New Developments in Fuzzy Sets, Intuitionistic Fuzzy Sets, Generalized Nets and Related Topics Volume II: Applications

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Dedicated to Professor Beloslav Riečan on his 75th anniversary

Generalized net model of cytokinin/auxin interactions for plant root formation

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Abstract

Using the apparatus of Generalized nets a generalized net model that represents the complex intercellular molecular interactions induced from two plant hormone families - auxins and cytokinins is developed. Presented here GN is a model of upper level of regulation of these interactions achieved through one central protein. The GN model takes into account the presence of one or the two hormones and describes their coordinated or antagonistic action. Depending on different concentration levels the GN model is capable of self regulation. Different levels of hormone or regulating protein may lead the cell cycle to differentiation or division.

Keywords: generalized net, auxin, cytokinin, molecular interactions, self regulation.

1   Introduction

The advancement of biotechnological sciences relies heavily on the design of accurate models that not only are consistent with the experimentally established correlations but are also capable of predicting and extrapolating expected results with high degree of certainty. Naturally, the more detailed the model, the more

precise its result are but beyond some reasonable level its complexity may render it practically unusable.

Recently attempts have been made to describe various models, optimization procedures, control loops considering bioprocesses, based on Generalized nets [11, 12, 13, 14, 15, 16, 17]. The theory of the Generalized nets (GN) [2, 3, 5] proved to be quite successful when applied to the description of the functioning of expert systems, machine learning and different technological processes. Up to now GNs are used as a tool for modelling of parallel processes in several areas [1, 2, 3, 4, 5] - economics, transport, medicine, computer technologies etc. Already GN are used to model genetic networks [7]. Genetic networks are an approximation mathematical model that is consistent with the contemporary knowledge on gene-gene interactions. As in all models various assumptions on the nature of such relations are made (whether they will be expressed as differential equations, probabilistic distributions, topological criterion, etc. is a choice predetermined by the structure of the data implemented in the model).

The apparatus of generalized nets can easily and efficiently represent the specific intercellular molecular interactions. For example, if it is considered plant development, meristems are key element. Post-embryonic plant growth and development are sustained by meristems. The meristem itself is composed of a small population of perpetually embryonic (meristematic) cells. These cells grow and divide, giving rise to new cells, but never mature themselves. Thus there is always a source of new cells at the tip of the root. These meristems are characterized by an indeterminate growth pattern: one that is not finite, but, in theory at least, could continue throughout the lifetime of the plant. The generation of plant roots is an intense process which involves the interaction of the meristem tissue and several growth regulators. Plant hormones regulate many aspects of plant growth and development. Both auxin and cytokinin have been known for a long time to act either synergistically or antagonistically to control several significant developmental processes [6, 8, 10, 18]. This process can also be characterized with intense molecular network of interactions. These interactions include molecular signaling and regulatory pathways.

In this paper the apparatus of Generalized net is used to describe the interaction of the pathways induced by the Regulation of Cytokinin/Auxin crosstalk in root meristem as a genetic net. Already a generalized net model that represents the intercellular molecular interactions induced from these two key plant hormone families was developed [9]. These hormones influence is realized antagonistically in the plant cell. There are two signaling pathways in the cell which are self regulated. 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

in [9] 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. Presented here GN is a model of upper level of regulation of these interactions achieved through one central protein. This protein regulates the expression of hormone dependant genes and it is regulated by the hormones.

2 Regulation of Cytokinin/Auxin crosstalk in root meristem

The formation of roots in plants is a very complex process. The process involves the action of two hormone families: Cytokinin and Auxin, and a rigid regulatory system which guides the cells into division or proliferation. The root meristem can be divided into three zones proximal meristem (PM) where cell division occurs; cells differentiate and elongate in the elongation differentiation zone (EDZ) and the transition zone (TZ) which is the boundary between dividing and expanding cells (Fig. 1(a)) [6].

The generalized net model shown in this work represents a model of the interaction of plant hormones Auxin and Cytokinin in root meristem cell located in the transition zone. Hormones from the auxin family promote proliferation of the cells while hormones from the Cytokinin family induce differentiation of the cells. The regulation of these processes in the root meristem is achieved with the help of central regulating protein: SHY2. The regulation of synthesis and degradation of this protein is done by the hormones. This interaction between the hormones and the SHY2 protein can be described as a self regulating network.

