Multi-Entity Bayesian Network (MEBN)

Unit # 8

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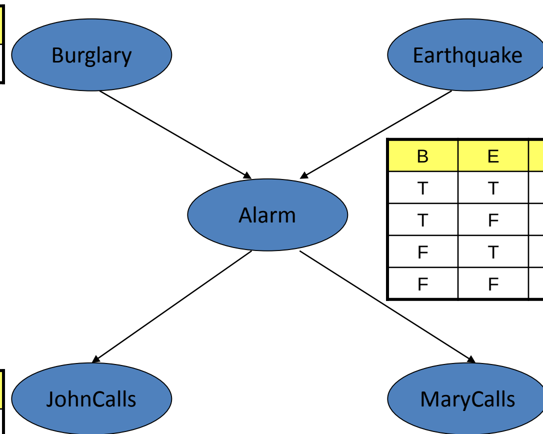
Bayesian Networks

- A Bayesian network is a probabilistic graphical model that represent a set of variables and their conditional dependencies via a directed acyclic graph.
- The innate ability of Bayesian networks to capture uncertainty has made them widely applicable in real-life domains that are non-deterministic in nature.

Earthquake Example (Pearl)



P(B)
0.1

P(E)
0.02

B	E	P(A|B,E)
T	T	0.95
T	F	0.94
F	T	0.29
F	F	0.001

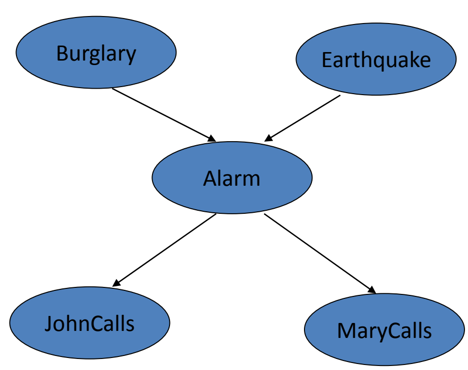
A	P(J|A)
T	0.9
F	0.05

A	P(M|A)
T	0.7
F	0.01

Propositional Logic Example

- E: there is an earthquake
- B: there is a burglary
- A: Alarm goes off
- J: John calls
- M: Marry calls

- E V B => A
- A=> J $\wedge$ M



Moving to FOL

- E: there is an earthquake
- B: there is a burglary
- A: Alarm goes off
- If x is a neighbor, x calls

- E V B => A
- A $\wedge$ neighbors (x) => calls(x)

Example

- *"Overall sale of a newly published book is highly influenced by the rating of its author(s). Author rating, in turn, is dependent on how good or bad the readers have rated his previous books"*

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Example

- What if an author has written multiple books?

Example

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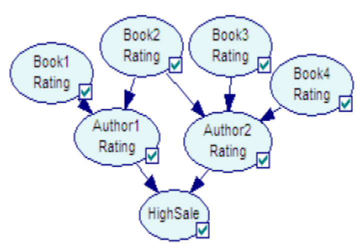
Example

- Similarly, some of the books may be written by multiple authors.



- The propositional nature of Bayesian network represents particular instances of real-world objects, rather than their generalized concept.

Propositional Logic

author1Rating ← book1Rating ∧ book2Rating ∧ book3Rating
book4Sale ← author1Rating

First-Order Logic

- The first-order logic based representation of the same scenario is given below:

Book(X); Author(Y); WrittenBy(X,Y)
AuthorRating(A)← WrittenBy(B,A), BookRating(B)
HighSale(B) ← WrittenBy(B,A), AuthorRating(A)

Bayesian Network - Limitation

- Bayesian networks are propositional in nature and represent particular instances of a domain rather than its generalized concept.
- This behavior limits their power of expression and hinders their use in variety of situations.

First-Order Logic - Limitation

- First-order logic (FOL) enjoys considerable power of expression necessary to model complex real-world situations.
- However, logics alone are deterministic in nature and that limits their applicability in uncertain environments.

