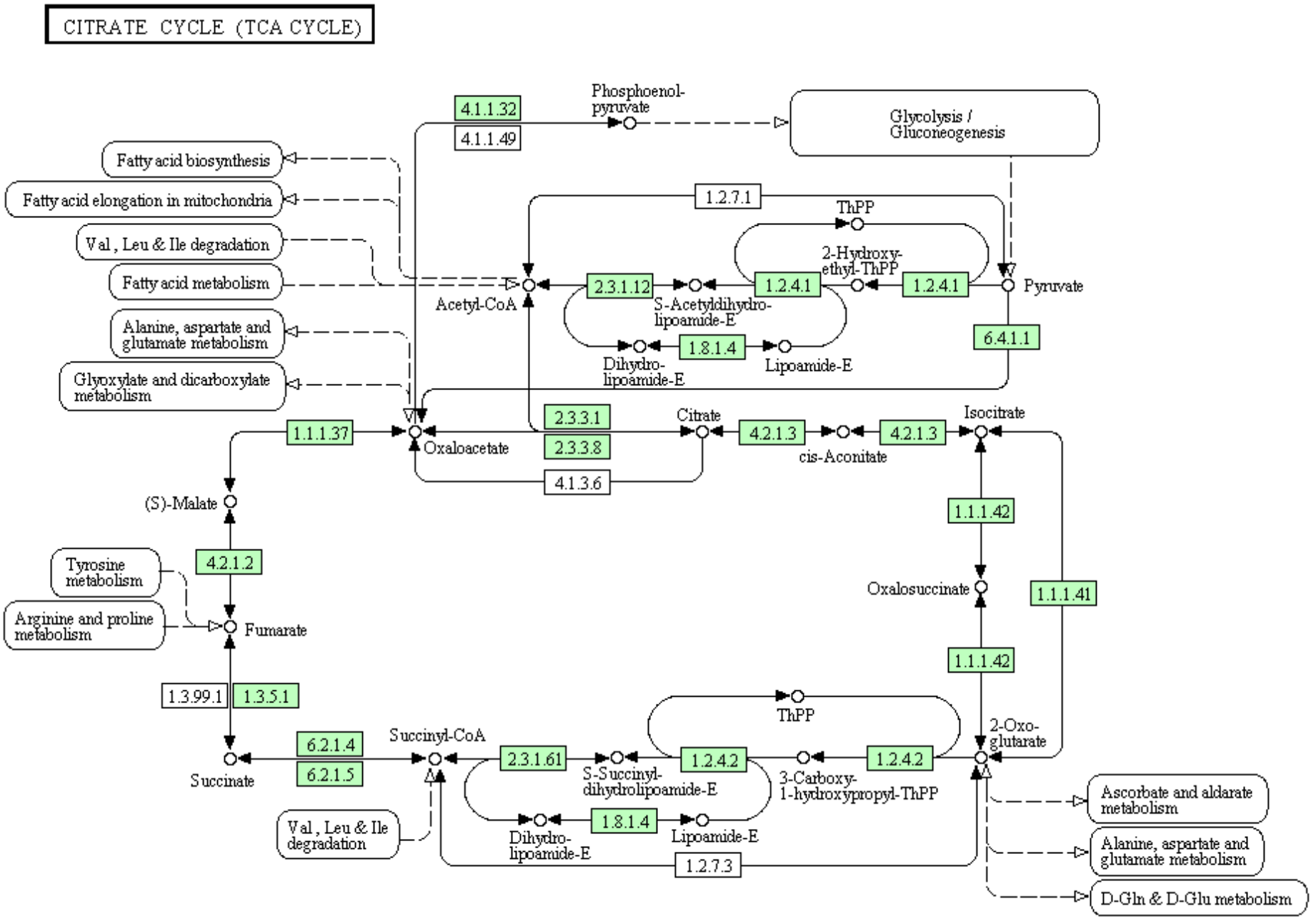
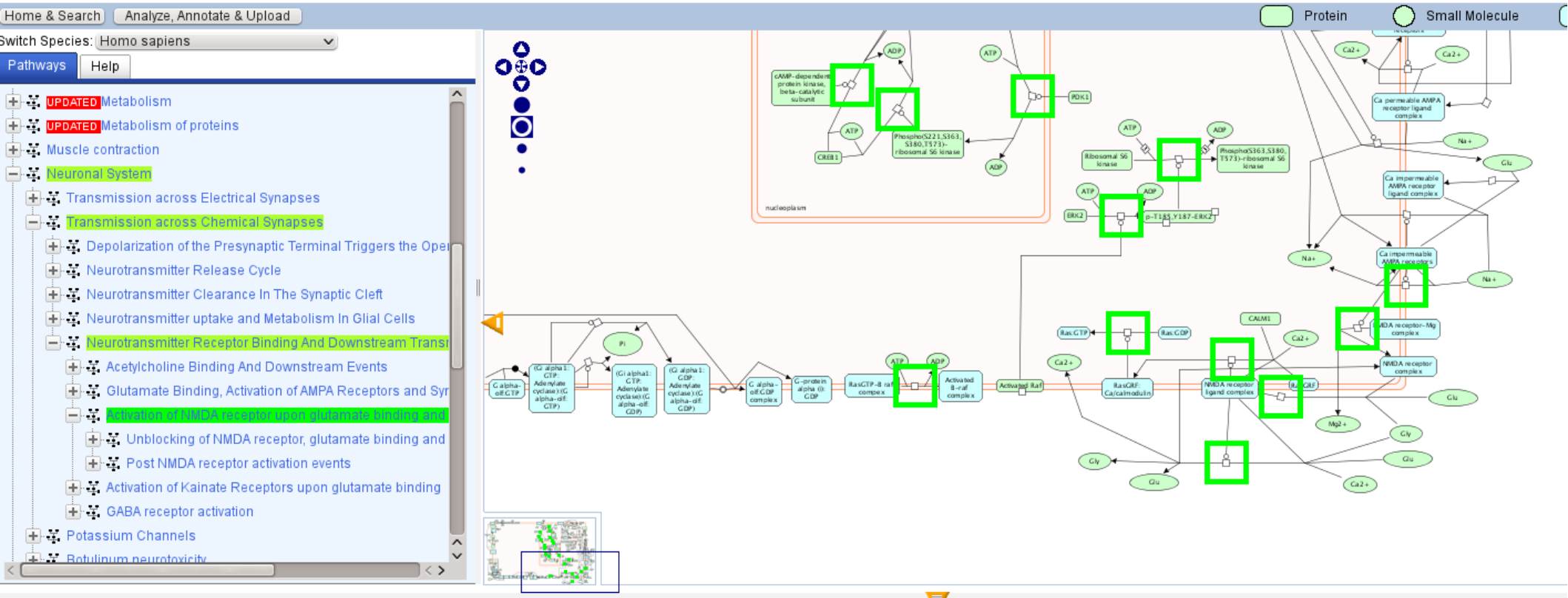
http://www.genome.jp/kegg/pathway.html



http://www.reactome.org



Activation of NMDA receptor upon glutamate binding and postsynaptic events

Stable identifier	REACT_20563.2
Authored	Mahajan, SS, 2009-10-29
Reviewed	Tukey, D, 2009-11-17

NMDA receptors are a subtype of ionotropic glutamate receptors that are specifically activated by a glutamate agonist N-methyl-D-aspartate (NMDA). Activation of NMDA receptor involves opening of the ion channel that allows the influx of Ca2+. NMDA receptors synaptic strength and are predominantly involved in the synaptic plasticity that pertain to learning and memory. A unique feature of NMDA receptor unlike other glutamate receptors is the requirement of dual activation of the NMDA receptor, which require bo activation. At resting membrane potential the NMDA receptors are blocked by Mg2+. The voltage dependent Mg2+ block is relieved upon depolarization of the post-synpatic membrane . The ligand dependent activation of the NMDA receptor requires co-activ glycine. NMDA receptors are coincidence detector, and are activated only if there is simultaneous activation of both pre and post-synaptic cell. Upon activation NMDA receptors allow the influx of Ca2+ that initiates various molecular signaling cascades that memory.

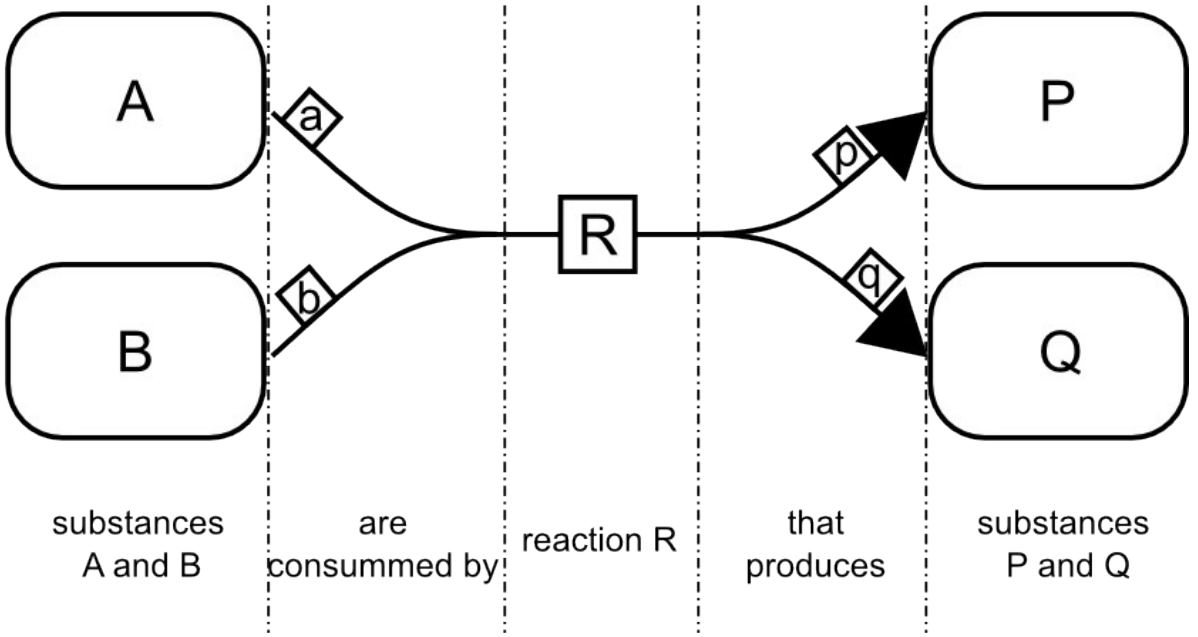
Organism	Homo sapiens
Cellular compartment	extracellular region GO plasma membrane GO cytoplasm GO nucleoplasm GO

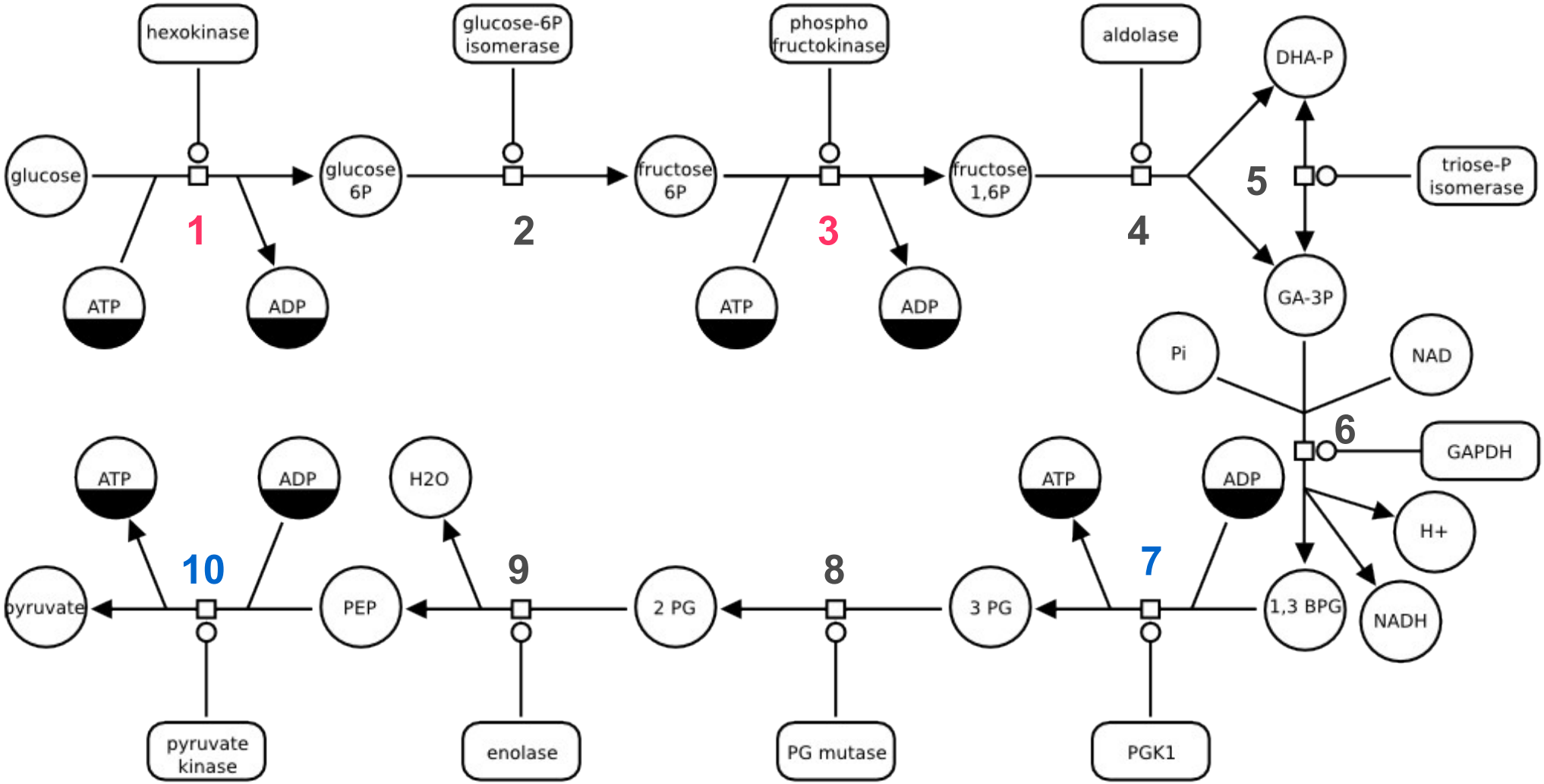
References

Cohen, S, Greenberg, ME *Communication between the synapse and the nucleus in neuronal development, plasticity, and disease* 2008 Annu Rev Cell Dev Biol PubMed

	Activation of NMDA receptor upon glutamate binding and postsynaptic events [Dictyostelium discoideum] Activation of NMDA receptor upon glutamate binding and postsynaptic events [Schizosaccharomyces pombe] Activation of NMDA receptor upon glutamate binding and postsynaptic events [Saccharomyces cerevisiae] Activation of NMDA receptor upon glutamate binding and postsynaptic events [Caenorhabditis elegans]

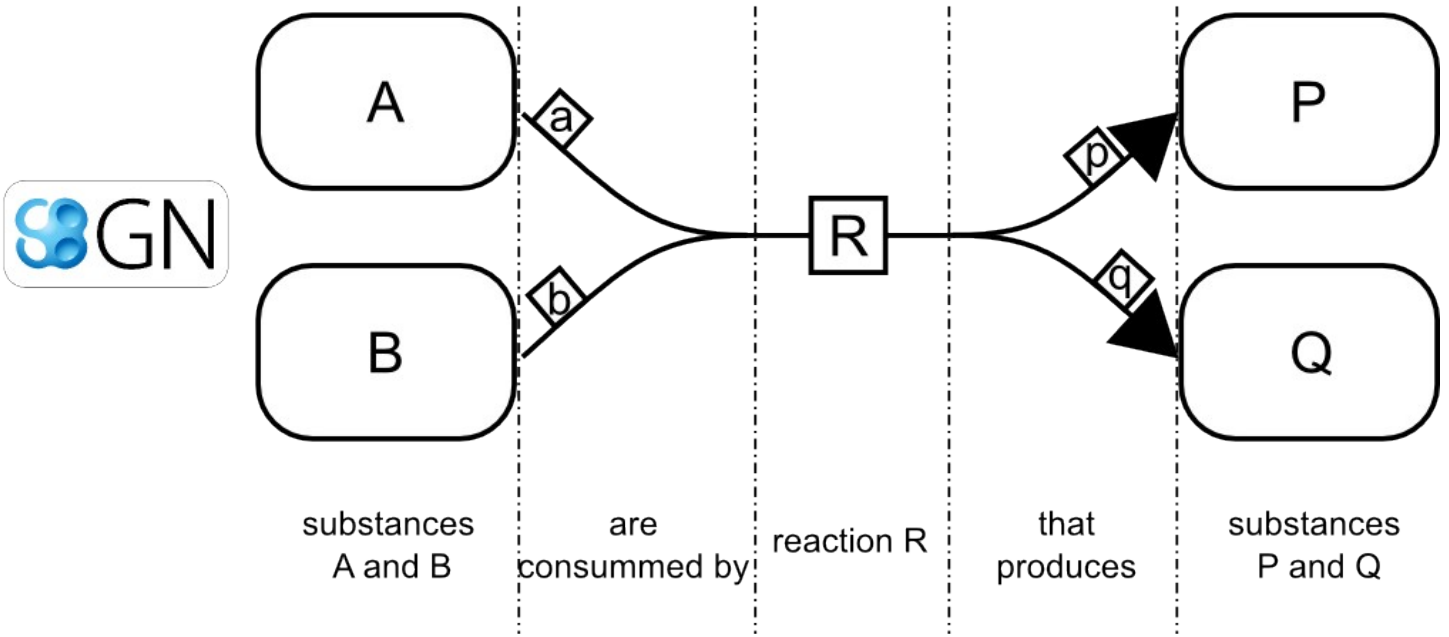
A biochemical reaction is a process





ATP is consumed by processes 1 and 3, and produced by processes 7 and 10

A biochemical reaction is a process



The Systems Biology Graphical Notation

http://sbgn.org/

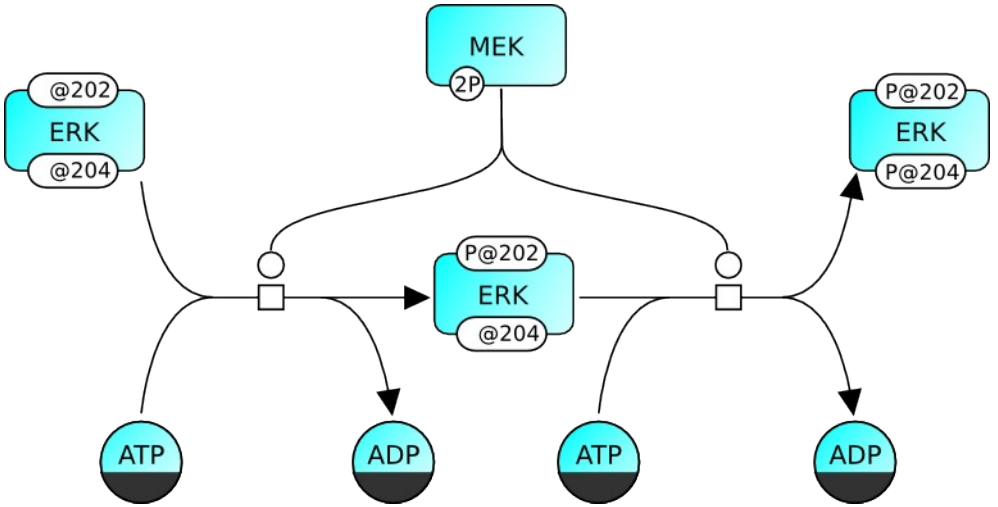
Unambiguous consensual visual notation

- An unambiguous way of graphically describing and interpreting biochemical and cellular events
- Limited amount of symbols
  Re-use existing symbols

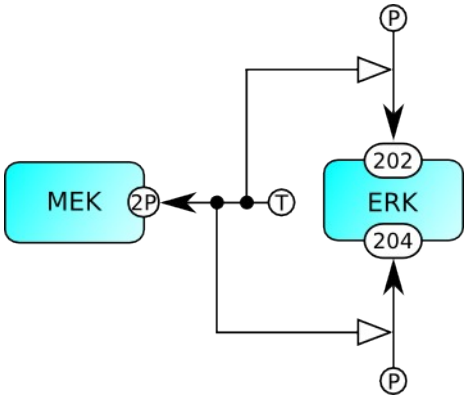
  ☞ Smooth learning curve
- Can represent logical or mechanistic models, biochemical pathways, at different levels of granularity
- Detailed technical specification, precise data-models, standard API and growing software support
- Developed over four years by a diverse community, including biologists, modellers, computer scientists etc.

Graph trinity: three languages in one notation

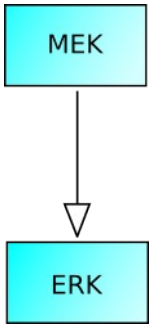
Process Descriptions



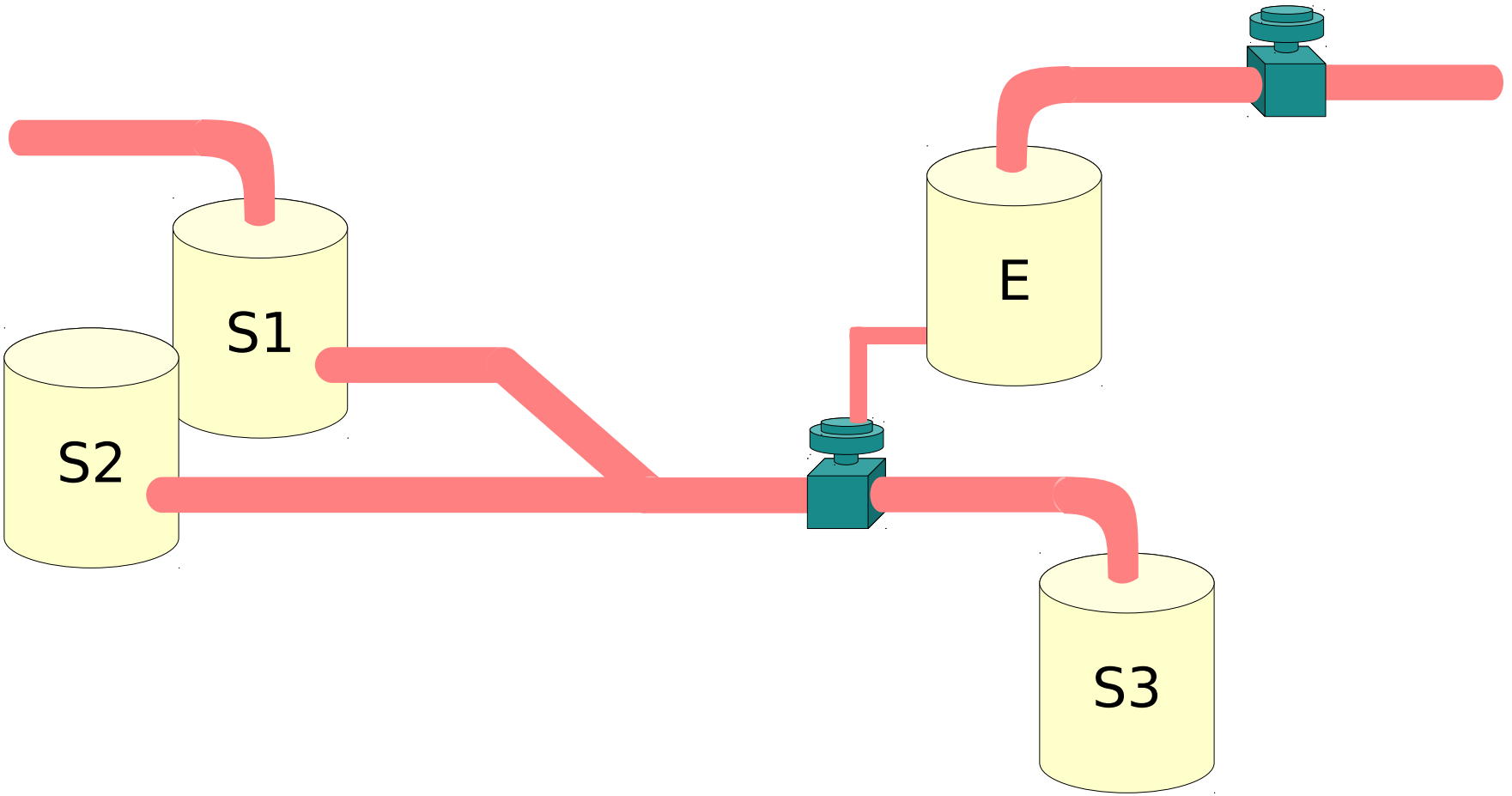
Entity Relationships



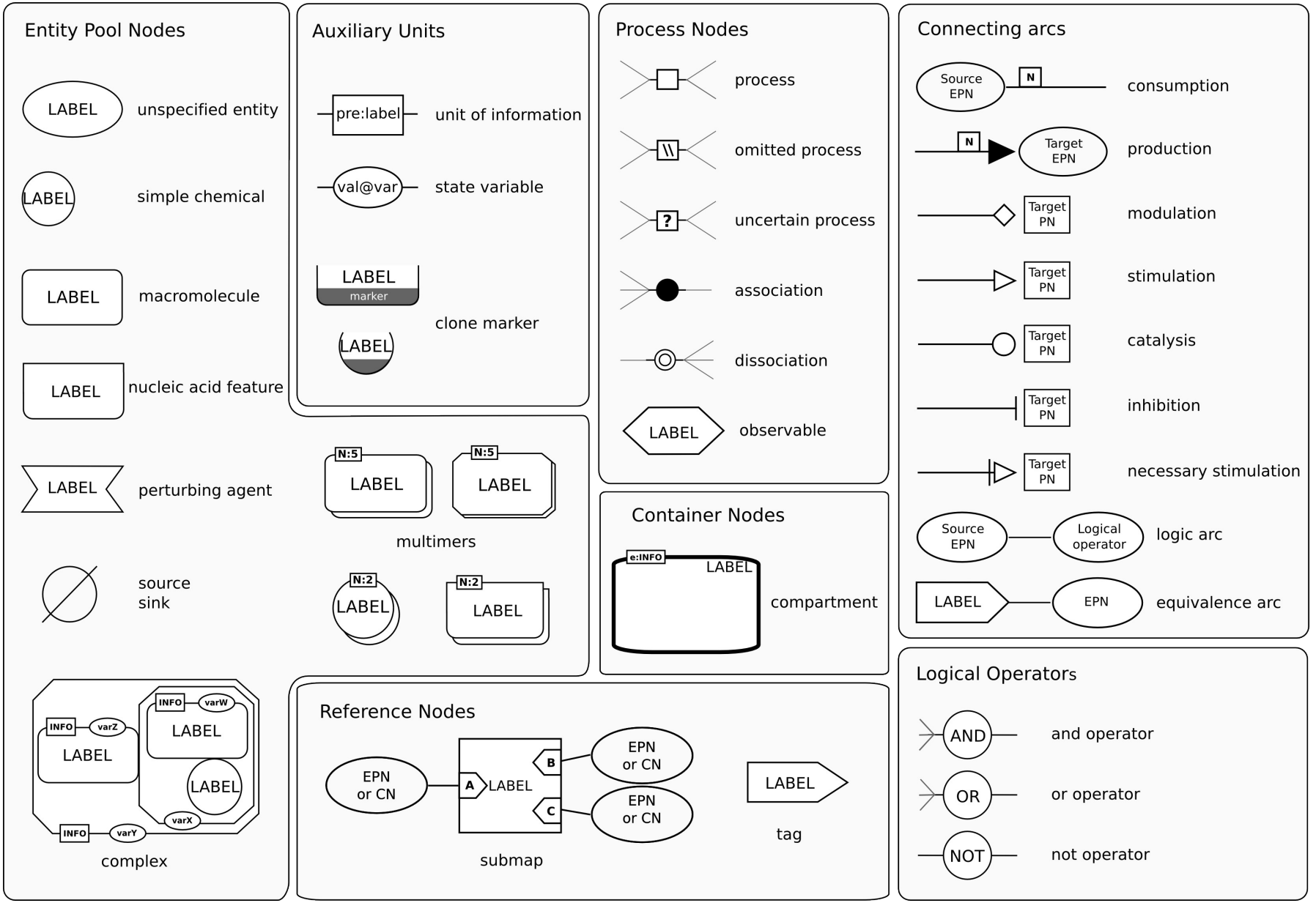
Activity Flows



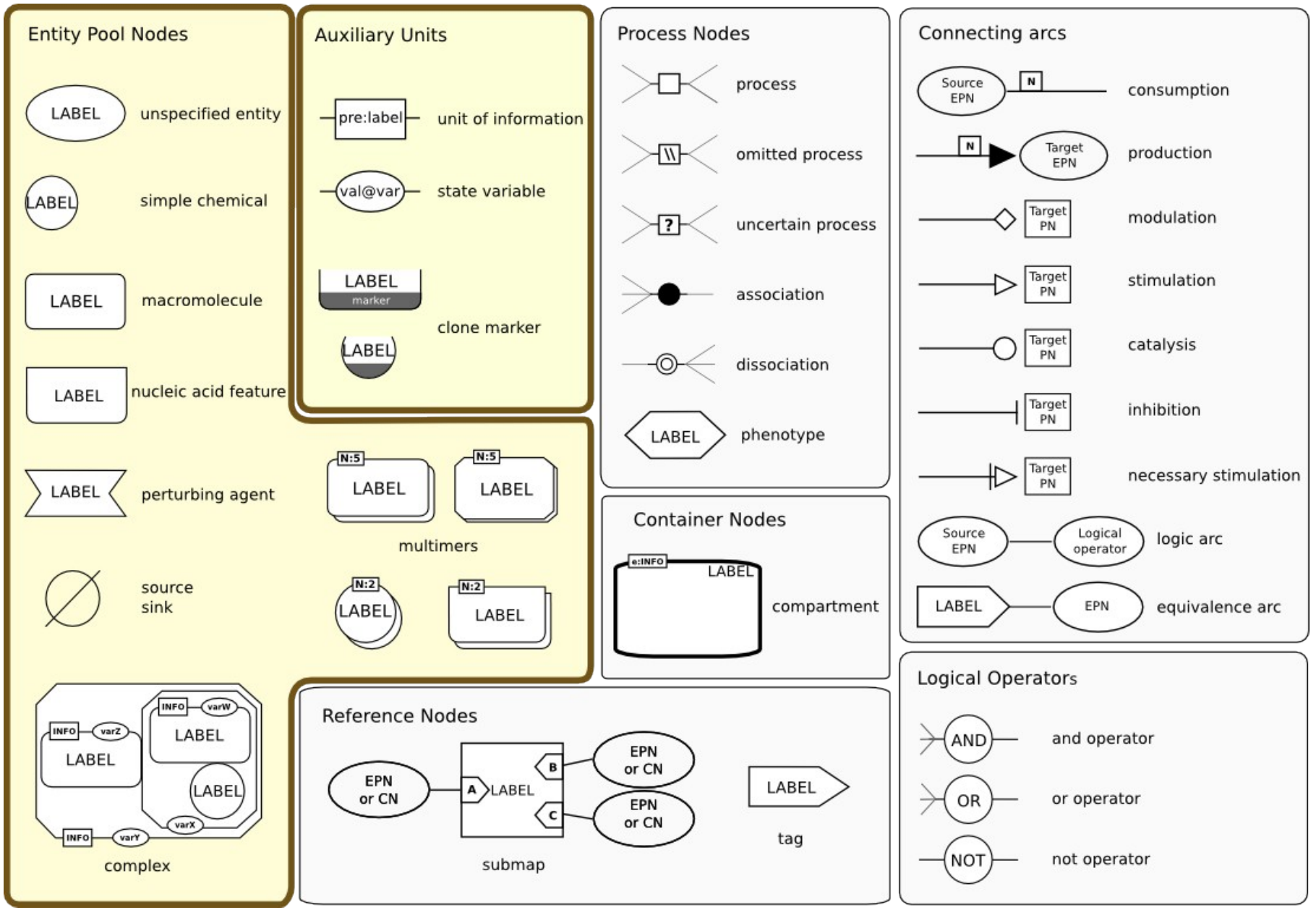
Process Descriptions can be viewed as pipelines



