SBML Model Report

Model name: "Troein2011_ClockCircuit-_OstreococcusTauri"

May 6, 2016

1 General Overview

This is a document in SBML Level 2 Version 4 format. This model was created by the following three authors: Andrew J Millar[1], Vijayalakshmi Chelliah[2] and Troein Carl[3] at August nineth 2011 at 4:20 p. m. and last time modified at April eighth 2016 at 5:02 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	14
events	0	constraints	0
reactions	30	function definitions	21
global parameters	29	unit definitions	2
rules	1	initial assignments	0

Model Notes

This model is from the article:
Multiple light inputs to a simple clock circuit allow complex biological rhythms
Troein C, Corellou F, Dixon LE, van Ooijen G, O'Neill JS, Bouget FY, Millar AJ. Plant J.2011

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Abstract:
Circadian clocks are biological timekeepers that allow living cells to time their activity in anticipation of predictable environmental changes. Detailed understanding of the circadian network of higher plants, such as Arabidopsis thaliana, is hampered by the high number of partially redundant genes. However, the picoeukaryotic alga Ostreococcus tauri, which was recently shown to possess a small number of non-redundant clock genes, presents an attractive alternative target for detailed modelling of circadian clocks in the green lineage. Based on extensive time-series data from in vivo reporter gene assays, we developed a model of the Ostreococcus clock as a feedback loop between the genes TOC1 and CCA1. The model reproduces the dynamics of the transcriptional and translational reporters over a range of photoperiods. Surprisingly, the model is also able to predict the transient behaviour of the clock when the light conditions are altered. Despite the apparent simplicity of the clock circuit, it displays considerable complexity in its response to changing light conditions. Systematic screening of the effects of altered day length revealed a complex relationship between phase and photoperiod, which is also captured by the model. The complex light response is shown to stem from circadian gating of light-dependent mechanisms. This study provides insights into the contributions of light inputs to the Ostreococcus clock. The model suggests that a high number of light-dependent reactions are important for flexible timing in a circadian clock with only one feedback loop.

Note: Two-gene model of the Ostreococcus circadian clock

This is a model of the circadian clock of Ostreococcus tauri, with a negative feedback loop between TOC1 and CCA1 (a.k.a. LHY) and multiple light inputs. It was used and described in Troein et al., Plant Journal (2011).

The model incorporates luciferase reporters, and in this SBML model the four different versions of the model for transcriptional and translational reporter lines (pTOC1::LUC, pCCA1::LUC, TOC1-LUC and CCA1-LUC) are all accessible by setting one of the rep_X parameters to 1 and the others to 0. You can also set all four to 0 to only simulate the non-reporter core of the system.

Input to the system should be provided by modifying the „light„ function. An implementation of LD 12:12 is provided as an example, but the model was also used with more complicated light regimes that vary between data sets and are not convenient to express directly in SBML.

The functions „ox_cca1„ and „ox_toc1„ can be altered to add overexpression of CCA1 and TOC1. Setting either to x gives additional, constitutive transcription at x times the maximal (and typically not realizable) transcription rate of the native gene. The overexpression mutant fits in Figure 7 of Troein et al. (2011) used ox_cca1 = 0.115 and oc_toc1 = 0.0584, respectively.

The functions „copies_toc1„ and „copies_cca1„ are normally 1 but can be lowered to simulate knockdown experiments. The functions „transcription„ „translation„ and „proteasome„ can be modified to simulate the effects of altering the overall rate of transcription, translation and protein degradation.

The parameters were fitted specifically to data from transgenic reporter lines TOC8, pTOC3, LHY7 and pLHY7 (Corellou et al., Plant Cell 2009). Parameters that begin with „effcopies„ describe the effective number of copies of CCA1 or TOC1 in the respective translational fusion lines, with anything above 1 due to the fusion proteins.

For the model fitting, the initial values were fitted to the data in the various time courses. The

initial values given here correspond to the limit cycle of the system in LD 12:12. The system converges to the limit cycle in just a few days under most light conditions, so these initial values are biologically meaningful.

The species cca1luc_c and cca1luc_n have been merged into cca1luc (which corresponds to the observable luminescence signal), because Copasi refused to run the system otherwise. For TOC1-LUC, the predicted output signal is the sum of toc1luc_1 and toc1luc_2.

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 `time`

Definition 3600 s

2.2 Unit `substance`

Definition nmol

2.3 Unit `volume`

Notes Litre is the predefined SBML unit for `volume`.

Definition l

2.4 Unit `area`

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

Definition m^2

2.5 Unit `length`

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

Definition m

3 Compartment

This model contains one compartment.

Table 2: Properties of all compartments.

Id	Name	SBO	Spatial Dimensions	Size	Unit	Constant	Outside
`compartment`	compartment	0000290	3	1	litre	☑	

3.1 Compartment `compartment`

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

Name compartment

SBO:0000290 physical compartment

4 Species

This model contains 14 species. Section 9 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
acc	acc	compartment	$\mathrm{nmol} \cdot \mathrm{l}^{-1}$	⊟	⊟
toc1_mrna	toc1_mrna	compartment	$\mathrm{nmol} \cdot \mathrm{l}^{-1}$	⊟	⊟
toc1_1	toc1_1	compartment	$\mathrm{nmol} \cdot \mathrm{l}^{-1}$	⊟	⊟
toc1_2	toc1_2	compartment	$\mathrm{nmol} \cdot \mathrm{l}^{-1}$	⊟	⊟
cca1_mrna	cca1_mrna	compartment	$\mathrm{nmol} \cdot \mathrm{l}^{-1}$	⊟	⊟
cca1_c	cca1_c	compartment	$\mathrm{nmol} \cdot \mathrm{l}^{-1}$	⊟	⊟
cca1_n	cca1_n	compartment	$\mathrm{nmol} \cdot \mathrm{l}^{-1}$	⊟	⊟
toc1luc_mrna	toc1luc_mrna	compartment	$\mathrm{nmol} \cdot \mathrm{l}^{-1}$	⊟	⊟
toc1luc_1	toc1luc_1	compartment	$\mathrm{nmol} \cdot \mathrm{l}^{-1}$	⊟	⊟
toc1luc_2	toc1luc_2	compartment	$\mathrm{nmol} \cdot \mathrm{l}^{-1}$	⊟	⊟
cca1luc_mrna	cca1luc_mrna	compartment	$\mathrm{nmol} \cdot \mathrm{l}^{-1}$	⊟	⊟
cca1luc	cca1luc	compartment	$\mathrm{nmol} \cdot \mathrm{l}^{-1}$	⊟	⊟
luc_mrna	luc_mrna	compartment	$\mathrm{nmol} \cdot \mathrm{l}^{-1}$	⊟	⊟
luc	luc	compartment	$\mathrm{nmol} \cdot \mathrm{l}^{-1}$	⊟	⊟

5 Parameters

This model contains 29 global parameters.

Table 4: Properties of each parameter.

Id	Name	SBO	Value	Unit	Constant
toc1luc	toc1luc		0.000		☐
D_luc	D_luc	0000349	0.183		☑
D_mrna_luc	D_mrna_luc	0000356	1.000		☑
acc_rate	acc_rate	0000009	0.082		☑
R_toc1_cca1	R_toc1_cca1	0000009	1.087		☑
H_toc1_cca1	H_toc1_cca1	0000009	2.078		☑
L_toc1	L_toc1	0000153	10^{-4}		☑
R_toc1_acc	R_toc1_acc	0000153	0.231		☑
D_mrna_toc1	D_mrna_toc1	0000356	0.292		☑
T_toc1	T_toc1	0000153	0.770		☑
Di_toc1_12_l	Di_toc1_12_l	0000153	0.136		☑
Di_toc1_12_d	Di_toc1_12_d	0000153	0.327		☑
D_toc1_2_l	D_toc1_2_l	0000356	0.462		☑
D_toc1_2_d	D_toc1_2_d	0000356	0.357		☑
H_cca1_toc1	H_cca1_toc1	0000153	2.501		☑
R_cca1_toc1_2_l	R_cca1_toc1_2_l	0000153	3.275		☑
R_cca1_toc1_2_d	R_cca1_toc1_2_d	0000153	1.386		☑
D_mrna_cca1	D_mrna_cca1	0000356	1.331		☑
T_cca1	T_cca1	0000153	4.905		☑
Di_cca1_cn	Di_cca1_cn	0000009	10.000		☑
D_cca1_l	D_cca1_l	0000356	0.424		☑
D_cca1_d	D_cca1_d	0000356	0.269		☑
effcopies_cca1_LHY7	effcopies_cca1_LHY7	0000009	1.140		☑
effcopies_toc1_TOC8	effcopies_toc1_TOC8	0000009	1.000		☑
parameter_1	T_luc	0000009	1.000		☑
parameter_2	rep_TOC1	0000009	0.000		☑
parameter_3	rep_pTOC1	0000009	0.000		☑
parameter_4	rep_CCA1	0000009	0.000		☑
parameter_5	rep_pCCA1	0000009	0.000		☑

6 Function definitions

This is an overview of 21 function definitions.

