Dynamic Influence Nets: An Extension of Timed Influence Nets for Modeling Dynamic Uncertain Situations

Sajjad Haider

Alexander H. Levis

June 14, 2005

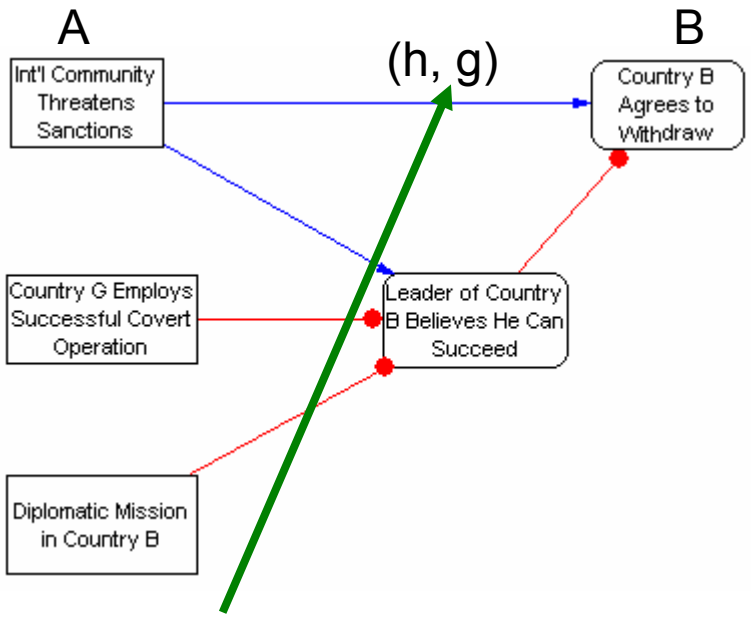
10th International CCRTS, McLean VA

Outline of the Presentation

- Technical Background
  - Influence Nets
  - Timed Influence Nets
- Limitations of Timed Influence Nets
  - Different sequences of Actions have no impact on the final probability of achieving a desired effect
  - Influences are assumed to be time-invariant
- Proposed Methodology
  - Adding memory to the nodes in a TIN
  - Modeling of time-varying influences
- Dynamic Influence Nets
- Conclusions

Influence Nets

- **A set of random variables that makes up the nodes of an IN. All the variables in the IN have binary states.**
- **A set of directed links that connect pairs of nodes.**
- **Each link has associated with it a pair of parameters that shows the causal strength of the link (usually denoted as h and g values).**



h is Influence of A on B: Analogous to P(B | A)

g is Influence of ¬A on B: Analogous to P(B | ¬A)

