

SBML Model Report

Model name: “Sarma2012 - Oscillations in MAPK cascade (S2), inclusion of external signalling module”



May 5, 2016

1 General Overview

This is a document in SBML Level 2 Version 4 format. This model was created by the following three authors: Nick Juty¹, Vijayalakshmi Chelliah² and Uddipan Sarma³ at March 18th 2013 at 2:06 p. m. and last time modified at April eighth 2016 at 5:24 p. m. Table 1 provides an overview of the quantities of all components of this model.

Table 1: Number of components in this model, which are described in the following sections.

Element	Quantity	Element	Quantity
compartment types	0	compartments	1
species types	0	species	13
events	0	constraints	0
reactions	12	function definitions	12
global parameters	0	unit definitions	2
rules	0	initial assignments	0

Model Notes

Sarma2012 - Oscillations in MAPK cascade (S2), inclusion of external signalling module

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Two plausible designs (S1 and S2) of coupled positive and negative feedback loops of MAPK cascade has been described in this paper. This model corresponds to model S2 that comprises negative feedback from MK-PP to MKKK-P layer coupled to positive feedback from MK-PP to MKK-PP layer. In addition, a positive feedback loop from S2 to the phosphorylation step of Kinase X has been introduced.

This model is described in the article: [Oscillations in MAPK cascade triggered by two distinct designs of coupled positive and negative feedback loops](#). Sarma U, Ghosh I. BMC Res Notes. 2012 Jun 13;5:287.

Abstract:

BACKGROUND:

Feedback loops, both positive and negative are embedded in the Mitogen Activated Protein Kinase (MAPK) cascade. In the three layer MAPK cascade, both feedback loops originate from the terminal layer and their sites of action are either of the two upstream layers. Recent studies have shown that the cascade uses coupled positive and negative feedback loops in generating oscillations. Two plausible designs of coupled positive and negative feedback loops can be elucidated from the literature; in one design the positive feedback precedes the negative feedback in the direction of signal flow and vice-versa in another. But it remains unexplored how the two designs contribute towards triggering oscillations in MAPK cascade. Thus it is also not known how amplitude, frequency, robustness or nature (analogous/digital) of the oscillations would be shaped by these two designs.

RESULTS:

We built two models of MAPK cascade that exhibited oscillations as function of two underlying designs of coupled positive and negative feedback loops. Frequency, amplitude and nature (digital/analogous) of oscillations were found to be differentially determined by each design. It was observed that the positive feedback emerging from an oscillating MAPK cascade and functional in an external signal processing module can trigger oscillations in the target module, provided that the target module satisfy certain parametric requirements. The augmentation of the two models was done to incorporate the nuclear-cytoplasmic shuttling of cascade components followed by induction of a nuclear phosphatase. It revealed that the fate of oscillations in the MAPK cascade is governed by the feedback designs. Oscillations were unaffected due to nuclear compartmentalization owing to one design but were completely abolished in the other case.

CONCLUSION:

The MAPK cascade can utilize two distinct designs of coupled positive and negative feedback loops to trigger oscillations. The amplitude, frequency and robustness of the oscillations in presence or absence of nuclear compartmentalization were differentially determined by two designs of coupled positive and negative feedback loops. A positive feedback from an oscillating MAPK cascade was shown to induce oscillations in an external signal processing module, uncovering a novel regulatory aspect of MAPK signal processing.

This model is hosted on [BioModels Database](#) and identified by: [MODEL1112190005](#).

To cite BioModels Database, please use: [BioModels Database: An enhanced, curated and annotated resource for published quantitative kinetic models](#).

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coded model have been dedicated to the publicdomain worldwide. Please refer to [CC0 Public DomainDedication](#) for more information.

2 Unit Definitions

This is an overview of five unit definitions of which three are predefined by SBML and not mentioned in the model.

2.1 Unit volume

Name volume

Definition ml

2.2 Unit substance

Name substance

Definition nmol

2.3 Unit area

Notes Square metre is the predefined SBML unit for area since SBML Level 2 Version 1.

Definition m²

2.4 Unit length

Notes Metre is the predefined SBML unit for length since SBML Level 2 Version 1.

Definition m

2.5 Unit time

Notes Second is the predefined SBML unit for time.

Definition s

3 Compartment

This model contains one compartment.

Table 2: Properties of all compartments.

Id	Name	SBO	Spatial Dimensions	Size	Unit	Constant	Outside
compartment_0	compartment		3	1	litre	<input checked="" type="checkbox"/>	

3.1 Compartment `compartment_0`

This is a three dimensional compartment with a constant size of one ml.

Name `compartment`

4 Species

This model contains 13 species. Section 7 provides further details and the derived rates of change of each species.

Table 3: Properties of each species.

Id	Name	Compartment	Derived Unit	Constant	Boundary Condition
species_0	MKKK	compartment_0	$\text{nmol} \cdot \text{ml}^{-1}$	\square	\square
species_1	MKKK_P	compartment_0	$\text{nmol} \cdot \text{ml}^{-1}$	\square	\square
species_2	MKK	compartment_0	$\text{nmol} \cdot \text{ml}^{-1}$	\square	\square
species_3	MKK_P	compartment_0	$\text{nmol} \cdot \text{ml}^{-1}$	\square	\square
species_4	MKK_PP	compartment_0	$\text{nmol} \cdot \text{ml}^{-1}$	\square	\square
species_5	M	compartment_0	$\text{nmol} \cdot \text{ml}^{-1}$	\square	\square
species_6	M_P	compartment_0	$\text{nmol} \cdot \text{ml}^{-1}$	\square	\square
species_7	M_PP	compartment_0	$\text{nmol} \cdot \text{ml}^{-1}$	\square	\square
species_8	P1	compartment_0	$\text{nmol} \cdot \text{ml}^{-1}$	\square	\square
species_9	P2	compartment_0	$\text{nmol} \cdot \text{ml}^{-1}$	\square	\square
species_10	P3	compartment_0	$\text{nmol} \cdot \text{ml}^{-1}$	\square	\square
species_11	X	compartment_0	$\text{nmol} \cdot \text{ml}^{-1}$	\square	\square
species_12	X_P	compartment_0	$\text{nmol} \cdot \text{ml}^{-1}$	\square	\square

5 Function definitions

This is an overview of twelve function definitions.