The regulator protein SHY2 down regulates the expression of Auxin responses and represses the PIN family proteins, which are transporter proteins for Auxin, it also represses the IPT5 enzyme, responsible for cytokinin synthesis. SHY2 is itself regulated by auxin; it is marked for proteasome degradation through auxin-dependent recognition by the SCFTIR1 complex. High levels of Auxin in the cell lead to SHY2 degradation. Lowering the concentration of SHY2 unlocks the Auxin responses and the cell starts to divide. This also stops the repression of the IPT5 enzyme and unlocks the production of cytokinins. Cytokinins block the auxin responses which stop the proliferation and prepare the cell for differentiation and elongation. Cytokinin also induces the expression of SHY2 through the AHK3/ARR1,ARR12 cytokinin signaling pathway, which also suppresses Auxin response genes (Fig. 1(b)) [6].
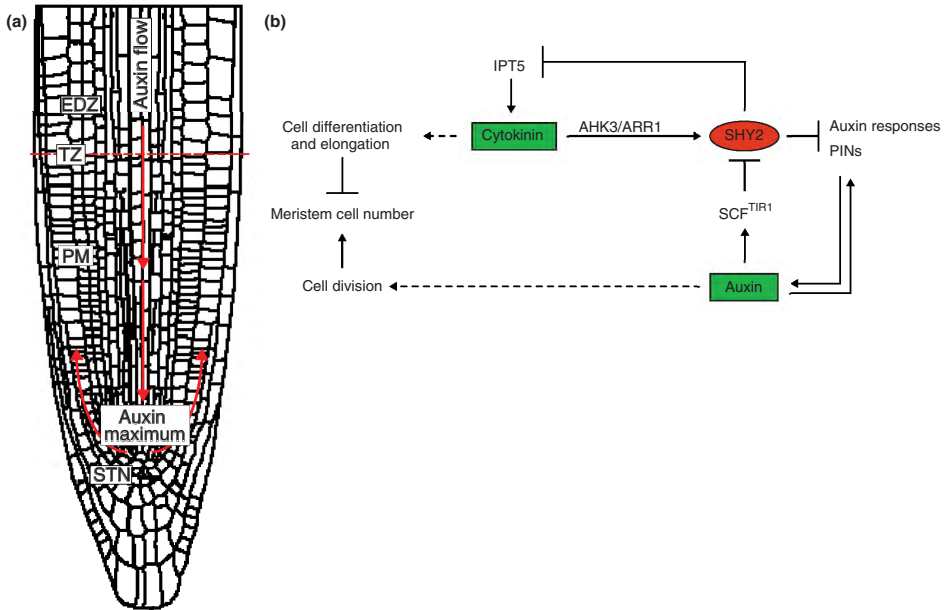
Figure 1: Citokinin/Auxin interactions

3 GN-model of Cytokinin/Auxin interactions for plant root formation

Initially, in places $l_1, l_3, l_5, l_{11}, l_{17}$, stay tokens $\alpha, \beta, \gamma, \delta, \varepsilon$, with initial and current characteristics:

"Initial concentration of AUX",

"Initial concentration of PIN",

"Initial concentration of IPT5",

"Initial concentration of SCF",

"Initial concentration of SHY2".

The GN-model of Cytokinin/Auxin interactions for plant root formation is presented in Fig. 2.

Token α enters place l_1 with a characteristic "Concentration of AUX" and token β enters the net in the first transition with a characteristic "Concentration of PIN".
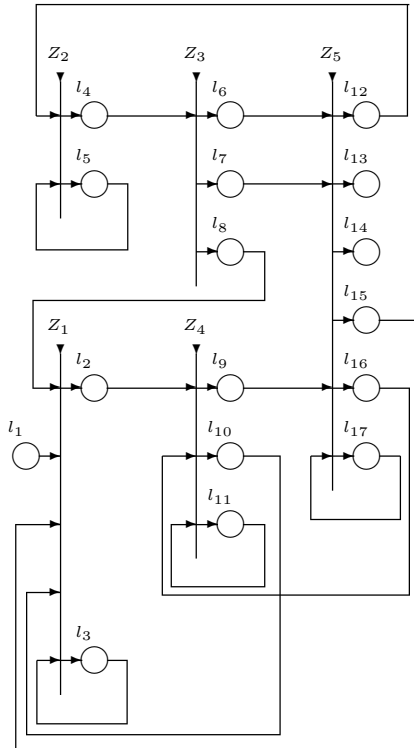
Figure 2: GN-model of Cytokinin/Auxin interactions for plant root formation