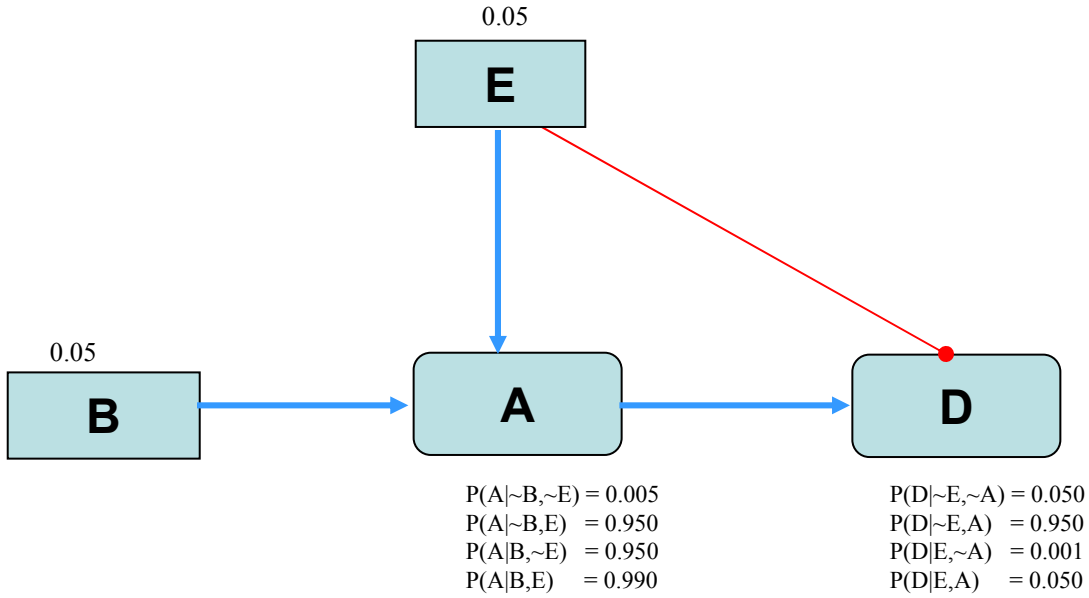
Positive Impact

Negative Impact

Root Nodes

Non-root Nodes

Probability Propagation in Influence Nets



$$P(A) = P(A|\sim B,\sim E)P(\sim B)P(\sim E) + P(A|\sim B,E)P(\sim B)P(E) + P(A|B,\sim E)P(B)P(\sim E) + P(A|B,E)P(B)P(E)$$
$$= 0.005 \times 0.95 \times 0.99 + 0.95 \times 0.95 \times 0.01 + 0.95 \times 0.05 \times 0.99 + 0.99 \times 0.05 \times 0.01$$
$$= 0.06$$

$$P(D) = P(D|\sim E,\sim A)P(\sim E)P(\sim A) + P(D|\sim E,A)P(\sim E)P(A) + P(D|E,\sim A)P(E)P(\sim A) + P(D \mid E, A)P(E)P(A)$$
$$= 0.05 \times 0.99 \times 0.94 + 0.95 \times 0.99 \times 0.06 + 0.001 \times 0.01 \times 0.94 + 0.05 \times 0.01 \times 0.06$$
$$= 0.11$$

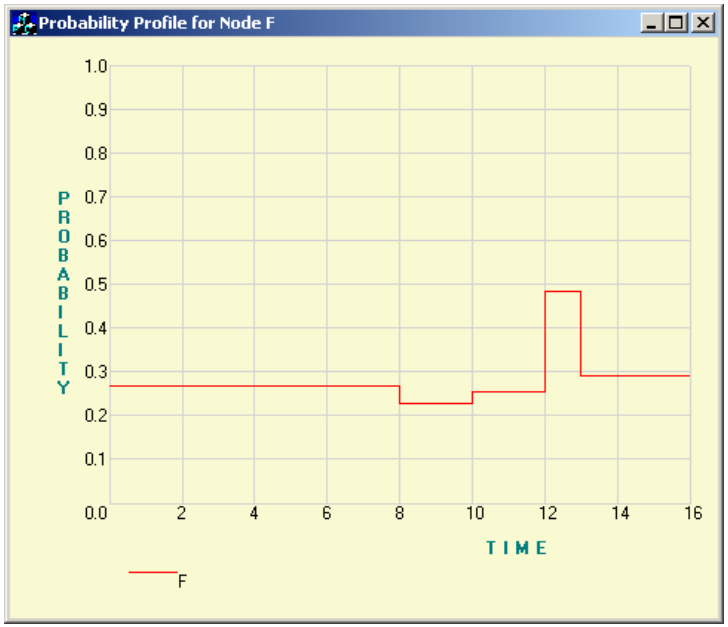
Specification of a Timed Influence Net

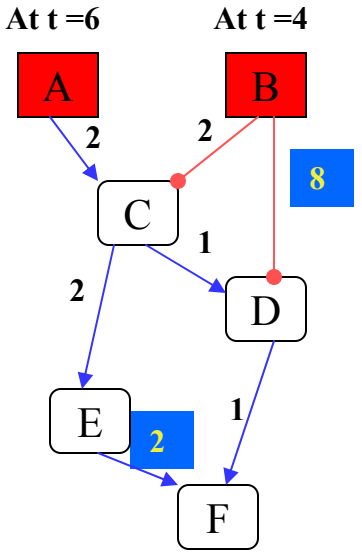
The specification of a TIN require the following additional parameters besides the one required for by an ordinary IN:

