Design and Implementation of Speech Recognition Systems

Fall 2014
Ming Li

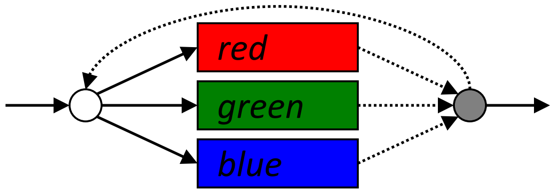
Class 11: Backpointer tables
Nov 6th

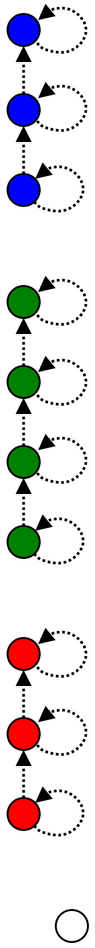
Thanks to Professor Bhiksha Raj for the contribution of the slides

Backpointers in Viterbi search

- In Viterbi search, we retain a pointer to the best previous state at all trellis nodes
- This is performed even when we are recognizing continuous speech
  - From Grammars etc.

Trellis with Complete Set of Backpointers





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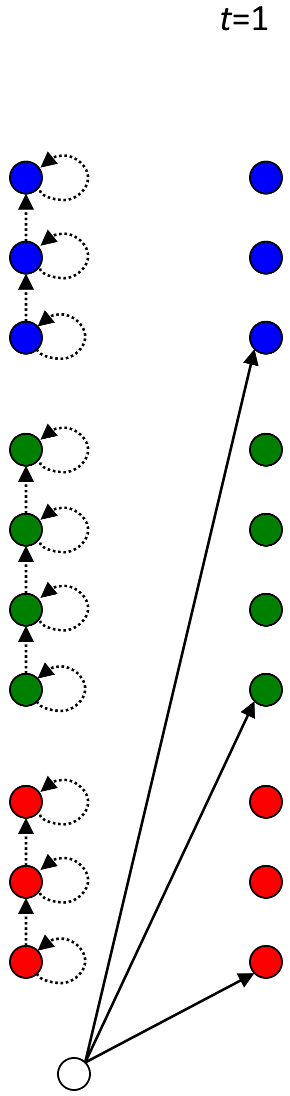

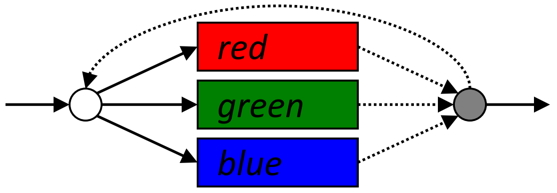

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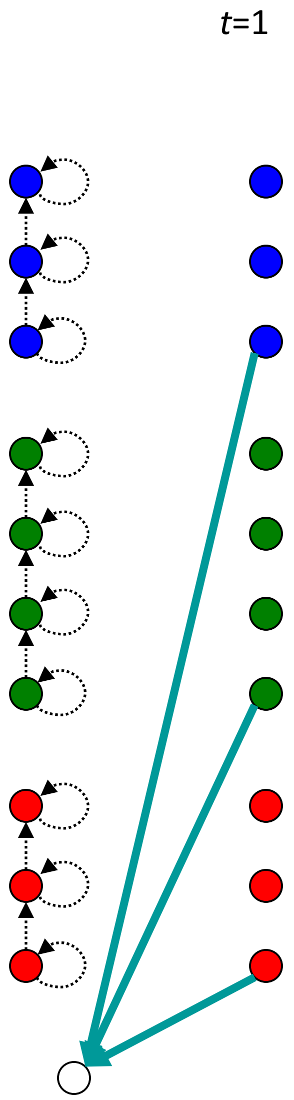

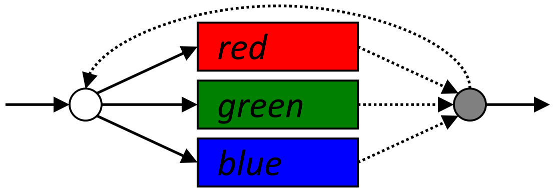

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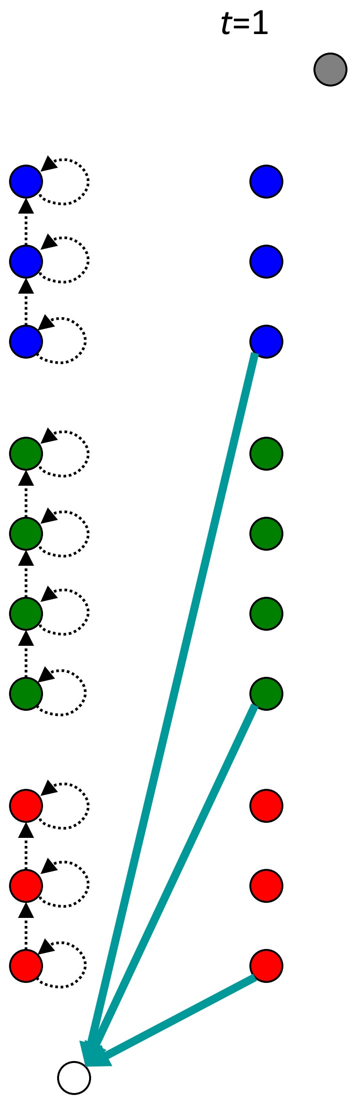

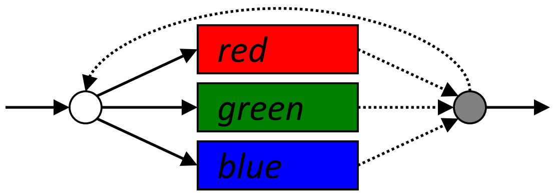

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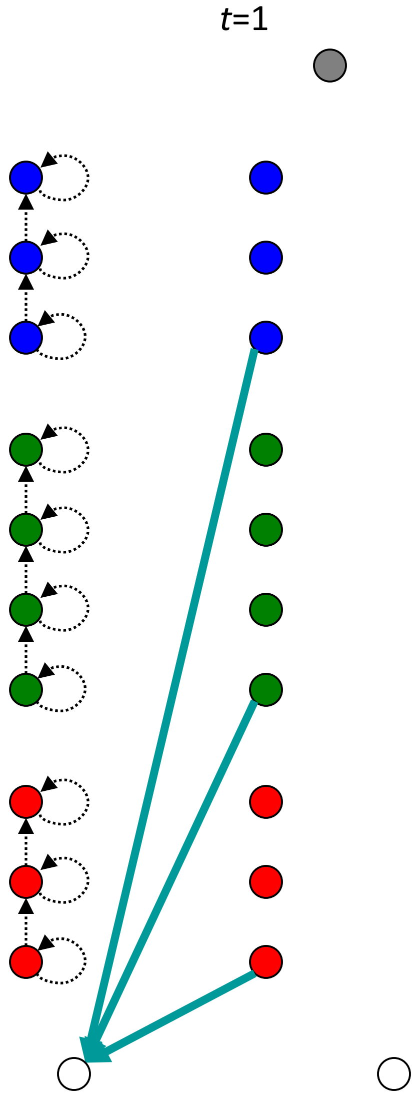

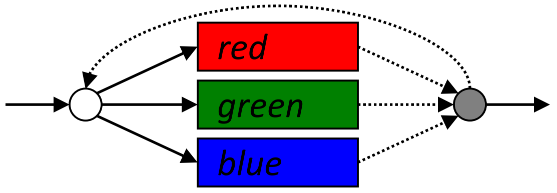

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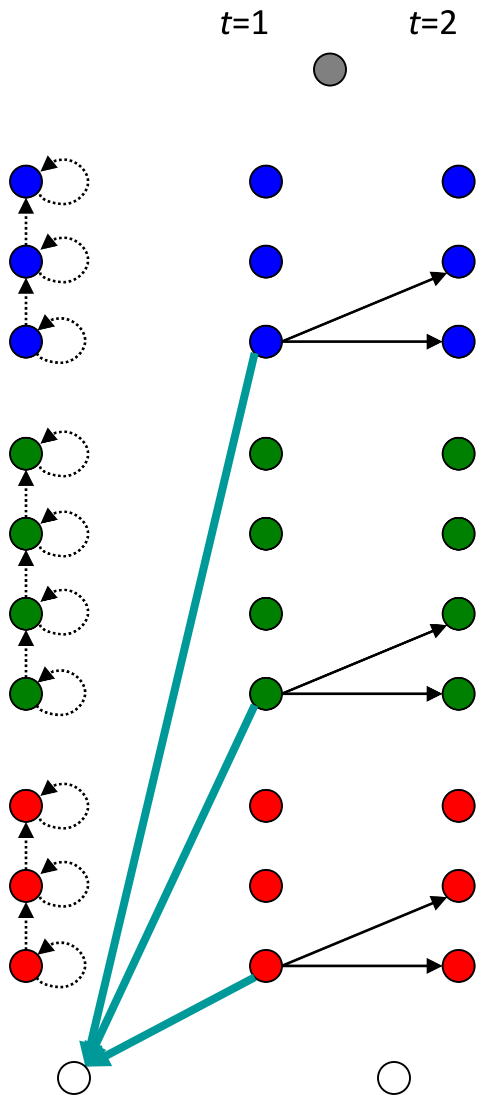

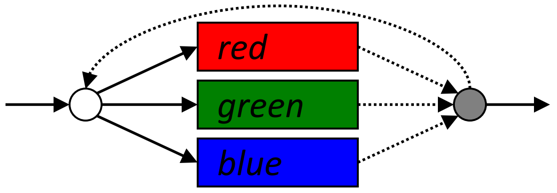

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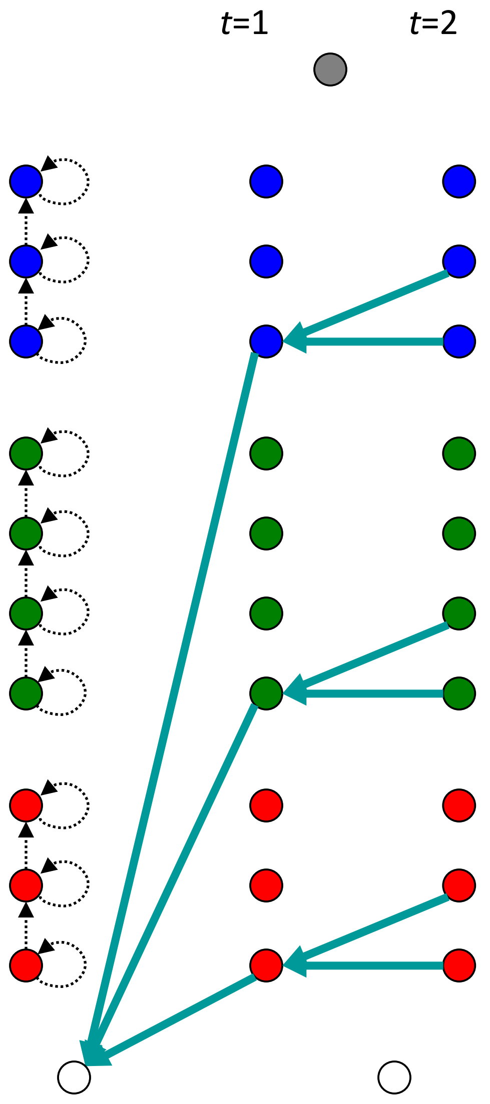

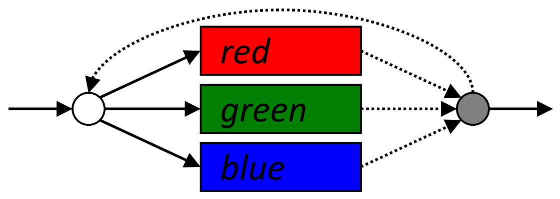

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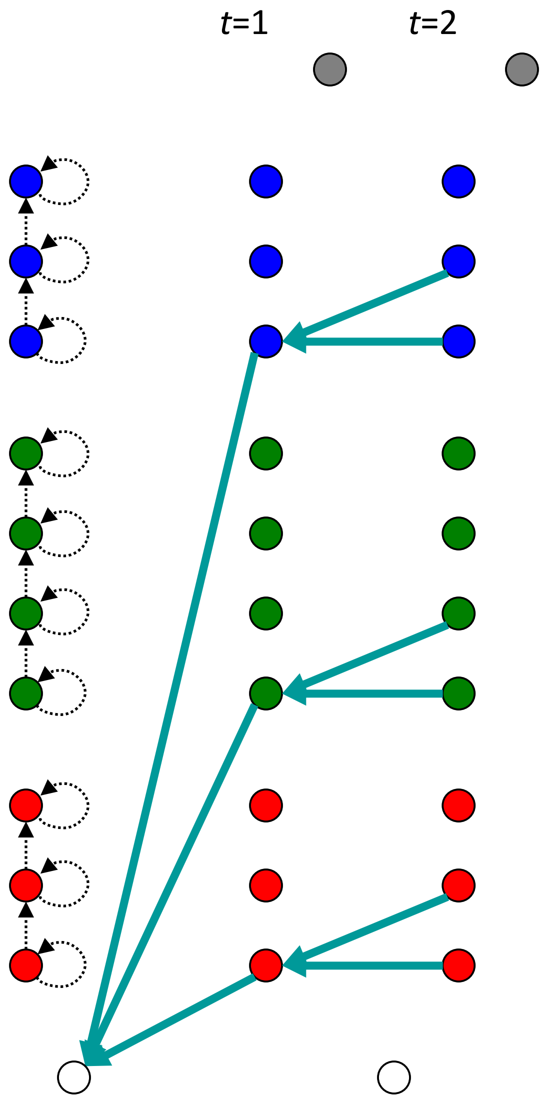

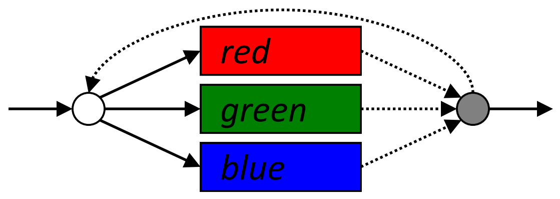

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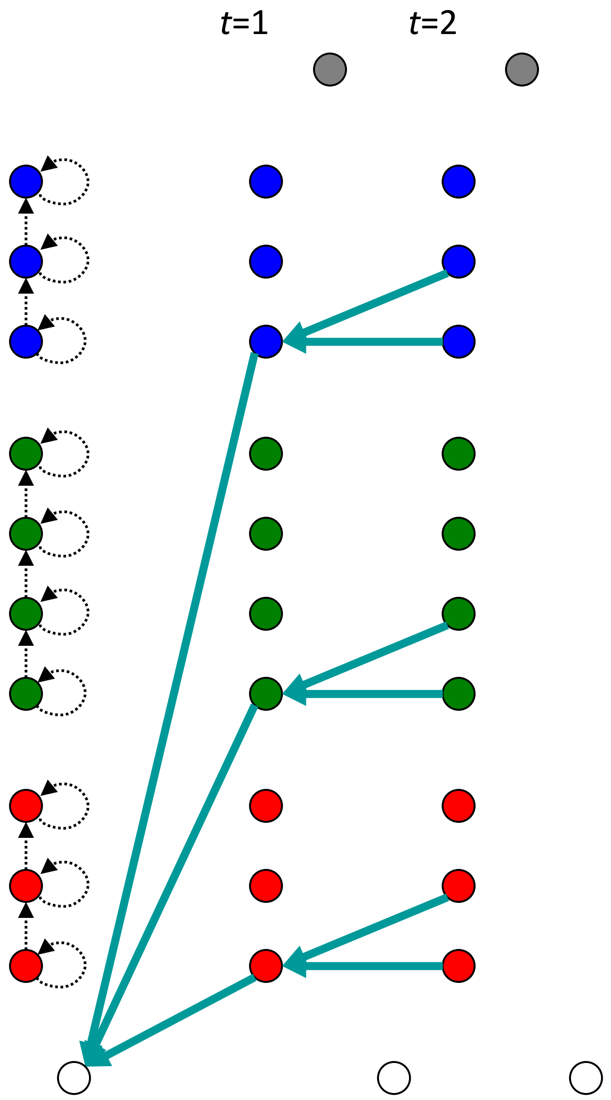

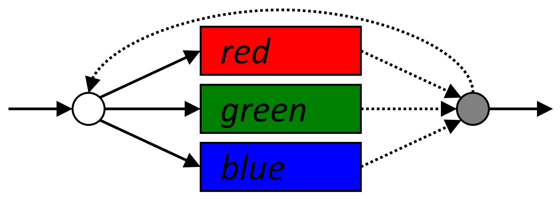

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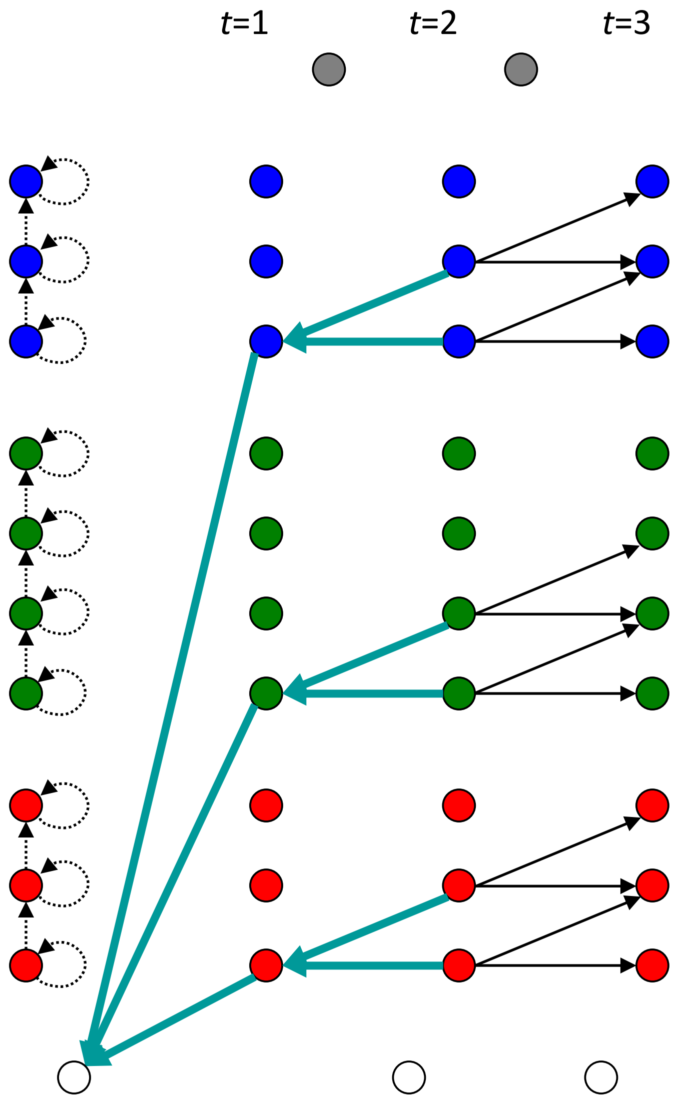

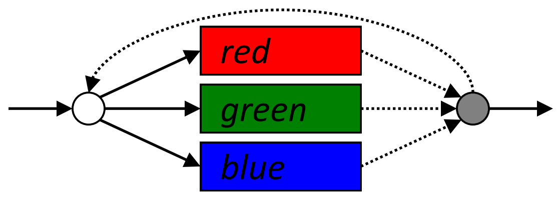

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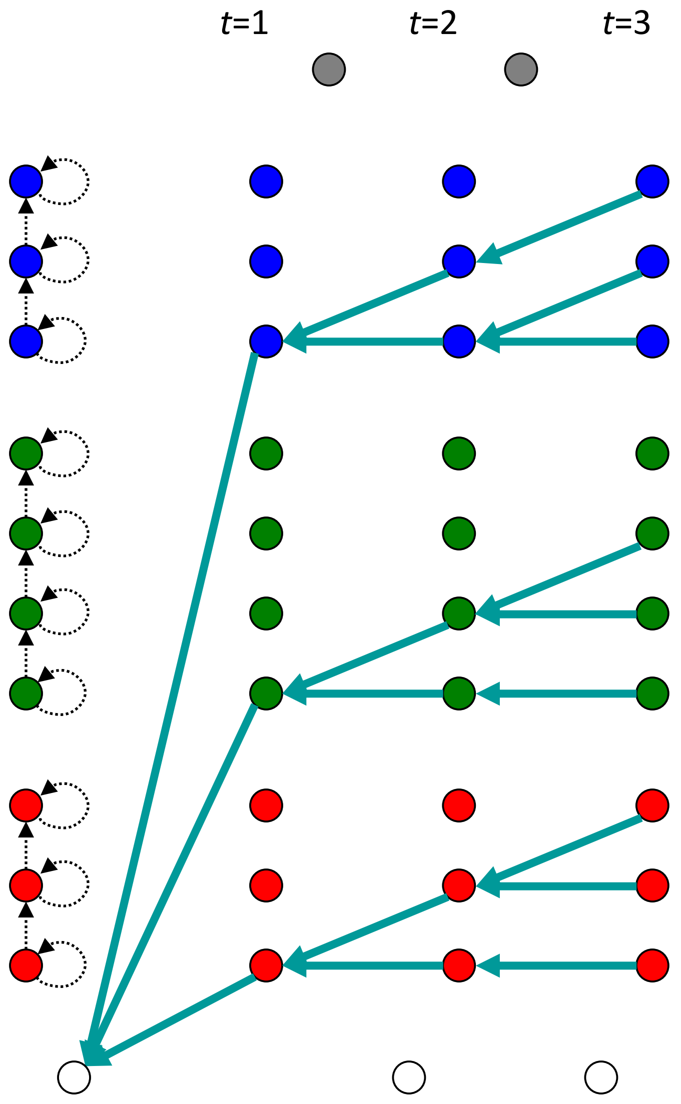

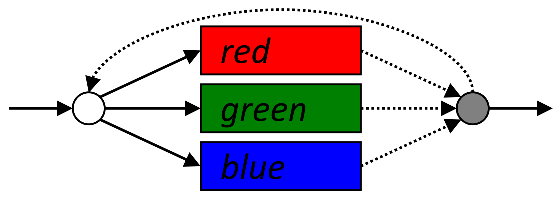

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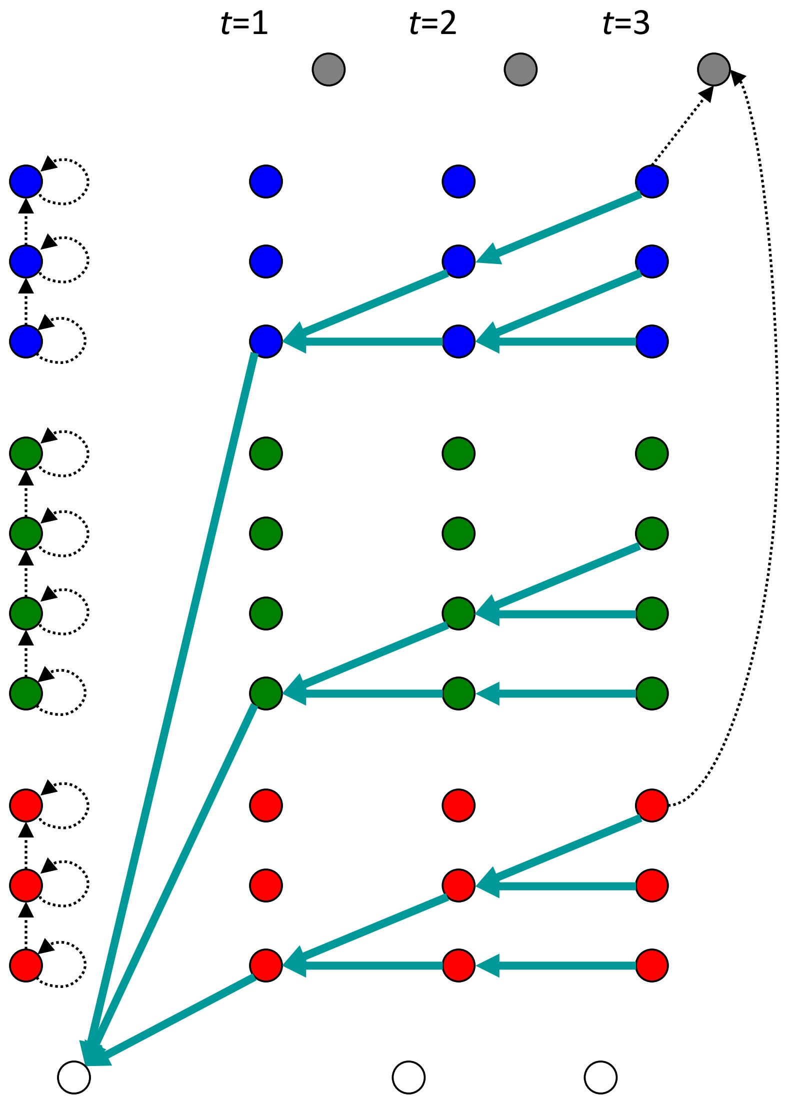

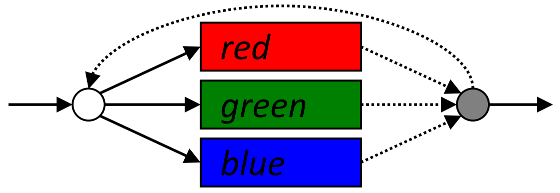

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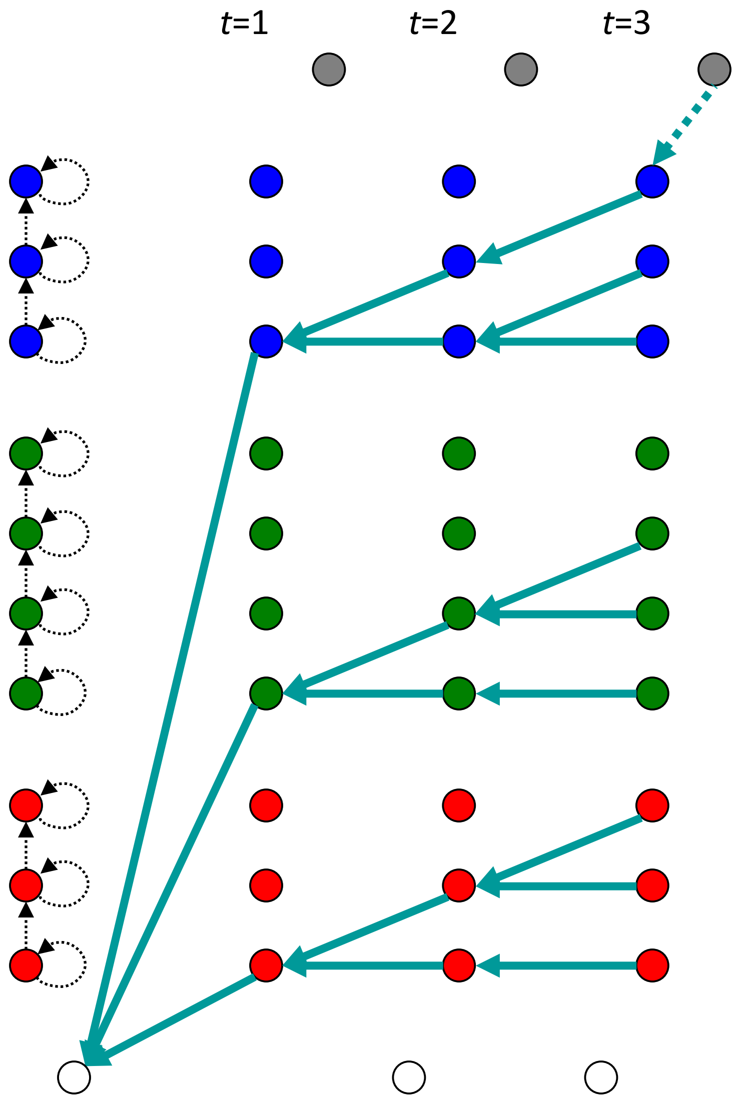

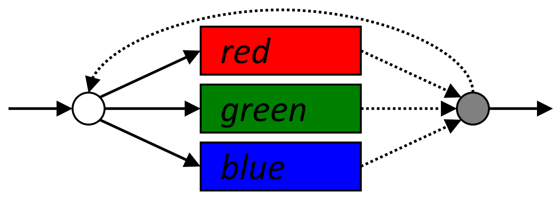

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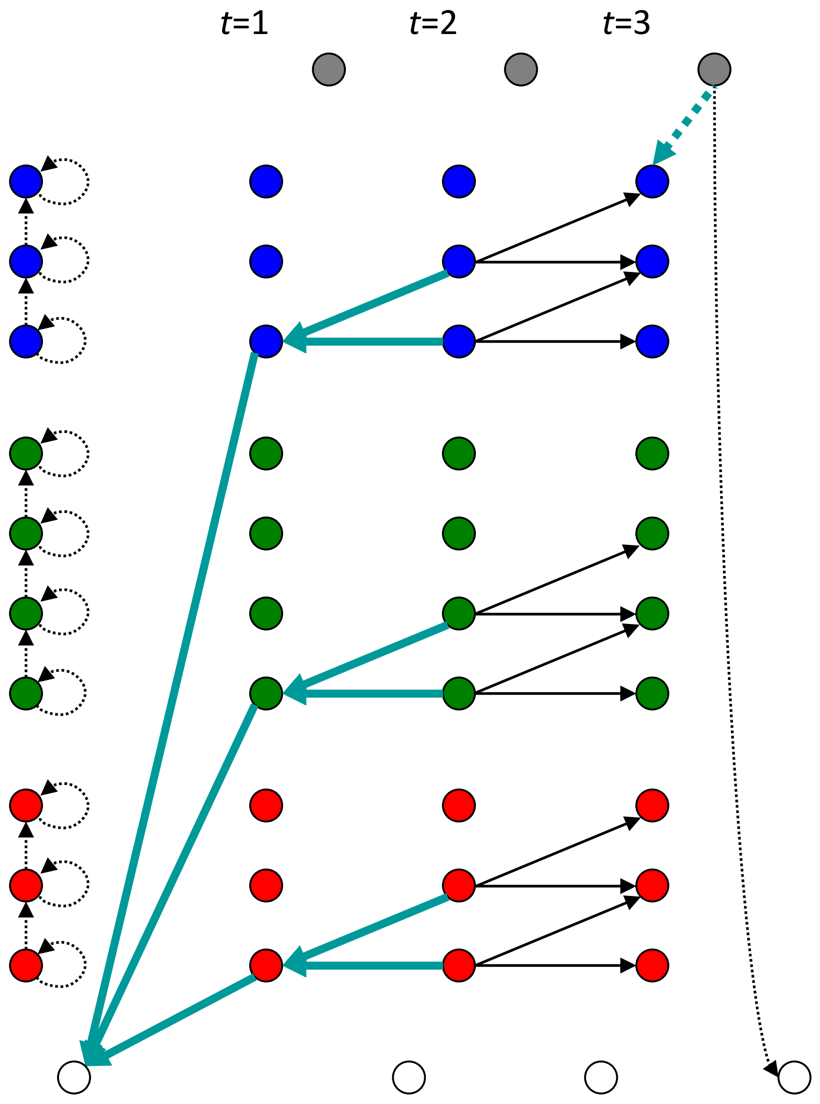

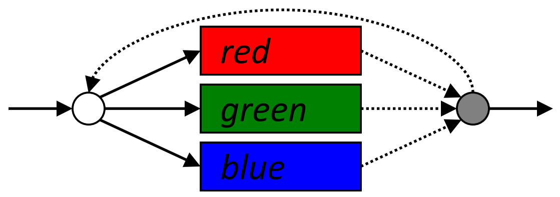

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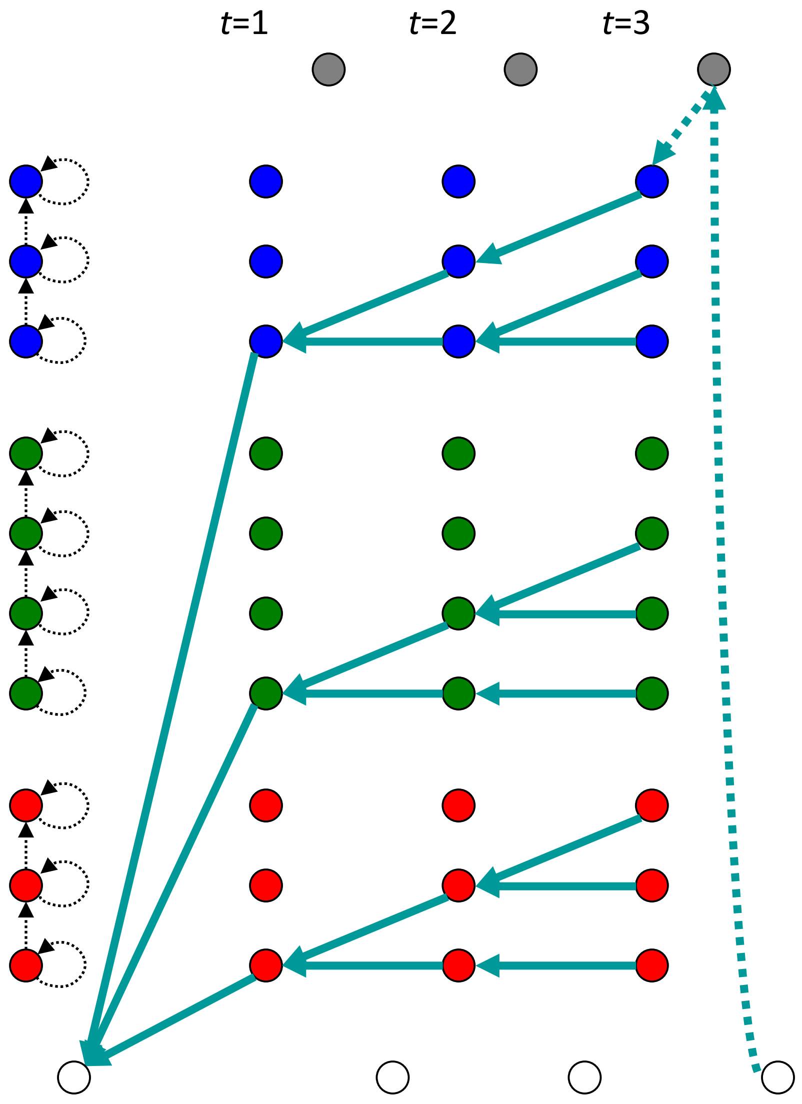

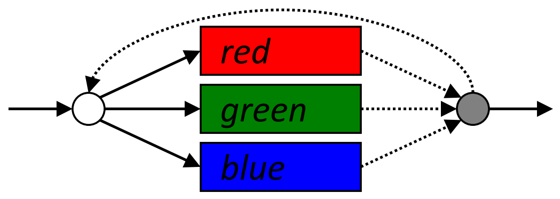

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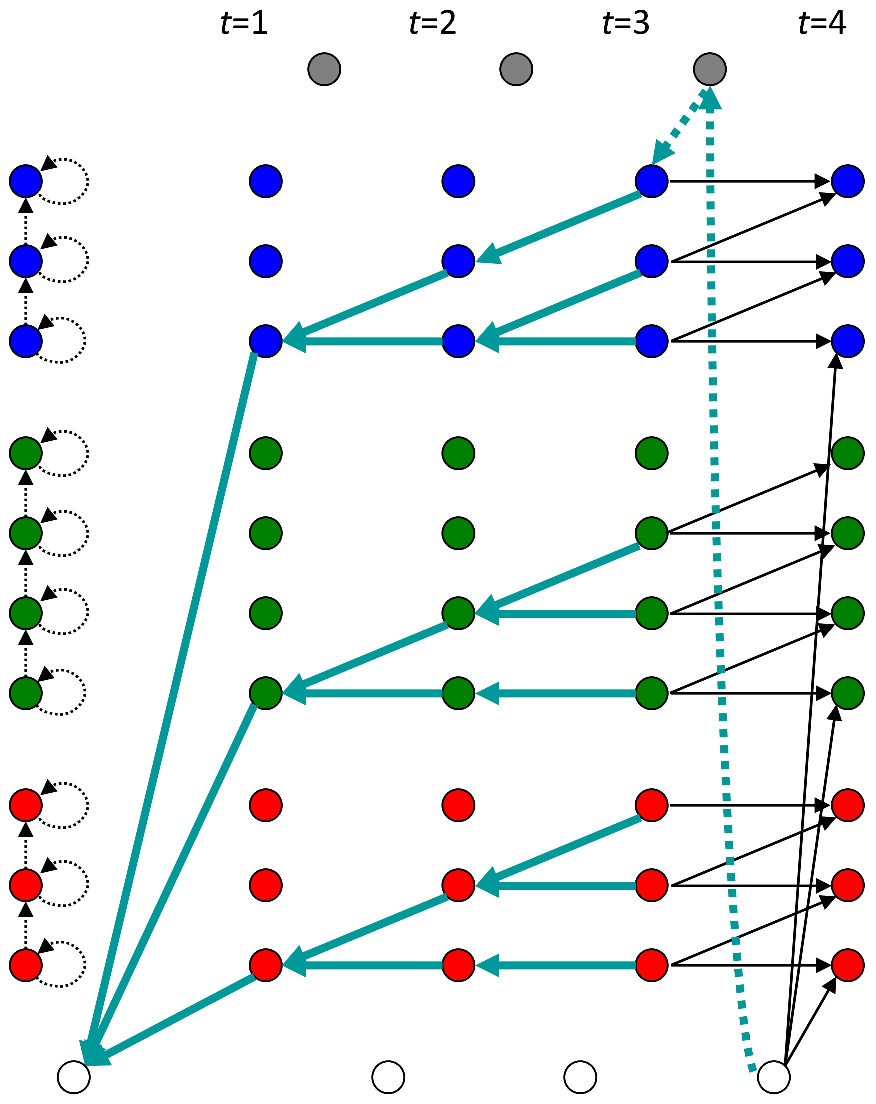

