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Generalized net model of cytokinin-auxin signalling interactions

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Abstract

A Generalized net model of the complex intercellular molecular interactions by two hormones is constructed.

Keywords: cytokinin-auxin signalling interaction, generalized net, model.

1 Introduction

In the paper a Generalized Net (GN; see [1, 2]) model of the complex intercellular molecular interactions by two hormones is described. The key plant hormone families - auxins and cytokinins, are considered. Cytokinin and auxin have long been recognized as crucial signalling molecules controlling plant growth and development. These two families have antagonistic influence on the plant cell, utilizing two self regulated pathways.

2 Cytokinin-auxin signalling interactions

Brief description of the cytokinin-auxin signalling interactions is presented below.

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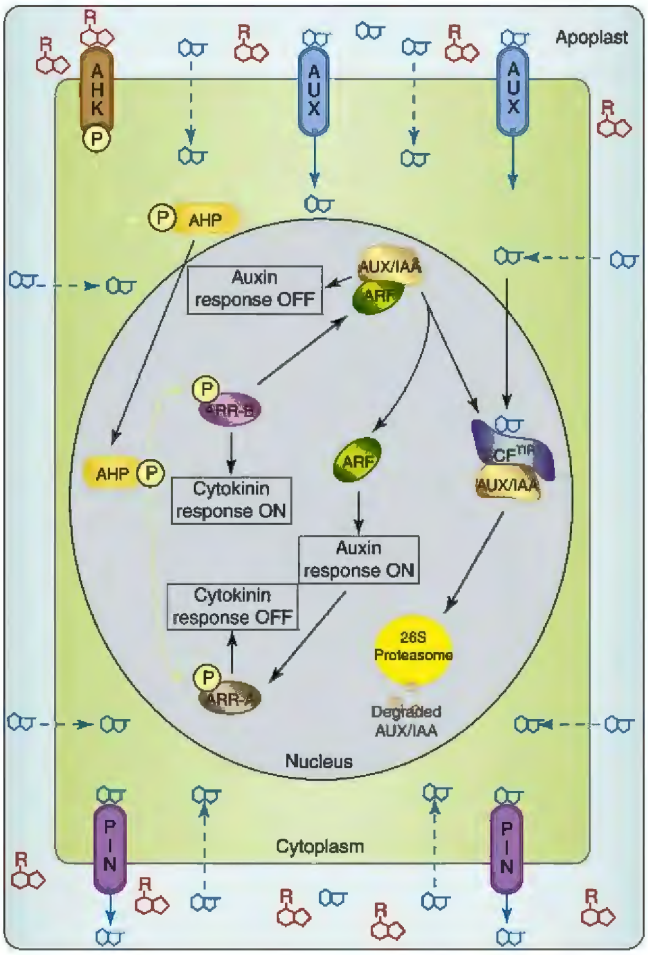

Figure 1: Cytokinin and auxin signalling interactions

Cytokinin responsive genes activation pathway starts with the Arabidopsis His Kinase (AHK) receptor. This receptor is able to phosphorilate itself and transfer this phosphoryl group to the next participant from the signaling pathway, thus activating it. This is the Arabidopsis His Phosphotransfer Protein (AHP). There are several AHP proteins in this protein family. They transfer the phosphoryl group to the nucleus and transfer the phosphoryl group to the type-A or type-B ARR (Arabidopsis Response Regulators) cytokinin primary response gene. The type-B ARRs act as transcription factors and their phosphorylation activates the transcription of the cytokinin-regulated genes, including the type-A ARRs (cy-

tokinin response ON). Phosphorylated type-A ARRs activate negative regulation of cytokinin signalling through as yet unknown mechanisms (cytokinin response OFF).