5.1 Function definition `function_4_1_1`

Name `function_4_1_1`

Arguments `A`, `K1`, `Ka`, `V1`, `[species_0]`, `[species_7]`

Mathematical Expression

$$\frac{\frac{V1 \cdot [species_0]}{K1}}{1 + \frac{[species_0]}{K1}} \cdot \frac{1 + \frac{A \cdot [species_7]}{Ka}}{1 + \frac{[species_7]}{Ka}} \quad (1)$$

5.2 Function definition `function_4_3_1`

Name `function_4_3_1`

Arguments `K3`, `KI`, `k3`, `[species_1]`, `[species_2]`, `[species_3]`, `[species_7]`

Mathematical Expression

$$\frac{\frac{k3 \cdot [species_1] \cdot [species_2]}{K3}}{\left(1 + \frac{[species_2]}{K3} + \frac{[species_3]}{K3}\right) \cdot \left(1 + \frac{[species_7]}{KI}\right)} \quad (2)$$

5.3 Function definition `function_4_4_1`

Name `function_4_4_1`

Arguments `K4`, `KI`, `k4`, `[species_1]`, `[species_2]`, `[species_3]`, `[species_7]`

Mathematical Expression

$$\frac{\frac{k4 \cdot [species_1] \cdot [species_3]}{K4}}{\left(1 + \frac{[species_2]}{K4} + \frac{[species_3]}{K4}\right) \cdot \left(1 + \frac{[species_7]}{KI}\right)} \quad (3)$$

5.4 Function definition `function_4_7_1`

Name `function_4_7_1`

Arguments `K7`, `k7`, `[species_4]`, `[species_5]`, `[species_6]`

Mathematical Expression

$$\frac{\frac{k7 \cdot [species_4] \cdot [species_5]}{K7}}{1 + \frac{[species_5]}{K7} + \frac{[species_6]}{K7}} \quad (4)$$

5.5 Function definition [function_4_8_1](#)

Name function_4_8_1

Arguments K8, k8, [species_4], [species_5], [species_6]

Mathematical Expression

$$\frac{\frac{k8 \cdot [\text{species}_4] \cdot [\text{species}_6]}{K8}}{1 + \frac{[\text{species}_5]}{K8} + \frac{[\text{species}_6]}{K8}} \quad (5)$$

5.6 Function definition [function_4_2_1](#)

Name function_4_2_1

Arguments K2, k2, [species_1], [species_8]

Mathematical Expression

$$\frac{\frac{k2 \cdot [\text{species}_8] \cdot [\text{species}_1]}{K2}}{1 + \frac{[\text{species}_1]}{K2}} \quad (6)$$

5.7 Function definition [function_4_5_1](#)

Name function_4_5_1

Arguments K5, k5, [species_3], [species_4], [species_9]

Mathematical Expression

$$\frac{\frac{k5 \cdot [\text{species}_9] \cdot [\text{species}_4]}{K5}}{1 + \frac{[\text{species}_4]}{K5} + \frac{[\text{species}_3]}{K5}} \quad (7)$$

5.8 Function definition [function_4_6_1](#)

Name function_4_6_1

Arguments K6, k6, [species_3], [species_4], [species_9]

Mathematical Expression

$$\frac{\frac{k6 \cdot [\text{species}_9] \cdot [\text{species}_3]}{K6}}{1 + \frac{[\text{species}_4]}{K6} + \frac{[\text{species}_3]}{K6}} \quad (8)$$

5.9 Function definition [function_4_9_1](#)

Name function_4_9_1

Arguments K9, k9, [species_10], [species_6], [species_7]

Mathematical Expression

$$\frac{\frac{k9 \cdot [\text{species}_{10}] \cdot [\text{species}_7]}{K9}}{1 + \frac{[\text{species}_7]}{K9} + \frac{[\text{species}_6]}{K9}} \quad (9)$$

5.10 Function definition [function_4_10_1](#)

Name function_4_10_1

Arguments K10, k10, [species_10], [species_6], [species_7]

Mathematical Expression

$$\frac{\frac{k10 \cdot [\text{species}_{10}] \cdot [\text{species}_6]}{K10}}{1 + \frac{[\text{species}_7]}{K10} + \frac{[\text{species}_6]}{K10}} \quad (10)$$

5.11 Function definition [function_1](#)

Name 11

Arguments V11, X, K11, A, [species_7], Ka

Mathematical Expression

$$\frac{\frac{V11 \cdot X}{K11}}{1 + \frac{X}{K11}} \cdot \frac{1 + \frac{A \cdot [\text{species}_7]}{Ka}}{1 + \frac{[\text{species}_7]}{Ka}} \quad (11)$$

5.12 Function definition [function_2](#)

Name 12

Arguments V12, X_P, K12

Mathematical Expression

$$\frac{V12 \cdot X_P}{K12 + X_P} \quad (12)$$

6 Reactions

This model contains twelve reactions. All reactions are listed in the following table and are subsequently described in detail. If a reaction is affected by a modifier, the identifier of this species is written above the reaction arrow.