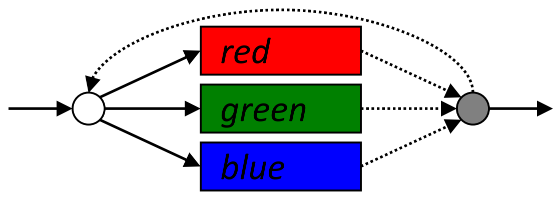

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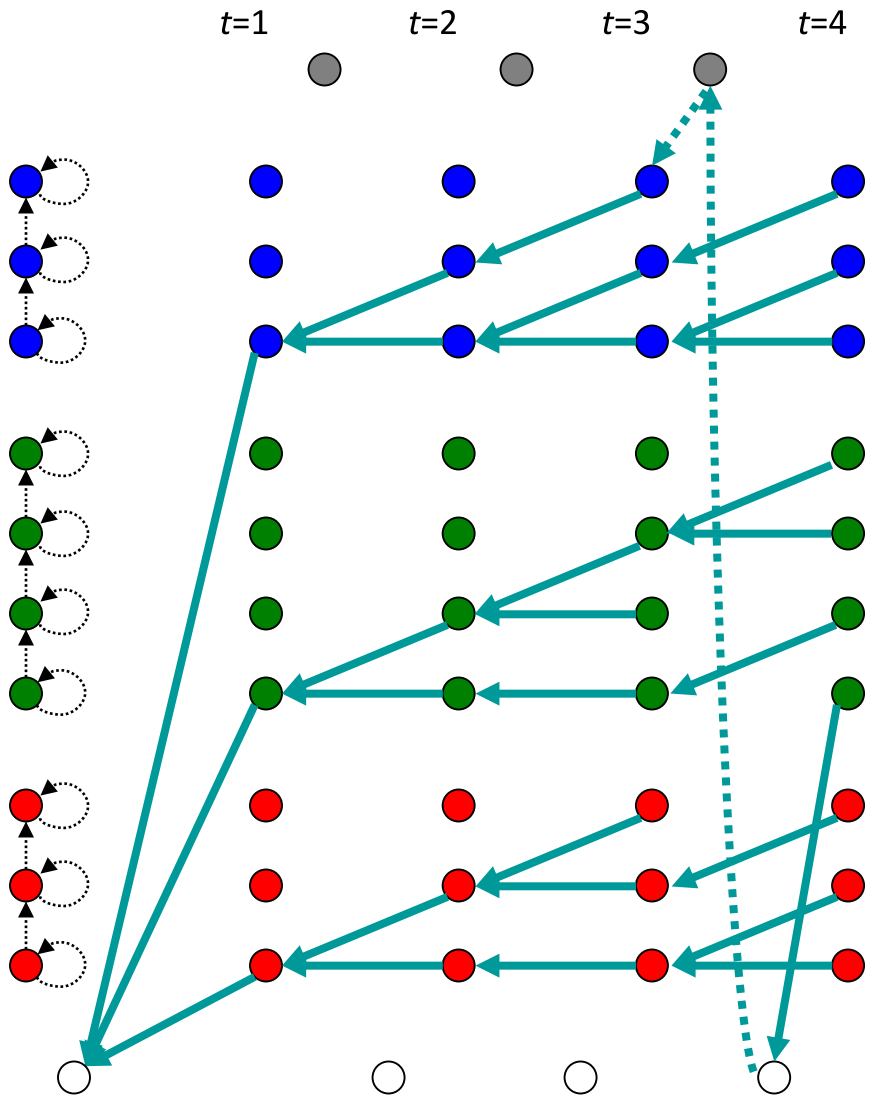

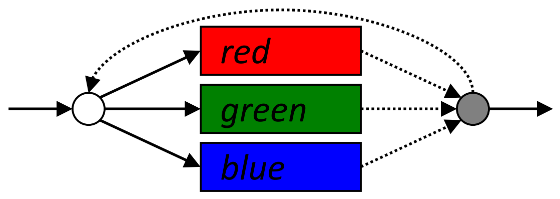

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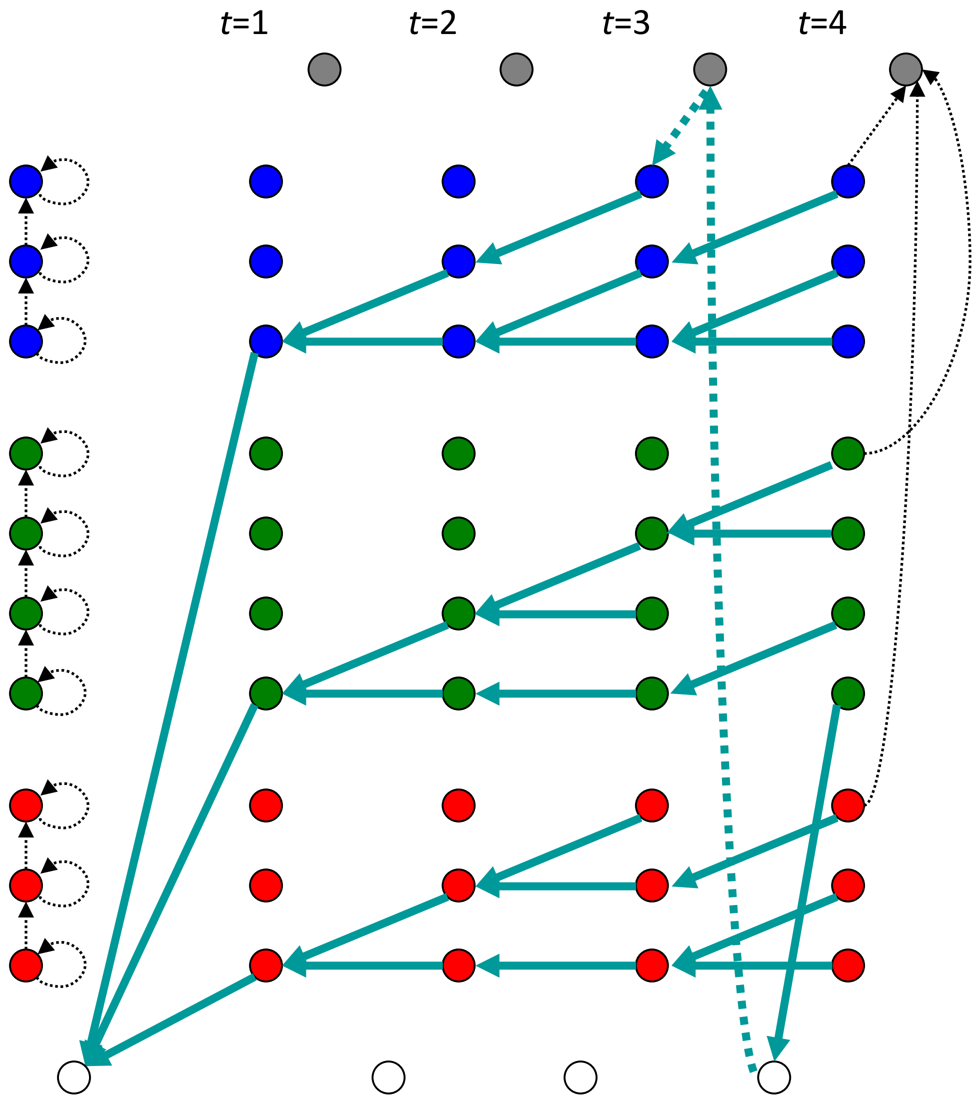

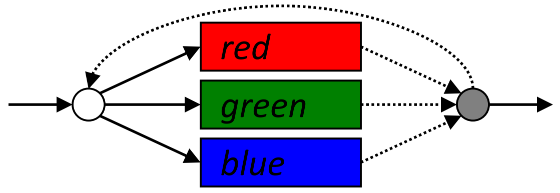

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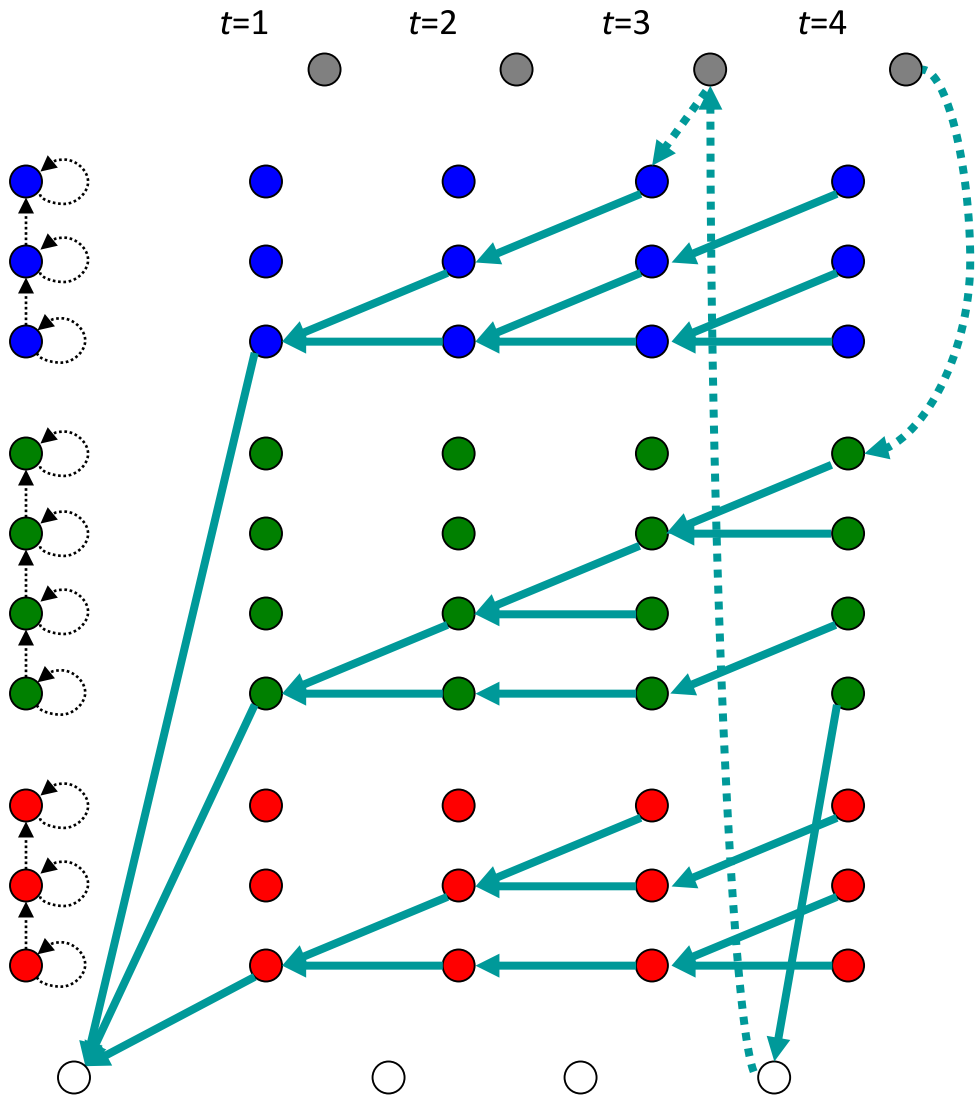

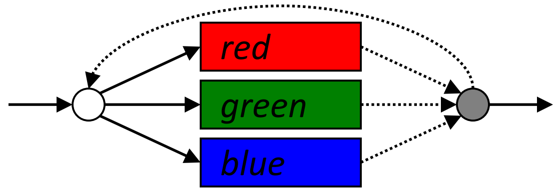

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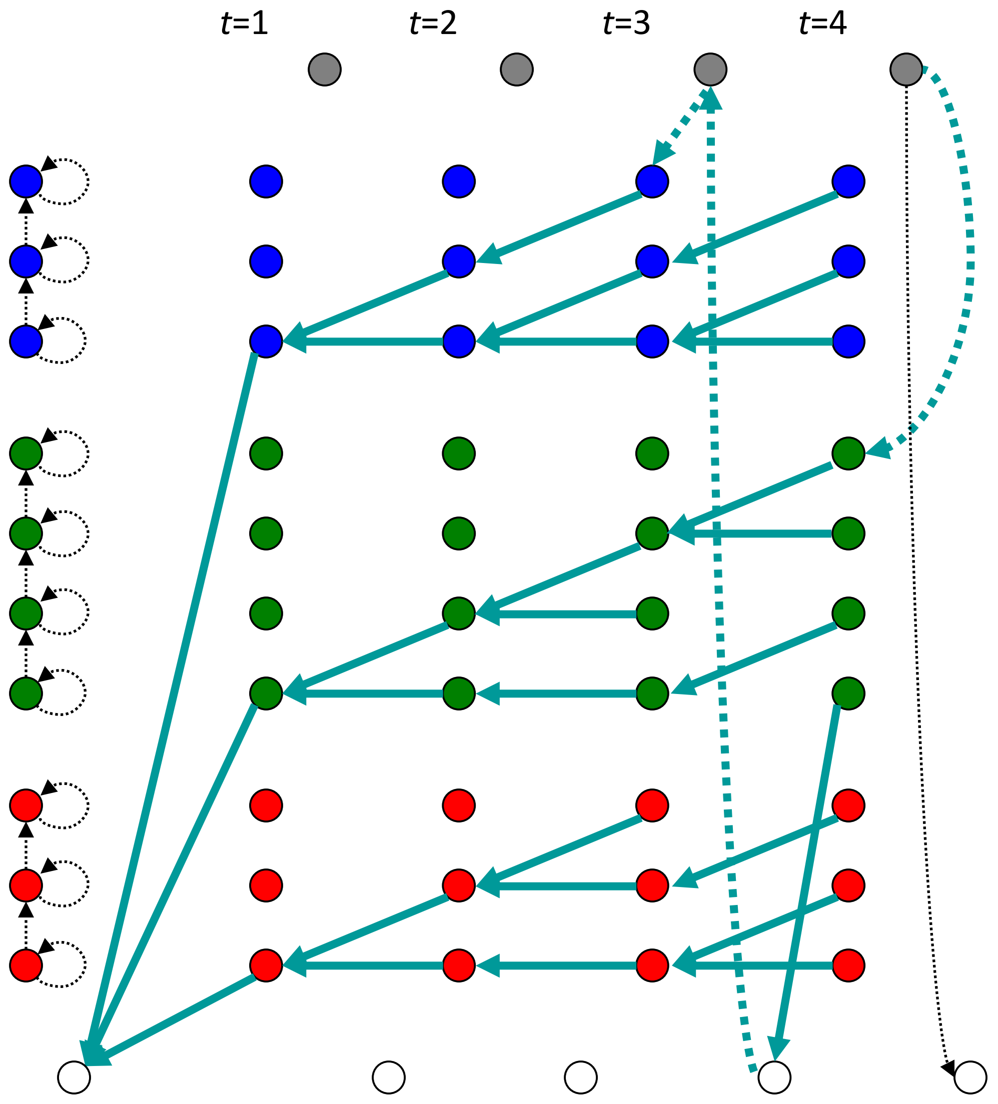

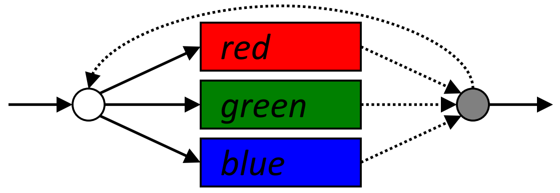

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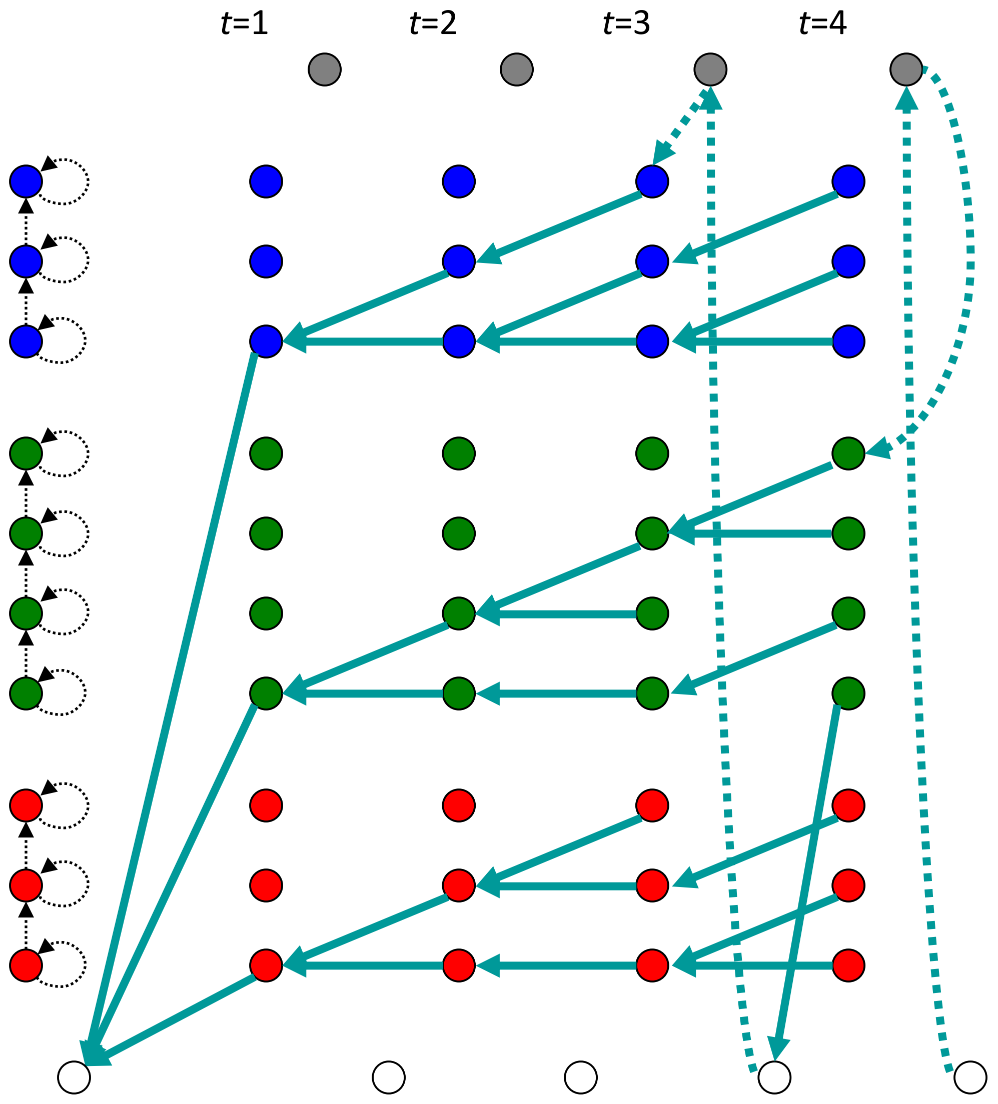

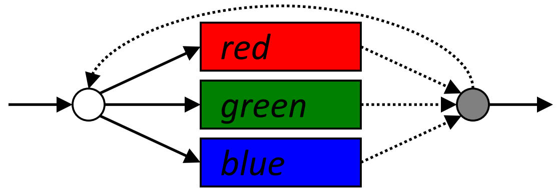

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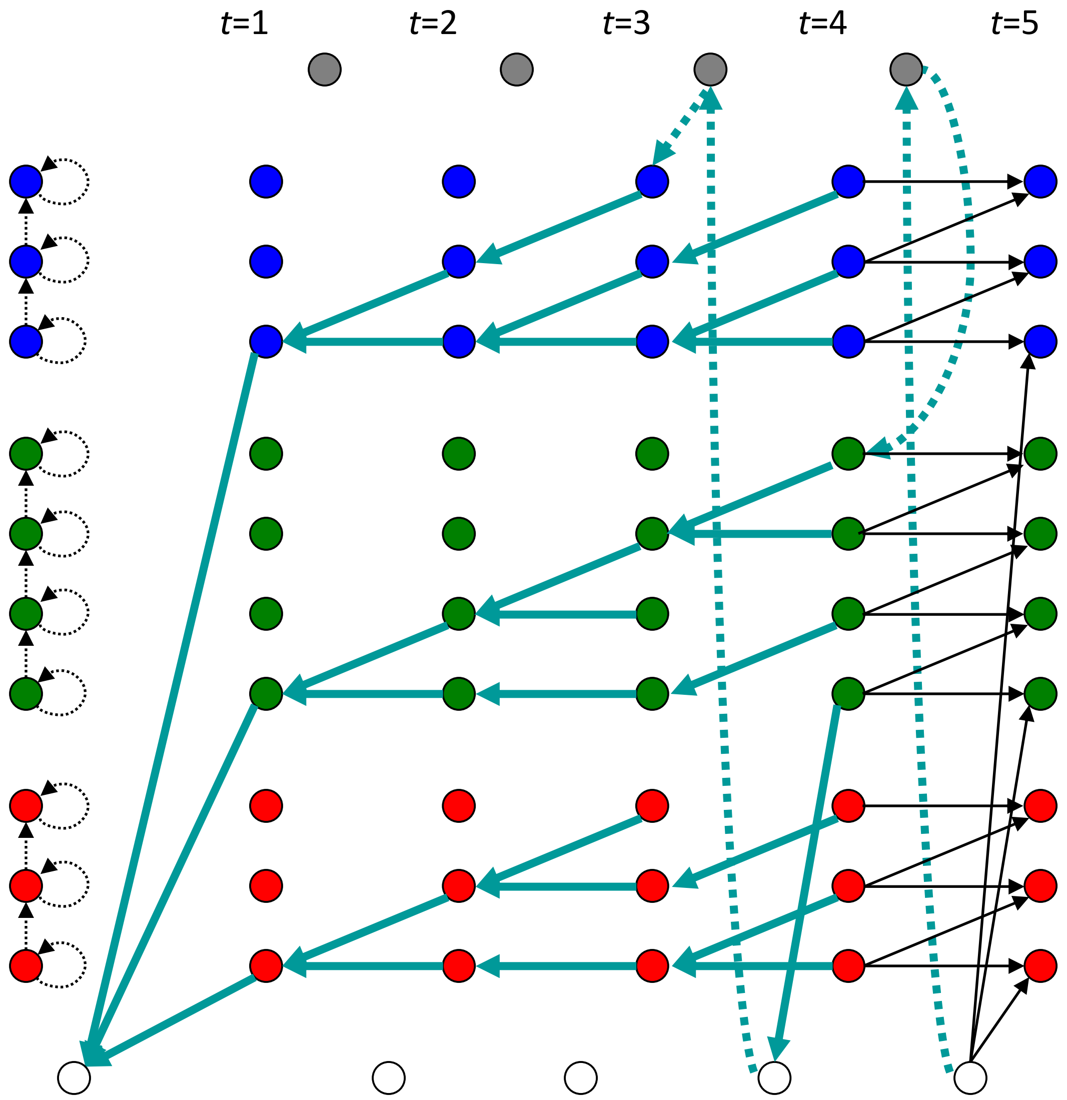

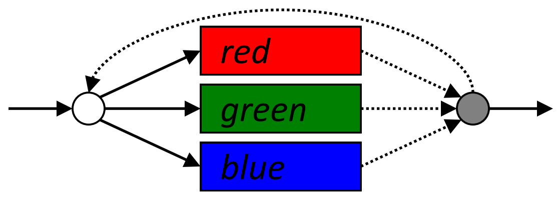

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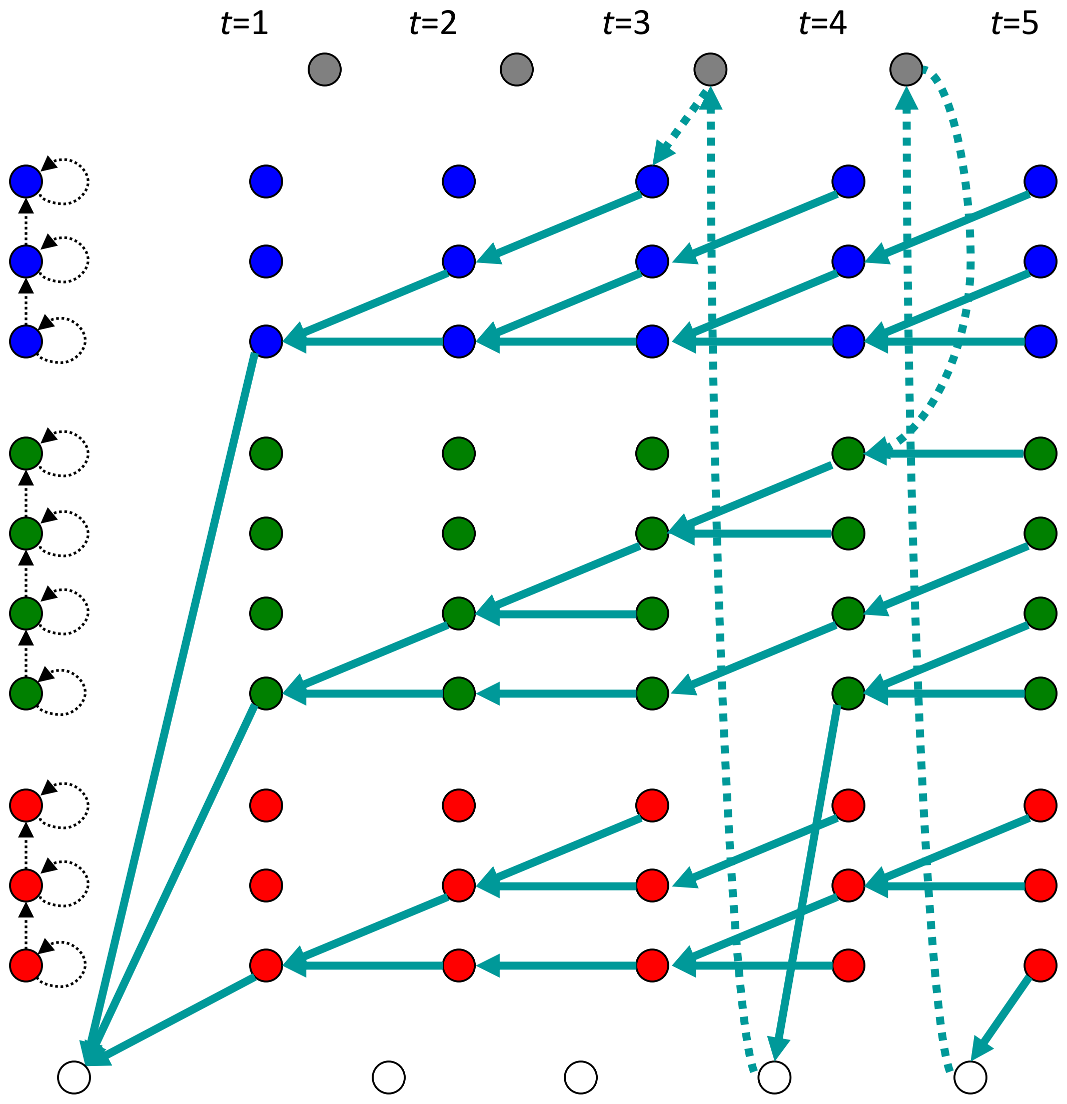

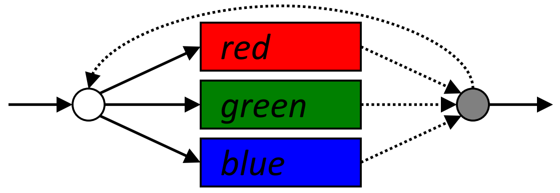

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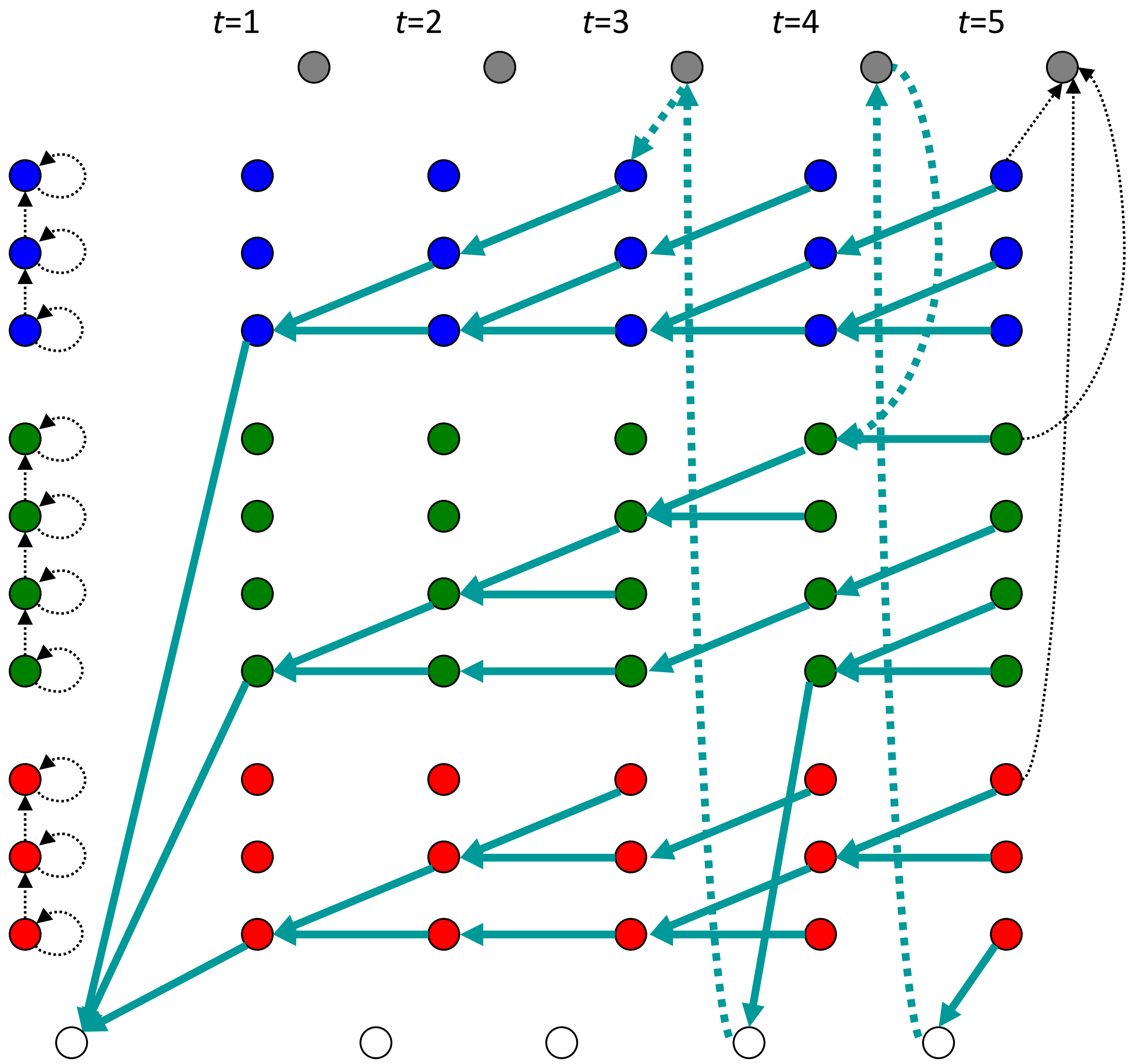

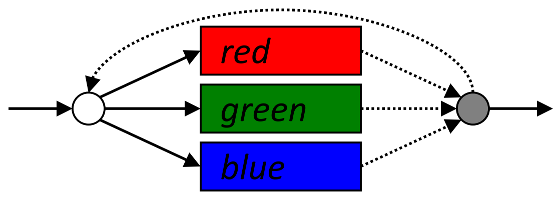

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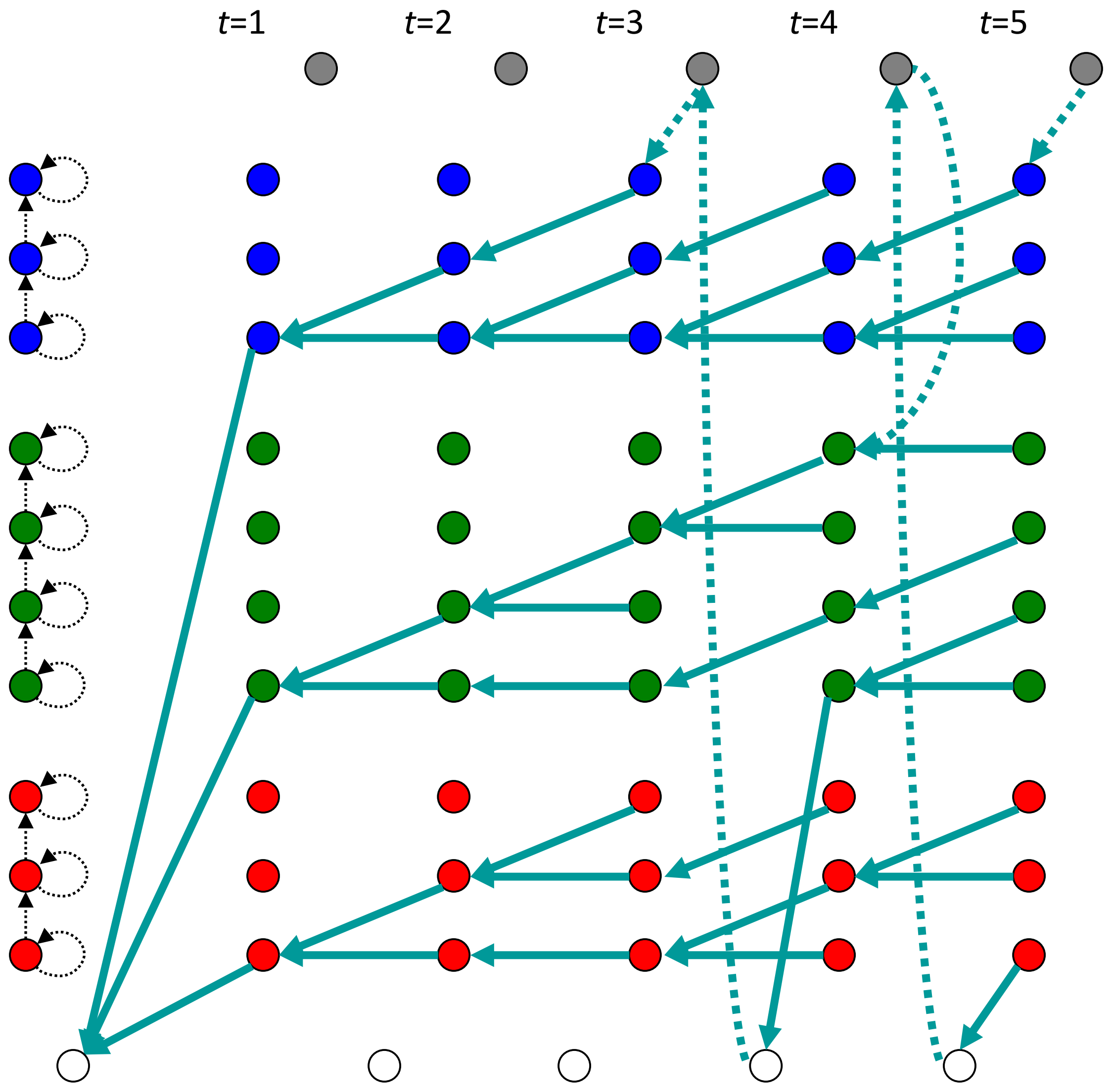

