Transforming Timed Influence Nets into Time Sliced Bayesian Networks

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System Architectures Lab
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Outline

- Introduction of Time Sliced Bayesian Networks and Timed Influence Nets
- Need for the transformation algorithm.
- Explanation of the transformation algorithm
- Application of the algorithm
- Conclusions and future research direction

Advantages of Probabilistic Belief Networks

64 probability values are required to represent the joint distribution of 6 binary state variables, i.e., $2^6 = 64$

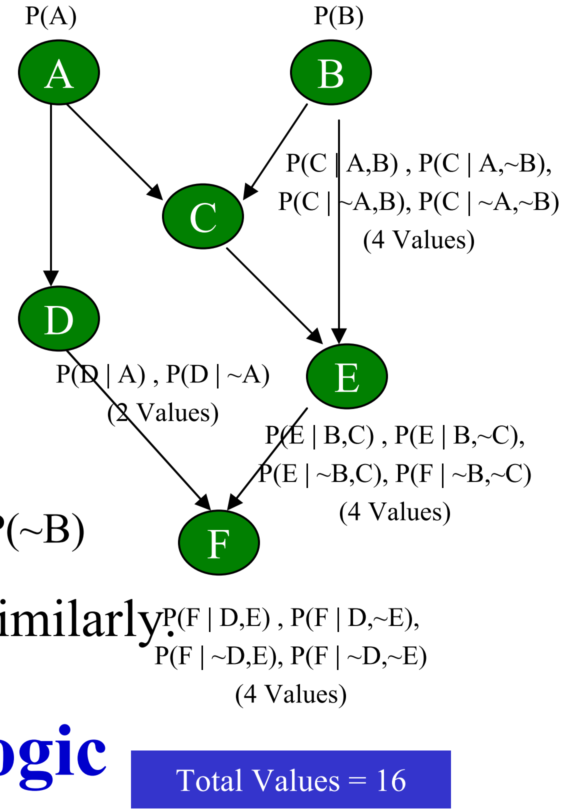
Probabilistic Network representations can reduce this number significantly

The joint distribution is computed as

P(A,B,C,D,E,F) = P(F | D,E)P(D | A)P(E | B,C)P(C | A,B)P(A)P(B)

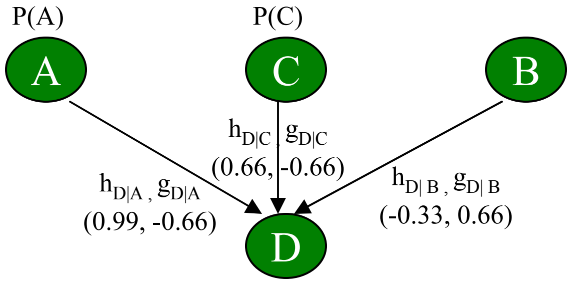
P(A,B,~C,~D, E,F) = P(F | ~D,E)P(~D | A)P(E | ~B,C)P(C | A,~B)P(A)P(~B)

Probabilities for other 62 combinations can be found out similarly.



CAusal STrength (CAST) Logic

- Inputs have ranges from –1 to 1.
- $h_{D|A}$ is analogous (but not equal) to P(D | A) while $g_{D|A}$ is analogous (but not equal) to P(D | ~A).



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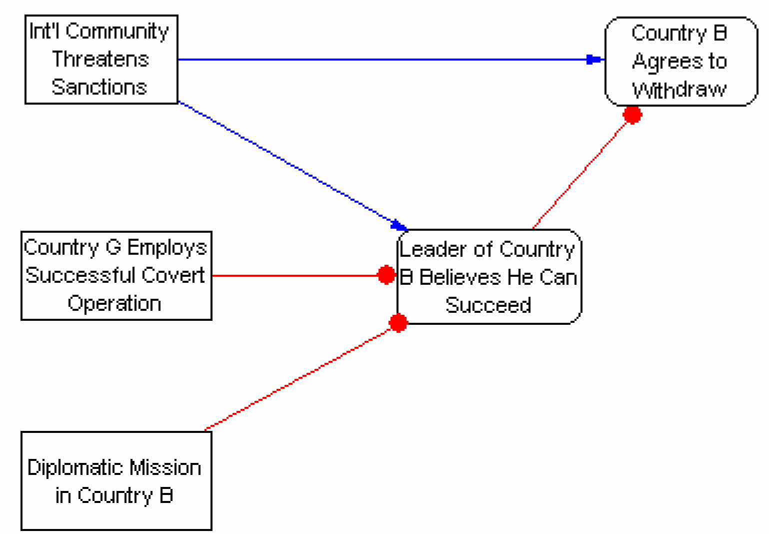
Influence Nets

Probabilistic Belief Networks that use CAST Logic for model specification are termed as Influence Nets.