6.1 Function definition `LD1212`

Name LD1212

Argument tod

Mathematical Expression

$$\left\lceil \frac{\sin\left(\frac{\pi \cdot \mathrm{tod}}{12}\right)}{2} \right\rceil \tag{1}$$

6.2 Function definition `function_2`

Name Light accumulator decrease

Arguments acc_rate, [acc]

Mathematical Expression

$$\mathrm{acc\_rate} \cdot [\mathrm{acc}] \tag{2}$$

6.3 Function definition `light`

Name light

Argument tod

Mathematical Expression

$$\mathrm{LD1212}\,(\mathrm{tod}) \tag{3}$$

6.4 Function definition `transcription`

Name transcription

Argument t

Mathematical Expression

$$1 + 0 \cdot \mathrm{t} \tag{4}$$

6.5 Function definition `ox_toc1`

Name ox_toc1

Argument t

Mathematical Expression

$$0 \cdot \mathrm{t} \tag{5}$$

6.6 Function definition copies_toc1

Name copies_toc1

Argument t

Mathematical Expression

$$1 + 0 \cdot t \tag{6}$$

6.7 Function definition copies_cca1

Name copies_cca1

Argument t

Mathematical Expression

$$1 + 0 \cdot t \tag{7}$$

6.8 Function definition ox_cca1

Name ox_cca1

Argument t

Mathematical Expression

$$0 \cdot t \tag{8}$$

6.9 Function definition translation

Name translation

Argument t

Mathematical Expression

$$1 + 0 \cdot t \tag{9}$$

6.10 Function definition proteasome

Name proteasome

Argument t

Mathematical Expression

$$1 + 0 \cdot t \tag{10}$$

6.11 Function definition Translation

Name Translation

Arguments t, T, mrna

Mathematical Expression

$$\text{translation}\,(\text{t}) \cdot \text{T} \cdot \text{mrna} \tag{11}$$

6.12 Function definition function_4

Name Light-dependent protein decay

Arguments t, D_l, D_d, level

Mathematical Expression

$$\text{proteasome}\,(\text{t}) \cdot (\text{light}\,(\text{t}) \cdot \text{D\_l} + (1 - \text{light}\,(\text{t})) \cdot \text{D\_d}) \cdot \text{level} \tag{12}$$

6.13 Function definition function_5

Name Light-dependent transport

Arguments t, Di_l, Di_d, level

Mathematical Expression

$$(\text{light}\,(\text{t}) \cdot \text{Di\_l} + (1 - \text{light}\,(\text{t})) \cdot \text{Di\_d}) \cdot \text{level} \tag{13}$$

6.14 Function definition function_7

Name LUC transcription for pTOC1

Arguments t, R_toc1_acc, [acc], R_toc1_cca1, [cca1_n], H_toc1_cca1, rep_pTOC1, L_toc1

Mathematical Expression

$$\frac{\text{rep\_pTOC1} \cdot \text{transcription}\,(\text{t}) \cdot (\text{L\_toc1} + \text{R\_toc1\_acc} \cdot [\text{acc}])}{1 + \text{L\_toc1} + \text{R\_toc1\_acc} \cdot [\text{acc}] + (\text{R\_toc1\_cca1} \cdot [\text{cca1\_n}])^{\text{H\_toc1\_cca1}}} \tag{14}$$

6.15 Function definition function_8

Name TOC1-LUC transcription

Arguments t, R_toc1_acc, [acc], R_toc1_cca1, [cca1_n], H_toc1_cca1, rep_TOC1, L_toc1

Mathematical Expression

$$\frac{\text{rep\_TOC1} \cdot \text{transcription}\,(\text{t}) \cdot \text{copies\_toc1}\,(\text{t}) \cdot (\text{L\_toc1} + \text{R\_toc1\_acc} \cdot [\text{acc}])}{1 + \text{L\_toc1} + \text{R\_toc1\_acc} \cdot [\text{acc}] + (\text{R\_toc1\_cca1} \cdot [\text{cca1\_n}])^{\text{H\_toc1\_cca1}}} \tag{15}$$

6.16 Function definition function_9

Name LUC transcription for pCCA1

Arguments t, [toc1_2], R_cca1_toc1_2_l, R_cca1_toc1_2_d, H_cca1_toc1, rep_pCCA1

Mathematical Expression

$$\frac{\text{rep\_pCCA1} \cdot \text{transcription}(t) \cdot ([\text{toc1\_2}] \cdot (\text{light}(t) \cdot \text{R\_cca1\_toc1\_2\_l} + (1 - \text{light}(t)) \cdot \text{R\_cca1\_toc1\_2\_d}))^{\text{H\_cca1\_toc1}}}{([\text{toc1\_2}] \cdot (\text{light}(t) \cdot \text{R\_cca1\_toc1\_2\_l} + (1 - \text{light}(t)) \cdot \text{R\_cca1\_toc1\_2\_d}))^{\text{H\_cca1\_toc1}} + 1} \quad (16)$$

6.17 Function definition function_10

Name CCA1-LUC transcription

Arguments t, [toc1_2], R_cca1_toc1_2_l, R_cca1_toc1_2_d, H_cca1_toc1, rep_CCA1

Mathematical Expression

$$\frac{\text{rep\_CCA1} \cdot \text{transcription}(t) \cdot \text{copies\_cca1}(t) \cdot ([\text{toc1\_2}] \cdot (\text{light}(t) \cdot \text{R\_cca1\_toc1\_2\_l} + (1 - \text{light}(t)) \cdot \text{R\_cca1\_toc1\_2}}{([\text{toc1\_2}] \cdot (\text{light}(t) \cdot \text{R\_cca1\_toc1\_2\_l} + (1 - \text{light}(t)) \cdot \text{R\_cca1\_toc1\_2\_d}))^{\text{H\_cca1\_toc1}} + 1} \quad (17)$$

6.18 Function definition tf_output

Name tf_output

Arguments reporter, effcopies, tf

Mathematical Expression

$$(1 + \text{reporter} \cdot (\text{effcopies} - 1)) \cdot \text{tf} \quad (18)$$

6.19 Function definition function_1

Name Light accumulator increase

Arguments acc_rate, t

Mathematical Expression

$$\text{acc\_rate} \cdot \text{light}(t) \quad (19)$$

6.20 Function definition function_3

Name TOC1 transcription

Arguments R_toc1_acc, [acc], R_toc1_cca1, H_toc1_cca1, [cca1_n], t, L_toc1, rep_CCA1, effcopies_cca1_LHY7

Mathematical Expression

$$\text{transcription}(t) \cdot \left(\text{ox\_toc1}(t) \right. \tag{20}$$

$$+ \frac{\text{copies\_toc1}(t) \cdot (\text{L\_toc1} + \text{R\_toc1\_acc} \cdot [\text{acc}])}{1 + \text{L\_toc1} + \text{R\_toc1\_acc} \cdot [\text{acc}] + (\text{R\_toc1\_cca1} \cdot \text{tf\_output}(\text{rep\_CCA1}, \text{effcopies\_cca1\_LHY7}, [\text{cca1\_n}]))^{\text{H\_toc1\_cca1}}}$$

6.21 Function definition function_6

Name CCA1 transcription

Arguments t, [toc1_2], R_cca1_toc1_2_l, R_cca1_toc1_2_d, H_cca1_toc1, rep_TOC1, effcopies_toc1_TOC8

Mathematical Expression

$$\text{transcription}(t) \cdot \left(\text{ox\_cca1}(t) \right. \tag{21}$$

$$+ \frac{\text{copies\_cca1}(t) \cdot (\text{tf\_output}(\text{rep\_TOC1}, \text{effcopies\_toc1\_TOC8}, [\text{toc1\_2}]) \cdot (\text{light}(t) \cdot \text{R\_cca1\_toc1\_2\_l} + (1 - \text{light}(t)$$

$$(\text{tf\_output}(\text{rep\_TOC1}, \text{effcopies\_toc1\_TOC8}, [\text{toc1\_2}]) \cdot (\text{light}(t) \cdot \text{R\_cca1\_toc1\_2\_l} + (1 - \text{light}(t)) \cdot \text{R\_cca1}$$

7 Rule

This is an overview of one rule.