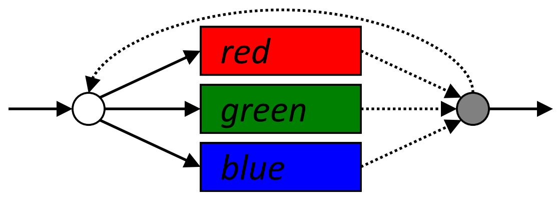

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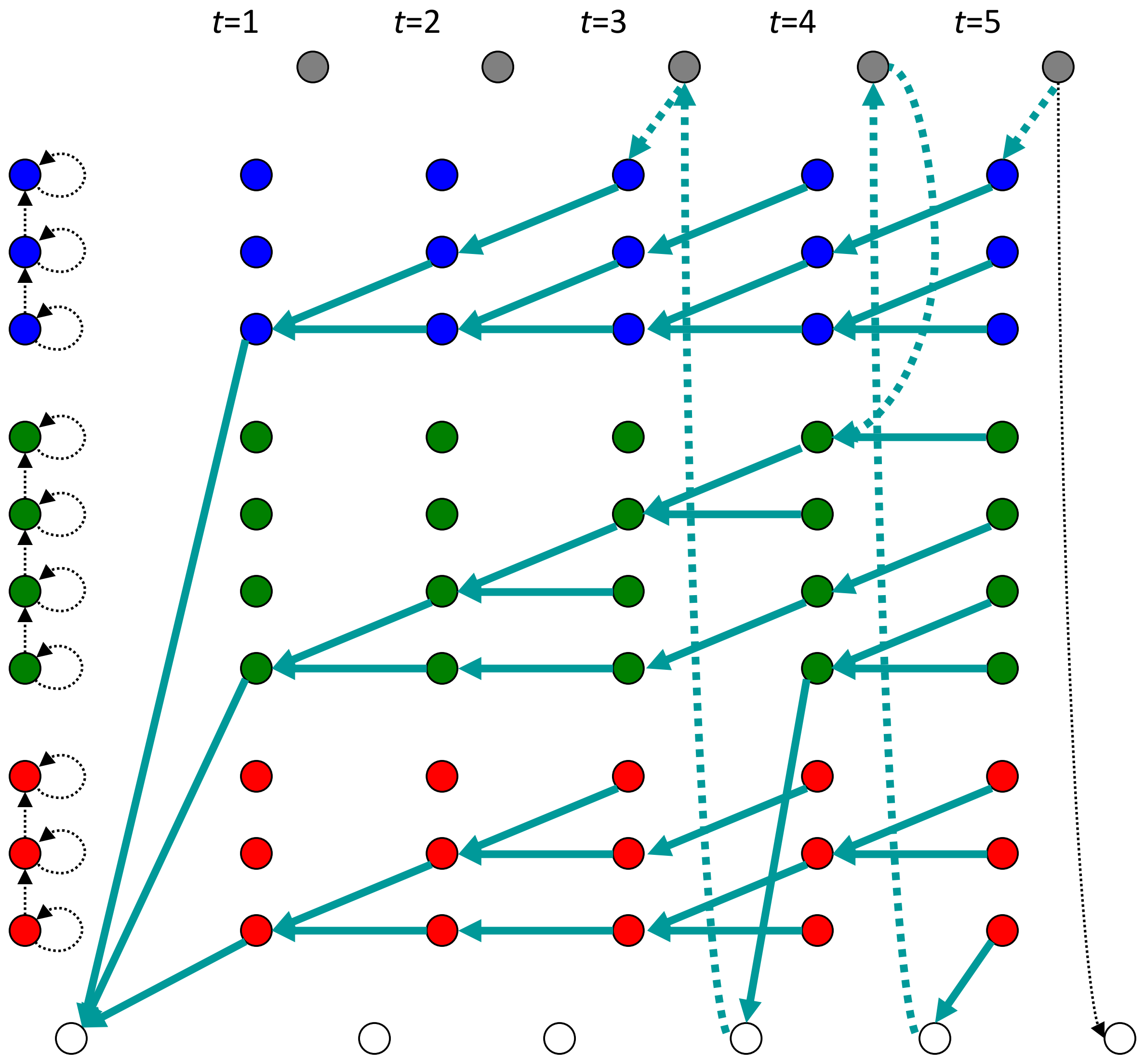

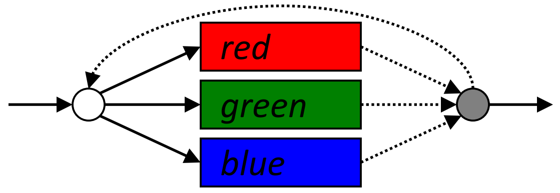

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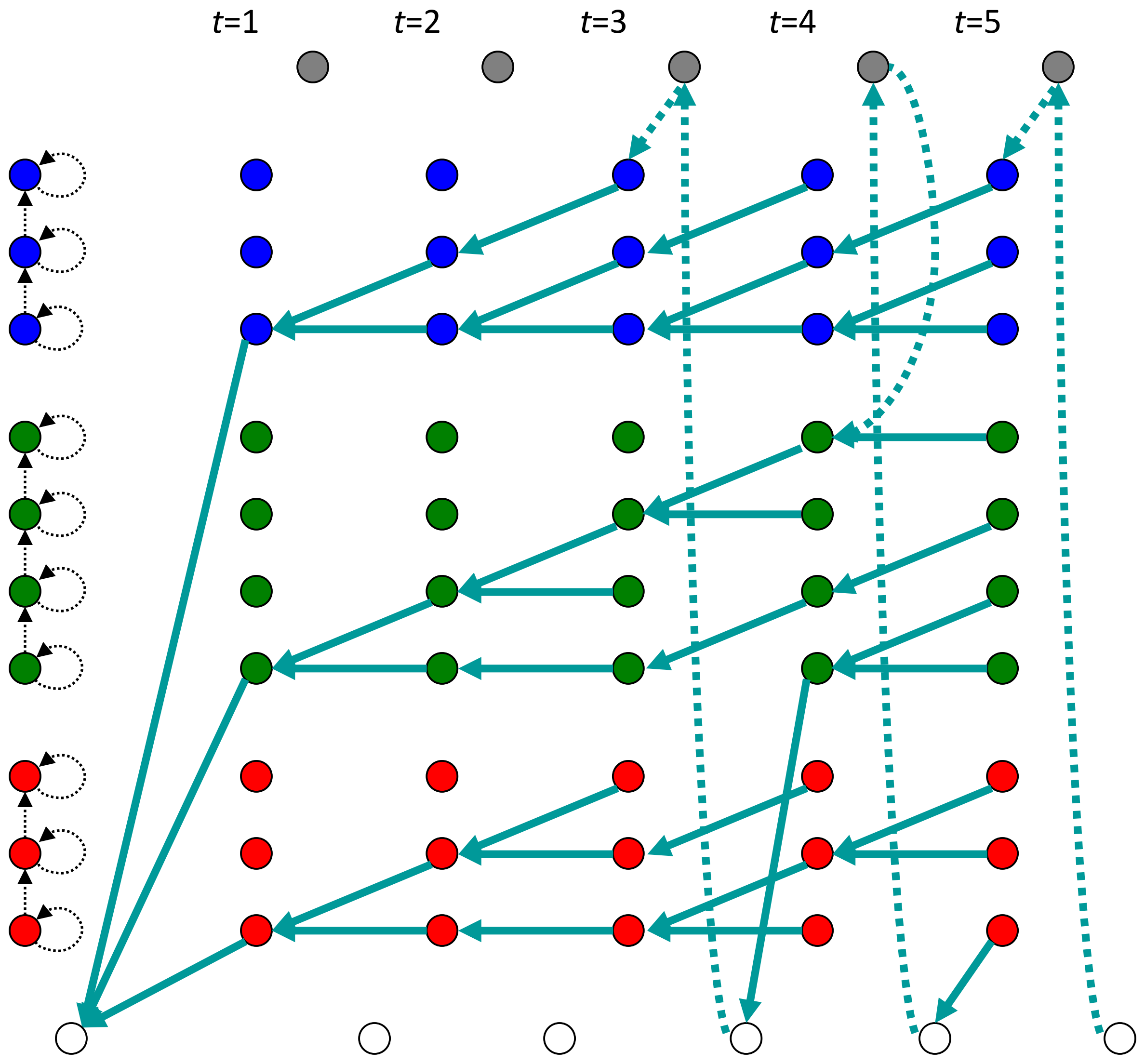

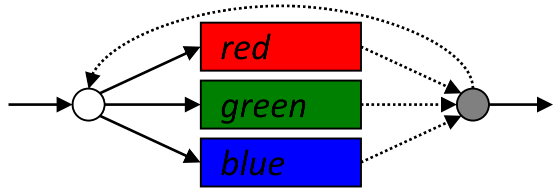

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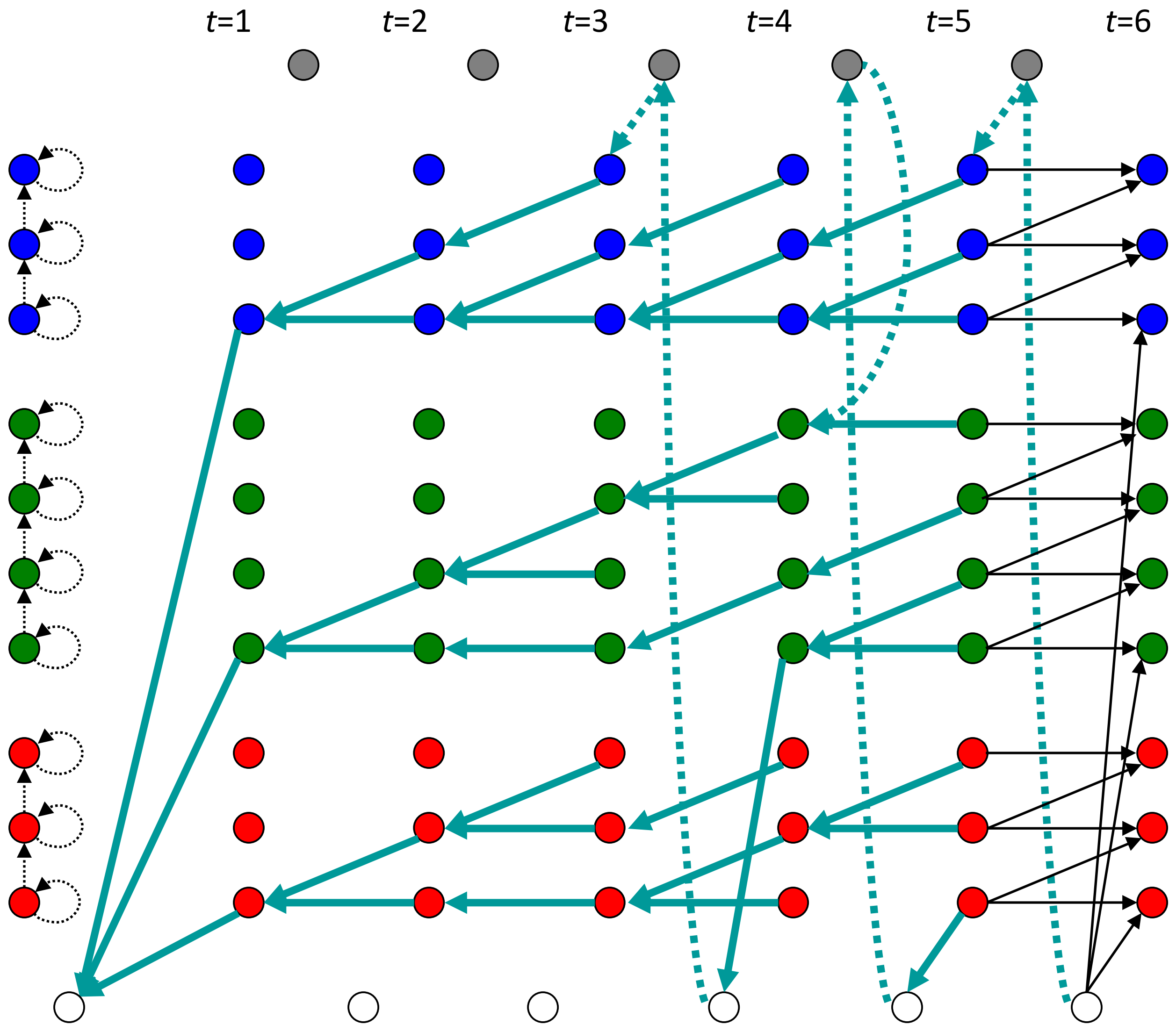

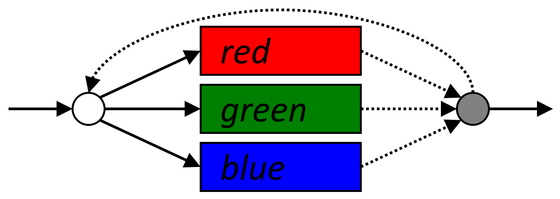

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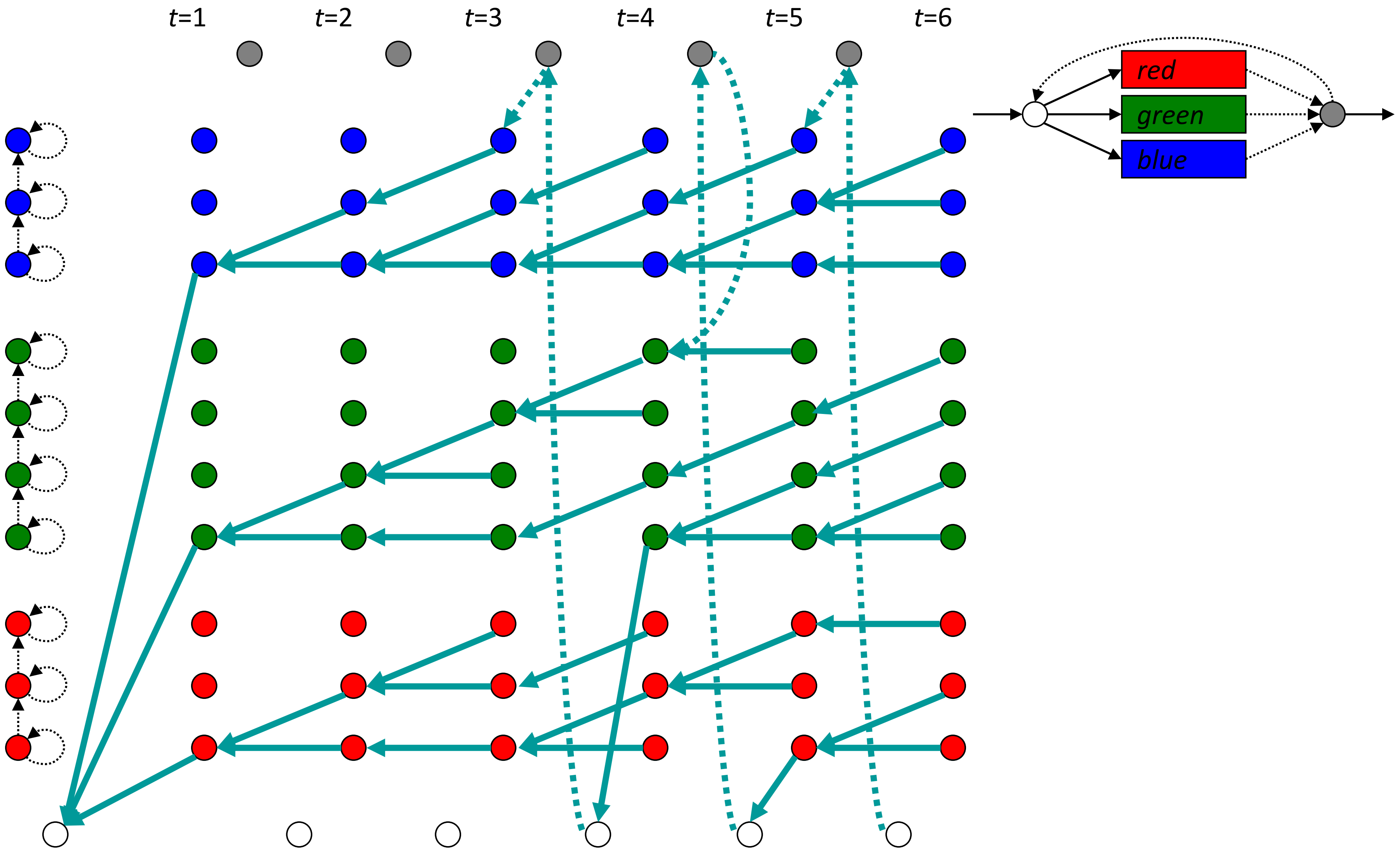

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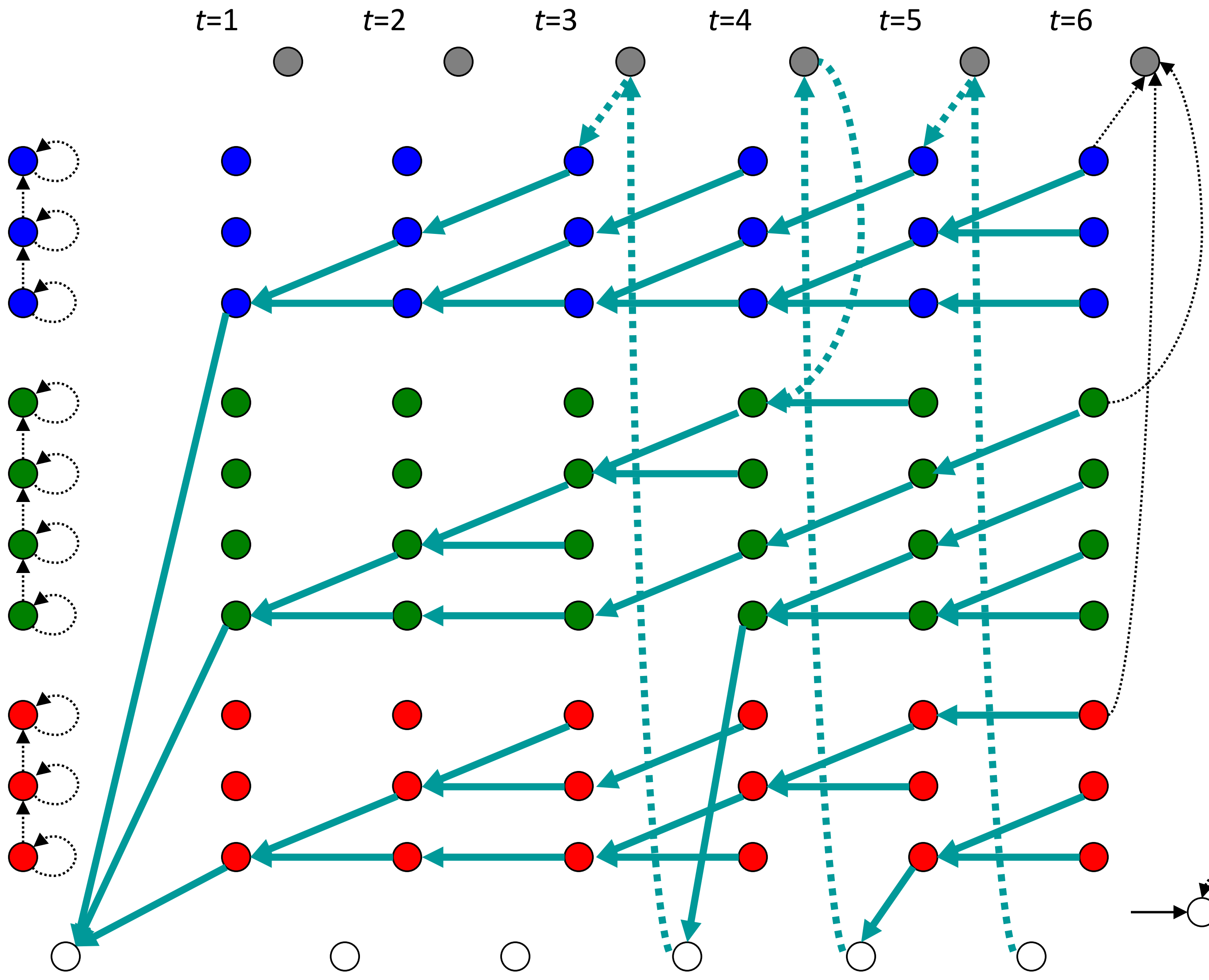

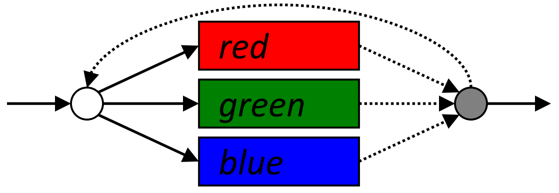

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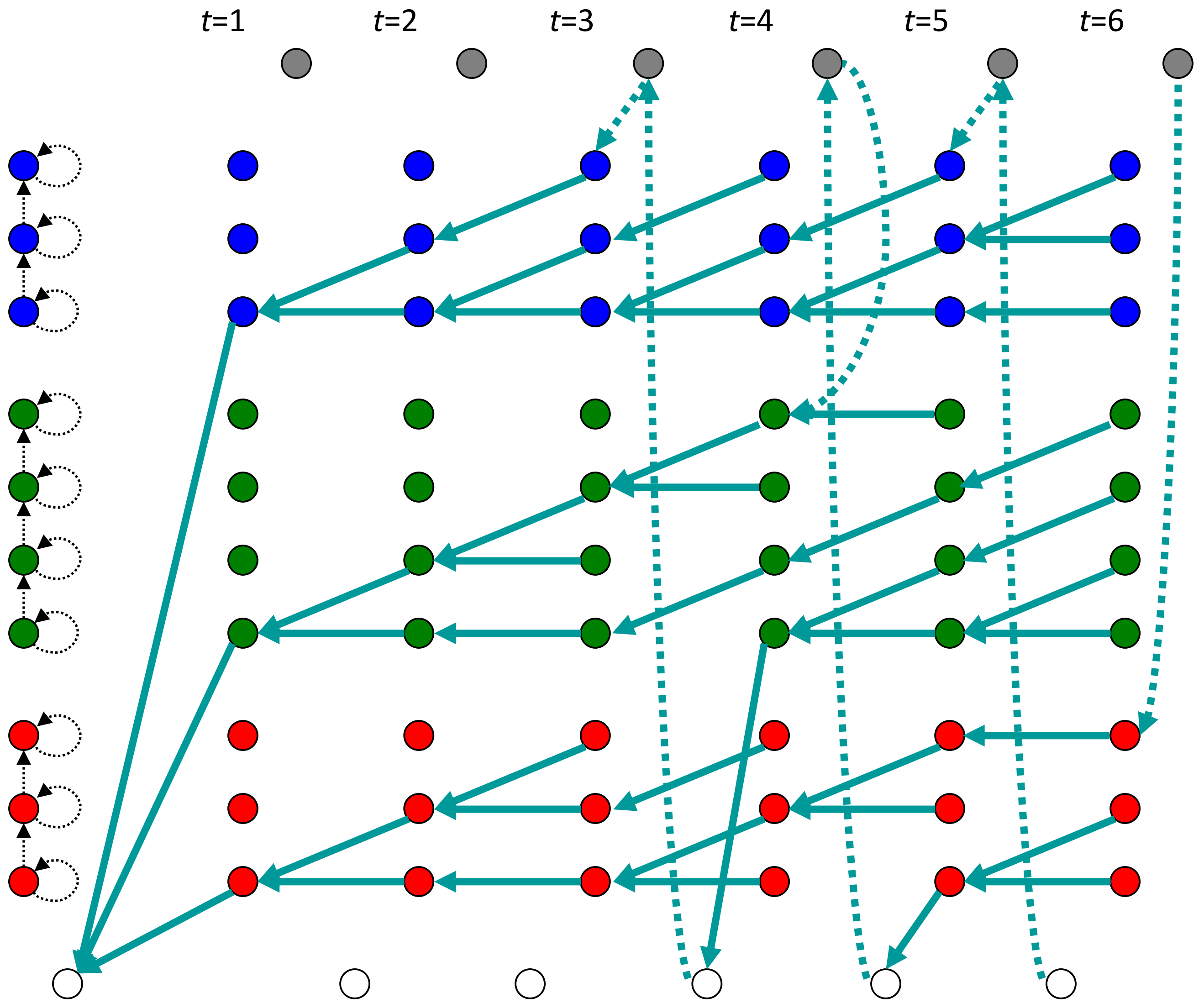

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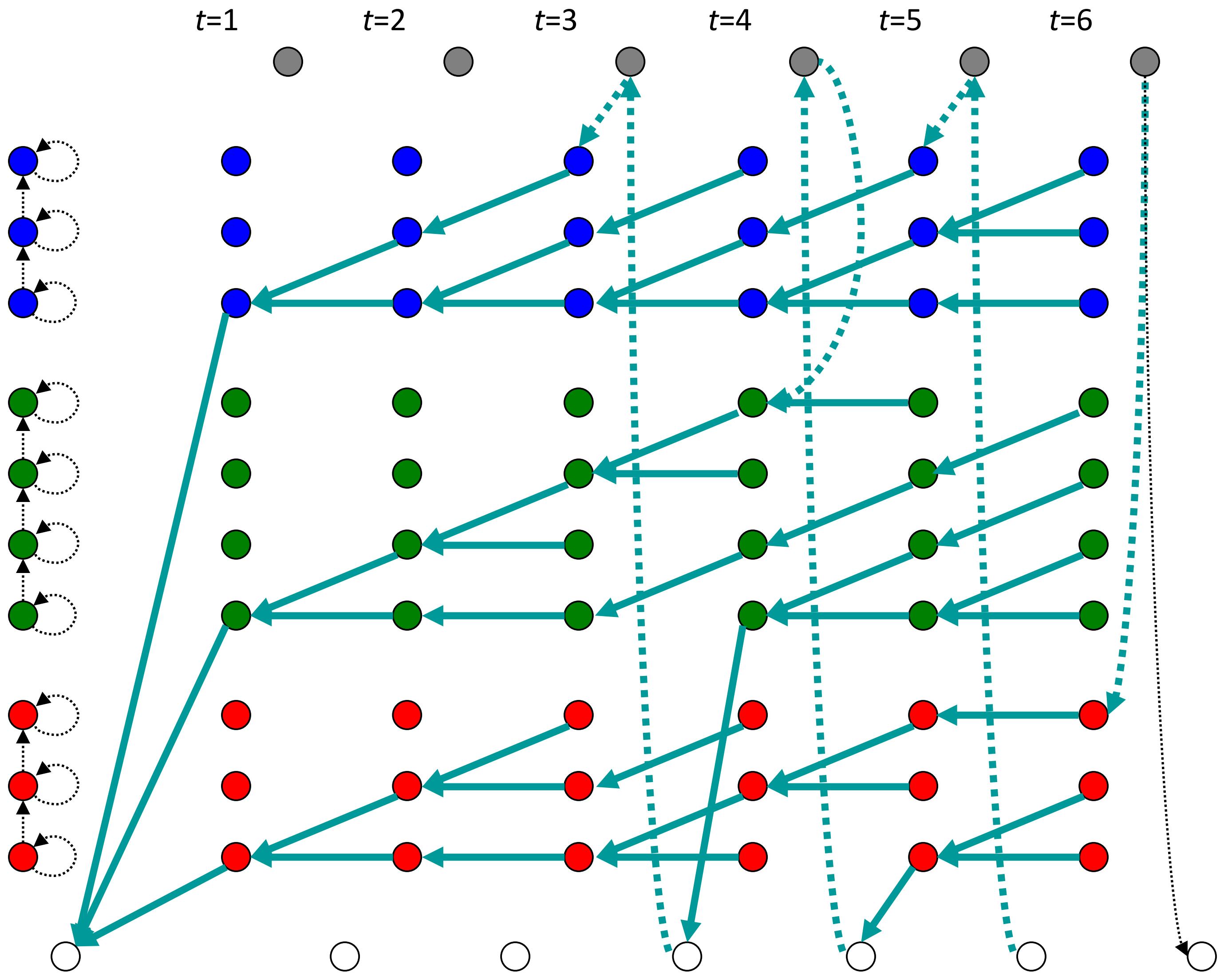

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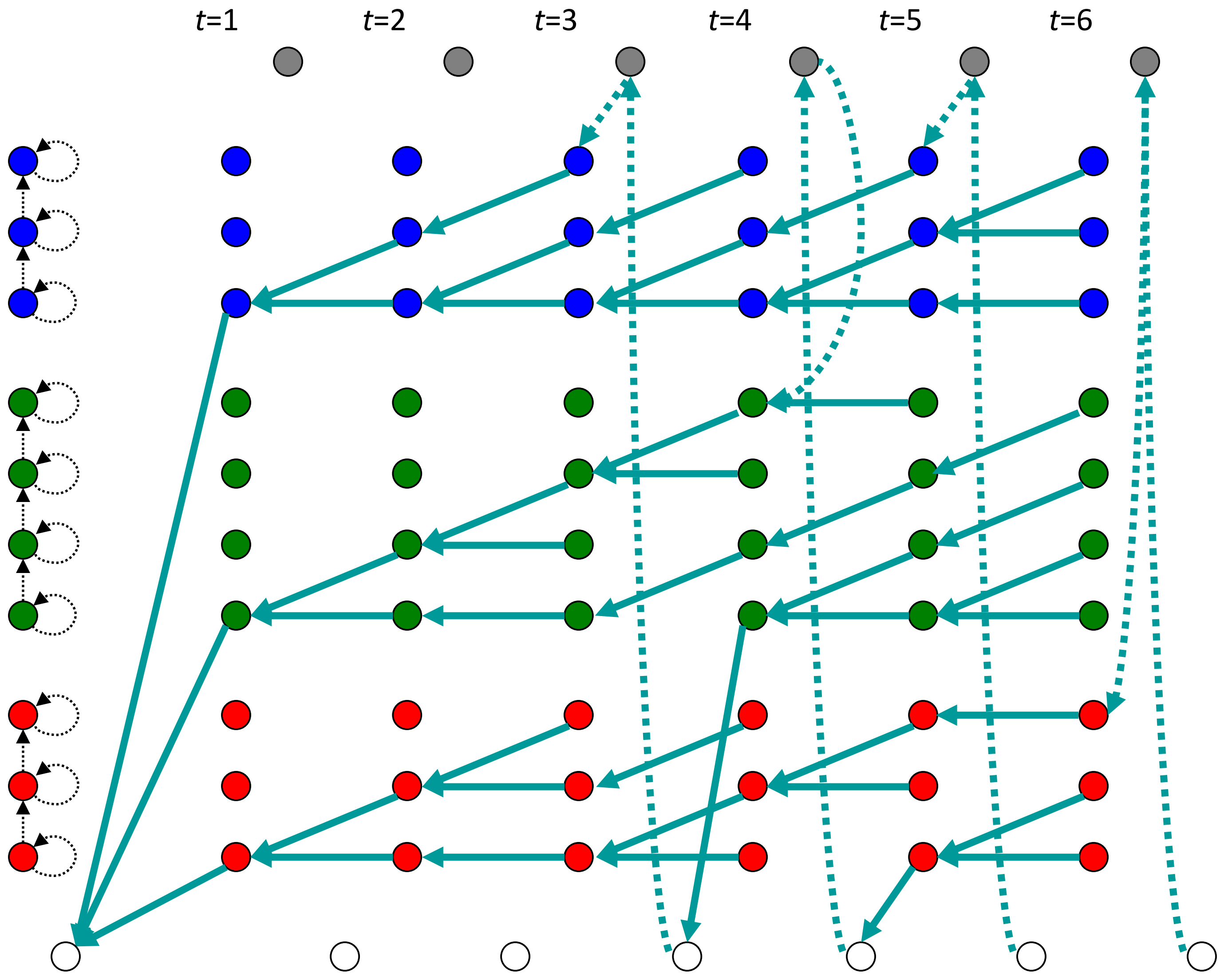

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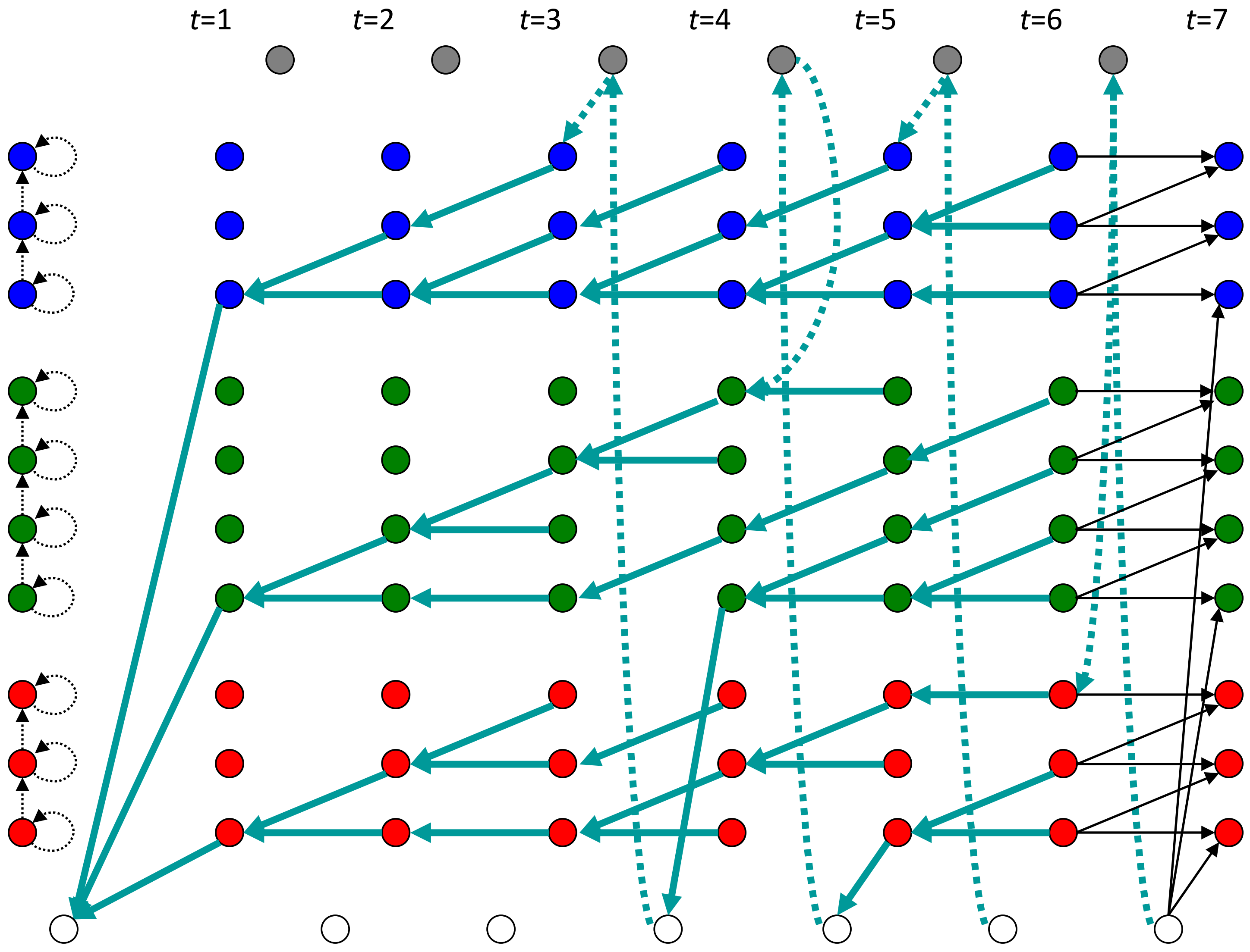