The current implementation of Influence Nets assume that the parents of a node are marginally independent.

Root Nodes　　　Non-root Nodes

Root Nodes typically represents actionable events



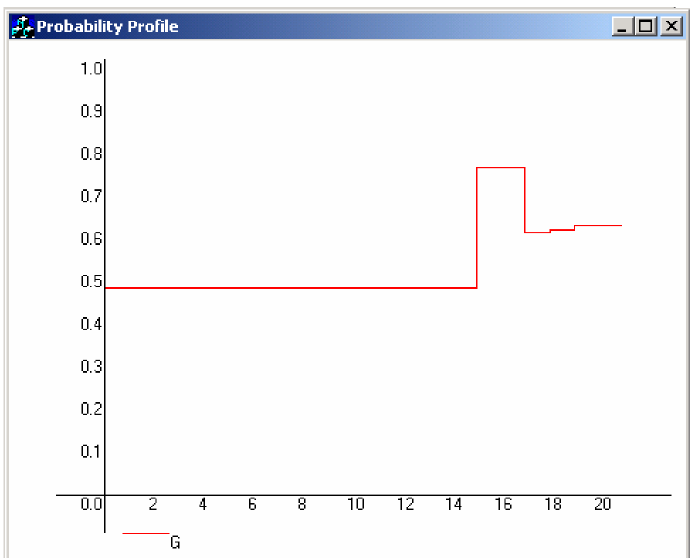
Positive Impact

Negative Impact

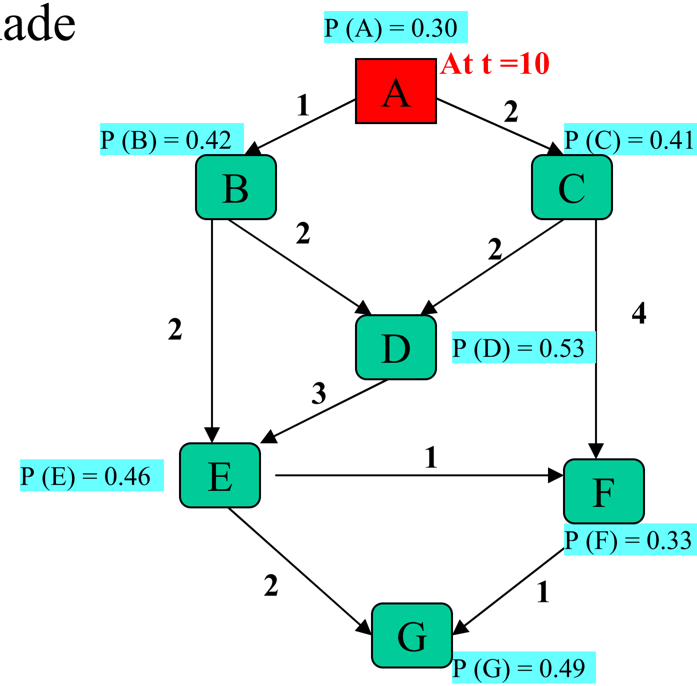
Timed Influence Nets

Timed Influence Nets have following additional parameters

- A time delay is associated with each arc.
- A time delay is associated with each node.
- Each actionable event is assigned time stamp(s) at which the decision(s) regarding the state of that action is(are) made