Multi-entity Bayesian Network (MEBN)

- MEBN provides a framework to give logic based representation of Bayesian networks.
- MEBN was developed by Dr. Laskey's group at George Mason University, VA.
- MEBN overcomes the propositional nature of Bayesian networks and provides more power and flexibility to model complex real-world scenarios.
- MEBN is not a computer language such as Java or C++, or an application such as Netica or Hugin.
- Rather, it is formal system that instantiates first-order Bayesian logic.

MEBN

- MTheory
  - MFrag
    - Resident Nodes
    - Context Nodes
    - Input Nodes
- SSBN

RoboCup Soccer Simulation 3D

- Two teams of autonomous soccer agents play football with each other
- Key characteristics of RoboCup Soccer Simulation that makes it a challenging environment are:
  - Team based environment
  - Dynamic environment
  - Autonomous agents
  - Partial-observability
  - Limited communication among agents
  - High uncertainty due to locomotion, noisy perception and the presence of adversaries

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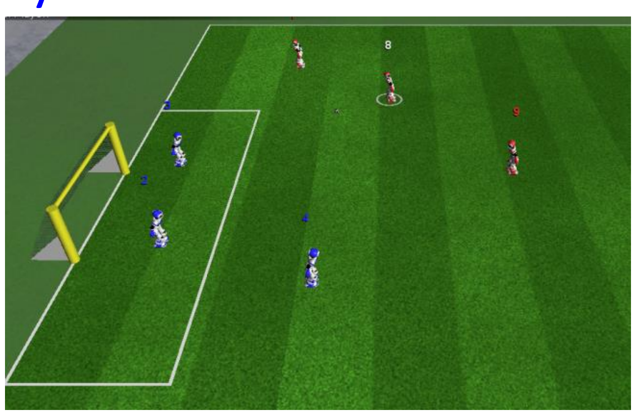
Bayesian Networks in Soccer



- The player in possession of ball has options to either dribble or shoot the ball or give it as pass to a fellow player.
- The player would keep into mind the possibility of pass interception by opponents and pass reception by teammates.

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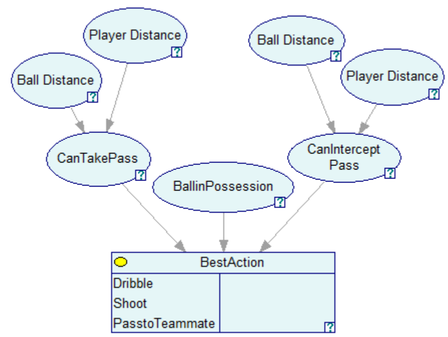
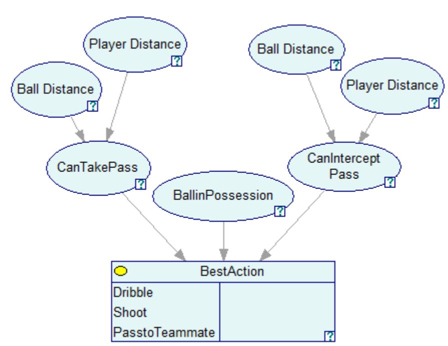
Bayesian Networks in Soccer

- Bayesian Network to predict best action of a player in the presence of a teammate and an opponent.
- Despite their wide acceptability, Bayesian networks are propositional in nature and lack power of expression required for representing knowledge in complex dynamic real-world.

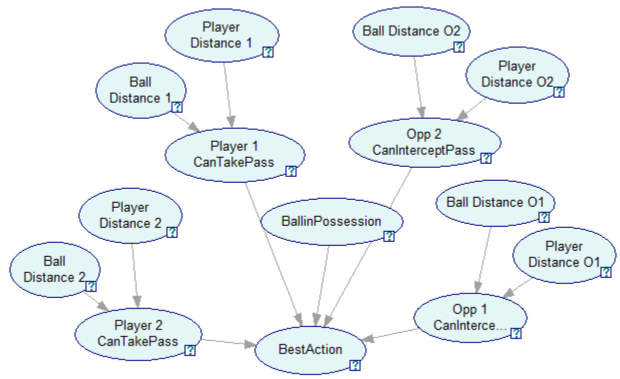


Limitation – Propositional Nature



- What if there are two teammates and two opponents around ?
  - The current model will not serve and we need a new model