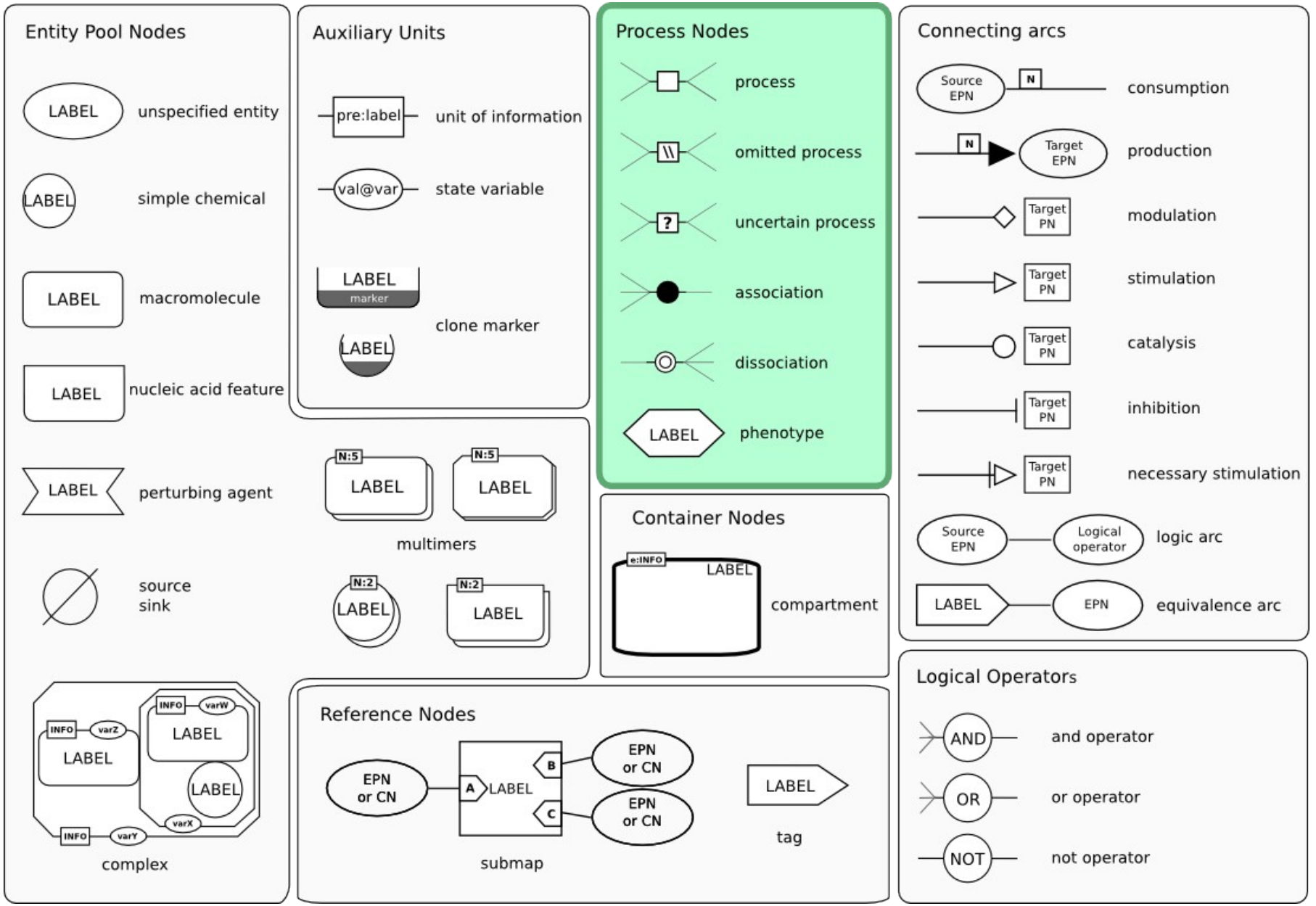
SBGN Process Diagram L1 reference card



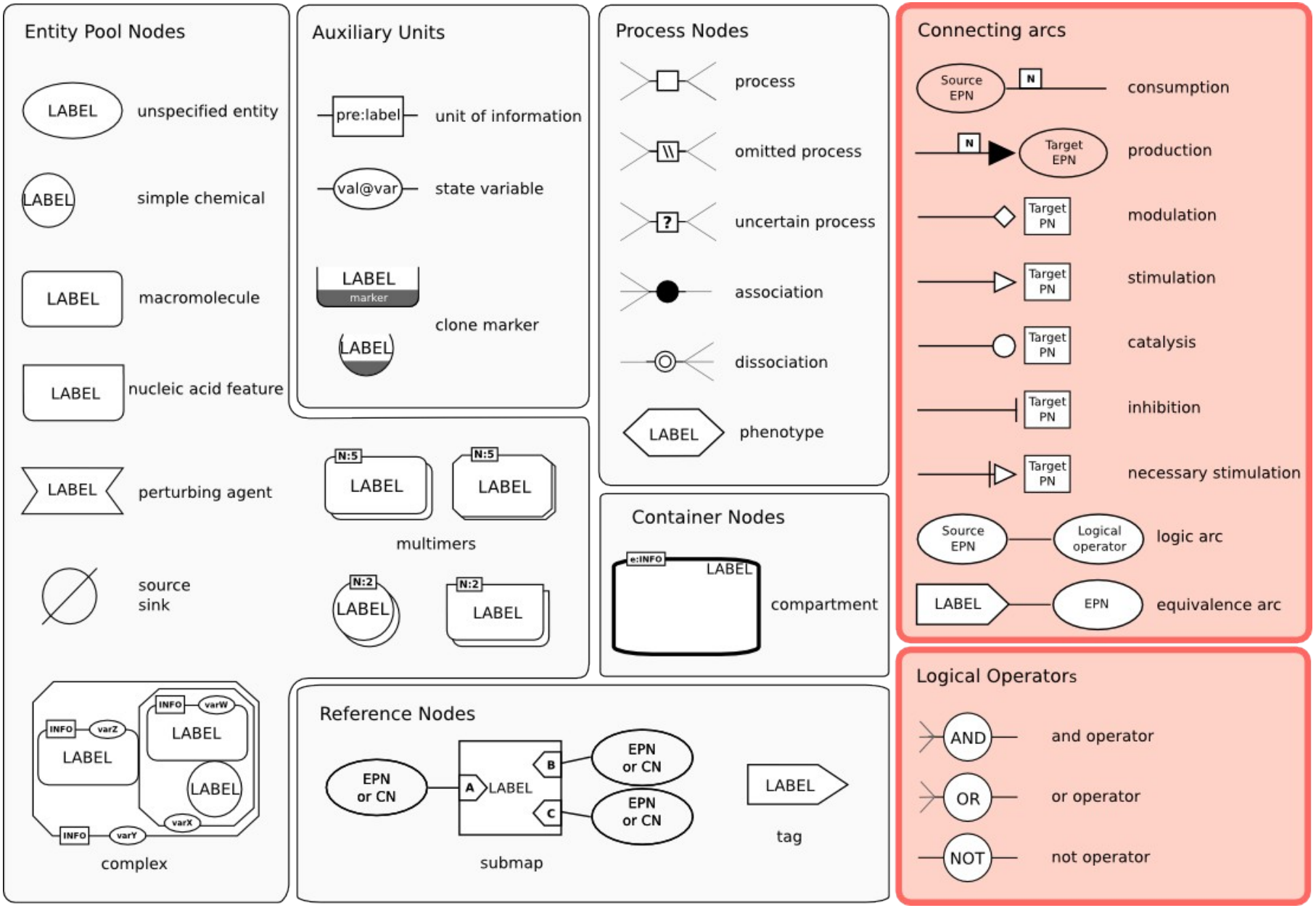
Entity Pool Nodes



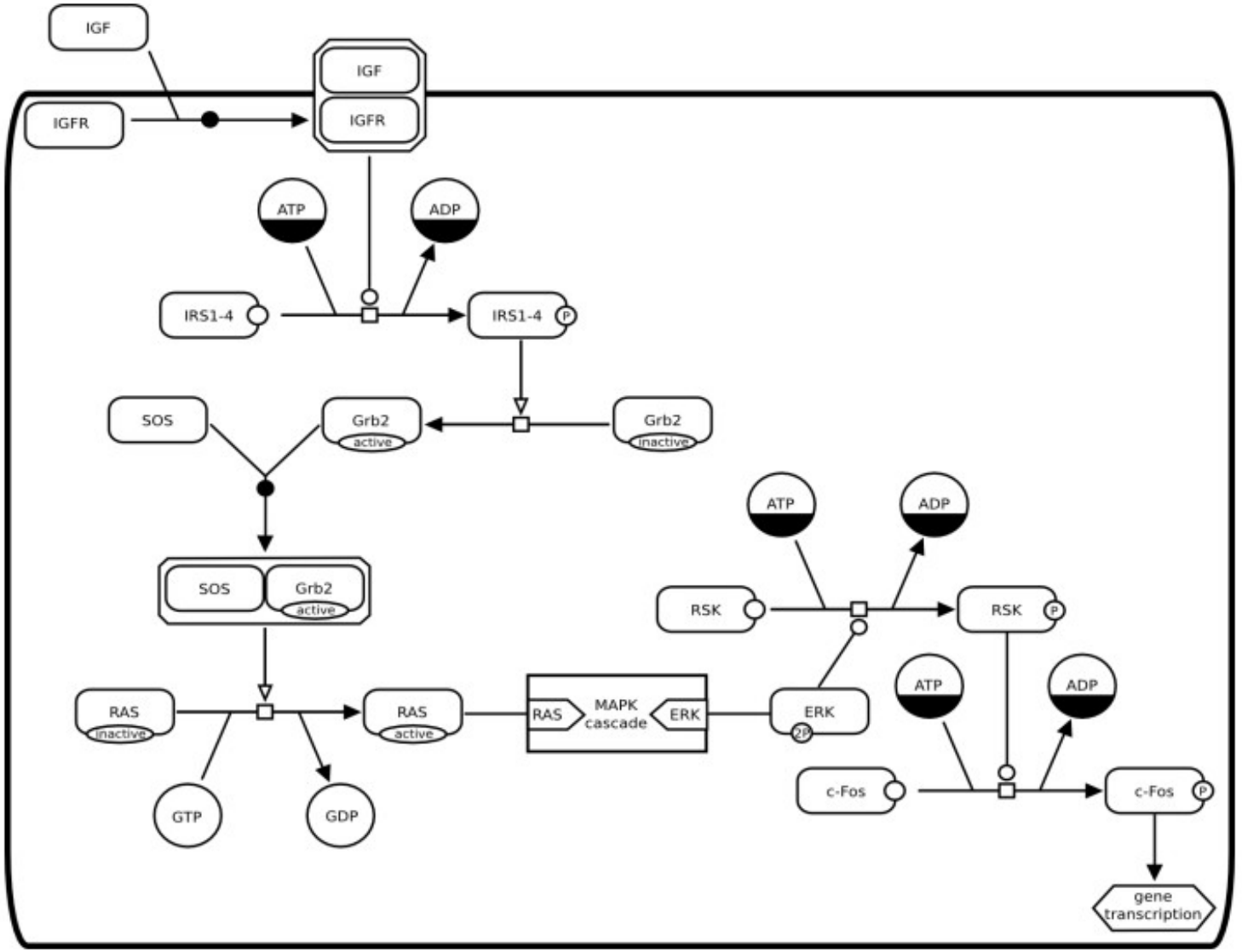
Process Nodes



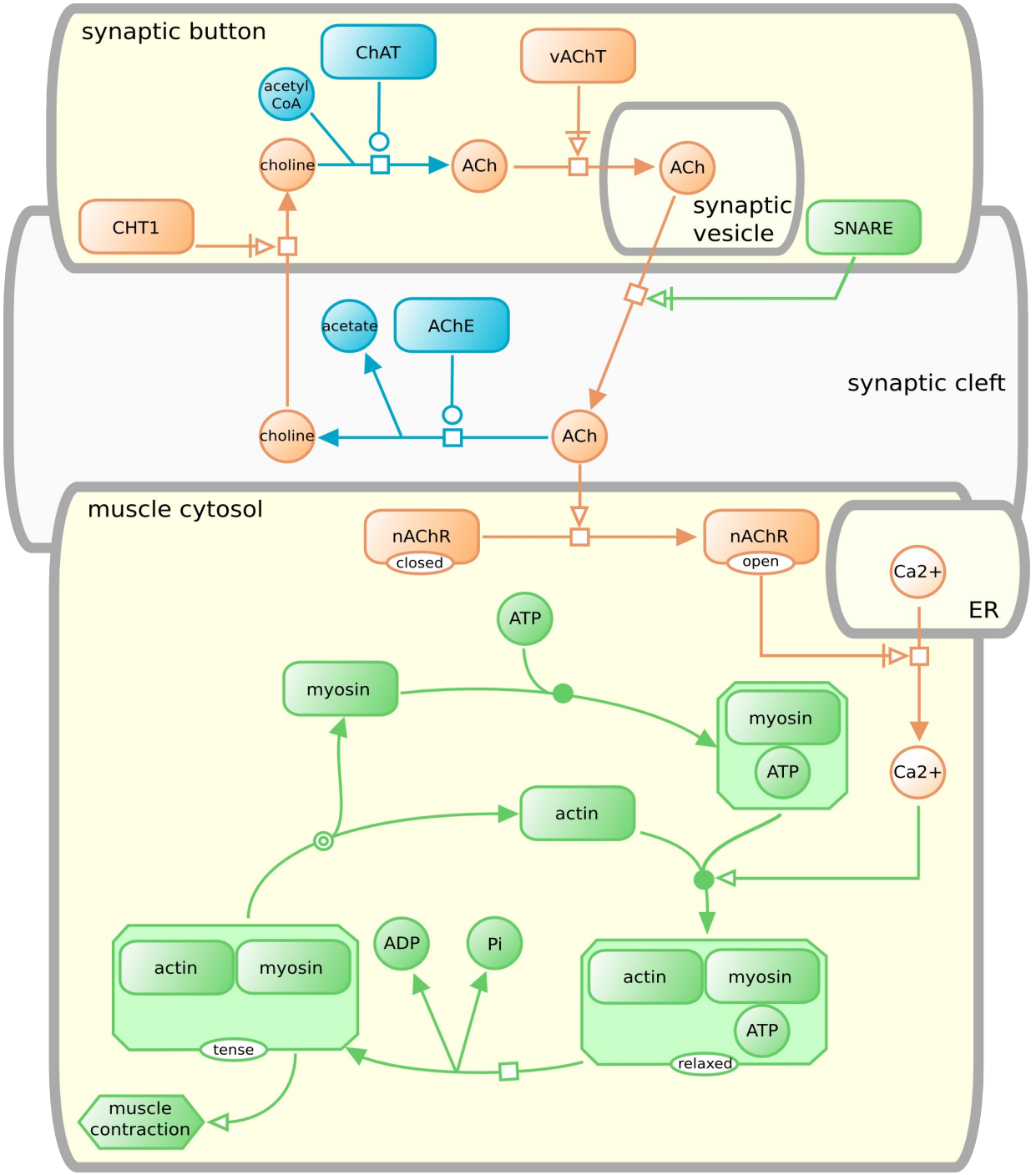
Connecting arcs

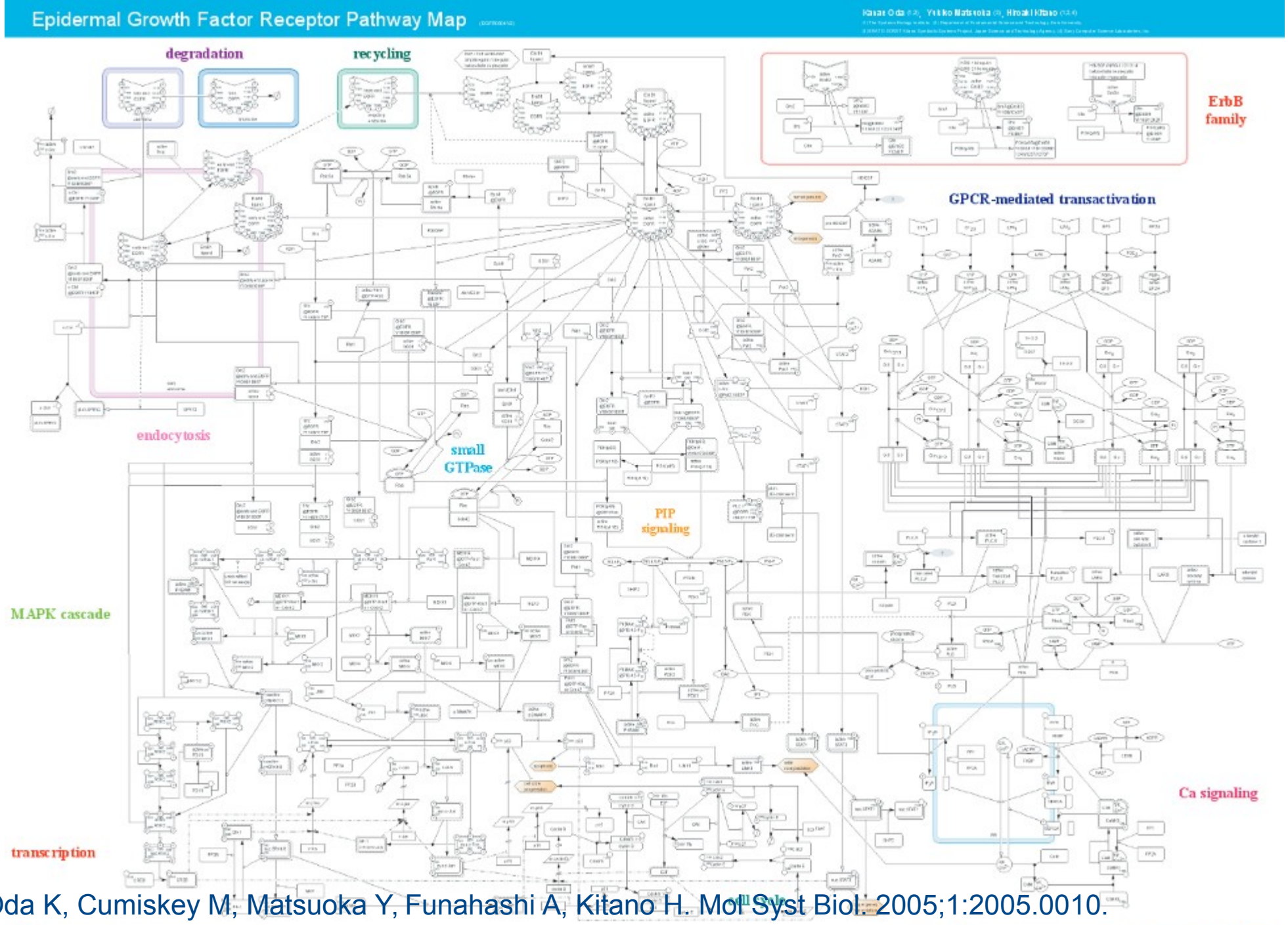


Signalling


IGF
IGFR
IGF
IGFR
ATP
ADP
IRS1-4
IRS1-4
P
SOS
Grb2
active
Grb2
inactive
SOS
Grb2
active
ATP
ADP
RSK
RSK
P
RAS
inactive
RAS
active
RAS
MAPK
cascade
ERK
ERK
2P
ATP
ADP
GTP
GDP
c-Fos
c-Fos
P
gene
transcription

Multicellular



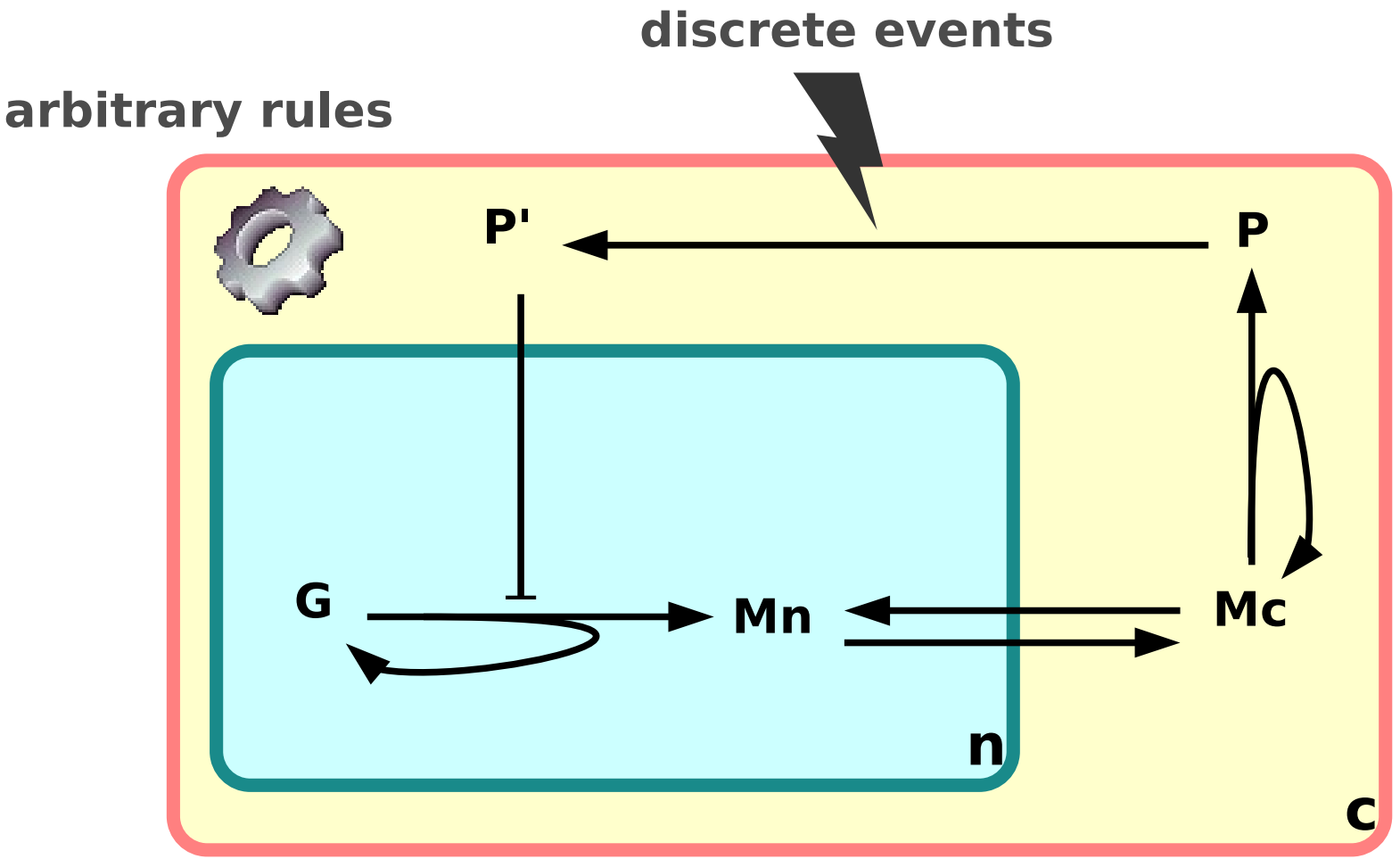


Oda K, Cumiskey M, Matsuoka Y, Funahashi A, Kitano H. Mol Syst Biol. 2005;1:2005.0010.

The Systems Biology Markup Language

http://sbml.org/

Systems Biology Markup Language



Systems Biology Markup Language

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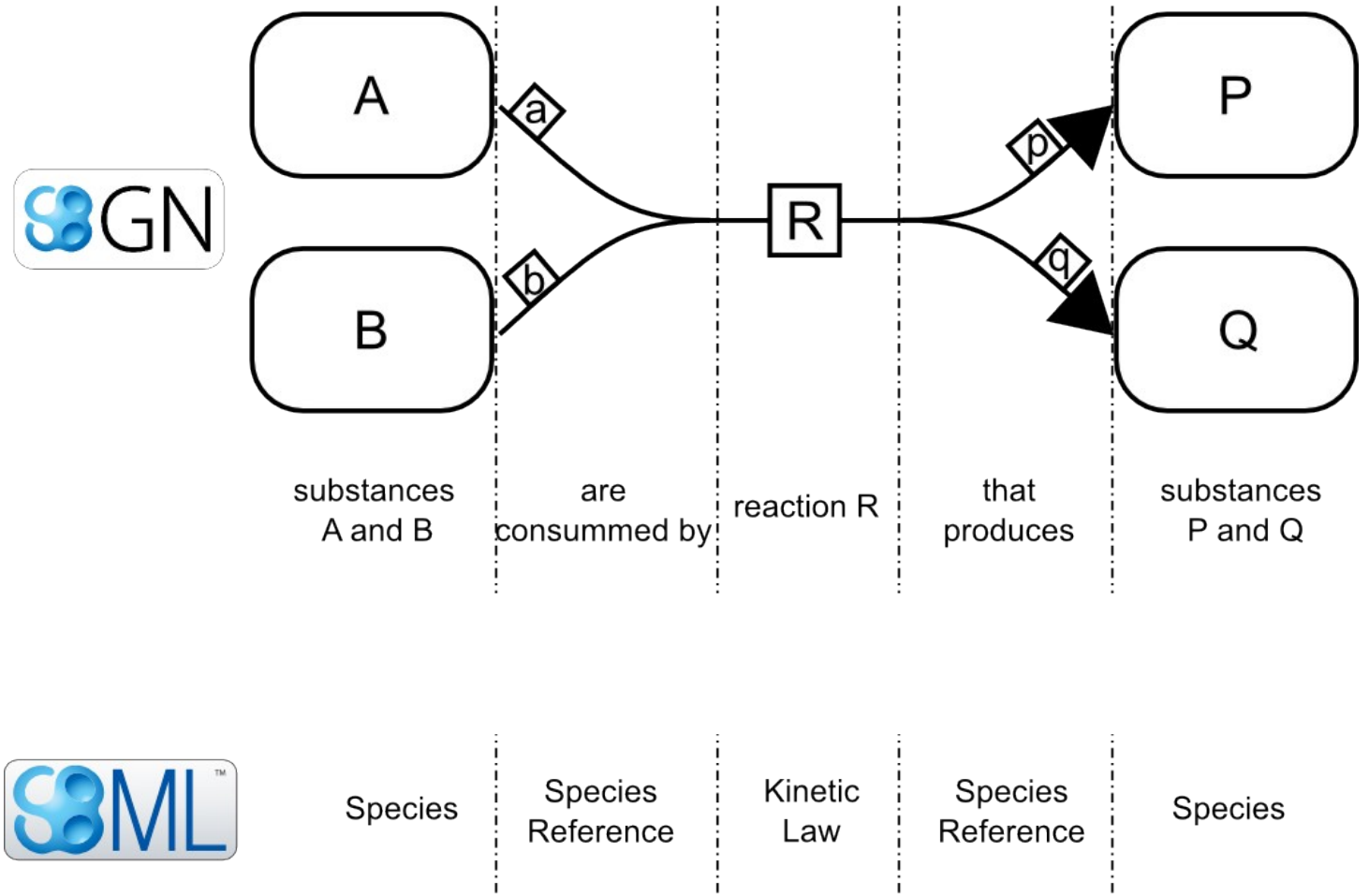
      xmlns="http://www.sbml.org/sbml/level3/version1/core">
  <model>
    <listOfFunctionDefinitions> <!-- --> </listOfFunctionDefinitions>
    <listOfUnitDefinitions> <!-- --> </listOfUnitDefinitions>
    <listOfCompartments> <!-- --> </listOfCompartments>
    <listOfSpecies> <!-- --> </listOfSpecies>
    <listOfParameters> <!-- --> </listOfParameters>
    <listOfInitialAssignments> <!-- --> </listOfInitialAssignments>
    <listOfRules> <!-- --> </listOfRules>
    <listOfConstraints> <!-- --> </listOfConstraints>
    <listOfReactions> <!-- --> </listOfReactions>
    <listOfEvents> <!-- --> </listOfEvents>
  </model>
</sbml>
```

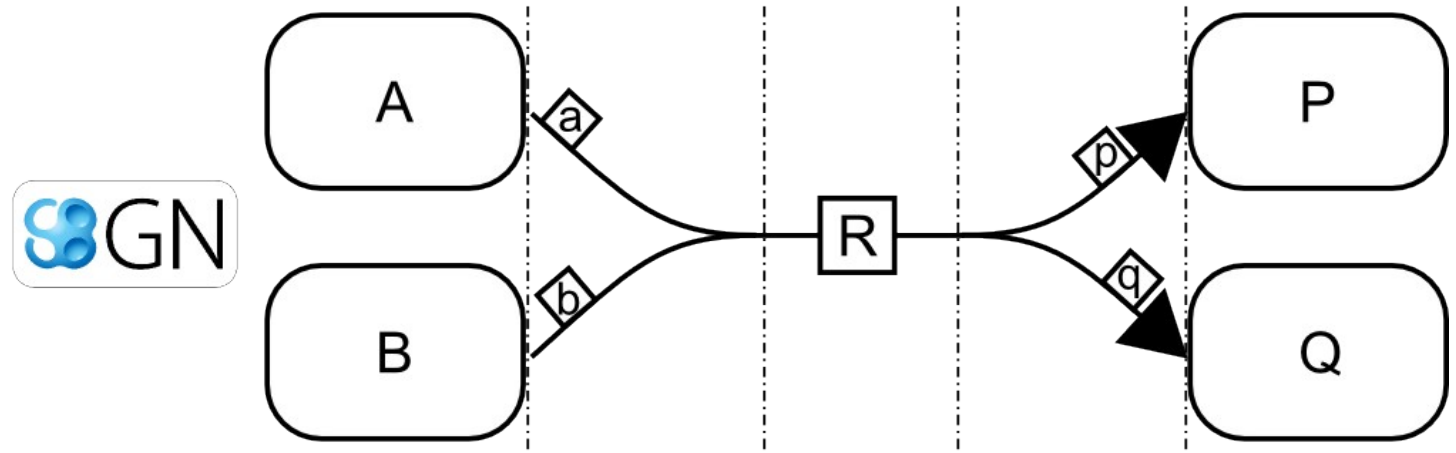
variables

relationships

A biochemical reaction is a process



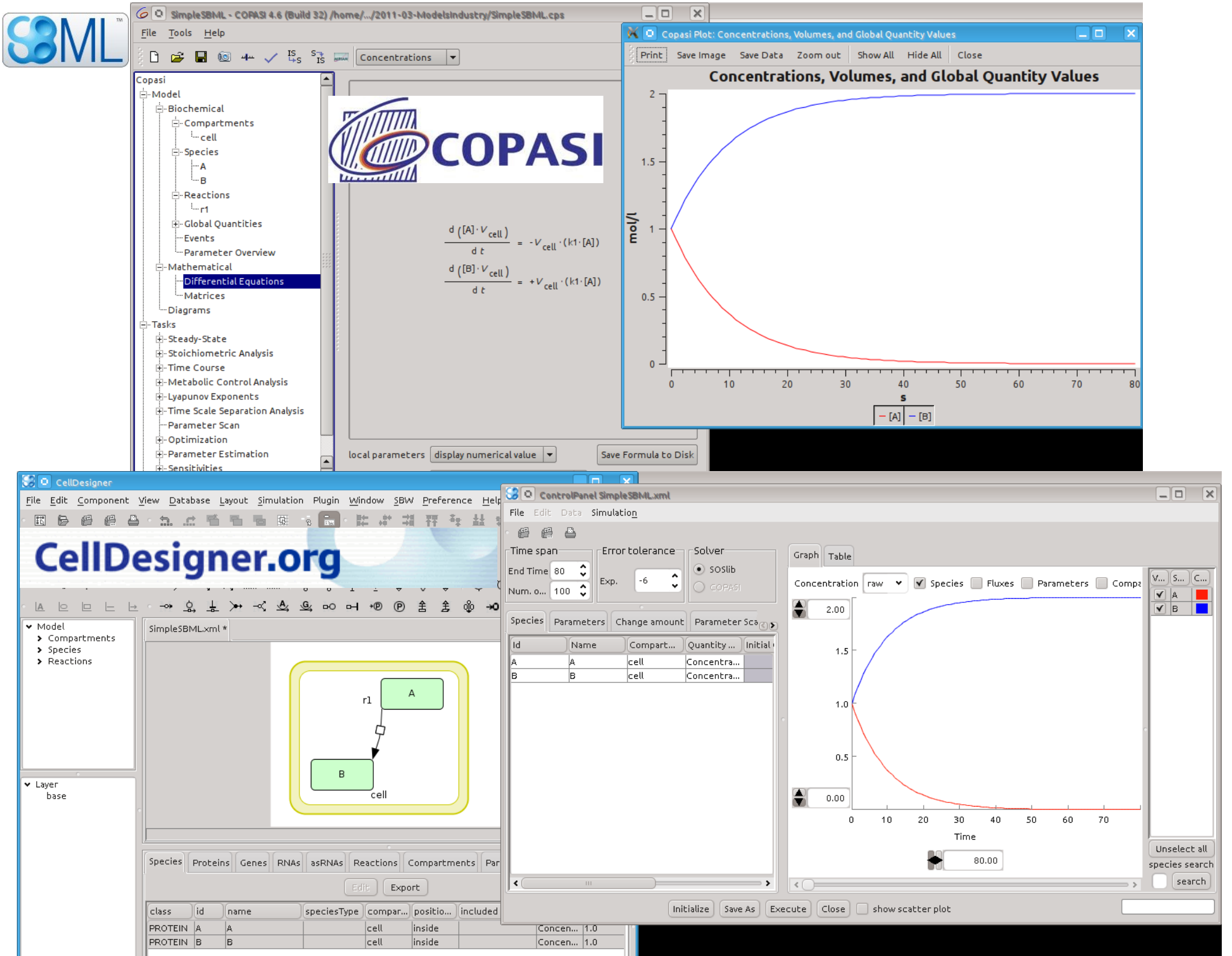
A biochemical reaction is a process



	substances A and B	are consummed by	reaction R	that produces	substances P and Q
	SBO:0000240 material entity	SBO:0000394 consumption	SBO:0000375 process	SBO:0000393 production	SBO:0000240 material entity
SBML	Species	Species Reference	Kinetic Law	Species Reference	Species