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





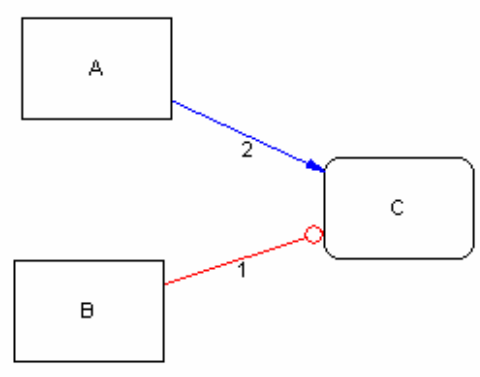
Problem Statement

Given

- **A Dynamic Uncertain Situation**
- **A Set of Desired Effects**
- **A Set of Actionable Events**
  - **How to capture certain dynamic situations**
    - **Modeling of time-varying influences**
      - **Strength of the influence changes over time**
      - **Influence vanishes over time**
    - **Modeling of memory to help in identifying**
      - **Impact of repetitive actions on the desired effects**
      - **Impact of different sequence of actions on the desired effect**

Time-Varying Influence (Persistence of Influence)

- **Current implementation of TINs models time-invariant influences**
- **A scheme is proposed for modeling time-varying influences**
- **A list of influences along with their time of effect is specified for each arc in a TIN**
- **The proposed scheme can be used to model time-dependent structural changes in a TIN**



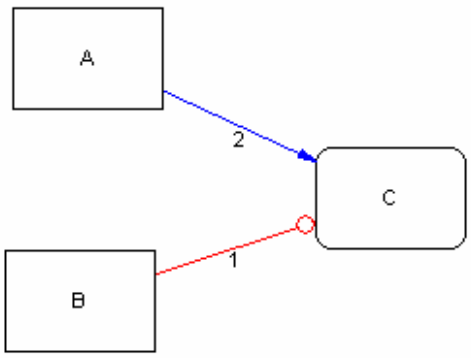
Influence of A on C when information at A is t time units old
Strong: $2 \leq t < 4$
Moderate: $4 \leq t \leq 6$
Low: $t > 6$

Influence of B on C when information at B is t time units old
Strong: $1 \leq t < 3$
Low: $t > 3$

Time-Varying Influence (Cont'd)

P(A) = 0.05 @ 0
= 1.0 @ 4

P(B) = 0.1 @ 0
= 0.6 @ 7
= 1.0 @ 10



Influence of A on C when information at A is t time units old
Strong: $2 \leq t < 4$
Moderate: $4 \leq t \leq 6$
Low: $t > 6$

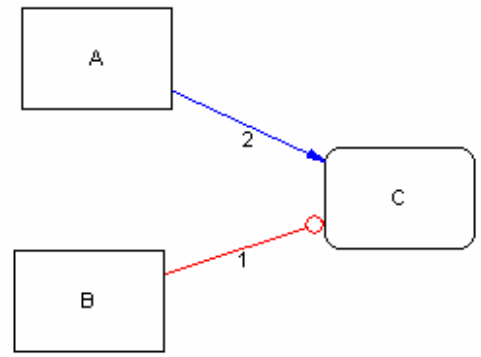
Influence of B on C when information at B is t time units old
Strong: $1 \leq t < 3$
Low: $t > 3$