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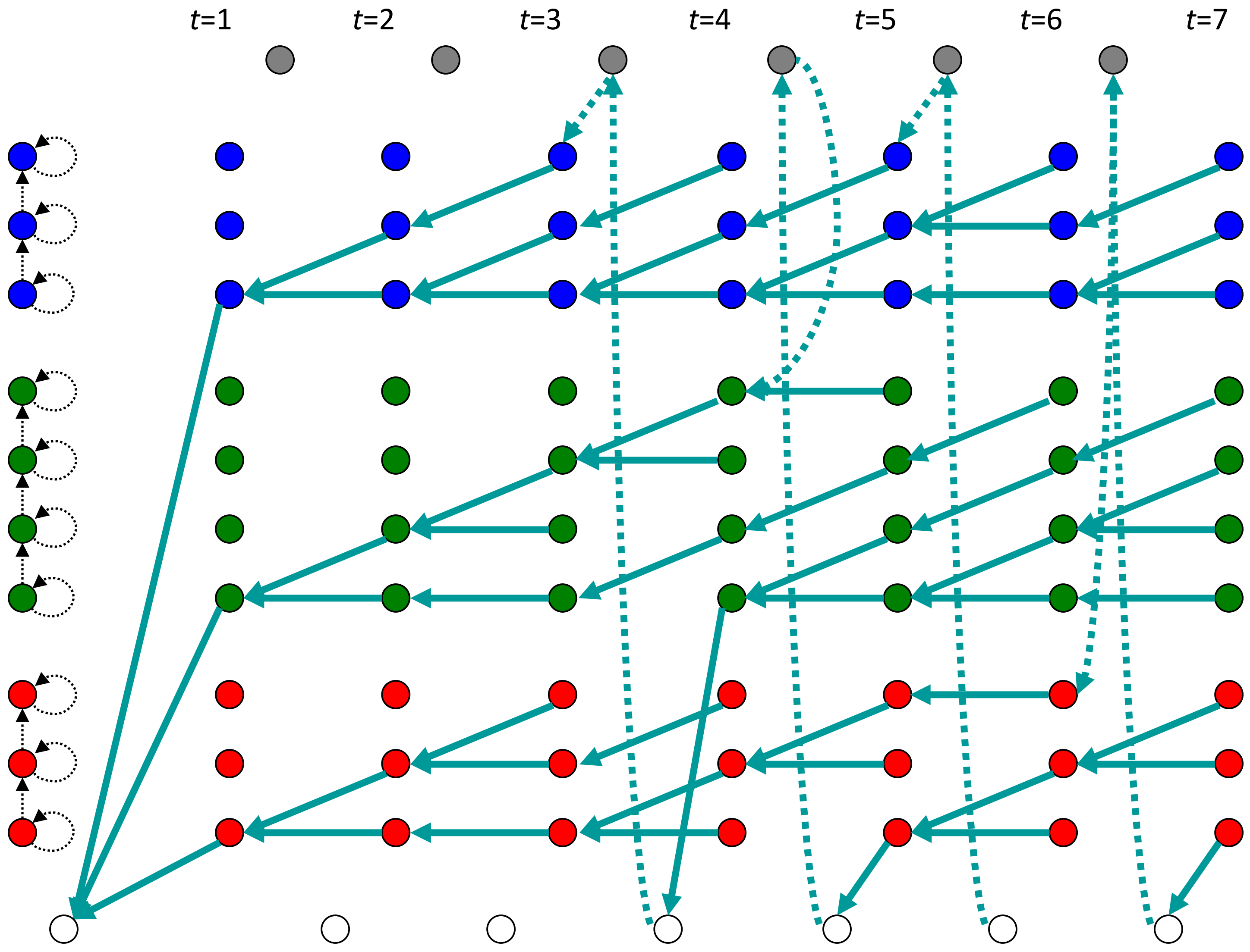

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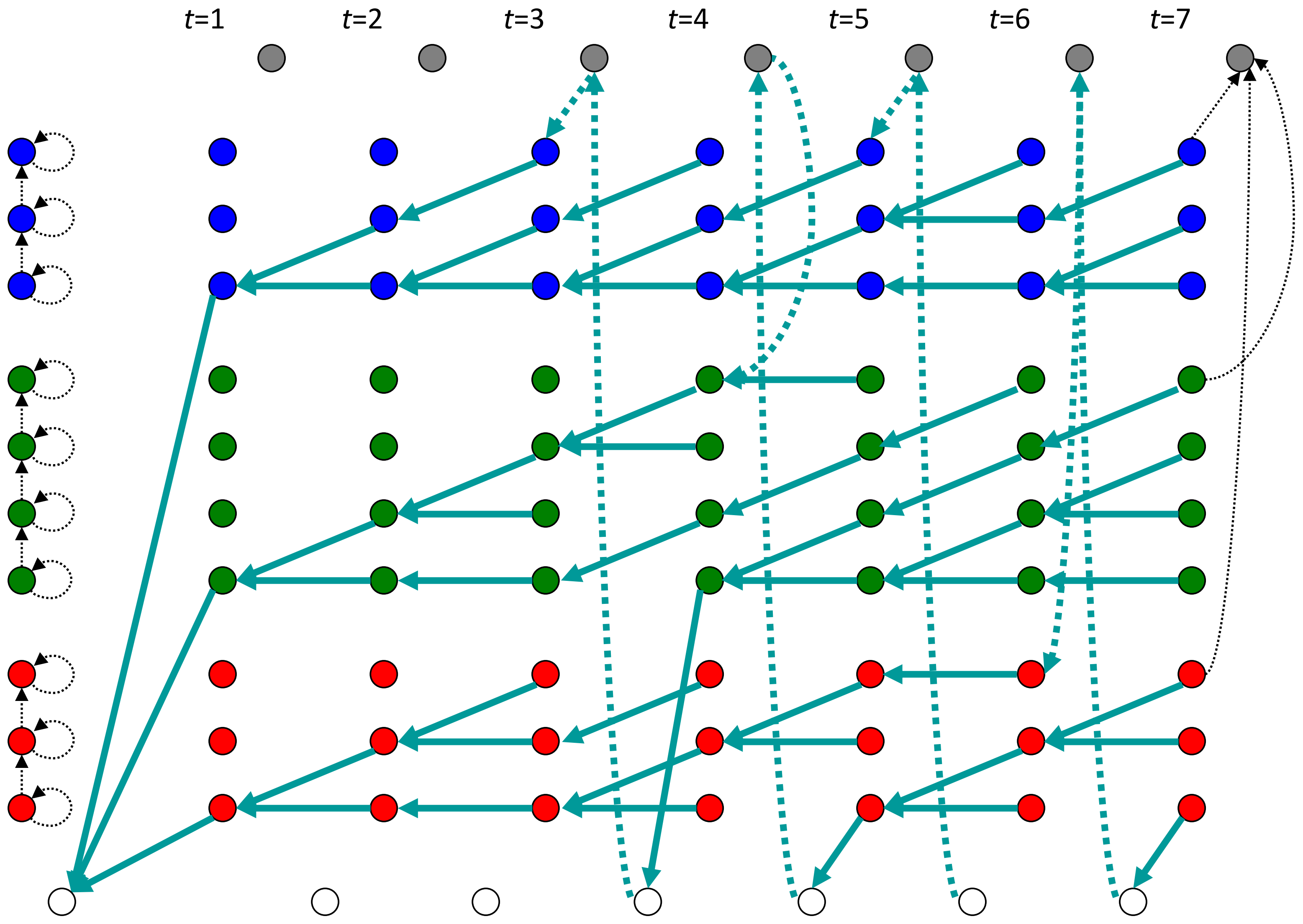

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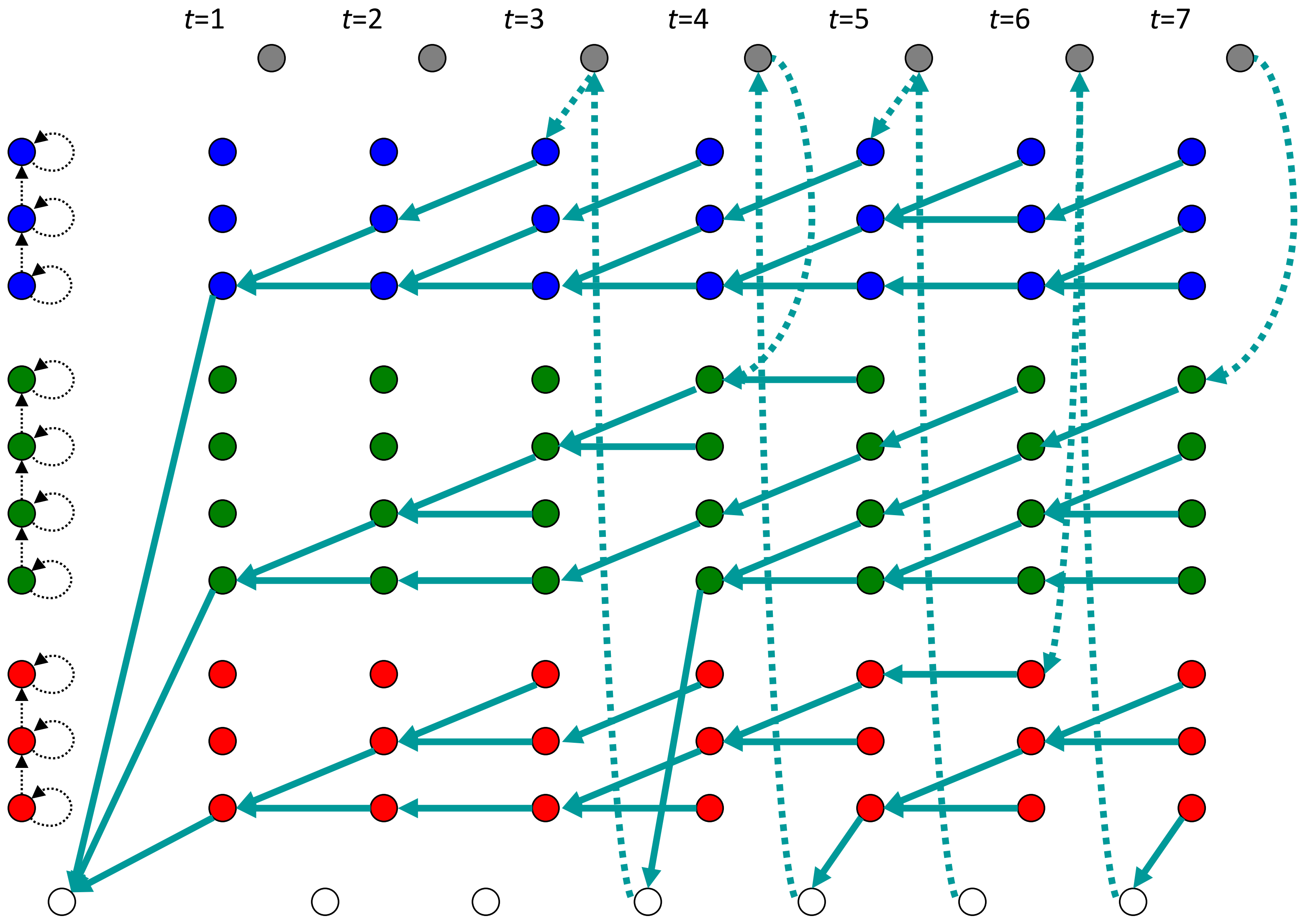

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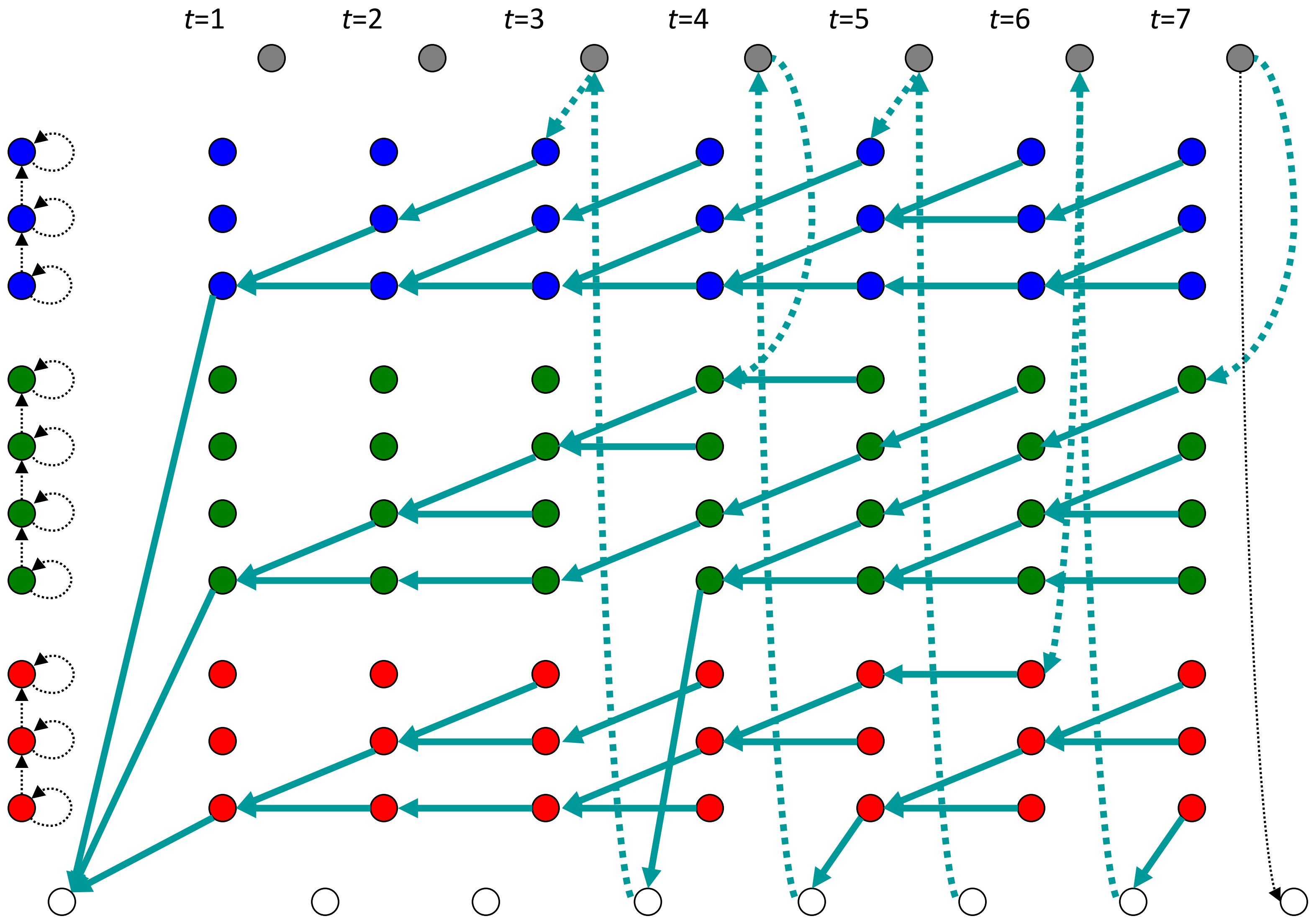

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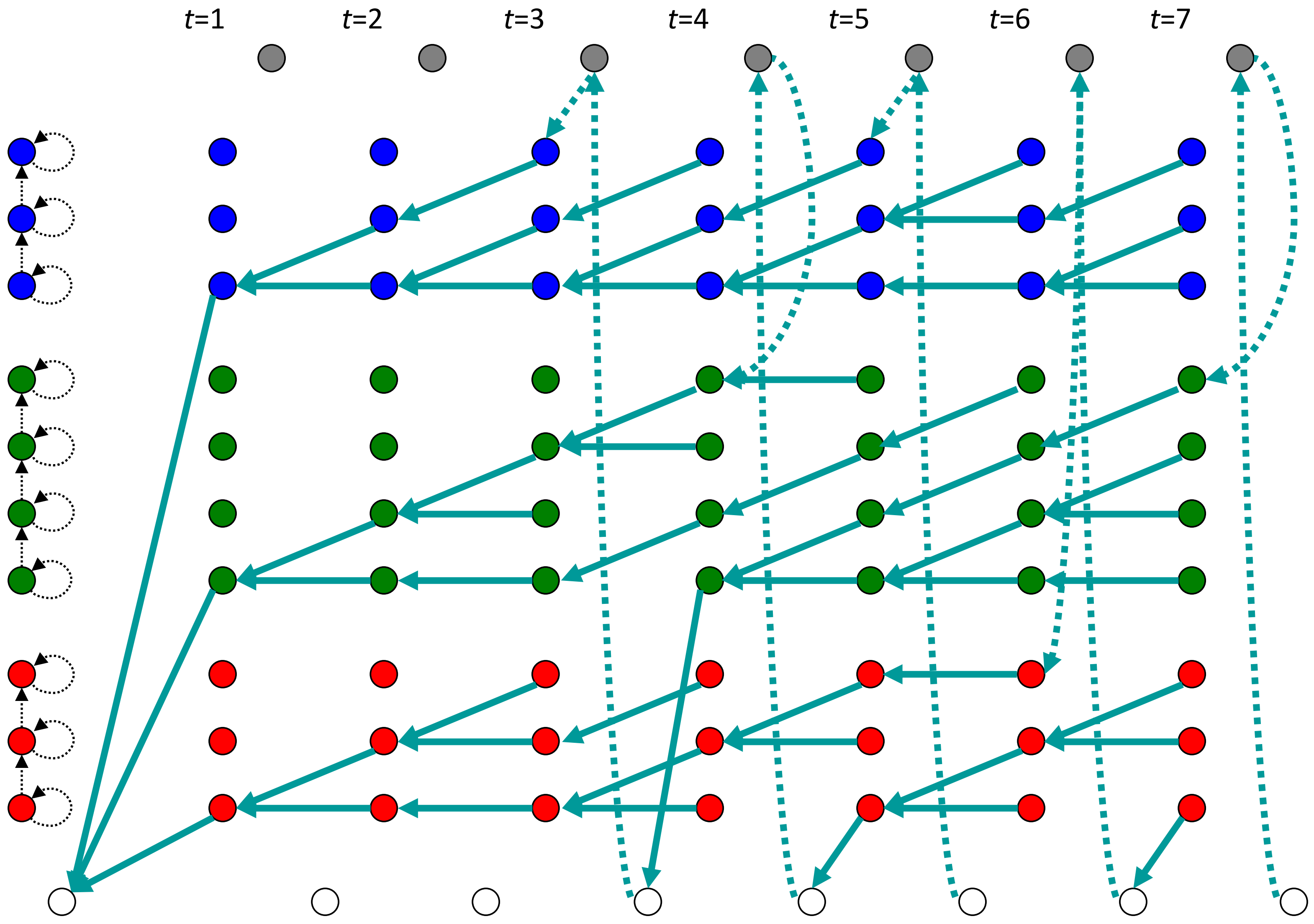

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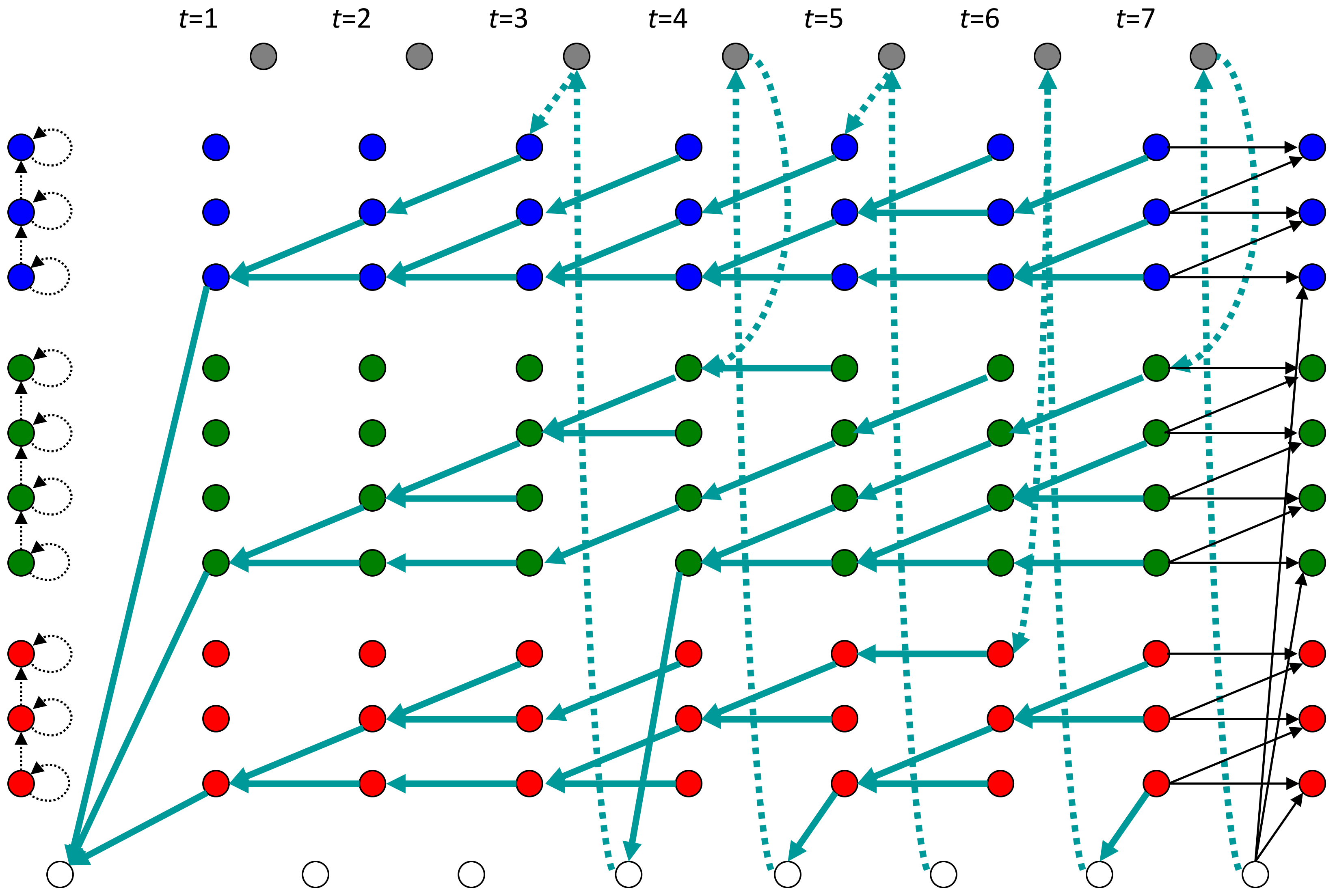

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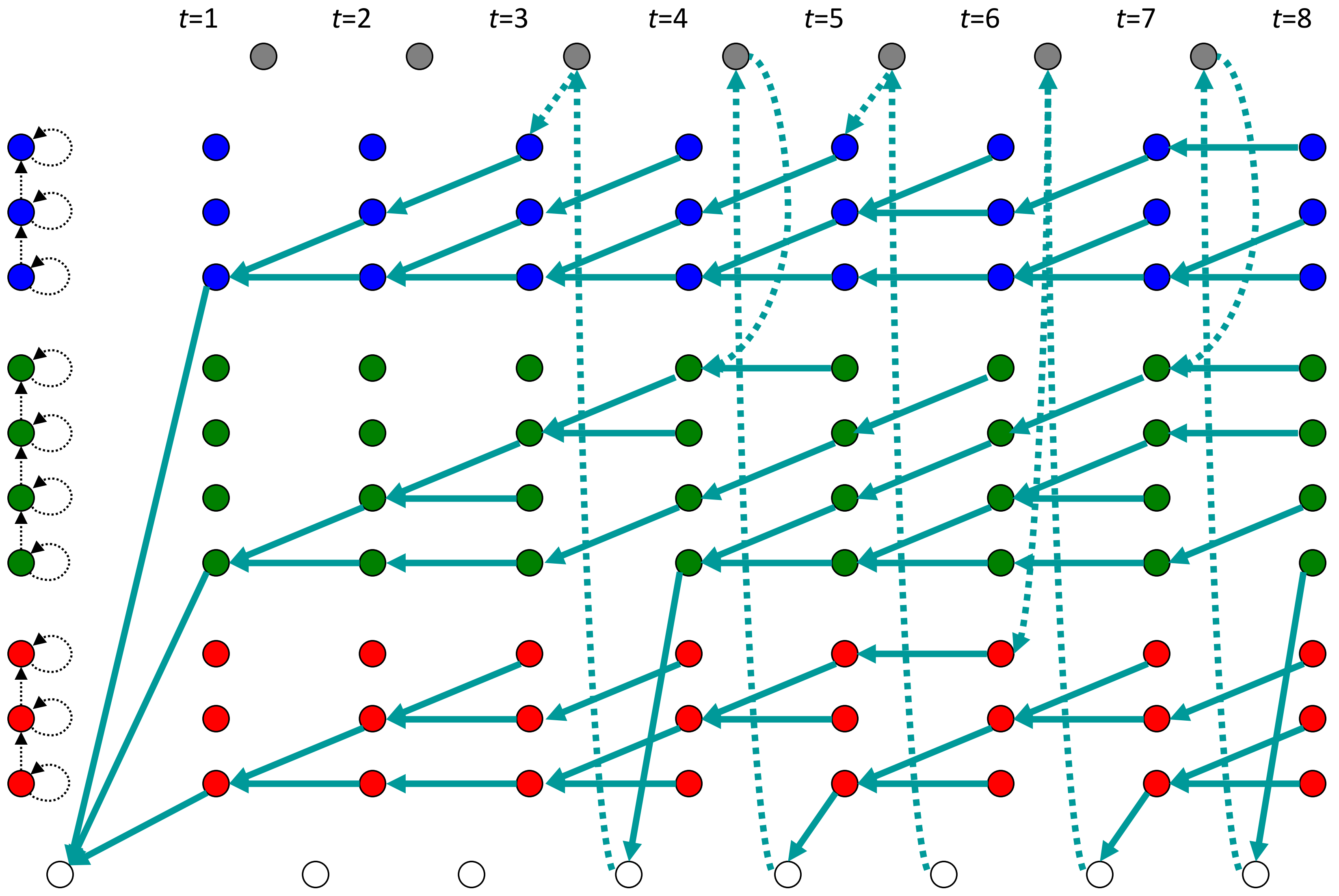


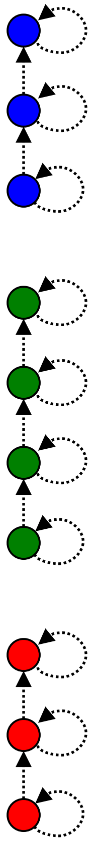
Using Backpointers

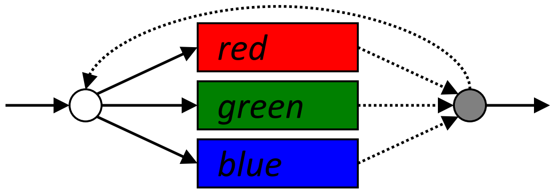
- Retaining the complete set of back pointers can be very expensive
  - In terms of memory

- Solution: Only retain back pointers to the entry into words
  - Which can be stored separately as a "backpointer table"

Trellis with Complete Set of Backpointers

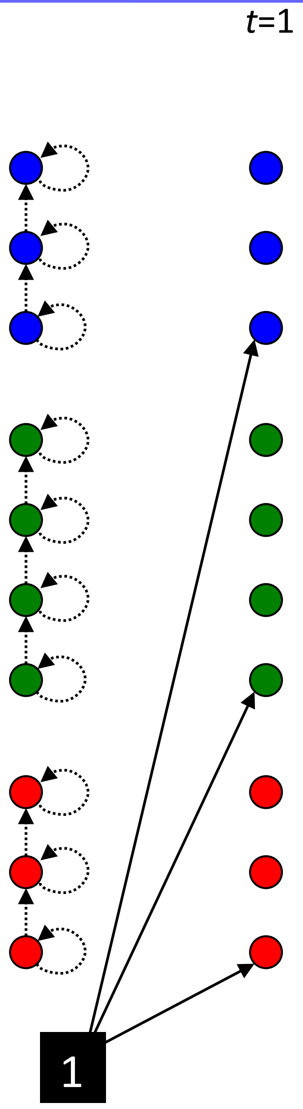
1, t=0, scr1,p=0,…





1 ●

Trellis with Complete Set of Backpointers



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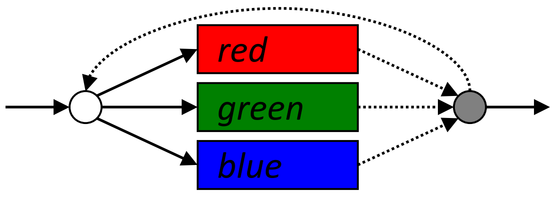

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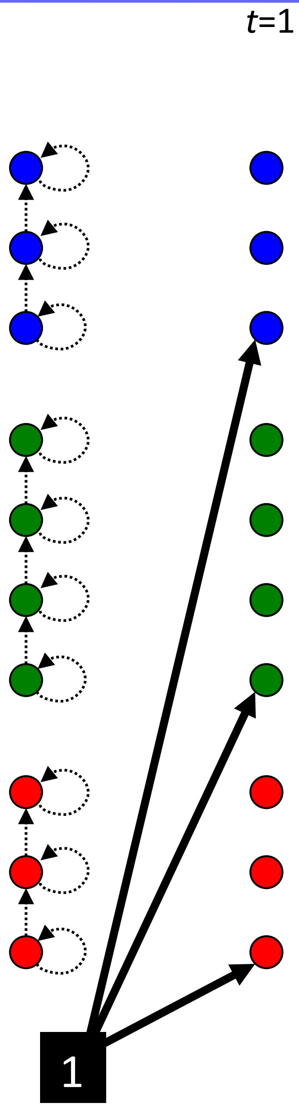

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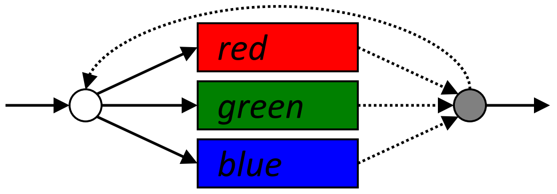

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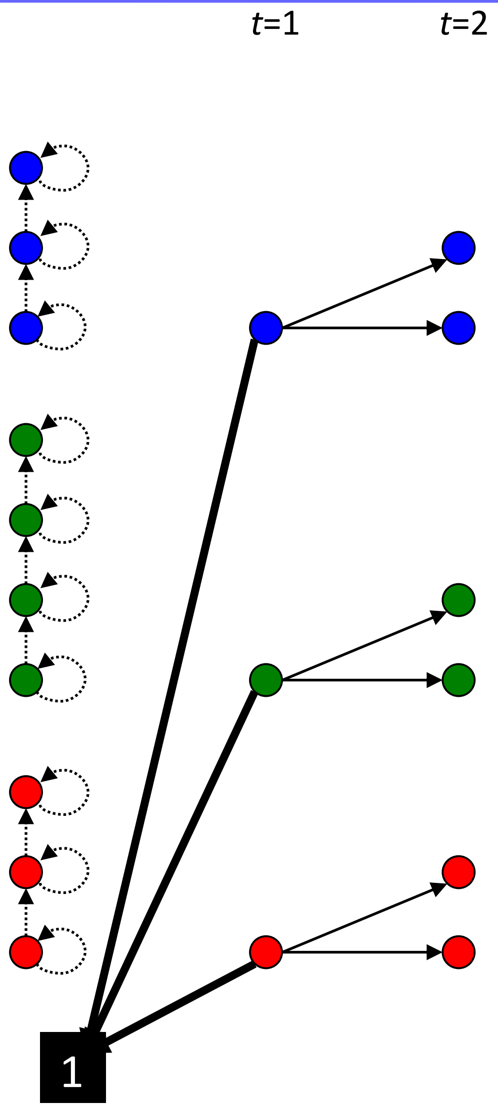

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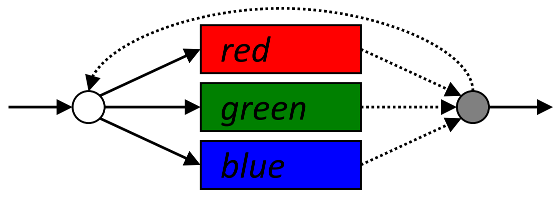

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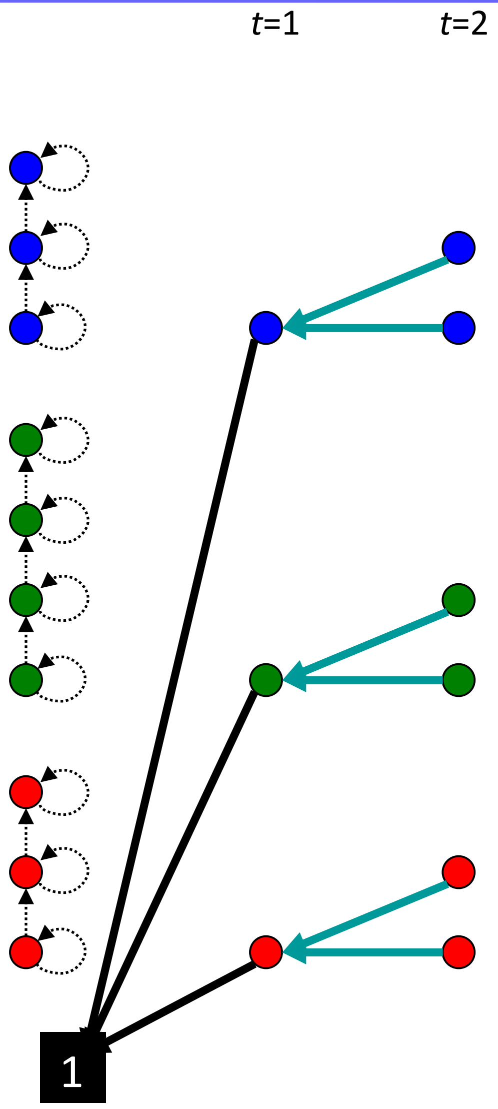

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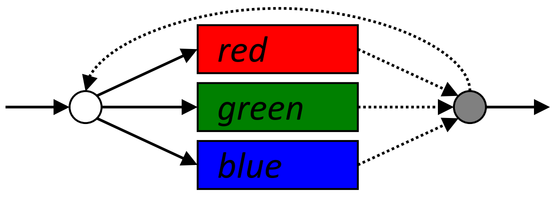

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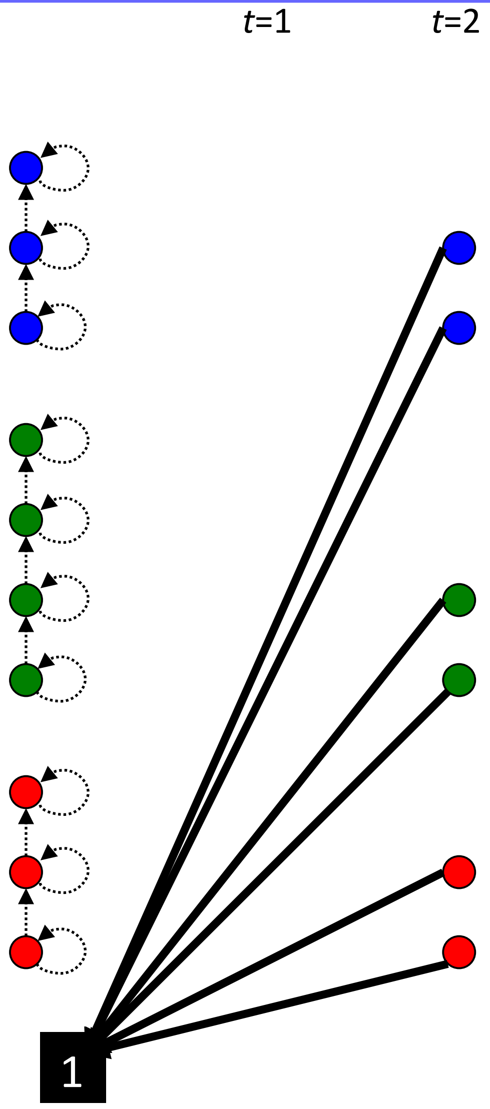

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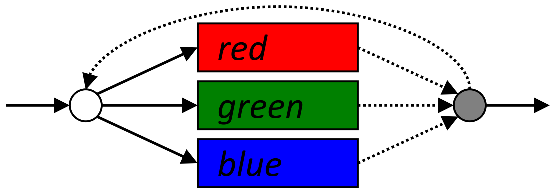