```xml
<?xml version="1.0" encoding="UTF-8"?>
<sbml xmlns="http://www.sbml.org/sbml/level2/version4" level="2" version="4">
  <model name="Simple Model">
    <listOfCompartments>
      <compartment id="cell" size="1" />
    </listOfCompartments>
    <listOfSpecies>
      <species id="A" compartment="cell" initialConcentration="1"/>
      <species id="B" compartment="cell" initialConcentration="1"/>
    </listOfSpecies>
    <listOfParameters>
      <parameter id="k1" value="0.1"/>
    </listOfParameters>
    <listOfReactions>
      <reaction id="r1" reversible="false">
      <listOfReactants>
          <speciesReference species="A"/>
        </listOfReactants>
        <listOfProducts>
          <speciesReference species="B"/>
        </listOfProducts>
        <kineticLaw>
          <math xmlns="http://www.w3.org/1998/Math/MathML">
            <apply>
              <times/>
              <ci> cell </ci>
              <ci> k1 </ci>
              <ci> A </ci>
            </apply>
          </math>
        </kineticLaw>
      </reaction>
    </listOfReactions>
  </model>
</sbml>
```

A very simple SBML file (A ⟶ B)


SBML
SimpleSBML - COPASI 4.6 (Build 32) /home/.../2011-03-ModelsIndustry/SimpleSBML.cps
File Tools Help
Concentrations
Copasi
Model
Biochemical
Compartments
cell
Species
A
B
Reactions
r1
Global Quantities
Events
Parameter Overview
Mathematical
Differential Equations
Matrices
Diagrams
Tasks
Steady-State
Stoichiometric Analysis
Time Course
Metabolic Control Analysis
Lyapunov Exponents
Time Scale Separation Analysis
Parameter Scan
Optimization
Parameter Estimation
Sensitivities
COPASI
d([A]·V_cell)/dt = -V_cell·(k1·[A])
d([B]·V_cell)/dt = +V_cell·(k1·[A])
local parameters
display numerical value
Save Formula to Disk
Copasi Plot: Concentrations, Volumes, and Global Quantity Values
Print Save Image Save Data Zoom out Show All Hide All Close
Concentrations, Volumes, and Global Quantity Values
mol/l
s
[A] [B]
CellDesigner
File Edit Component View Database Layout Simulation Plugin Window SBW Preference Help
CellDesigner.org
Model
Compartments
Species
Reactions
Layer
base
SimpleSBML.xml *
r1
A
B
cell
Species Proteins Genes RNAs asRNAs Reactions Compartments
Edit Export
class id name speciesType compar... positio... included
PROTEIN A A cell inside Concen... 1.0
PROTEIN B B cell inside Concen... 1.0
ControlPanel SimpleSBML.xml
File Edit Data Simulation
Time span
End Time 80
Num. o... 100
Error tolerance
Exp. -6
Solver
SOSlib
COPASI
Species Parameters Change amount Parameter Sca
Id Name Compart... Quantity ... Initial
A A cell Concentra...
B B cell Concentra...
Graph Table
Concentration raw
Species Fluxes Parameters Compa
2.00
0.00
Time
80.00
V... S... C...
A
B
Unselect all
species search
search
Initialize Save As Execute Close show scatter plot

- Core package – public specification
- Flux balance constraint – public specification
- Model composition – public specification
- Qualitative models – public specification
- Graph Layout – public specification
- Graph rendering – specification finalised
- Complex species – specification finalised
- Groups - specification finalised
- Distributions and ranges - specification under discussion
- Spatial diffusion – specification under discussion
- Enhanced metadata – specification under discussion
- Arrays and sets – specification proposed
- Dynamic structures - discussed

SBML Level 3 is modular

SBML.org — The Systems Biology Markup Language

Welcome to the portal for the **Systems Biology Markup Language** (**SBML**), a free and open interchange format for computer models of biological processes. SBML is useful for models of metabolism, cell signaling, and more. It **continues to be evolved and expanded** by an international community.

For the curious

What *is* SBML? Read our **introduction**, then perhaps browse the **mailing lists**, the **FAQ**, and look at the **SBML Level 3 package activities** to glimpse what's happening with SBML today.

For modelers

Looking for software that supports SBML? Our **software guide** lists over **250** systems. Are you instead looking for models? Visit **BioModels Database**, where you can find hundreds!

For software developers

Want to support SBML in your software? Read our **intro** and then the **specifications** to understand SBML in depth, then check our **libraries**, **test resources**, and also **3rd-party software**.

No matter how you use SBML, we invite you to sign up for news updates either through our **RSS feed**, our **Twitter feed**, or one of the **mailing lists**, and get involved with **community efforts** to help keep improving SBML. You can also call attention to your project's support of SBML by displaying the **SBML logo**.

SBML would not have been possible without support from **multiple agencies and organizations**, as well as intellectual contributions from many motivated individuals, including the **major contributors** who are shaping SBML Level 3.

SBML News

SBML Layout spec. released

(14 Aug.'13) The SBML Level 3 Layout V.1 specification has been finalized and released.

COMBINE 2013

(28 Jul.'13) Registration and a preliminary agenda for the September event are now available.

SBML Test Runner 3.0

(6 Jun.'13) A new version of the standalone Test Runner for the SBML Test Suite is now available.

Older news ...

Community News

SBML2GPML

(12 Sep.'13) This new PathVisio plugin allows SBML models to be imported.

CellNOpt 1.7.7

(12 Aug.'13) This logic-based modeling software system now supports SBML Level 3 Qualitative Models.

iNA 0.4.2 released

(11 Jun.'13) The new release offers a new plot editor and supports multi-core computations on MacOS.

SBML supporting tools

- LibSBML: free, open-source programming library to help you read, write, manipulate, translate, and validate SBML files. Written in C++, with bindings for: c#, Python, Java, Perl, Ruby, MatLab, Octave,
- JSBML: free, open-source, pure Java library for reading, writing, and manipulating SBML files (validation done via libSBML)
- SBML converters: Converter from and to SBML, including Octave, XPP, BioPAX, dot, SVG, MDL
- Software guide: 254 software, including modelling and simulation environement, databases, model processing

SBML Software Guide

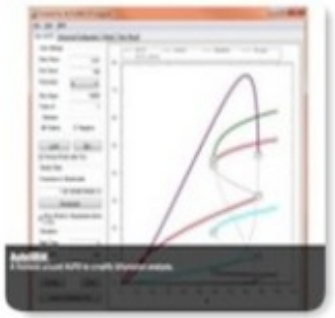
The following pages describe SBML-compatible software packages known to us. We offer different ways of viewing the information, all drawn from the same underlying data collected from the systems' developers via our **software survey**. The *Matrix* provides a table listing all known software and a variety of their features; the *Summary* provides general descriptions of most of the software; and the *Showcase* provides a sequential slideshow of a subset of the software.

Number of software packages listed in the matrix today: **254**.

Go to the SBML Software Matrix

Go to the SBML Software Summary

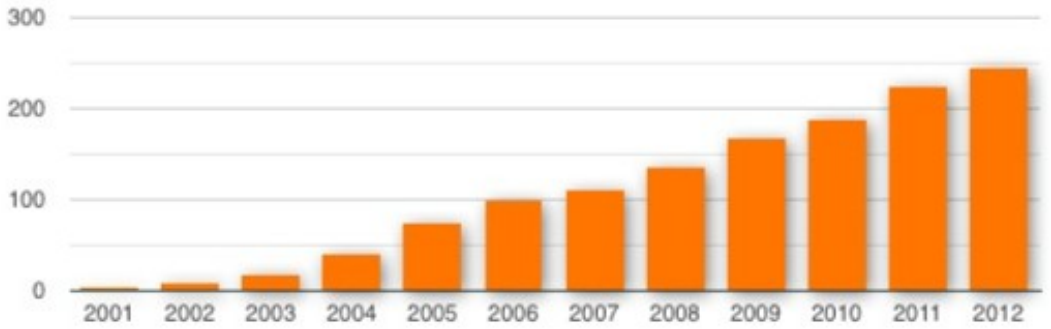
Go to the SBML Software Showcase



Please **use the survey form** to notify us about additions and suggestions.

Historical trend

The following graph shows the total number of known SBML-compatible software packages each year, as counted by the SBML Team. The counts shown are for approximately the middle of each year.

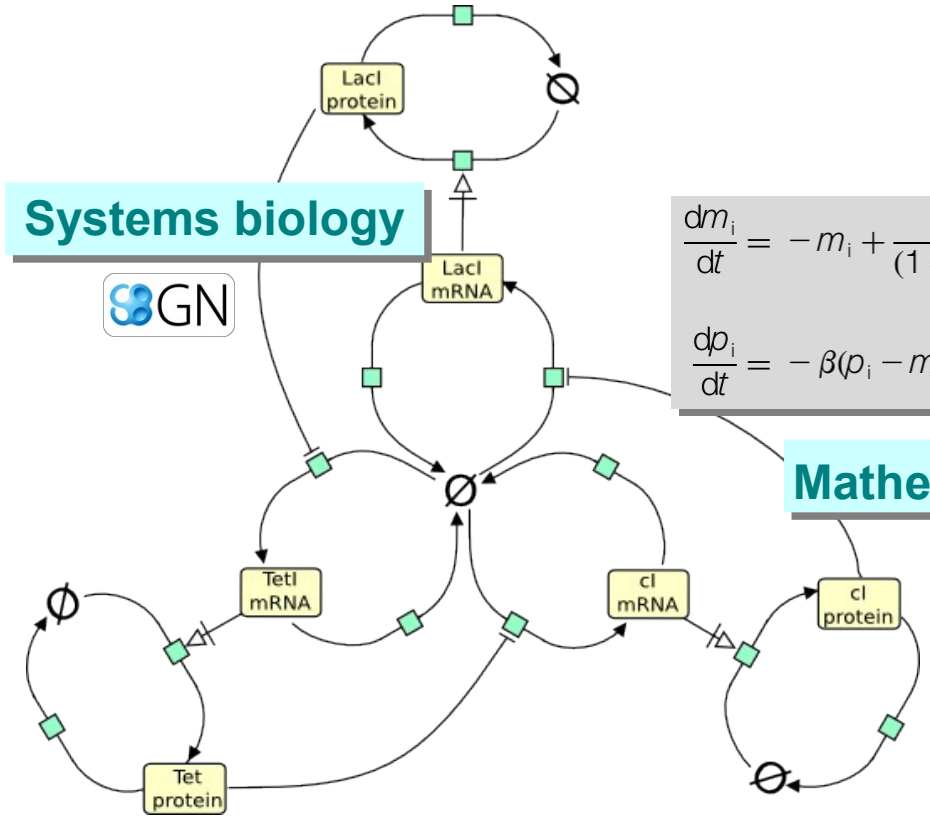


(Note: the flat period in 2007 is an artifact of inadequate record keeping rather than a lull in SBML software development.)

SBML conformance testing

The **SBML Test Suite** provides an operational means of testing SBML support in software simulation and analysis systems. Software authors can choose to make the test results for their software public in the **SBML Test Suite Database**, where you can

BioModels Database – http://www.ebi.ac.uk/biomodels



Systems biology

SBGN

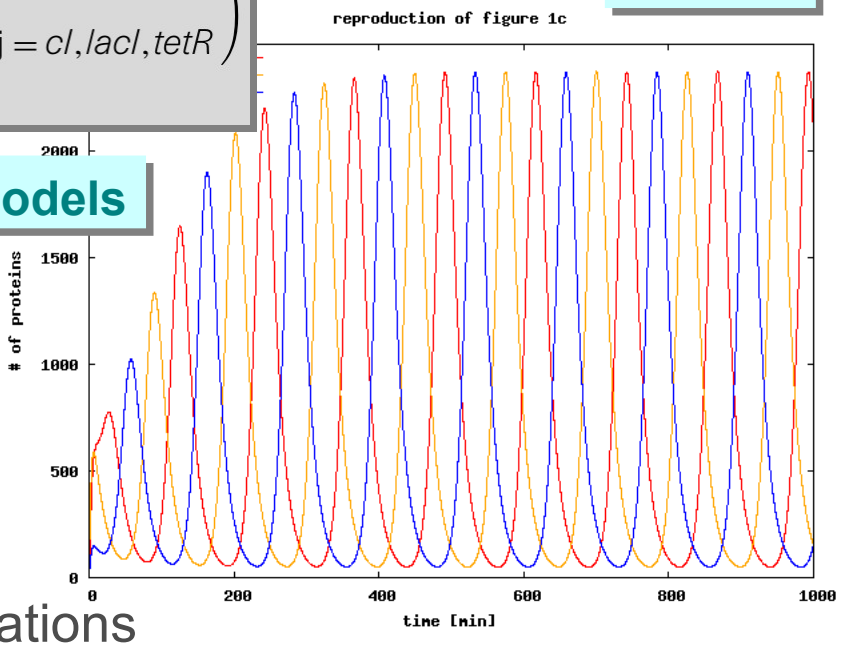
$$\frac{dm_i}{dt} = -m_i + \frac{\alpha}{(1+p_j^n)} + \alpha_0 \qquad \begin{pmatrix} i = lacI, tetR, cI \\ j = cI, lacI, tetR \end{pmatrix}$$

$$\frac{dp_i}{dt} = -\beta(p_i - m_i)$$

Mathematical models

SBML

curated



>140 000 models, >10 millions mathematical relations

Deposition advised by >300 journals, database > 600 citations

1.5 million page requests per year

Submission in SBML and CellML; Export in SBML, CellML, XPP, SciLab, BioPAX, Octave, PDF, VCML, SBGN

Babraham Institute

BioModels Database

Search
Advanced

BioModels Database serves as a reliable repository of computational models of biological processes. It hosts models described in peer-reviewed scientific literature and models generated automatically from pathway resources (Path2Models). A large number of models collected from literature are manually curated and semantically enriched with cross-references from external data resources. The resource allows scientific community to store, search and retrieve mathematical models of their interest. In addition, features such as generation of sub-models, online simulation, conversion of models into different representational formats, and programmatic access via web services, are provided.

 More information about BioModels Database can be found in the frequently asked questions (FAQ).

Models published in the literature

- Browse curated models
- Browse curated m… (Browse curated models)
- Browse curated models using Taxonomy
- Browse non-curated models

Browse the models in the curated branch. These models have been thoroughly curated, and model elements have been annotated with terms from controlled vocabularies as well as links to relevant data resources.

Path2Models

Submit a model

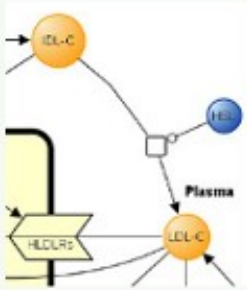
Links

- Main instance at EMBL-EBI, UK
- Mirror at Caltech, USA
- Project on SourceForge
- Web Services
- Download archived models

Model of the month

