

## Informatics 2D – Reasoning and Agents

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Lecture 28 – Dynamic Bayesian Networks  
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## Where are we?

Last time ...

- ▶ Inference in temporal models
- ▶ Discussed general model (forward-backward, Viterbi etc.)
- ▶ Specific instances: HMMs
- ▶ But what is the connection to Bayesian networks?

Today ...

- ▶ **Dynamic Bayesian Networks**

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Introduction  
Constructing DBNs  
Inference in DBNs  
Summary

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Transient failure  
Persistent failure

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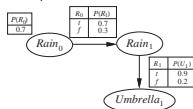
## Dynamic Bayesian Networks

- ▶ We've already seen an example of a DBN—Umbrella World
- ▶ A DBN is a BN describing a temporal probability model that can have *any number* of state variables  $\mathbf{X}_t$  and evidence variables  $\mathbf{E}_t$
- ▶ HMMs are DBNs with a single state and a single evidence variable
- ▶ But recall that one can *combine* a set of discrete (evidence or state) variables into a single variable (whose values are tuples).
- ▶ So every discrete-variable DBN can be described as a HMM.
- ▶ So why bother with DBNs?
- ▶ Because **decomposing a complex system into constituent variables, as a DBN does, ameliorates sparseness in the temporal probability model**

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## Constructing DBNs

- ▶ We have to specify prior distribution of state variables  $\mathbf{P}(\mathbf{X}_0)$ , transition model  $\mathbf{P}(\mathbf{X}_{t+1}|\mathbf{X}_t)$ , and sensor model  $\mathbf{P}(\mathbf{E}_t|\mathbf{X}_t)$
- ▶ Also, we have to fix topology of nodes
- ▶ Stationarity assumption  
most convenient to specify topology for first slice
- ▶ Umbrella world example:



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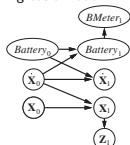
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## An example

- ▶ Consider a battery-driven robot moving in the  $X \times Y$  plane
- ▶ Let  $\mathbf{X}_t = (X_t, Y_t)$  and  $\dot{\mathbf{X}}_t = (\dot{X}_t, \dot{Y}_t)$  state variables for position and velocity, and  $\mathbf{Z}_t$  measurements of position (e.g. GPS)
- ▶ Add  $Battery_t$  for battery charge level and  $BMeter_t$  for the measurement of it
- ▶ We obtain the following basic model:



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## Modelling failure

- ▶ Assume  $Battery_t$  and  $BMeter_t$  take on discrete values (e.g. integer between 0 and 5)
- ▶ These variables should be identically distributed (CPT=identity matrix) unless error creeps in
- ▶ One way to model error is through **Gaussian error model**, i.e. a small Gaussian error is added to the meter reading
- ▶ We can approximate this also for the discrete case through an appropriate distribution
- ▶ But problem is usually much worse: sensor failure rather than inaccurate measurements

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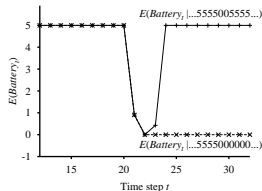
## Transient failure

- ▶ **Transient failure**: sensor occasionally sends inaccurate data
- ▶ Robot example: after 20 consecutive readings of 5 suddenly  $BMeter_{21} = 0$
- ▶ In Gaussian error model belief about  $Battery_{21}$  depends on:
  - ▶ Sensor model:  $P(BMeter_{21} = 0 | Battery_{21})$  and
  - ▶ Prediction model:  $P(Battery_{21} | BMeter_{1:20})$
- ▶ If probability of large sensor error is smaller than sudden transition to 0, then with high probability battery is considered empty
- ▶ A measurement of zero at  $t = 22$  will make this (almost) certain
- ▶ After a reading of 5 at  $t = 23$  the probability of full battery will go back to high level
- ▶ But robot made completely wrong judgement ...

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## Transient failure

- ▶ Curves for prediction depending on whether  $BMeter_t$  is only 0 for  $t = 22/23$  or whether it stays 0 indefinitely



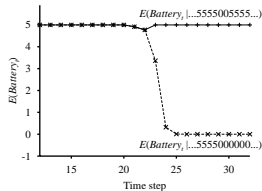
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## Transient failure model

- ▶ To handle failure properly, sensor model must include possibility of failure
- ▶ Simplest failure model: assign small probability to incorrect values, e.g.  $P(BMeter_t = 0 | Battery_t = 5) = 0.03$
- ▶ When faced with 0 reading, provided that predicted probability of empty battery is much less than 0.03, best explanation is failure
- ▶ This model is much less susceptible to failure, because an explanation is available
- ▶ However, it cannot cope with persistent failure either

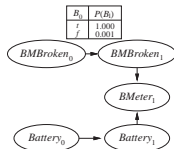
## Transient failure model

- ▶ Handling transient failure with explicit error models
- ▶ In case of permanent failure the robot will (wrongly) believe the battery is empty



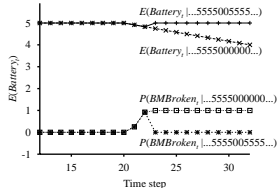
## Persistent failure

- ▶ **Persistent failure models** describe how sensor behaves under normal conditions and after failure
- ▶ Add additional variable  $BMBroken$ , and CPT to next  $BMBroken$  state has a very small probability if not broken, but 1.0 if broken before (**persistence arc**)
- ▶ When  $BMBroken$  is true,  $BMeter$  will be 0 regardless of  $Battery$ :



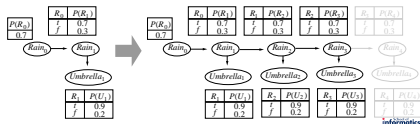
## Persistent failure

- ▶ In case of temporary blip probability of broken sensor rises quickly but goes back if 5 is observed
- ▶ In case of persistent failure, robot assumes discharge of battery at "normal" rate



## Exact inference in DBNs

- ▶ Since DBNs are BNs, we already have inference algorithms like variable elimination
- ▶ Essentially DBN equivalent to infinite "unfolded" BN, but slices beyond required inference period are irrelevant
- ▶ **Unrolling**: reproducing basic time slice to accommodate observation sequence



## Exact inference in DBNs

- ▶ Exact inference in DBNs is intractable, and this is a major problem.
- ▶ There are approximate inference methods that work well in practice.
- ▶ This issue is currently a hot topic in AI...

## Summary

- ▶ Account of time and uncertainty complete
- ▶ Looked at general Markovian models
- ▶ HMMs
- ▶ DBNs as general case
- ▶ Quite intractable, but powerful
- ▶ Next time: **Decision Making under Uncertainty**