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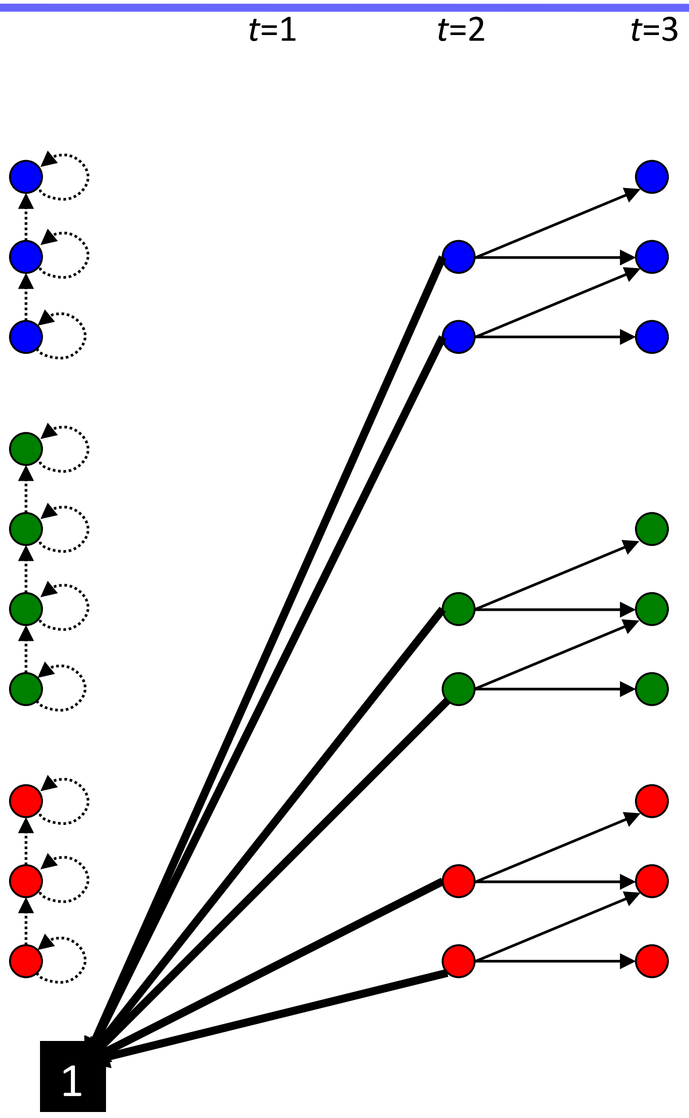

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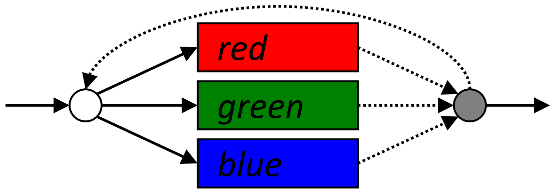

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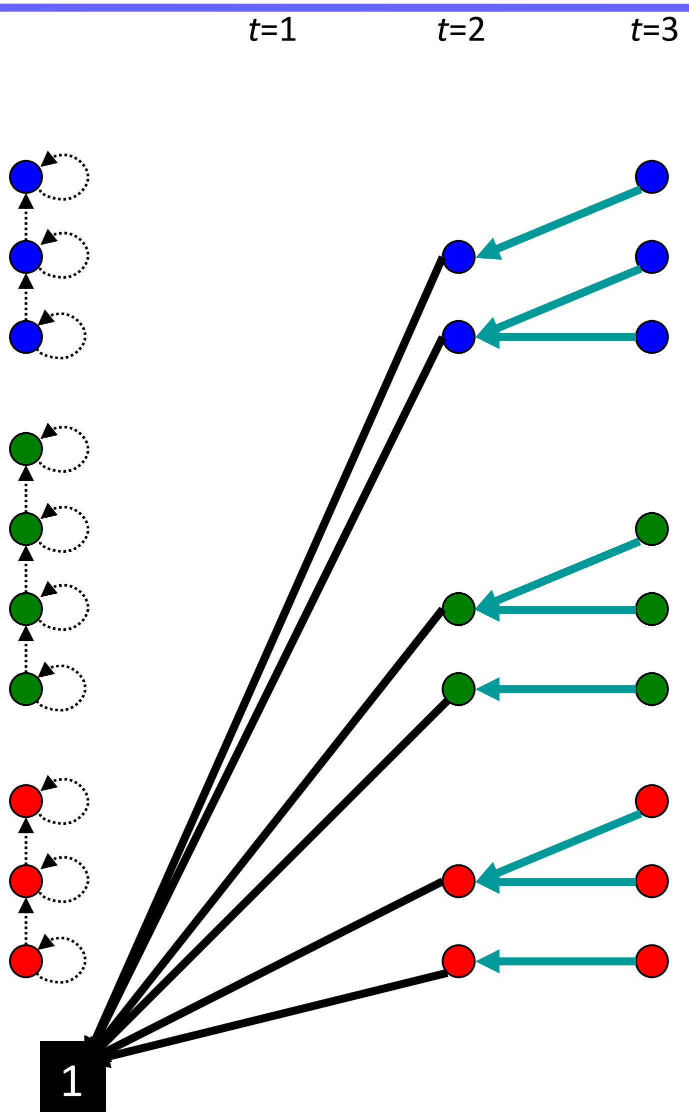

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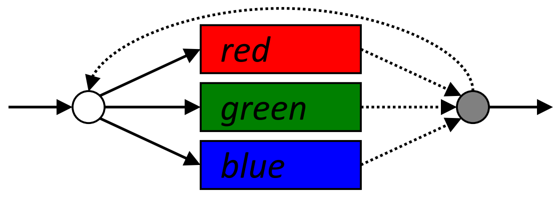

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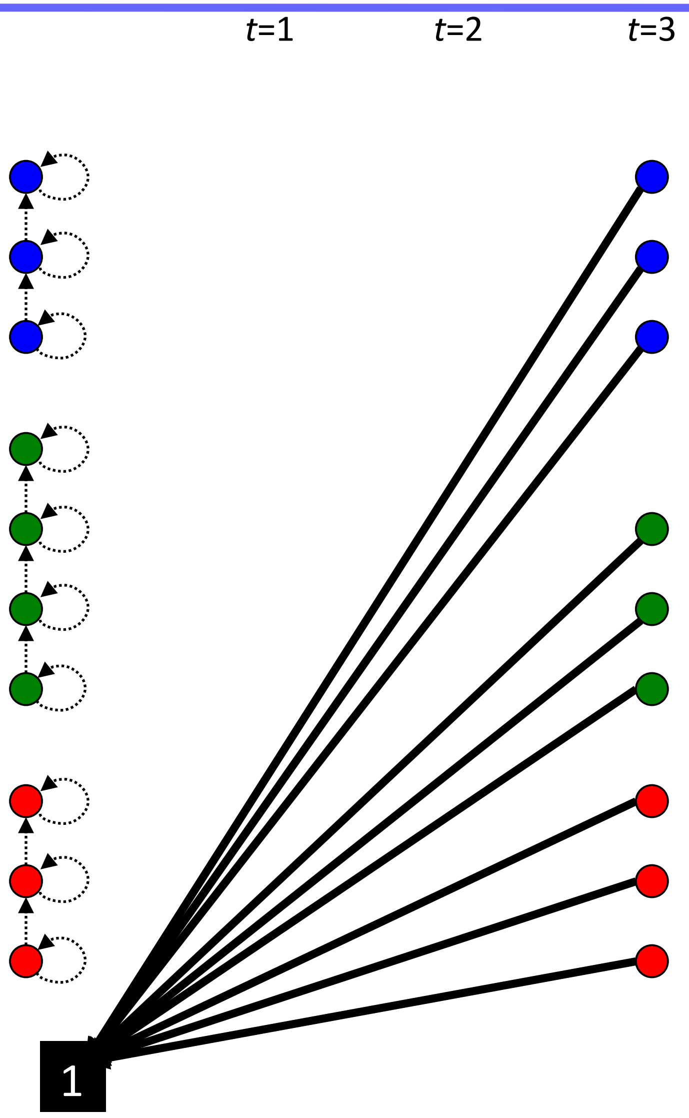

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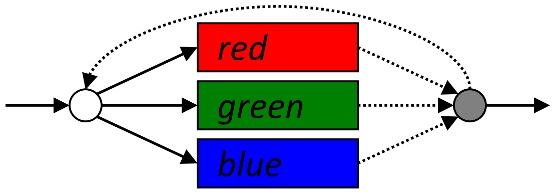

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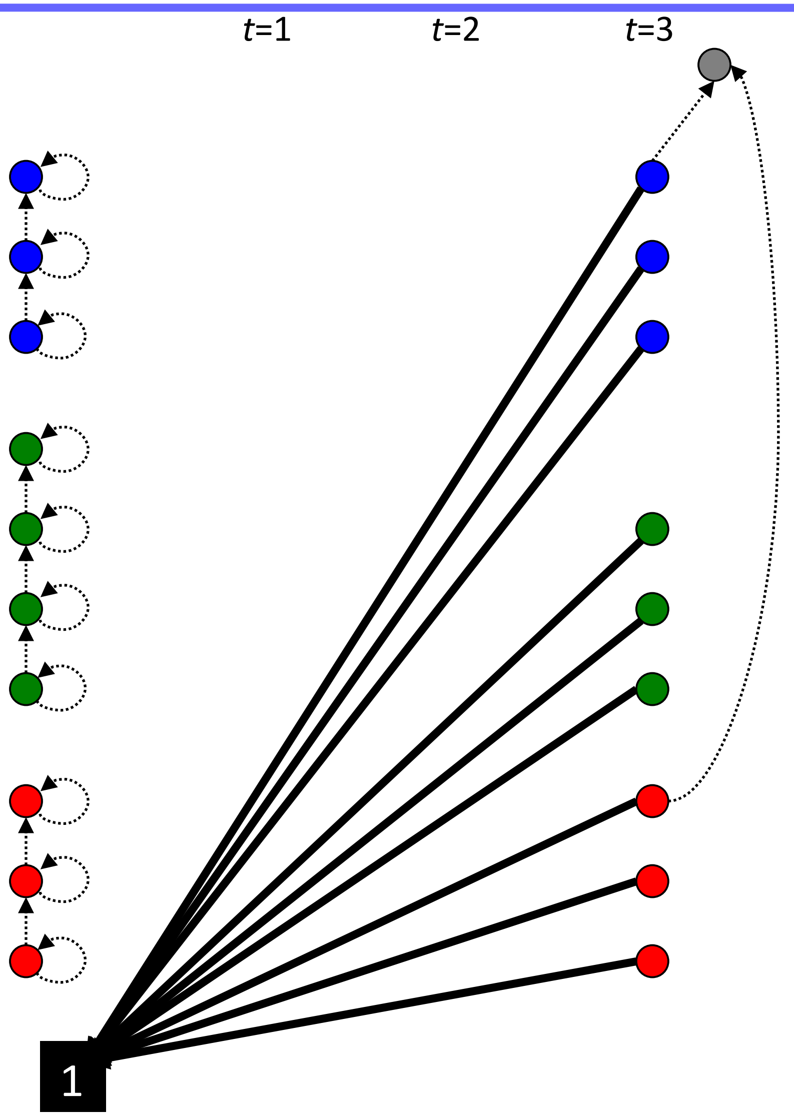

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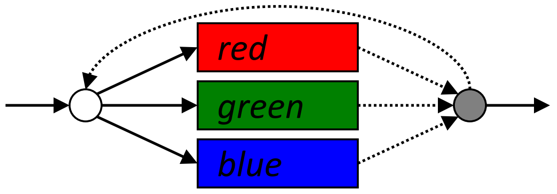

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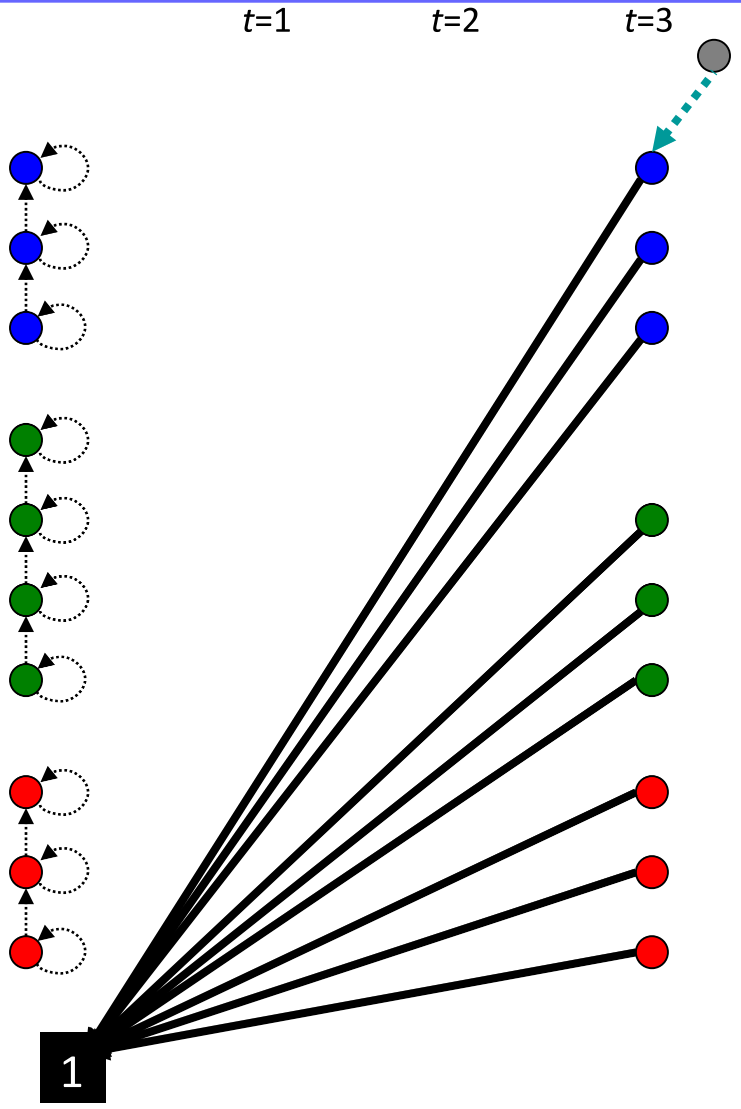

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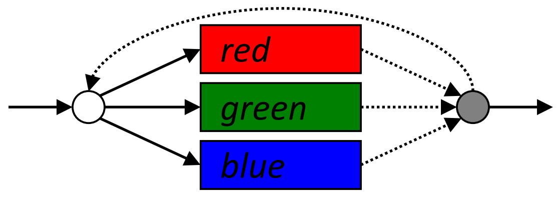

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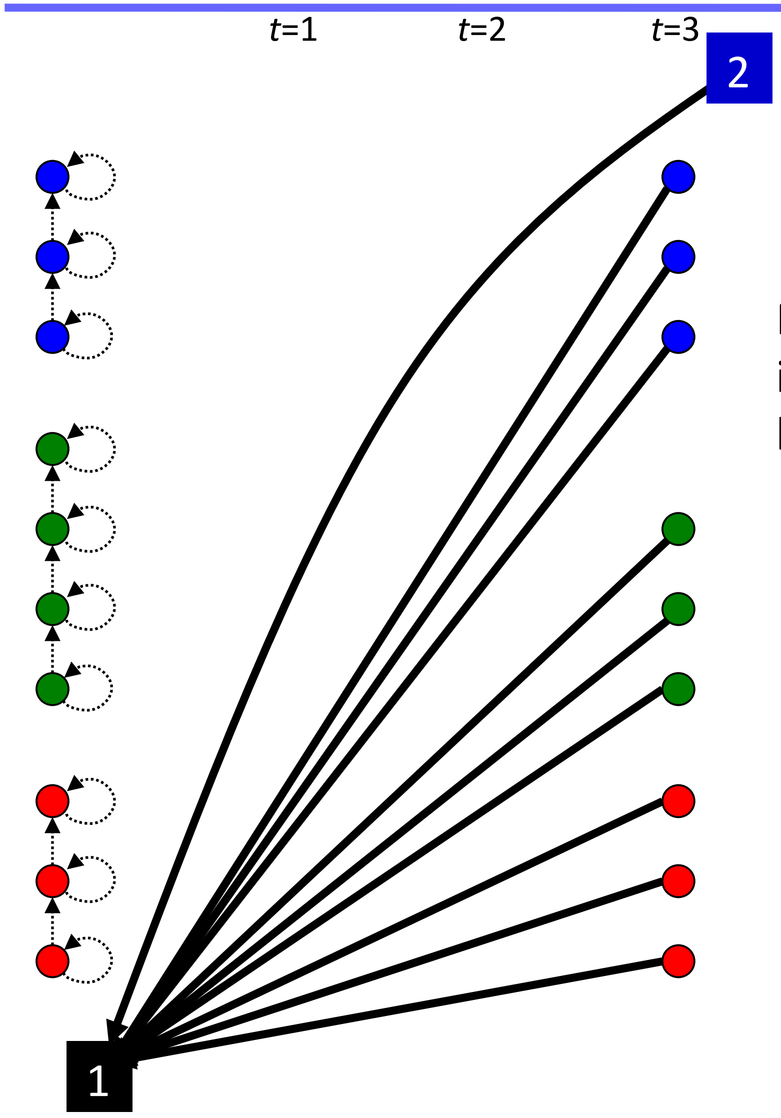
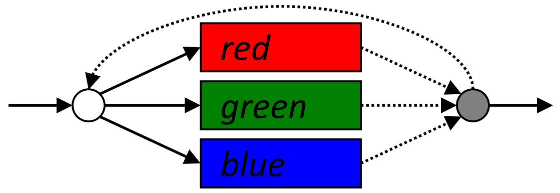


1, t=0, scr1,p=0,...
2, t=3, scr2,p=1,...

Retain backpointers (and add the to the table) if deleting them will result in loss of word history



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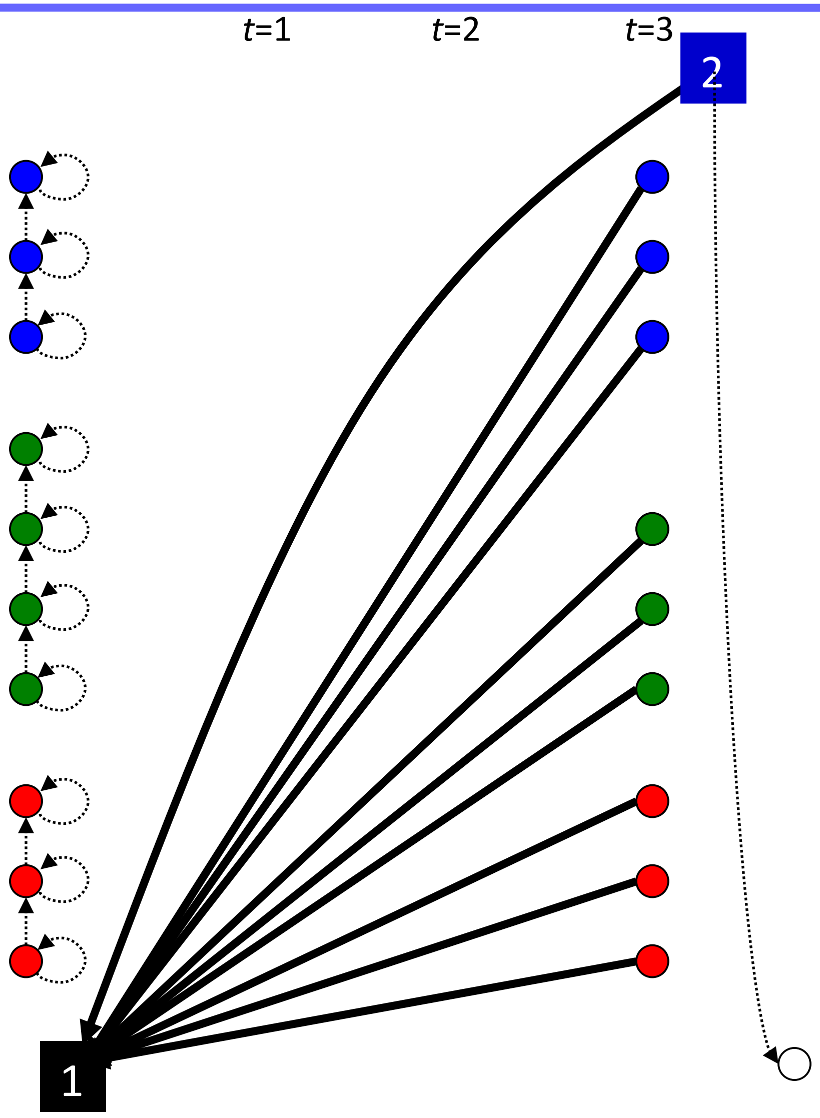

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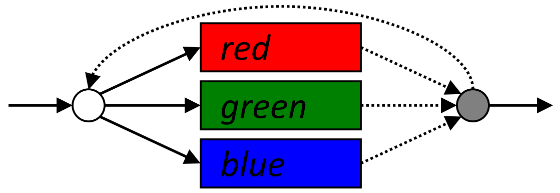

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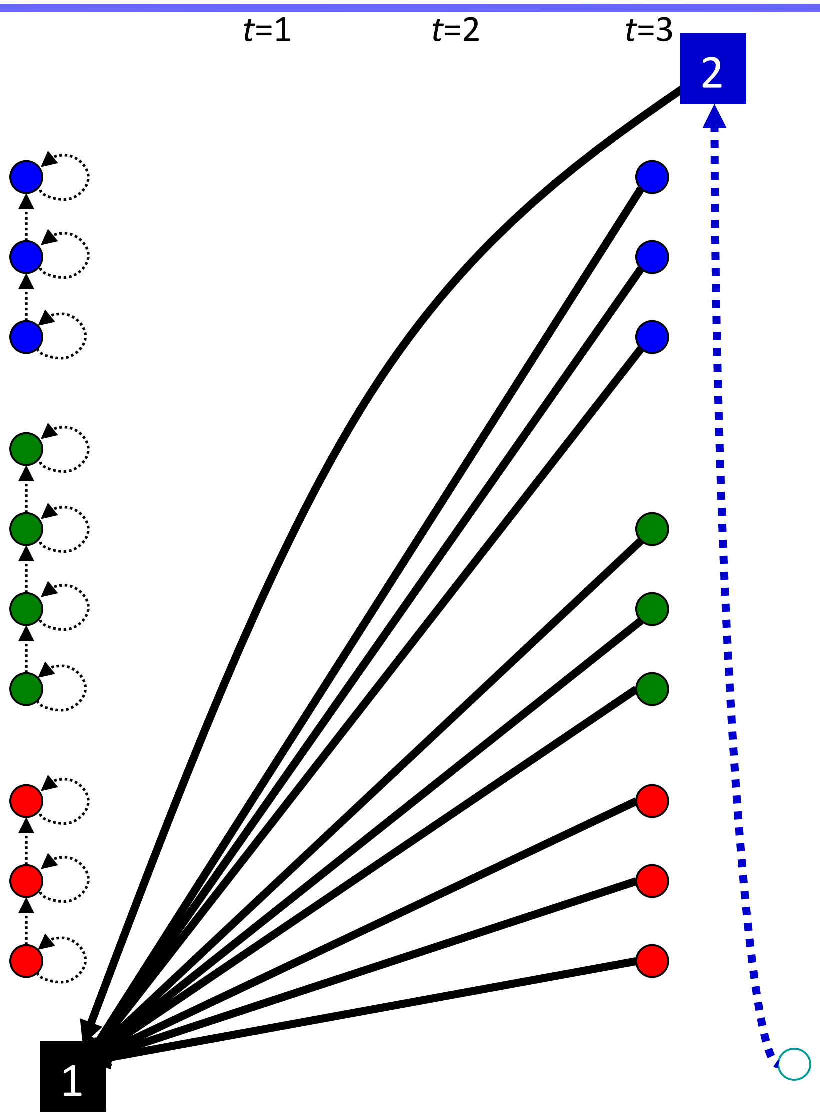

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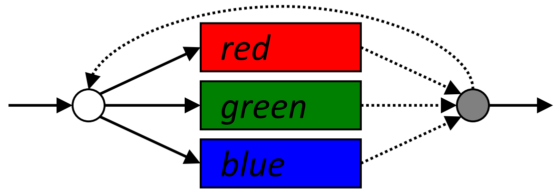

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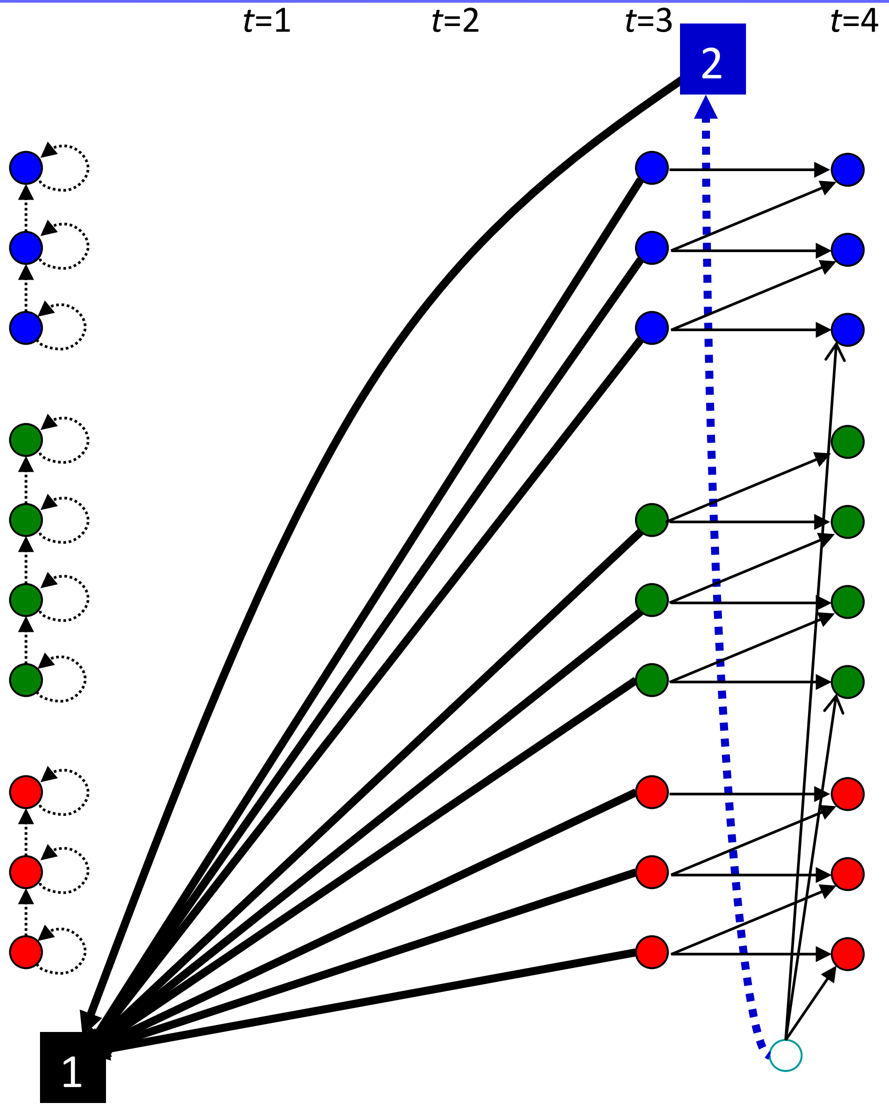

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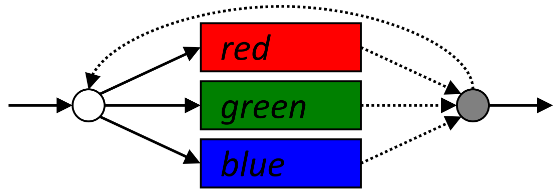

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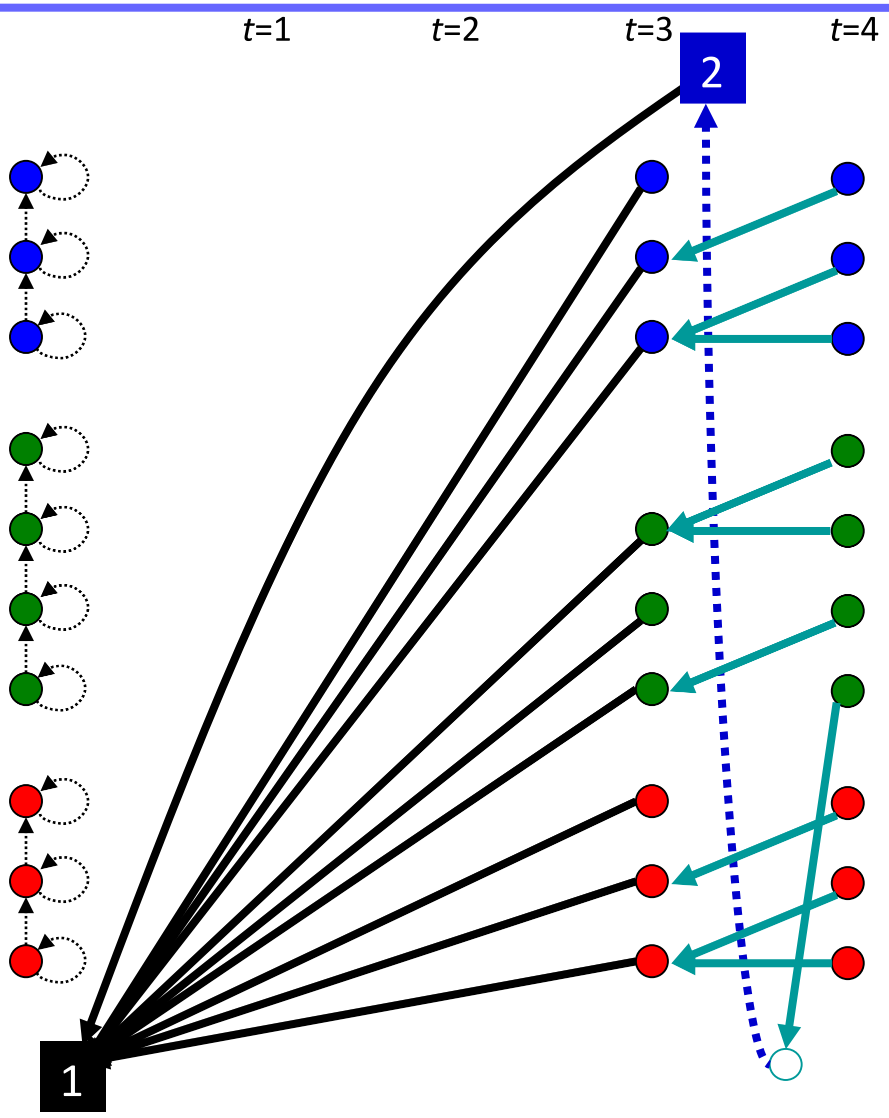

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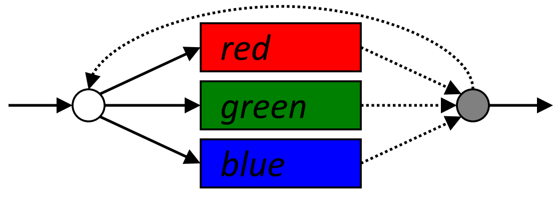

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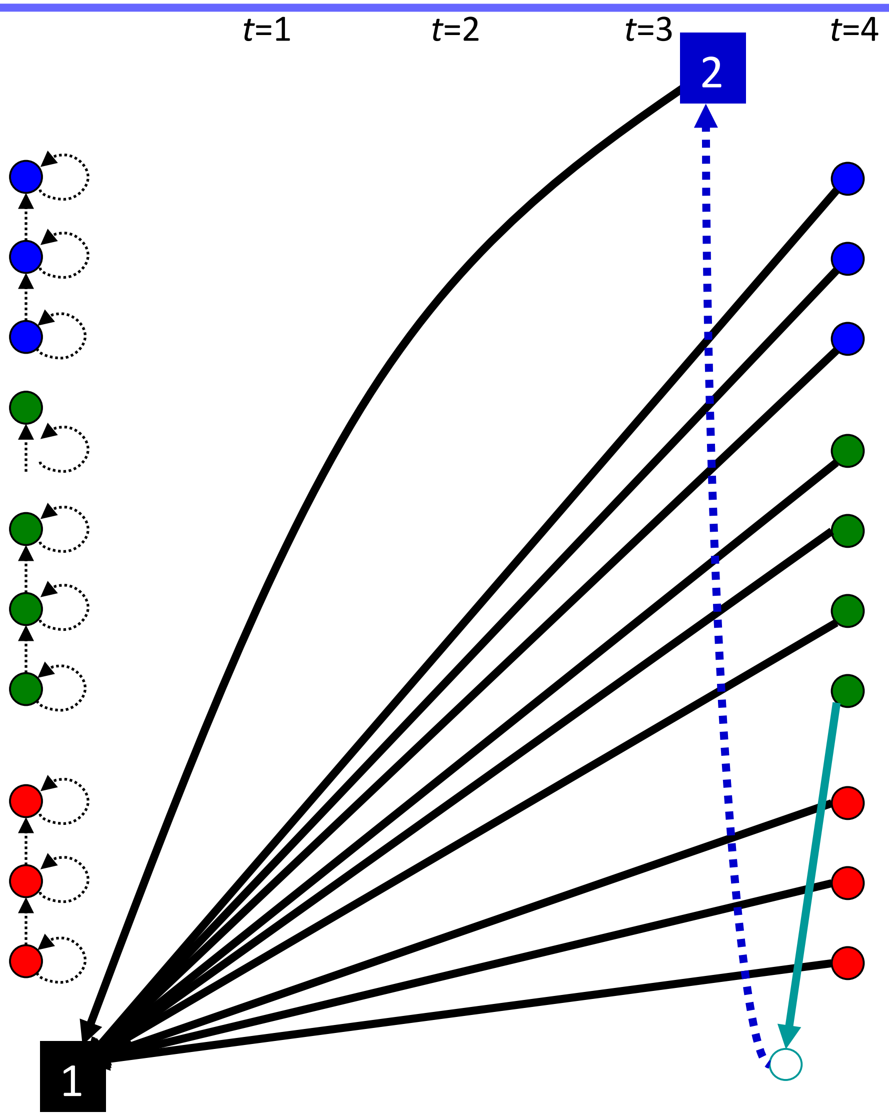

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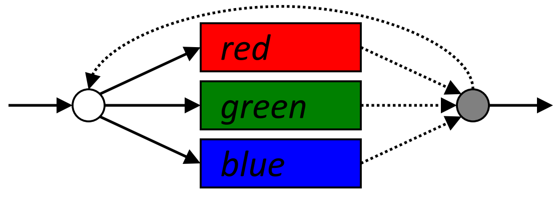

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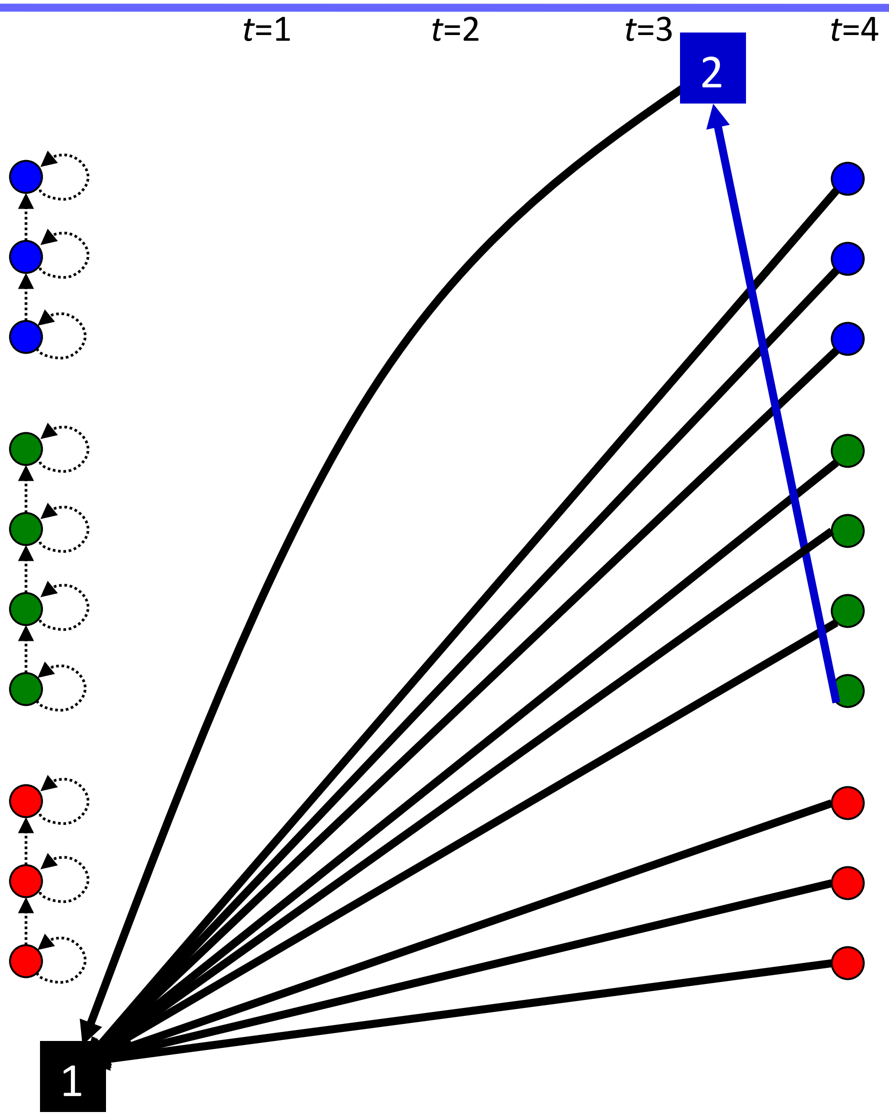