October, 2013

Why LDL-C rises with age? The model presented here demonstrates that mechanistic changes to cholesterol absorption and LDL-C removal from the plasma with age, can result in a significant rise in LDL-C.



Please read more...

News

Follow us on Twitter

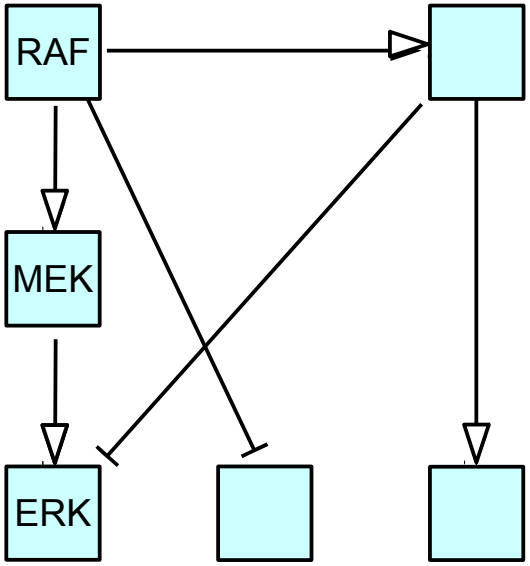
8 October 2013 **SPARQL endpoint available**

The EBI launched a RDF platform. This provides access to various bioinformatics resources (including BioModels Database) using Semantic Web technologies (SPARQL endpoints and RDF dumps are available). Read more about this news.

18 June 2013 **25th release**

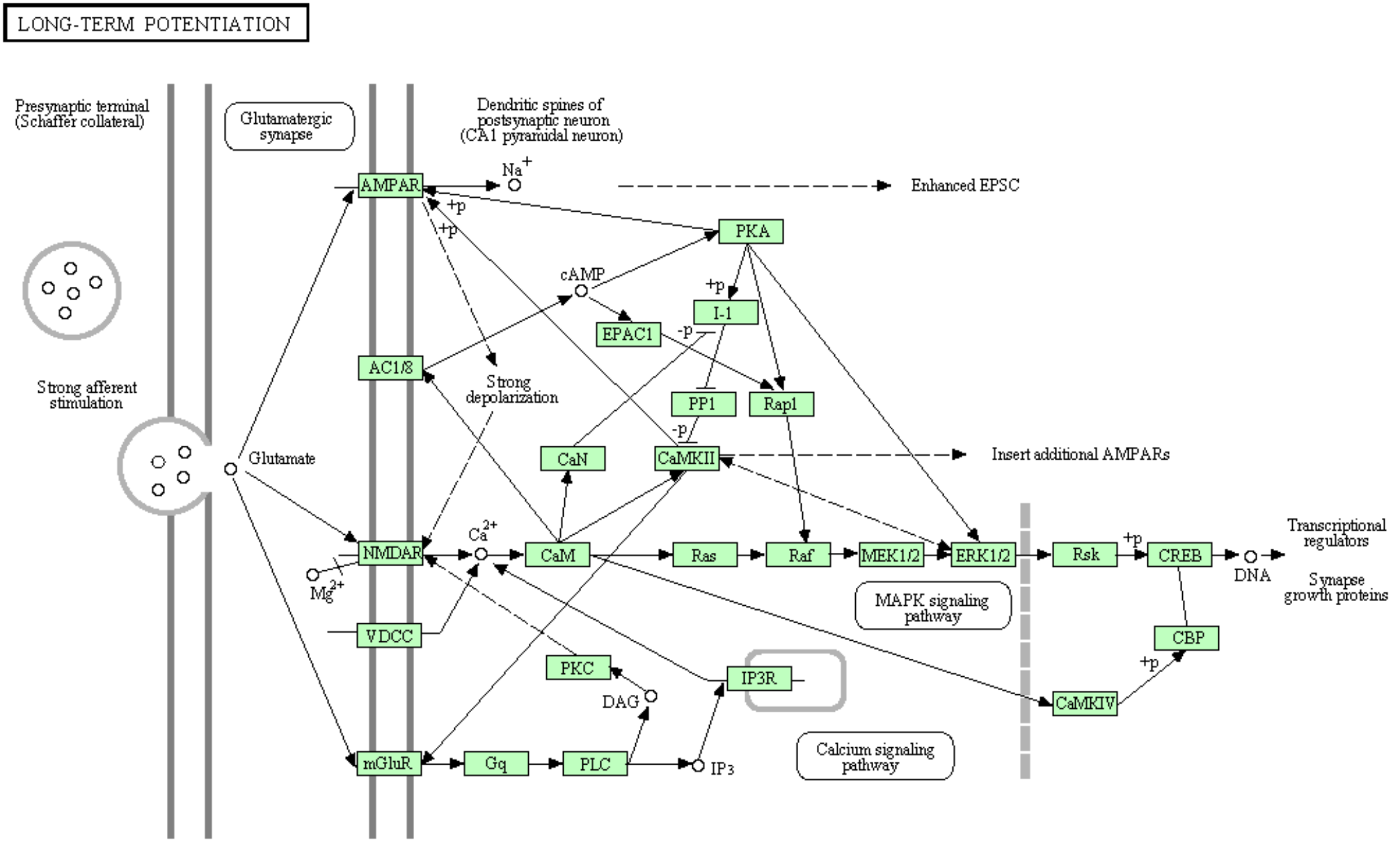
We are pleased to announce the twenty-fifth release of BioModels Database! The resource now publicly provides 143013 models. Numerous new models have been made available, several have been updated and various new features have been unveiled.

Activity-Flows (influence diagrams)



- Directional
- Sequential
- Non-mechanistic
- Logical modelling
- Signalling pathways, gene regulatory networks

http://www.genome.jp/kegg/pathway.html



http://stke.sciencemag.org/cm/

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Pathway Information
Overviews
Print Version
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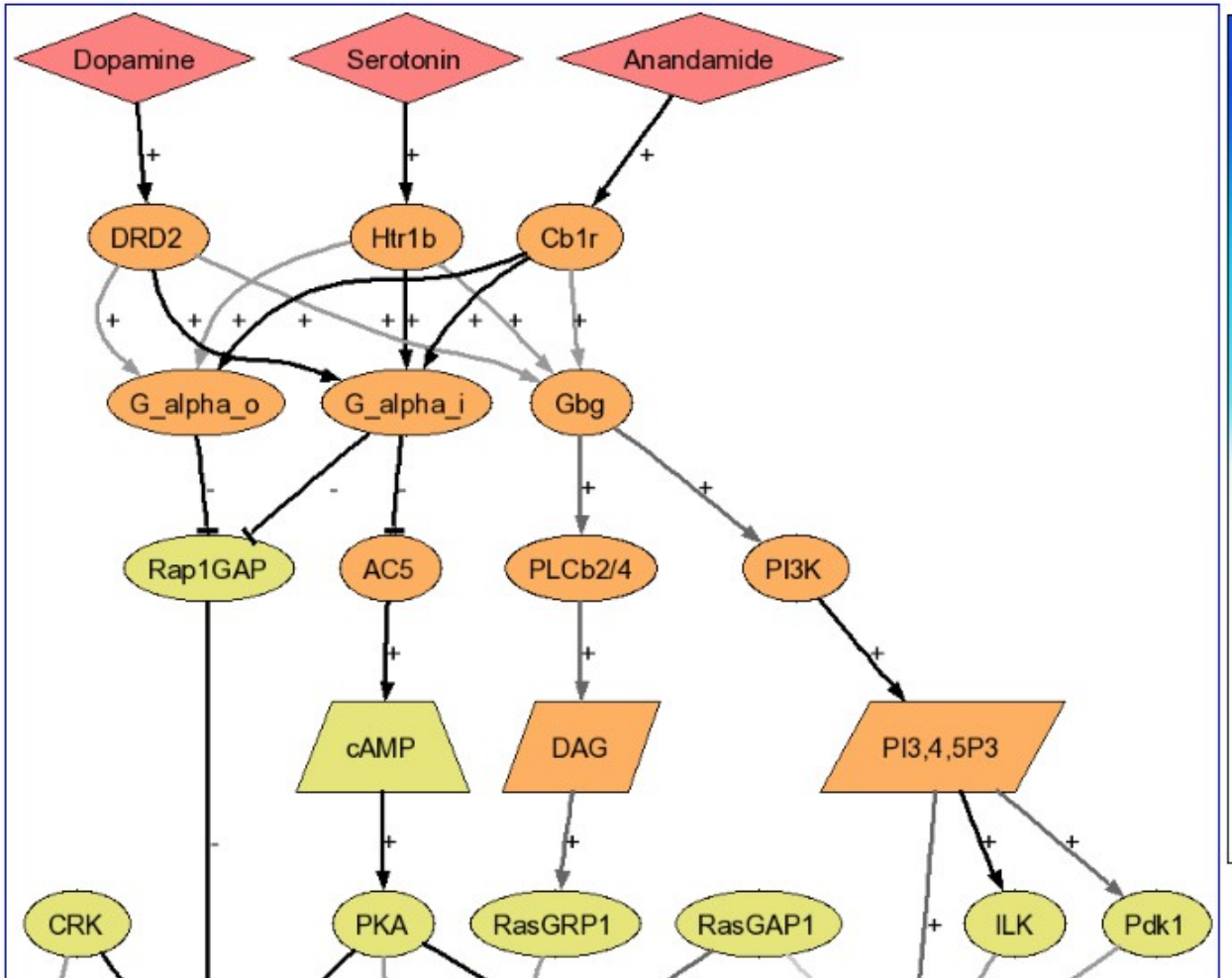
Glossary
Request Permission to Use
Related Content
More Information on Related Content
Search Google Scholar for:
Articles by Malayan, A.
Search PubMed for:
Articles by Malayan, A.
Find Citing Articles in:
CrossRef
Scopus
Help & Feedback
Database of Cell Signaling Help
Feedback
My Science Signaling
My Folders
My Alerts
My Display Settings
My Saved Searches
My Directory Information
Sign In

Pathway Information

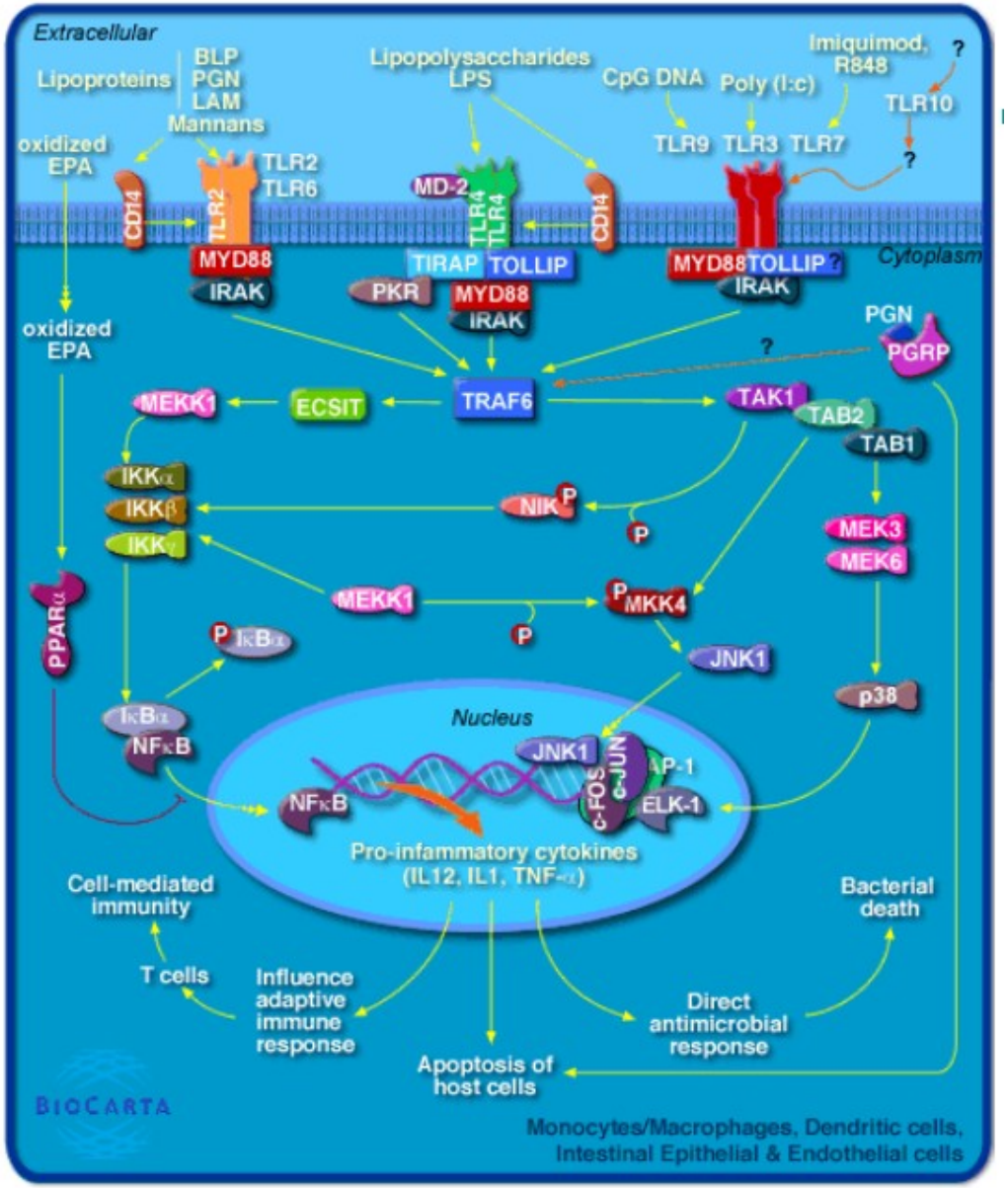
Neuro2A Differentiation by G alpha i/o Pathway

Authorities: Avi Malayan, et al.
Organism: vertebrates : mammals : Rodentia : mice
Tissue Cell: nervous system : central nervous system : neurons
Citations: Literature
Scope: Specific
Canonical Pathways: G alpha i Pathway

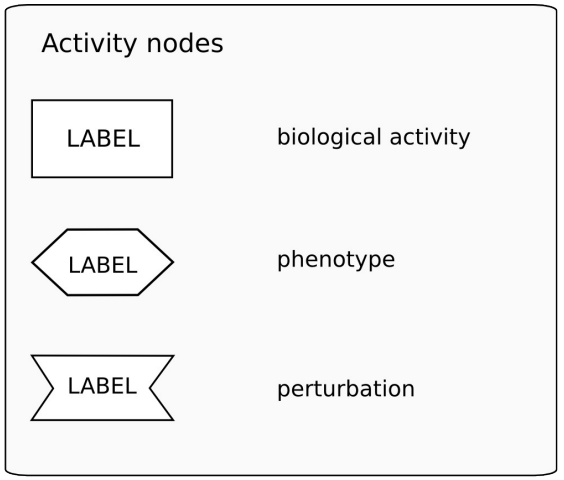
Pathway
View Connections Map Legend
Get SVG Pathway Image

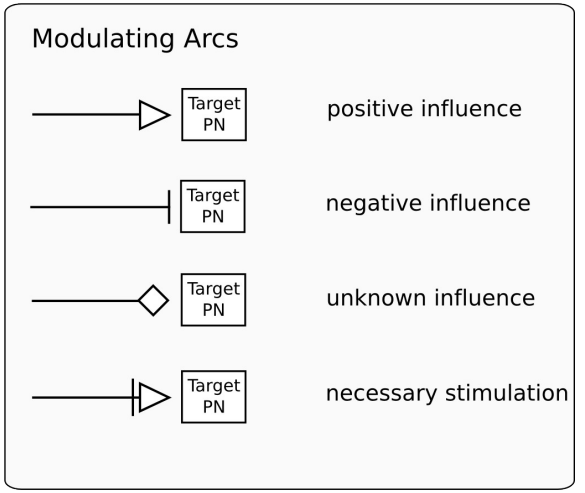


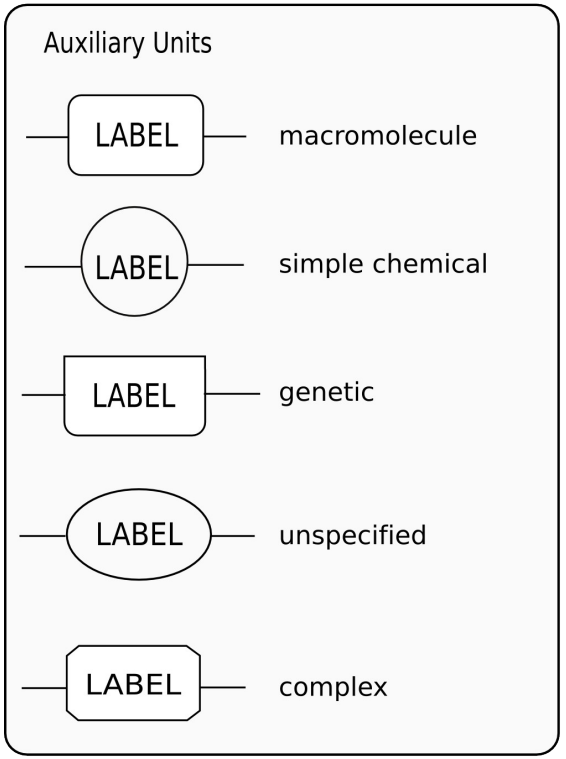
http://cgap.nci.nih.gov/Pathways/BioCarta.org

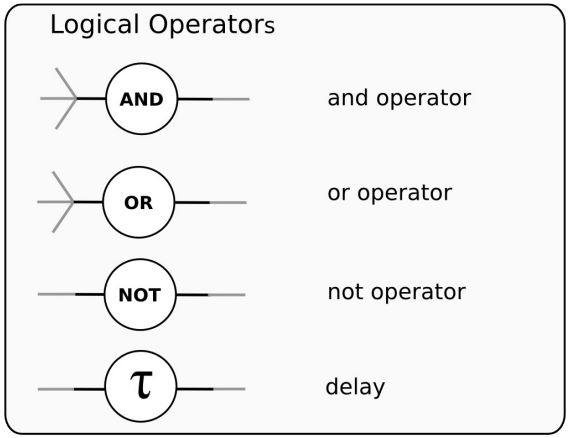


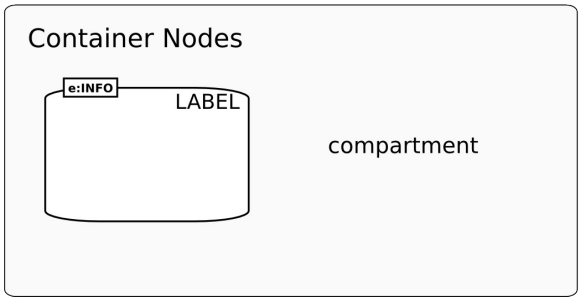
SBGN Activity Flows L1 reference card



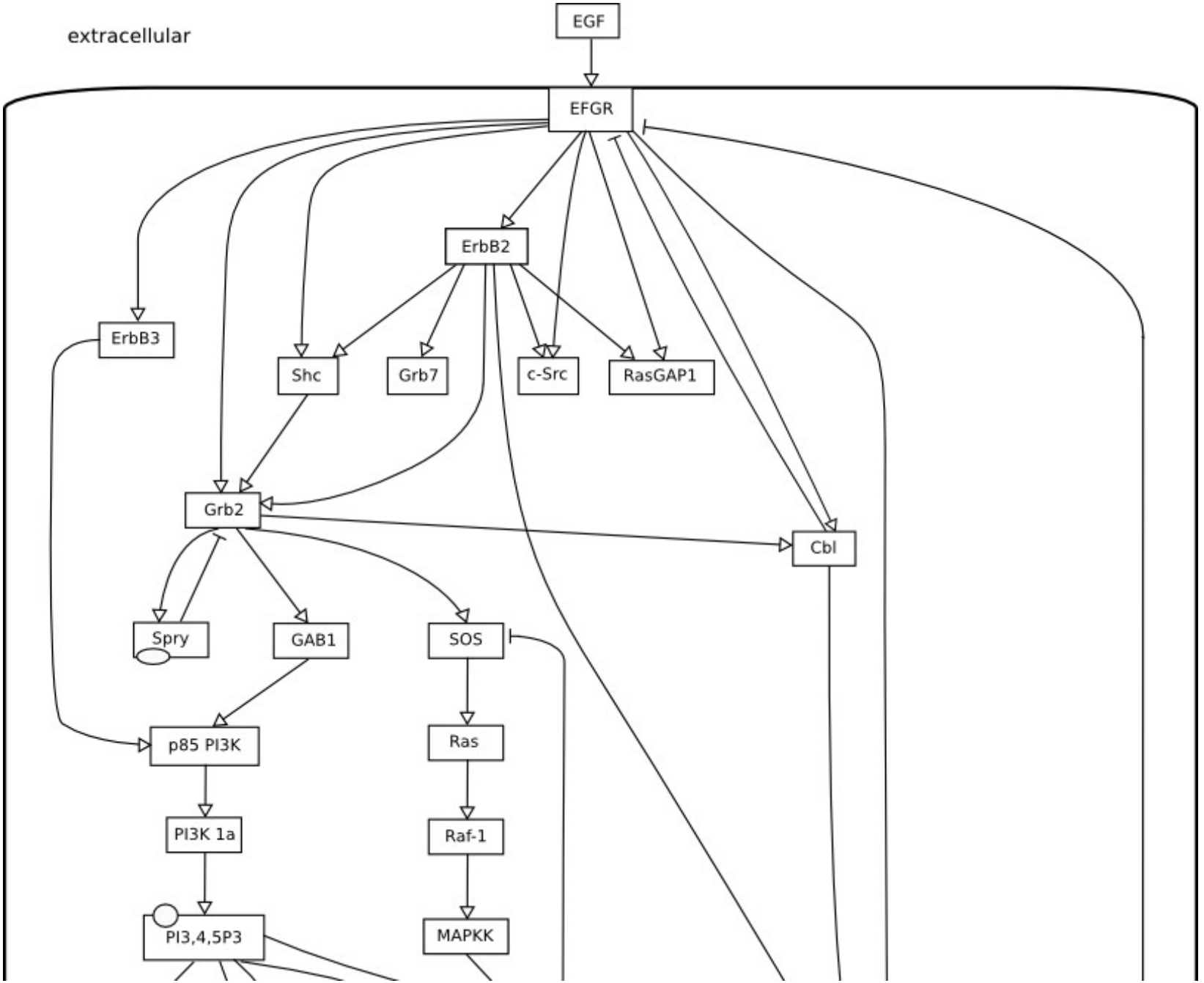




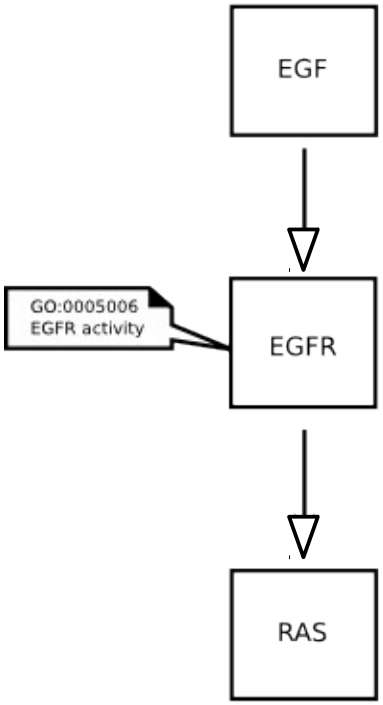




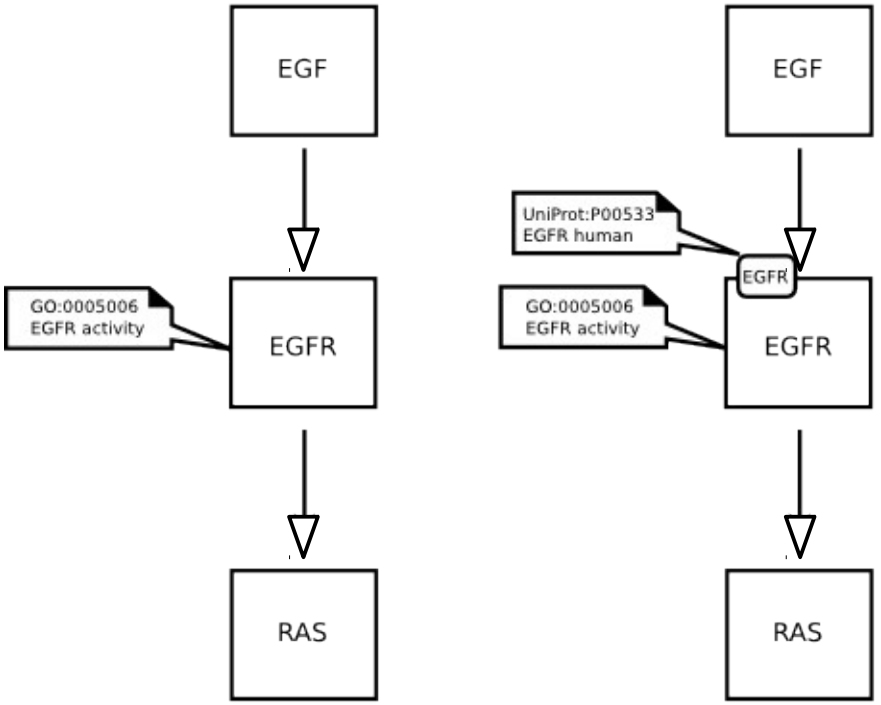
Example of Activity Flow map



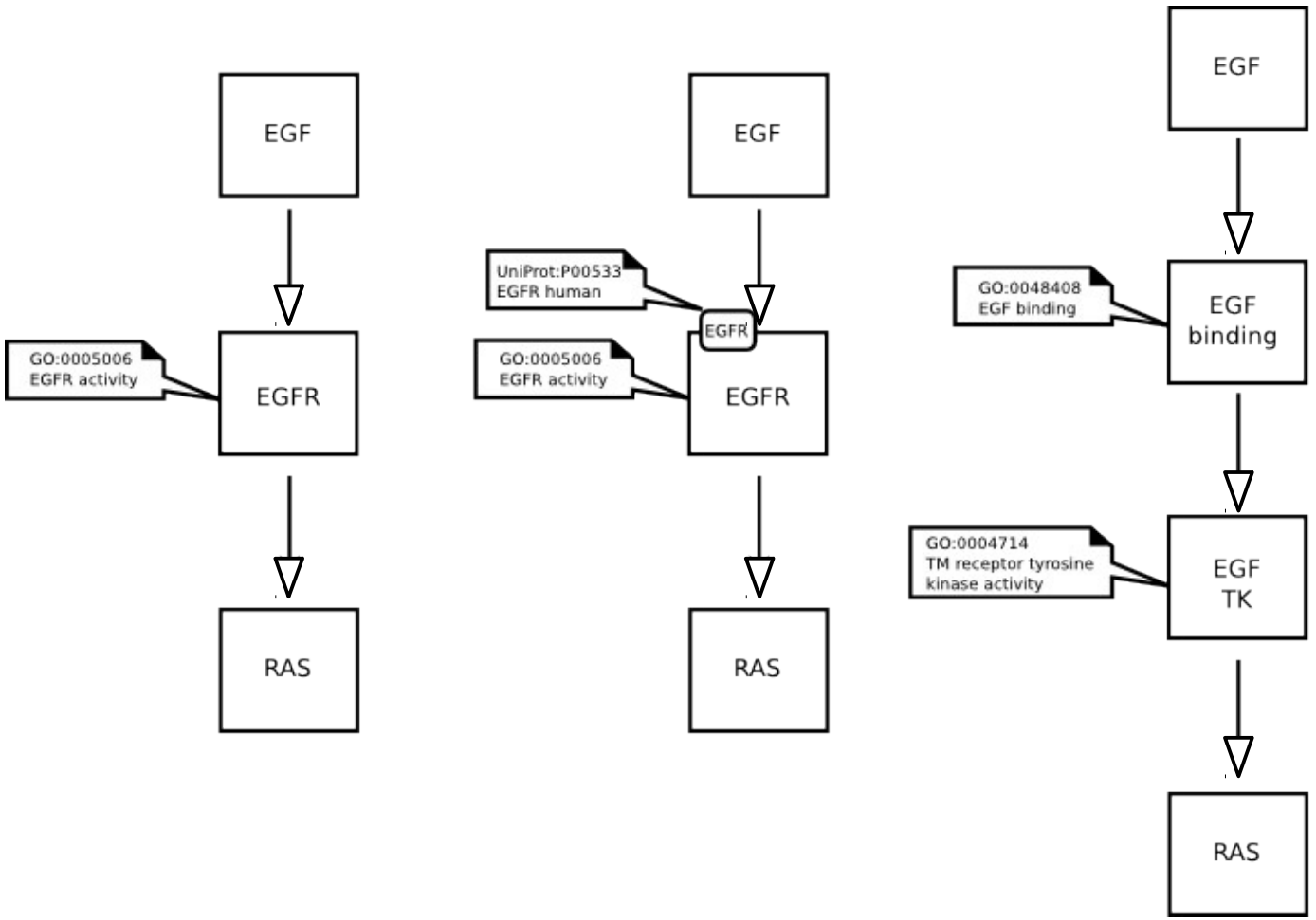
TIMTOWTDI



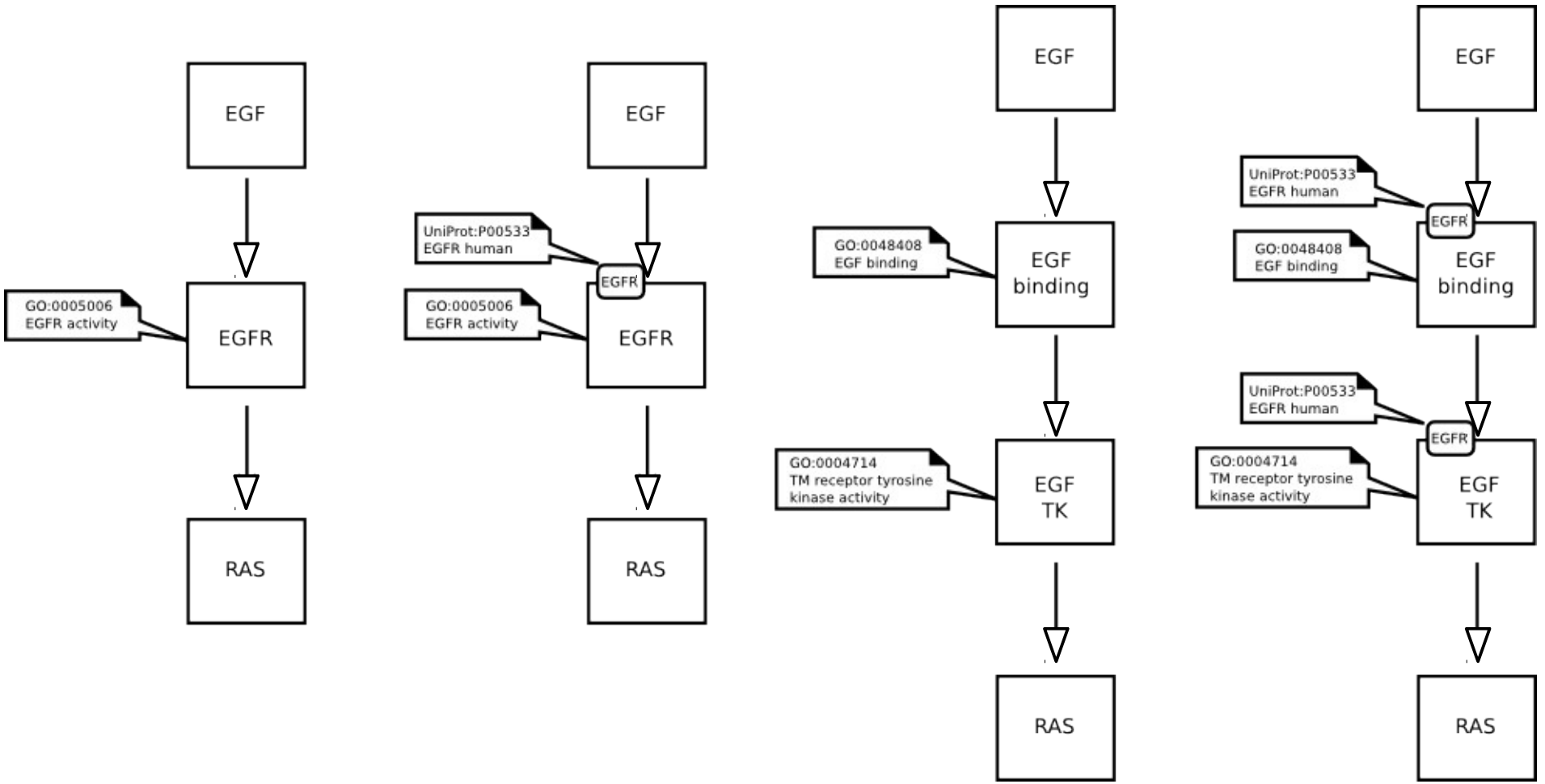
TIMTOWTDI


EGF
GO:0005006
EGFR activity
EGFR
RAS
EGF
UniProt:P00533
EGFR human
EGFR
GO:0005006
EGFR activity
EGFR
RAS

TIMTOWTDI

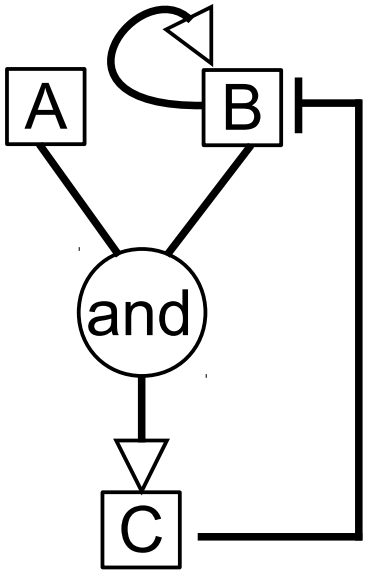

EGF
GO:0005006
EGFR activity
EGFR
RAS
EGF
UniProt:P00533
EGFR human
EGFR
GO:0005006
EGFR activity
EGFR
RAS
EGF
GO:0048408
EGF binding
EGF
binding
GO:0004714
TM receptor tyrosine
kinase activity
EGF
TK
RAS

TIMTOWTDI

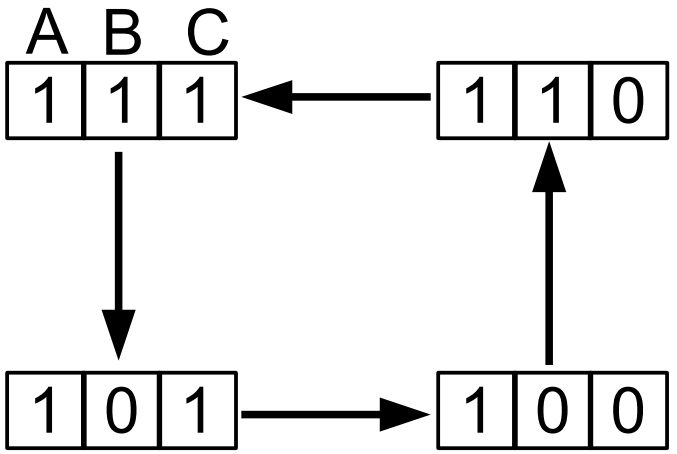

EGF
GO:0005006
EGFR activity
EGFR
RAS
EGF
UniProt:P00533
EGFR human
EGFR
GO:0005006
EGFR activity
EGFR
RAS
EGF
GO:0048408
EGF binding
EGF
binding
GO:0004714
TM receptor tyrosine
kinase activity
EGF
TK
RAS
EGF
UniProt:P00533
EGFR human
EGFR
GO:0048408
EGF binding
EGF
binding
UniProt:P00533
EGFR human
EGFR
GO:0004714
TM receptor tyrosine
kinase activity
EGF
TK
RAS

Logical models

- Variables can take a discrete number of values, at least 2
- Transitions of output are expressed as logical combinations of input values
- Simulations can be:
  synchronous: all the nodes are updated at once
  asynchronous: nodes are updated one after the other
- One can add delays, inputs etc.



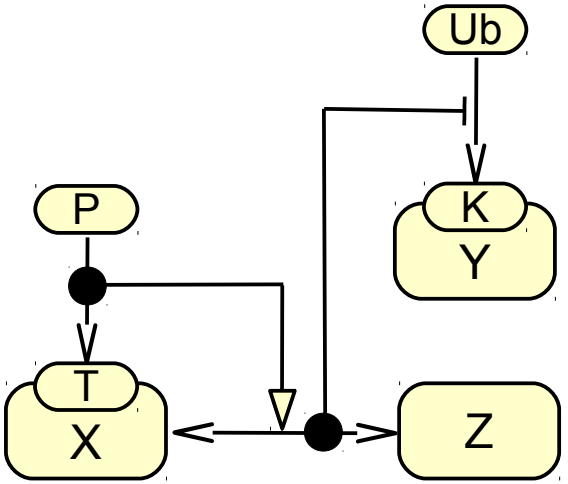
Influence diagram



state diagram

SBML Qual

Entity Relationships



- Directional
- Non-sequential
- Mechanistic
- Rule-based modelling
- Molecular Biology
- “Open world”
- Independent rules: no explosion

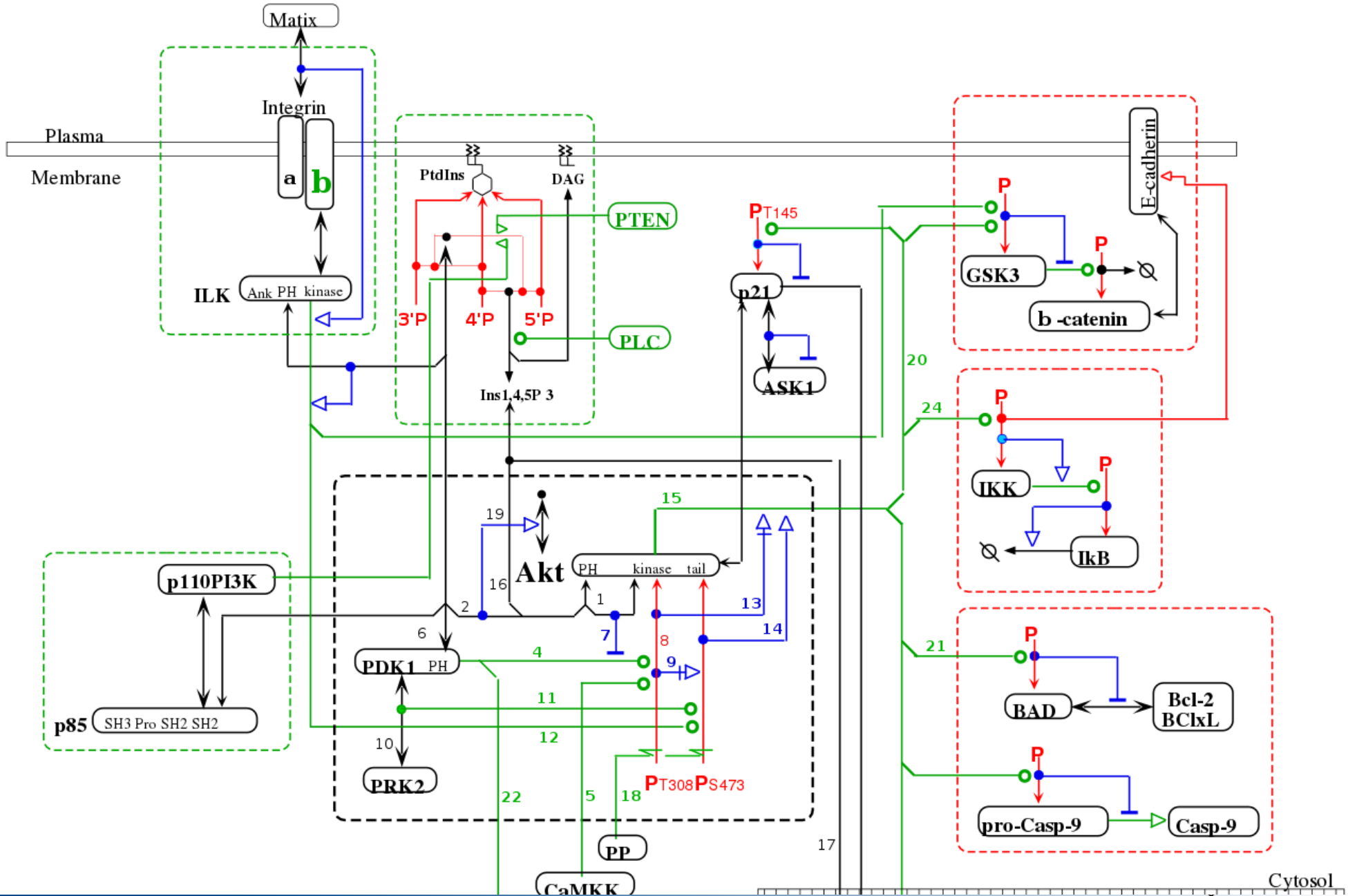
http://discover.nci.nih.gov/mim/

Map description

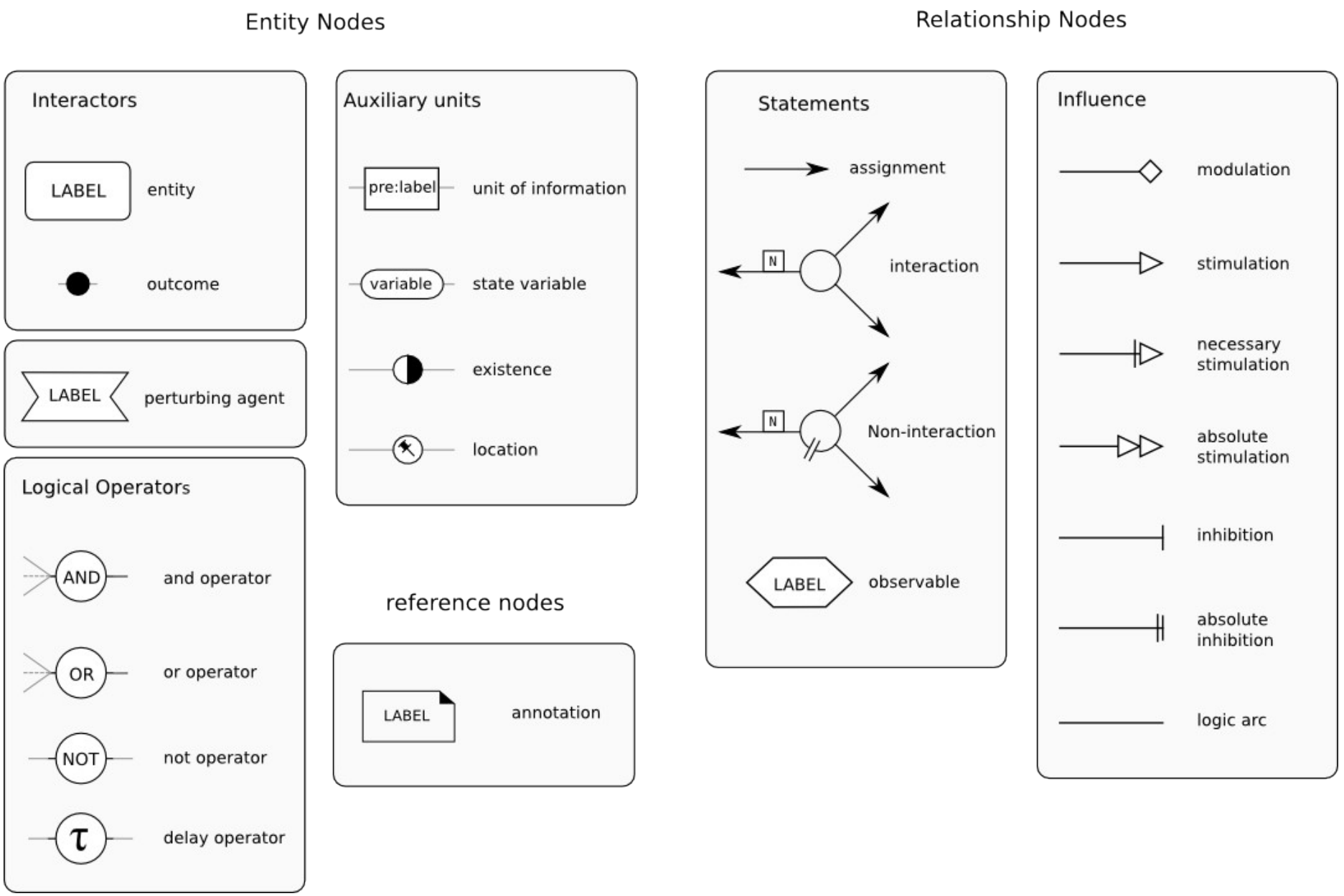
(see System Requirements)

AKT

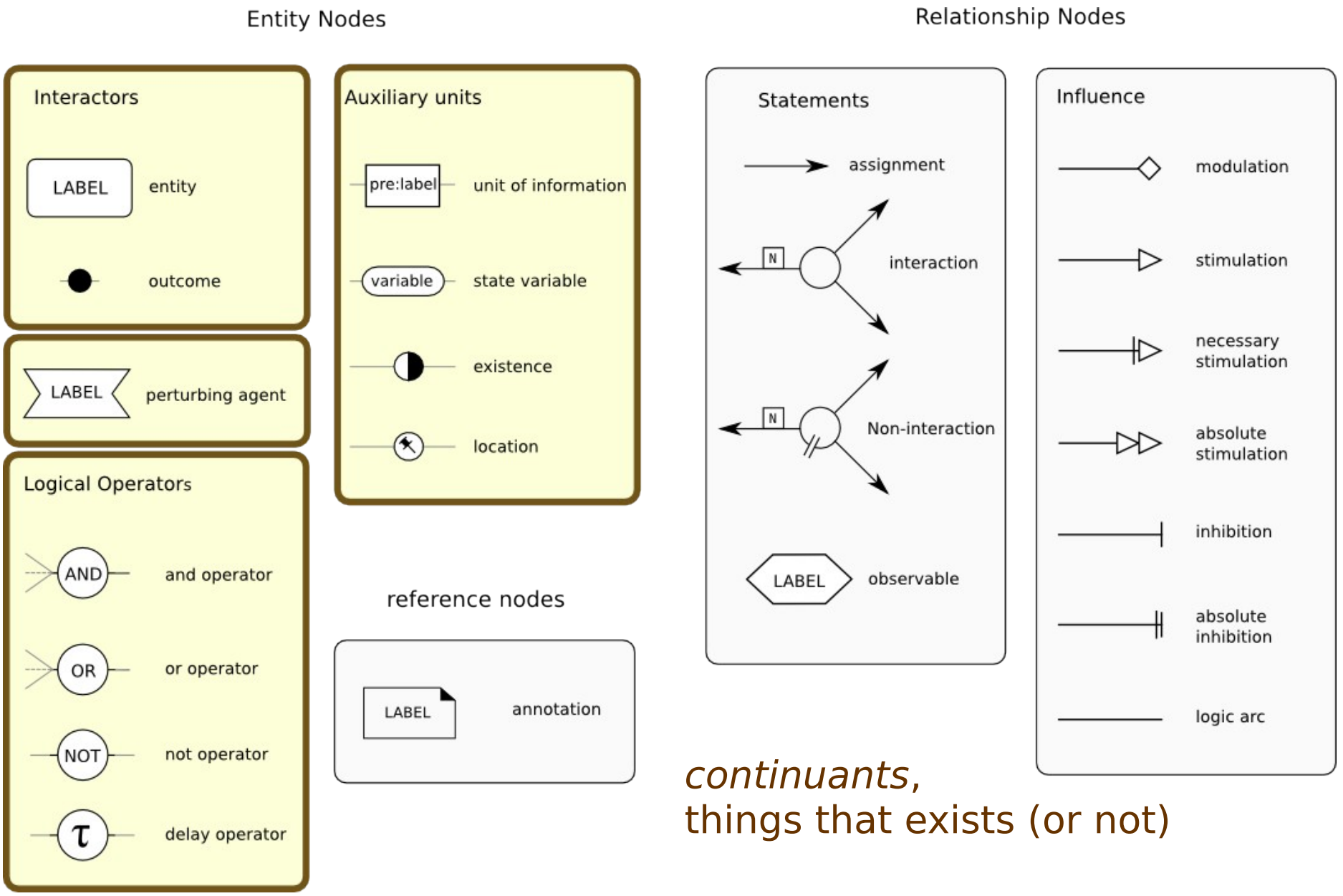
Click here to return to original map size



SBGN Entity Relationships L1 reference card

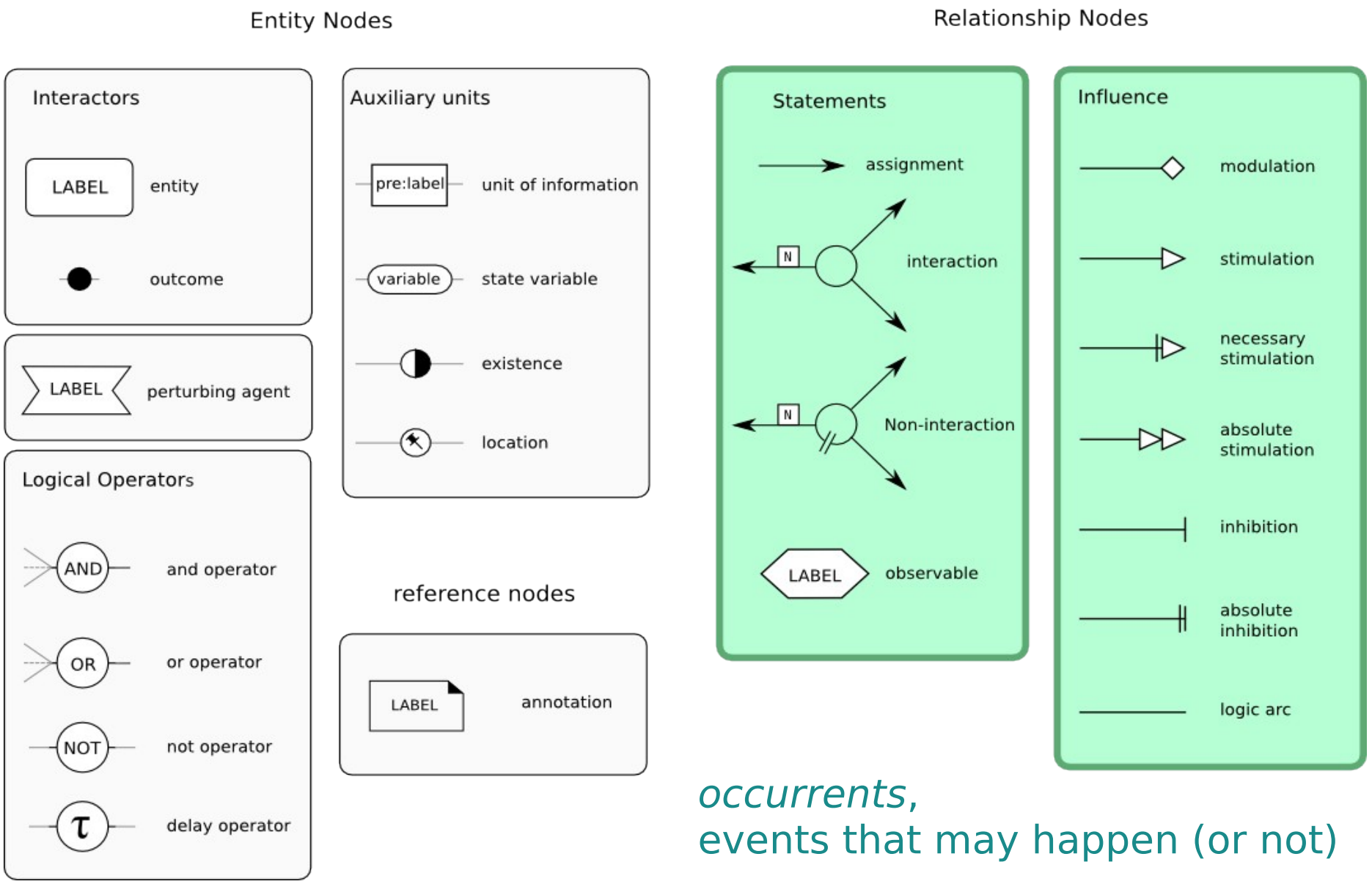


SBGN Entity Relationships L1 reference card



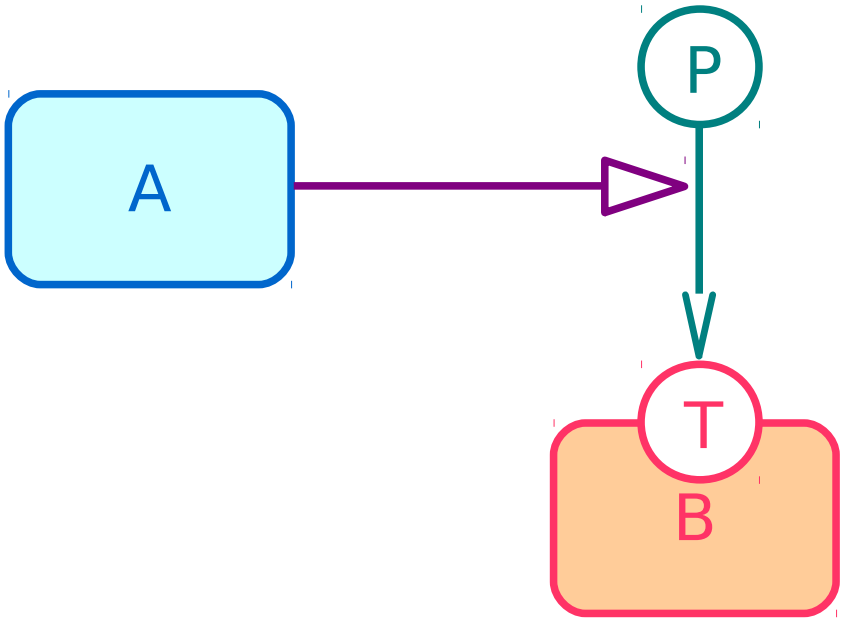
continuants,
things that exists (or not)

SBGN Entity Relationships L1 reference card

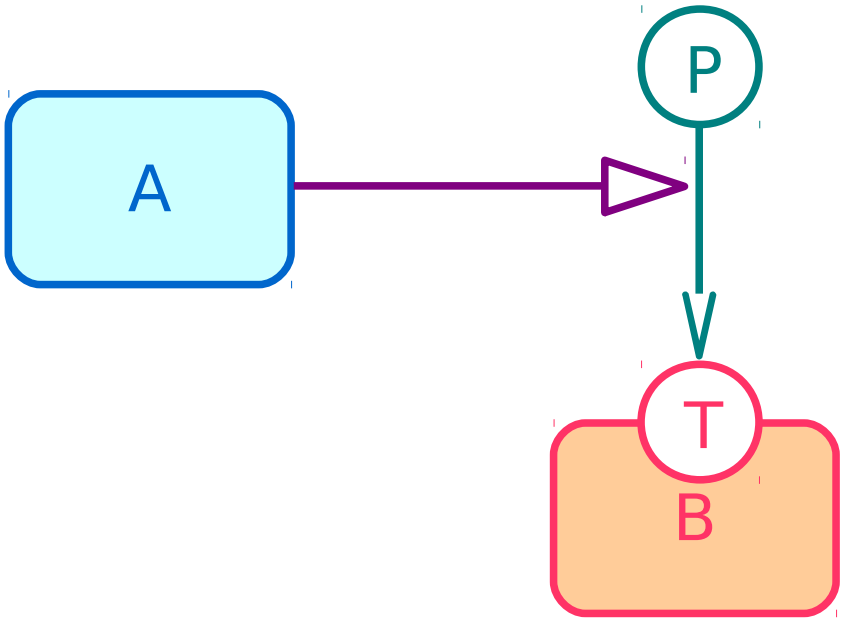


occurrents,
events that may happen (or not)

Entity Relationships can be viewed as rules

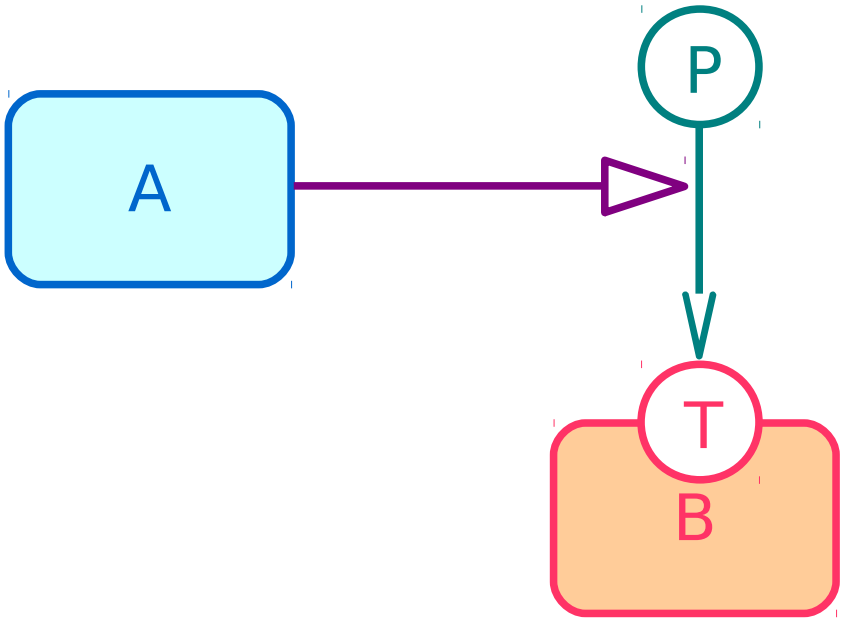


Entity Relationships can be viewed as rules



If A exists, the assignment of the value P to the state variable T of B is increased

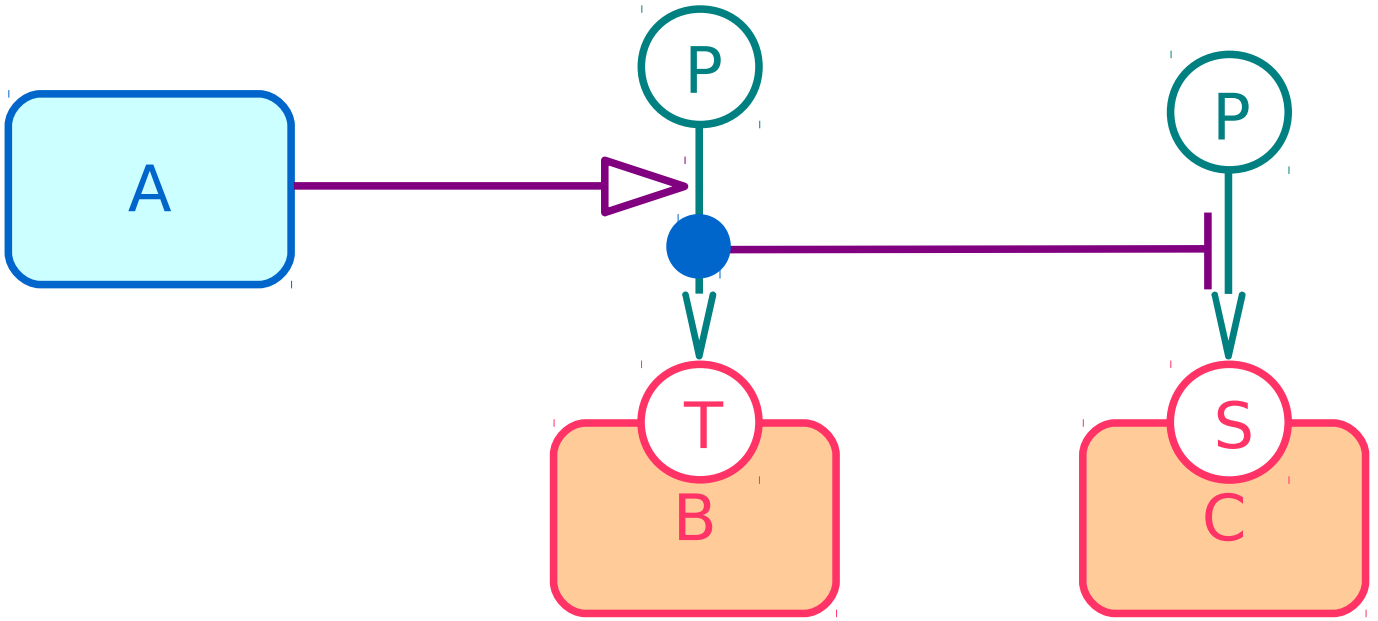
Entity Relationships can be viewed as rules



If A exists, the assignment of the value P to the state variable T of B is increased

(A stimulates the phosphorylation of B on the threonine)

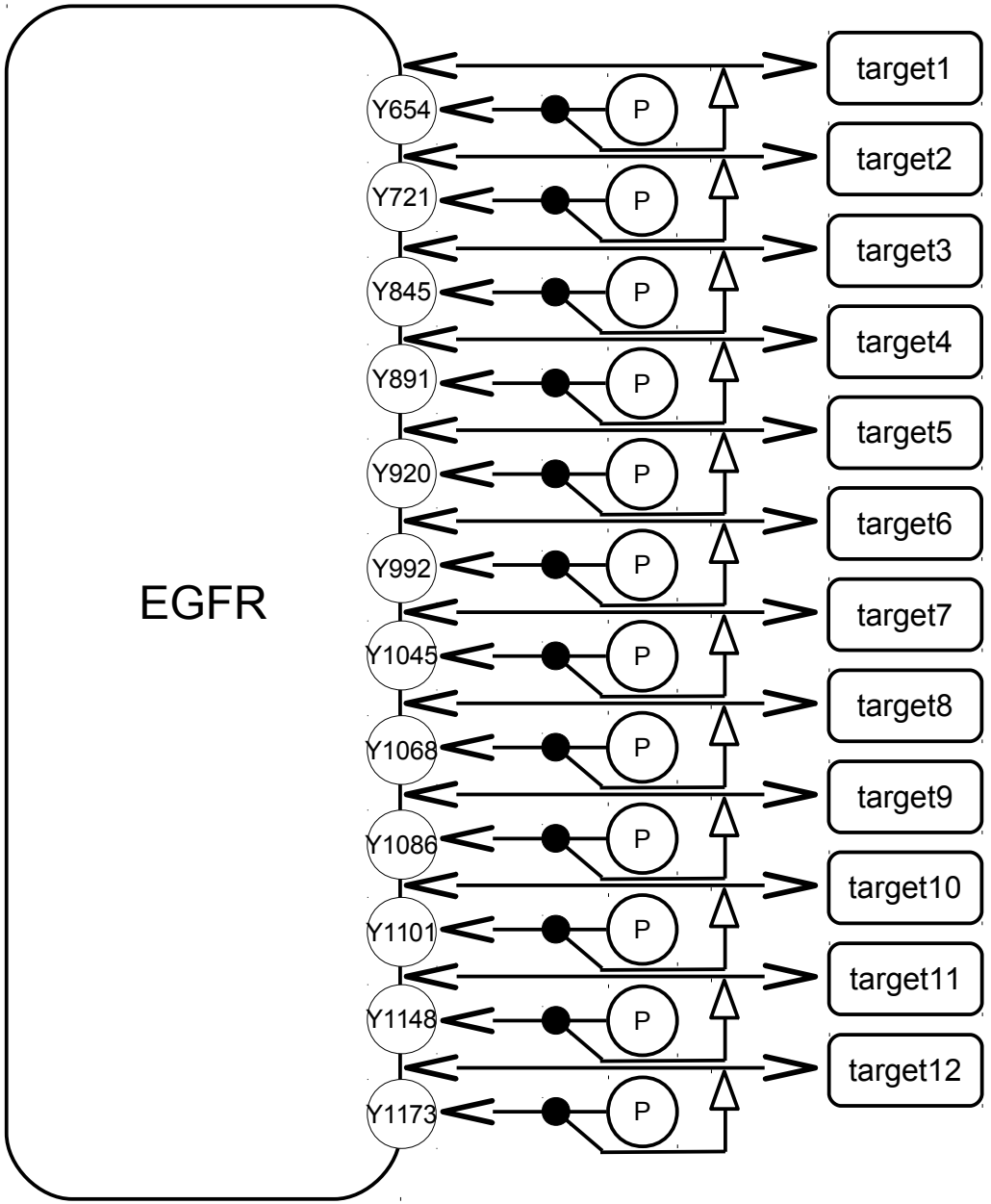
Entity Relationships can be viewed as rules



If A exists, the assignment of the value P to the state variable T of B is increased

If P is assigned to the state variable T of B, the assignment of the value P to the state variable S of B is decreased

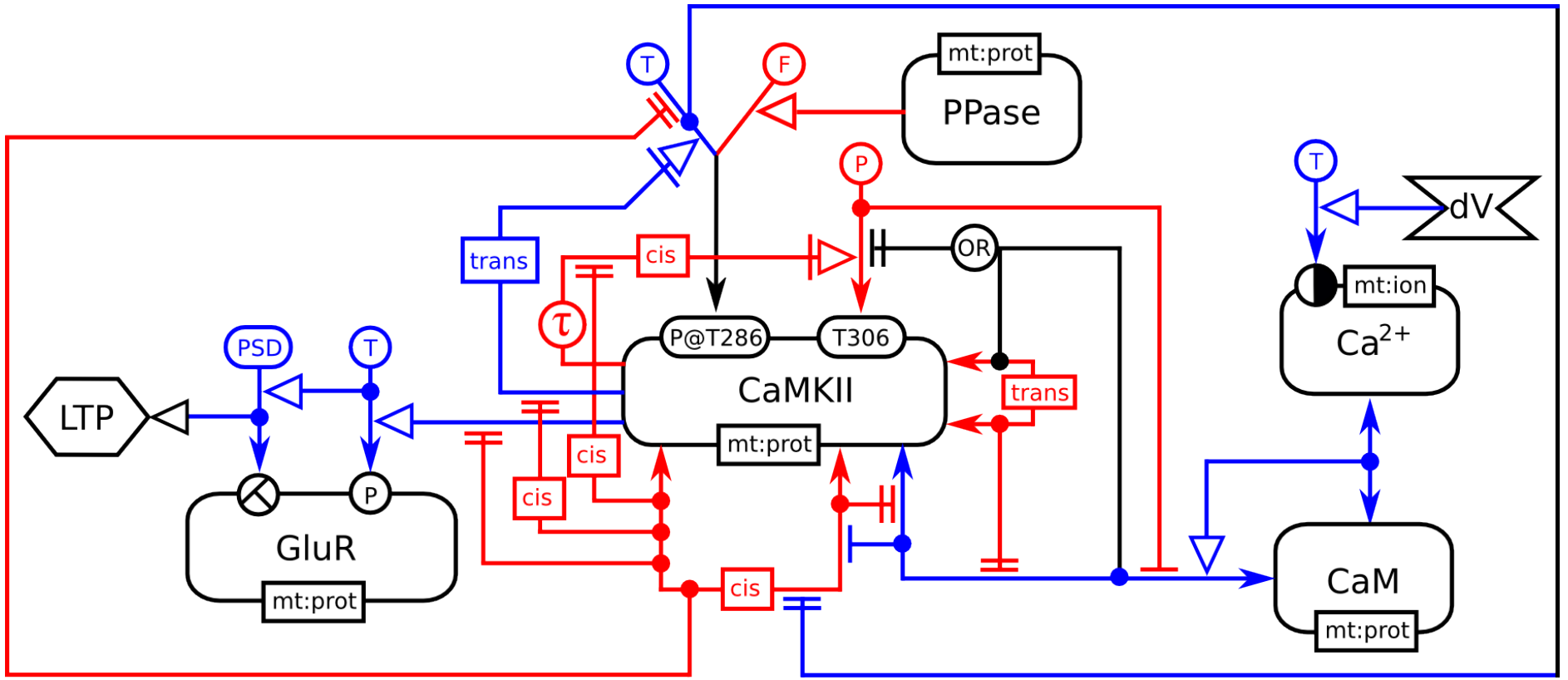
Multistate and combinatorial explosion



Process Descriptions:
"once a state variable value,
always a state variable value"

2^{12} = 4096 states
(i.e. EPN glyphs) for EGFR
and 4096 complexes between
EGFR and targets

Regulation of synaptic plasticity by calcium



Rule-based modelling

- Kappa http://www.kappalanguage.org/

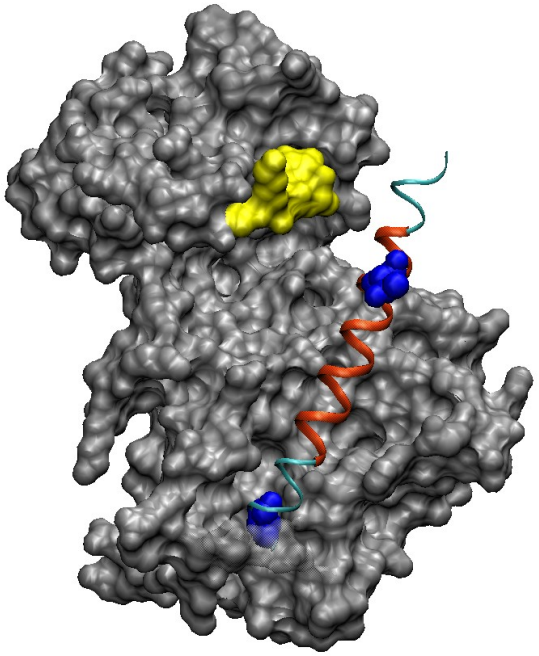
  English: "Unphosphorylated Site1 of A binds to Site1 of B"
  Kappa: A(Site1~u),B(Site1) -> A(Site1~u!1),B(Site1!1)

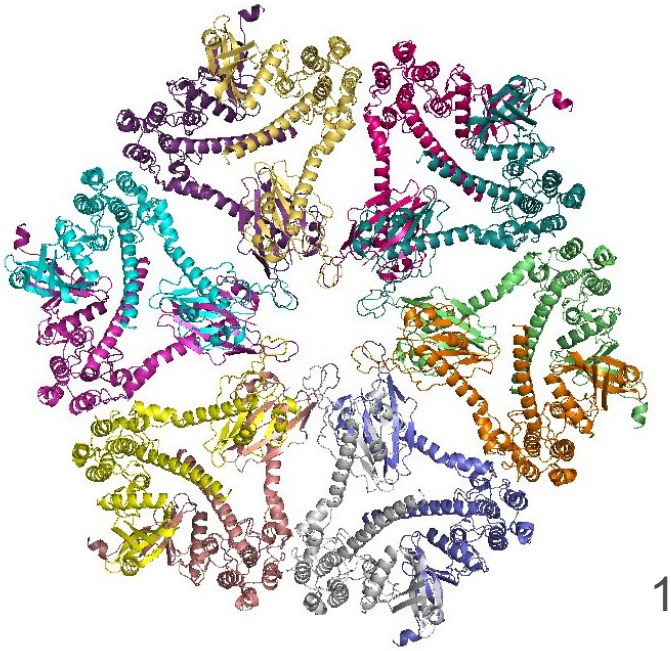
- BioNetGen http://bionetgen.org/

  English: “unbound EGF receptor site binds to unbound receptor ligand site”
  EGF(R) + EGFR(L) <-> EGF(R!1).EGFR(L!1) kp1, km1

Multi

Multi-state nature of CaMKII and rule-based modelling



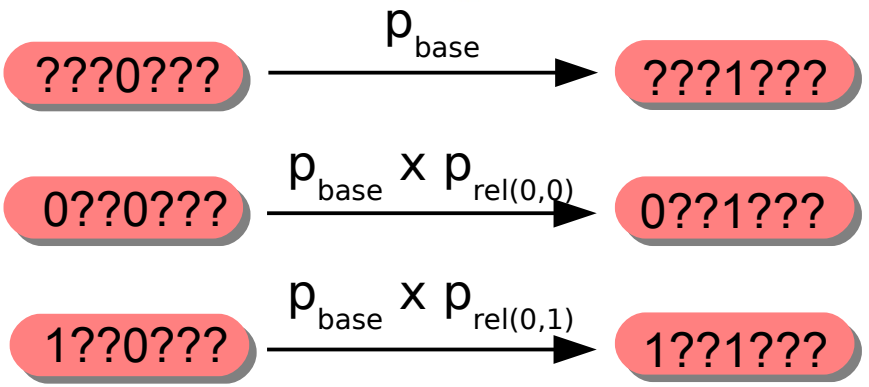


12 monomers

5 binary state variables

Open/Closed
T286 P/nonP
T306 P/nonP
CaM on low affinity
CaM on high affinity

2^{60} states = 1 billions of billions



Flags '?' do not affect the reaction

4 species are necessary and not 128

2 reactions are necessary and not 64

Simulation with StochSim

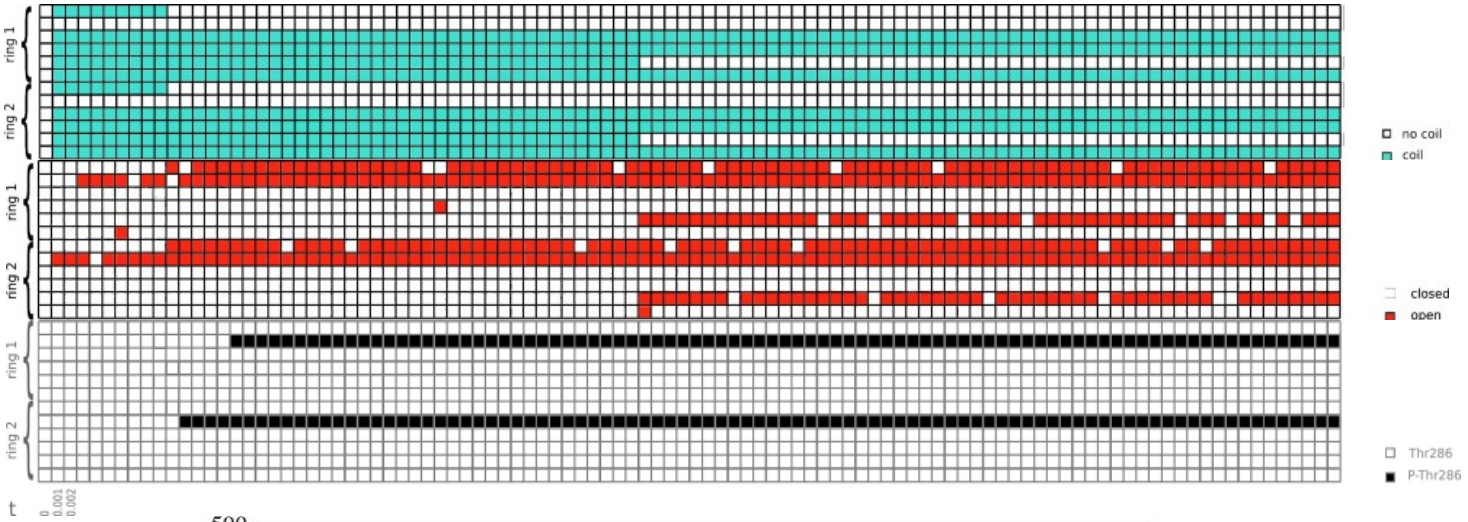
time

single oligomer

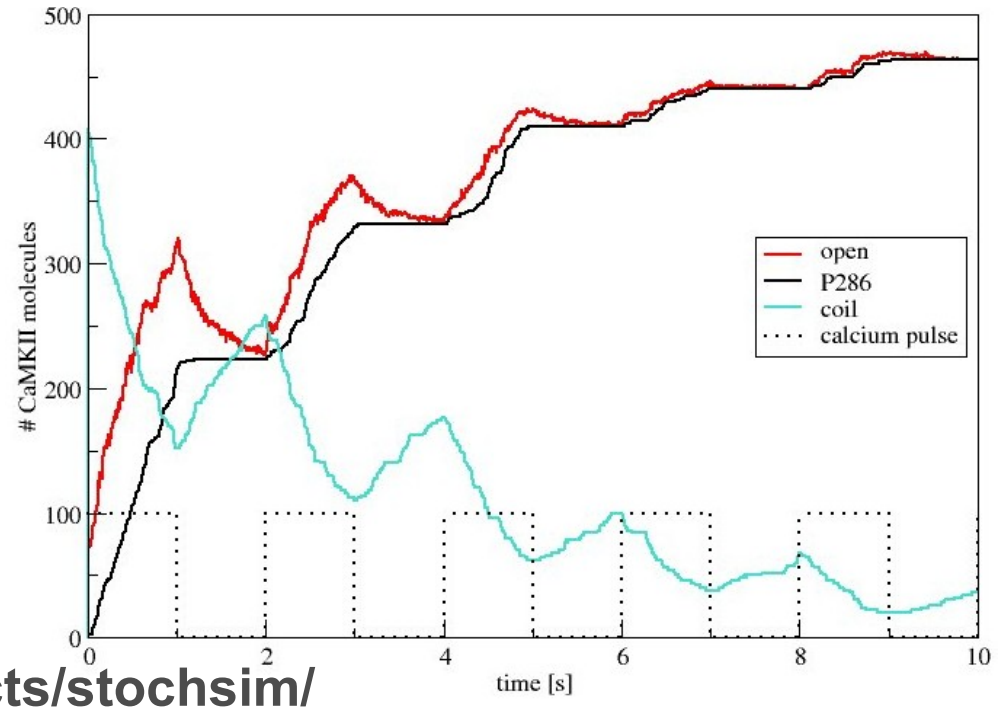
dimer coil

open

T286P



population of multimers



http://sourceforge.net/projects/stochsim/

Biological Pathway Exchange format

http://biopax.org/

BioPAX is a data format and an ontology

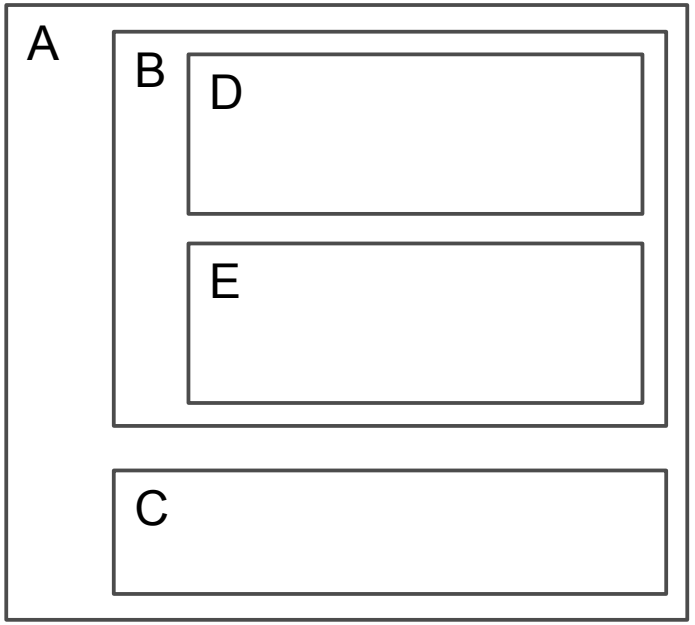
- **RDF/OWL**-based language to represent biological pathways at the molecular and cellular level
- Covers molecular and genetic interactions, metabolic network, signalling pathways, gene regulatory networks
- **Interactions**: Control (Catalysis, Modulation, TemplateReactionRegulation), Conversion (BiochemicalReaction, ComplexAssembly, Degradation, Transport, TransportWithBiochemicalReaction), GeneticInteraction, MolecularInteraction, TemplateReaction
- **Physical entities**: Complex, DNA, DNARegion, Protein, RNA, RNARegion, SmallMolecule
- **Utility classes**: BioSource, ChemicalStructure, ControlledVocabulary, DeltaG, EntityFeature, EntityReference, Evidence, ExperimentalForm, kPrime, PathwayStep, Provenance, Score, SequenceLocation, Stoichiometry, Xref

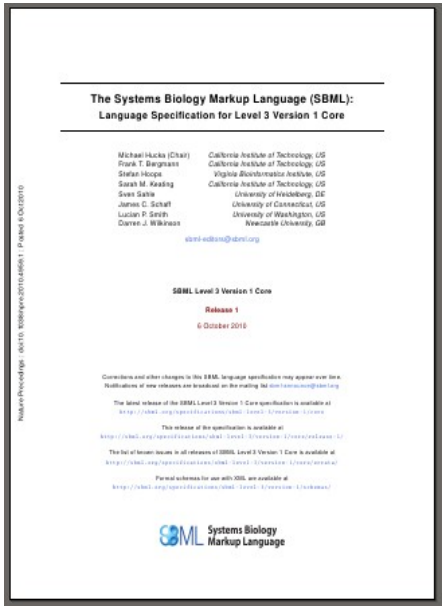
Resource Description Framework - RDF

- Language of the semantic web
- Semantic entirely embedded in the language (does not require external schemas and specifications)
- Series of statements

Subject	Predicate	Object
EGFR	*located_in*	plasma membrane
P00533	OBO_REL:0000008	GO:0005886
(UniProt)	(OBO Relation ontology)	(Gene Ontology)

“XML” Vs RDF



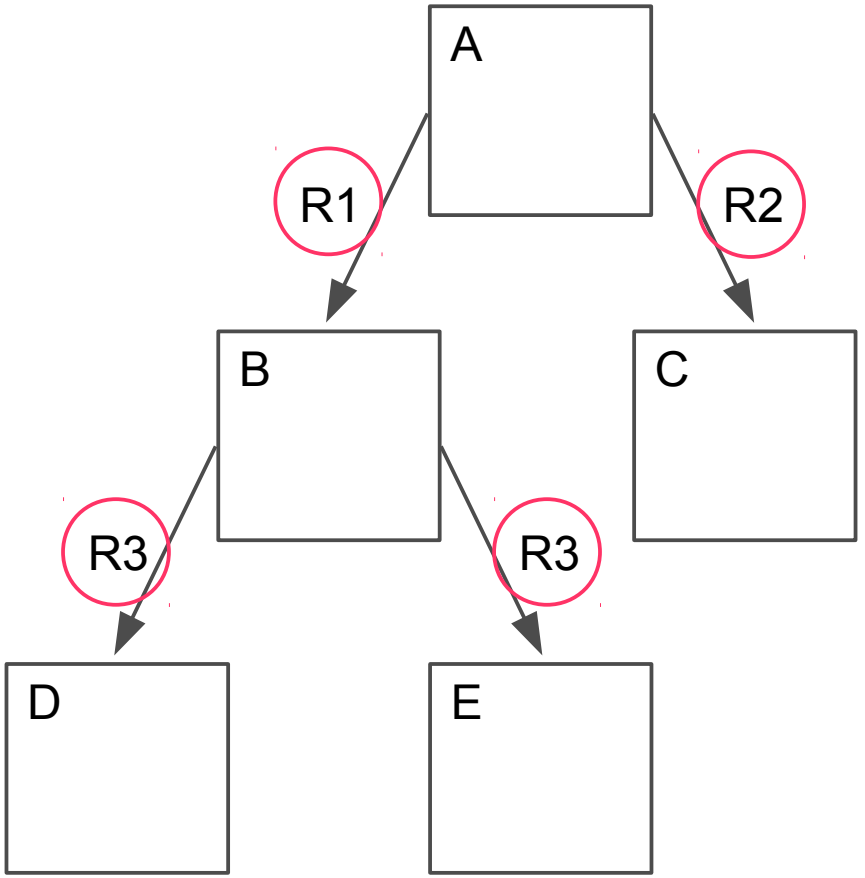

The Systems Biology Markup Language (SBML):
Language Specification for Level 3 Version 1 Core

SBML Level 3 Version 1 Core

Release 1

6 October 2010

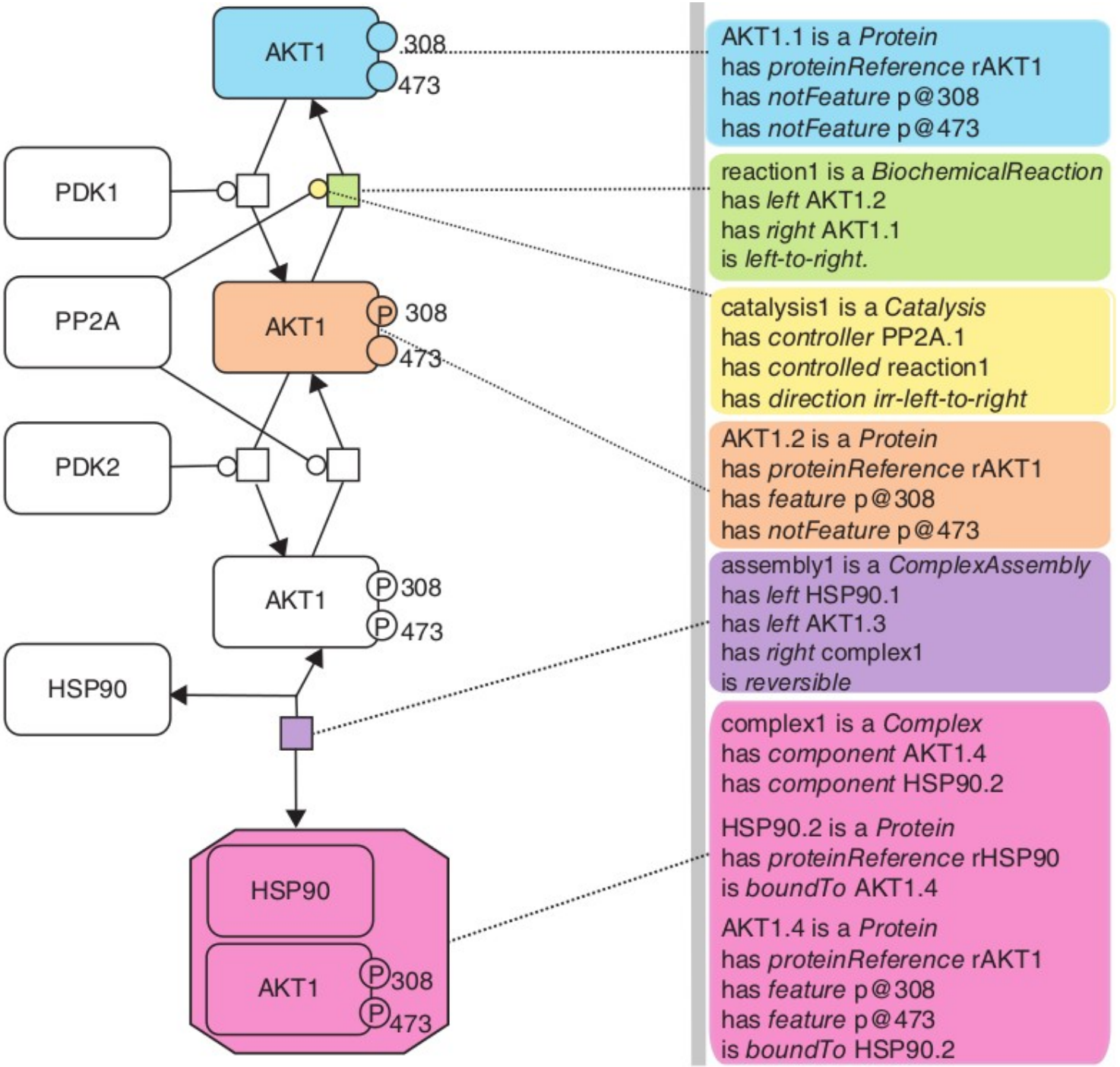
Relationships defined in another document



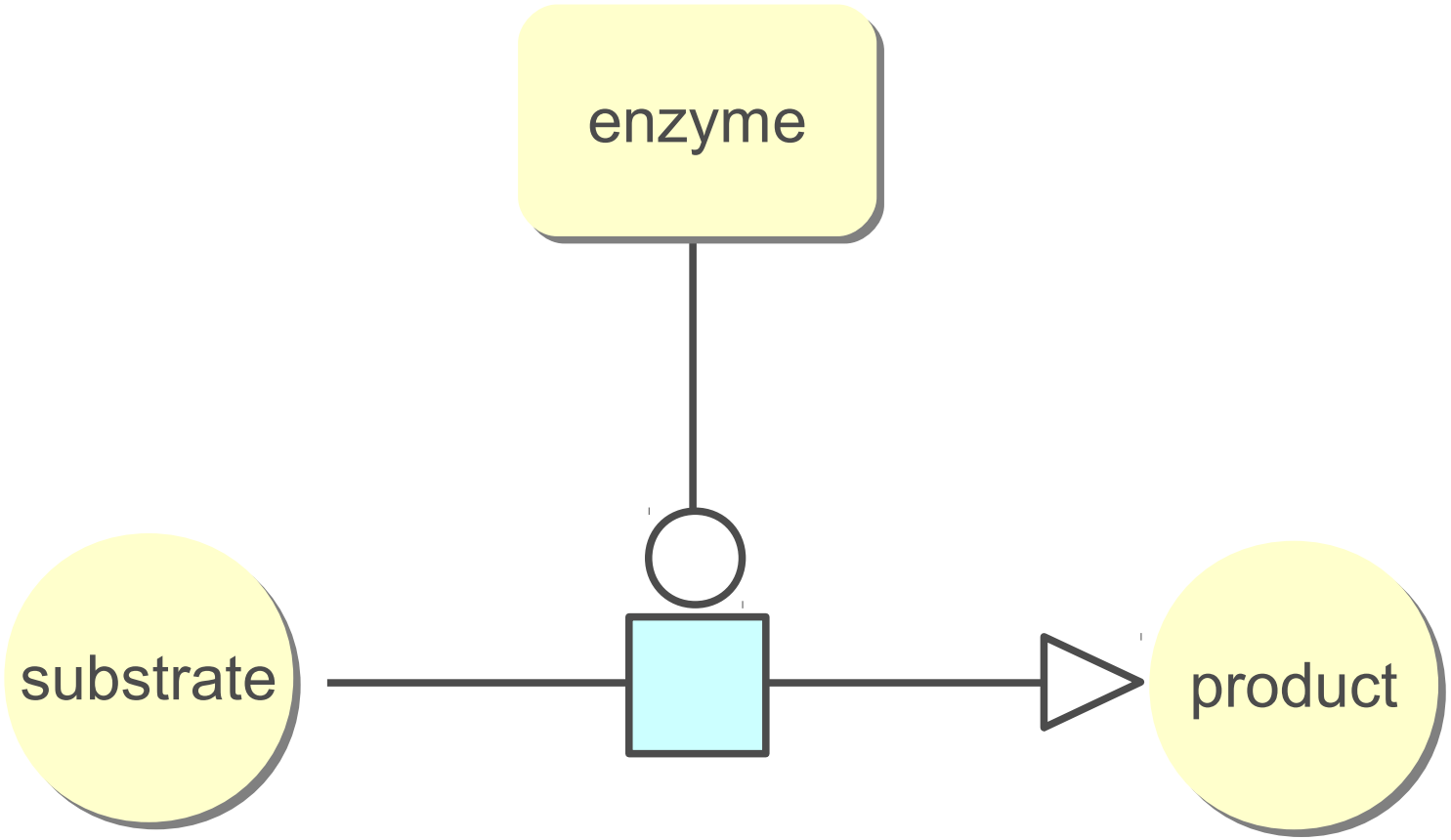
Relationships defined in the pathway

Web Ontology Language - OWL

- BioPAX contains classes, relations and properties, constraints, objects, values.
- Classes are arranged in a specialisation hierarchy. E.g. a “protein” is a “physical entity”
- Classes may have properties of specific types. The types are linked to other classes by relations. E.g. “reaction X” has *participant* “protein P”. An attribute is a property that has a simple type.
- Constraints define allowable values and connexions. E.g. “MOLECULAR_WT” must be a positive real number
- Objects are instances of classes.


AKT1
308
473
PDK1
PP2A
AKT1
P
308
473
PDK2
AKT1
P
308
P
473
HSP90
HSP90
AKT1
P
308
P
473
AKT1.1 is a Protein
has proteinReference rAKT1
has notFeature p@308
has notFeature p@473
reaction1 is a BiochemicalReaction
has left AKT1.2
has right AKT1.1
is left-to-right.
catalysis1 is a Catalysis
has controller PP2A.1
has controlled reaction1
has direction irr-left-to-right
AKT1.2 is a Protein
has proteinReference rAKT1
has feature p@308
has notFeature p@473
assembly1 is a ComplexAssembly
has left HSP90.1
has left AKT1.3
has right complex1
is reversible
complex1 is a Complex
has component AKT1.4
has component HSP90.2
HSP90.2 is a Protein
has proteinReference rHSP90
is boundTo AKT1.4
AKT1.4 is a Protein
has proteinReference rAKT1
has feature p@308
has feature p@473
is boundTo HSP90.2

A catalysis in BioPAX



A catalysis in BioPAX (L2)