- **C is updated at time: 6, 8, 11**
- **At time 6: P(A) @ 4 is used, while P(B) @ 0 is used**
  - **Information coming from A is 2 time units old**
  - **Information coming from B is 6 time units old**
    - **C has strong influence of A and low influence of B at time 6**
- **At time 8: P(A) @ 4 is used, while P(B) @ 7 is used**
  - **Information coming from A is 4 time units old**
  - **Information coming from B is 1 time units old**
    - **C has moderate influence of A and strong influence of B at time 8**

Non-Stationary Conditional Probabilities

P(A) = 0.05 @ 0
= 1.0 @ 4

P(B) = 0.1 @ 0
= 0.6 @ 7
= 1.0 @ 10



Influence of A on C when information at A is t time units old
Strong: $2 \leq t < 4$
Moderate: $4 \leq t \leq 6$
Low: $t > 6$

Influence of B on C when information at B is t time units old
Strong: $1 \leq t < 3$
Low: $t > 3$

		Time	
Parents Combination	**6**	**8**	**11**
P(C|¬A,¬B)	**0.07**	**0.85**	**0.93**
P(C|¬A, B)	**0.03**	**0.02**	**0.03**
P(C| A,¬B)	**0.97**	**0.98**	**0.97**
P(C| A, B)	**0.93**	**0.15**	**0.07**

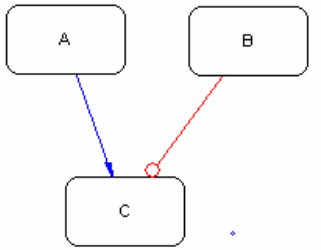
Problem Statement

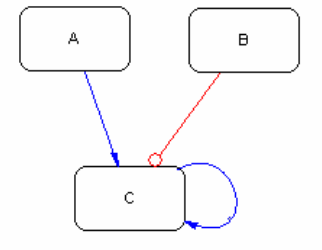
Given

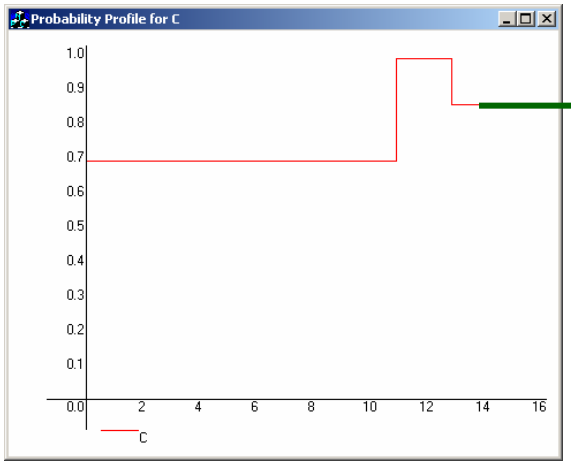
- ❑ **A Dynamic Uncertain Situation**
- ❑ **A Set of Desired Effects**
- ❑ **A Set of Actionable Events**
  - **How to capture certain dynamic situations**
    - **Modeling of time-varying influences**
      - **Strength of the influence changes over time**
      - **Influence vanishes over time**
    - **Modeling of memory to help in identifying**
      - **Impact of repetitive actions on the desired effects**
      - **Impact of different sequence of actions on the desired effect**

Adding Memory to the Nodes in a TIN

- Current implementation of TINs assume that the nodes are memoryless
  - The impact of different sequences of actions is not captured.
- An approach is proposed that adds memory to the nodes in a TIN
  - A self-loop is added to each node whose current state is dependent on its previous state.