7.1 Rule toc1luc

Rule toc1luc is an assignment rule for parameter toc1luc:

$$\text{toc1luc} = [\text{toc1luc\_1}] + [\text{toc1luc\_2}] \tag{22}$$

Derived unit $\text{nmol} \cdot \text{l}^{-1}$

8 Reactions

This model contains 30 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 5: Overview of all reactions

№	Id	Name	Reaction Equation	SBO
1	reaction_1	Light accumulator increase	$\emptyset \longrightarrow$ acc	0000393
2	reaction_2	Light accumulator decrease	acc $\longrightarrow \emptyset$	0000179
3	reaction_3	TOC1 transcription	$\emptyset \xrightarrow{\text{acc, cca1\_n}}$ toc1_mrna	0000183
4	reaction_4	TOC1 degradation	toc1_2 $\longrightarrow \emptyset$	0000179
5	reaction_5	TOC1 translation	$\emptyset \xrightarrow{\text{toc1\_mrna}}$ toc1_1	0000184
6	reaction_6	TOC1 conversion	toc1_1 $\longrightarrow$ toc1_2	0000182
7	reaction_7	TOC1 mRNA degradation	toc1_mrna $\longrightarrow \emptyset$	0000179
8	reaction_8	CCA1 transcription	$\emptyset \xrightarrow{\text{toc1\_2}}$ cca1_mrna	0000183
9	reaction_9	CCA1 mRNA degradation	cca1_mrna $\longrightarrow \emptyset$	0000179
10	reaction_10	CCA1 translation	$\emptyset \xrightarrow{\text{cca1\_mrna}}$ cca1_c	0000184
11	reaction_11	CCA1 nuclear transport	cca1_c $\longrightarrow$ cca1_n	0000185
12	reaction_12	CCA1 degradation, cytosol	cca1_c $\longrightarrow \emptyset$	0000179
13	reaction_13	CCA1 degradation, nucleus	cca1_n $\longrightarrow \emptyset$	0000179
14	reaction_14	LUC transcription, pTOC1	$\emptyset \xrightarrow{\text{acc, cca1\_n}}$ luc_mrna	0000183
15	reaction_15	LUC mRNA degradation	luc_mrna $\longrightarrow \emptyset$	0000179
16	reaction_16	LUC translation	$\emptyset \xrightarrow{\text{luc\_mrna}}$ luc	0000184
17	reaction_17	LUC decay	luc $\longrightarrow \emptyset$	0000179
18	reaction_18	TOC1-LUC transcription	$\emptyset \xrightarrow{\text{acc, cca1\_n}}$ toc1luc_mrna	0000183
19	reaction_19	TOC1-LUC mRNA degradation	toc1luc_mrna $\longrightarrow \emptyset$	0000179
20	reaction_20	TOC1-LUC translation	$\emptyset \xrightarrow{\text{toc1luc\_mrna}}$ toc1luc_1	0000184

№	Id	Name	Reaction Equation	SBO
21	reaction_21	TOC1-LUC conversion	$\text{toc1luc\_1} \longrightarrow \text{toc1luc\_2}$	0000182
22	reaction_22	TOC1-LUC degradation	$\text{toc1luc\_2} \longrightarrow \emptyset$	0000179
23	reaction_23	TOC1-LUC(1) deactivation	$\text{toc1luc\_1} \longrightarrow \emptyset$	0000176
24	reaction_24	TOC1-LUC(2) deactivation	$\text{toc1luc\_2} \longrightarrow \emptyset$	0000176
25	reaction_25	LUC transcription, pCCA1	$\emptyset \xrightarrow{\text{toc1\_2}} \text{luc\_mrna}$	0000183
26	reaction_26	CCA1-LUC transcription	$\emptyset \xrightarrow{\text{toc1\_2}} \text{cca1luc\_mrna}$	0000183
27	reaction_27	CCA1-LUC mRNA degradation	$\text{cca1luc\_mrna} \longrightarrow \emptyset$	0000179
28	reaction_28	CCA1-LUC translation	$\emptyset \xrightarrow{\text{cca1luc\_mrna}} \text{cca1luc}$	0000184
29	reaction_30	CCA1-LUC degradation	$\text{cca1luc} \longrightarrow \emptyset$	0000179
30	reaction_32	CCA1-LUC deactivation	$\text{cca1luc} \longrightarrow \emptyset$	0000176

8.1 Reaction reaction_1

This is an irreversible reaction of no reactant forming one product.

Name Light accumulator increase

SBO:0000393 production

Reaction equation

$$\emptyset \longrightarrow \text{acc} \tag{23}$$

Product

Table 6: Properties of each product.

Id	Name	SBO
acc	acc	

Kinetic Law

Derived unit contains undeclared units

$$v_1 = \text{vol}\left(\text{compartment}\right) \cdot \text{function\_1}\left(\text{acc\_rate}, \text{time}\right) \tag{24}$$

$$\text{function\_1}\left(\text{acc\_rate}, \text{t}\right) = \text{acc\_rate} \cdot \text{light}\left(\text{t}\right) \tag{25}$$

$$\text{function\_1}\left(\text{acc\_rate}, \text{t}\right) = \text{acc\_rate} \cdot \text{light}\left(\text{t}\right) \tag{26}$$

8.2 Reaction reaction_2

This is an irreversible reaction of one reactant forming no product.

Name Light accumulator decrease

SBO:0000179 degradation

Reaction equation

$$\text{acc} \longrightarrow \emptyset \tag{27}$$

Reactant

Table 7: Properties of each reactant.

Id	Name	SBO
acc	acc	

Kinetic Law

Derived unit contains undeclared units

$$v_2 = \mathrm{vol}\,(\mathrm{compartment}) \cdot \mathrm{function\_2}\,(\mathrm{acc\_rate}, [\mathrm{acc}]) \tag{28}$$

$$\mathrm{function\_2}\,(\mathrm{acc\_rate}, [\mathrm{acc}]) = \mathrm{acc\_rate} \cdot [\mathrm{acc}] \tag{29}$$

$$\mathrm{function\_2}\,(\mathrm{acc\_rate}, [\mathrm{acc}]) = \mathrm{acc\_rate} \cdot [\mathrm{acc}] \tag{30}$$

8.3 Reaction reaction_3

This is an irreversible reaction of no reactant forming one product influenced by two modifiers.

Name TOC1 transcription

SBO:0000183 transcription

Reaction equation

$$\emptyset \xrightarrow{\mathrm{acc},\ \mathrm{cca1\_n}} \mathrm{toc1\_mrna} \tag{31}$$

Modifiers

Table 8: Properties of each modifier.

Id	Name	SBO
acc	acc	
cca1_n	cca1_n	

Product

Table 9: Properties of each product.

Id	Name	SBO
toc1_mrna	toc1_mrna	

Kinetic Law

Derived unit contains undeclared units

$$v_3 = \mathrm{vol}\left(\mathrm{compartment}\right) \cdot \mathrm{function\_3}\left(\mathrm{R\_toc1\_acc}, [\mathrm{acc}], \mathrm{R\_toc1\_cca1}, \mathrm{H\_toc1\_cca1}, [\mathrm{cca1\_n}], \mathrm{time}, \mathrm{L\_toc1}, \mathrm{parameter\_4}, \mathrm{effcopies\_cca1\_LHY7}\right) \tag{32}$$

$$\mathrm{function\_3}\left(\mathrm{R\_toc1\_acc}, [\mathrm{acc}], \mathrm{R\_toc1\_cca1}, \mathrm{H\_toc1\_cca1}, [\mathrm{cca1\_n}], \mathrm{t}, \mathrm{L\_toc1}, \mathrm{rep\_CCA1}, \mathrm{effcopies\_cca1\_LHY7}\right) = \mathrm{transcription}\left(\mathrm{t}\right) \cdot \left(\mathrm{ox\_toc1}\left(\mathrm{t}\right) + \frac{\mathrm{copies\_toc1}\left(\mathrm{t}\right) \cdot \left(\mathrm{L\_toc1} + \mathrm{R\_toc1\_acc} \cdot [\mathrm{acc}]\right)}{1 + \mathrm{L\_toc1} + \mathrm{R\_toc1\_acc} \cdot [\mathrm{acc}] + \left(\mathrm{R\_toc1\_cca1} \cdot \mathrm{tf\_output}\left(\mathrm{rep\_CCA1}, \mathrm{effcopies\_cca1\_LHY7}, [\mathrm{cca1\_n}]\right)\right)^{\mathrm{H\_toc1\_c}}}\right) \tag{33}$$

$$\mathrm{function\_3}\left(\mathrm{R\_toc1\_acc}, [\mathrm{acc}], \mathrm{R\_toc1\_cca1}, \mathrm{H\_toc1\_cca1}, [\mathrm{cca1\_n}], \mathrm{t}, \mathrm{L\_toc1}, \mathrm{rep\_CCA1}, \mathrm{effcopies\_cca1\_LHY7}\right) = \mathrm{transcription}\left(\mathrm{t}\right) \cdot \left(\mathrm{ox\_toc1}\left(\mathrm{t}\right) + \frac{\mathrm{copies\_toc1}\left(\mathrm{t}\right) \cdot \left(\mathrm{L\_toc1} + \mathrm{R\_toc1\_acc} \cdot [\mathrm{acc}]\right)}{1 + \mathrm{L\_toc1} + \mathrm{R\_toc1\_acc} \cdot [\mathrm{acc}] + \left(\mathrm{R\_toc1\_cca1} \cdot \mathrm{tf\_output}\left(\mathrm{rep\_CCA1}, \mathrm{effcopies\_cca1\_LHY7}, [\mathrm{cca1\_n}]\right)\right)^{\mathrm{H\_toc1\_c}}}\right) \tag{34}$$

8.4 Reaction `reaction_4`

This is an irreversible reaction of one reactant forming no product.

Name TOC1 degradation

SBO:0000179 degradation

Reaction equation

$$\mathrm{toc1\_2} \longrightarrow \emptyset \tag{35}$$

Reactant

Table 10: Properties of each reactant.