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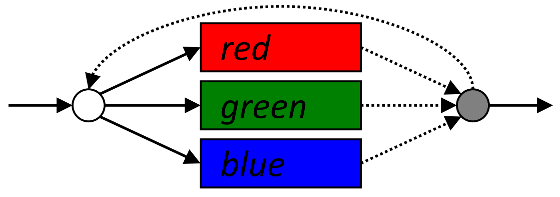

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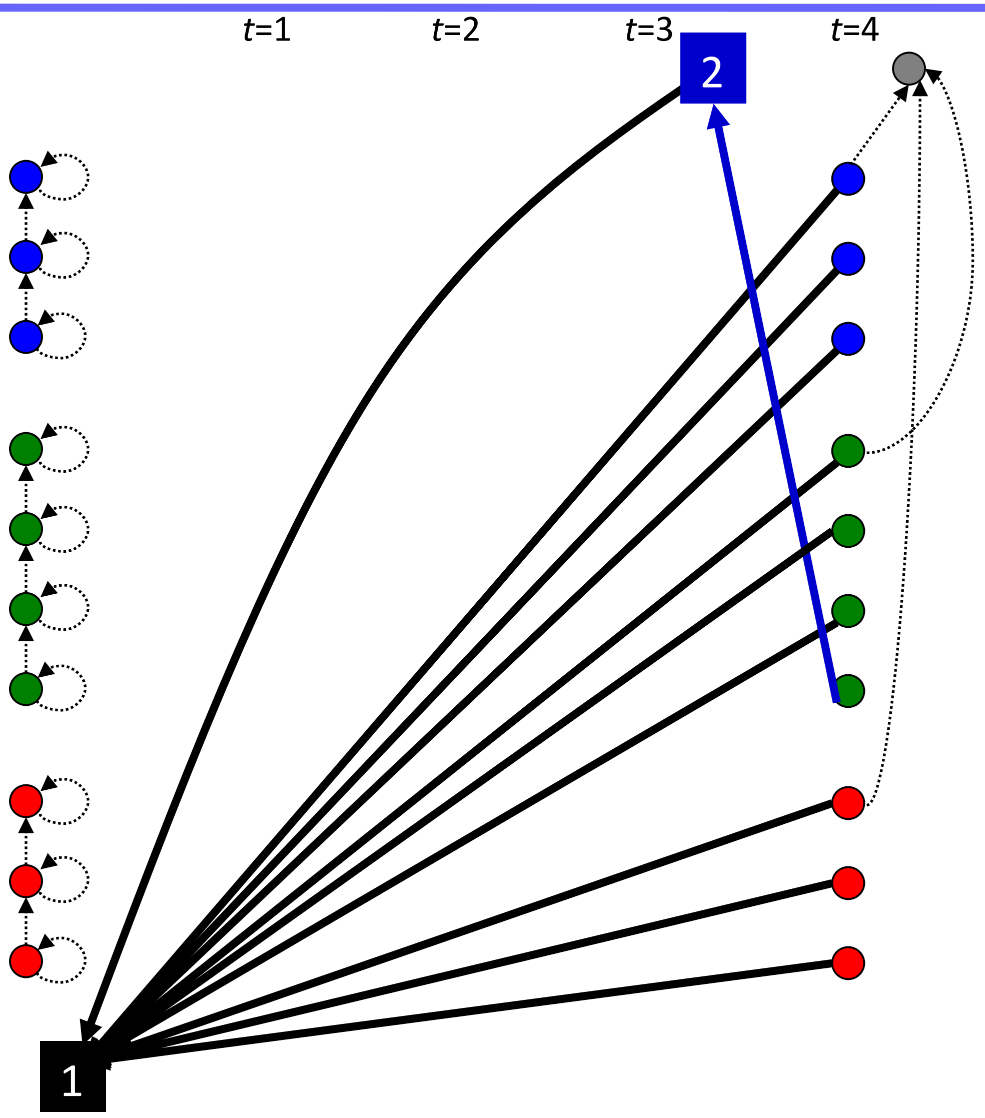

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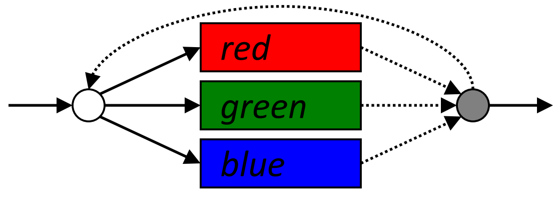

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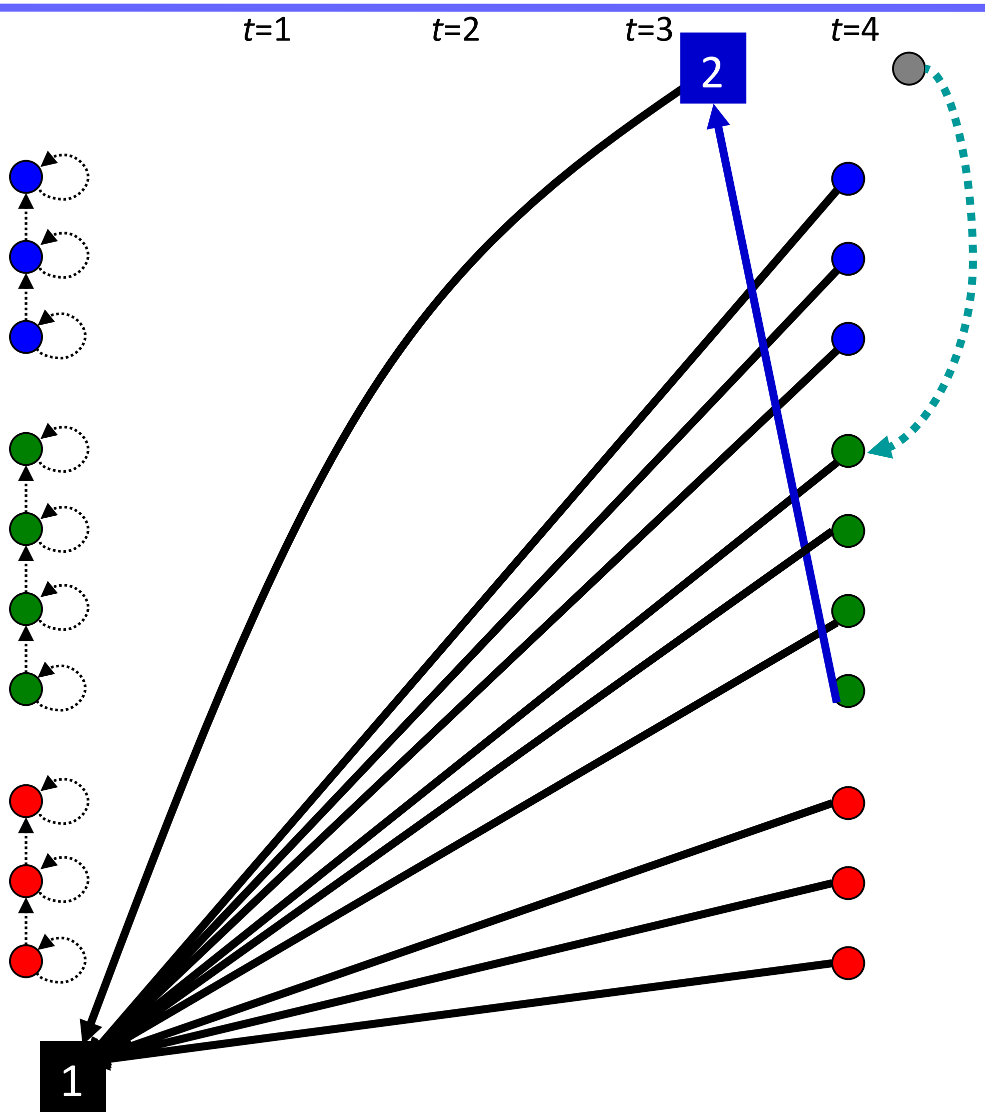

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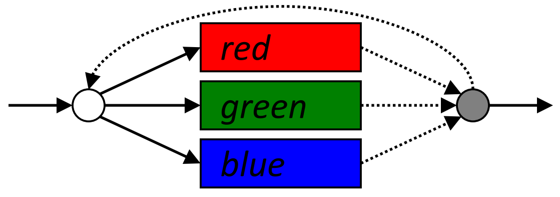

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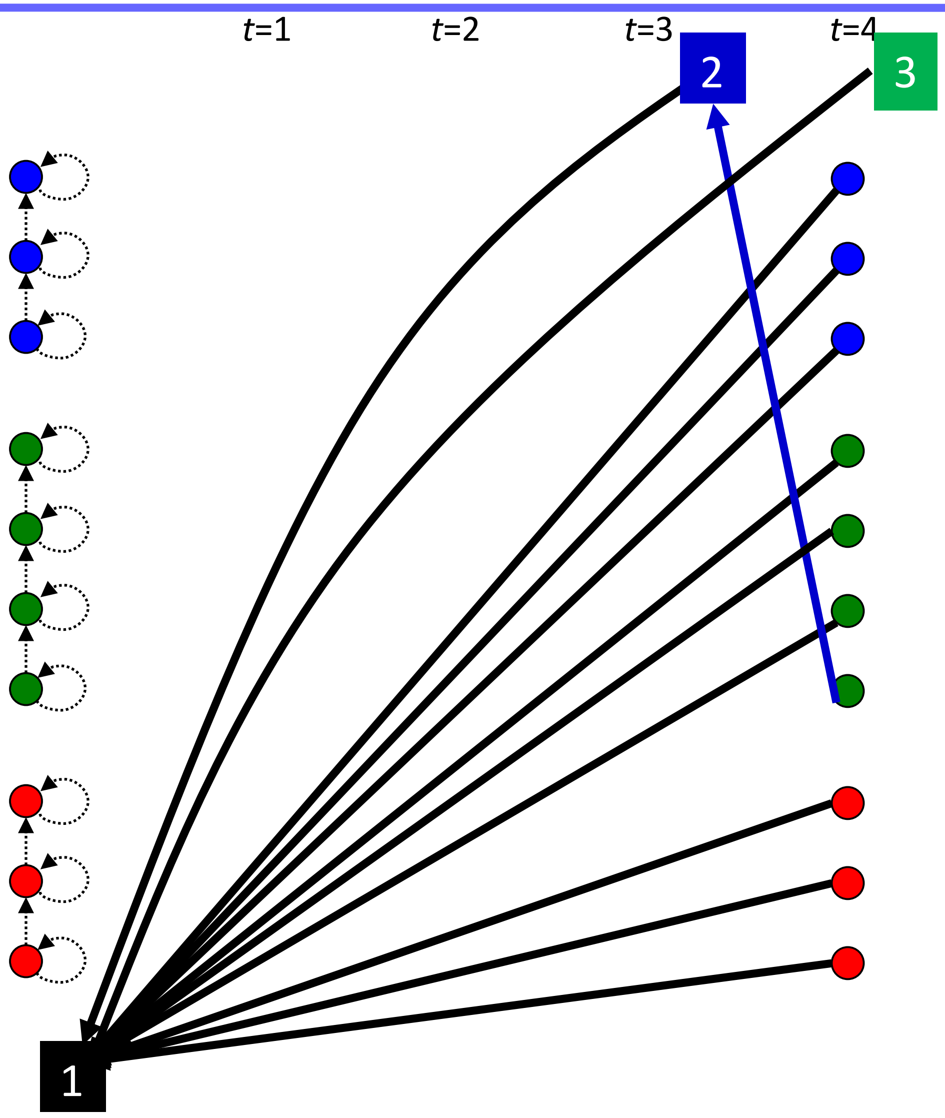

1, t=0, scr1,p=0,…
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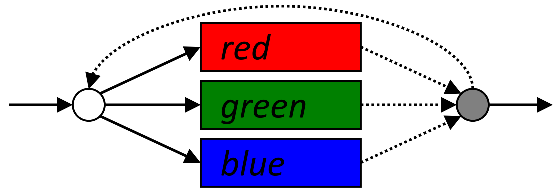
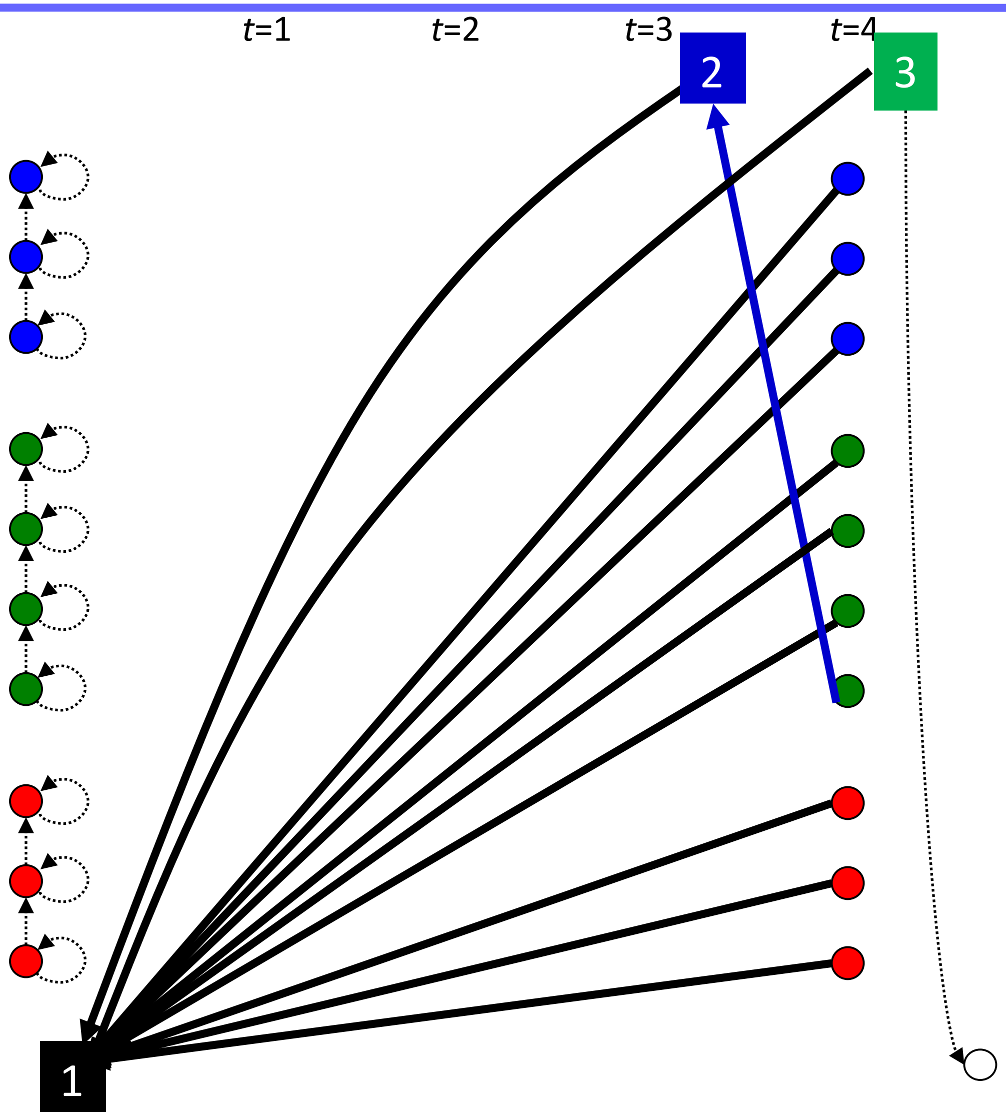
3, t=4, scr3,p=1,…

Retain backpointers (and add the to the table) if deleting them will result in loss of word history



Backpointer table entries also have information about word identity (indicated by color in the figure)

Trellis with Complete Set of Backpointers



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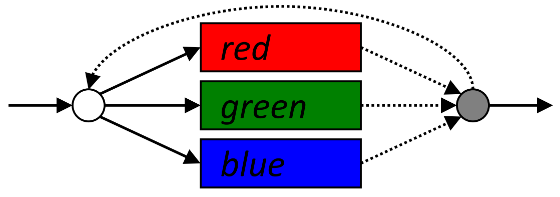

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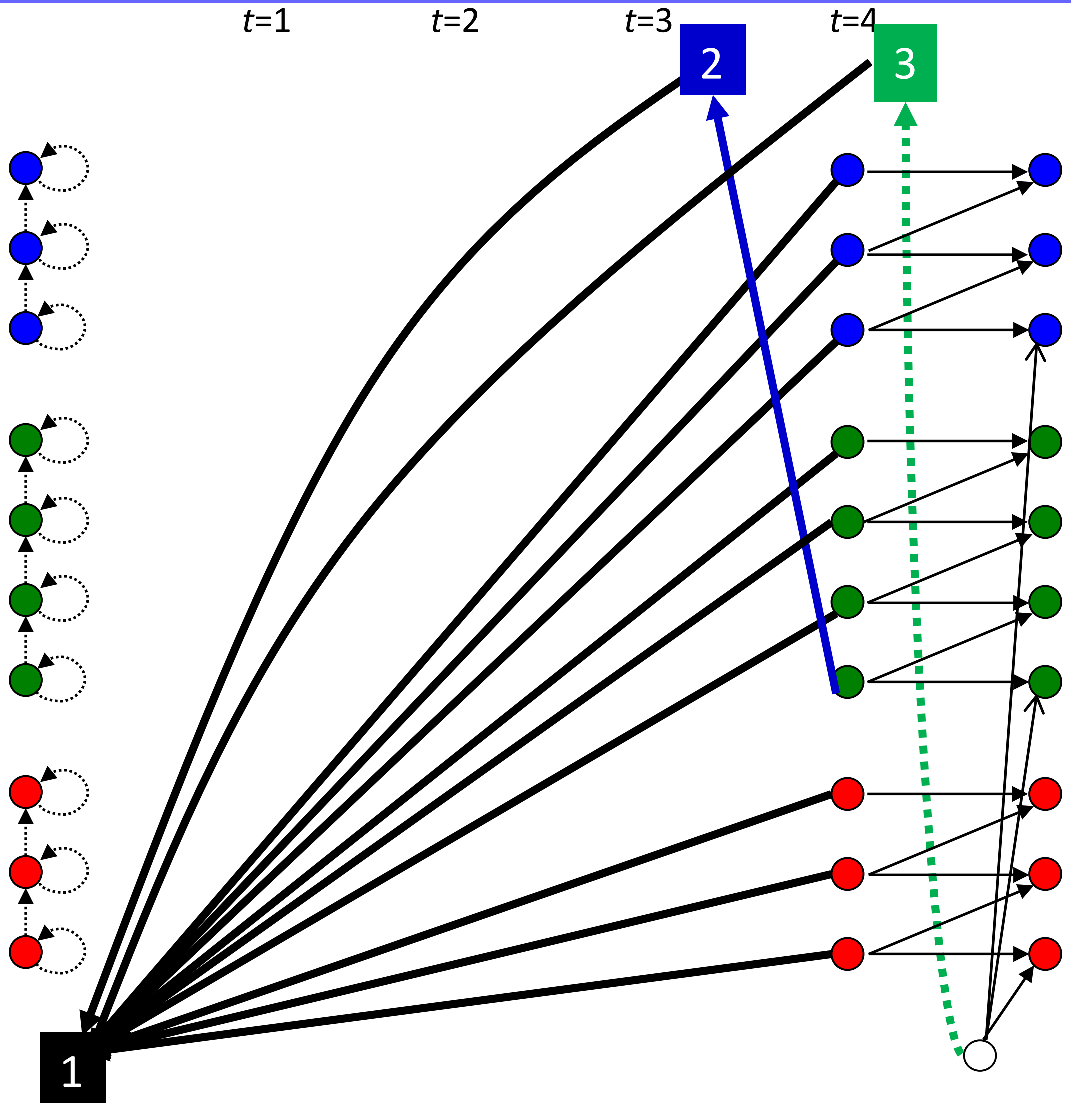

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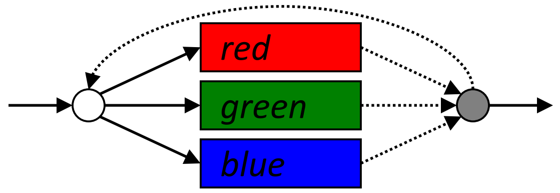

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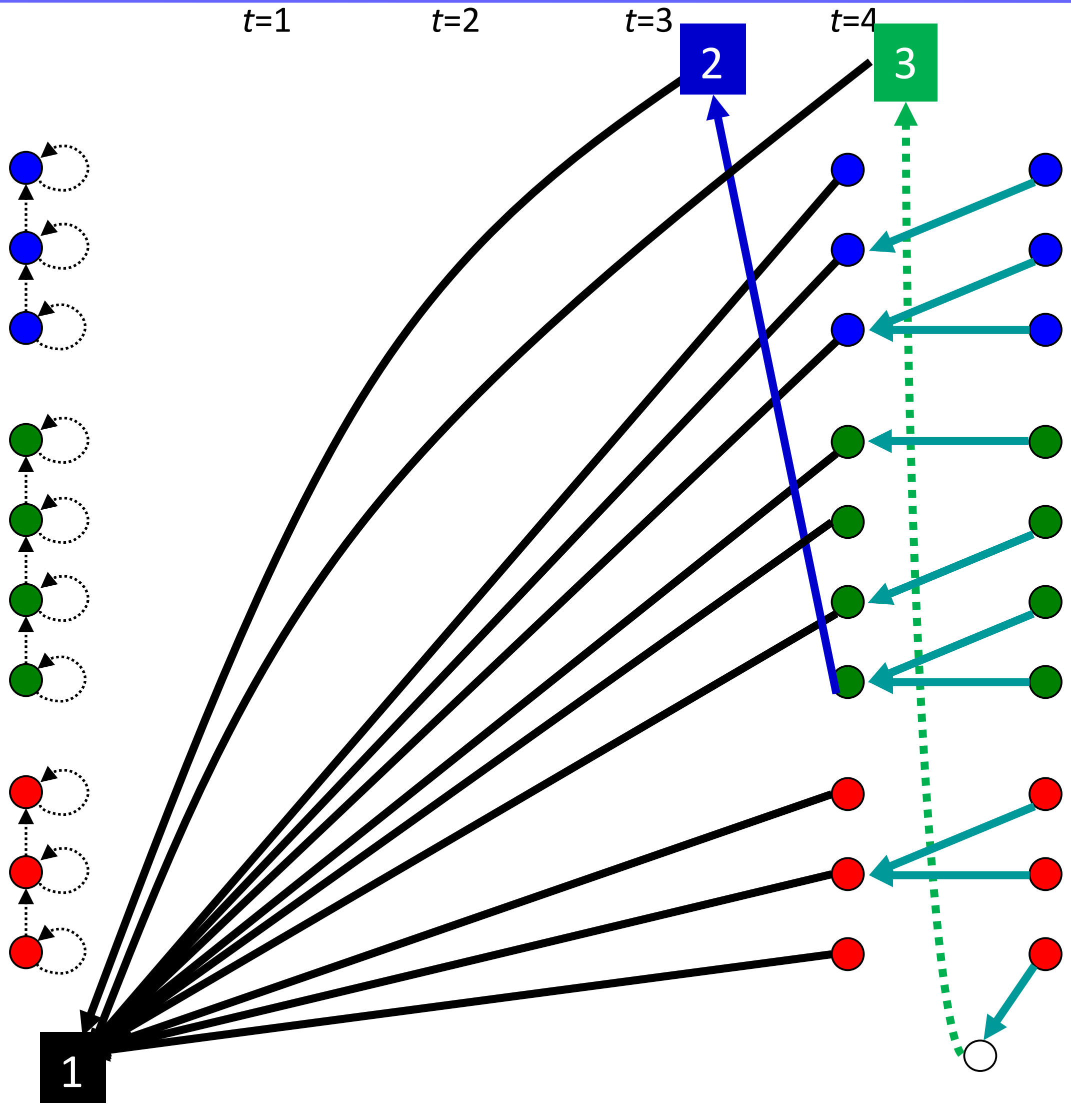

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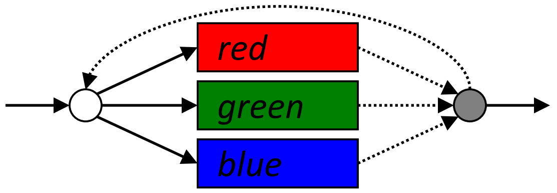

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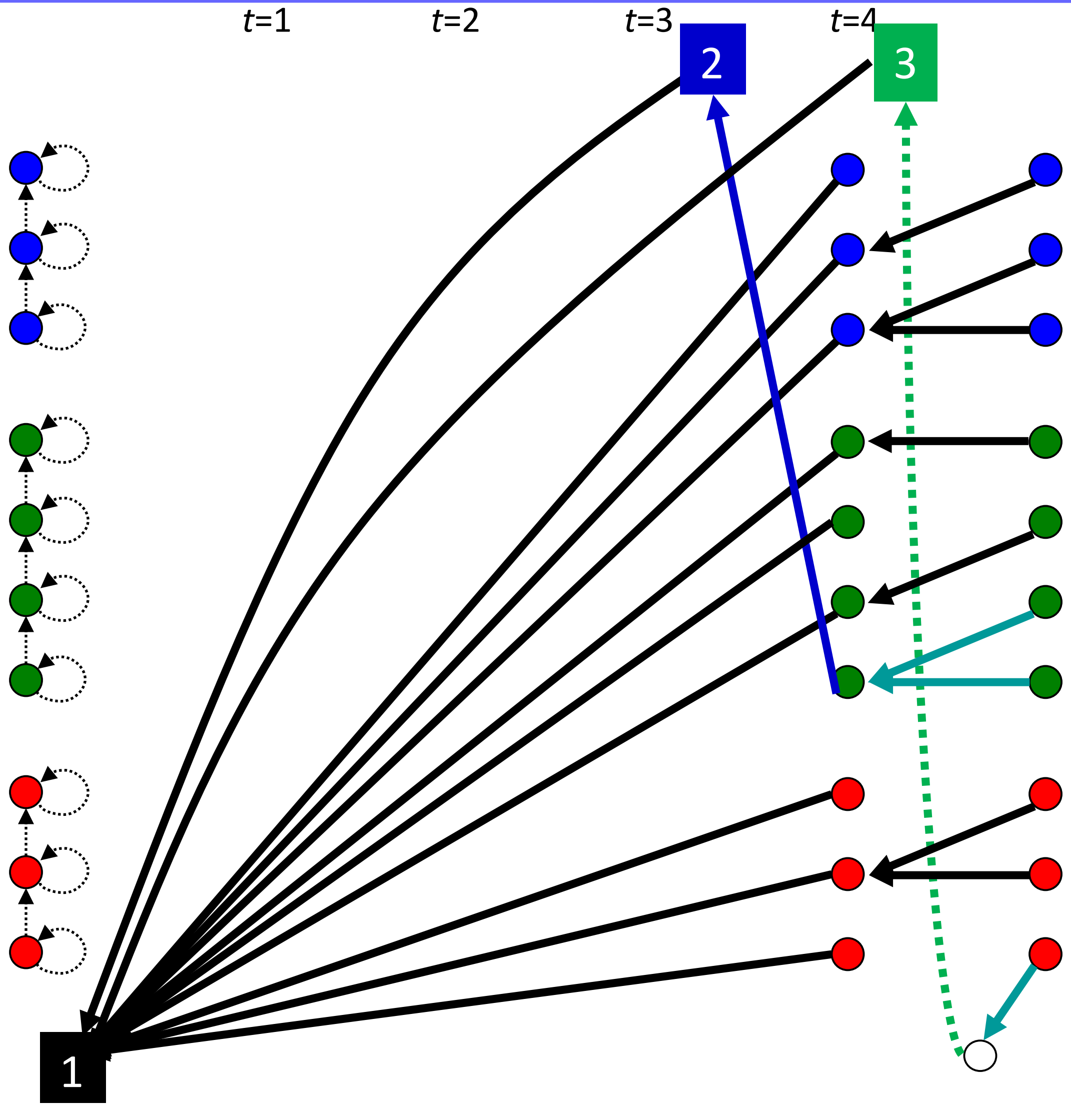

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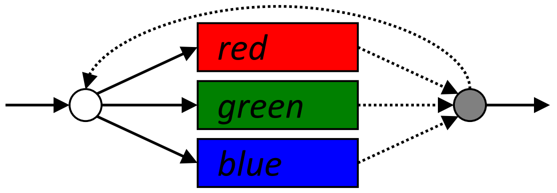

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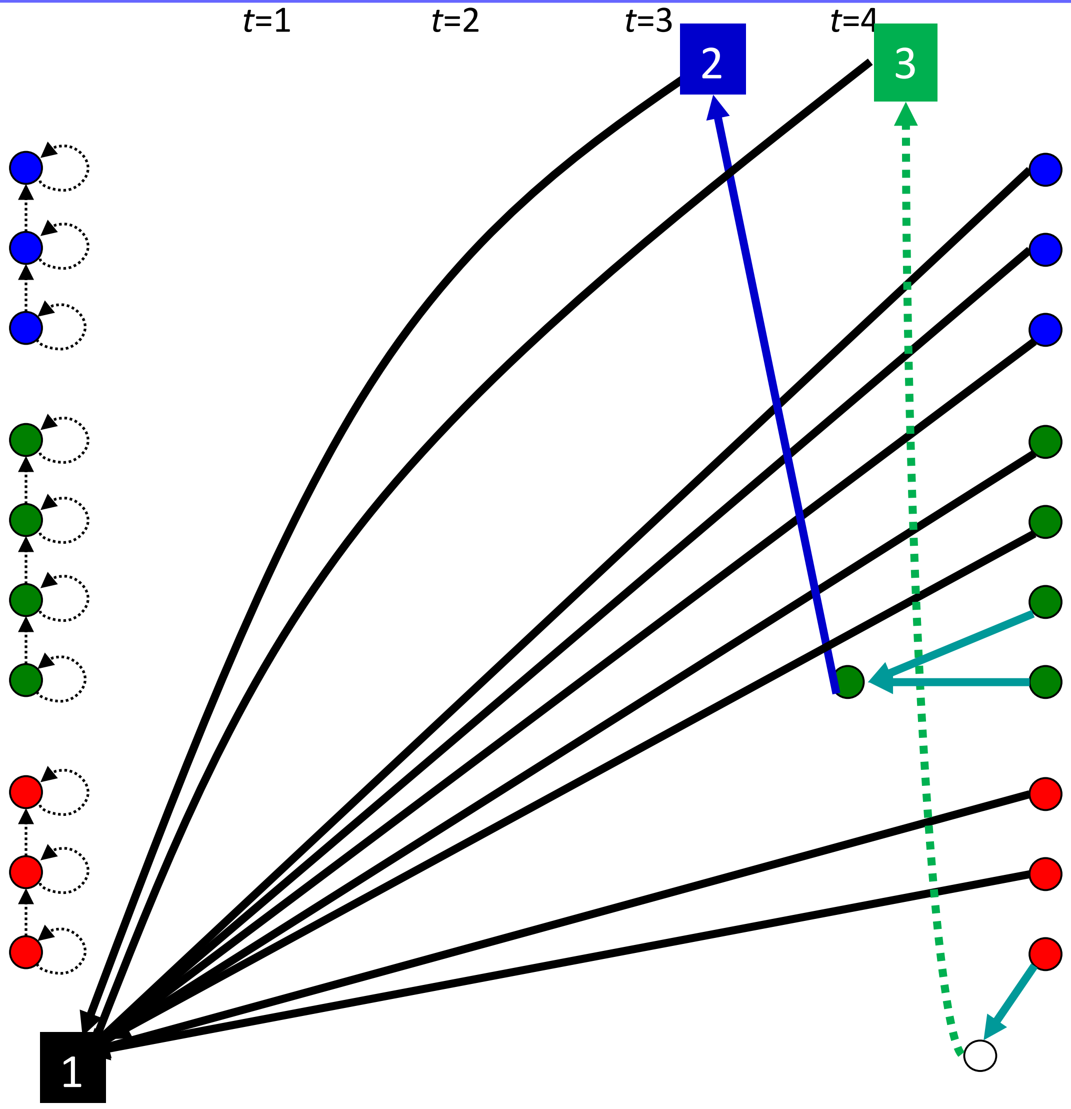

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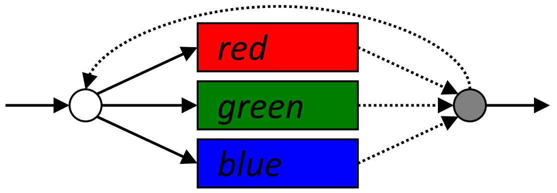

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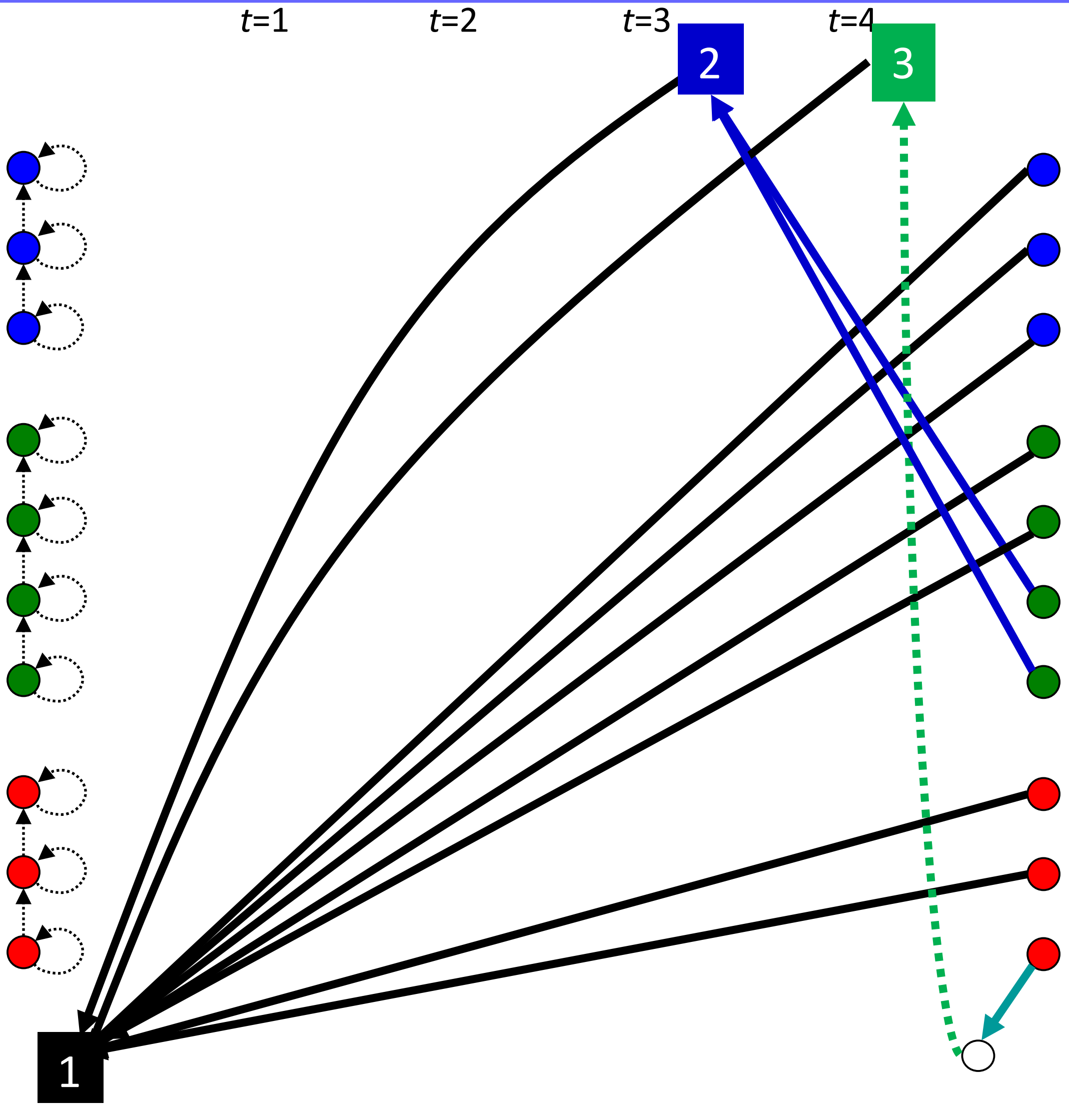