0	0.488
15	0.771
17	0.616
18	0.624
19	0.632



A: t = 10 B: t = 11 C: t = 12 D: t = 13, 14 E: t = 13, 16, 17

F: t = 14, 16, 17, 18 G: t = 15, 17, 18, 19

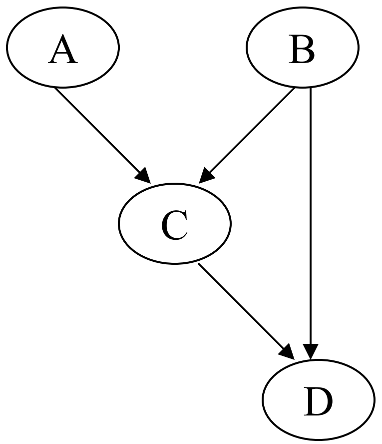
Time Sliced Bayesian Network

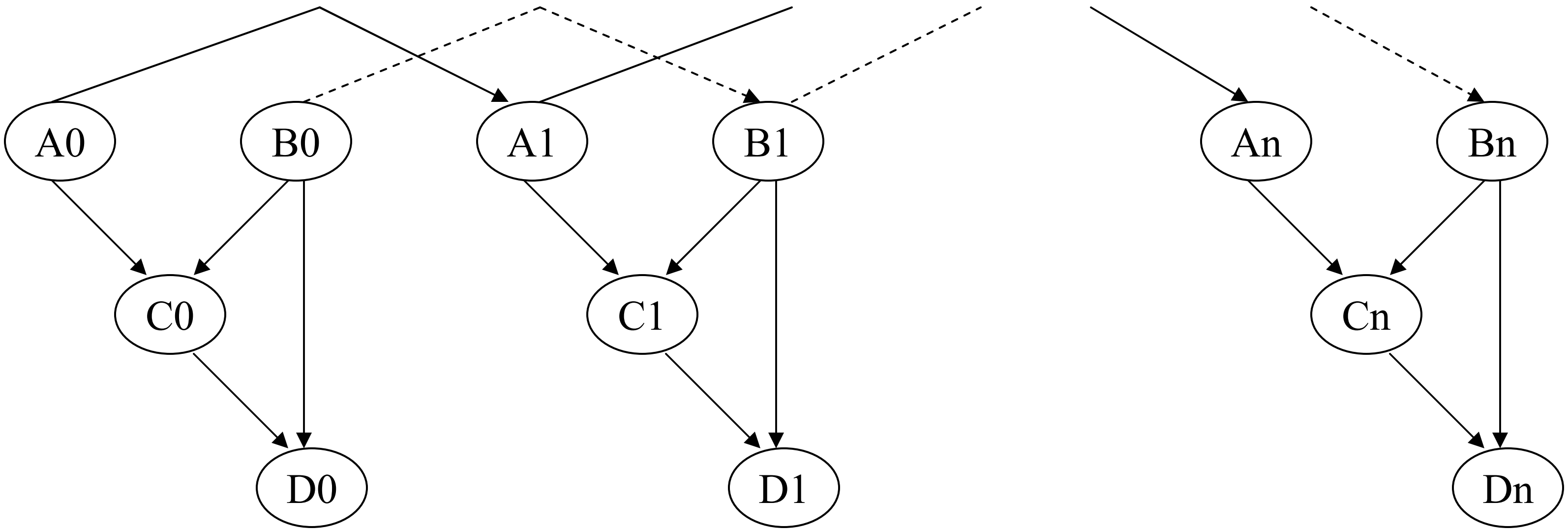
The text book approach of building TSBN is

Specify a static Bayesian Network

Specify the temporal dependencies that exist between the nodes in different time slices.

Unroll the model for a given number of time slices.