Table 4: Overview of all reactions

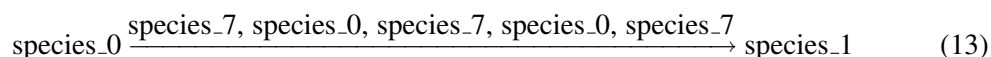
Nº	Id	Name	Reaction Equation	SBO
1	reaction_0	1	species_0 $\xrightarrow{\text{species}_7, \text{species}_0, \text{species}_7, \text{species}_0, \text{species}_7}$ species_1	
2	reaction_1	3	species_2 $\xrightarrow{\text{species}_1, \text{species}_3, \text{species}_7, \text{species}_1, \text{species}_2, \text{species}_3, \text{species}_7, \text{species}_1}$ species_3	
3	reaction_2	4	species_3 $\xrightarrow{\text{species}_1, \text{species}_2, \text{species}_7, \text{species}_1, \text{species}_2, \text{species}_3, \text{species}_7, \text{species}_1}$ species_4	
4	reaction_3	7	species_5 $\xrightarrow{\text{species}_4, \text{species}_6, \text{species}_4, \text{species}_5, \text{species}_6, \text{species}_4, \text{species}_5, \text{species}_6}$ species_6	
5	reaction_4	8	species_6 $\xrightarrow{\text{species}_4, \text{species}_5, \text{species}_4, \text{species}_5, \text{species}_6, \text{species}_4, \text{species}_5, \text{species}_6}$ species_7	
6	reaction_5	2	species_1 $\xrightarrow{\text{species}_8, \text{species}_1, \text{species}_8, \text{species}_1, \text{species}_8}$ species_0	
7	reaction_6	5	species_4 $\xrightarrow{\text{species}_9, \text{species}_3, \text{species}_3, \text{species}_4, \text{species}_9, \text{species}_3, \text{species}_4, \text{species}_9}$ species_5	
8	reaction_7	6	species_3 $\xrightarrow{\text{species}_9, \text{species}_4, \text{species}_3, \text{species}_4, \text{species}_9, \text{species}_3, \text{species}_4, \text{species}_9}$ species_6	
9	reaction_8	9	species_7 $\xrightarrow{\text{species}_{10}, \text{species}_6, \text{species}_5, \text{species}_{10}, \text{species}_6, \text{species}_7, \text{species}_{10}}$ species_8	
10	reaction_9	10	species_6 $\xrightarrow{\text{species}_{10}, \text{species}_7, \text{species}_5, \text{species}_{10}, \text{species}_6, \text{species}_7, \text{species}_{10}}$ species_9	
11	reaction_10	11	species_11 $\xrightarrow{\text{species}_7, \text{species}_{11}, \text{species}_7, \text{species}_{11}, \text{species}_7}$ species_12	
12	reaction_11	12	species_12 $\xrightarrow{\text{species}_{12}, \text{species}_{12}}$ species_11	

6.1 Reaction `reaction_0`

This is an irreversible reaction of one reactant forming one product influenced by five modifiers.

Name 1

Reaction equation



Reactant

Table 5: Properties of each reactant.

Id	Name	SBO
species_0	MKKK	

Modifiers

Table 6: Properties of each modifier.

Id	Name	SBO
species_7	M_PP	
species_0	MKKK	
species_7	M_PP	
species_0	MKKK	
species_7	M_PP	

Product

Table 7: Properties of each product.

Id	Name	SBO
species_1	MKKK_P	

Kinetic Law

Derived unit contains undeclared units

$$v_1 = \text{vol}(\text{compartment_0}) \cdot \text{function_4_1_1}(A, K1, Ka, V1, [\text{species_0}], [\text{species_7}]) \quad (14)$$

$$\text{function_4_1_1}(A, K1, Ka, V1, [\text{species_0}], [\text{species_7}]) = \frac{\frac{V1 \cdot [\text{species_0}]}{K1}}{1 + \frac{[\text{species_0}]}{K1}} \cdot \frac{1 + \frac{A \cdot [\text{species_7}]}{Ka}}{1 + \frac{[\text{species_7}]}{Ka}} \quad (15)$$

$$\text{function_4_1_1}(A, K1, Ka, V1, [\text{species_0}], [\text{species_7}]) = \frac{\frac{V1 \cdot [\text{species_0}]}{K1}}{1 + \frac{[\text{species_0}]}{K1}} \cdot \frac{1 + \frac{A \cdot [\text{species_7}]}{Ka}}{1 + \frac{[\text{species_7}]}{Ka}} \quad (16)$$

Table 8: Properties of each parameter.

Id	Name	SBO	Value	Unit	Constant
A	A		100.0		✓
K1	K1		15.0		✓
Ka	Ka		500.0		✓
V1	V1		6.0		✓

6.2 Reaction [reaction_1](#)

This is an irreversible reaction of one reactant forming one product influenced by eleven modifiers.

Name 3

Reaction equation

$$\text{species_2} \xrightarrow{\text{species_1, species_3, species_7, species_1, species_2, species_3, species_7, species_1, species_2, species_3, species_2}} \quad (17)$$

Reactant

Table 9: Properties of each reactant.

Id	Name	SBO
species_2	MKK	

Modifiers

Table 10: Properties of each modifier.

Id	Name	SBO
species_1	MKKK_P	
species_3	MKK_P	

Id	Name	SBO
species_7	M_PP	
species_1	MKKK_P	
species_2	MKK	
species_3	MKK_P	
species_7	M_PP	
species_1	MKKK_P	
species_2	MKK	
species_3	MKK_P	
species_7	M_PP	

Product

Table 11: Properties of each product.

Id	Name	SBO
species_3	MKK_P	

Kinetic Law

Derived unit contains undeclared units

$$v_2 = \text{vol}(\text{compartment}_0) \cdot \text{function_4_3_1}(K3, KI, k3, [\text{species}_1], [\text{species}_2], [\text{species}_3], [\text{species}_7]) \quad (18)$$

$$\begin{aligned} & \text{function_4_3_1}(K3, KI, k3, [\text{species}_1], [\text{species}_2], [\text{species}_3], [\text{species}_7]) \\ &= \frac{\frac{k3 \cdot [\text{species}_1] \cdot [\text{species}_2]}{K3}}{\left(1 + \frac{[\text{species}_2]}{K3} + \frac{[\text{species}_3]}{K3}\right) \cdot \left(1 + \frac{[\text{species}_7]}{KI}\right)} \end{aligned} \quad (19)$$

$$\begin{aligned} & \text{function_4_3_1}(K3, KI, k3, [\text{species}_1], [\text{species}_2], [\text{species}_3], [\text{species}_7]) \\ &= \frac{\frac{k3 \cdot [\text{species}_1] \cdot [\text{species}_2]}{K3}}{\left(1 + \frac{[\text{species}_2]}{K3} + \frac{[\text{species}_3]}{K3}\right) \cdot \left(1 + \frac{[\text{species}_7]}{KI}\right)} \end{aligned} \quad (20)$$

Table 12: Properties of each parameter.