```
<!-- physicalEntities -->

<bp:smallMolecule rdf:ID="smallMolecule1" />
<bp:smallMolecule rdf:ID="smallMolecule2" />
<bp:protein rdf:ID="protein1">

<!-- physicalEntityParticipants -->

<bp:physicalEntityParticipant rdf:ID="substrate">
    <bp:STOICHIOMETRIC-COEFFICIENT>1.0</bp:STOICHIOMETRIC-COEFFICIENT>
    <bp:PHYSICAL-ENTITY rdf:resource="#smallMolecule1" />
</bp:physicalEntityParticipant>
<bp:physicalEntityParticipant rdf:ID="product">
    <bp:STOICHIOMETRIC-COEFFICIENT>1.0</bp:STOICHIOMETRIC-COEFFICIENT>
    <bp:PHYSICAL-ENTITY rdf:resource="#smallMolecule2" />
</bp:physicalEntityParticipant>
<bp:physicalEntityParticipant rdf:ID="enzyme">
    <bp:PHYSICAL-ENTITY rdf:resource="#protein1" />
</bp:physicalEntityParticipant>

<!-- physicalInteractions -->

<bp:biochemicalReaction rdf:ID="biochemicalReaction1">
    <bp:LEFT rdf:resource="#substrate">
    <bp:RIGHT rdf:resource="#product">
</bp:biochemicalReaction>
<bp:catalysis rdf:ID="catalysis1">
    <bp:CONTROLLER rdf:resource="#enzyme" />
    <bp:CONTROLLED rdf:resource="#biochemicalReaction1"
</bp:catalysis>
```

A catalysis in BioPAX (L2)

```
<!-- physicalEntityParticipants -->

<bp:physicalEntityParticipant rdf:ID="substrate">
    <bp:STOICHIOMETRIC-COEFFICIENT>1.0</bp:STOICHIOMETRIC-COEFFICIENT>
    <bp:PHYSICAL-ENTITY>
        <bp:smallMolecule rdf:ID="smallMolecule1" />
    </bp:PHYSICAL-ENTITY>
</bp:physicalEntityParticipant>
<bp:physicalEntityParticipant rdf:ID="product">
    <bp:STOICHIOMETRIC-COEFFICIENT>1.0</bp:STOICHIOMETRIC-COEFFICIENT>
    <bp:PHYSICAL-ENTITY>
        <bp:smallMolecule rdf:ID="smallMolecule2" />
    </bp:PHYSICAL-ENTITY>
</bp:physicalEntityParticipant>
<bp:physicalEntityParticipant rdf:ID="enzyme">
    <bp:PHYSICAL-ENTITY>
        <bp:protein rdf:ID="protein1">
    </bp:PHYSICAL-ENTITY>
</bp:physicalEntityParticipant>

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<bp:biochemicalReaction rdf:ID="biochemicalReaction1">
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</bp:catalysis>
```


A catalysis in BioPAX (L2)

```
<!-- physicalInteractions -->

<bp:biochemicalReaction rdf:ID="biochemicalReaction1">
    <bp:LEFT>
        <bp:physicalEntityParticipant>
            <bp:STOICHIOMETRIC-COEFFICIENT>1.0</bp:STOICHIOMETRIC-COEFFICIENT>
            <bp:PHYSICAL-ENTITY>
                <bp:smallMolecule rdf:ID="smallMolecule1" />
            </bp:PHYSICAL-ENTITY>
        </bp:physicalEntityParticipant>
    </bp:LEFT>
    <bp:RIGHT>
        <bp:physicalEntityParticipant rdf:ID="product">
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            <bp:PHYSICAL-ENTITY>
                <bp:smallMolecule rdf:ID="smallMolecule2" />
            </bp:PHYSICAL-ENTITY>
        </bp:physicalEntityParticipant>
    </bp:RIGHT>
</bp:biochemicalReaction>

<bp:catalysis rdf:ID="catalysis1">
    <bp:CONTROLLER/>
        <bp:physicalEntityParticipant rdf:ID="enzyme">
            <bp:PHYSICAL-ENTITY>
                <bp:protein rdf:ID="protein1">
            </bp:PHYSICAL-ENTITY>
        </bp:physicalEntityParticipant>
    </bp:CONTROLLER>
    <bp:CONTROLLED rdf:resource=”#biochemicalReaction1”
</bp:catalysis>
```


A catalysis in BioPAX (L2)