$$Z_1 = \langle\{l_1, l_3, l_{10}, l_{12}, l_{16}\}, \{l_2, l_3\},$$

	l_2	l_3
l_1	W_1	$false$
l_3	$true$	$true$
l_8	$true$	$true$
l_{10}	$false$	$true$
l_{15}	W_1	$false$

$$\vee(\wedge(l_1, l_3), \vee(l_8, l_{15}), \rangle.$$

where $W_1 =$ "Existance of token in place l_3 and SHY2 concentartion $\geq$ critical concentration and no existance in place l_8 ".

Token γ enters the net in the second transition with a characteristic "Concentration of IPT5".

The form of the second transition is:

$$Z_2 = \langle\{l_5, l_{13}\}, \{l_4, l_5\},$$

	l_4	l_5
l_5	W_2	$true$
l_{12}	$true$	$false$

$, \wedge(l_5, l_{12})\rangle.$

where $W_2 =$ "Existance of token in place l_{13} ".

The form of the third transition is:

$$Z_3 = \langle\{l_4\}, \{l_6, l_7, l_8\},$$

	l_6	l_7	l_8
l_4	$true$	$true$	$true$

$, \wedge(l_4)\rangle.$

Token δ enters the net in the fourth transition with a characteristic "Concentration of SCF".

The form of the fourth transition is:

$$Z_4 = \langle\{l_2, l_{11}, l_{16}\}, \{l_9, l_{10}, l_{11}\},$$

	l_9	l_{10}	l_{11}
l_2	$true$	$true$	$false$
l_{11}	$true$	$false$	$true$
l_{16}	$true$	$false$	$true$

$, \wedge(l_2, l_{11})\rangle.$

Token γ enters the net in fifth transition with a characteristic "Concentration of SHY2". The form of the fifth transition is:

$$Z_5 = \langle\{l_6, l_7, l_9, l_{17}\}, \{l_{12}, l_{13}, l_{14}, l_{15}, l_{16}, l_{17}\}, r_5, \vee(\wedge(l_6, l_6), l_{10}\rangle.$$

$r_5 =$		l_{12}	l_{13}	l_{14}	l_{15}	l_{16}	l_{17}
	l_6	$false$	$true$	$false$	$false$	$false$	$false$
	l_7	$false$	$false$	$false$	$false$	$false$	$true$
	l_9	$false$	$false$	$true$	$true$	$false$	$true$
	l_{17}	W_3	$false$	$false$	W_4	$false$	$true$

where
W_3 = "SHY2 concentartion is $\leq$ critical concentration";
$W_4 = \neg W_3$.

Thus, described GN-model of Cytokinin/Auxin crosstalk in plant root formation simulates the molecular interactions in account of concentration of hormones and central regulating protein. Depending on different concentration levels the GN model is capable of self regulation. Different levels of hormone or regulating protein may lead the cell cycle to differentiation or division.

4   Conclusion

In this paper generalized net model that represents the complex intercellular molecular interactions induced from two plant hormone families - auxins and cytokinins is presented. These two families have a key role in the plant cell cycle. Whenever a set of responsive genes for one of auxins or cytokinins hormon is activated it suppresses the activation of the responsive genes for the other. Previously the authors have developed a generalized net model that represents the intercellular molecular interactions induced from these two hormone families. Presented here GN is a model of upper level of regulation of these interactions achieved through one central protein. The GN model takes into account the presence of one or the two hormones and describes their coordinated or antagonistic action. Depending on different concentration levels the GN model is capable of self regulation. Different levels of hormone or regulating protein may lead the cell cycle to differentiation or division.

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 Tenth International Workshop on Intuitionistic Fuzzy Sets and Generalized Nets (IWIFSGN-2011) organized in Warsaw on September 30, 2011 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:

Http://www.ibspan.waw.pl/ifs2011

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 Tenth International Workshop on Intuitionistic Fuzzy Sets and Generalized Nets (IWIFSGN-2011) 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.