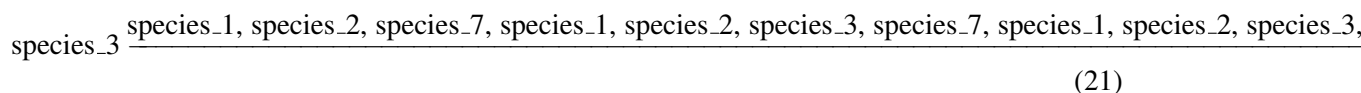
Id	Name	SBO	Value	Unit	Constant
K3	K3		20.0		✓
KI	KI		9.0		✓
k3	k3		0.1		✓

6.3 Reaction `reaction_2`

This is an irreversible reaction of one reactant forming one product influenced by eleven modifiers.

Name 4

Reaction equation



Reactant

Table 13: Properties of each reactant.

Id	Name	SBO
species_3	MKK_P	

Modifiers

Table 14: Properties of each modifier.

Id	Name	SBO
species_1	MKKK_P	
species_2	MKK	
species_7	M_PP	
species_1	MKKK_P	
species_2	MKK	
species_3	MKK_P	
species_7	M_PP	
species_1	MKKK_P	
species_2	MKK	
species_3	MKK_P	
species_7	M_PP	

Product

Table 15: Properties of each product.

Id	Name	SBO
species_4	MKK_PP	

Kinetic Law

Derived unit contains undeclared units

$$v_3 = \text{vol}(\text{compartment}_0) \cdot \text{function_4_4_1}(K4, KI, k4, [\text{species}_1], [\text{species}_2], [\text{species}_3], [\text{species}_7]) \quad (22)$$

$$\begin{aligned} & \text{function_4_4_1}(K4, KI, k4, [\text{species}_1], [\text{species}_2], [\text{species}_3], [\text{species}_7]) \\ &= \frac{\frac{k4 \cdot [\text{species}_1] \cdot [\text{species}_3]}{K4}}{\left(1 + \frac{[\text{species}_2]}{K4} + \frac{[\text{species}_3]}{K4}\right) \cdot \left(1 + \frac{[\text{species}_7]}{KI}\right)} \end{aligned} \quad (23)$$

$$\begin{aligned} & \text{function_4_4_1}(K4, KI, k4, [\text{species}_1], [\text{species}_2], [\text{species}_3], [\text{species}_7]) \\ &= \frac{\frac{k4 \cdot [\text{species}_1] \cdot [\text{species}_3]}{K4}}{\left(1 + \frac{[\text{species}_2]}{K4} + \frac{[\text{species}_3]}{K4}\right) \cdot \left(1 + \frac{[\text{species}_7]}{KI}\right)} \end{aligned} \quad (24)$$

Table 16: Properties of each parameter.

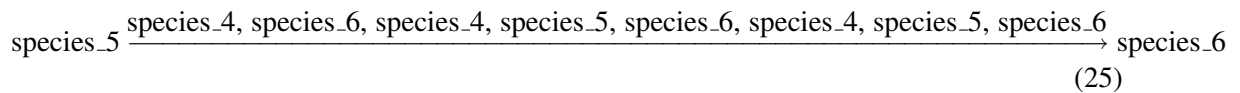
Id	Name	SBO	Value	Unit	Constant
K4	K4		20.0		<input checked="" type="checkbox"/>
KI	KI		9.0		<input checked="" type="checkbox"/>
k4	k4		0.1		<input checked="" type="checkbox"/>

6.4 Reaction `reaction_3`

This is an irreversible reaction of one reactant forming one product influenced by eight modifiers.

Name 7

Reaction equation



Reactant

Table 17: Properties of each reactant.

Id	Name	SBO
species_5	M	

Modifiers

Table 18: Properties of each modifier.

Id	Name	SBO
species_4	MKK_PP	
species_6	M_P	
species_4	MKK_PP	
species_5	M	
species_6	M_P	
species_4	MKK_PP	
species_5	M	
species_6	M_P	

Product

Table 19: Properties of each product.

Id	Name	SBO
species_6	M_P	

Kinetic Law

Derived unit contains undeclared units

$$v_4 = \text{vol}(\text{compartment}_0) \cdot \text{function_4_7_1}(K7, k7, [\text{species}_4], [\text{species}_5], [\text{species}_6]) \quad (26)$$

$$\text{function_4_7_1}(K7, k7, [\text{species}_4], [\text{species}_5], [\text{species}_6]) = \frac{\frac{k7 \cdot [\text{species}_4] \cdot [\text{species}_5]}{K7}}{1 + \frac{[\text{species}_5]}{K7} + \frac{[\text{species}_6]}{K7}} \quad (27)$$

$$\text{function_4_7_1}(K7, k7, [\text{species}_4], [\text{species}_5], [\text{species}_6]) = \frac{\frac{k7 \cdot [\text{species}_4] \cdot [\text{species}_5]}{K7}}{1 + \frac{[\text{species}_5]}{K7} + \frac{[\text{species}_6]}{K7}} \quad (28)$$

Table 20: Properties of each parameter.

