A hybrid approach to dialogue management based on probabilistic rules

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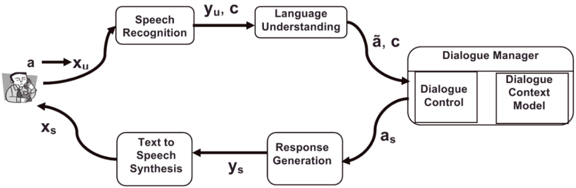
15th June 2016

Outline

1. Motivation
2. Probabilistic rules
3. Evaluation
4. Conclusion

Motivation

Dialogue Management [1]



Proper solutions:

- Hand-crafted / rule-based models (e.g. ISU)
- Statistical models (e.g. POMDP)

Motivation

Bottlenecks

- Hand-crafted / rule-based models
  - assume complete observability
  - no errors and uncertainty
  - knowledge base has to be completely specified beforehand
- Statistical models
  - depend on large amount of data leading to high costs for data acquisition
  - have a huge state space

Motivation

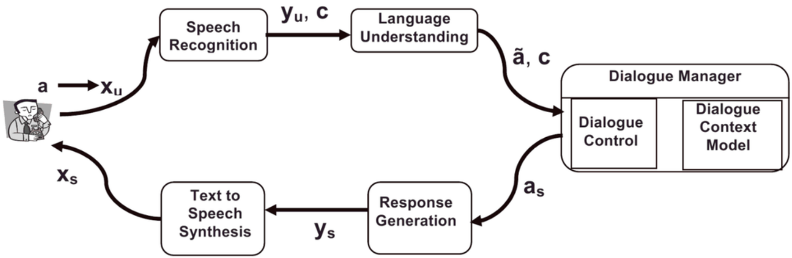
Target: Combine advantages into a hybrid system

- Hand-crafted / rule-based models
  - precisely tailored for various behaviour
- Statistical models
  - handle errors and uncertainty

Approach: Pierre Lison, 2014, “A hybrid approach to dialogue management based on **probabilistic rules**” [2]

Probabilistic rules

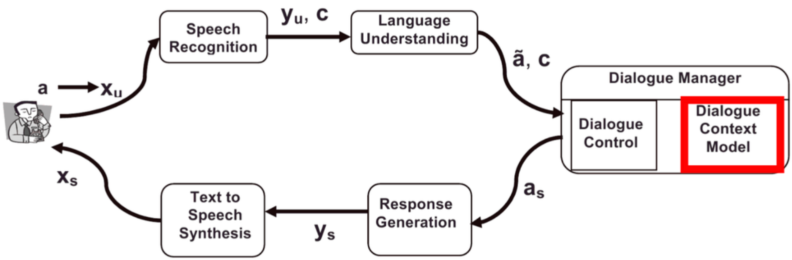
Dialogue Management [1]



Probabilistic rules

Dialogue Management [1]

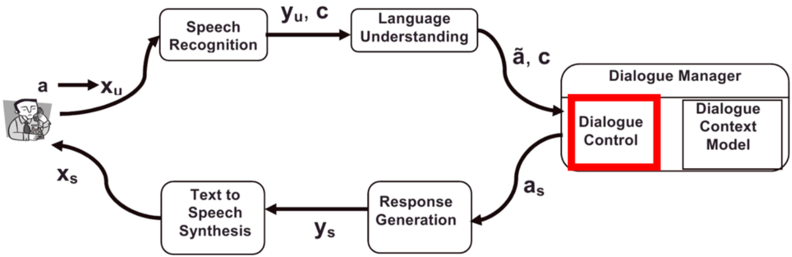
- Dialogue Context Model → **Probability rules**



Probabilistic rules

Dialogue Management [1]

- Dialogue Context Model → **Probability rules**
- Dialogue Control → **Utility rules**