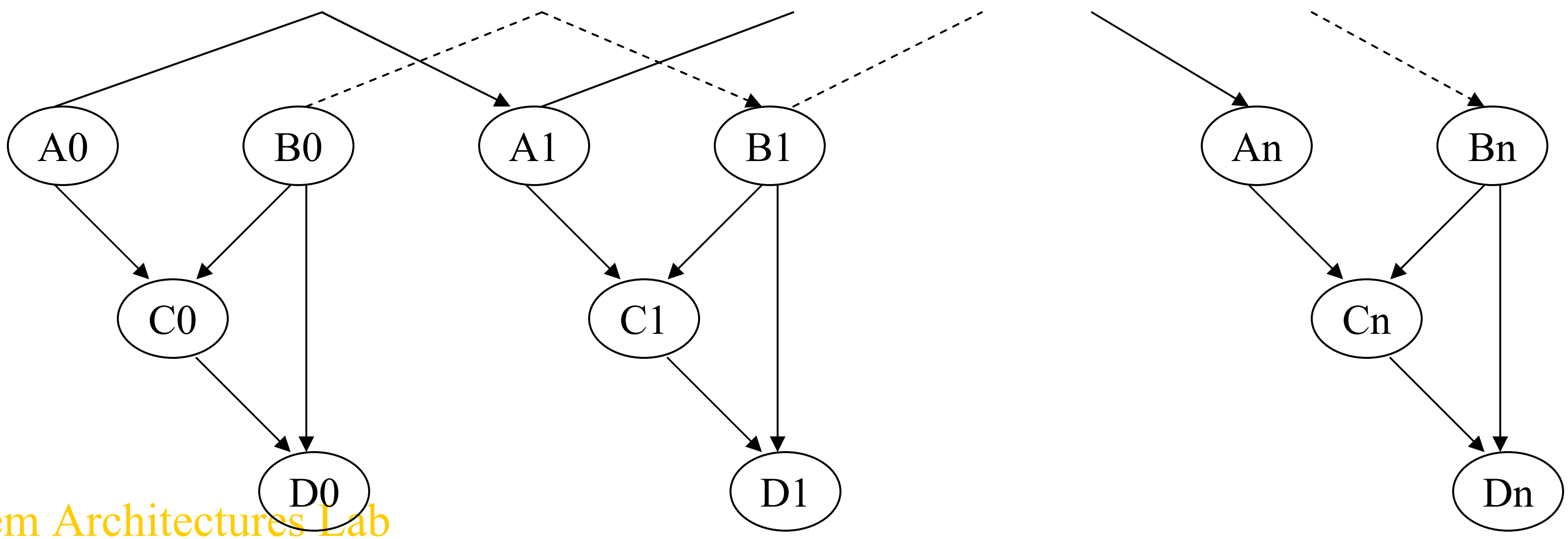




Time Sliced Bayesian Network (Cont..)

A TSBN is a Bayesian Network where

- Nodes are indexed by time
- Time is integer valued and begins at zero
- The local distribution for a variable can depend on
  - any variable that precedes it in time
  - variables at the same time that are prior to it in node ordering



Motivation

Advantages of TINs

- Simpler knowledge elicitation
- Courses of Actions (COA) specification is easier
- Model Reading is easier

Disadvantages of TINs

- Limited capability for execution monitoring

Advantages of TSBNs

- Variety of algorithms available for execution monitoring

Disadvantages of TSBNs

- Knowledge elicitation is intractable
- Model Reading is not easy

Pre-Processing of TIN

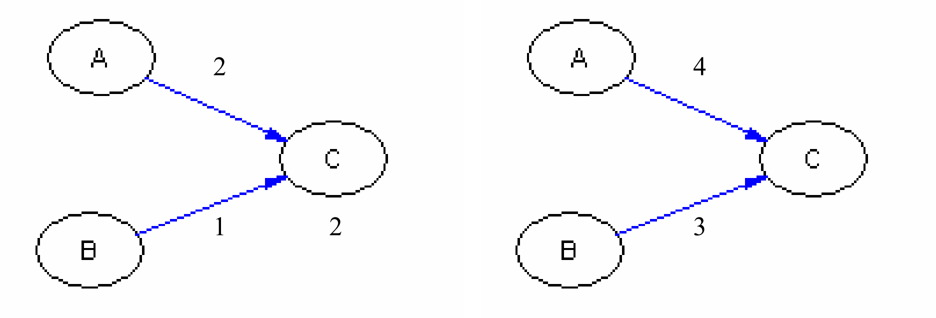
Let TIN = (V, E, P, D_V, D_E, A) where

V: Set of Nodes E: Set of Edges P: Joint Distribution of Random Variables

D_V: Delay Associated with Nodes D_E: Delay Associated with Arcs

A: Input Scenario

Before executing the transformation algorithm the delays on the nodes are reassigned to the arcs



TIN = (V, E, P, D_V, D_E, A) → TIN = (V, E, P, D, A)

The Transformation Algorithm

Given TIN = (**V**, **E**, **P**, **D**, **A**)

1. Find the maximum path length between the root nodes and target nodes, i.e.,

M = $\max_{i,j}[P_{i,j}]$ where

$P_{i,j}$: path between nodes i and j such that i, k $\in$ V and $\neg\exists$ (k, i) $\in$ E

2. Construct a TSBN (**V1, E1, P1**) where

V1: $\forall\, v \in$ **V** add v_i to **V1** where i = 0, 1, …, M

= $\{v_i \mid v \in$ **V**, i = 0, 1, …., M$\}$

E1 = $\{(x_i, y_j) \mid$ i = max (0, j – D(x, y)); x, y $\in$ **V** and i, j = 0, 1, …., M$\}$

P1: **P** when indices are ignored

For example, $P(y_i \mid x_i) = P(y \mid x)$ when x, y $\in$ **V** and x_i, $y_j \in$ **V1**.