Id	Name	SBO
`toc1_2`	toc1_2	

Kinetic Law

Derived unit contains undeclared units

$$v_4 = \mathrm{vol}\left(\mathrm{compartment}\right) \cdot \mathrm{function\_4}\left(\mathrm{time}, \mathrm{D\_toc1\_2\_l}, \mathrm{D\_toc1\_2\_d}, \left[\mathrm{toc1\_2}\right]\right) \tag{36}$$

$$\mathrm{function\_4}\left(\mathrm{t}, \mathrm{D\_l}, \mathrm{D\_d}, \mathrm{level}\right) = \mathrm{proteasome}\left(\mathrm{t}\right) \cdot \left(\mathrm{light}\left(\mathrm{t}\right) \cdot \mathrm{D\_l} + \left(1 - \mathrm{light}\left(\mathrm{t}\right)\right) \cdot \mathrm{D\_d}\right) \cdot \mathrm{level} \tag{37}$$

$$\mathrm{function\_4}\left(\mathrm{t}, \mathrm{D\_l}, \mathrm{D\_d}, \mathrm{level}\right) = \mathrm{proteasome}\left(\mathrm{t}\right) \cdot \left(\mathrm{light}\left(\mathrm{t}\right) \cdot \mathrm{D\_l} + \left(1 - \mathrm{light}\left(\mathrm{t}\right)\right) \cdot \mathrm{D\_d}\right) \cdot \mathrm{level} \tag{38}$$

8.5 Reaction `reaction_5`

This is an irreversible reaction of no reactant forming one product influenced by one modifier.

Name TOC1 translation

SBO:0000184 translation

Reaction equation

$$\emptyset \xrightarrow{\mathrm{toc1\_mrna}} \mathrm{toc1\_1} \tag{39}$$

Modifier

Table 11: Properties of each modifier.

Id	Name	SBO
`toc1_mrna`	toc1_mrna	

Product

Table 12: Properties of each product.

Id	Name	SBO
`toc1_1`	toc1_1	

Kinetic Law

Derived unit contains undeclared units

$$v_5 = \mathrm{vol}\left(\mathrm{compartment}\right) \cdot \mathrm{Translation}\left(\mathrm{time}, \mathrm{T\_toc1}, \left[\mathrm{toc1\_mrna}\right]\right) \tag{40}$$

$$\mathrm{Translation}\left(\mathrm{t}, \mathrm{T}, \mathrm{mrna}\right) = \mathrm{translation}\left(\mathrm{t}\right) \cdot \mathrm{T} \cdot \mathrm{mrna} \tag{41}$$

$$\text{Translation}\,(\text{t},\text{T},\text{mrna}) = \text{translation}\,(\text{t}) \cdot \text{T} \cdot \text{mrna} \tag{42}$$

8.6 Reaction `reaction_6`

This is an irreversible reaction of one reactant forming one product.

Name TOC1 conversion

SBO:0000182 conversion

Reaction equation

$$\text{toc1\_1} \longrightarrow \text{toc1\_2} \tag{43}$$

Reactant

Table 13: Properties of each reactant.

Id	Name	SBO
`toc1_1`	toc1_1	

Product

Table 14: Properties of each product.

Id	Name	SBO
`toc1_2`	toc1_2	

Kinetic Law

Derived unit contains undeclared units

$$v_6 = \text{vol}\,(\text{compartment}) \cdot \text{function\_5}\,(\text{time}, \text{Di\_toc1\_12\_l}, \text{Di\_toc1\_12\_d}, [\text{toc1\_1}]) \tag{44}$$

$$\text{function\_5}\,(\text{t}, \text{Di\_l}, \text{Di\_d}, \text{level}) = (\text{light}\,(\text{t}) \cdot \text{Di\_l} + (1 - \text{light}\,(\text{t})) \cdot \text{Di\_d}) \cdot \text{level} \tag{45}$$

$$\text{function\_5}\,(\text{t}, \text{Di\_l}, \text{Di\_d}, \text{level}) = (\text{light}\,(\text{t}) \cdot \text{Di\_l} + (1 - \text{light}\,(\text{t})) \cdot \text{Di\_d}) \cdot \text{level} \tag{46}$$

8.7 Reaction `reaction_7`

This is an irreversible reaction of one reactant forming no product.

Name TOC1 mRNA degradation

SBO:0000179 degradation

Reaction equation

$$\text{toc1\_mrna} \longrightarrow \emptyset \tag{47}$$

Reactant

Table 15: Properties of each reactant.

Id	Name	SBO
toc1_mrna	toc1_mrna	

Kinetic Law

Derived unit contains undeclared units

$$v_7 = \text{vol}(\text{compartment}) \cdot \text{D\_mrna\_toc1} \cdot [\text{toc1\_mrna}] \tag{48}$$

8.8 Reaction reaction_8

This is an irreversible reaction of no reactant forming one product influenced by one modifier.

Name CCA1 transcription

SBO:0000183 transcription

Reaction equation

$$\emptyset \xrightarrow{\text{toc1\_2}} \text{cca1\_mrna} \tag{49}$$

Modifier

Table 16: Properties of each modifier.

Id	Name	SBO
toc1_2	toc1_2	

Product

Table 17: Properties of each product.

Id	Name	SBO
cca1_mrna	cca1_mrna	

Kinetic Law

Derived unit contains undeclared units

$$v_8 = \mathrm{vol}\,(\mathrm{compartment}) \cdot \mathrm{function\_6}\,(\mathrm{time}, [\mathrm{toc1\_2}], \mathrm{R\_cca1\_toc1\_2\_l}, \mathrm{R\_cca1\_toc1\_2\_d}, \mathrm{H\_cca1\_toc1}, \mathrm{parameter\_2}, \mathrm{effcopies\_toc1\_TOC8}) \tag{50}$$

$$\mathrm{function\_6}\,(\mathrm{t}, [\mathrm{toc1\_2}], \mathrm{R\_cca1\_toc1\_2\_l}, \mathrm{R\_cca1\_toc1\_2\_d}, \mathrm{H\_cca1\_toc1}, \mathrm{rep\_TOC1}, \mathrm{effcopies\_toc1\_TOC8}) = \mathrm{transcription}\,(\mathrm{t}) \cdot \left(\mathrm{ox\_cca1}\,(\mathrm{t}) + \frac{\mathrm{copies\_cca1}\,(\mathrm{t}) \cdot (\mathrm{tf\_output}\,(\mathrm{rep\_TOC1}, \mathrm{effcopies\_toc1\_TOC8}, [\mathrm{toc1\_2}]) \cdot (\mathrm{light}\,(\mathrm{t}) \cdot \mathrm{R\_cca1\_toc1\_2\_l} + (1 - \mathrm{light}\,(\mathrm{t})) \cdot \mathrm{R\_cca1\_toc1\_2\_d}) + \mathrm{H\_cca1\_toc1})^{\mathrm{n}}}{(\mathrm{tf\_output}\,(\mathrm{rep\_TOC1}, \mathrm{effcopies\_toc1\_TOC8}, [\mathrm{toc1\_2}]) \cdot (\mathrm{light}\,(\mathrm{t}) \cdot \mathrm{R\_cca1\_toc1\_2\_l} + (1 - \mathrm{light}\,(\mathrm{t})) \cdot \mathrm{R\_cca1\_toc1\_2\_d}) + \mathrm{H\_cca1\_toc1})^{\mathrm{n}} + 1} \right) \tag{51}$$

$$\mathrm{function\_6}\,(\mathrm{t}, [\mathrm{toc1\_2}], \mathrm{R\_cca1\_toc1\_2\_l}, \mathrm{R\_cca1\_toc1\_2\_d}, \mathrm{H\_cca1\_toc1}, \mathrm{rep\_TOC1}, \mathrm{effcopies\_toc1\_TOC8}) = \mathrm{transcription}\,(\mathrm{t}) \cdot \left(\mathrm{ox\_cca1}\,(\mathrm{t}) + \frac{\mathrm{copies\_cca1}\,(\mathrm{t}) \cdot (\mathrm{tf\_output}\,(\mathrm{rep\_TOC1}, \mathrm{effcopies\_toc1\_TOC8}, [\mathrm{toc1\_2}]) \cdot (\mathrm{light}\,(\mathrm{t}) \cdot \mathrm{R\_cca1\_toc1\_2\_l} + (1 - \mathrm{light}\,(\mathrm{t})) \cdot \mathrm{R\_cca1\_toc1\_2\_d}) + \mathrm{H\_cca1\_toc1})^{\mathrm{n}}}{(\mathrm{tf\_output}\,(\mathrm{rep\_TOC1}, \mathrm{effcopies\_toc1\_TOC8}, [\mathrm{toc1\_2}]) \cdot (\mathrm{light}\,(\mathrm{t}) \cdot \mathrm{R\_cca1\_toc1\_2\_l} + (1 - \mathrm{light}\,(\mathrm{t})) \cdot \mathrm{R\_cca1\_toc1\_2\_d}) + \mathrm{H\_cca1\_toc1})^{\mathrm{n}} + 1} \right) \tag{52}$$

8.9 Reaction `reaction_9`

This is an irreversible reaction of one reactant forming no product.

Name CCA1 mRNA degradation

SBO:0000179 degradation

Reaction equation

$$\mathrm{cca1\_mrna} \longrightarrow \emptyset \tag{53}$$

Reactant

Table 18: Properties of each reactant.

Id	Name	SBO
`cca1_mrna`	cca1_mrna	

Kinetic Law

Derived unit contains undeclared units

$$v_9 = \mathrm{vol}\,(\mathrm{compartment}) \cdot \mathrm{D\_mrna\_cca1} \cdot [\mathrm{cca1\_mrna}] \tag{54}$$

8.10 Reaction `reaction_10`

This is an irreversible reaction of no reactant forming one product influenced by one modifier.