```
<!-- physicalInteractions -->

<bp:catalysis rdf:ID="catalysis1">
    <bp:CONTROLLER/>
        <bp:physicalEntityParticipant rdf:ID="enzyme">
            <bp:PHYSICAL-ENTITY>
                <bp:protein rdf:ID="protein1">
            </bp:PHYSICAL-ENTITY>
        </bp:physicalEntityParticipant>
    </bp:CONTROLLER>
    <bp:CONTROLLED>
        <bp:biochemicalReaction rdf:ID="biochemicalReaction1">
            <bp:LEFT>
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                    <bp:STOICHIOMETRIC-COEFFICIENT>1.0</bp:STOICHIOMETRIC-COEFFICIENT>
                    <bp:PHYSICAL-ENTITY>
                        <bp:smallMolecule rdf:ID="smallMolecule1" />
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                </bp:physicalEntityParticipant>
            </bp:LEFT>
            <bp:RIGHT>
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                    <bp:PHYSICAL-ENTITY>
                        <bp:smallMolecule rdf:ID="smallMolecule2" />
                    </bp:PHYSICAL-ENTITY>
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            </bp:RIGHT>
        </bp:biochemicalReaction>
    </bp:CONTROLLED>
</bp:catalysis>
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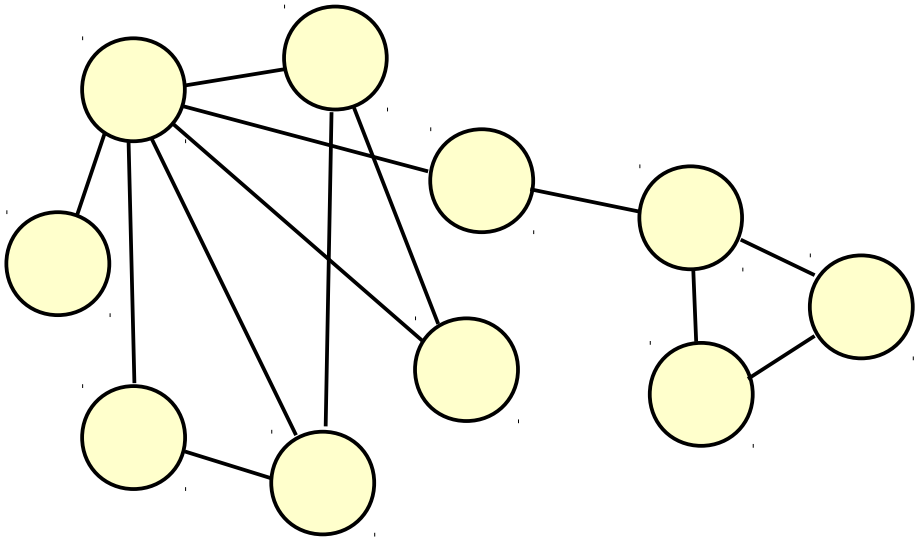
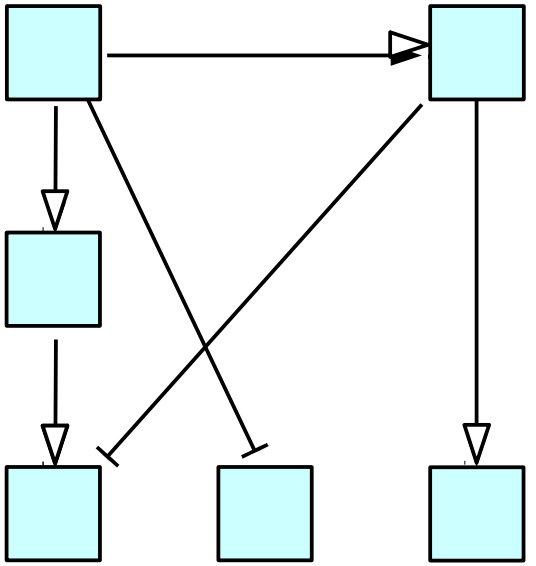
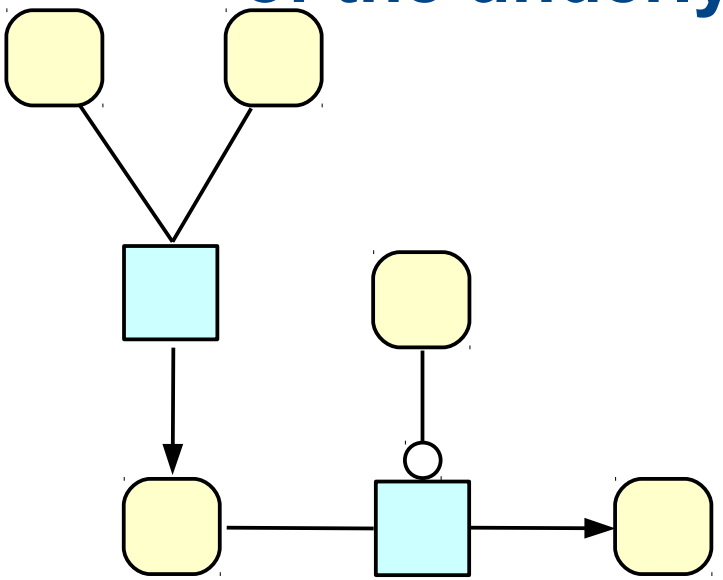
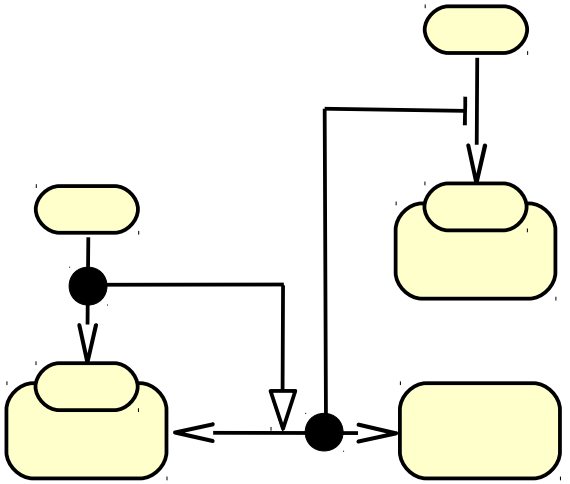




The four views are orthogonal projections of the underlying biological phenomena





Biochemical pathways

What is a “pathway”

Wikipedia (October 14th 2013): “In biochemistry, metabolic pathways are series of chemical reactions occurring within a cell. In each pathway, a principal chemical is modified by a series of chemical reactions. Enzymes catalyze these reactions [...]”

Different types: Signalling pathways, metabolic networks, gene regulatory networks ...

Many “pathway” databases:

Biocarta, Bio/MetaCyc, Ingenuity IPA, KEGG Pathway, Panther pathways, Reactome, STKE, Wikipathways etc.

➜ Detailed representation of reality based on observation

What is a “model”

Wikipedia (October 14th 2013): “A mathematical model is a description of a system using mathematical concepts and language.”

A model is made up of variables, functions and constraints

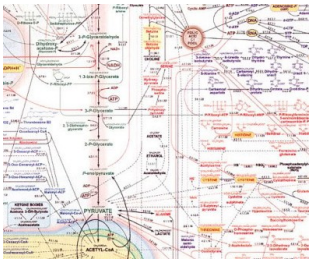
Different types: Dynamical models, logical models, rule-based models, multi-agent models, statistical models ...

Different levels of granularity for the variables and precision for the functions, based on the questions being asked and the data available

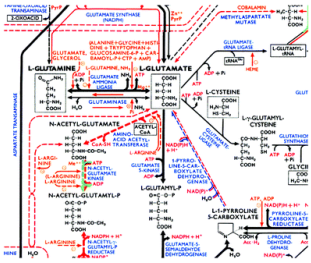
➜ Abstract representation of reality based on needs

Biochemical pathways are old … or not so much

- Gortner, R.A. *Outlines of Biochemistry* (Wiley, New York, 1949)
- Nicholson (1970)



Michal (1984)



Biochemical pathways are old … or not so much

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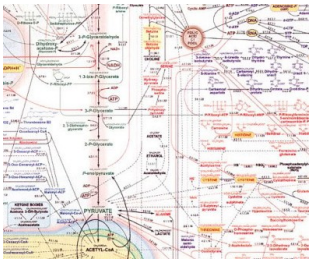
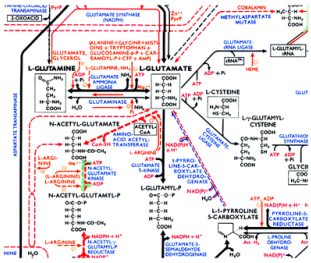


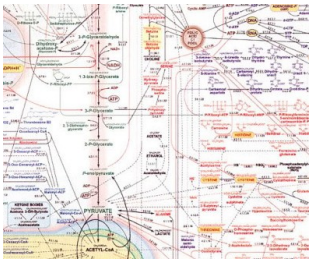
Michal (1984)



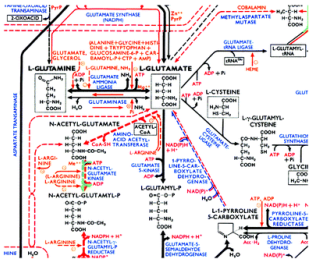
"Hand drawing" on paper
→ no software-based browsing, processing and analysis

Biochemical pathways are old … or not so much

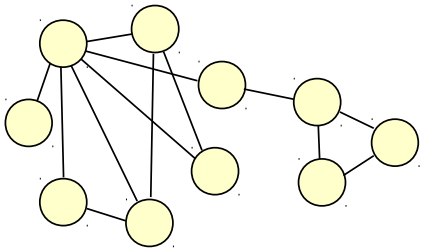
- Gortner, R.A. *Outlines of Biochemistry* (Wiley, New York, 1949)
- Nicholson (1970)

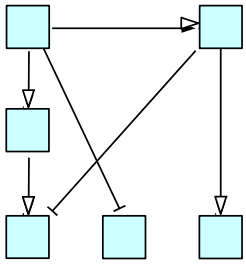


Michal (1984)

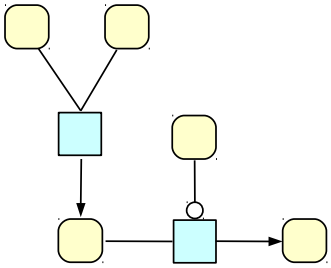


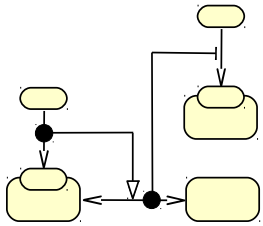
- 1990s: high-throughput data generation → Large amount of knowledge
  increase in computing power → automatic reconstruction, browsing and analysis
- Databases: KEGG (1995), EcoCyc (1994), Reactome (2000)
- Formats: BioPAX (2000), SBML (2000), PSI-MI (2002)



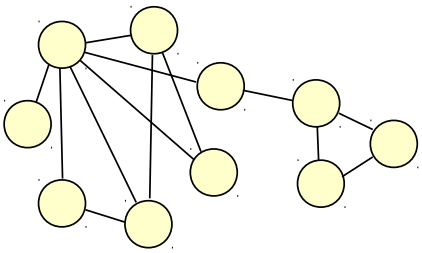


The four views of systems biology



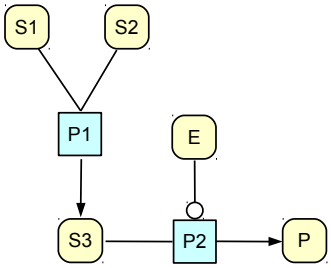


Interaction networks



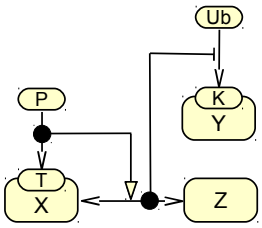
- Non-directional
- Non-sequential
- Non-mechanistic
- Statistical modelling
- Functional genomics

Process Descriptions



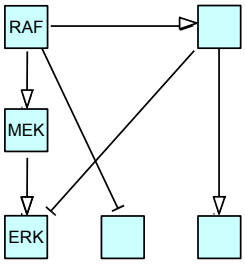
- Directional
- Sequential
- Mechanistic
- Process modelling
- Biochemistry, Metabolic networks
- Generally within “closed world”
- Subjected to combinatorial explosion

Entity Relationships

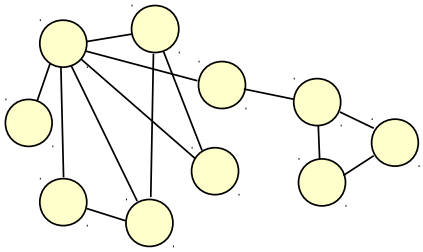


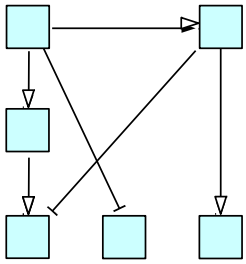
- Directional
- Non-sequential
- Mechanistic
- Rule-based modelling
- Molecular Biology
- “Open world”
- Independent rules: no explosion

Activity-Flows (influence diagrams)

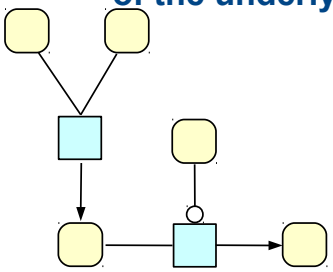


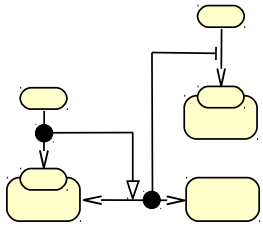
- Directional
- Sequential
- Non-mechanistic
- Logical modelling
- Signalling pathways, gene regulatory networks

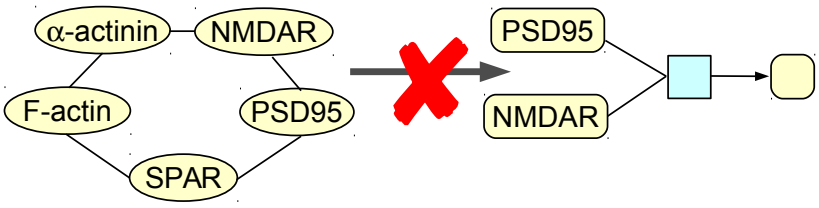


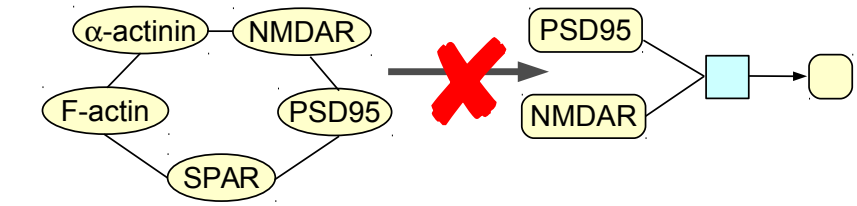


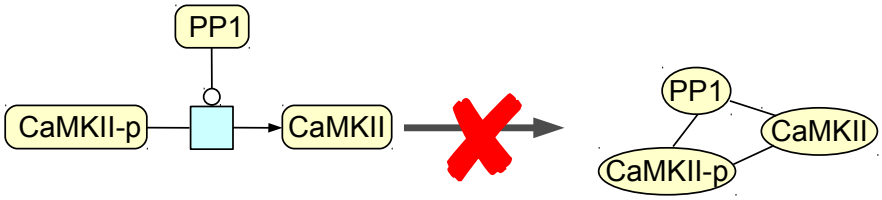
The four views are orthogonal projections of the underlying biological phenomena






α-actinin
NMDAR
F-actin
PSD95
SPAR
PSD95
NMDAR


α-actinin
NMDAR
F-actin
PSD95
SPAR
PSD95
NMDAR


PP1
CaMKII-p
CaMKII
PP1
CaMKII
CaMKII-p

Open world

Anything not explicitly stated is unknown

Failure to observe does not imply inexistence

New pieces of knowledge do not affect prior pieces

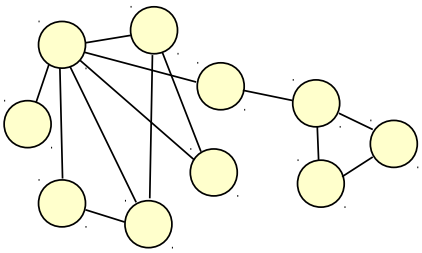
Closed world

Anything not explicitly stated does not exist

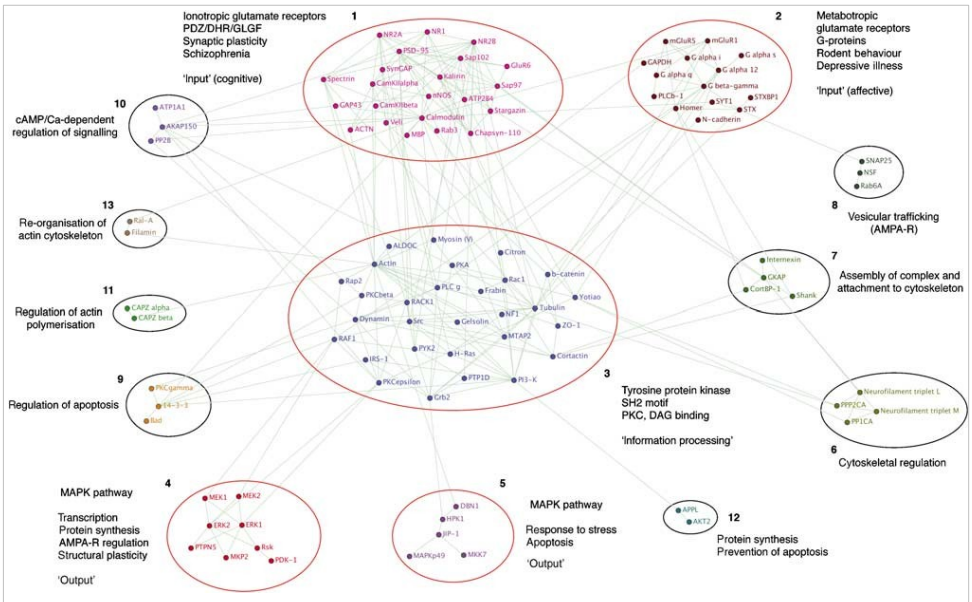
Failure to observe implies inexistence

New pieces of knowledge might change the meaning of prior pieces

Interaction networks

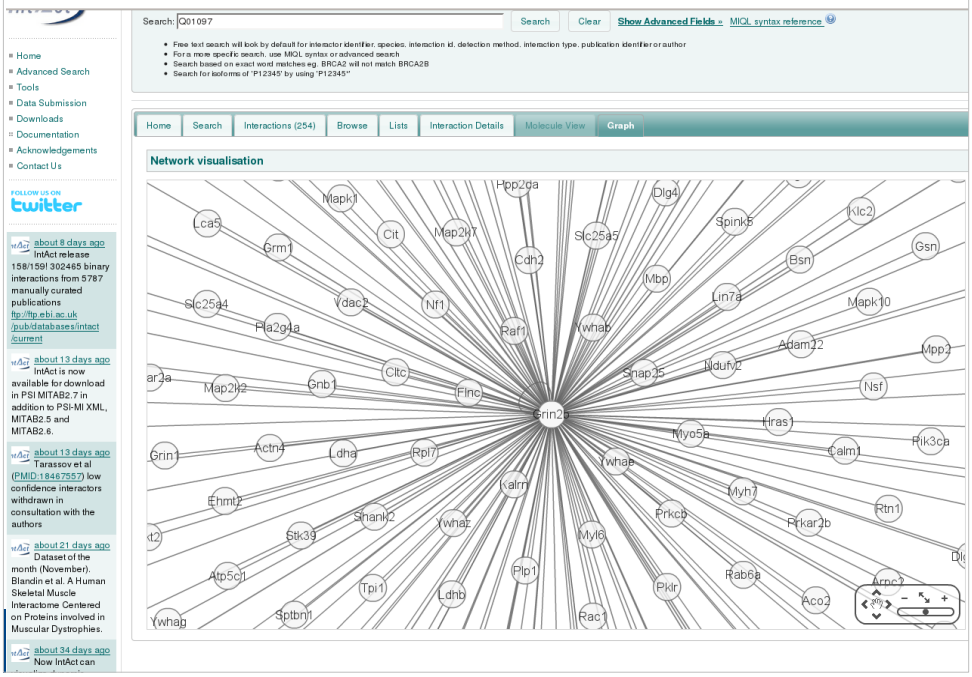


- Non-directional
- Non-sequential
- Non-mechanistic
- Statistical modelling
- Functional genomics



Pocklington AJ, Cumiskey M, Armstrong JD, Grant SG. Mol Syst Biol. 2006;2:2006.0023.

http://www/ebi.ac.uk/IntAct



about 8 days ago
IntAct release 158/159| 302465 binary interactions from 5787 manually curated publications ftp://ftp.ebi.ac.uk/pub/databases/intact/current

about 13 days ago
IntAct is now available for download in PSI MITAB2.7 in addition to PSI-MI XML, MITAB2.5 and MITAB2.6.

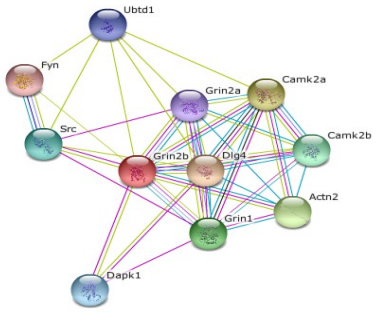
about 13 days ago
Tarassov et al (PMID:18467557) low confidence interactors withdrawn in consultation with the authors

about 21 days ago
Dataset of the month (November). Blandin et al. A Human Skeletal Muscle Interactome Centered on Proteins involved in Muscular Dystrophies.

about 34 days ago
Now IntAct can

http://string-db.org/

Home · Download · Help/Info STRING 9.0



This is the **evidence view**. Different line colors represent the types of evidence for the association.

(requires Flash player 10 or better)

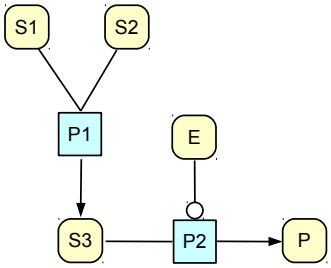
Your Input:

Grin2b glutamate receptor, ionotropic, NMDA2B (epsilon 2) Gene; NMDA receptor subtype of glutamate-gated ion channels with high calcium permeability and voltage-dependent sensitivity to magnesium. Mediated by glycine (1482 aa)
(Mus musculus)

Predicted Functional Partners:

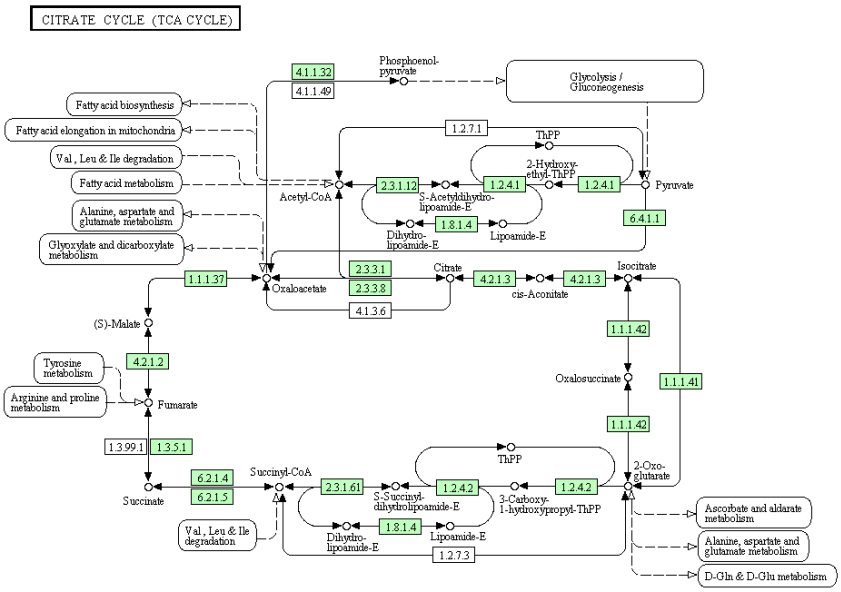
Neighborhood
Gene Fusion
Co-occurrence
Coexpression
Experiments
Databases
Textmining
(Homology)
Score

Process Descriptions

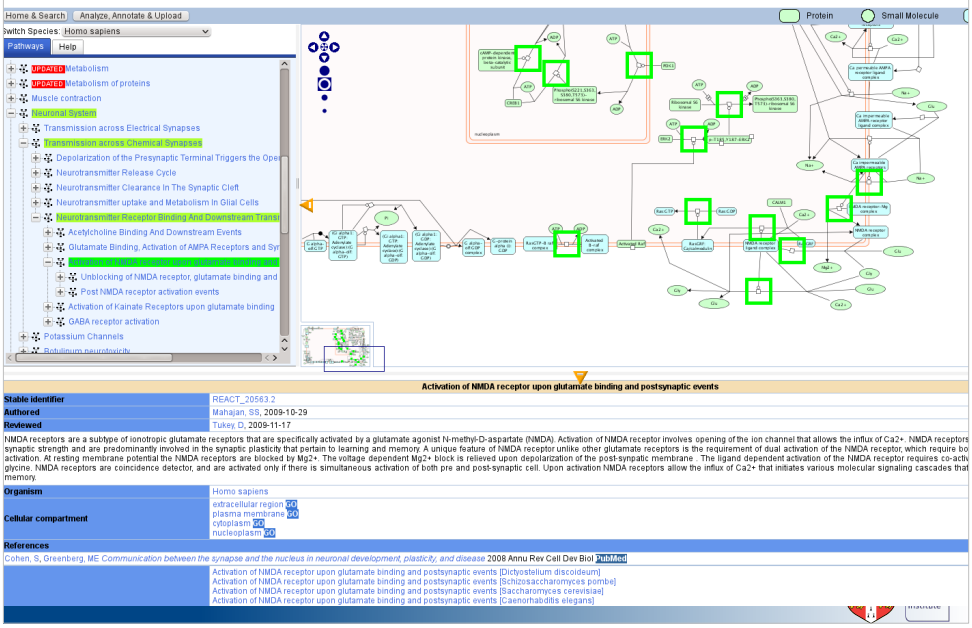


- Directional
- Sequential
- Mechanistic
- Process modelling
- Biochemistry, Metabolic networks
- Generally within “closed world”
- Subjected to combinatorial explosion

http://www.genome.jp/kegg/pathway.html



http://www.reactome.org



Activation of NMDA receptor upon glutamate binding and postsynaptic events

Stable identifier	REACT_20563.2
Authored	Mahajan, SS, 2009-10-29
Reviewed	Tukey, D, 2009-11-17

NMDA receptors are a subtype of ionotropic glutamate receptors that are specifically activated by a glutamate agonist N-methyl-D-aspartate (NMDA). Activation of NMDA receptor involves opening of the ion channel that allows the influx of Ca2+. NMDA receptors synaptic strength and are predominantly involved in the synaptic plasticity that pertain to learning and memory. A unique feature of NMDA receptor unlike other glutamate receptors is the requirement of dual activation of the NMDA receptor, which require bo activation. At resting membrane potential the NMDA receptors are blocked by Mg2+. The voltage dependent Mg2+ block is relieved upon depolarization of the post-synaptic membrane . The ligand dependent activation of the NMDA receptor requires co-activ glycine. NMDA receptors are coincidence detector, and are activated only if there is simultaneous activation of both pre and post-synaptic cell. Upon activation NMDA receptors allow the influx of Ca2+ that initiates various molecular signaling cascades that memory.

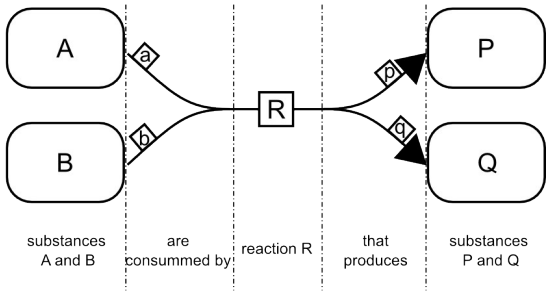
Organism	Homo sapiens
Cellular compartment	extracellular region GO plasma membrane GO cytoplasm GO nucleoplasm GO

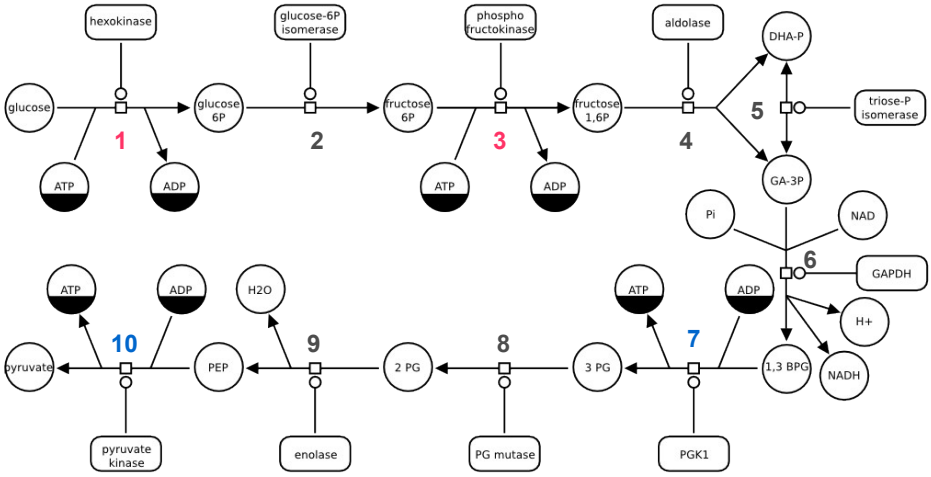
References

Cohen, S, Greenberg, ME *Communication between the synapse and the nucleus in neuronal development, plasticity, and disease* 2008 Annu Rev Cell Dev Biol PubMed

Activation of NMDA receptor upon glutamate binding and postsynaptic events [Dictyostelium discoideum]
Activation of NMDA receptor upon glutamate binding and postsynaptic events [Schizosaccharomyces pombe]
Activation of NMDA receptor upon glutamate binding and postsynaptic events [Saccharomyces cerevisiae]
Activation of NMDA receptor upon glutamate binding and postsynaptic events [Caenorhabditis elegans]

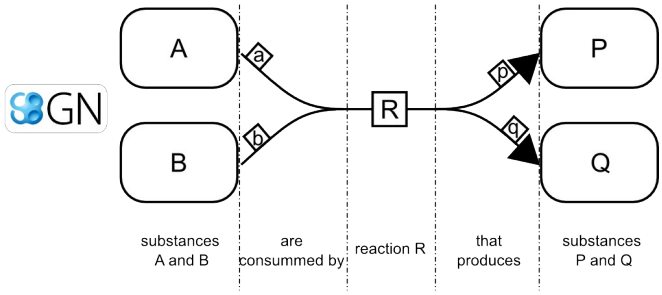
A biochemical reaction is a process



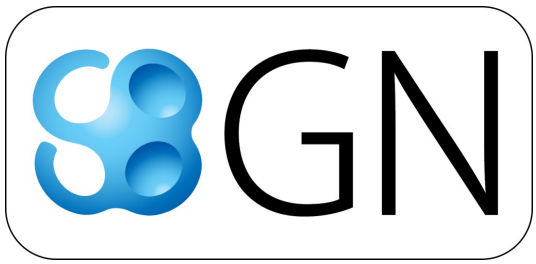


ATP is consumed by processes 1 and 3, and produced by processes 7 and 10

A biochemical reaction is a process



The Systems Biology Graphical Notation



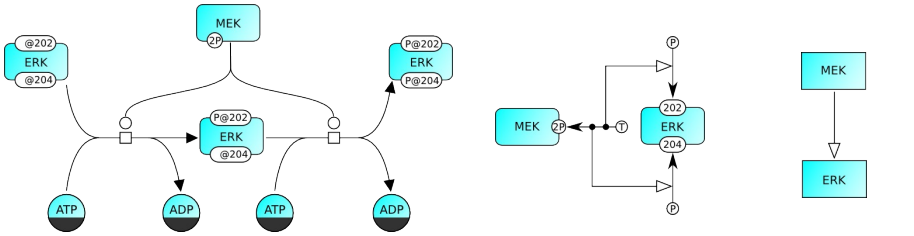
http://sbgn.org/

Unambiguous consensual visual notation

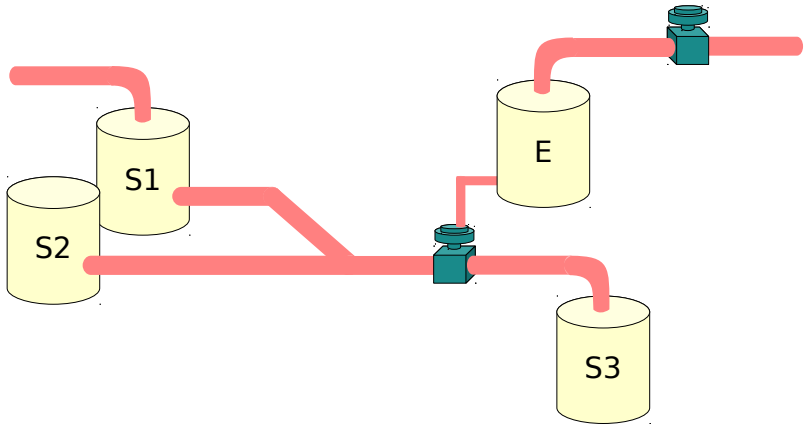
- An unambiguous way of graphically describing and interpreting biochemical and cellular events
- Limited amount of symbols
  Re-use existing symbols
  ☞ Smooth learning curve
- Can represent logical or mechanistic models, biochemical pathways, at different levels of granularity
- Detailed technical specification, precise data-models, standard API and growing software support
- Developed over four years by a diverse community, including biologists, modellers, computer scientists etc.