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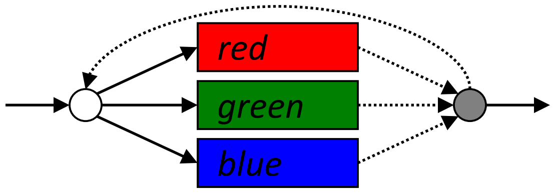

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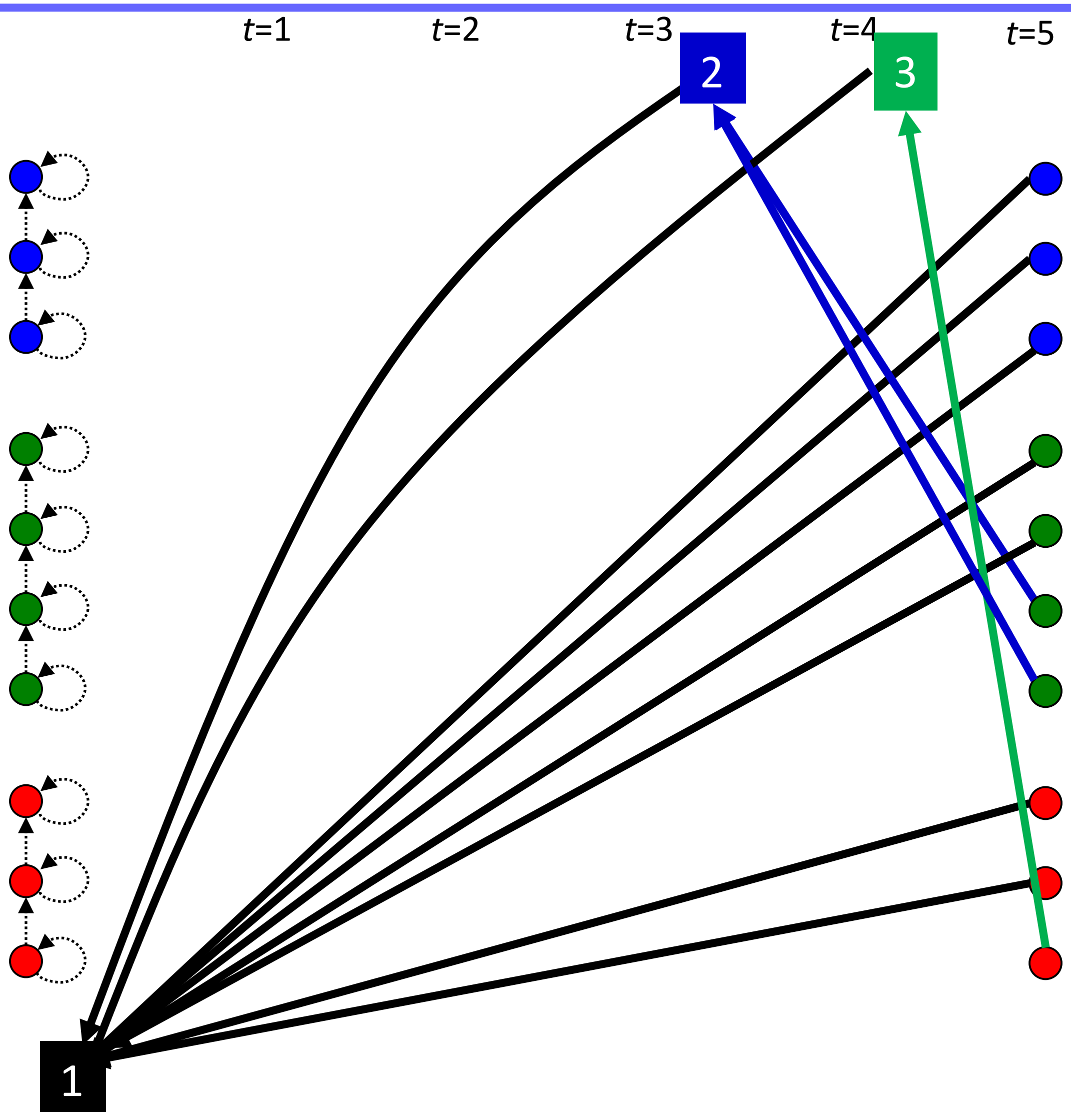

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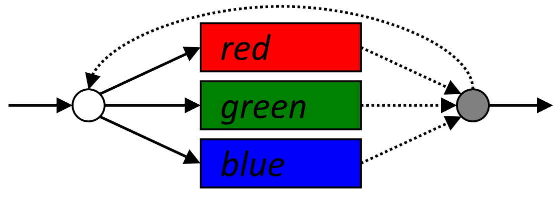

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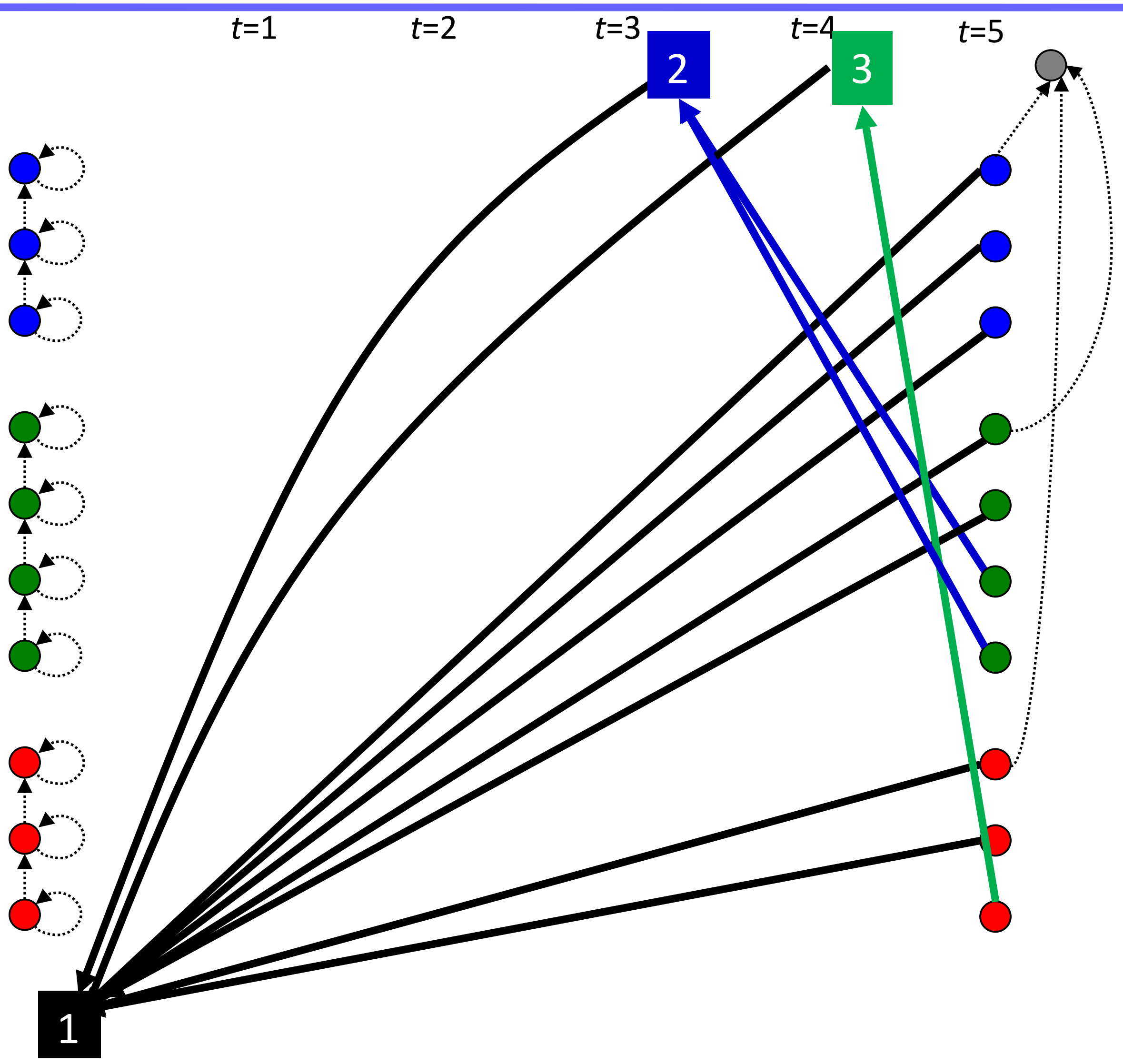

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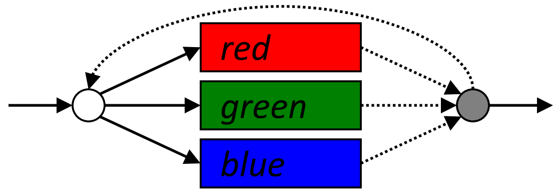

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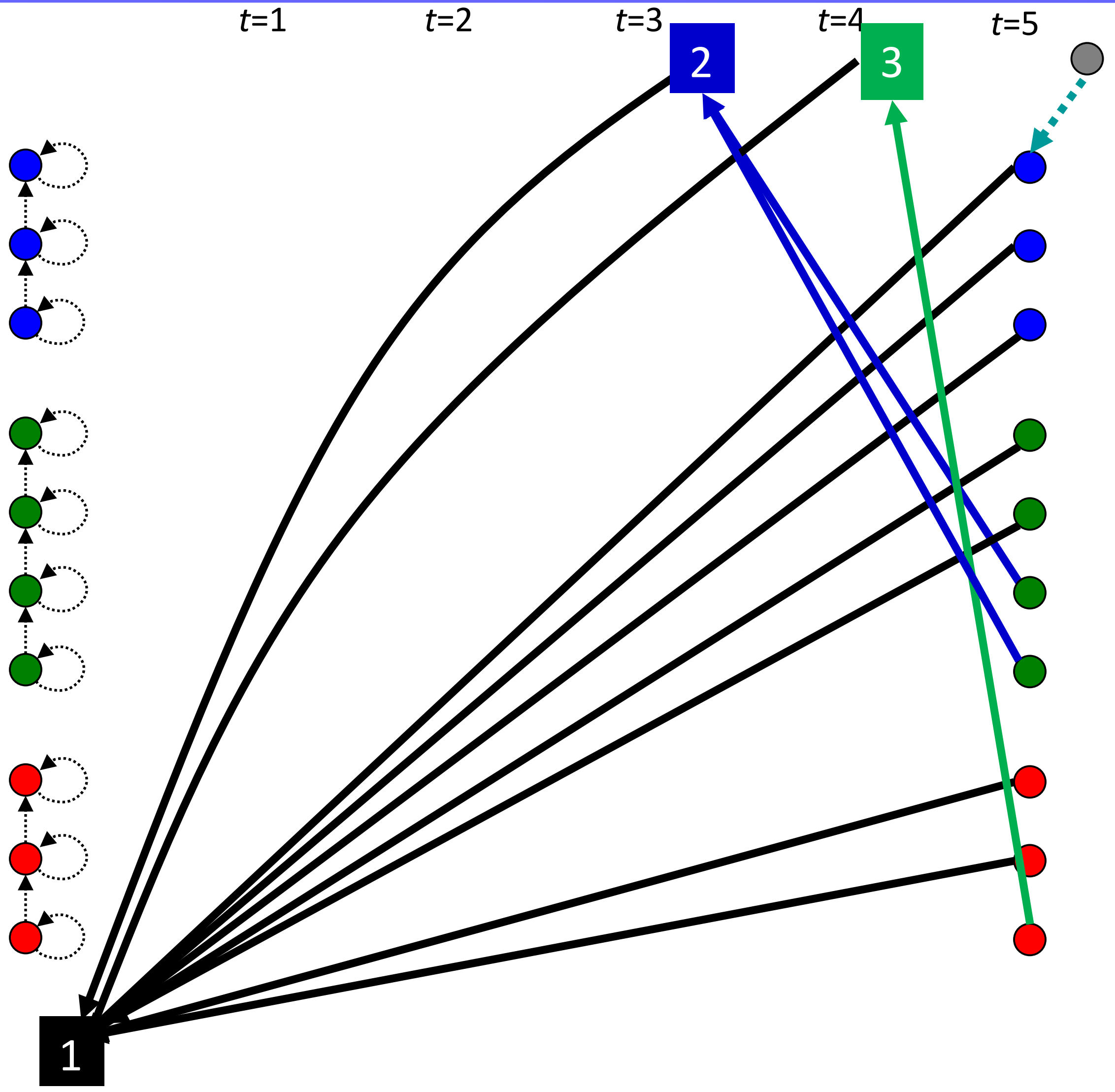

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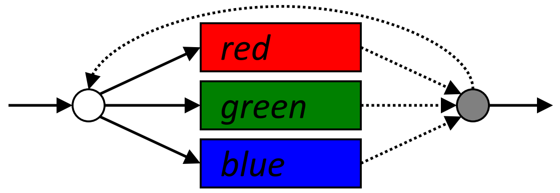
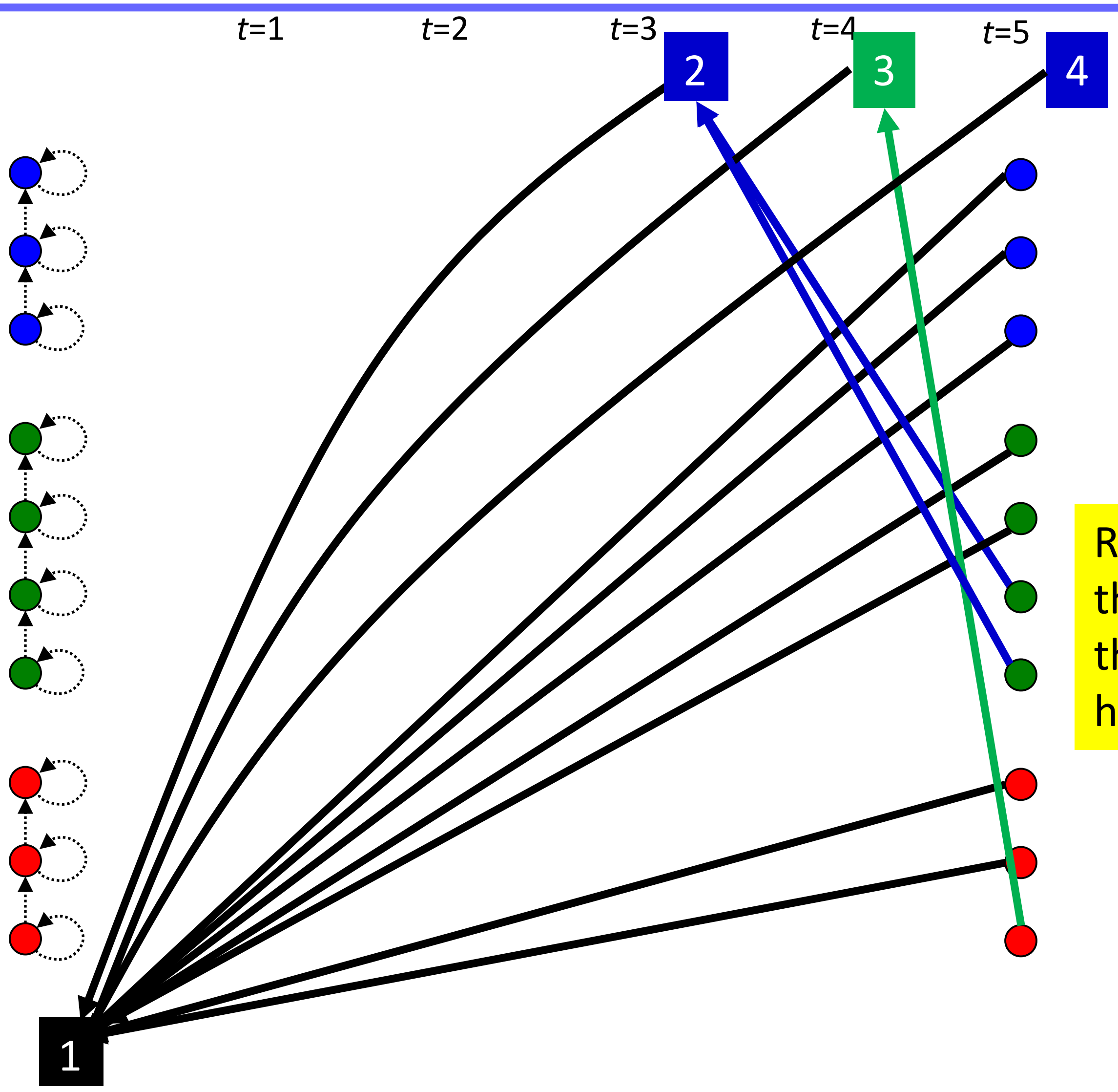


Trellis with Complete Set of Backpointers



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3, t=4, scr3,p=1,…
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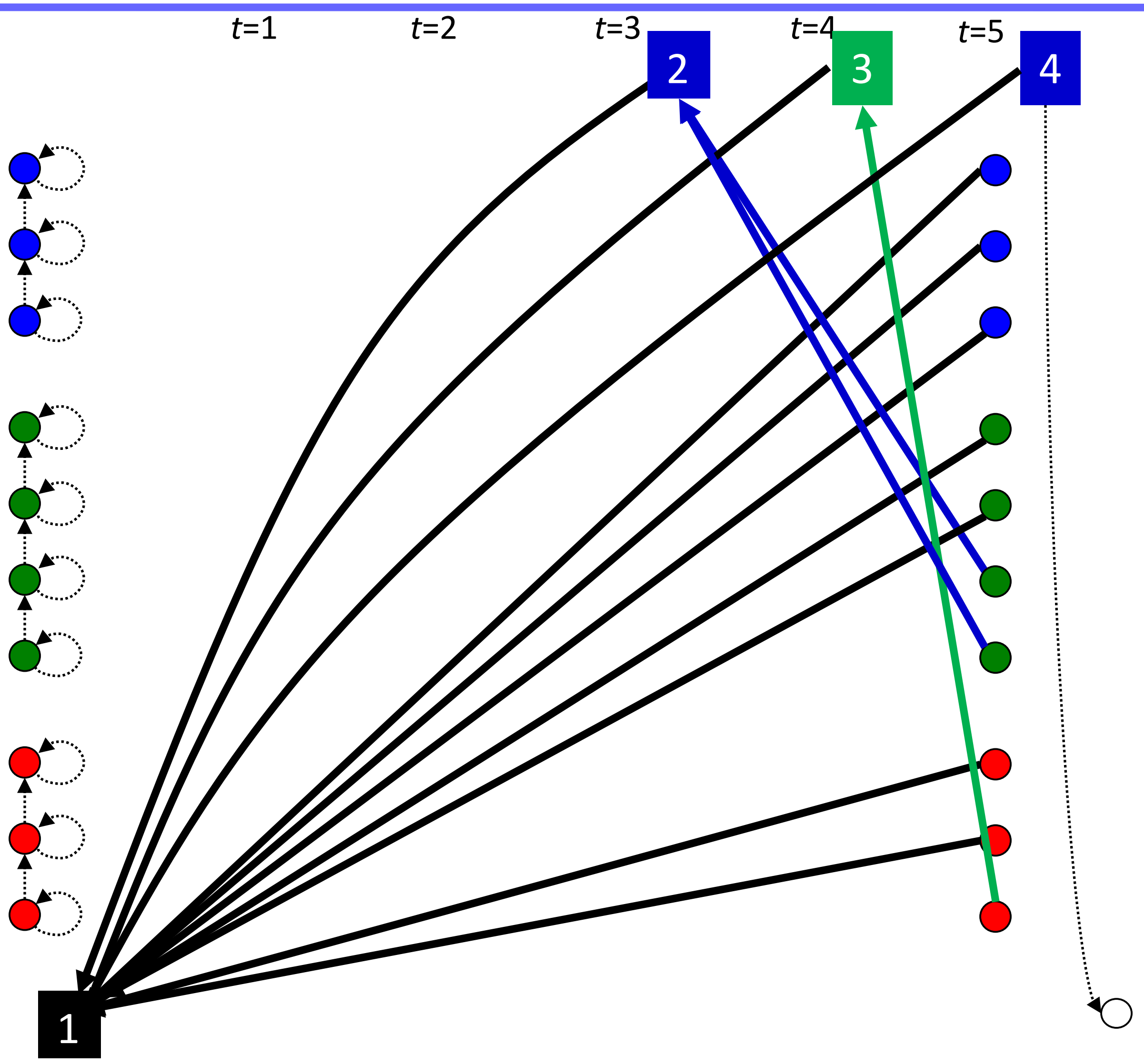
Retain backpointers (and add them to the table) if deleting them will result in loss of word history

Trellis with Complete Set of Backpointers



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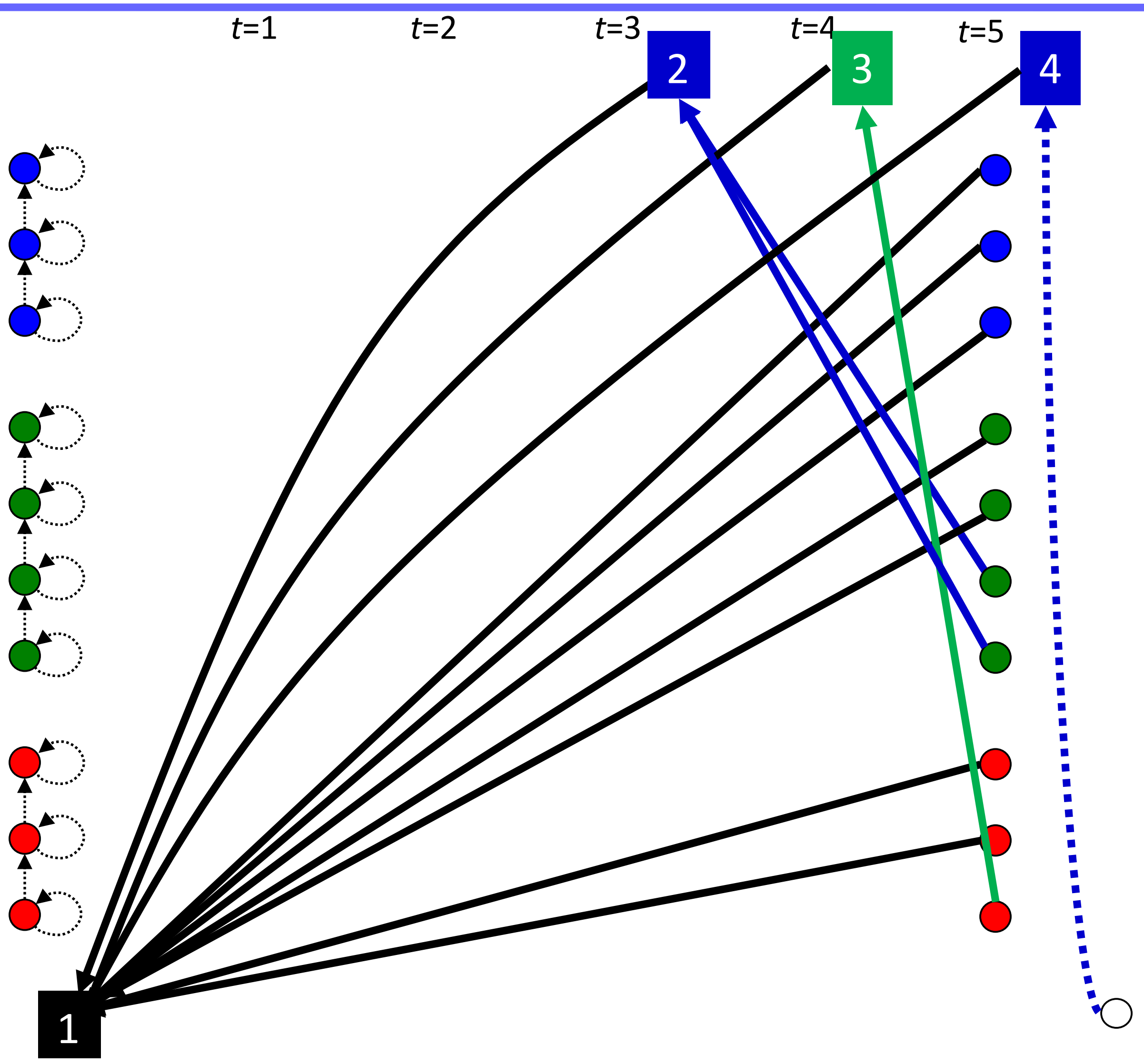
Trellis with Complete Set of Backpointers



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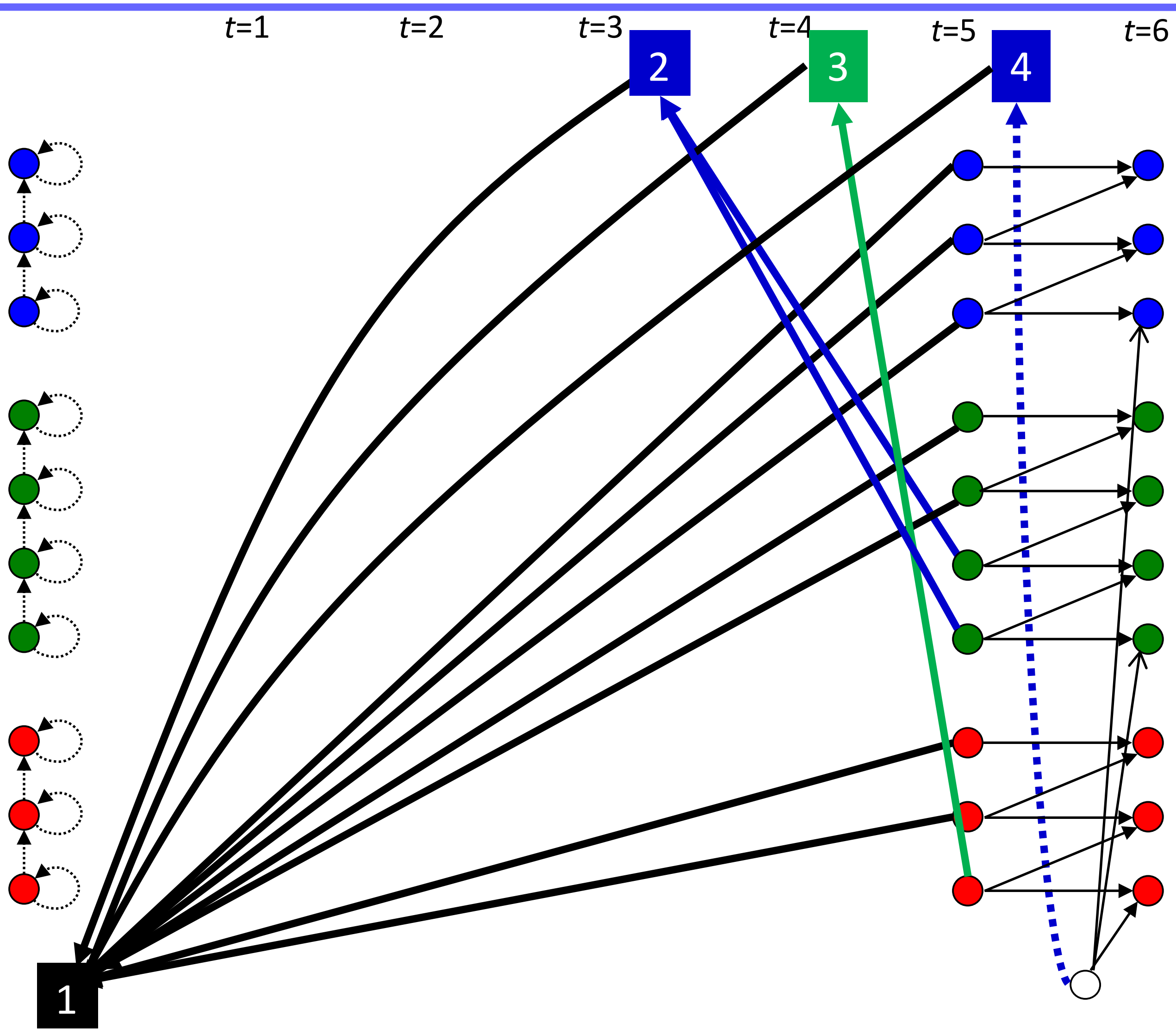
3, t=4, scr3,p=1,…

4, t=5, scr4,p=1,…

Trellis with Complete Set of Backpointers



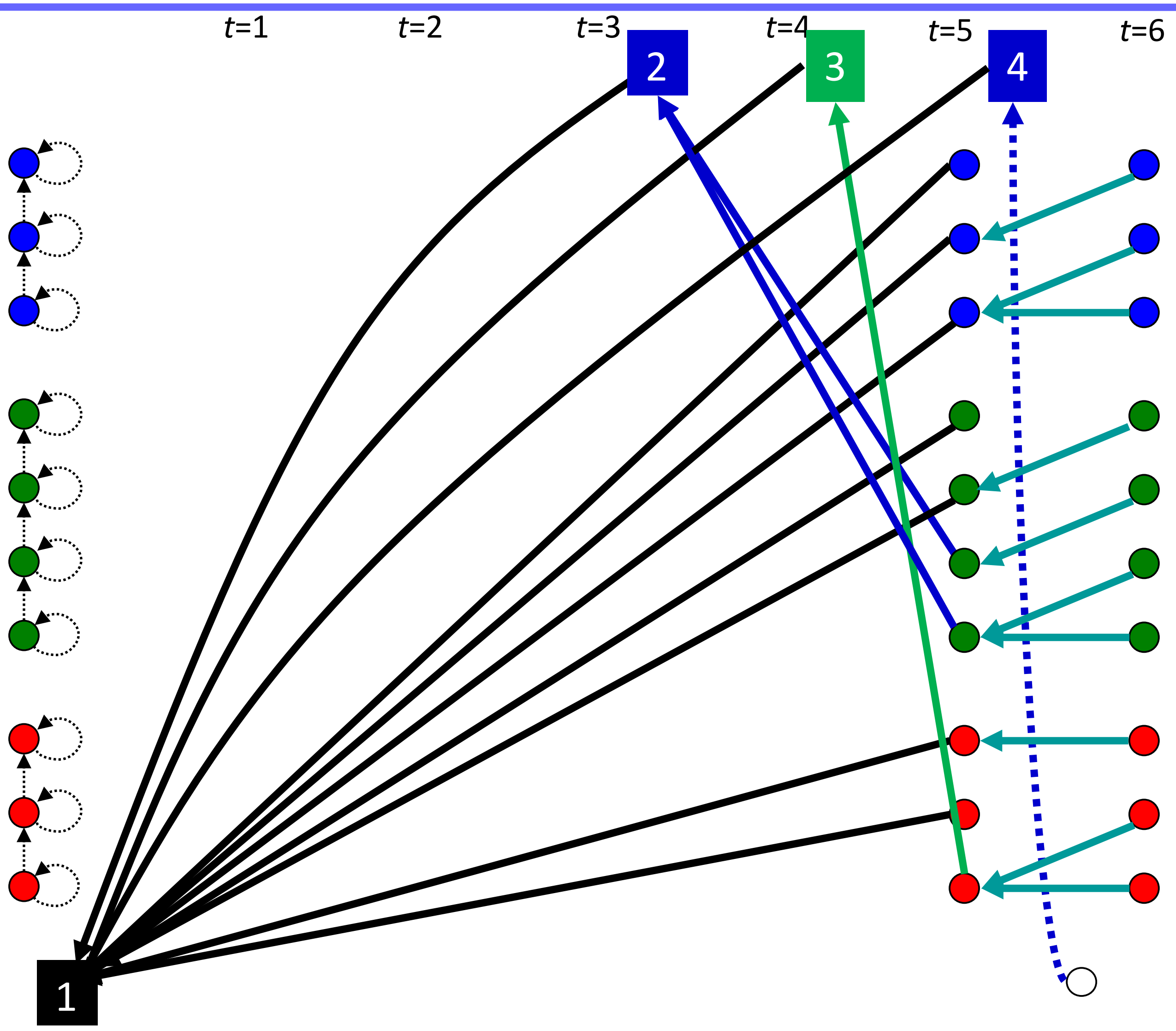
1, t=0, scr1,p=0,…

2, t=3, scr2,p=1,…

3, t=4, scr3,p=1,…

4, t=5, scr4,p=1,…

Trellis with Complete Set of Backpointers



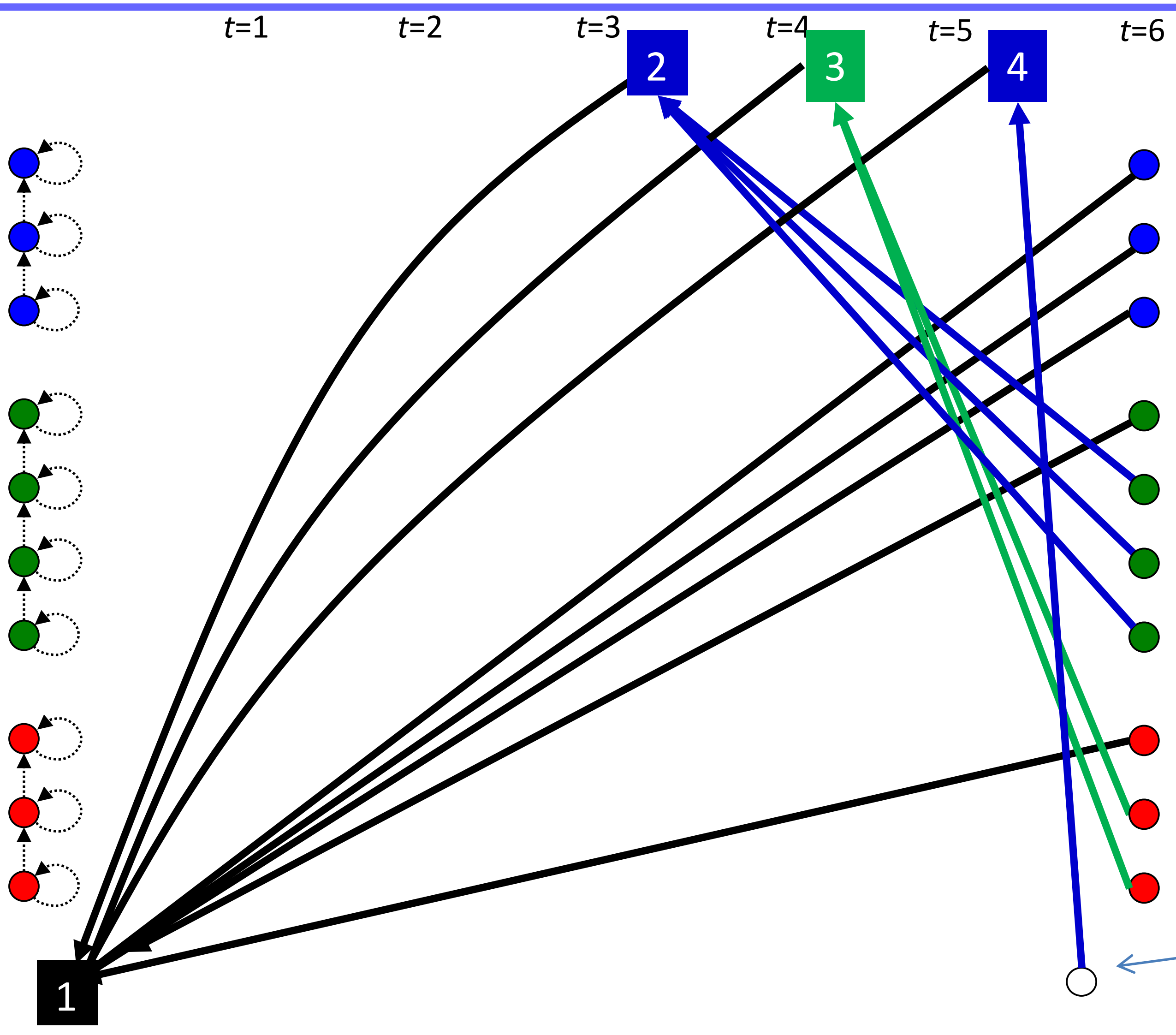
1, t=0, scr1,p=0,…

2, t=3, scr2,p=1,…

3, t=4, scr3,p=1,…

4, t=5, scr4,p=1,…

Trellis with Complete Set of Backpointers



1, t=0, scr1,p=0,…

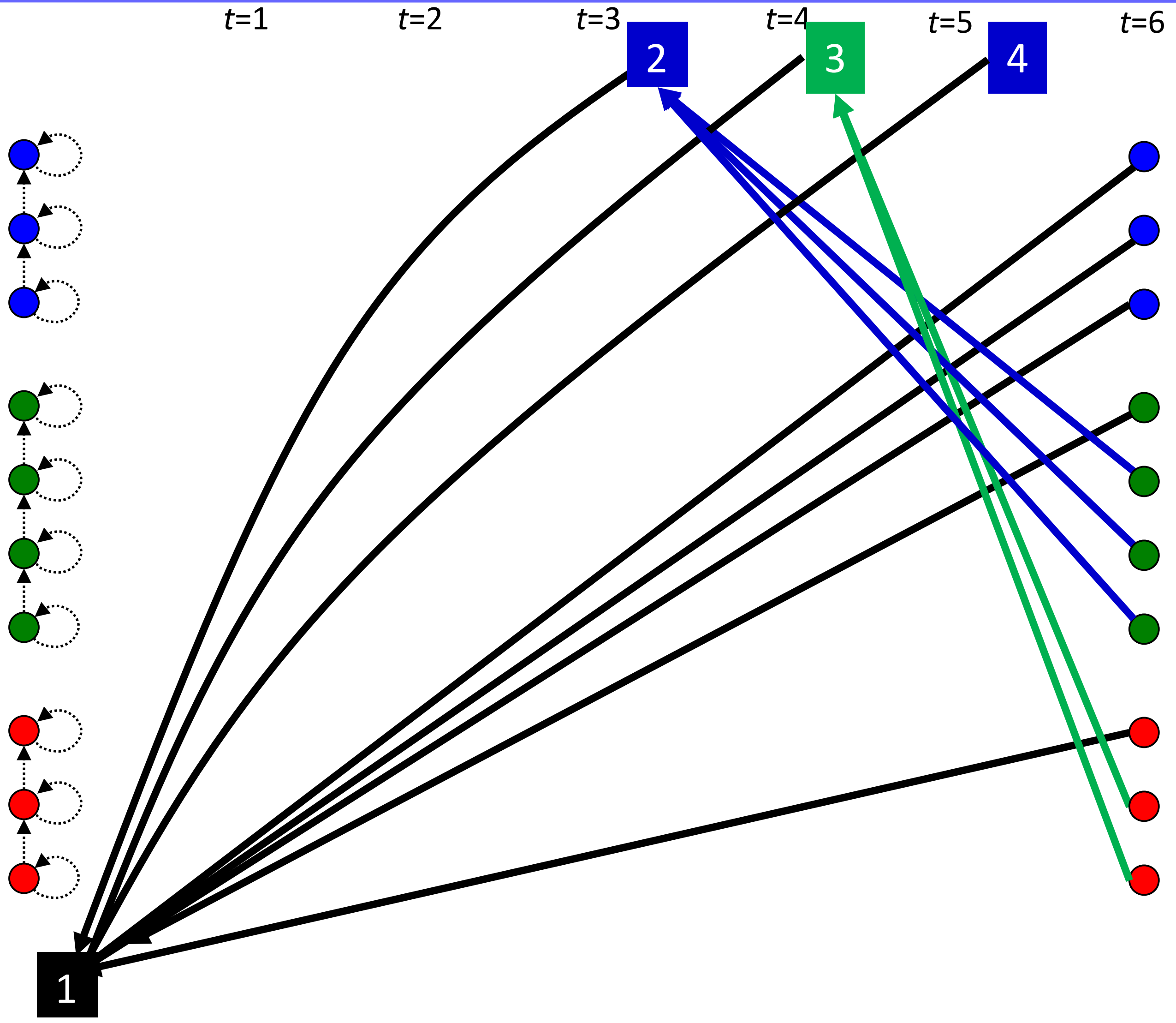
2, t=3, scr2,p=1,…

3, t=4, scr3,p=1,…

4, t=5, scr4,p=1,…

Note: This node will not propagate further (its time is up)