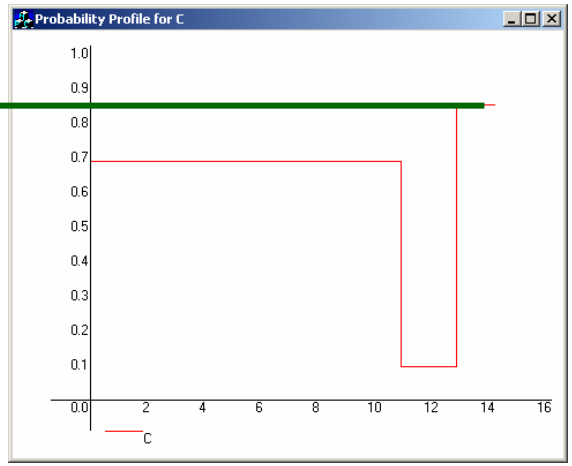






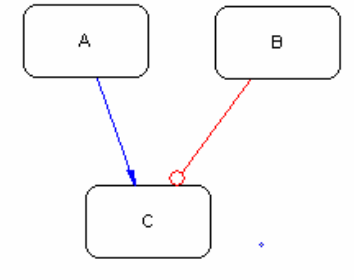
A @ 10, B @ 12

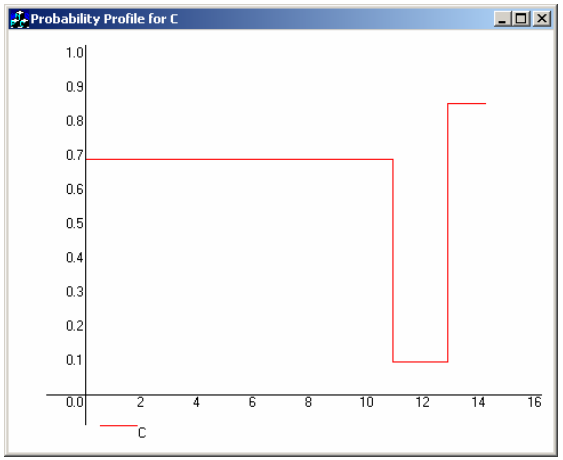
Same Final Probability

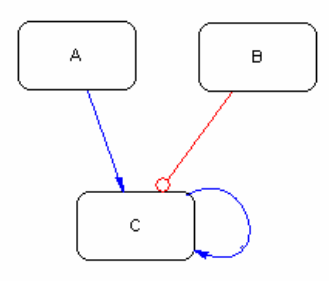


B @ 10, A @ 12

Adding Memory to the Nodes in a TIN (Cont'd)