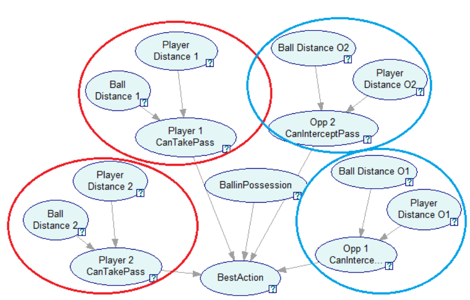
Limitation – Propositional Nature



- We need different Bayesian networks for different configuration of teammates and opponents.

Limitation – Lack of modularity

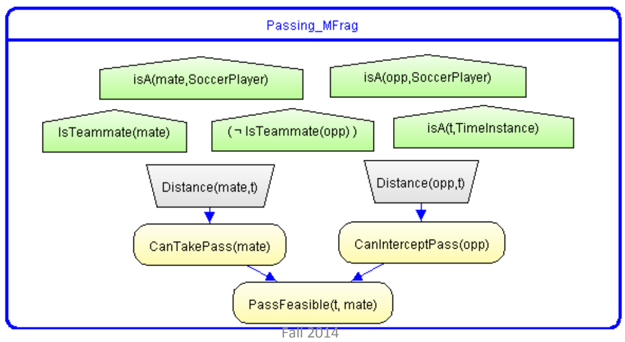
- For each teammates /opponents, we have to repeat certain structures



- As number of teammates/opponents grow, the model would become difficult to manage.

MFrag

- The key building block of a MEBN model is MFrag.
- Mfrag is to MEBN what class is to Object Oriented model
- An MFrag is a parameterized fragment of a MEBN model that groups interrelated random variables which collectively represent a single concept.



MFrag

- Mfrag contains three type of nodes:
  - *Resident Nodes*: The Yellow rectangles are resident nodes which are equivalent to the random variables in Bayesian networks and their probability distributions are defined in the same MFrag,
  - *Input Nodes*: The gray trapezoids are resident nodes defined in some other MFrag to maintain modularity and are used here as input nodes to connect two MFrags.
  - *Context Nodes*: The green pentagons are context nodes which are boolean in nature and must be evaluated to *True* in order for the given MFrag to be instantiated. The probability distribution exhibited by the resident nodes can only be applied if they satisfy all the context nodes in the MFrag.

Customized Local Probability Distribution

- MEBN provides a generalized language interface to define probability distributions. These distributions may look like:
  - *"If the ball is in opponent region surrounded by one or more opponent players, then giving the pass to a teammate (if possible) is the most favorable option (with probability 0.7). In the absence of such nearby teammates, 'Pass' is not a viable option and the player will decide either to dribble or shoot the ball depending upon the number of opponent players around."*

Customized Local Probability Distribution

Table 1– Local Probability Distribution in MEBN

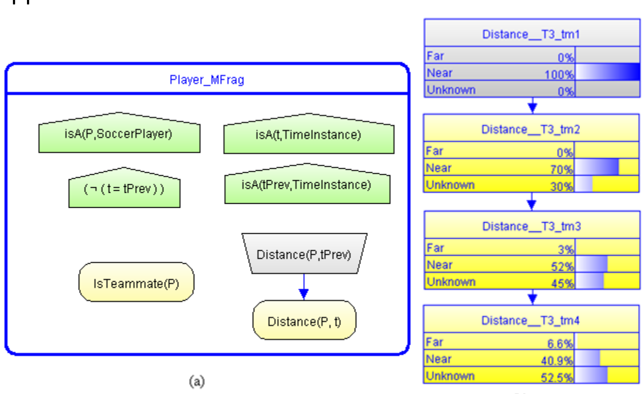
```
if any g have (BallinRegion=OpponentRegion) [
          if any opp have ( Distance=Near ) [
                    if any mate have (PassFeasible=true)
                              [Dribble = max(0; 0.3 - ( 0.1*cardinality(opp))),
                              Pass = 0.7,
                              Shoot = min(0.3; 0.1*cardinality(opp))]
                    else
                             [Dribble = max(0; 0.95 - ( 0.2*cardinality(opp))),
                              Pass = 0.05,
                              Shoot = min(0.95; 0.2*cardinality(opp))]
          ]else
                    [ Dribble = 0.7,   Pass = 0.05,   Shoot = 0.25]
]
else[      if any opp have ( Distance=Near )
                    [ Dribble = 0.05, Pass = 0.25,  Shoot = 0.7]
          Else
                    [Dribble = 0.8,Pass = 0.1,Shoot =0.1]]
```