Name CCA1 translation

SBO:0000184 translation

Reaction equation

$$\emptyset \xrightarrow{\mathrm{cca1\_mrna}} \mathrm{cca1\_c} \tag{55}$$

Modifier

Table 19: Properties of each modifier.

Id	Name	SBO
`cca1_mrna`	cca1_mrna	

Product

Table 20: Properties of each product.

Id	Name	SBO
`cca1_c`	cca1_c	

Kinetic Law

Derived unit contains undeclared units

$$v_{10} = \mathrm{vol}\,(\mathrm{compartment}) \cdot \mathrm{Translation}\,(\mathrm{time}, \mathrm{T\_cca1}, [\mathrm{cca1\_mrna}]) \tag{56}$$

$$\mathrm{Translation}\,(\mathrm{t}, \mathrm{T}, \mathrm{mrna}) = \mathrm{translation}\,(\mathrm{t}) \cdot \mathrm{T} \cdot \mathrm{mrna} \tag{57}$$

$$\mathrm{Translation}\,(\mathrm{t}, \mathrm{T}, \mathrm{mrna}) = \mathrm{translation}\,(\mathrm{t}) \cdot \mathrm{T} \cdot \mathrm{mrna} \tag{58}$$

8.11 Reaction reaction_11

This is an irreversible reaction of one reactant forming one product.

Name CCA1 nuclear transport

SBO:0000185 transport reaction

Reaction equation

$$\text{cca1\_c} \longrightarrow \text{cca1\_n} \tag{59}$$

Reactant

Table 21: Properties of each reactant.

Id	Name	SBO
cca1_c	cca1_c	

Product

Table 22: Properties of each product.

Id	Name	SBO
cca1_n	cca1_n	

Kinetic Law

Derived unit contains undeclared units

$$v_{11} = \text{vol}(\text{compartment}) \cdot \text{Di\_cca1\_cn} \cdot [\text{cca1\_c}] \tag{60}$$

8.12 Reaction reaction_12

This is an irreversible reaction of one reactant forming no product.

Name CCA1 degradation, cytosol

SBO:0000179 degradation

Reaction equation

$$\text{cca1\_c} \longrightarrow \emptyset \tag{61}$$

Reactant

Table 23: Properties of each reactant.

Id	Name	SBO
cca1_c	cca1_c	

Kinetic Law

Derived unit contains undeclared units

$$v_{12} = \mathrm{vol}(\mathrm{compartment}) \cdot \mathrm{function\_4}(\mathrm{time}, \mathrm{D\_cca1\_l}, \mathrm{D\_cca1\_d}, [\mathrm{cca1\_c}]) \quad (62)$$

$$\mathrm{function\_4}(\mathrm{t}, \mathrm{D\_l}, \mathrm{D\_d}, \mathrm{level}) = \mathrm{proteasome}(\mathrm{t}) \cdot (\mathrm{light}(\mathrm{t}) \cdot \mathrm{D\_l} + (1 - \mathrm{light}(\mathrm{t})) \cdot \mathrm{D\_d}) \cdot \mathrm{level} \quad (63)$$

$$\mathrm{function\_4}(\mathrm{t}, \mathrm{D\_l}, \mathrm{D\_d}, \mathrm{level}) = \mathrm{proteasome}(\mathrm{t}) \cdot (\mathrm{light}(\mathrm{t}) \cdot \mathrm{D\_l} + (1 - \mathrm{light}(\mathrm{t})) \cdot \mathrm{D\_d}) \cdot \mathrm{level} \quad (64)$$

8.13 Reaction reaction_13

This is an irreversible reaction of one reactant forming no product.

Name CCA1 degradation, nucleus

SBO:0000179 degradation

Reaction equation

$$\mathrm{cca1\_n} \longrightarrow \emptyset \quad (65)$$

Reactant

Table 24: Properties of each reactant.

Id	Name	SBO
cca1_n	cca1_n	

Kinetic Law

Derived unit contains undeclared units

$$v_{13} = \mathrm{vol}(\mathrm{compartment}) \cdot \mathrm{function\_4}(\mathrm{time}, \mathrm{D\_cca1\_l}, \mathrm{D\_cca1\_d}, [\mathrm{cca1\_n}]) \quad (66)$$

$$\mathrm{function\_4}(\mathrm{t}, \mathrm{D\_l}, \mathrm{D\_d}, \mathrm{level}) = \mathrm{proteasome}(\mathrm{t}) \cdot (\mathrm{light}(\mathrm{t}) \cdot \mathrm{D\_l} + (1 - \mathrm{light}(\mathrm{t})) \cdot \mathrm{D\_d}) \cdot \mathrm{level} \quad (67)$$

$$\mathrm{function\_4}(\mathrm{t}, \mathrm{D\_l}, \mathrm{D\_d}, \mathrm{level}) = \mathrm{proteasome}(\mathrm{t}) \cdot (\mathrm{light}(\mathrm{t}) \cdot \mathrm{D\_l} + (1 - \mathrm{light}(\mathrm{t})) \cdot \mathrm{D\_d}) \cdot \mathrm{level} \quad (68)$$

8.14 Reaction reaction_14

This is an irreversible reaction of no reactant forming one product influenced by two modifiers.

Name LUC transcription, pTOC1

SBO:0000183 transcription

Reaction equation

$$\emptyset \xrightarrow{\text{acc, cca1\_n}} \text{luc\_mrna} \tag{69}$$

Modifiers

Table 25: Properties of each modifier.

Id	Name	SBO
acc	acc	
cca1_n	cca1_n	

Product

Table 26: Properties of each product.

Id	Name	SBO
luc_mrna	luc_mrna	

Kinetic Law

Derived unit contains undeclared units

$$v_{14} = \text{vol}(\text{compartment}) \cdot \text{function\_7}(\text{time}, \text{R\_toc1\_acc}, [\text{acc}], \text{R\_toc1\_cca1}, [\text{cca1\_n}], \text{H\_toc1\_cca1}, \text{parameter\_3}, \text{L\_toc1}) \tag{70}$$

$$\text{function\_7}(\text{t}, \text{R\_toc1\_acc}, [\text{acc}], \text{R\_toc1\_cca1}, [\text{cca1\_n}], \text{H\_toc1\_cca1}, \text{rep\_pTOC1}, \text{L\_toc1}) = \frac{\text{rep\_pTOC1} \cdot \text{transcription}(\text{t}) \cdot (\text{L\_toc1} + \text{R\_toc1\_acc} \cdot [\text{acc}])}{1 + \text{L\_toc1} + \text{R\_toc1\_acc} \cdot [\text{acc}] + (\text{R\_toc1\_cca1} \cdot [\text{cca1\_n}])^{\text{H\_toc1\_cca1}}} \tag{71}$$

$$\text{function\_7}(\text{t}, \text{R\_toc1\_acc}, [\text{acc}], \text{R\_toc1\_cca1}, [\text{cca1\_n}], \text{H\_toc1\_cca1}, \text{rep\_pTOC1}, \text{L\_toc1}) = \frac{\text{rep\_pTOC1} \cdot \text{transcription}(\text{t}) \cdot (\text{L\_toc1} + \text{R\_toc1\_acc} \cdot [\text{acc}])}{1 + \text{L\_toc1} + \text{R\_toc1\_acc} \cdot [\text{acc}] + (\text{R\_toc1\_cca1} \cdot [\text{cca1\_n}])^{\text{H\_toc1\_cca1}}} \tag{72}$$

8.15 Reaction `reaction_15`

This is an irreversible reaction of one reactant forming no product.

Name LUC mRNA degradation

SBO:0000179 degradation

Reaction equation

$$\text{luc\_mrna} \longrightarrow \emptyset \tag{73}$$

Reactant

Table 27: Properties of each reactant.

Id	Name	SBO
`luc_mrna`	luc_mrna	

Kinetic Law

Derived unit contains undeclared units

$$v_{15} = \text{vol}\,(\text{compartment}) \cdot \text{D\_mrna\_luc} \cdot [\text{luc\_mrna}] \tag{74}$$

8.16 Reaction `reaction_16`

This is an irreversible reaction of no reactant forming one product influenced by one modifier.

Name LUC translation

SBO:0000184 translation

Reaction equation

$$\emptyset \xrightarrow{\text{luc\_mrna}} \text{luc} \tag{75}$$

Modifier

Table 28: Properties of each modifier.

Id	Name	SBO
`luc_mrna`	luc_mrna	

Product

Table 29: Properties of each product.

Id	Name	SBO
`luc`	luc	

Kinetic Law

Derived unit contains undeclared units

$$v_{16} = \mathrm{vol}\,(\mathrm{compartment}) \cdot \mathrm{Translation}\,(\mathrm{time}, \mathrm{parameter\_1}, [\mathrm{luc\_mrna}]) \tag{76}$$

$$\mathrm{Translation}\,(\mathrm{t}, \mathrm{T}, \mathrm{mrna}) = \mathrm{translation}\,(\mathrm{t}) \cdot \mathrm{T} \cdot \mathrm{mrna} \tag{77}$$

$$\mathrm{Translation}\,(\mathrm{t}, \mathrm{T}, \mathrm{mrna}) = \mathrm{translation}\,(\mathrm{t}) \cdot \mathrm{T} \cdot \mathrm{mrna} \tag{78}$$

8.17 Reaction `reaction_17`

This is an irreversible reaction of one reactant forming no product.