Regulator molecules from the auxin family enter into the cell and its nucleus and influence directly the auxin responsive genes activation pathway. There are two possible ways of transfer into the cell. Auxins can defuse freely through the plasma membrane or they are actively taken up from the apoplast by the action of influx transporters, and actively transported out of the cell by auxin efflux carriers, the PIN proteins. Auxin flux direction (solid blue arrows) depends on the PIN subcellular asymmetric localization. When auxin concentration in the nucleus is low it heterodimerize with the ARF (Auxin Response Factor) transcription factors, repressing the transcription of the auxin-response genes (auxin response OFF). At high auxin concentrations, auxin binds to the TIR1 (Transport Inhibitor Response 1) receptor, stimulating the interaction of the Aux/IAAs proteins with the SCFTIR1 ubiquitin-ligase complex (SKP1, CDC53/CULLIN, F-box), thus promoting their degradation by the 26S proteasome. The consequent reduction in levels of Aux/IAA proteins releases the ARFs from their inhibition, inducing the expression of auxin-responsive genes (auxin response ON).

3 GN-model of cytokinin-auxin signalling interactions

All notations for the GN and its components are given in [1, 2].

Th GN-model contains 11 transitions and 30 places (see Fig. 2).

Initially, in places $l_3, l_5, l_7, l_8, l_{14}, l_{18}$, stay tokens $\beta, \gamma, \varepsilon, \delta, \theta, \sigma$, with initial and current characteristics:

"Initial concentration of P",

"Initial concentration of AHP",

"Initial concentration of free ARF",

"Initial concentration of AUX",

"Initial concentration of Free SCFTIR1 ubiquitin-ligase complex",

"Initial concentration of ARR-B.

Token α enters place l_1 with initial characteristic "Hormone Cytokinine/Receptor(AHK)iteraction".

$$Z_1 = \langle \{l_1, l_3, l_{28}\}, \{l_2, l_3\}, \begin{array}{c|cc} & l_2 & l_3 \\ \hline l_1 & false & true \\ l_3 & W_{3,2} & true \\ l_{28} & false & true \end{array}, \wedge(l_1, l_3) \rangle.$$

where $W_{3,2}$ = "Completed Cytokinine/AHK interaction".

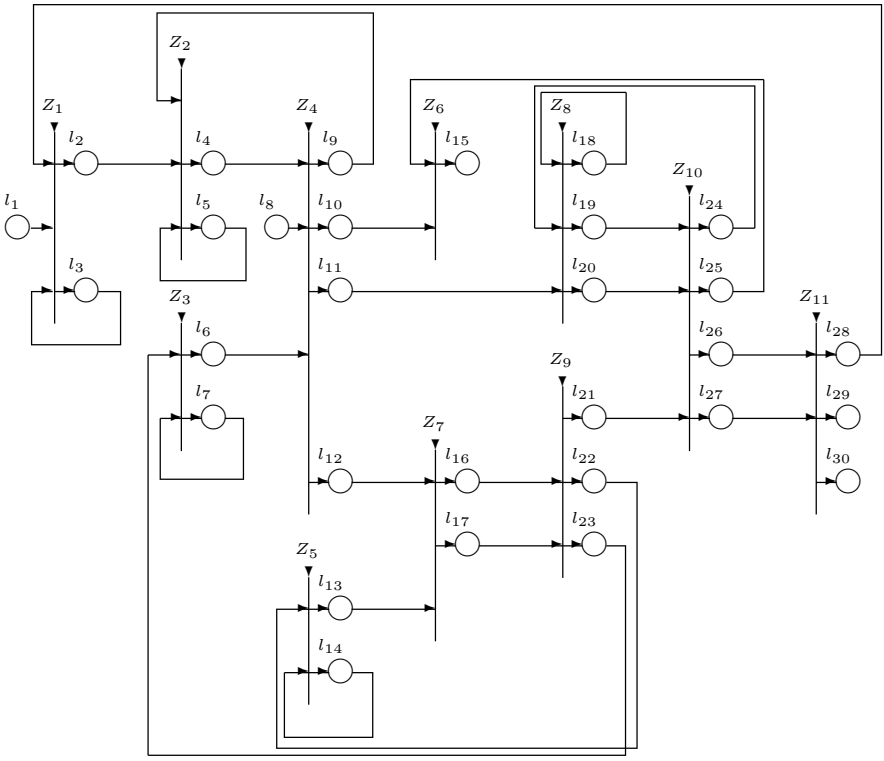

Fig. 2.