This step draws the nodes in the TSBN for M time slices. The connections are drawn between the non-root nodes and their parents. The following step is required once an input scenario is determined.

3. Let S = maximum time stamp associated with the root nodes as provided by the input scenario:

(Add S additional time slices in the TSBN obtained in the previous step by following the procedure outlined in Step 2.

(The resultant network is the modified TSBN (**V1, E1, P1**) where

V1 = $\{v_i \mid v \in$ **V**, i = 0, 1, …., M+S$\}$

E1 = $\{(x_i, y_j) \mid$ i = max (0, j – D(x, y)); x, y $\in$ **V** and i, j = 0, 1, …., M+S $\}$

P1: **P** when indices are ignored

(Let **R1** = Set of Root Nodes where **R1** $\subset$ **V1**. $\forall\, r \in$ **R1** connect r_{t-1} to r_t where t = 1, 2, …, M+S, unless t is the time at which the variable is set to a state.

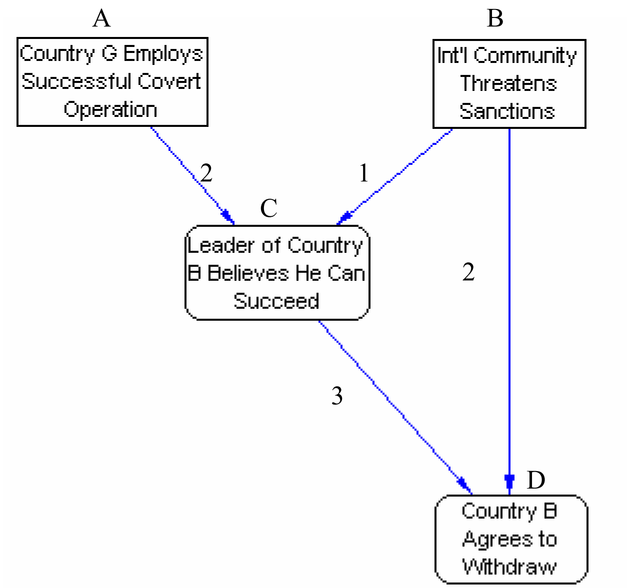
Step 1 Of the Algorithm

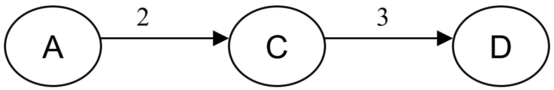
Given TIN = (**V, E, P, D, A**)

1. Find the maximum path length between the root nodes and target nodes, i.e.,

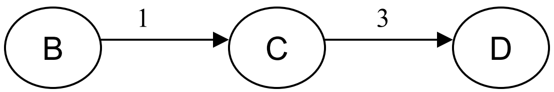
$M = \max_{i,j}[P_{i,j}]$ where

$P_{i,j}$: path between nodes i and j such that i, k $\in$ V and $\neg\exists$ (k, i) $\in$ E