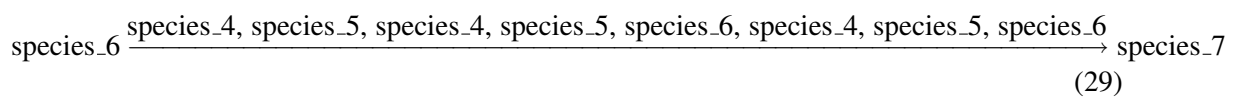
Id	Name	SBO	Value	Unit	Constant
K7	K7		20.0		<input checked="" type="checkbox"/>
k7	k7		0.1		<input checked="" type="checkbox"/>

6.5 Reaction `reaction_4`

This is an irreversible reaction of one reactant forming one product influenced by eight modifiers.

Name 8

Reaction equation



Reactant

Table 21: Properties of each reactant.

Id	Name	SBO
species_6	M_P	

Modifiers

Table 22: Properties of each modifier.

Id	Name	SBO
species_4	MKK_PP	
species_5	M	
species_4	MKK_PP	
species_5	M	
species_6	M_P	
species_4	MKK_PP	
species_5	M	
species_6	M_P	

Product

Table 23: Properties of each product.

Id	Name	SBO
species_7	M_PP	

Kinetic Law

Derived unit contains undeclared units

$$v_5 = \text{vol}(\text{compartment}_0) \cdot \text{function_4_8_1}(K8, k8, [\text{species}_4], [\text{species}_5], [\text{species}_6]) \quad (30)$$

$$\text{function_4_8_1}(K8, k8, [\text{species}_4], [\text{species}_5], [\text{species}_6]) = \frac{\frac{k8 \cdot [\text{species}_4] \cdot [\text{species}_6]}{K8}}{1 + \frac{[\text{species}_5]}{K8} + \frac{[\text{species}_6]}{K8}} \quad (31)$$

$$\text{function_4_8_1}(K8, k8, [\text{species}_4], [\text{species}_5], [\text{species}_6]) = \frac{\frac{k8 \cdot [\text{species}_4] \cdot [\text{species}_6]}{K8}}{1 + \frac{[\text{species}_5]}{K8} + \frac{[\text{species}_6]}{K8}} \quad (32)$$

Table 24: Properties of each parameter.

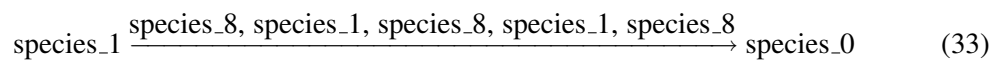
Id	Name	SBO	Value	Unit	Constant
K8	K8		20.0		<input checked="" type="checkbox"/>
k8	k8		0.1		<input checked="" type="checkbox"/>

6.6 Reaction `reaction_5`

This is an irreversible reaction of one reactant forming one product influenced by five modifiers.

Name 2

Reaction equation



Reactant

Table 25: Properties of each reactant.

Id	Name	SBO
species_1	MKKK_P	

Modifiers

Table 26: Properties of each modifier.

Id	Name	SBO
species_8	P1	
species_1	MKKK_P	
species_8	P1	
species_1	MKKK_P	
species_8	P1	

Product

Table 27: Properties of each product.

Id	Name	SBO
species_0	MKKK	

Kinetic Law

Derived unit contains undeclared units

$$v_6 = \text{vol}(\text{compartment}_0) \cdot \text{function_4_2_1}(K2, k2, [\text{species}_1], [\text{species}_8]) \quad (34)$$

$$\text{function_4_2_1}(K2, k2, [\text{species}_1], [\text{species}_8]) = \frac{\frac{k2 \cdot [\text{species}_8] \cdot [\text{species}_1]}{K2}}{1 + \frac{[\text{species}_1]}{K2}} \quad (35)$$

$$\text{function_4_2_1}(K2, k2, [\text{species}_1], [\text{species}_8]) = \frac{\frac{k2 \cdot [\text{species}_8] \cdot [\text{species}_1]}{K2}}{1 + \frac{[\text{species}_1]}{K2}} \quad (36)$$

Table 28: Properties of each parameter.

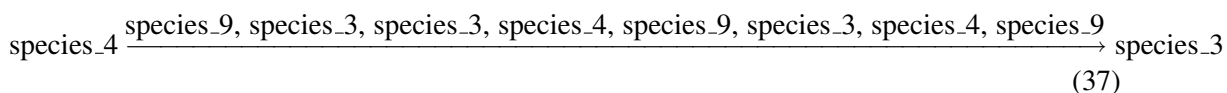
Id	Name	SBO	Value	Unit	Constant
K2	K2		100.0		✓
k2	k2		0.1		✓

6.7 Reaction `reaction_6`

This is an irreversible reaction of one reactant forming one product influenced by eight modifiers.

Name 5

Reaction equation



Reactant

Table 29: Properties of each reactant.

Id	Name	SBO
species_4	MKK_PP	

Modifiers

Table 30: Properties of each modifier.

Id	Name	SBO
species_9	P2	
species_3	MKK_P	
species_3	MKK_P	
species_4	MKK_PP	
species_9	P2	
species_3	MKK_P	
species_4	MKK_PP	
species_9	P2	

Product

Table 31: Properties of each product.

Id	Name	SBO
species_3	MKK_P	

Kinetic Law

Derived unit contains undeclared units

$$v_7 = \text{vol}(\text{compartment}_0) \cdot \text{function_4_5_1}(K5, k5, [\text{species}_3], [\text{species}_4], [\text{species}_9]) \quad (38)$$

$$\text{function_4_5_1}(K5, k5, [\text{species}_3], [\text{species}_4], [\text{species}_9]) = \frac{\frac{k5 \cdot [\text{species}_9] \cdot [\text{species}_4]}{K5}}{1 + \frac{[\text{species}_4]}{K5} + \frac{[\text{species}_3]}{K5}} \quad (39)$$

$$\text{function_4_5_1}(K5, k5, [\text{species}_3], [\text{species}_4], [\text{species}_9]) = \frac{\frac{k5 \cdot [\text{species}_9] \cdot [\text{species}_4]}{K5}}{1 + \frac{[\text{species}_4]}{K5} + \frac{[\text{species}_3]}{K5}} \quad (40)$$

Table 32: Properties of each parameter.