Name LUC decay

SBO:0000179 degradation

Reaction equation

$$\mathrm{luc} \longrightarrow \emptyset \tag{79}$$

Reactant

Table 30: Properties of each reactant.

Id	Name	SBO
`luc`	luc	

Kinetic Law

Derived unit contains undeclared units

$$v_{17} = \mathrm{vol}\,(\mathrm{compartment}) \cdot \mathrm{D\_luc} \cdot [\mathrm{luc}] \tag{80}$$

8.18 Reaction reaction_18

This is an irreversible reaction of no reactant forming one product influenced by two modifiers.

Name TOC1-LUC transcription

SBO:0000183 transcription

Reaction equation

$$\emptyset \xrightarrow{\text{acc, cca1\_n}} \text{toc1luc\_mrna} \tag{81}$$

Modifiers

Table 31: Properties of each modifier.

Id	Name	SBO
acc	acc	
cca1_n	cca1_n	

Product

Table 32: Properties of each product.

Id	Name	SBO
toc1luc_mrna	toc1luc_mrna	

Kinetic Law

Derived unit contains undeclared units

$$v_{18} = \text{vol}(\text{compartment}) \cdot \text{function\_8}(\text{time}, \text{R\_toc1\_acc}, [\text{acc}], \text{R\_toc1\_cca1}, [\text{cca1\_n}], \text{H\_toc1\_cca1}, \text{parameter\_2}, \text{L\_toc1}) \tag{82}$$

$$\text{function\_8}(t, \text{R\_toc1\_acc}, [\text{acc}], \text{R\_toc1\_cca1}, [\text{cca1\_n}], \text{H\_toc1\_cca1}, \text{rep\_TOC1}, \text{L\_toc1}) = \frac{\text{rep\_TOC1} \cdot \text{transcription}(t) \cdot \text{copies\_toc1}(t) \cdot (\text{L\_toc1} + \text{R\_toc1\_acc} \cdot [\text{acc}])}{1 + \text{L\_toc1} + \text{R\_toc1\_acc} \cdot [\text{acc}] + (\text{R\_toc1\_cca1} \cdot [\text{cca1\_n}])^{\text{H\_toc1\_cca1}}} \tag{83}$$

$$\text{function\_8}(t, \text{R\_toc1\_acc}, [\text{acc}], \text{R\_toc1\_cca1}, [\text{cca1\_n}], \text{H\_toc1\_cca1}, \text{rep\_TOC1}, \text{L\_toc1}) = \frac{\text{rep\_TOC1} \cdot \text{transcription}(t) \cdot \text{copies\_toc1}(t) \cdot (\text{L\_toc1} + \text{R\_toc1\_acc} \cdot [\text{acc}])}{1 + \text{L\_toc1} + \text{R\_toc1\_acc} \cdot [\text{acc}] + (\text{R\_toc1\_cca1} \cdot [\text{cca1\_n}])^{\text{H\_toc1\_cca1}}} \tag{84}$$

8.19 Reaction `reaction_19`

This is an irreversible reaction of one reactant forming no product.

Name TOC1-LUC mRNA degradation

SBO:0000179 degradation

Reaction equation

$$\text{toc1luc\_mrna} \longrightarrow \emptyset \tag{85}$$

Reactant

Table 33: Properties of each reactant.

Id	Name	SBO
`toc1luc_mrna`	toc1luc_mrna	

Kinetic Law

Derived unit contains undeclared units

$$v_{19} = \text{vol}\,(\text{compartment}) \cdot \text{D\_mrna\_toc1} \cdot [\text{toc1luc\_mrna}] \tag{86}$$

8.20 Reaction `reaction_20`

This is an irreversible reaction of no reactant forming one product influenced by one modifier.

Name TOC1-LUC translation

SBO:0000184 translation

Reaction equation

$$\emptyset \xrightarrow{\text{toc1luc\_mrna}} \text{toc1luc\_1} \tag{87}$$

Modifier

Table 34: Properties of each modifier.

Id	Name	SBO
`toc1luc_mrna`	toc1luc_mrna	

Product

Table 35: Properties of each product.

Id	Name	SBO
toc1luc_1	toc1luc_1	

Kinetic Law

Derived unit contains undeclared units

$$v_{20} = \mathrm{vol}\,(\mathrm{compartment}) \cdot \mathrm{Translation}\,(\mathrm{time}, \mathrm{T\_toc1}, [\mathrm{toc1luc\_mrna}]) \tag{88}$$

$$\mathrm{Translation}\,(\mathrm{t}, \mathrm{T}, \mathrm{mrna}) = \mathrm{translation}\,(\mathrm{t}) \cdot \mathrm{T} \cdot \mathrm{mrna} \tag{89}$$

$$\mathrm{Translation}\,(\mathrm{t}, \mathrm{T}, \mathrm{mrna}) = \mathrm{translation}\,(\mathrm{t}) \cdot \mathrm{T} \cdot \mathrm{mrna} \tag{90}$$

8.21 Reaction reaction_21

This is an irreversible reaction of one reactant forming one product.

Name TOC1-LUC conversion

SBO:0000182 conversion

Reaction equation

$$\mathrm{toc1luc\_1} \longrightarrow \mathrm{toc1luc\_2} \tag{91}$$

Reactant

Table 36: Properties of each reactant.

Id	Name	SBO
toc1luc_1	toc1luc_1	

Product

Table 37: Properties of each product.

Id	Name	SBO
toc1luc_2	toc1luc_2	

Id	Name	SBO

Kinetic Law

Derived unit contains undeclared units

$$v_{21} = \mathrm{vol}\,(\mathrm{compartment}) \cdot \mathrm{function\_5}\,(\mathrm{time}, \mathrm{Di\_toc1\_12\_l}, \mathrm{Di\_toc1\_12\_d}, [\mathrm{toc1luc\_1}]) \quad (92)$$

$$\mathrm{function\_5}\,(\mathrm{t}, \mathrm{Di\_l}, \mathrm{Di\_d}, \mathrm{level}) = (\mathrm{light}\,(\mathrm{t}) \cdot \mathrm{Di\_l} + (1 - \mathrm{light}\,(\mathrm{t})) \cdot \mathrm{Di\_d}) \cdot \mathrm{level} \quad (93)$$

$$\mathrm{function\_5}\,(\mathrm{t}, \mathrm{Di\_l}, \mathrm{Di\_d}, \mathrm{level}) = (\mathrm{light}\,(\mathrm{t}) \cdot \mathrm{Di\_l} + (1 - \mathrm{light}\,(\mathrm{t})) \cdot \mathrm{Di\_d}) \cdot \mathrm{level} \quad (94)$$

8.22 Reaction `reaction_22`

This is an irreversible reaction of one reactant forming no product.

Name TOC1-LUC degradation

SBO:0000179 degradation

Reaction equation

$$\mathrm{toc1luc\_2} \longrightarrow \emptyset \quad (95)$$

Reactant

Table 38: Properties of each reactant.

Id	Name	SBO
`toc1luc_2`	toc1luc_2	

Kinetic Law

Derived unit contains undeclared units

$$v_{22} = \mathrm{vol}\,(\mathrm{compartment}) \cdot \mathrm{function\_4}\,(\mathrm{time}, \mathrm{D\_toc1\_2\_l}, \mathrm{D\_toc1\_2\_d}, [\mathrm{toc1luc\_2}]) \quad (96)$$

$$\mathrm{function\_4}\,(\mathrm{t}, \mathrm{D\_l}, \mathrm{D\_d}, \mathrm{level}) = \mathrm{proteasome}\,(\mathrm{t}) \cdot (\mathrm{light}\,(\mathrm{t}) \cdot \mathrm{D\_l} + (1 - \mathrm{light}\,(\mathrm{t})) \cdot \mathrm{D\_d}) \cdot \mathrm{level} \quad (97)$$

$$\mathrm{function\_4}\,(\mathrm{t}, \mathrm{D\_l}, \mathrm{D\_d}, \mathrm{level}) = \mathrm{proteasome}\,(\mathrm{t}) \cdot (\mathrm{light}\,(\mathrm{t}) \cdot \mathrm{D\_l} + (1 - \mathrm{light}\,(\mathrm{t})) \cdot \mathrm{D\_d}) \cdot \mathrm{level} \quad (98)$$

8.23 Reaction reaction_23

This is an irreversible reaction of one reactant forming no product.

Name TOC1-LUC(1) deactivation

SBO:0000176 biochemical reaction

Reaction equation

$$\text{toc1luc\_1} \longrightarrow \emptyset \tag{99}$$

Reactant

Table 39: Properties of each reactant.

Id	Name	SBO
toc1luc_1	toc1luc_1	

Kinetic Law

Derived unit contains undeclared units

$$v_{23} = \text{vol}\,(\text{compartment}) \cdot \text{D\_luc} \cdot [\text{toc1luc\_1}] \tag{100}$$

8.24 Reaction reaction_24

This is an irreversible reaction of one reactant forming no product.