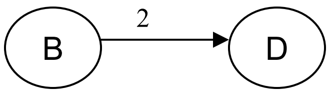




Path Length: 5



Path Length: 4



Path Length: 2

Step 2 Of the Algorithm

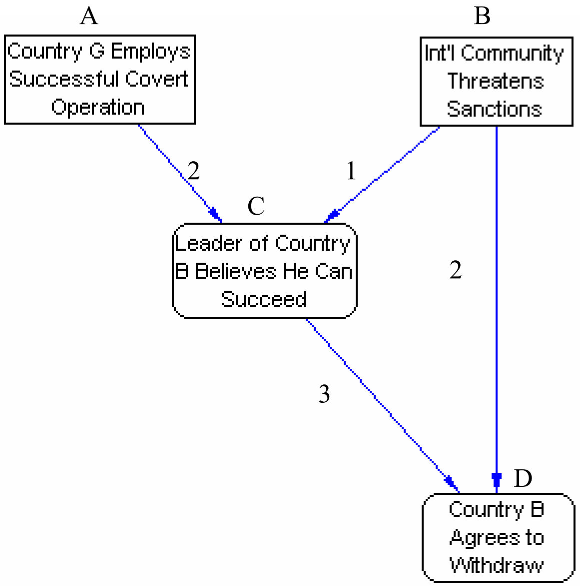
2. Construct a TSBN (**V1, E1, P1**) where

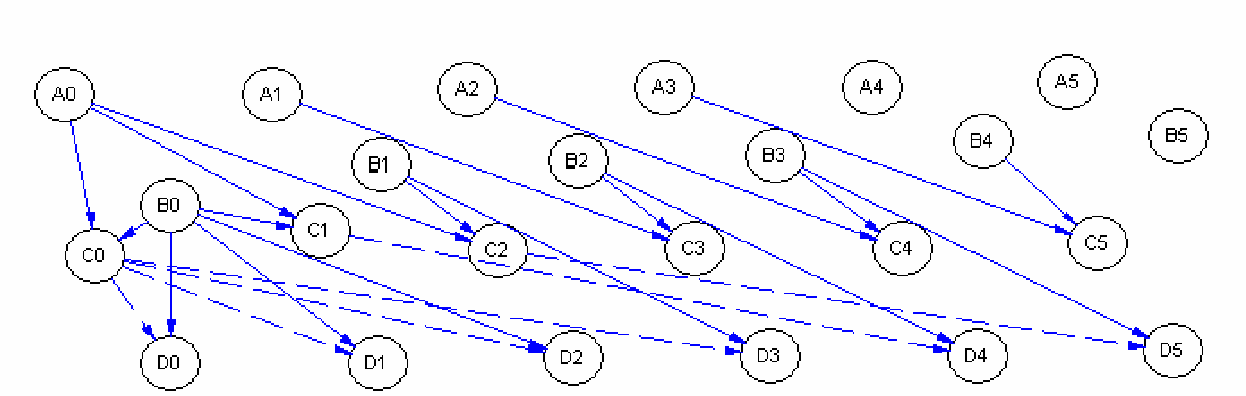
V1: $\forall\ \nu \in$ **V** add ν_i to **V1** where i = 0, 1, …, M

= $\{\nu_i \mid \nu \in$ **V**, i = 0, 1, …., M$\}$

E1 = $\{(x_i, y_j) \mid i = \max(0, j - D(x, y));\ x, y \in$ **V** and i, j = 0, 1, …., M$\}$

P1: **P** when indices are ignored





Step 3 Of the Algorithm

3. Let S = maximum time stamp associated with the root nodes as provided by the input scenario:

(a) Add S additional time slices in the TSBN obtained in the previous step by following the procedure outlined in Step 2.

(b) The resultant network is the modified TSBN (**V1, E1, P1**) where

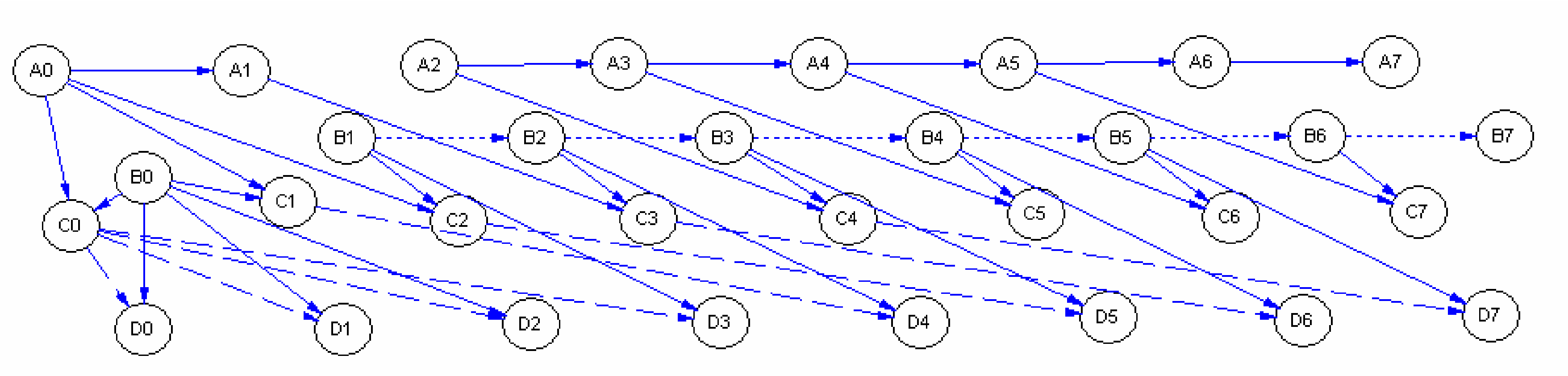
V1 = $\{v_i \mid v \in$ **V**, i = 0, 1, …., M+S$\}$

