

Influence of update schemes on boolean networks

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Abstract—In this paper we will introduce boolean networks (BN) and their relevance to gene regulatory networks (GRN). We will have a closer look on update schemes. Specifically, synchronous, sequential and asynchronous update schemes and their effect on the behavior of BN and GRN respectively.

1 INTRODUCTION

Possible points to mention here:

- Explain shortly gene regulatory networks (GRN)
- Explain why boolean networks are used to model GRN
- Maybe mention history of boolean networks
- Set the focus to the update scheme as it seems to be rarely covered in the field of GRNs
- Possible open question about which update scheme might be best to model GRNs. Answer to this must follow in the conclusion

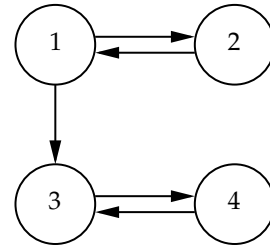
2 BOOLEAN NETWORKS

A boolean network consists of nodes $x_i(t)$ that have a boolean state, either 0 or 1, at a point in time t . Each node has a corresponding update function $x_i(t+1) = f_i(x_1(t), x_2(t), \dots, x_n(t))$ expressing the new state of $x_i(t+1)$. The state of the boolean network can be describe as a boolean number $x_1x_2 \dots x_n$ where each node is replaced with the corresponding state.

Consider the boolean network shown in fig. 1. Assume the current state is 0011, meaning that x_1, x_2 are 0 and x_3, x_4 are 1. The next state when applying the update function all at once is 1011. Updating the network multiple times creates a trajectory, which is the sequence of the states starting from the initial state. With our example, the trajectory is $0011 \rightarrow 1011 \rightarrow 1101 \rightarrow 0100 \rightarrow \dots$. Each trajectory in a reasonably small boolean network eventually reaches one of two scenarios. Either it falls into a state that doesn't change when updated, called attractor, or it falls into a cycle of states. In the example, there are 2 cycles of length 8 visible in fig. 2.

2.1 Notation

Define clear notation used throughout the paper. Position of this subsection could change to be part of the Introduction instead.



$$\begin{aligned}
 f_1 &= \neg x_2 \\
 f_2 &= x_1 \\
 f_3 &= x_1 \oplus x_4 \\
 f_4 &= x_3
 \end{aligned}$$

Fig. 1. Example of a boolean network with four nodes. Each vertex indicates that a node is part of the update function of the other node. For instance x_1 is part of f_2 and f_3 .

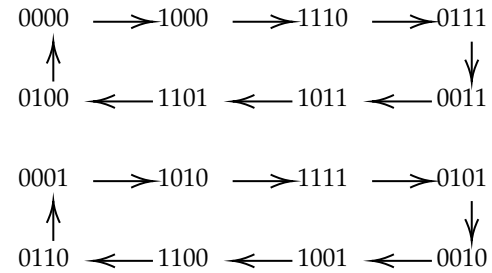


Fig. 2. State graph of the boolean network shown in fig. 1 using synchronous update scheme.

3 UPDATE SCHEMES

Explain different update schemes including characteristics for behavior especially chaotic behavior. These will mostly focus on boolean networks only. Maybe mention of use-cases for each update scheme.

3.1 Synchronous scheme

The Synchronous (also known as Parallel) update scheme assumes that every node is updated at once.

3.2 Sequential scheme

close to synchronous. the nodes update in a specific order and take into account the updated input node if that node had been updated before/is positioned earlier in the sequence

3.3 Block-sequential scheme

mix of synchronous and sequential. predefined blocks update sequential, inside a block the update follows the synchronous scheme

3.4 Asynchronous deterministic

one node is updated per tick following a specific sequence

3.5 Asynchronous generalized

same as asynchronous deterministic with the slight change that within the sequence nodes may appear multiple times.

4 RELEVANCE FOR GENE REGULATORY NETWORKS

Tie the update schemes and their different outcomes or behavior to GRN.

Emphasizing the drawbacks of asynchronous models when applied to GRN e.g. it takes way to long to update a GRN using asynchronous deterministic for it to have an effect; assuming that one update takes a few minutes, when the whole process can take days to complete.[\[1\]](#)

5 CONCLUSION

Not yet included: robustness! might be covered for each update scheme individually.

References: [\[1\]](#)[\[2\]](#)[\[3\]](#)[\[4\]](#)[\[5\]](#)

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Fig. 3. graph of all possible states for a boolean network using a synchronous update scheme

Fig. 4. example graph of boolean network showcasing grouping of specific nodes.