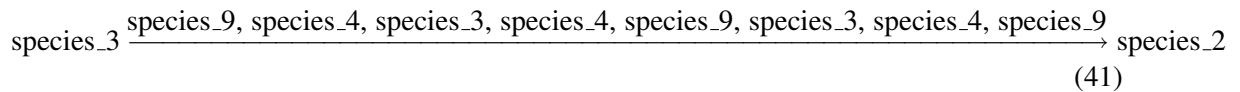
Id	Name	SBO	Value	Unit	Constant
K5	K5		20.00		<input checked="" type="checkbox"/>
k5	k5		0.02		<input checked="" type="checkbox"/>

6.8 Reaction `reaction_7`

This is an irreversible reaction of one reactant forming one product influenced by eight modifiers.

Name 6

Reaction equation



Reactant

Table 33: Properties of each reactant.

Id	Name	SBO
species_3	MKK_P	

Modifiers

Table 34: Properties of each modifier.

Id	Name	SBO
species_9	P2	
species_4	MKK_PP	

Id	Name	SBO
species_3	MKK_P	
species_4	MKK_PP	
species_9	P2	
species_3	MKK_P	
species_4	MKK_PP	
species_9	P2	

Product

Table 35: Properties of each product.

Id	Name	SBO
species_2	MKK	

Kinetic Law

Derived unit contains undeclared units

$$v_8 = \text{vol}(\text{compartment}_0) \cdot \text{function_4_6_1}(K6, k6, [\text{species}_3], [\text{species}_4], [\text{species}_9]) \quad (42)$$

$$\text{function_4_6_1}(K6, k6, [\text{species}_3], [\text{species}_4], [\text{species}_9]) = \frac{\frac{k6 \cdot [\text{species}_9] \cdot [\text{species}_3]}{K6}}{1 + \frac{[\text{species}_4]}{K6} + \frac{[\text{species}_3]}{K6}} \quad (43)$$

$$\text{function_4_6_1}(K6, k6, [\text{species}_3], [\text{species}_4], [\text{species}_9]) = \frac{\frac{k6 \cdot [\text{species}_9] \cdot [\text{species}_3]}{K6}}{1 + \frac{[\text{species}_4]}{K6} + \frac{[\text{species}_3]}{K6}} \quad (44)$$

Table 36: Properties of each parameter.

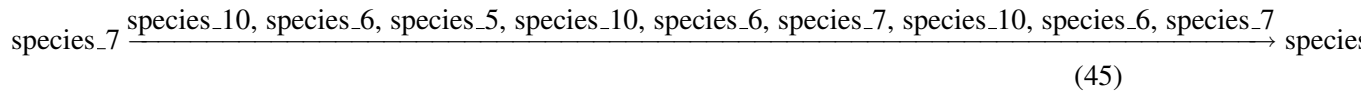
Id	Name	SBO	Value	Unit	Constant
K6	K6		20.00		<input checked="" type="checkbox"/>
k6	k6		0.02		<input checked="" type="checkbox"/>

6.9 Reaction `reaction_8`

This is an irreversible reaction of one reactant forming one product influenced by nine modifiers.

Name 9

Reaction equation



Reactant

Table 37: Properties of each reactant.

Id	Name	SBO
species_7	M_PP	

Modifiers

Table 38: Properties of each modifier.

Id	Name	SBO
species_10	P3	
species_6	M_P	
species_5	M	
species_10	P3	
species_6	M_P	
species_7	M_PP	
species_10	P3	
species_6	M_P	
species_7	M_PP	

Product

Table 39: Properties of each product.

Id	Name	SBO
species_6	M_P	

Kinetic Law

Derived unit contains undeclared units

$$v_9 = \text{vol}(\text{compartment}_0) \cdot \text{function_4_9_1}(K_9, k_9, [\text{species_10}], [\text{species_6}], [\text{species_7}]) \quad (46)$$

$$\text{function_4_9_1}(K_9, k_9, [\text{species_10}], [\text{species_6}], [\text{species_7}]) = \frac{\frac{k_9 \cdot [\text{species_10}] \cdot [\text{species_7}]}{K_9}}{1 + \frac{[\text{species_7}]}{K_9} + \frac{[\text{species_6}]}{K_9}} \quad (47)$$

$$\text{function_4_9_1}(K9, k9, [\text{species_10}], [\text{species_6}], [\text{species_7}]) = \frac{\frac{k9 \cdot [\text{species_10}] \cdot [\text{species_7}]}{K9}}{1 + \frac{[\text{species_7}]}{K9} + \frac{[\text{species_6}]}{K9}} \quad (48)$$

Table 40: Properties of each parameter.

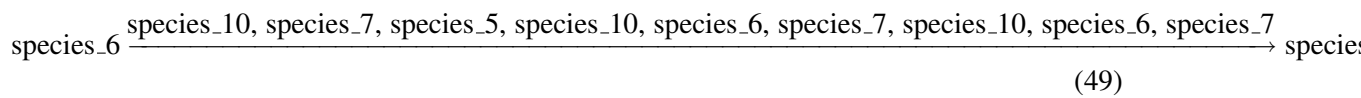
Id	Name	SBO	Value	Unit	Constant
K9	K9		20.00		<input checked="" type="checkbox"/>
k9	k9		0.02		<input checked="" type="checkbox"/>

6.10 Reaction `reaction_9`

This is an irreversible reaction of one reactant forming one product influenced by nine modifiers.

Name 10

Reaction equation



Reactant

Table 41: Properties of each reactant.

Id	Name	SBO
species_6	M_P	

Modifiers

Table 42: Properties of each modifier.

Id	Name	SBO
species_10	P3	
species_7	M_PP	
species_5	M	
species_10	P3	
species_6	M_P	
species_7	M_PP	
species_10	P3	
species_6	M_P	
species_7	M_PP	

Id	Name	SBO
----	------	-----

Product

Table 43: Properties of each product.