E1 = $\{(x_i, y_j) \mid i = \max(0, j - D(x, y)); x, y \in$ **V** and i, j = 0, 1, …., M+S $\}$

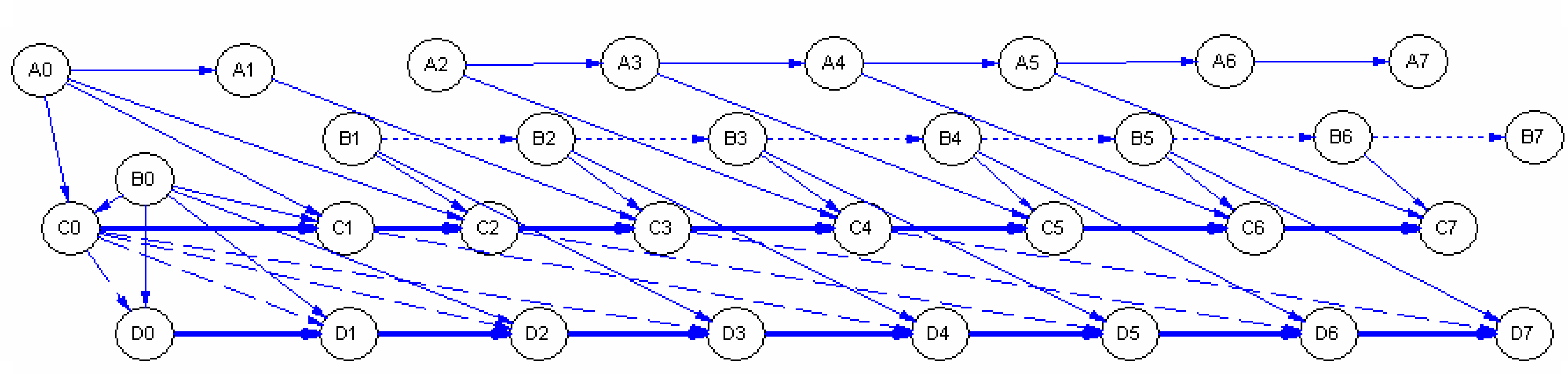
P1: **P** when indices are ignored

(c) Let **R1** = Set of Root Nodes where **R1** $\subset$ **V1**. $\forall r \in$ **R1** connect r_{t-1} to r_t where t = 1, 2, …, M+S, unless t is the time at which the variable is set to a state.

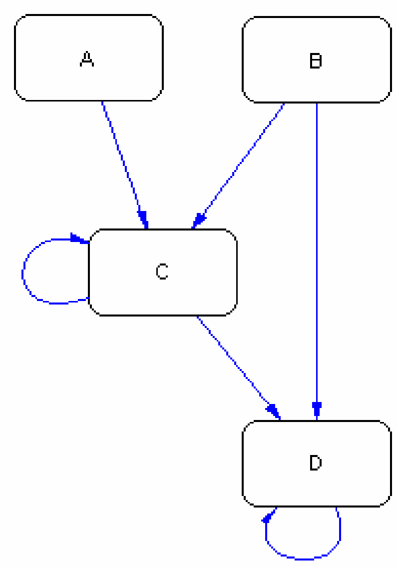
Let A is taken at time 2 while B is taken at time 1