Trellis with Complete Set of Backpointers



1, t=0, scr1,p=0,…

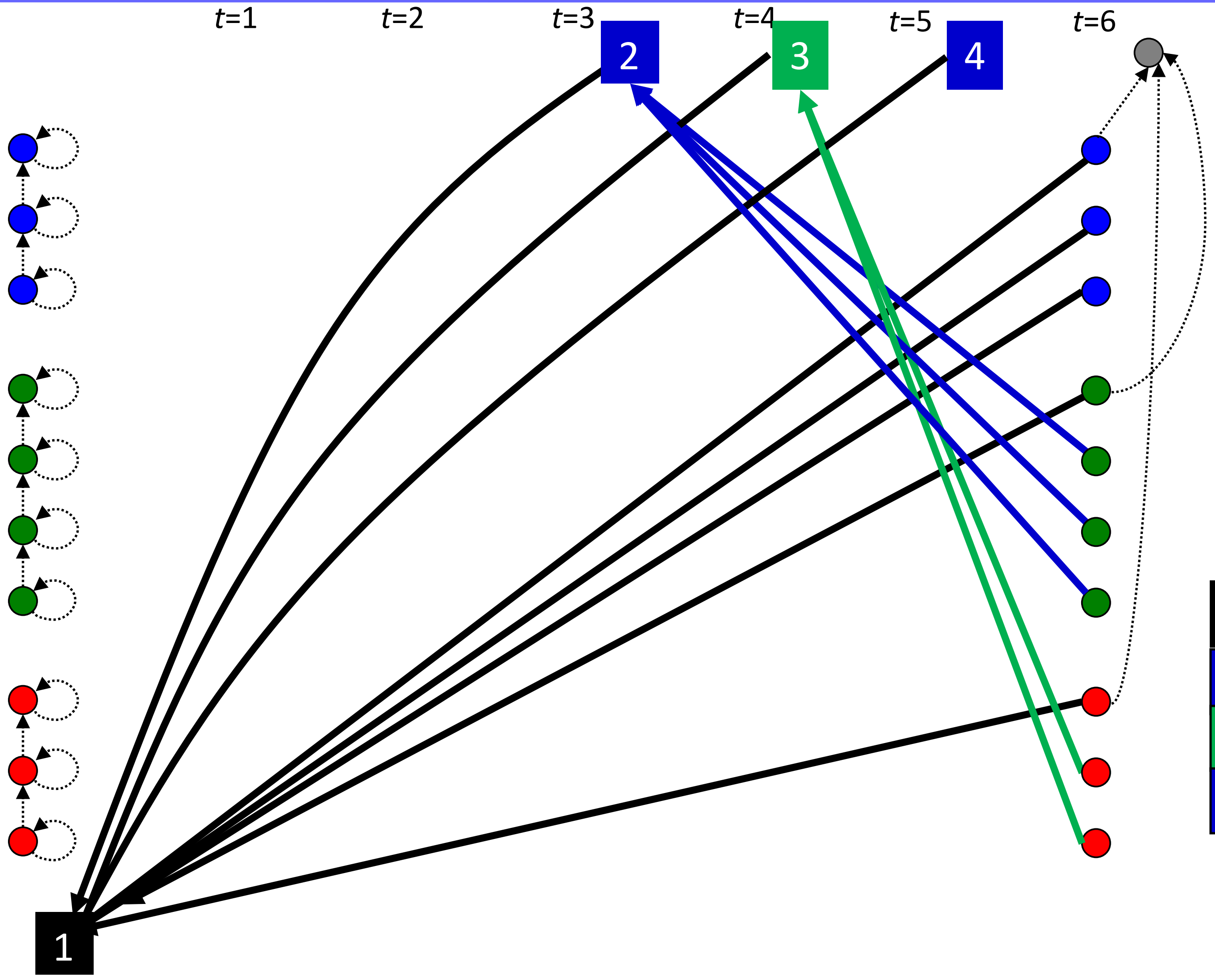
2, t=3, scr2,p=1,…

3, t=4, scr3,p=1,…

4, t=5, scr4,p=1,…

Can delete the node and its backpointer if desired

Trellis with Complete Set of Backpointers



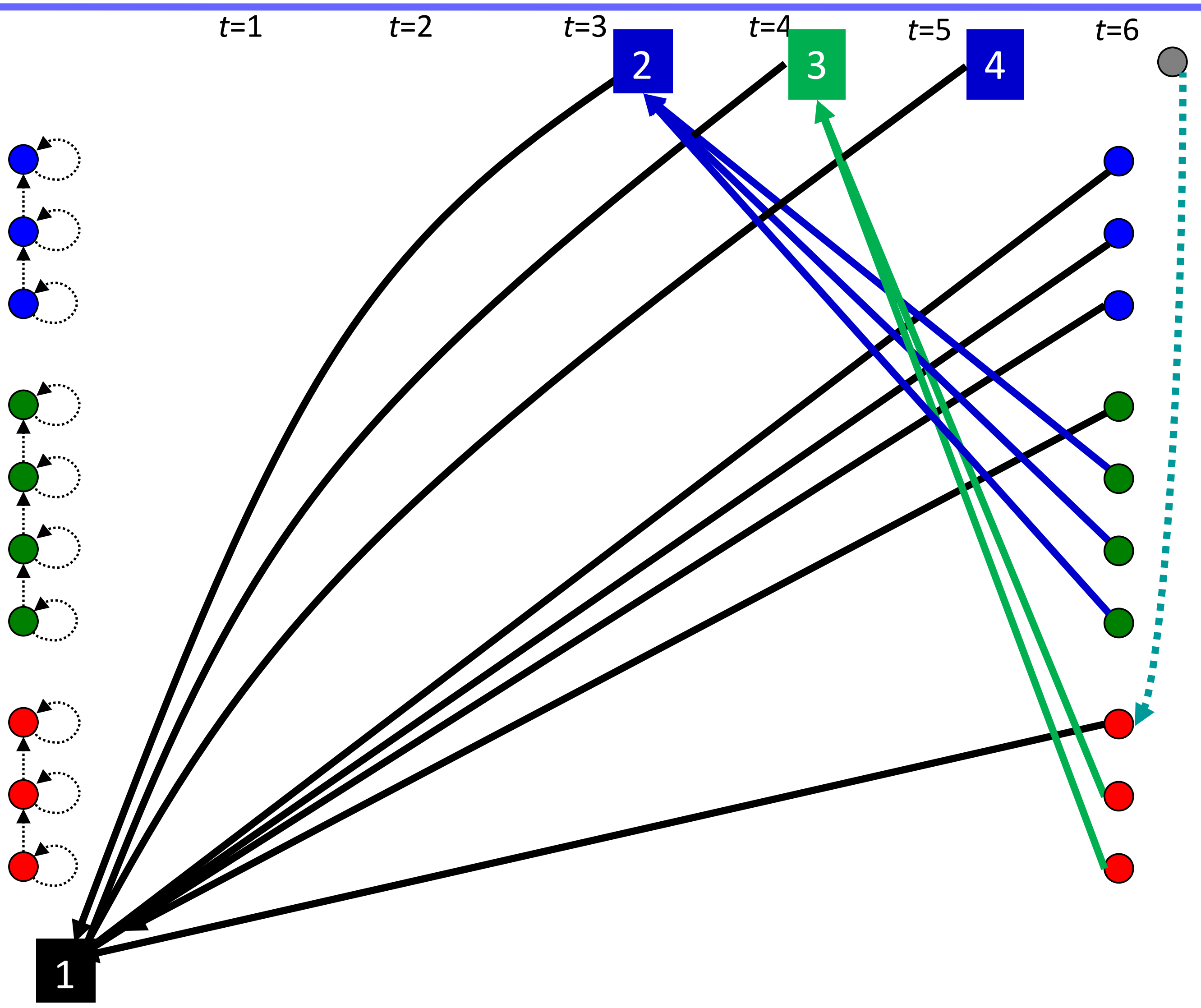
1, t=0, scr1,p=0,…

2, t=3, scr2,p=1,…

3, t=4, scr3,p=1,…

4, t=5, scr4,p=1,…

Trellis with Complete Set of Backpointers



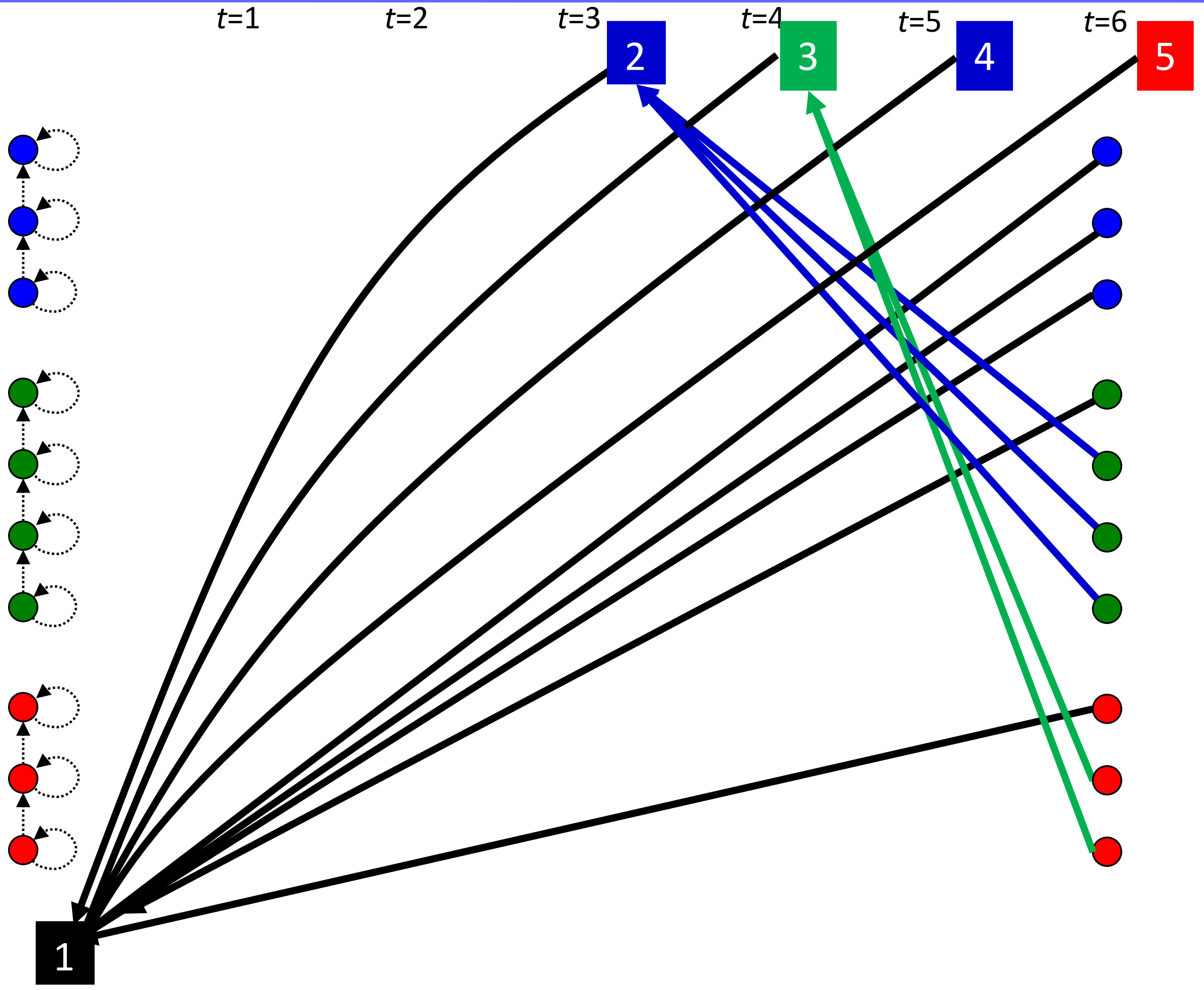
1, t=0, scr1,p=0,…

2, t=3, scr2,p=1,…

3, t=4, scr3,p=1,…

4, t=5, scr4,p=1,…

Trellis with Complete Set of Backpointers



1, t=0, scr1,p=0,…

2, t=3, scr2,p=1,…

3, t=4, scr3,p=1,…

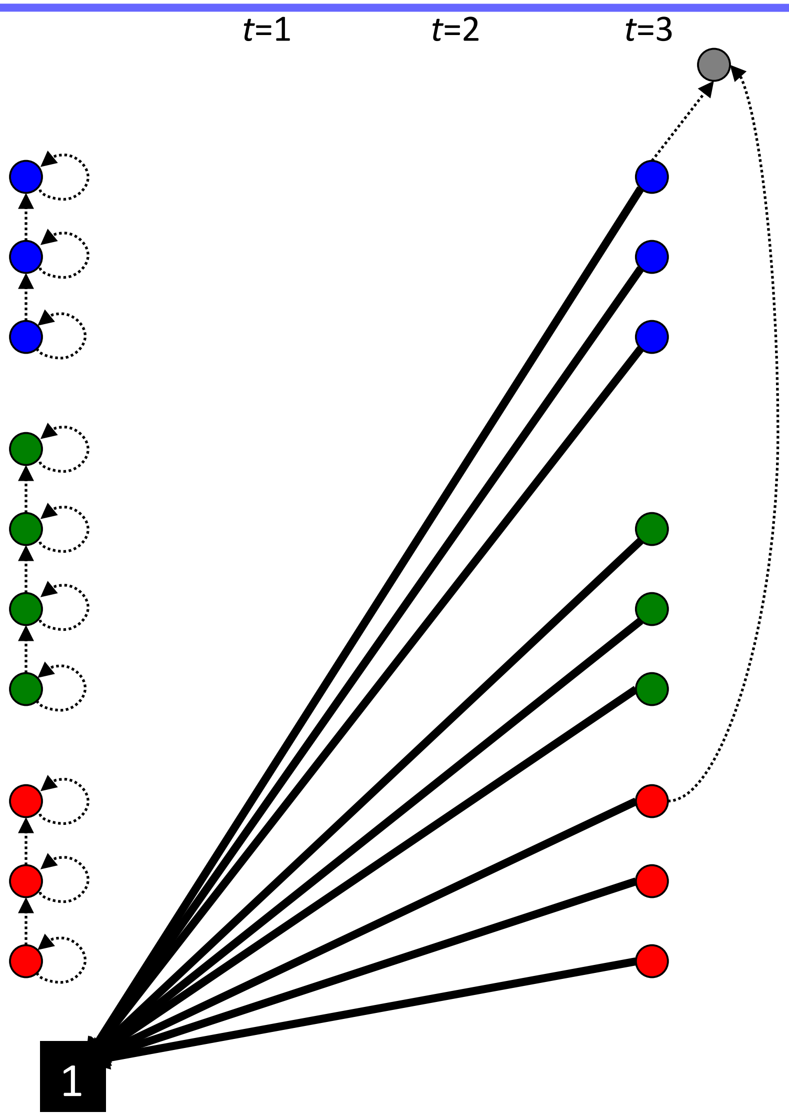
4, t=5, scr4,p=1,…

5, t=6, scr5,p=1,…

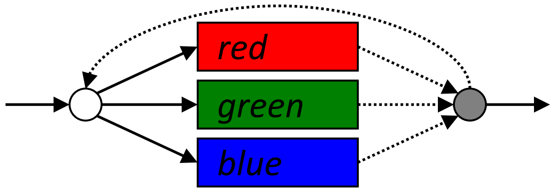
Using Backpointers

- The Backpointer table in the previous figure only retains sufficient history to obtain the best hypothesis
- Sometimes we would like to retain additional information in the backpointer table that tells us what other words were considered (not pruned out) during recognition
  - e.g. when we want to create lattices for finding N-best hypotheses or to compute confidence
- In this case the backpointer table is expanded to include *all* trellis nodes at the final states of words
  - Additionally, all trellis nodes corresponding to non-emitting nodes may also be stored

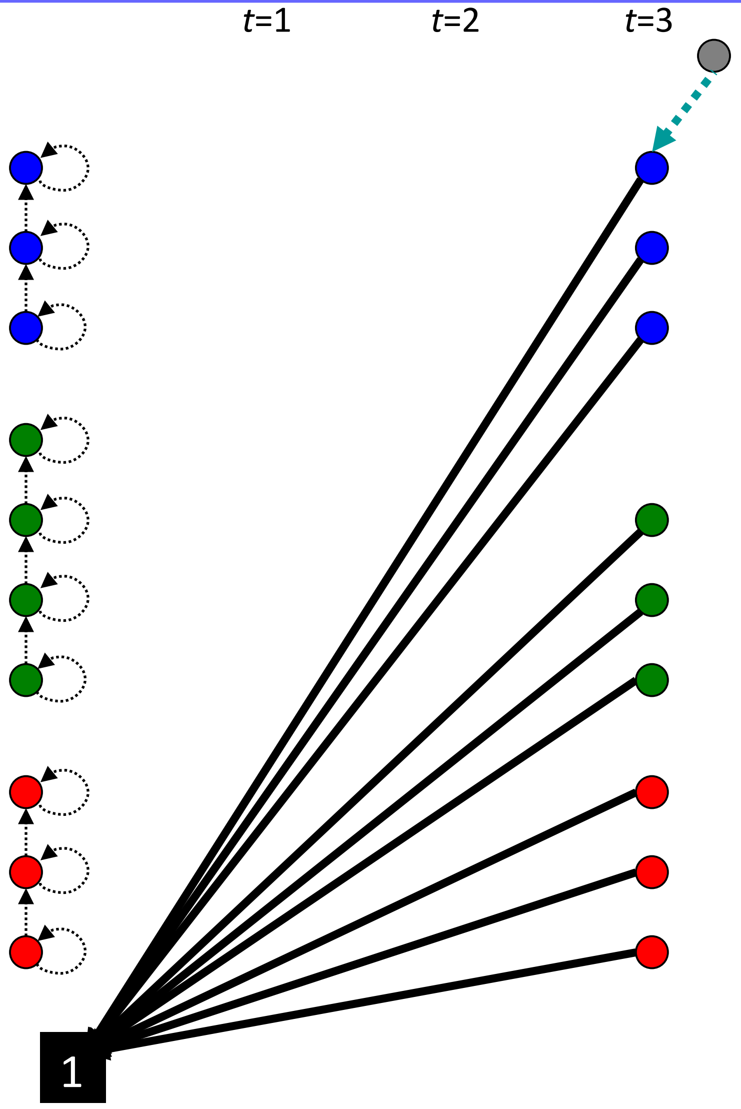
Regular BP Table



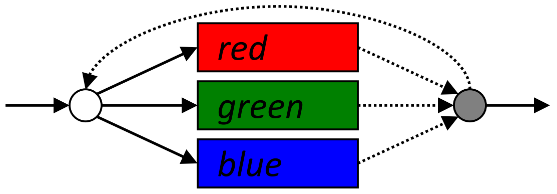
1, t=0, scr1,p=0,…



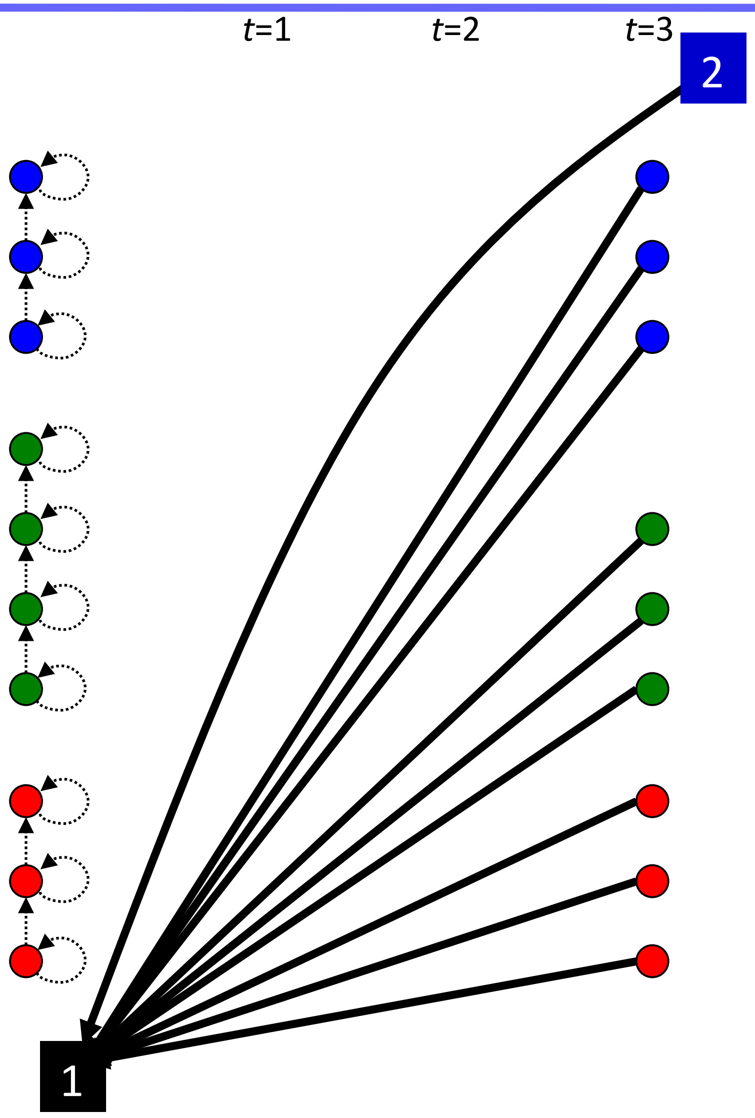
Regular Trellis



1, t=0, scr1,p=0,…

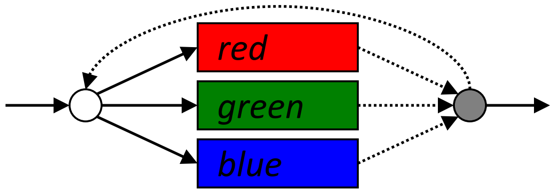


Regular Trellis

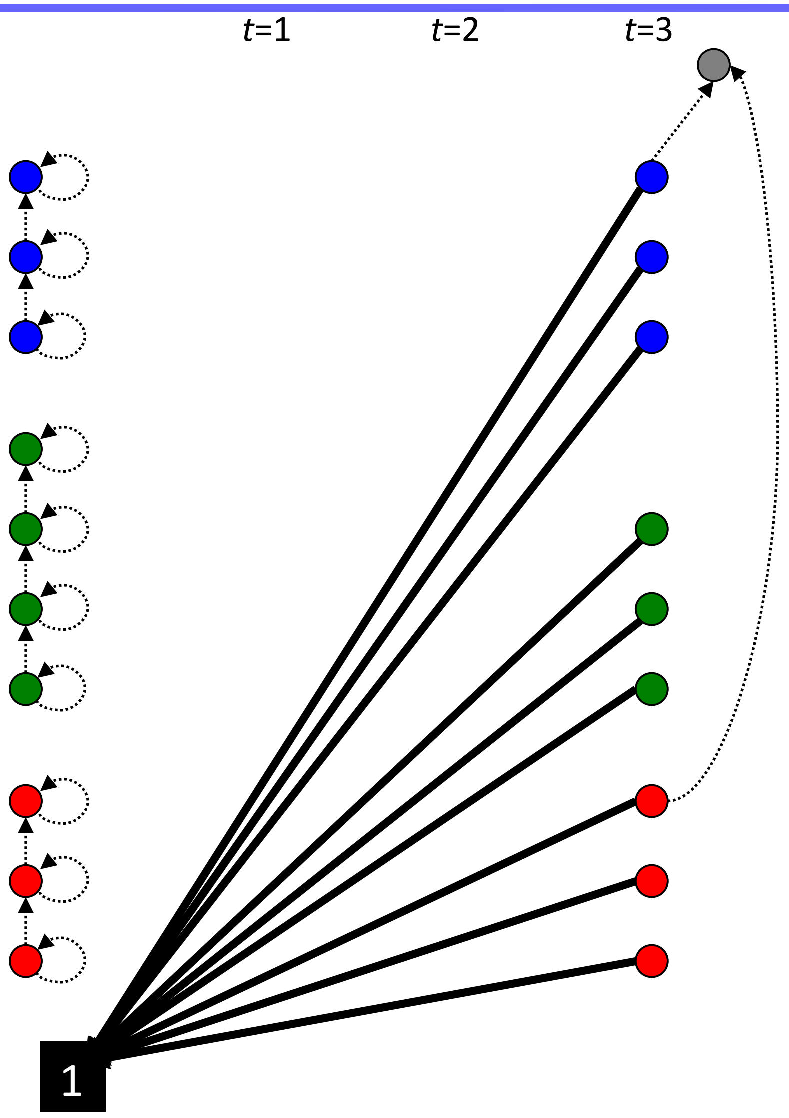


1, t=0, scr1,p=0,…

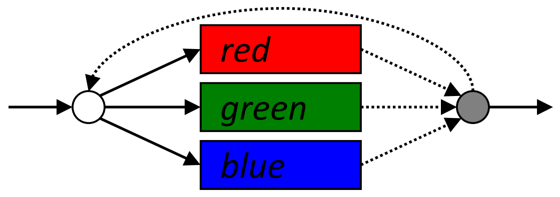
2, t=3, scr2,p=1,…



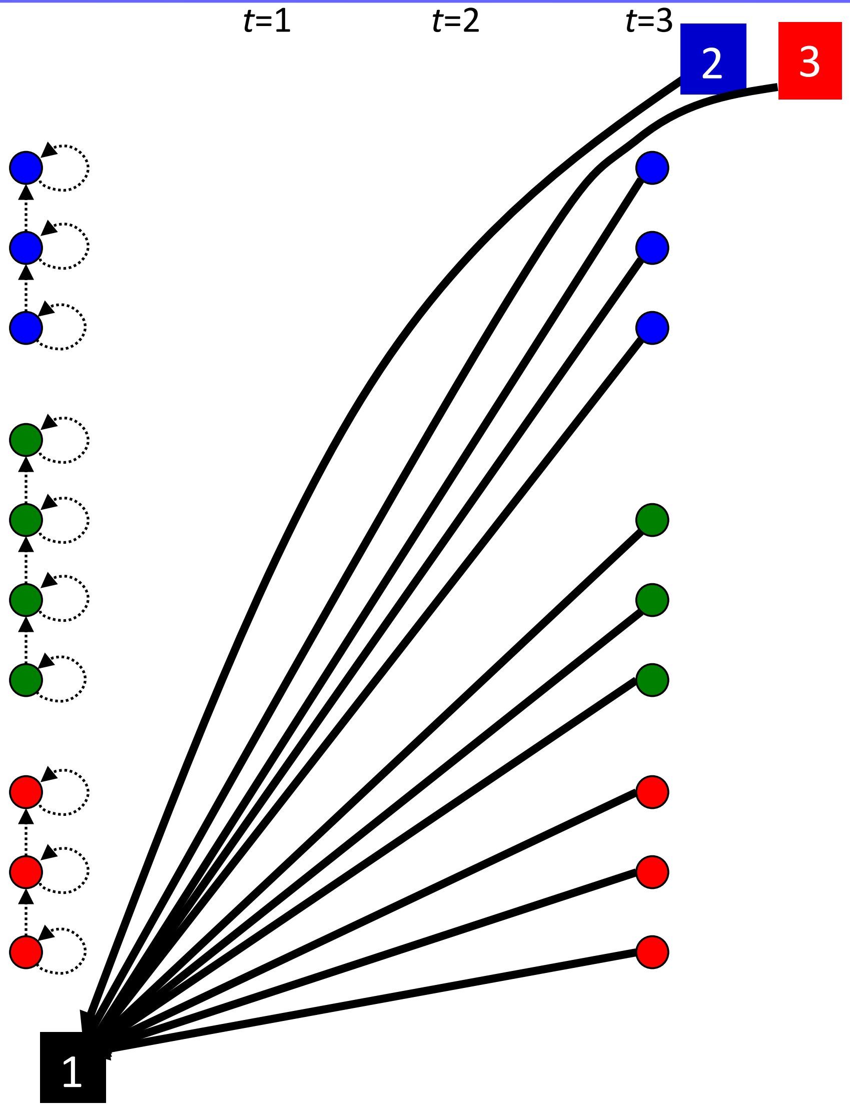
EXTENDED TRELLIS



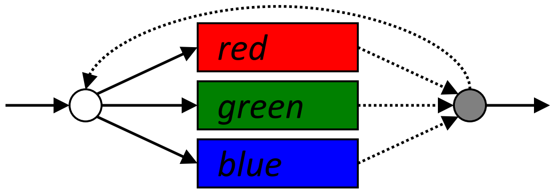
1, t=0, scr1,p=0,…



EXTENDED TRELLIS

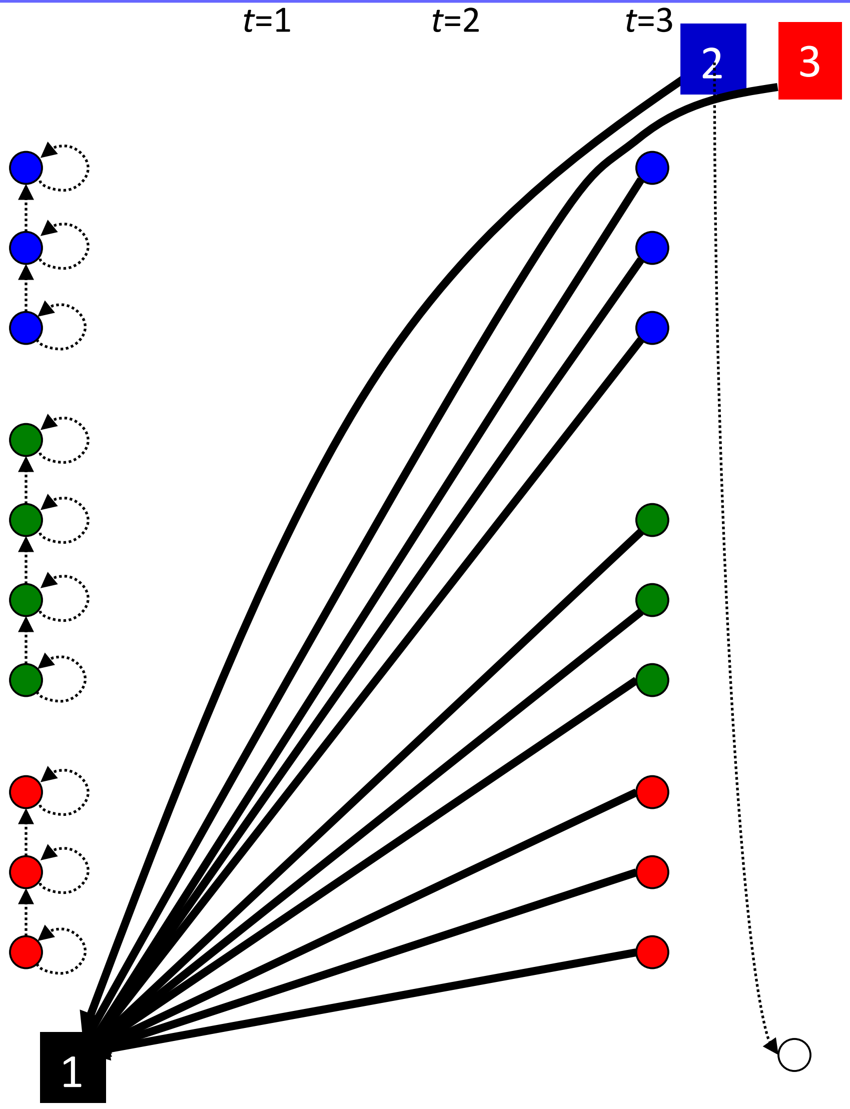


1, t=0, scr1,p=0,…
2, t=3, scr2,p=1,…
3, t=3, scr3,p=1,…

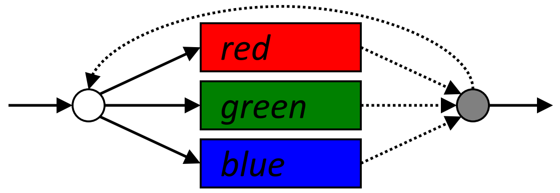


FAILED cross-word transitions too enter the backpointer table

EXTENDED TRELLIS



1, t=0, scr1,p=0,…
2, t=3, scr2,p=1,…
3, t=3, scr3,p=1,…



FAILED cross-word transitions too enter the backpointer table
BUT DO NOT PROPAGATE FURTHER

Using Backpointers

- Even with extended backpointer sets (including word ending and null-state entries), back pointer tables can be much smaller than retaining a full backpointer matrix, one for each trellis node

- Backpointers need not be stored as tables. They can, in fact be stored explicitly in tree format

- The entries in the backpointer table may also contain information about the *forward* transition
  - E.g. word-ending lattice-node backpointer table entries may additionally point forward to the subsequent null-state
  - This information may be used to derive lattices directly from BP tables

Decoding – finesse

- The final computational and memory expense of decoding depends on the *size* of the language HMM
- When composed from HMMs of words (or phonemes, as we will see later), it can get quite large
  - Particularly from redundant non-emitting states
- The HMM must be *minimized*
  - Topic for another day..