Recursive MFrag

- Recursive situations can be used to conceptualize many real-world scenarios.
  - For instance, if a team-mate was previously seen close to the ball but is now no longer in the visual range of a soccer agent, then belief regarding its distances could persist or degrade at a measured rate for some appropriate time.
  - This mimics the behavior of memory in people. Hence if a player is not seen at time t+1, its probability of being at a certain position at t+1 can be inferred from its position at time t which in turn can be derived from its position at earlier time instances.
  - This belief should not remain constant forever, rather it should decrease as the time passes by and after some time the agent will no longer believe the fellow player is located at the position last seen. This is a type of recursive relationship with a varying number of time slices.

Recursive Mfrag (Cont'd)

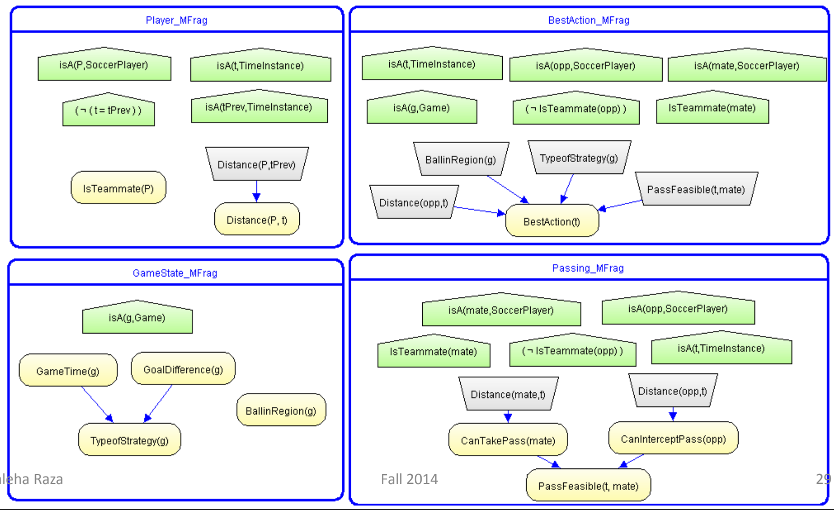
MEBN provides a generic representation of such recursive relationships that supports n^{th} level recursion.



(a) (b)

MTheory

- Different concepts in the problems domain are structured in multiple MFrags and a collection of these MFrags forms MTheory.



MTheory

- Just like a Class Model in Object-Oriented Paradigm, MTheory provides a blueprint of the structures involved and their relationships.
- The particular instance of the problem is created by adding *findings* to the MTheory.
- Findings are similar to facts in first-order logic and provide situation specific information to the model.

Findings

"The first half of the game is going on and the goal difference is 0. The ball is in opponent region. There are 3 teammates (t1,t2,t3) and 3 opponents (o1,o2,o3). Players t3 and o2 are 'Near' the player possessing the ball while t1, t2 and o1 are 'far'. No explicit information is available regarding the position of o3. The model has been asked to suggest the best action for the player "