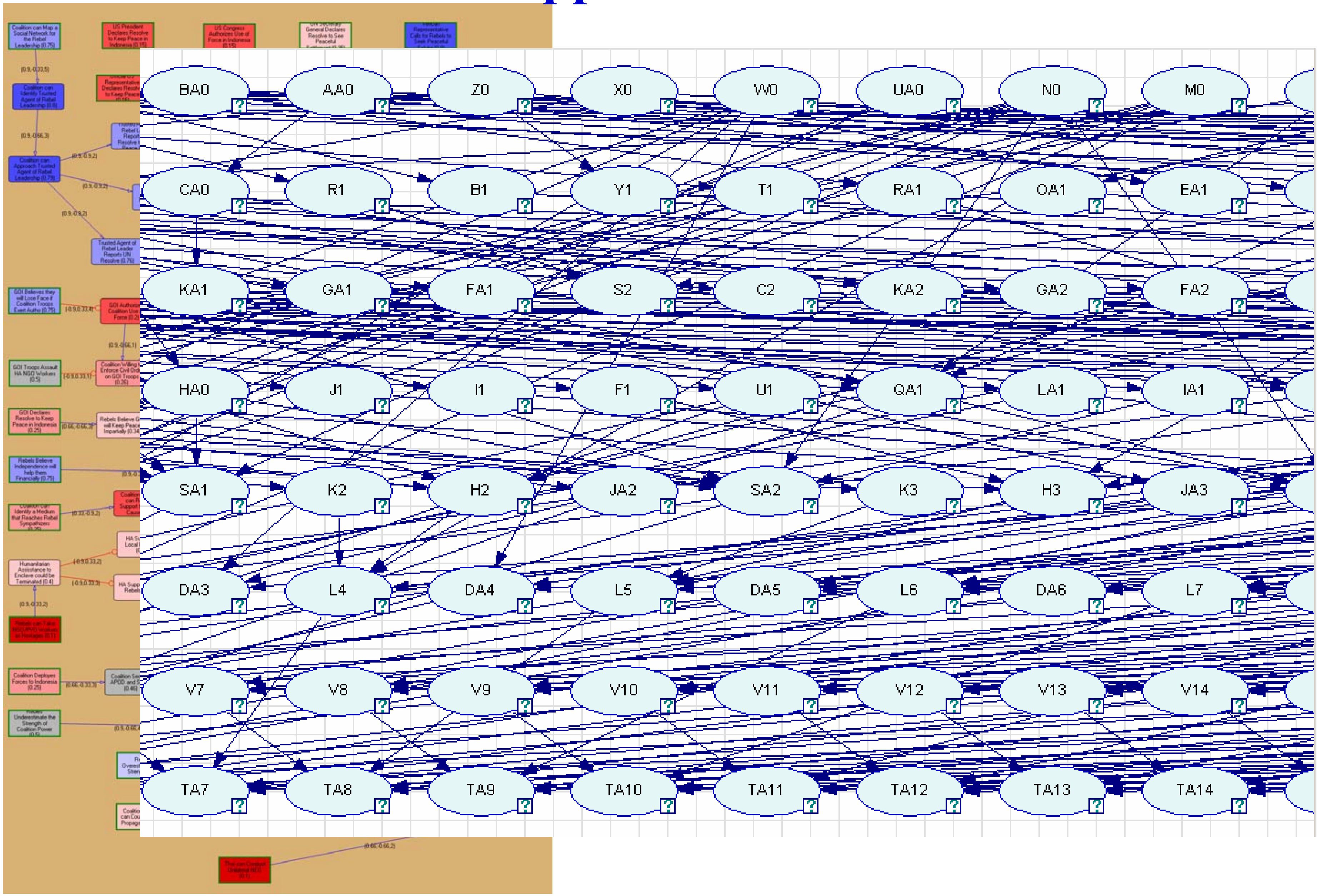
Temporal Dependencies Among Non-Root Nodes



A self-loop can be added to the Influence Net that represents the dependency among a non-root node (or represents memory)



Application



Conclusions

- An algorithm is presented that transforms TINs into TSBNs.
- TINs are easier to use for
  - ❑Knowledge elicitation
  - ❑COA specification
  - ❑Understanding model
- TSBNs are good for belief updating.
- The idea is to use
  - ❑TINs as a front end tool for model building and course of action selection.
  - ❑Real-Time execution monitoring is accomplished by using the TSBN as a back end tool.