Token β enters place l_2 with a characteristic "PAHK (Phosphorylated Arabidopsis His Kinase)".

$$Z_2 = \langle \{l_2, l_5, l_9\}, \{l_4, l_5\}, \begin{array}{c|cc} & l_4 & l_5 \\ \hline l_2 & true & false \\ l_5 & true & true \\ l_9 & false & true \end{array}, \wedge(l_2, l_5) \rangle.$$

Token β enters place l_4 with a characteristic "PAHP (Phosphorylated Arabidopsis His Phosphotransfer Protein)".

$$Z_3 = \langle \{l_7, l_{22}\}, \{l_6, l_7\}, \begin{array}{c|cc} & l_6 & l_7 \\ \hline l_7 & W_{7,6} & true \\ l_{22} & false & true \end{array}, \wedge(l_7) \rangle.$$

where
$W_{7,6}$ = "True if there is token in place l_8";

Tokens ε has a characteristic "ARF free" in place l_6.

$$Z_4 = \langle \{l_4, l_6, l_8\}, \{l_9, l_{10}, l_{11}, l_{12}\}, \begin{array}{c|cccc} & l_9 & l_{10} & l_{11} & l_{12} \\ \hline l_4 & true & false & true & false \\ l_6 & false & false & false & W_{6,12} \\ l_8 & false & W_{8,10} & false & W_{8,12} \end{array},$$

$$\wedge(l_4, l_6), l_8) \rangle.$$

where
$W_{6,12} = W_{8,12}$ = "High concentration of Auxin in place l_8";
$W_{8,10}$ = "Low concentration of Auxin in place l_8".

Token γ enters place l_9 with a characteristic "Concentration of AHP", token δ enters place l_{10} with a characteristic "Negative response from AUX and positive response from Cytokinine", token β enters place l_{11} with a characteristic "Concentration of P" and token δ enters place l_{12} with a characteristic "AUX/ARF".

$$Z_5 = \langle \{l_{14}, l_{22}\}, \{l_{13}, l_{14}\}, \begin{array}{c|cc} & l_{13} & l_{14} \\ \hline l_{14} & W_{14,13} & true \\ l_{22} & false & true \end{array}, \wedge(l_{14}) \rangle.$$

where
$W_{14,13}$ = "Existence of token in place l_{12}".

$$Z_6 = \langle \{l_{10}, l_{25}\}, \{l_{15}\}, \begin{array}{c|c} & l_{15} \\ \hline l_{10} & W_{10,15} \\ l_{25} & W_{25,15} \end{array}, \wedge(l_{25}) \rangle.$$

where
$W_{10,15}$ = "Existence of token in place l_{25}";
$W_{25,15}$ = "ARR-B concentration in place l_{25} is below the critical ARR-B concentration".

Token θ enters place l_{13} with a characteristic "Free SCFTIR1" and token α enters place l_{15} with a characteristic "Positive response of Cytokinin".

$$Z_7 = \langle \{l_{12}, l_{13}\}, \{l_{16}, l_{17}\}, \begin{array}{c|cc} & l_{16} & l_{17} \\ \hline l_{12} & true & true \\ l_{13} & false & W_{13,17} \end{array}, \wedge(l_{12}, l_{13}) \rangle.$$

where
$W_{13,17}$ = "Existence of token in place l_{12}".

Token ε obtains the characteristic "Free ARF" in place l_{16} and token δ – "AUX/SCF" in place l_{17}.

$$Z_8 = \langle \{l_{11}, l_{18}, l_{24}\}, \{l_{18}, l_{19}, l_{20}\}, \begin{array}{c|ccc} & l_{18} & l_{19} & l_{20} \\ \hline l_{11} & false & false & true \\ l_{18} & true & W_{18,19} & false \\ l_{24} & W_{24,18} & false & false \end{array}, \wedge(l_{11}, l_{18}) \rangle.$$

where
$W_{18,19}$ = "Existence of token in place l_{11}",
$W_{24,18}$ = "ARR-B concentration in place l_{25} is equal to the critical ARR-B concentration".