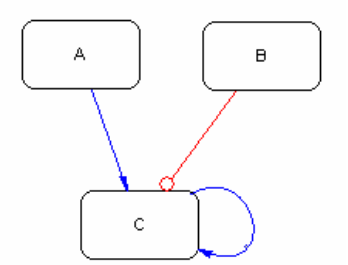




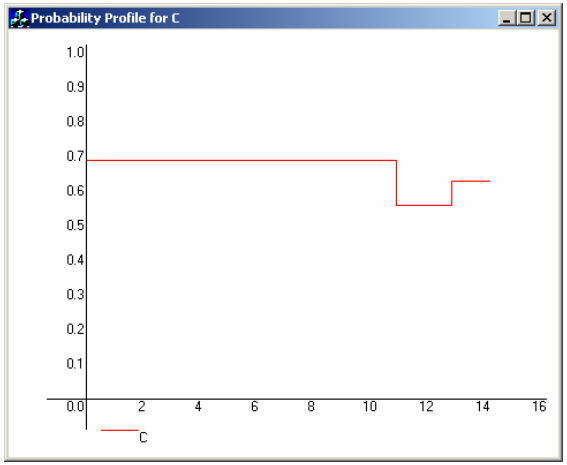


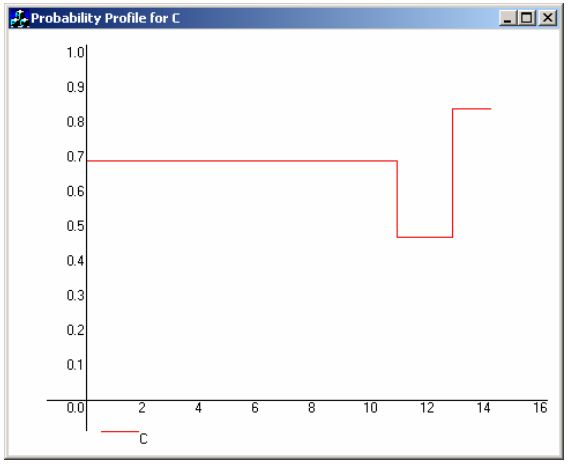
(0.33, -0.33)
Weak Memory

B @ 10, A @ 12



(0.90, -0.90)
Strong Memory

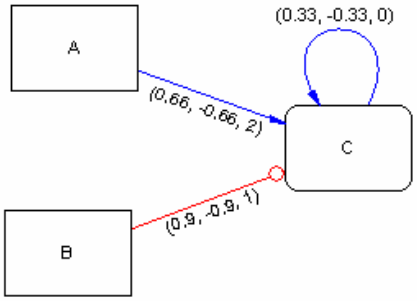




Dynamic Influence Nets

- **Timed Influence Nets with**
  - **Time-varying influences**
  - **Memory represented by a self-loop**

P(A) = 0.05 @ 0
= 1.0 @ 4

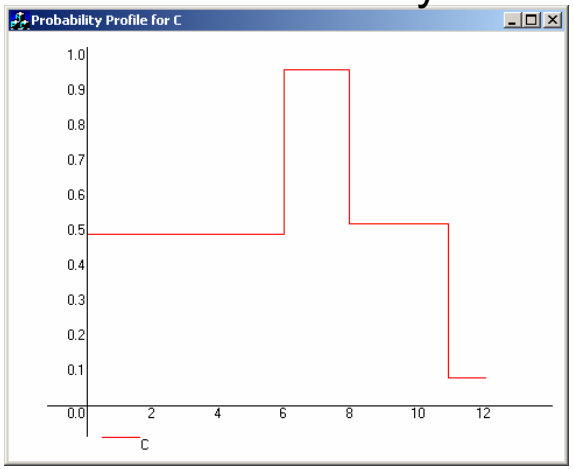


P(B) = 0.1 @ 0
= 0.6 @ 7
= 1.0 @ 10

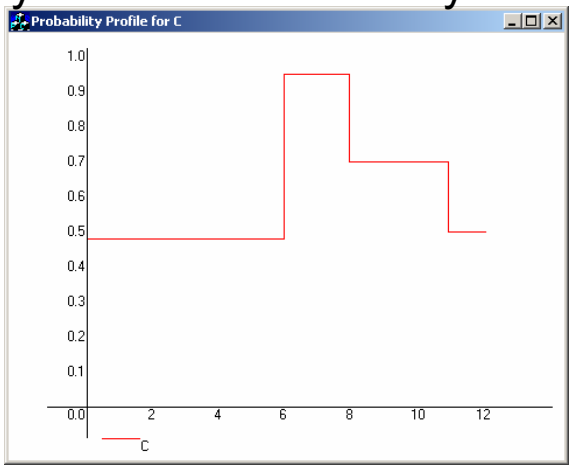
Influence of A on C when information at A is t time units old
Strong: $2 \leq t < 4$
Moderate: $4 \leq t \leq 6$
Low: $t > 6$

Influence of B on C when information at B is t time units old
Strong: $1 \leq t < 3$
Low: $t > 3$

Probability Profile Produced by a DIN



Probability Profile Produced by a TIN



Summary

- Extended the knowledge elicitation interface of TINs so that they can capture time-varying cause-effect relationship
  - Instead of providing a single-valued strength of cause-effect relationship, a system modeler can specify multi-valued strengths of cause-effect relationship along with their time of effectiveness
- Added a mechanism to incorporate memory in a TIN to capture the impact of repetitive actions and different sequence of actions on the desired effect
  - A self-loop is added to a node that captures memory of the node
  - The strength of the self-loop specify whether the modeled memory is weak or strong
- Together these two features capture the impact of repetitive actions

Questions?