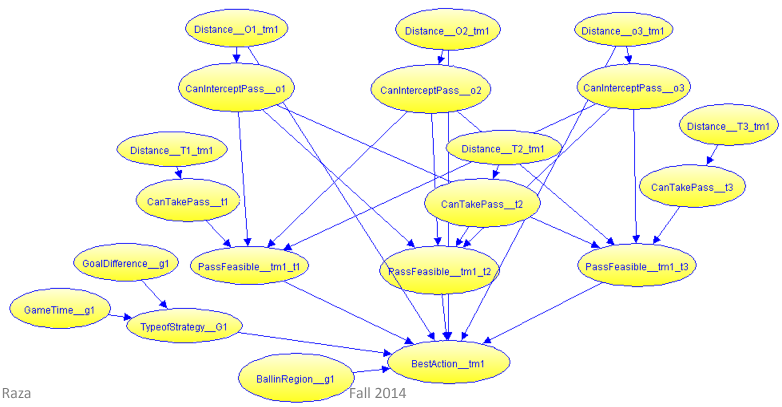
GameTime(g1 (Game)) = firstHalf
GoalDifference(g1 (Game)) = zero
BallinRegion(g1 (Game)) = opponentRegion
isTeammate(t1 (SoccerPlayer)) = true
isTeammate(t2 (SoccerPlayer)) = true
isTeammate(t3 (SoccerPlayer)) = true
isTeammate(o1 (SoccerPlayer)) = false
isTeammate(o2 (SoccerPlayer)) = false
isTeammate(o3 (SoccerPlayer)) = false
Distance(t1 (SoccerPlayer), tm0 (TimeInstance)) = Far
Distance(t2 (SoccerPlayer), tm0 (TimeInstance)) = Far
Distance(t3 (SoccerPlayer), tm0 (TimeInstance)) = Near
Distance(o1 (SoccerPlayer), tm0 (TimeInstance)) = Near
Distance(o2 (SoccerPlayer), tm0 (TimeInstance)) = Far

Querying MEBN model

- Once instantiated with findings, the model can now be queried to find updated beliefs of different random variables.
- **Query**: *BestAction(t0) ?*
- Instantiating and querying a model result in the generation of a *situation specific Bayesian network* (SSBN).

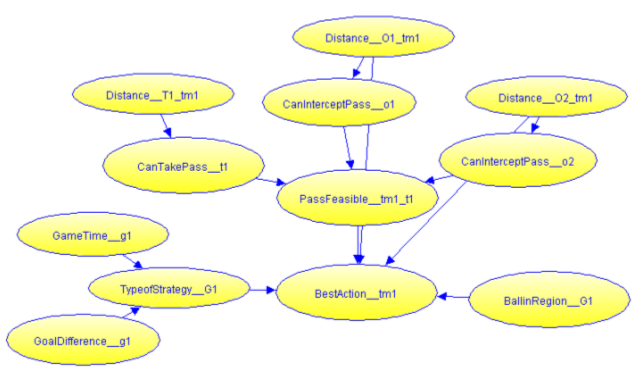
Situation Specific Bayesian Network (SSBN)

- SSBN is a Bayesian network that includes only those nodes from MTheory that are essential to answer a given query.



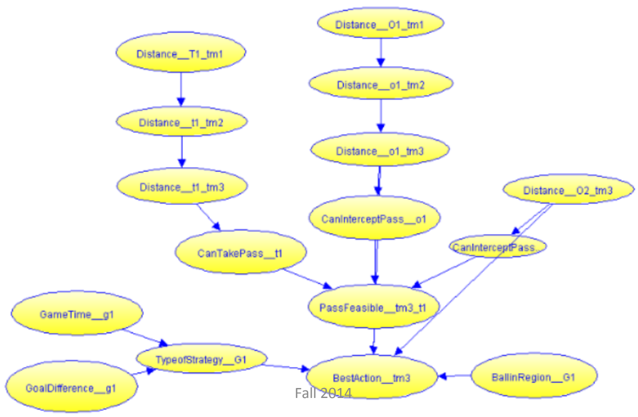
SSBN (Cont'd)

- If there are only two opponents and one teammate.



SSBN (Cont'd)

- When tm1 and o1 were seen at time 1 but no explicit information is available at time 3.



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Situation Specific Bayesian Network (SSBN) (Cont'd)

- As per different game situations, MEBN model can generate respective SSBN on the fly.
- Standard Bayesian network inference mechanisms are applied on SSBN to compute answers.

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UnbBayes Demo