Token σ obtains the characteristic "Concentration of ARR-B" in place l_{19}, token β – characteristic "P" in place l_{20}.

$$Z_9 = \langle \{l_{16}, l_{17}\}, \{l_{21}, l_{22}, l_{23}\}, \begin{array}{c|ccc} & l_{21} & l_{22} & l_{23} \\ \hline l_{16} & false & false & true \\ l_{17} & true & true & false \end{array}, \wedge(l_{16}, l_{17}) \rangle.$$

Token δ obtains the characteristic "AUX" in place l_{21}, token θ – "Free SCF" in place l_{22}, and token ε – "Free ARF" in place l_{23}.

$$Z_{10} = \langle \{l_{19}, l_{20}, l_{21}\}, \{l_{24}, l_{25}, l_{26}, l_{27}\}, \begin{array}{c|cccc} & l_{24} & l_{25} & l_{26} & l_{27} \\ \hline l_{19} & true & W_{19,25} & false & false \\ l_{20} & false & W_{20,25} & W_{20,26} & false \\ l_{21} & false & false & false & true \end{array},$$

$$\vee(\wedge(l_{19}, l_{20}), \wedge(l_{21})) \rangle.$$

where
$W_{19,25}$ = "Existence of token in place l_{20}",
$W_{20,25}$ = "True until the critical ARR-B concentration is reached",
$W_{20,26}$ = "True after the critical ARR-B concentration is reached".

The following characteristic are obtained:

Token σ in place l_{24} – "ARR-B",

token β in place l_{25} – "Activation signal for Cytokinin positive response",

token β in place l_{26} – "P",

token δ in place l_{27} – "AUX".

$$Z_{11} = \langle \{l_{26}, l_{27}\}, \{l_{28}, l_{29}, l_{30}\}, \begin{array}{c|ccc} & l_{28} & l_{29} & l_{30} \\ \hline l_{26} & W_{26,28} & W_{26,29} & false \\ l_{27} & false & true & true \end{array}, \vee(l_{26}, l_{27}) \rangle.$$

where
$W_{26,28}$ = "True if there is existence of token in place l_{27}",
$W_{26,29} = \neg W_{26,28}$.

Token β obtains a characteristic "P" in place l_{28} and "Negative response of Cytokinin" in place l_{29}. Token δ obtains a characteristic "Positive response of AUX" in place l_{30}.

4 Conclusion

A generalized net model that represents the complex intercellular molecular interactions induced from two key plant hormone families - auxins and cytokinins is developed. These two families have antagonistic influence on the plant cell. There are two signaling pathways in the cell which are self regulated and lead to different path in the cell's life cycle. Whenever a set of responsive genes for one of these hormones is activated it suppresses the activation of the responsive genes for the other. The presented here GN-model described accurately all interactions between genes considering the interactions between their products. The GN-model takes into account the presence of one or the two hormones and describes their coordinated action.

Acknowledgements

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The papers presented in this Volume 2 constitute a collection of contributions, both of a foundational and applied type, by both well-known experts and young researchers in various fields of broadly perceived intelligent systems.
It may be viewed as a result of fruitful discussions held during the Ninth International Workshop on Intuitionistic Fuzzy Sets and Generalized Nets (IWIFSGN-2010) organized in Warsaw on October 8, 2010 by the Systems Research Institute, Polish Academy of Sciences, in Warsaw, Poland, Institute of Biophysics and Biomedical Engineering, Bulgarian Academy of Sciences in Sofia, Bulgaria, and WIT - Warsaw School of Information Technology in Warsaw, Poland, and co-organized by: the Matej Bel University, Banska Bystrica, Slovakia, Universidad Publica de Navarra, Pamplona, Spain, Universidade de Tras-Os-Montes e Alto Douro, Vila Real, Portugal, and the University of Westminster, Harrow, UK:

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The consecutive International Workshops on Intuitionistic Fuzzy Sets and Generalized Nets (IWIFSGNs) have been meant to provide a forum for the presentation of new results and for scientific discussion on new developments in foundations and applications of intuitionistic fuzzy sets and generalized nets pioneered by Professor Krassimir T. Atanassov. Other topics related to broadly perceived representation and processing of uncertain and imprecise information and intelligent systems have also been included. The Ninth International Workshop on Intuitionistic Fuzzy Sets and Generalized Nets (IWIFSGN-2010) is a continuation of this undertaking, and provides many new ideas and results in the areas concerned.

We hope that a collection of main contributions presented at the Workshop, completed with many papers by leading experts who have not been able to participate, will provide a source of much needed information on recent trends in the topics considered.

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