Graph trinity: three languages in one notation

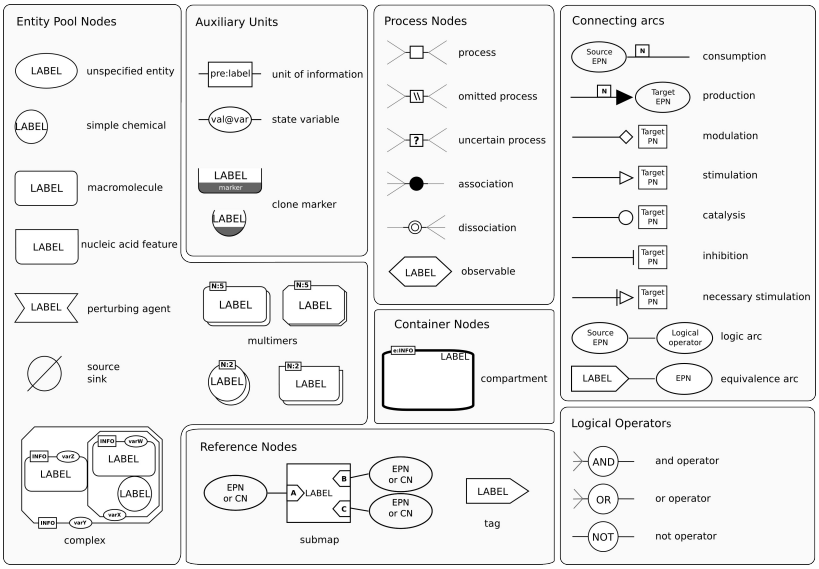
Process Descriptions | Entity Relationships | Activity Flows



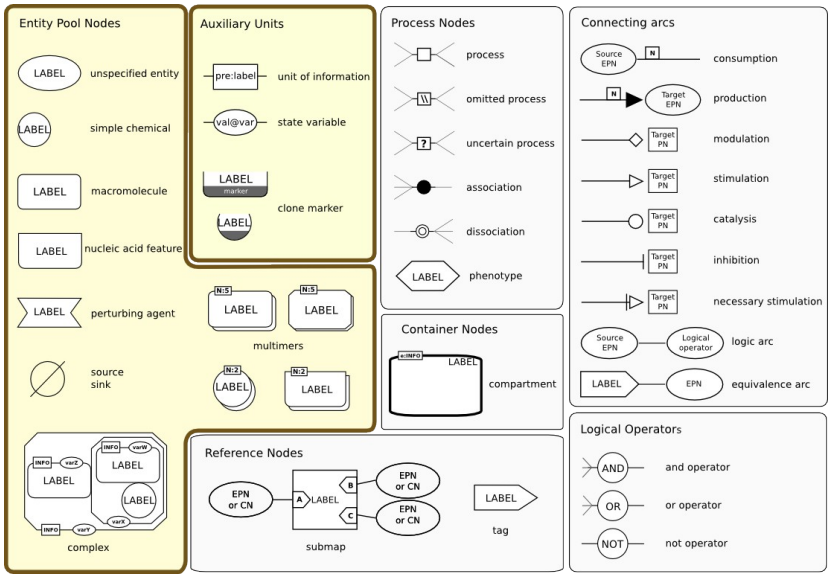
Process Descriptions can be viewed as pipelines



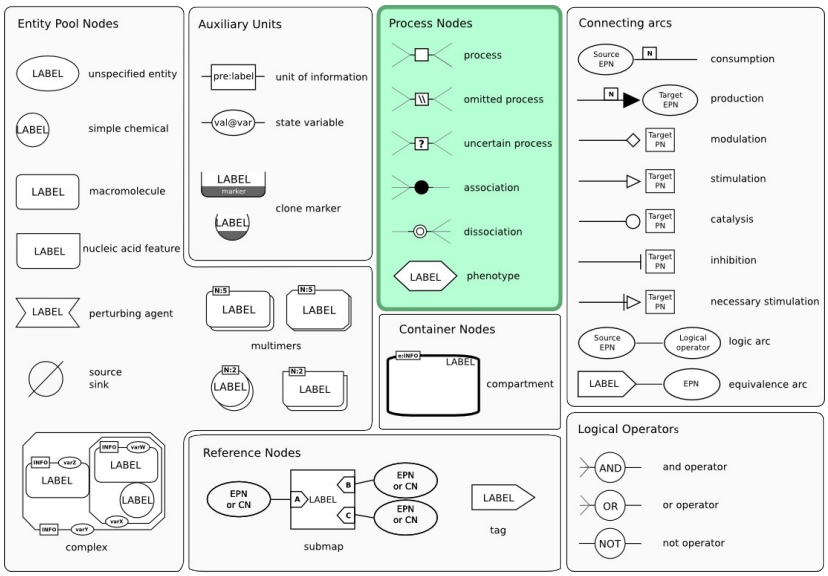
SBGN Process Diagram L1 reference card



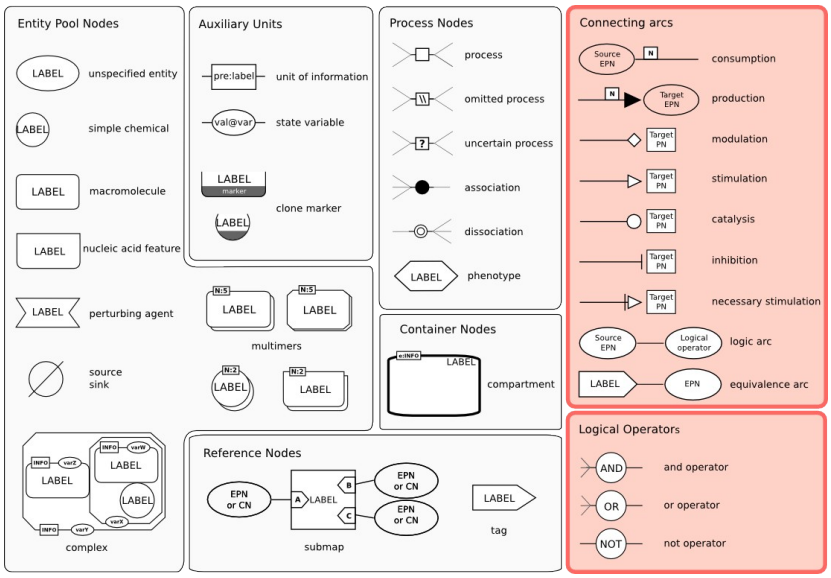
Entity Pool Nodes



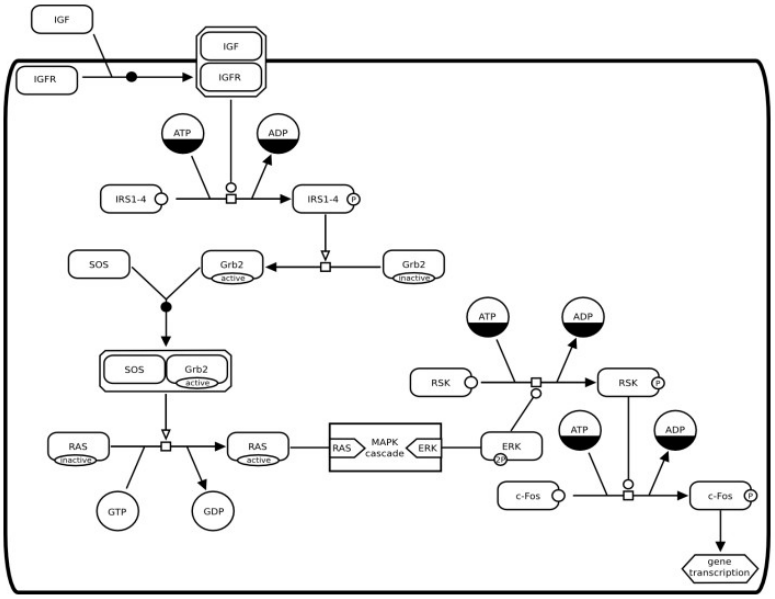
Process Nodes



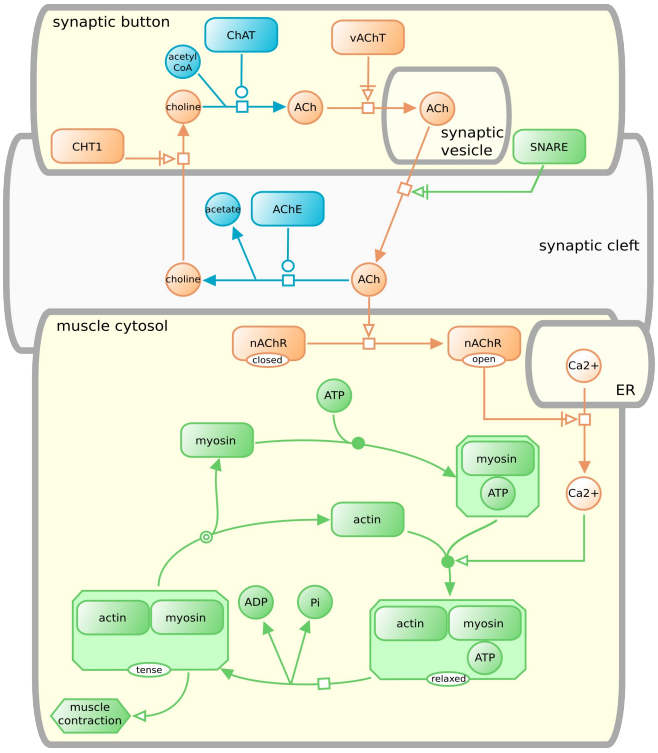
Connecting arcs

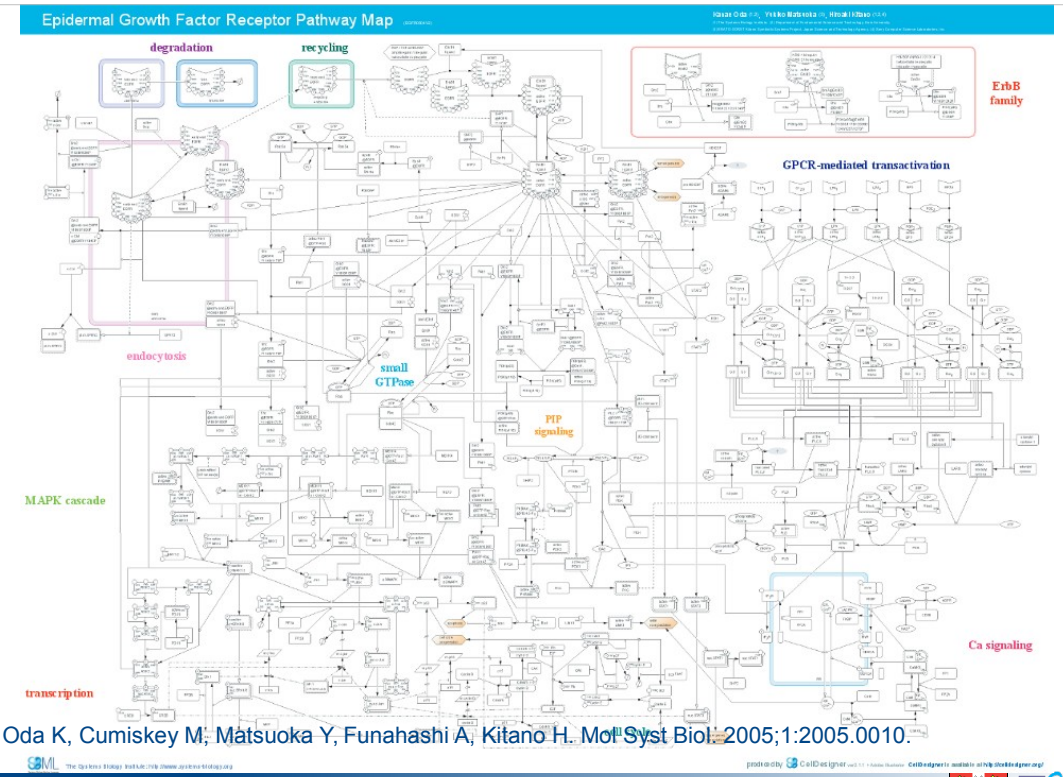


Signalling


IGF
IGFR
IGF
IGFR
ATP
ADP
IRS1-4
IRS1-4
P
SOS
Grb2
active
Grb2
inactive
SOS
Grb2
active
RAS
inactive
RAS
active
GTP
GDP
RAS
MAPK
cascade
ERK
ATP
ADP
RSK
RSK
P
ATP
ADP
c-Fos
c-Fos
P
gene
transcription

Multicellular



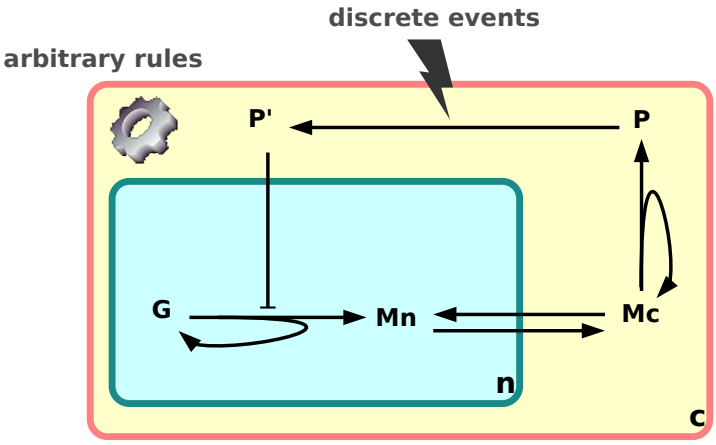


Oda K, Cumiskey M, Matsuoka Y, Funahashi A, Kitano H. Mol Syst Biol. 2005;1:2005.0010.

The Systems Biology Markup Language

http://sbml.org/

Systems Biology Markup Language



Systems Biology Markup Language

```
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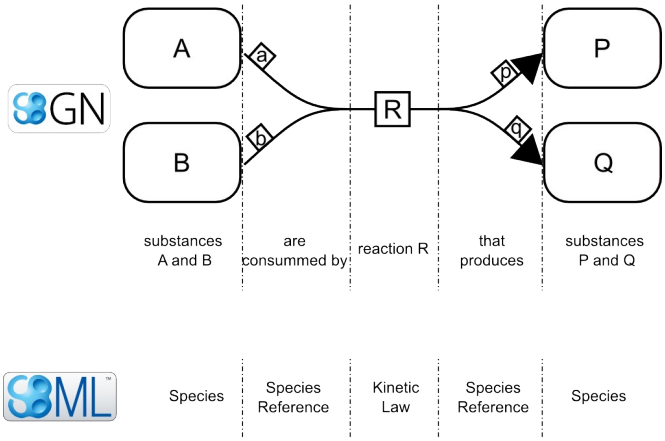
      xmlns="http://www.sbml.org/sbml/level3/version1/core">
  <model>
    <listOfFunctionDefinitions> <!-- --> </listOfFunctionDefinitions>
    <listOfUnitDefinitions> <!-- --> </listOfUnitDefinitions>
    <listOfCompartments> <!-- --> </listOfCompartments>
    <listOfSpecies> <!-- --> </listOfSpecies>
    <listOfParameters> <!-- --> </listOfParameters>
    <listOfInitialAssignments> <!-- --> </listOfInitialAssignments>
    <listOfRules> <!-- --> </listOfRules>
    <listOfConstraints> <!-- --> </listOfConstraints>
    <listOfReactions> <!-- --> </listOfReactions>
    <listOfEvents> <!-- --> </listOfEvents>
  </model>
</sbml>
```