Id	Name	SBO
species_5	M	

Kinetic Law

Derived unit contains undeclared units

$$v_{10} = \text{vol}(\text{compartment}_0) \cdot \text{function_4_10_1}(\text{K10}, \text{k10}, [\text{species_10}], [\text{species_6}], [\text{species_7}]) \quad (50)$$

$$\text{function_4_10_1}(\text{K10}, \text{k10}, [\text{species_10}], [\text{species_6}], [\text{species_7}]) = \frac{\frac{\text{k10} \cdot [\text{species_10}] \cdot [\text{species_6}]}{\text{K10}}}{1 + \frac{[\text{species_7}]}{\text{K10}} + \frac{[\text{species_6}]}{\text{K10}}} \quad (51)$$

$$\text{function_4_10_1}(\text{K10}, \text{k10}, [\text{species_10}], [\text{species_6}], [\text{species_7}]) = \frac{\frac{\text{k10} \cdot [\text{species_10}] \cdot [\text{species_6}]}{\text{K10}}}{1 + \frac{[\text{species_7}]}{\text{K10}} + \frac{[\text{species_6}]}{\text{K10}}} \quad (52)$$

Table 44: Properties of each parameter.

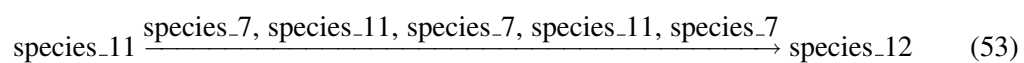
Id	Name	SBO	Value	Unit	Constant
K10	K10		20.00		<input checked="" type="checkbox"/>
k10	k10		0.02		<input checked="" type="checkbox"/>

6.11 Reaction `reaction_10`

This is an irreversible reaction of one reactant forming one product influenced by five modifiers.

Name 11

Reaction equation



Reactant

Table 45: Properties of each reactant.

Id	Name	SBO
species_11	X	

Modifiers

Table 46: Properties of each modifier.

Id	Name	SBO
species_7	M_PP	
species_11	X	
species_7	M_PP	
species_11	X	
species_7	M_PP	

Product

Table 47: Properties of each product.

Id	Name	SBO
species_12	X_P	

Kinetic Law

Derived unit contains undeclared units

$$v_{11} = \text{vol}(\text{compartment}_0) \cdot \text{function}_1(V_{11}, [\text{species}_11], K_{11}, A, [\text{species}_7], K_a) \quad (54)$$

$$\text{function}_1(V_{11}, X, K_{11}, A, [\text{species}_7], K_a) = \frac{\frac{V_{11} \cdot X}{K_{11}}}{1 + \frac{X}{K_{11}}} \cdot \frac{1 + \frac{A \cdot [\text{species}_7]}{K_a}}{1 + \frac{[\text{species}_7]}{K_a}} \quad (55)$$

$$\text{function}_1(V_{11}, X, K_{11}, A, [\text{species}_7], K_a) = \frac{\frac{V_{11} \cdot X}{K_{11}}}{1 + \frac{X}{K_{11}}} \cdot \frac{1 + \frac{A \cdot [\text{species}_7]}{K_a}}{1 + \frac{[\text{species}_7]}{K_a}} \quad (56)$$

Table 48: Properties of each parameter.

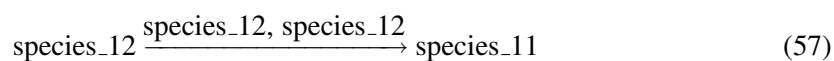
Id	Name	SBO	Value	Unit	Constant
V11	V11		0.1		<input checked="" type="checkbox"/>
K11	K11		50.0		<input checked="" type="checkbox"/>
A	A		100.0		<input checked="" type="checkbox"/>
Ka	Ka		500.0		<input checked="" type="checkbox"/>

6.12 Reaction `reaction_11`

This is an irreversible reaction of one reactant forming one product influenced by two modifiers.

Name 12

Reaction equation



Reactant

Table 49: Properties of each reactant.

Id	Name	SBO
species_12	X_P	

Modifiers

Table 50: Properties of each modifier.

Id	Name	SBO
species_12	X_P	
species_12	X_P	

Product

Table 51: Properties of each product.

Id	Name	SBO
species_11	X	

Kinetic Law

Derived unit contains undeclared units

$$v_{12} = \text{vol}(\text{compartment}_0) \cdot \text{function}_2(V_{12}, [\text{species}_{12}], K_{12}) \quad (58)$$

$$\text{function}_2(V_{12}, X_P, K_{12}) = \frac{V_{12} \cdot X_P}{K_{12} + X_P} \quad (59)$$

$$\text{function}_2(V_{12}, X_P, K_{12}) = \frac{V_{12} \cdot X_P}{K_{12} + X_P} \quad (60)$$

Table 52: Properties of each parameter.

Id	Name	SBO	Value	Unit	Constant
V12	V12		0.5		<input checked="" type="checkbox"/>
K12	K12		50.0		<input checked="" type="checkbox"/>

7 Derived Rate Equations

When interpreted as an ordinary differential equation framework, this model implies the following set of equations for the rates of change of each species.

Identifiers for kinetic laws highlighted in gray cannot be verified to evaluate to units of SBML substance per time. As a result, some SBML interpreters may not be able to verify the consistency of the units on quantities in the model. Please check if

- parameters without an unit definition are involved or
- volume correction is necessary because the `hasOnlySubstanceUnits` flag may be set to `false` and `spacialDimensions` > 0 for certain species.