Name TOC1-LUC(2) deactivation

SBO:0000176 biochemical reaction

Reaction equation

$$\text{toc1luc\_2} \longrightarrow \emptyset \tag{101}$$

Reactant

Table 40: Properties of each reactant.

Id	Name	SBO
toc1luc_2	toc1luc_2	

Kinetic Law

Derived unit contains undeclared units

$$v_{24} = \mathrm{vol}\,(\mathrm{compartment}) \cdot \mathrm{D\_luc} \cdot [\mathrm{toc1luc\_2}] \tag{102}$$

8.25 Reaction `reaction_25`

This is an irreversible reaction of no reactant forming one product influenced by one modifier.

Name LUC transcription, pCCA1

SBO:0000183 transcription

Reaction equation

$$\emptyset \xrightarrow{\mathrm{toc1\_2}} \mathrm{luc\_mrna} \tag{103}$$

Modifier

Table 41: Properties of each modifier.

Id	Name	SBO
`toc1_2`	toc1_2	

Product

Table 42: Properties of each product.

Id	Name	SBO
`luc_mrna`	luc_mrna	

Kinetic Law

Derived unit contains undeclared units

$$v_{25} = \mathrm{vol}\,(\mathrm{compartment}) \cdot \mathrm{function\_9}\,(\mathrm{time}, [\mathrm{toc1\_2}], \mathrm{R\_cca1\_toc1\_2\_1}, \mathrm{R\_cca1\_toc1\_2\_d}, \mathrm{H\_cca1\_toc1}, \mathrm{parameter\_5}) \tag{104}$$

$$\mathrm{function\_9}\,(\mathrm{t}, [\mathrm{toc1\_2}], \mathrm{R\_cca1\_toc1\_2\_1}, \mathrm{R\_cca1\_toc1\_2\_d}, \mathrm{H\_cca1\_toc1}, \mathrm{rep\_pCCA1}) \tag{105}$$
$$= \frac{\mathrm{rep\_pCCA1} \cdot \mathrm{transcription}\,(\mathrm{t}) \cdot ([\mathrm{toc1\_2}] \cdot (\mathrm{light}\,(\mathrm{t}) \cdot \mathrm{R\_cca1\_toc1\_2\_1} + (1 - \mathrm{light}\,(\mathrm{t})) \cdot \mathrm{R\_cca1\_toc1\_2\_d}))^{\mathrm{H\_cca1\_toc}}}{([\mathrm{toc1\_2}] \cdot (\mathrm{light}\,(\mathrm{t}) \cdot \mathrm{R\_cca1\_toc1\_2\_1} + (1 - \mathrm{light}\,(\mathrm{t})) \cdot \mathrm{R\_cca1\_toc1\_2\_d}))^{\mathrm{H\_cca1\_toc1}} + 1}$$

$$\text{function\_9}(\text{t}, [\text{toc1\_2}], \text{R\_cca1\_toc1\_2\_l}, \text{R\_cca1\_toc1\_2\_d}, \text{H\_cca1\_toc1}, \text{rep\_pCCA1}) \tag{106}$$
$$= \frac{\text{rep\_pCCA1} \cdot \text{transcription}(\text{t}) \cdot ([\text{toc1\_2}] \cdot (\text{light}(\text{t}) \cdot \text{R\_cca1\_toc1\_2\_l} + (1 - \text{light}(\text{t})) \cdot \text{R\_cca1\_toc1\_2\_d}))^{\text{H\_cca1\_toc}}}{([\text{toc1\_2}] \cdot (\text{light}(\text{t}) \cdot \text{R\_cca1\_toc1\_2\_l} + (1 - \text{light}(\text{t})) \cdot \text{R\_cca1\_toc1\_2\_d}))^{\text{H\_cca1\_toc1}} + 1}$$

8.26 Reaction `reaction_26`

This is an irreversible reaction of no reactant forming one product influenced by one modifier.

Name CCA1-LUC transcription

SBO:0000183 transcription

Reaction equation

$$\emptyset \xrightarrow{\text{toc1\_2}} \text{cca1luc\_mrna} \tag{107}$$

Modifier

Table 43: Properties of each modifier.

Id	Name	SBO
`toc1_2`	toc1_2	

Product

Table 44: Properties of each product.

Id	Name	SBO
`cca1luc_mrna`	cca1luc_mrna	

Kinetic Law

Derived unit contains undeclared units

$$v_{26} = \text{vol}(\text{compartment}) \cdot \text{function\_10}(\text{time}, [\text{toc1\_2}], \text{R\_cca1\_toc1\_2\_l}, \text{R\_cca1\_toc1\_2\_d}, \text{H\_cca1\_toc1}, \text{parameter\_4}) \tag{108}$$

$$\text{function\_10}(\text{t}, [\text{toc1\_2}], \text{R\_cca1\_toc1\_2\_l}, \text{R\_cca1\_toc1\_2\_d}, \text{H\_cca1\_toc1}, \text{rep\_CCA1}) \tag{109}$$
$$= \frac{\text{rep\_CCA1} \cdot \text{transcription}(\text{t}) \cdot \text{copies\_cca1}(\text{t}) \cdot ([\text{toc1\_2}] \cdot (\text{light}(\text{t}) \cdot \text{R\_cca1\_toc1\_2\_l} + (1 - \text{light}(\text{t})) \cdot \text{R\_cca1\_toc}}{([\text{toc1\_2}] \cdot (\text{light}(\text{t}) \cdot \text{R\_cca1\_toc1\_2\_l} + (1 - \text{light}(\text{t})) \cdot \text{R\_cca1\_toc1\_2\_d}))^{\text{H\_cca1\_toc1}} + 1}$$

$$\text{function\_10}\left(\text{t}, [\text{toc1\_2}], \text{R\_cca1\_toc1\_2\_l}, \text{R\_cca1\_toc1\_2\_d}, \text{H\_cca1\_toc1}, \text{rep\_CCA1}\right) \tag{110}$$
$$= \frac{\text{rep\_CCA1} \cdot \text{transcription}\left(\text{t}\right) \cdot \text{copies\_cca1}\left(\text{t}\right) \cdot \left([\text{toc1\_2}] \cdot \left(\text{light}\left(\text{t}\right) \cdot \text{R\_cca1\_toc1\_2\_l} + \left(1 - \text{light}\left(\text{t}\right)\right) \cdot \text{R\_cca1\_toc}\right.}{\left([\text{toc1\_2}] \cdot \left(\text{light}\left(\text{t}\right) \cdot \text{R\_cca1\_toc1\_2\_l} + \left(1 - \text{light}\left(\text{t}\right)\right) \cdot \text{R\_cca1\_toc1\_2\_d}\right)\right)^{\text{H\_cca1\_toc1}} + 1}$$

8.27 Reaction `reaction_27`

This is an irreversible reaction of one reactant forming no product.

Name CCA1-LUC mRNA degradation

SBO:0000179 degradation

Reaction equation

$$\text{cca1luc\_mrna} \longrightarrow \emptyset \tag{111}$$

Reactant

Table 45: Properties of each reactant.

Id	Name	SBO
`cca1luc_mrna`	cca1luc_mrna	

Kinetic Law

Derived unit contains undeclared units

$$v_{27} = \text{vol}\left(\text{compartment}\right) \cdot \text{D\_mrna\_cca1} \cdot [\text{cca1luc\_mrna}] \tag{112}$$

8.28 Reaction `reaction_28`

This is an irreversible reaction of no reactant forming one product influenced by one modifier.

Name CCA1-LUC translation

SBO:0000184 translation

Reaction equation

$$\emptyset \xrightarrow{\text{cca1luc\_mrna}} \text{cca1luc} \tag{113}$$

Modifier

Table 46: Properties of each modifier.

Id	Name	SBO
cca1luc_mrna	cca1luc_mrna	

Product

Table 47: Properties of each product.

Id	Name	SBO
cca1luc	cca1luc	

Kinetic Law

Derived unit contains undeclared units

$$v_{28} = \mathrm{vol}\,(\mathrm{compartment}) \cdot \mathrm{Translation}\,(\mathrm{time}, \mathrm{T\_cca1}, [\mathrm{cca1luc\_mrna}]) \tag{114}$$

$$\mathrm{Translation}\,(\mathrm{t}, \mathrm{T}, \mathrm{mrna}) = \mathrm{translation}\,(\mathrm{t}) \cdot \mathrm{T} \cdot \mathrm{mrna} \tag{115}$$

$$\mathrm{Translation}\,(\mathrm{t}, \mathrm{T}, \mathrm{mrna}) = \mathrm{translation}\,(\mathrm{t}) \cdot \mathrm{T} \cdot \mathrm{mrna} \tag{116}$$

8.29 Reaction reaction_30

This is an irreversible reaction of one reactant forming no product.

Name CCA1-LUC degradation

SBO:0000179 degradation

Reaction equation

$$\mathrm{cca1luc} \longrightarrow \emptyset \tag{117}$$

Reactant

Table 48: Properties of each reactant.