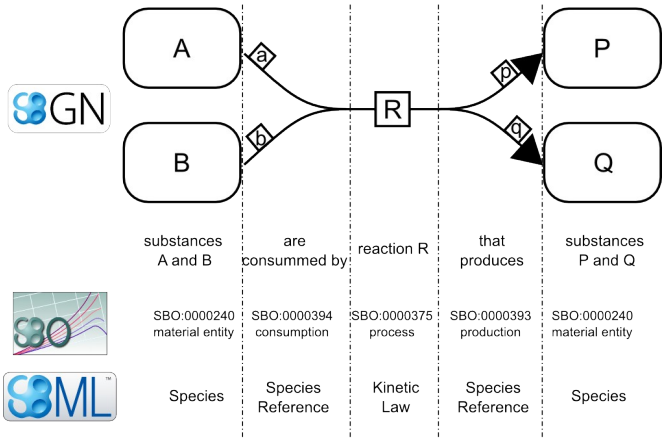
variables

relationships

A biochemical reaction is a process



A biochemical reaction is a process



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  <model name="Simple Model">
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      <compartment id="cell" size="1" />
    </listOfCompartments>
    <listOfSpecies>
      <species id="A" compartment="cell" initialConcentration="1"/>
      <species id="B" compartment="cell" initialConcentration="1"/>
    </listOfSpecies>
    <listOfParameters>
      <parameter id="k1" value="0.1"/>
    </listOfParameters>
    <listOfReactions>
      <reaction id="r1" reversible="false">
      <listOfReactants>
          <speciesReference species="A"/>
      </listOfReactants>
      <listOfProducts>
        <speciesReference species="B"/>
      </listOfProducts>
      <kineticLaw>
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          <apply>
            <times/>
            <ci> cell </ci>
            <ci> k1 </ci>
            <ci> A </ci>
          </apply>
        </math>
      </kineticLaw>
    </reaction>
    </listOfReactions>
  </model>
</sbml>
```
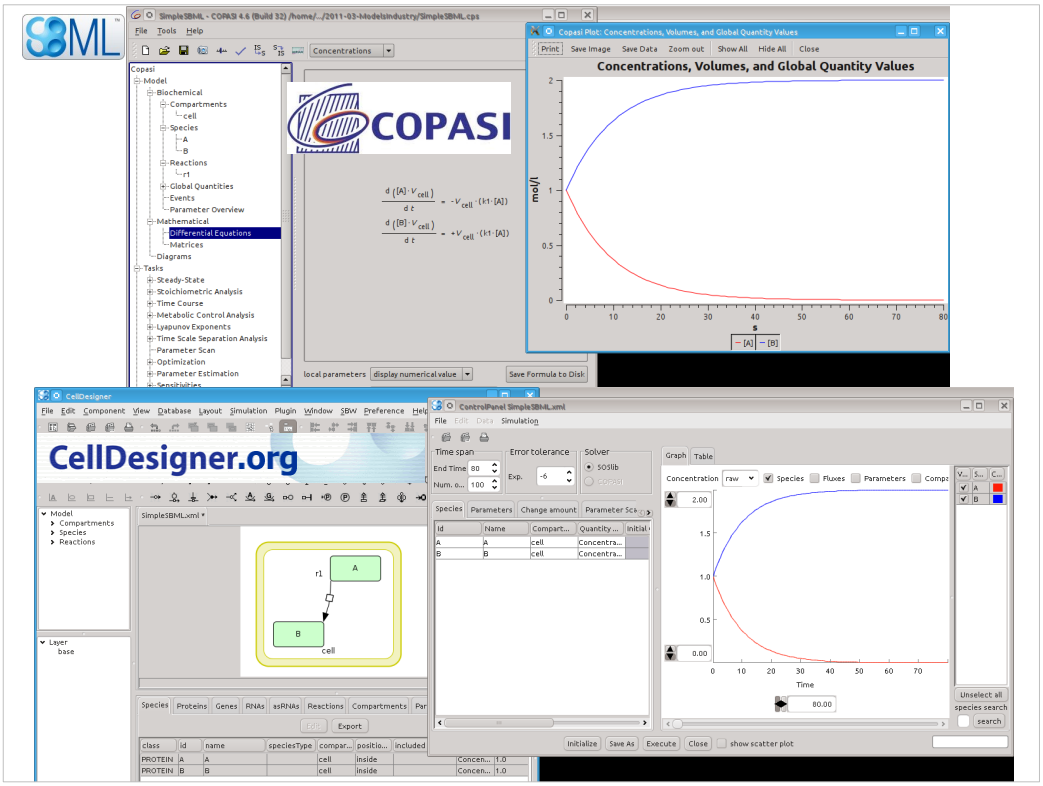
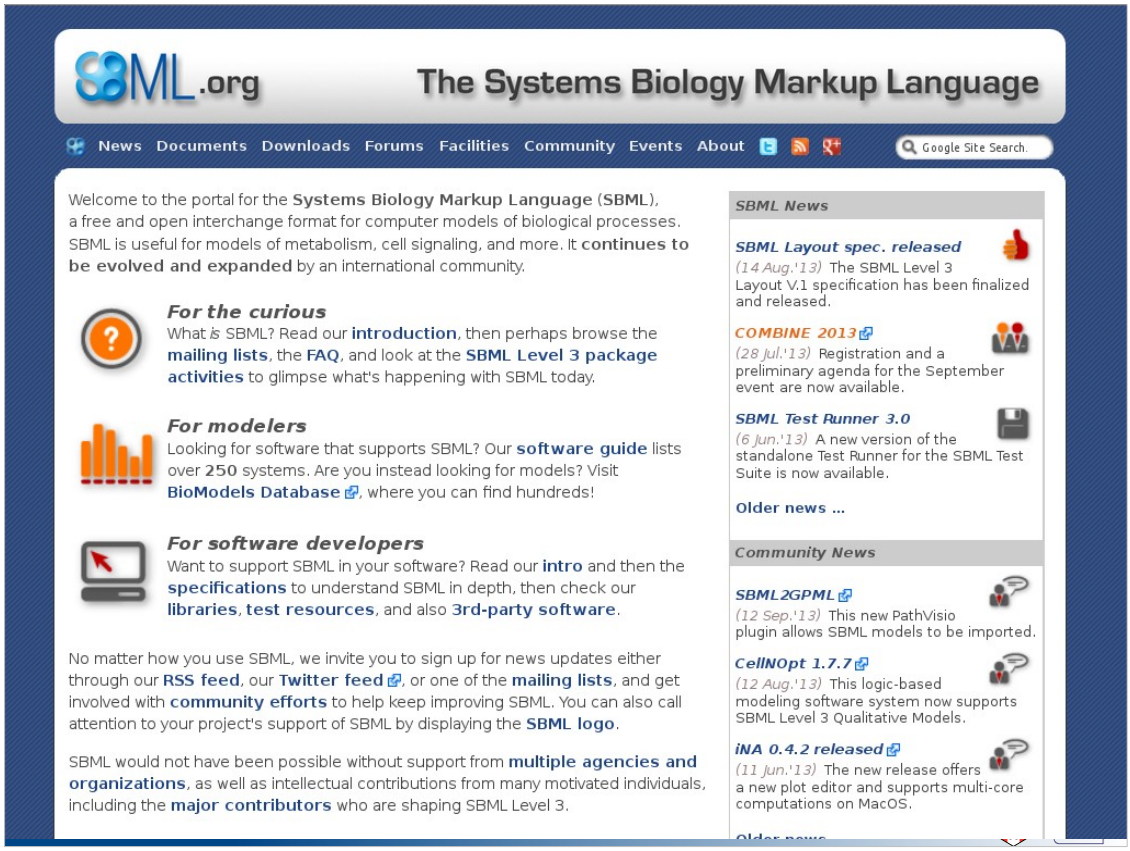

A very simple SBML file (A ⟶ B)


SBML
COPASI
Concentrations, Volumes, and Global Quantity Values
CellDesigner.org

- Core package – public specification
- Flux balance constraint – public specification
- Model composition – public specification
- Qualitative models – public specification
- Graph Layout – public specification
- Graph rendering – specification finalised
- Complex species – specification finalised
- Groups - specification finalised
- Distributions and ranges - specification under discussion
- Spatial diffusion – specification under discussion
- Enhanced metadata – specification under discussion
- Arrays and sets – specification proposed
- Dynamic structures - discussed

SBML Level 3 is modular


SBML.org
The Systems Biology Markup Language
News Documents Downloads Forums Facilities Community Events About
Google Site Search
Welcome to the portal for the Systems Biology Markup Language (SBML), a free and open interchange format for computer models of biological processes. SBML is useful for models of metabolism, cell signaling, and more. It continues to be evolved and expanded by an international community.
For the curious
What is SBML? Read our introduction, then perhaps browse the mailing lists, the FAQ, and look at the SBML Level 3 package activities to glimpse what's happening with SBML today.
For modelers
Looking for software that supports SBML? Our software guide lists over 250 systems. Are you instead looking for models? Visit BioModels Database, where you can find hundreds!
For software developers
Want to support SBML in your software? Read our intro and then the specifications to understand SBML in depth, then check our libraries, test resources, and also 3rd-party software.
No matter how you use SBML, we invite you to sign up for news updates either through our RSS feed, our Twitter feed, or one of the mailing lists, and get involved with community efforts to help keep improving SBML. You can also call attention to your project's support of SBML by displaying the SBML logo.
SBML would not have been possible without support from multiple agencies and organizations, as well as intellectual contributions from many motivated individuals, including the major contributors who are shaping SBML Level 3.
SBML News
SBML Layout spec. released
(14 Aug.'13) The SBML Level 3 Layout V.1 specification has been finalized and released.
COMBINE 2013
(28 Jul.'13) Registration and a preliminary agenda for the September event are now available.
SBML Test Runner 3.0
(6 Jun.'13) A new version of the standalone Test Runner for the SBML Test Suite is now available.
Older news ...
Community News
SBML2GPML
(12 Sep.'13) This new PathVisio plugin allows SBML models to be imported.
CellNOpt 1.7.7
(12 Aug.'13) This logic-based modeling software system now supports SBML Level 3 Qualitative Models.
iNA 0.4.2 released
(11 Jun.'13) The new release offers a new plot editor and supports multi-core computations on MacOS.

SBML supporting tools

- LibSBML: free, open-source programming library to help you read, write, manipulate, translate, and validate SBML files. Written in C++, with bindings for: c#, Python, Java, Perl, Ruby, MatLab, Octave,
- JSBML: free, open-source, pure Java library for reading, writing, and manipulating SBML files (validation done via libSBML)
- SBML converters: Converter from and to SBML, including Octave, XPP, BioPAX, dot, SVG, MDL
- Software guide: 254 software, including modelling and simulation environement, databases, model processing

SBML Software Guide

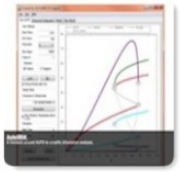
The following pages describe SBML-compatible software packages known to us. We offer different ways of viewing the information, all drawn from the same underlying data collected from the systems' developers via our **software survey**. The *Matrix* provides a table listing all known software and a variety of their features; the *Summary* provides general descriptions of most of the software; and the *Showcase* provides a sequential slideshow of a subset of the software.

Number of software packages listed in the matrix today: **254**.

Go to the SBML Software Matrix

Go to the SBML Software Summary

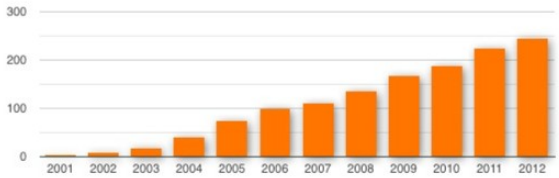
Go to the SBML Software Showcase



Please **use the survey form** to notify us about additions and suggestions.

Historical trend

The following graph shows the total number of known SBML-compatible software packages each year, as counted by the SBML Team. The counts shown are for approximately the middle of each year.

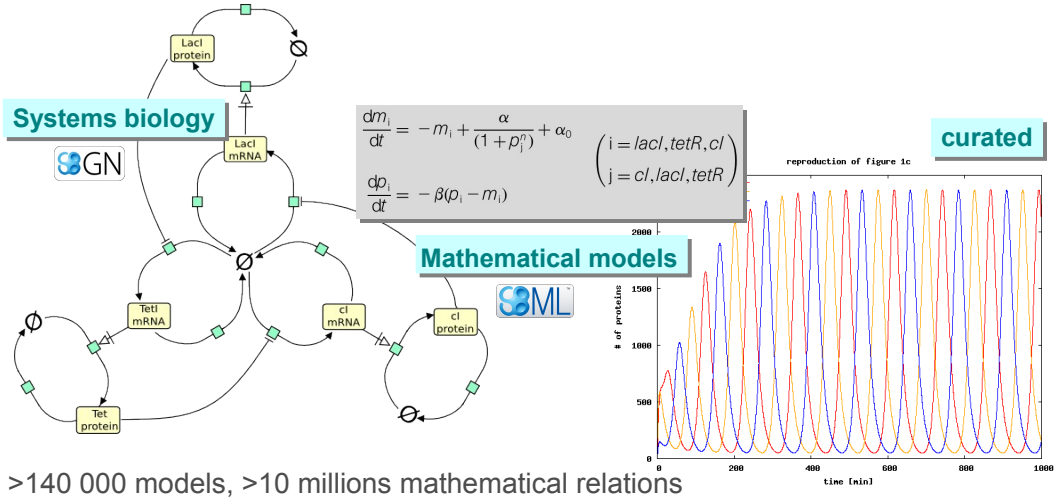


(Note: the flat period in 2007 is an artifact of inadequate record keeping rather than a lull in SBML software development.)

SBML conformance testing

The **SBML Test Suite** provides an operational means of testing SBML support in software simulation and analysis systems. Software authors can choose to make the test results for their software public in the **SBML Test Suite Database**, where you can

BioModels Database – http://www.ebi.ac.uk/biomodels



>140 000 models, >10 millions mathematical relations

Deposition advised by >300 journals, database > 600 citations

1.5 million page requests per year

Submission in SBML and CellML; Export in SBML, CellML, XPP, SciLab, BioPAX, Octave, PDF, VCML, SBGN

EMBL-EBI Services Research Training Industry About us

BioModels Database

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BioModels Database serves as a reliable repository of computational models of biological processes. It hosts models described in peer-reviewed scientific literature and models generated automatically from pathway resources (Path2Models). A large number of models collected from literature are manually curated and semantically enriched with cross-references from external data resources. The resource allows scientific community to store, search and retrieve mathematical models of their interest. In addition, features such as generation of sub-models, online simulation, conversion of models into different representational formats, and programmatic access via web services, are provided.

Models published in the literature

- Browse curated models
- Browse curated models using Taxonomy
- Browse non-curated models

Browse the models in the curated branch. These models have been thoroughly curated, and model elements have been annotated with terms from controlled vocabularies as well as links to relevant data resources.

Path2Models

Submit a model

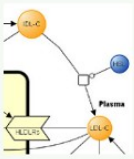
Links

- Main instance at EMBL-EBI, UK
- Mirror at Caltech, USA
- Project on SourceForge
- Web Services
- Download archived models

Model of the month

October, 2013

Why LDL-C rises with age? The model presented here demonstrates that mechanistic changes to cholesterol absorption and LDL-C removal from the plasma with age, can result in a significant rise in LDL-C.



Please read more...

News

Follow us on Twitter

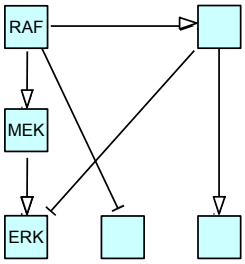
8 October 2013 **SPARQL endpoint available**

The EBI launched a RDF platform. This provides access to various bioinformatics resources (including BioModels Database) using Semantic Web technologies (SPARQL endpoints and RDF dumps are available). Read more about this news.

18 June 2013 **25th release**

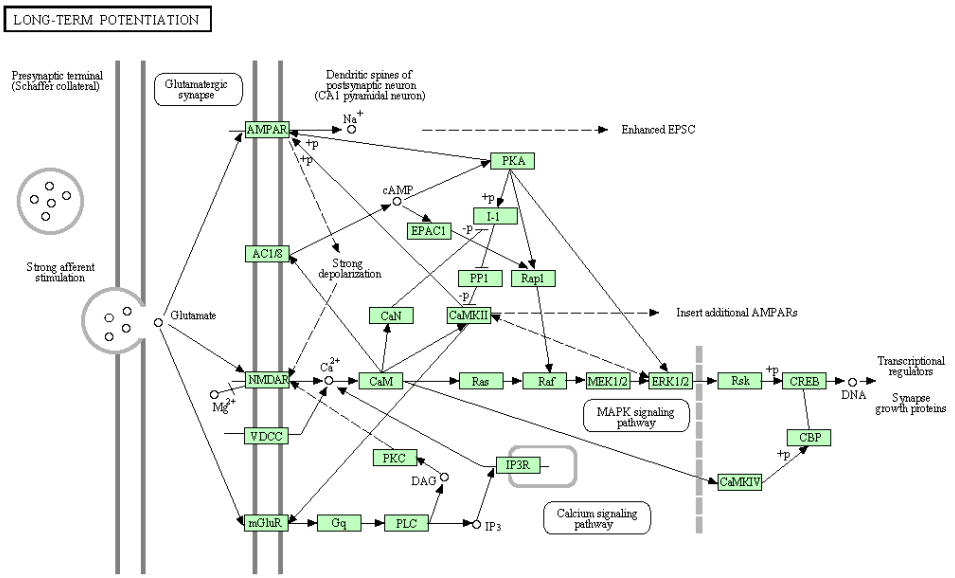
We are pleased to announce the twenty-fifth release of BioModels Database! The resource now publicly provides 143013 models. Numerous new models have been made available, several have been updated and various new

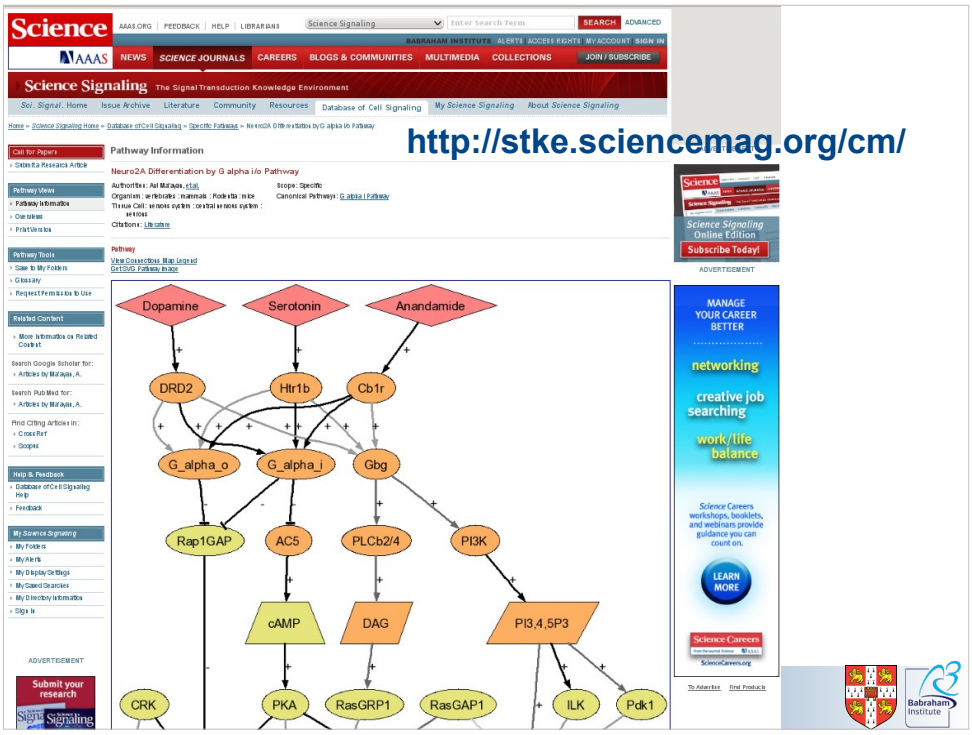
Activity-Flows (influence diagrams)



- Directional
- Sequential
- Non-mechanistic
- Logical modelling
- Signalling pathways, gene regulatory networks

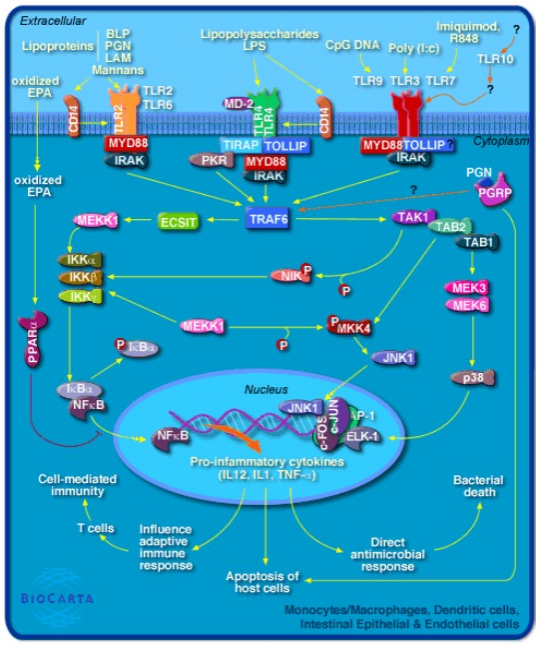
http://www.genome.jp/kegg/pathway.html



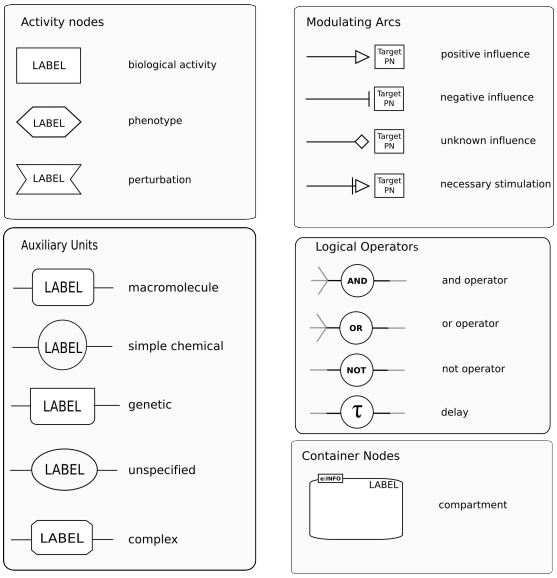


http://stke.sciencemag.org/cm/

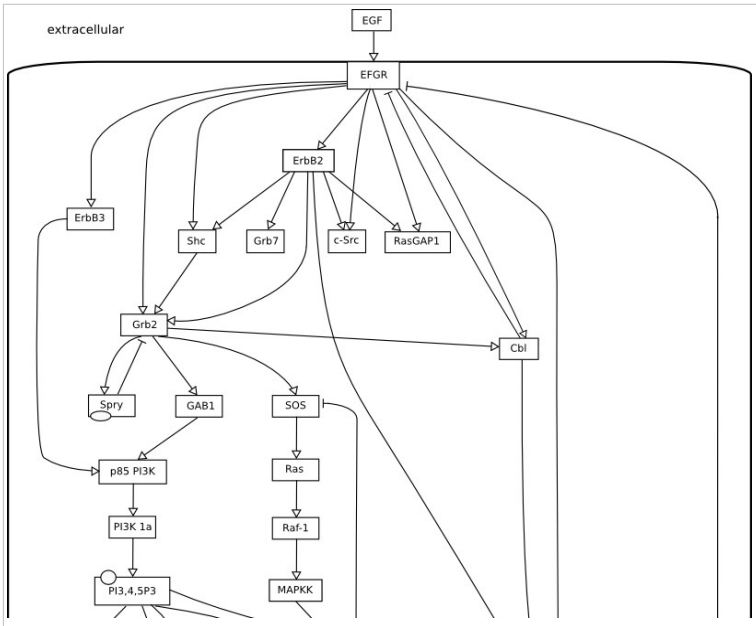
http://cgap.nci.nih.gov/Pathways/BioCarta.org



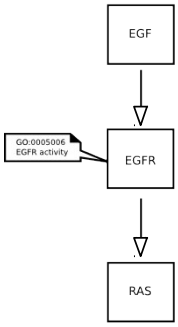
SBGN Activity Flows L1 reference card



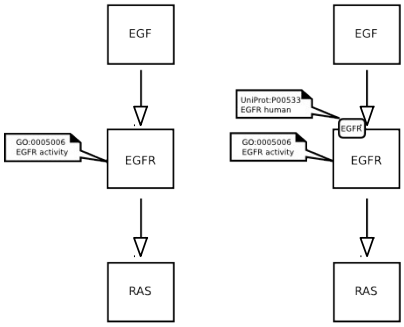
Example of Activity Flow map



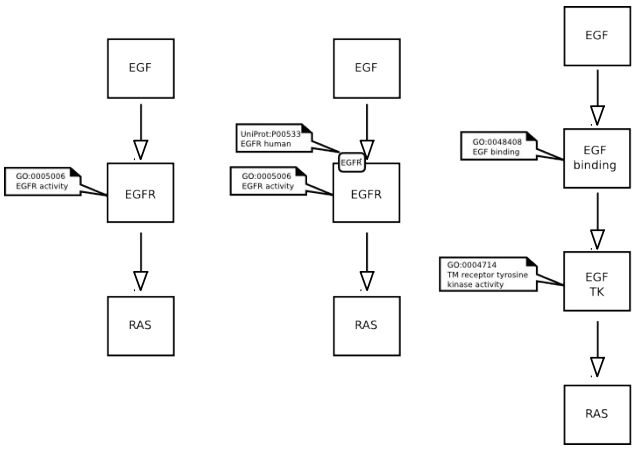
TIMTOWTDI



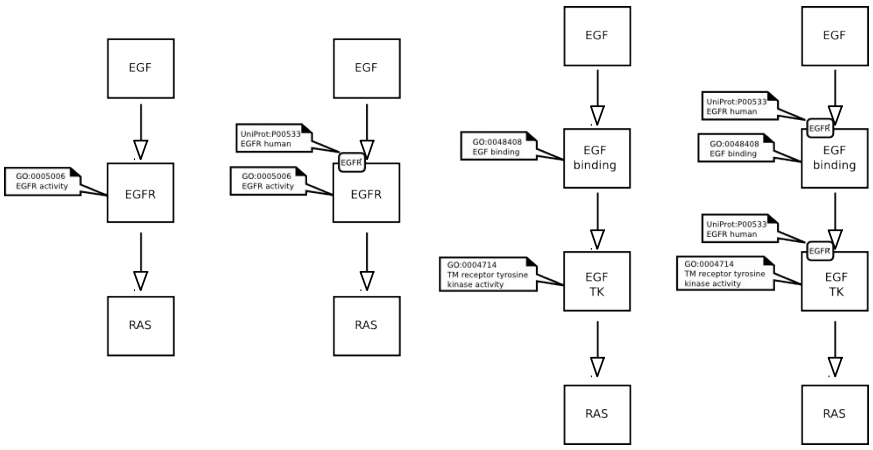
TIMTOWTDI


EGF
GO:0005006
EGFR activity
EGFR
RAS
EGF
UniProt:P00533
EGFR human
EGFR
GO:0005006
EGFR activity
EGFR
RAS

TIMTOWTDI

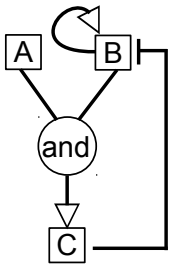

EGF
GO:0005006
EGFR activity
EGFR
RAS
EGF
UniProt:P00533
EGFR human
EGFR
GO:0005006
EGFR activity
EGFR
RAS
EGF
GO:0048408
EGF binding
EGF
binding
GO:0004714
TM receptor tyrosine
kinase activity
EGF
TK
RAS

TIMTOWTDI

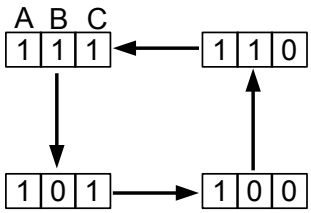

EGF
GO:0005006
EGFR activity
EGFR
RAS
EGF
UniProt:P00533
EGFR human
EGFR
GO:0005006
EGFR activity
EGFR
RAS
EGF
GO:0048408
EGF binding
EGF
binding
GO:0004714
TM receptor tyrosine
kinase activity
EGF
TK
RAS
EGF
UniProt:P00533
EGFR human
EGFR
GO:0048408
EGF binding
EGF
binding
UniProt:P00533
EGFR human
EGFR
GO:0004714
TM receptor tyrosine
kinase activity
EGF
TK
RAS

Logical models

- Variables can take a discrete number of values, at least 2
- Transitions of output are expressed as logical combinations of input values
- Simulations can be:
  synchronous: all the nodes are updated at once
  asynchronous: nodes are updated one after the other
- One can add delays, inputs etc.



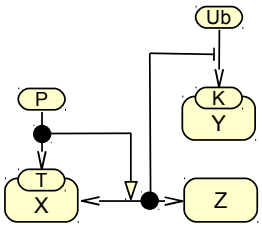
Influence diagram



state diagram

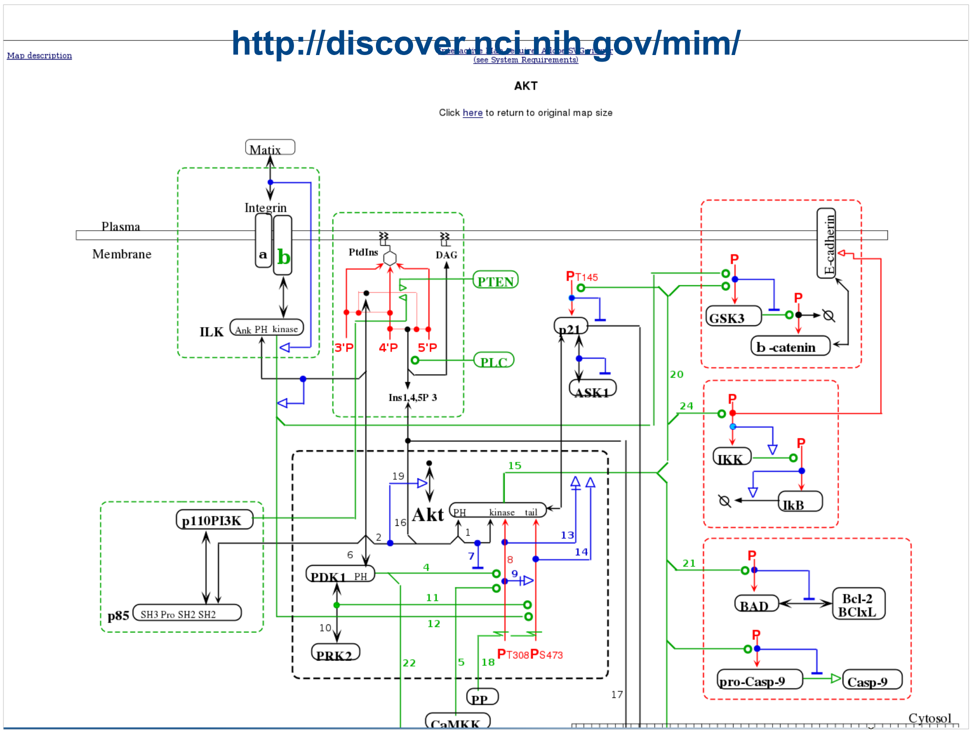
Qual

Entity Relationships

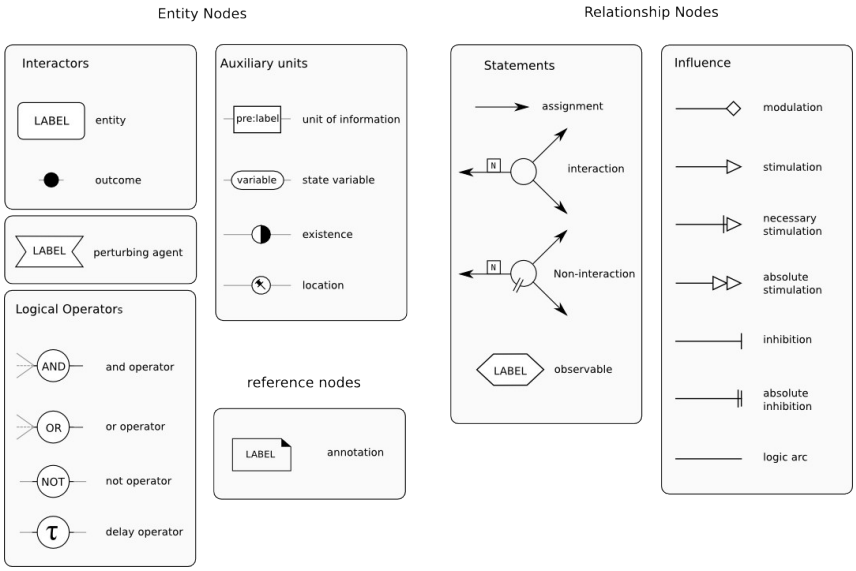


- Directional
- Non-sequential
- Mechanistic
- Rule-based modelling
- Molecular Biology
- “Open world”
- Independent rules: no explosion

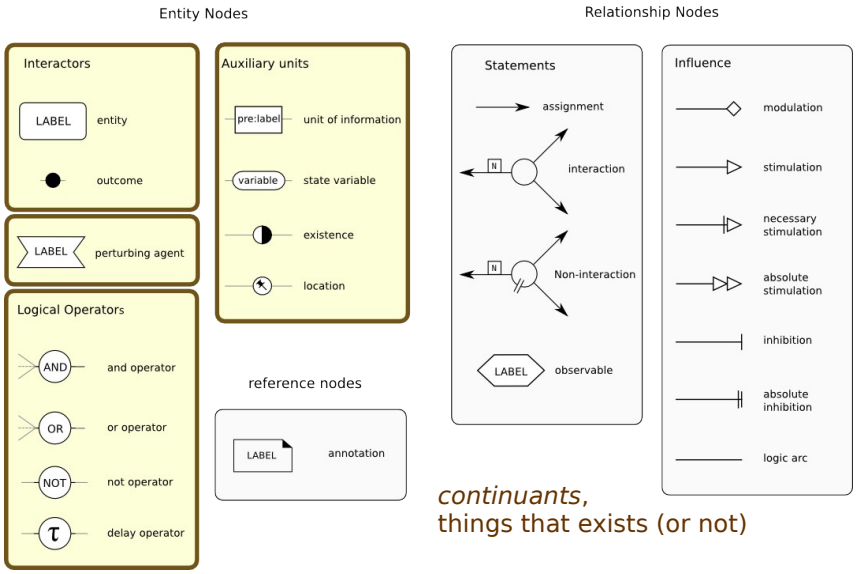
http://discover.nci.nih.gov/mim/



SBGN Entity Relationships L1 reference card

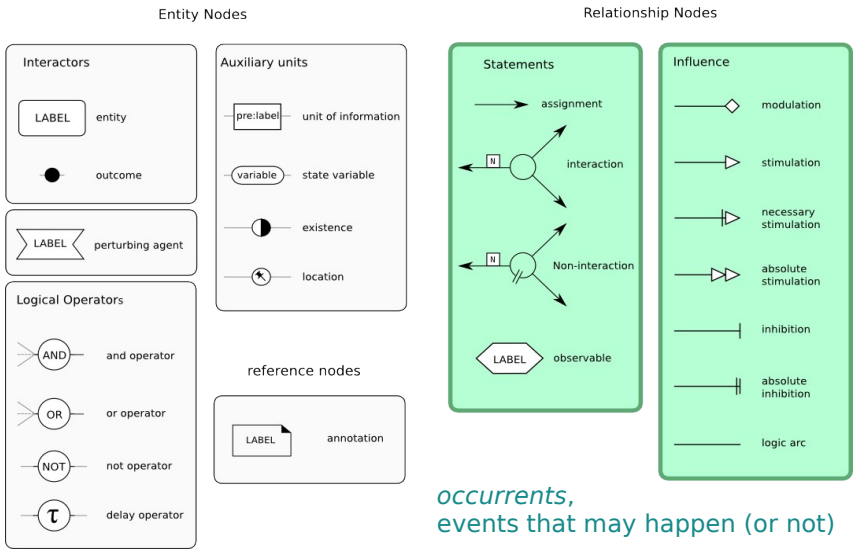


SBGN Entity Relationships L1 reference card



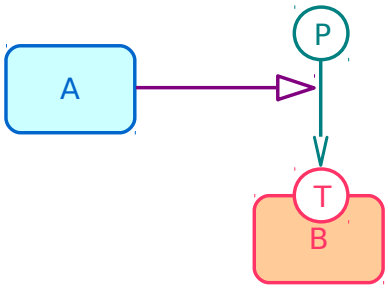
continuants,
things that exists (or not)

SBGN Entity Relationships L1 reference card

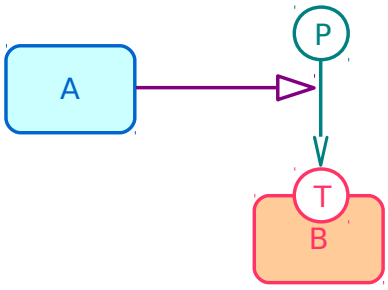


occurrents,
events that may happen (or not)

Entity Relationships can be viewed as rules

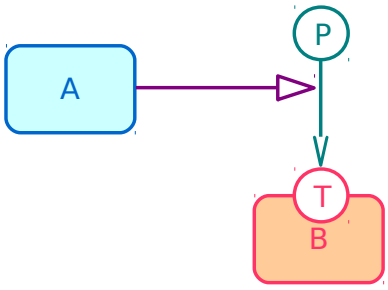


Entity Relationships can be viewed as rules



If A exists, the assignment of the value P to the state variable T of B is increased

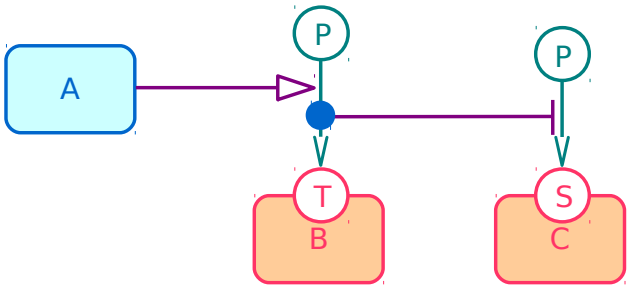
Entity Relationships can be viewed as rules



If A exists, the assignment of the value P to the state variable T of B is increased

(A stimulates the phosphorylation of B on the threonine)

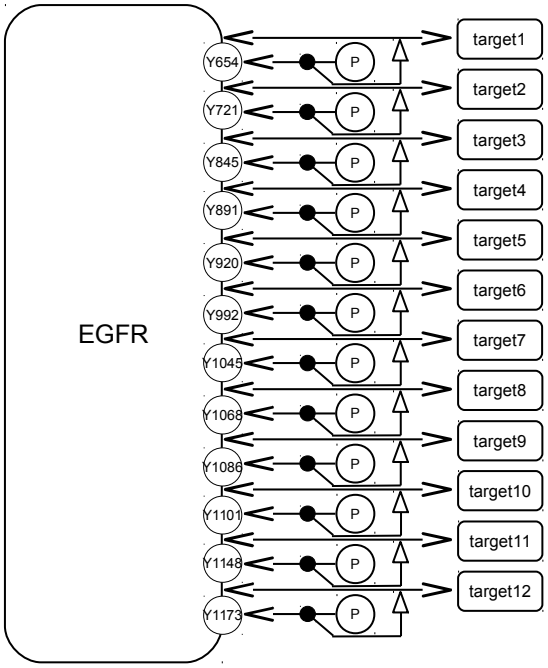
Entity Relationships can be viewed as rules



If A exists, the assignment of the value P to the state variable T of B is increased

If P is assigned to the state variable T of B, the assignment of the value P to the state variable S of B is decreased

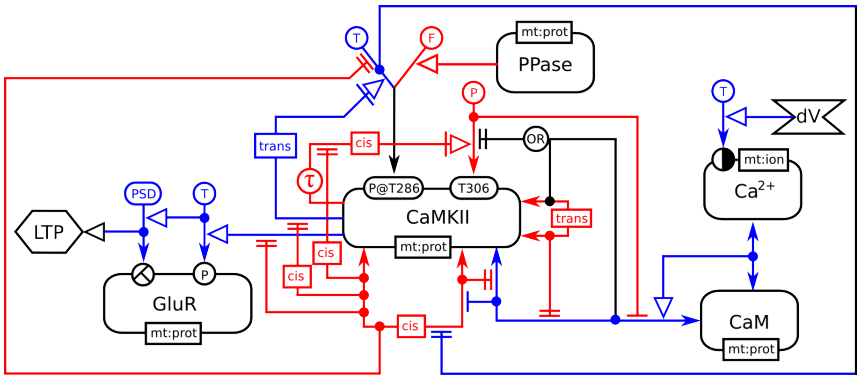
Multistate and combinatorial explosion



Process Descriptions:
"once a state variable value, always a state variable value"

2^{12} = 4096 states
(i.e. EPN glyphs) for EGFR
and 4096 complexes between
EGFR and targets

Regulation of synaptic plasticity by calcium



Rule-based modelling

- Kappa http://www.kappalanguage.org/

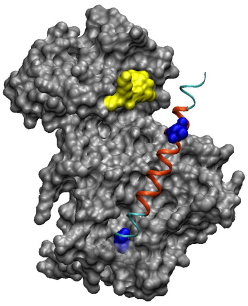
  English: "Unphosphorylated Site1 of A binds to Site1 of B"
  Kappa: A(Site1~u),B(Site1) -> A(Site1~u!1),B(Site1!1)

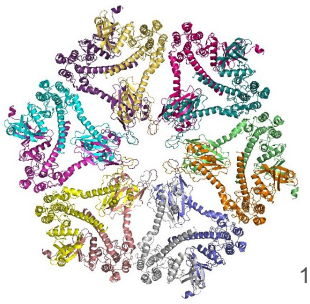
- BioNetGen http://bionetgen.org/

  English: “unbound EGF receptor site binds to unbound receptor ligand site”
  EGF(R) + EGFR(L) <-> EGF(R!1).EGFR(L!1) kp1, km1

Multi

Multi-state nature of CaMKII and rule-based modelling



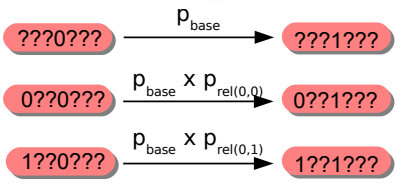


12 monomers

5 binary state variables

Open/Closed
T286 P/nonP
T306 P/nonP
CaM on low affinity
CaM on high affinity

2^{60} states = 1 billions of billions



Flags '?' do not affect the reaction

4 species are necessary and not 128

2 reactions are necessary and not 64

Simulation with StochSim

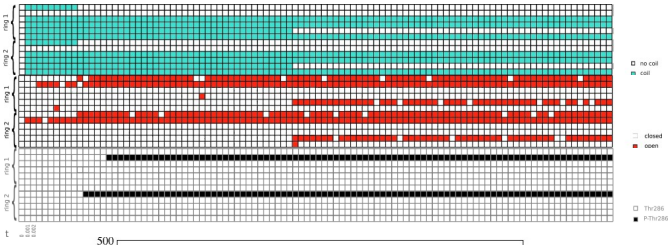
time

single oligomer

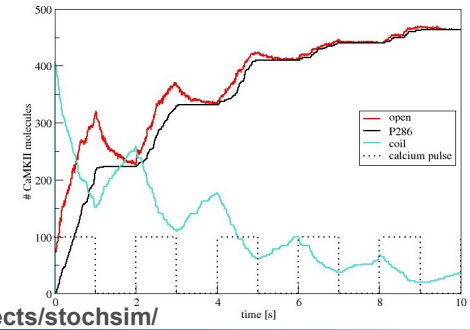
dimer coil

open

T286P



population of multimers



http://sourceforge.net/projects/stochsim/

Biological Pathway Exchange format

http://biopax.org/

BioPAX is a data format and an ontology

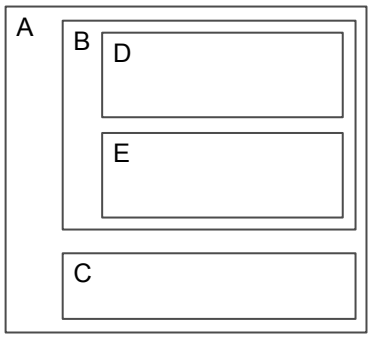
- **RDF/OWL**-based language to represent biological pathways at the molecular and cellular level
- Covers molecular and genetic interactions, metabolic network, signalling pathways, gene regulatory networks
- **Interactions**: Control (Catalysis, Modulation, TemplateReactionRegulation), Conversion (BiochemicalReaction, ComplexAssembly, Degradation, Transport, TransportWithBiochemicalReaction), GeneticInteraction, MolecularInteraction, TemplateReaction
- **Physical entities**: Complex, DNA, DNARegion, Protein, RNA, RNARegion, SmallMolecule
- **Utility classes**: BioSource, ChemicalStructure, ControlledVocabulary, DeltaG, EntityFeature, EntityReference, Evidence, ExperimentalForm, kPrime, PathwayStep, Provenance, Score, SequenceLocation, Stoichiometry, Xref

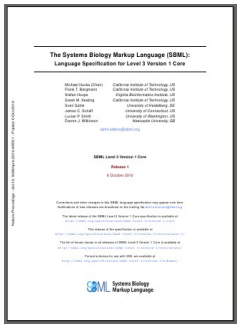
Resource Description Framework - RDF

- Language of the semantic web
- Semantic entirely embedded in the language (does not require external schemas and specifications)
- Series of statements

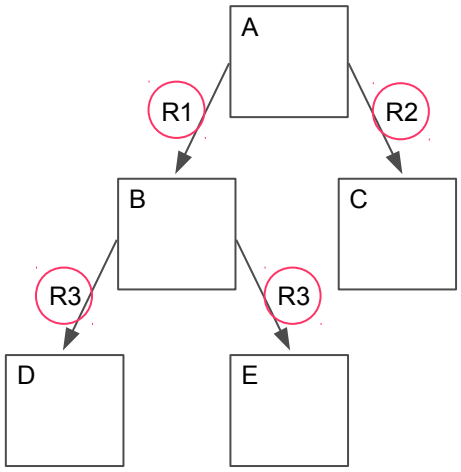
Subject	Predicate	Object
EGFR	*located_in*	plasma membrane
P00533	OBO_REL:0000008	GO:0005886
(UniProt)	(OBO Relation ontology)	(Gene Ontology)

“XML” Vs RDF





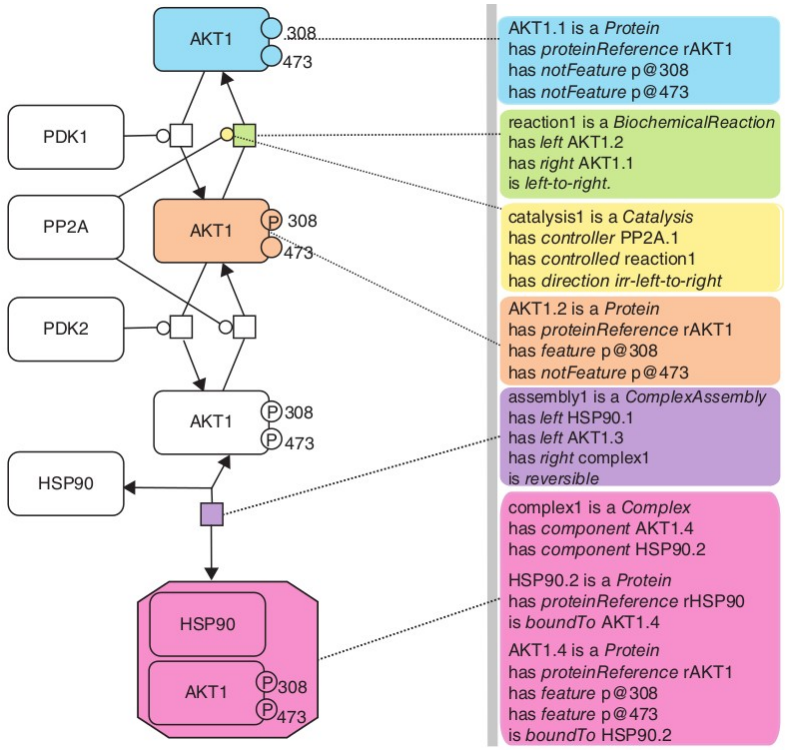
Relationships defined in another document



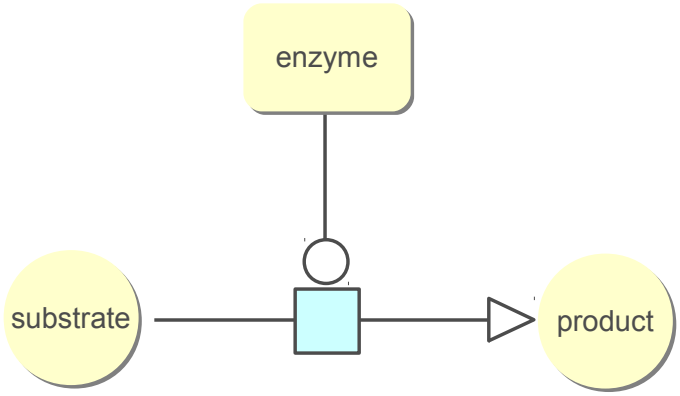
Relationships defined in the pathway

Web Ontology Language - OWL

- BioPAX contains classes, relations and properties, constraints, objects, values.
- Classes are arranged in a specialisation hierarchy. E.g. a “protein” is a “physical entity”
- Classes may have properties of specific types. The types are linked to other classes by relations. E.g. “reaction X” has *participant* “protein P”. An attribute is a property that has a simple type.
- Constraints define allowable values and connexions. E.g. “MOLECULAR_WT” must be a positive real number
- Objects are instances of classes.


AKT1
308
473
PDK1
PP2A
AKT1
P 308
473
PDK2
AKT1
P 308
P 473
HSP90
HSP90
AKT1
P 308
P 473
AKT1.1 is a Protein
has proteinReference rAKT1
has notFeature p@308
has notFeature p@473
reaction1 is a BiochemicalReaction
has left AKT1.2
has right AKT1.1
is left-to-right.
catalysis1 is a Catalysis
has controller PP2A.1
has controlled reaction1
has direction irr-left-to-right
AKT1.2 is a Protein
has proteinReference rAKT1
has feature p@308
has notFeature p@473
assembly1 is a ComplexAssembly
has left HSP90.1
has left AKT1.3
has right complex1
is reversible
complex1 is a Complex
has component AKT1.4
has component HSP90.2
HSP90.2 is a Protein
has proteinReference rHSP90
is boundTo AKT1.4
AKT1.4 is a Protein
has proteinReference rAKT1
has feature p@308
has feature p@473
is boundTo HSP90.2

A catalysis in BioPAX



A catalysis in BioPAX (L2)

```
<!-- physicalEntities -->

<bp:smallMolecule rdf:ID="smallMolecule1" />
<bp:smallMolecule rdf:ID="smallMolecule2" />
<bp:protein rdf:ID="protein1">

<!-- physicalEntityParticipants -->

<bp:physicalEntityParticipant rdf:ID="substrate">
    <bp:STOICHIOMETRIC-COEFFICIENT>1.0</bp:STOICHIOMETRIC-COEFFICIENT>
    <bp:PHYSICAL-ENTITY rdf:resource="#smallMolecule1" />
</bp:physicalEntityParticipant>
<bp:physicalEntityParticipant rdf:ID="product">
    <bp:STOICHIOMETRIC-COEFFICIENT>1.0</bp:STOICHIOMETRIC-COEFFICIENT>
    <bp:PHYSICAL-ENTITY rdf:resource="#smallMolecule2" />
</bp:physicalEntityParticipant>
<bp:physicalEntityParticipant rdf:ID="enzyme">
    <bp:PHYSICAL-ENTITY rdf:resource="#protein1" />
</bp:physicalEntityParticipant>

<!-- physicalInteractions -->

<bp:biochemicalReaction rdf:ID="biochemicalReaction1">
    <bp:LEFT rdf:resource="#substrate">
    <bp:RIGHT rdf:resource="#product">
</bp:biochemicalReaction>
<bp:catalysis rdf:ID="catalysis1">
    <bp:CONTROLLER rdf:resource="#enzyme" />
    <bp:CONTROLLED rdf:resource="#biochemicalReaction1"
</bp:catalysis>
```

A catalysis in BioPAX (L2)

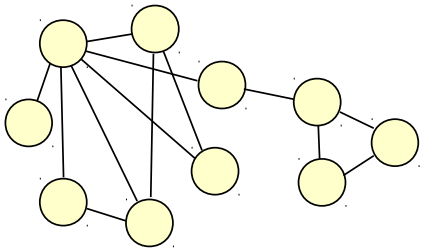
```
<!-- physicalEntityParticipants -->

<bp:physicalEntityParticipant rdf:ID="substrate">
    <bp:STOICHIOMETRIC-COEFFICIENT>1.0</bp:STOICHIOMETRIC-COEFFICIENT>
    <bp:PHYSICAL-ENTITY>
        <bp:smallMolecule rdf:ID="smallMolecule1" />
    </bp:PHYSICAL-ENTITY>
</bp:physicalEntityParticipant>
<bp:physicalEntityParticipant rdf:ID="product">
    <bp:STOICHIOMETRIC-COEFFICIENT>1.0</bp:STOICHIOMETRIC-COEFFICIENT>
    <bp:PHYSICAL-ENTITY>
        <bp:smallMolecule rdf:ID="smallMolecule2" />
    </bp:PHYSICAL-ENTITY>
</bp:physicalEntityParticipant>
<bp:physicalEntityParticipant rdf:ID="enzyme">
    <bp:PHYSICAL-ENTITY>
        <bp:protein rdf:ID="protein1">
    </bp:PHYSICAL-ENTITY>
</bp:physicalEntityParticipant>

<!-- physicalInteractions -->

<bp:biochemicalReaction rdf:ID="biochemicalReaction1">
    <bp:LEFT rdf:resource=”#substrate”>
    <bp:RIGHT rdf:resource=”#product”>
</bp:biochemicalReaction>
<bp:catalysis rdf:ID="catalysis1">
    <bp:CONTROLLER rdf:resource=”#enzyme” />
    <bp:CONTROLLED rdf:resource=”#biochemicalReaction1”
</bp:catalysis>
```

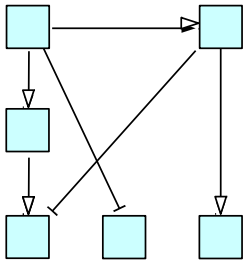

A catalysis in BioPAX (L2)

```
<!-- physicalInteractions -->

<bp:biochemicalReaction rdf:ID="biochemicalReaction1">
    <bp:LEFT>
        <bp:physicalEntityParticipant>
            <bp:STOICHIOMETRIC-COEFFICIENT>1.0</bp:STOICHIOMETRIC-COEFFICIENT>
            <bp:PHYSICAL-ENTITY>
                <bp:smallMolecule rdf:ID="smallMolecule1" />
            </bp:PHYSICAL-ENTITY>
        </bp:physicalEntityParticipant>
    </bp:LEFT>
    <bp:RIGHT>
        <bp:physicalEntityParticipant rdf:ID="product">
            <bp:STOICHIOMETRIC-COEFFICIENT>1.0</bp:STOICHIOMETRIC-COEFFICIENT>
            <bp:PHYSICAL-ENTITY>
                <bp:smallMolecule rdf:ID="smallMolecule2" />
            </bp:PHYSICAL-ENTITY>
        </bp:physicalEntityParticipant>
    </bp:RIGHT>
</bp:biochemicalReaction>

<bp:catalysis rdf:ID="catalysis1">
    <bp:CONTROLLER/>
        <bp:physicalEntityParticipant rdf:ID="enzyme">
            <bp:PHYSICAL-ENTITY>
                <bp:protein rdf:ID="protein1">
            </bp:PHYSICAL-ENTITY>
        </bp:physicalEntityParticipant>
    </bp:CONTROLLER>
    <bp:CONTROLLED rdf:resource=”#biochemicalReaction1”
</bp:catalysis>
```


A catalysis in BioPAX (L2)

```
<!-- physicalInteractions -->

<bp:catalysis rdf:ID="catalysis1">
    <bp:CONTROLLER/>
        <bp:physicalEntityParticipant rdf:ID="enzyme">
            <bp:PHYSICAL-ENTITY>
                <bp:protein rdf:ID="protein1">
            </bp:PHYSICAL-ENTITY>
        </bp:physicalEntityParticipant>
    </bp:CONTROLLER>
    <bp:CONTROLLED>
        <bp:biochemicalReaction rdf:ID="biochemicalReaction1">
            <bp:LEFT>
                <bp:physicalEntityParticipant>
                    <bp:STOICHIOMETRIC-COEFFICIENT>1.0</bp:STOICHIOMETRIC-COEFFICIENT>
                    <bp:PHYSICAL-ENTITY>
                        <bp:smallMolecule rdf:ID="smallMolecule1" />
                    </bp:PHYSICAL-ENTITY>
                </bp:physicalEntityParticipant>
            </bp:LEFT>
            <bp:RIGHT>
                <bp:physicalEntityParticipant rdf:ID="product">
                    <bp:STOICHIOMETRIC-COEFFICIENT>1.0</bp:STOICHIOMETRIC-COEFFICIENT>
                    <bp:PHYSICAL-ENTITY>
                        <bp:smallMolecule rdf:ID="smallMolecule2" />
                    </bp:PHYSICAL-ENTITY>
                </bp:physicalEntityParticipant>
            </bp:RIGHT>
        </bp:biochemicalReaction>
    </bp:CONTROLLED>
</bp:catalysis>
```



The four views are orthogonal projections of the underlying biological phenomena