7.1 Species `species_0`

Name MKKK

Initial concentration 999.999903688753 nmol · ml⁻¹

This species takes part in four reactions (as a reactant in [reaction_0](#) and as a product in [reaction_5](#) and as a modifier in [reaction_0](#), [reaction_0](#)).

$$\frac{d}{dt} \text{species}_0 = v_6 - v_1 \quad (61)$$

7.2 Species `species_1`

Name MKKK_P

Initial concentration 0 nmol · ml⁻¹

This species takes part in ten reactions (as a reactant in `reaction_5` and as a product in `reaction_0` and as a modifier in `reaction_1`, `reaction_1`, `reaction_1`, `reaction_2`, `reaction_2`, `reaction_2`, `reaction_5`, `reaction_5`).

$$\frac{d}{dt}\text{species}_1 = v_1 - v_6 \quad (62)$$

7.3 Species `species_2`

Name MKK

Initial concentration 3999.99961475501 nmol · ml⁻¹

This species takes part in seven reactions (as a reactant in `reaction_1` and as a product in `reaction_7` and as a modifier in `reaction_1`, `reaction_1`, `reaction_2`, `reaction_2`, `reaction_2`).

$$\frac{d}{dt}\text{species}_2 = v_8 - v_2 \quad (63)$$

7.4 Species `species_3`

Name MKK_P

Initial concentration 0 nmol · ml⁻¹

This species takes part in 14 reactions (as a reactant in `reaction_2`, `reaction_7` and as a product in `reaction_1`, `reaction_6` and as a modifier in `reaction_1`, `reaction_1`, `reaction_1`, `reaction_2`, `reaction_2`, `reaction_6`, `reaction_6`, `reaction_6`, `reaction_7`, `reaction_7`).

$$\frac{d}{dt}\text{species}_3 = v_2 + v_7 - v_3 - v_8 \quad (64)$$

7.5 Species `species_4`

Name MKK_PP

Initial concentration 0 nmol · ml⁻¹

This species takes part in 13 reactions (as a reactant in `reaction_6` and as a product in `reaction_2` and as a modifier in `reaction_3`, `reaction_3`, `reaction_3`, `reaction_4`, `reaction_4`, `reaction_4`, `reaction_6`, `reaction_6`, `reaction_7`, `reaction_7`, `reaction_7`).

$$\frac{d}{dt}\text{species}_4 = v_3 - v_7 \quad (65)$$

7.6 Species `species_5`

Name M

Initial concentration 999.999903688753 nmol · ml⁻¹

This species takes part in nine reactions (as a reactant in `reaction_3` and as a product in `reaction_9` and as a modifier in `reaction_3`, `reaction_3`, `reaction_4`, `reaction_4`, `reaction_4`, `reaction_8`, `reaction_9`).

$$\frac{d}{dt}\text{species}_5 = v_{10} - v_4 \quad (66)$$

7.7 Species `species_6`

Name M_P

Initial concentration 0 nmol · ml⁻¹

This species takes part in 14 reactions (as a reactant in `reaction_4`, `reaction_9` and as a product in `reaction_3`, `reaction_8` and as a modifier in `reaction_3`, `reaction_3`, `reaction_3`, `reaction_4`, `reaction_4`, `reaction_8`, `reaction_8`, `reaction_8`, `reaction_9`, `reaction_9`).

$$\frac{d}{dt}\text{species}_6 = v_4 + v_9 - v_5 - v_{10} \quad (67)$$

7.8 Species `species_7`

Name M_PP

Initial concentration 0 nmol · ml⁻¹

This species takes part in 19 reactions (as a reactant in `reaction_8` and as a product in `reaction_4` and as a modifier in `reaction_0`, `reaction_0`, `reaction_0`, `reaction_1`, `reaction_1`, `reaction_1`, `reaction_2`, `reaction_2`, `reaction_2`, `reaction_8`, `reaction_8`, `reaction_8`, `reaction_9`, `reaction_9`, `reaction_9`, `reaction_10`, `reaction_10`, `reaction_10`).

$$\frac{d}{dt}\text{species}_7 = v_5 - v_9 \quad (68)$$

7.9 Species `species_8`

Name P1

Initial concentration 99.9999903688752 nmol · ml⁻¹

This species takes part in three reactions (as a modifier in `reaction_5`, `reaction_5`, `reaction_5`).

$$\frac{d}{dt}\text{species}_8 = 0 \quad (69)$$

7.10 Species `species_9`

Name P2

Initial concentration 499.999951844377 nmol · ml⁻¹

This species takes part in six reactions (as a modifier in [reaction_6](#), [reaction_6](#), [reaction_6](#), [reaction_7](#), [reaction_7](#), [reaction_7](#)).

$$\frac{d}{dt}\text{species_9} = 0 \quad (70)$$

7.11 Species `species_10`

Name P3

Initial concentration 499.999951844377 nmol · ml⁻¹

This species takes part in six reactions (as a modifier in [reaction_8](#), [reaction_8](#), [reaction_8](#), [reaction_9](#), [reaction_9](#), [reaction_9](#)).

$$\frac{d}{dt}\text{species_10} = 0 \quad (71)$$

7.12 Species `species_11`

Name X

Initial concentration 99.9999903688752 nmol · ml⁻¹

This species takes part in four reactions (as a reactant in [reaction_10](#) and as a product in [reaction_11](#) and as a modifier in [reaction_10](#), [reaction_10](#)).

$$\frac{d}{dt}\text{species_11} = v_{12} - v_{11} \quad (72)$$

7.13 Species `species_12`

Name X_P

Initial concentration 0 nmol · ml⁻¹

This species takes part in four reactions (as a reactant in [reaction_11](#) and as a product in [reaction_10](#) and as a modifier in [reaction_11](#), [reaction_11](#)).

$$\frac{d}{dt}\text{species_12} = v_{11} - v_{12} \quad (73)$$

SBML²LaTeX was developed by Andreas Dräger^a, Hannes Planatscher^a, Dieudonné M Wouamba^a, Adrian Schröder^a, Michael Hucka^b, Lukas Endler^c, Martin Golebiewski^d and Andreas Zell^a. Please see <http://www.ra.cs.uni-tuebingen.de/software/SBML2LaTeX> for more information.

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