Id	Name	SBO
cca1luc	cca1luc	

Kinetic Law

Derived unit contains undeclared units

$$v_{29} = \mathrm{vol}(\mathrm{compartment}) \cdot \mathrm{function\_4}(\mathrm{time}, \mathrm{D\_cca1\_l}, \mathrm{D\_cca1\_d}, [\mathrm{cca1luc}]) \quad (118)$$

$$\mathrm{function\_4}(\mathrm{t}, \mathrm{D\_l}, \mathrm{D\_d}, \mathrm{level}) = \mathrm{proteasome}(\mathrm{t}) \cdot (\mathrm{light}(\mathrm{t}) \cdot \mathrm{D\_l} + (1 - \mathrm{light}(\mathrm{t})) \cdot \mathrm{D\_d}) \cdot \mathrm{level} \quad (119)$$

$$\mathrm{function\_4}(\mathrm{t}, \mathrm{D\_l}, \mathrm{D\_d}, \mathrm{level}) = \mathrm{proteasome}(\mathrm{t}) \cdot (\mathrm{light}(\mathrm{t}) \cdot \mathrm{D\_l} + (1 - \mathrm{light}(\mathrm{t})) \cdot \mathrm{D\_d}) \cdot \mathrm{level} \quad (120)$$

8.30 Reaction `reaction_32`

This is an irreversible reaction of one reactant forming no product.

Name CCA1-LUC deactivation

SBO:0000176 biochemical reaction

Reaction equation

$$\mathrm{cca1luc} \longrightarrow \emptyset \quad (121)$$

Reactant

Table 49: Properties of each reactant.

Id	Name	SBO
`cca1luc`	cca1luc	

Kinetic Law

Derived unit contains undeclared units

$$v_{30} = \mathrm{vol}(\mathrm{compartment}) \cdot \mathrm{D\_luc} \cdot [\mathrm{cca1luc}] \quad (122)$$

9 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.

9.1 Species `acc`

Name acc

SBO:0000236 physical entity representation

Initial concentration $0.272067372878265\ \mathrm{nmol}\cdot\mathrm{l}^{-1}$

This species takes part in five reactions (as a reactant in `reaction_2` and as a product in `reaction_1` and as a modifier in `reaction_3`, `reaction_14`, `reaction_18`).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{acc} = v_1 - v_2 \tag{123}$$

9.2 Species `toc1_mrna`

Name toc1_mrna

SBO:0000278 messenger RNA

Initial concentration $0.0385665277682963\ \mathrm{nmol}\cdot\mathrm{l}^{-1}$

This species takes part in three reactions (as a reactant in `reaction_7` and as a product in `reaction_3` and as a modifier in `reaction_5`).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{toc1\_mrna} = v_3 - v_7 \tag{124}$$

9.3 Species `toc1_1`

Name toc1_1

SBO:0000252 polypeptide chain

Initial concentration $0.206521274112594\ \mathrm{nmol}\cdot\mathrm{l}^{-1}$

This species takes part in two reactions (as a reactant in `reaction_6` and as a product in `reaction_5`).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{toc1\_1} = v_5 - v_6 \tag{125}$$

9.4 Species toc1_2

Name toc1_2

SBO:0000252 polypeptide chain

Initial concentration $0.312711901675853\ \text{nmol} \cdot \text{l}^{-1}$

This species takes part in five reactions (as a reactant in reaction_4 and as a product in reaction_6 and as a modifier in reaction_8, reaction_25, reaction_26).

$$\frac{\text{d}}{\text{d}t}\text{toc1\_2} = v_6 - v_4 \tag{126}$$

9.5 Species cca1_mrna

Name cca1_mrna

SBO:0000278 messenger RNA

Initial concentration $0.104555645465821\ \text{nmol} \cdot \text{l}^{-1}$

This species takes part in three reactions (as a reactant in reaction_9 and as a product in reaction_8 and as a modifier in reaction_10).

$$\frac{\text{d}}{\text{d}t}\text{cca1\_mrna} = v_8 - v_9 \tag{127}$$

9.6 Species cca1_c

Name cca1_c

SBO:0000252 polypeptide chain

Initial concentration $0.051315426489096\ \text{nmol} \cdot \text{l}^{-1}$

This species takes part in three reactions (as a reactant in reaction_11, reaction_12 and as a product in reaction_10).

$$\frac{\text{d}}{\text{d}t}\text{cca1\_c} = v_{10} - v_{11} - v_{12} \tag{128}$$

9.7 Species cca1_n

Name cca1_n

SBO:0000252 polypeptide chain

Initial concentration $3.07283764226433\ \text{nmol} \cdot \text{l}^{-1}$

This species takes part in five reactions (as a reactant in reaction_13 and as a product in reaction_11 and as a modifier in reaction_3, reaction_14, reaction_18).

$$\frac{\text{d}}{\text{d}t}\text{cca1\_n} = v_{11} - v_{13} \tag{129}$$

9.8 Species toc1luc_mrna

Name toc1luc_mrna

SBO:0000278 messenger RNA

Initial concentration $0\ \mathrm{nmol}\cdot\mathrm{l}^{-1}$

This species takes part in three reactions (as a reactant in reaction_19 and as a product in reaction_18 and as a modifier in reaction_20).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{toc1luc\_mrna} = v_{18} - v_{19} \tag{130}$$

9.9 Species toc1luc_1

Name toc1luc_1

SBO:0000252 polypeptide chain

Initial concentration $0\ \mathrm{nmol}\cdot\mathrm{l}^{-1}$

This species takes part in three reactions (as a reactant in reaction_21, reaction_23 and as a product in reaction_20).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{toc1luc\_1} = v_{20} - v_{21} - v_{23} \tag{131}$$

9.10 Species toc1luc_2

Name toc1luc_2

SBO:0000252 polypeptide chain

Initial concentration $0\ \mathrm{nmol}\cdot\mathrm{l}^{-1}$

This species takes part in three reactions (as a reactant in reaction_22, reaction_24 and as a product in reaction_21).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{toc1luc\_2} = v_{21} - v_{22} - v_{24} \tag{132}$$

9.11 Species cca1luc_mrna

Name cca1luc_mrna

SBO:0000278 messenger RNA

Initial concentration $0\ \mathrm{nmol}\cdot\mathrm{l}^{-1}$

This species takes part in three reactions (as a reactant in reaction_27 and as a product in reaction_26 and as a modifier in reaction_28).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{cca1luc\_mrna} = v_{26} - v_{27} \tag{133}$$

9.12 Species cca1luc

Name cca1luc

SBO:0000252 polypeptide chain

Initial concentration $0\ \mathrm{nmol}\cdot\mathrm{l}^{-1}$

This species takes part in three reactions (as a reactant in reaction_30, reaction_32 and as a product in reaction_28).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{cca1luc} = v_{28} - v_{29} - v_{30} \tag{134}$$

9.13 Species luc_mrna

Name luc_mrna

SBO:0000278 messenger RNA

Initial concentration $0\ \mathrm{nmol}\cdot\mathrm{l}^{-1}$

This species takes part in four reactions (as a reactant in reaction_15 and as a product in reaction_14, reaction_25 and as a modifier in reaction_16).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{luc\_mrna} = v_{14} + v_{25} - v_{15} \tag{135}$$

9.14 Species luc

Name luc

SBO:0000247 simple chemical

Initial concentration $0\ \mathrm{nmol}\cdot\mathrm{l}^{-1}$

This species takes part in two reactions (as a reactant in reaction_17 and as a product in reaction_16).

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathrm{luc} = v_{16} - v_{17} \tag{136}$$

A Glossary of Systems Biology Ontology Terms

SBO:0000009 kinetic constant: Numerical parameter that quantifies the velocity of a chemical reaction

SBO:0000153 forward rate constant: Numerical parameter that quantifies the forward velocity of a chemical reaction. This parameter encompasses all the contributions to the velocity except the quantity of the reactants

SBO:0000176 biochemical reaction: An event involving one or more chemical entities that modifies the electrochemical structure of at least one of the participants.

SBO:0000179 degradation: Complete disappearance of a physical entity

SBO:0000182 conversion: Biochemical reaction that results in the modification of some covalent bonds

SBO:0000183 transcription: Process through which a DNA sequence is copied to produce a complementary RNA

SBO:0000184 translation: Process in which a polypeptide chain is produced from a messenger RNA

SBO:0000185 transport reaction: Movement of a physical entity without modification of the structure of the entity

SBO:0000236 physical entity representation: Representation of an entity that may participate in an interaction, a process or relationship of significance.

SBO:0000247 simple chemical: Simple, non-repetitive chemical entity

SBO:0000252 polypeptide chain: Naturally occurring macromolecule formed by the repetition of amino-acid residues linked by peptidic bonds. A polypeptide chain is synthesized by the ribosome. CHEBI:1654

SBO:0000278 messenger RNA: A messenger RNA is a ribonucleic acid synthesized during the transcription of a gene, and that carries the information to encode one or several proteins

SBO:0000290 physical compartment: Specific location of space, that can be bounded or not. A physical compartment can have 1, 2 or 3 dimensions

SBO:0000349 inactivation rate constant: Kinetic constant describing the rate of an irreversible enzyme inactivation by decay of the active enzyme into its inactive form

SBO:0000356 decay constant: Kinetic constant characterising a mono-exponential decay. It is the inverse of the mean lifetime of the continuant being decayed. Its unit is“per tim”.

SBO:0000393 production: Generation of a material or conceptual entity.

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