Probability rules

$$
\begin{aligned}
&\forall \mathbf{x}, \\
&\quad \textbf{if}\,(c_1)\,\textbf{then} \\
&\quad\quad \begin{cases} P(E_1 = e_{1,1}) = \theta_{1,1} \\ \dots \\ P(E_1 = e_{1,m_1}) = \theta_{1,m_1} \end{cases} \\
&\quad \textbf{else if}\,(c_2)\,\textbf{then} \\
&\quad\quad \begin{cases} P(E_2 = e_{2,1}) = \theta_{2,1} \\ \dots \\ P(E_2 = e_{2,m_2}) = \theta_{2,m_2} \end{cases} \\
&\quad \dots
\end{aligned}
$$

c_i: Condition

E_i: Random variable

$e_{i,j}$: Effect

$\theta_{i,j}$: Probability

[2]

Conditions

- Input variables (ASR/SLU or internal state)
- Predicate logic (e.g. conjunction) and binary relations (e.g. equality)
- Free variables (universally quantified)

Example:

$$
\begin{aligned}
\forall x, \quad & \textbf{if } (a_u = RequestAction(x) \wedge a_m = Do(x)) \textbf{ then} \\
& \quad \left\{ P(a'_u = Confirm) = 0.2 \right. \\
& \textbf{else if } (a_u \neq RequestAction(x) \wedge a_m = Do(x)) \textbf{ then} \\
& \quad \left\{ \begin{array}{l} P(a'_u = Disconfirm) = 0.5 \\ P(a'_u = RequestAction(Stop)) = 0.3 \end{array} \right.
\end{aligned}
$$

[2]

Effects

- An effect assigns values to a set of output variables
- e.g., $e_{i,j} = \{a'_u = x\}$
- Each effect is assigned a probability $P(E_i = e_{i,j}) = \theta_{i,j}$

Example:

$$\forall x, \quad \textbf{if } (a_u = RequestAction(x) \wedge a_m = Do(x)) \textbf{ then}$$
$$\{ P(a'_u = Confirm) = 0.2$$
$$\textbf{else if } (a_u \neq RequestAction(x) \wedge a_m = Do(x)) \textbf{ then}$$
$$\begin{cases} P(a'_u = Disconfirm) = 0.5 \\ P(a'_u = RequestAction(Stop)) = 0.3 \end{cases}$$

[2]

Instantiation

r₁: $\forall x$,

if $(a_u = x \wedge a_m = AskRepeat)$ **then**

$$\left\{ P(a_u{}' = x) = 0.9 \right.$$

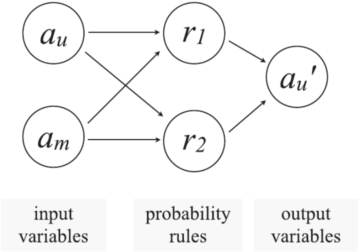
r₂: $\forall x$,

if $(a_u = RequestAction(x) \wedge a_m = Do(x))$ **then**

$$\left\{ P(a_u{}' = Confirm) = 0.2 \right.$$

else if $(a_u \neq RequestAction(x) \wedge a_m = Do(x))$ **then**

$$\begin{cases} P(a_u{}' = Disconfirm) = 0.5 \\ P(a_u{}' = RequestAction(Stop)) = 0.3 \end{cases}$$

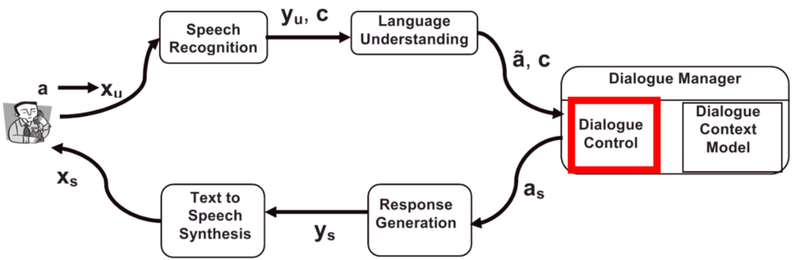


[2]

Probabilistic rules

Dialogue Management [1]

- Dialogue Context Model → **Probability rules**
- Dialogue Control → **Utility rules**



Utility rules

$$
\begin{aligned}
&\forall\, \mathbf{x},\\
&\quad \textbf{if}\,(c_1)\,\textbf{then}\\
&\quad\quad \begin{cases} U_1(d_{1,1}) = \theta_{1,1} \\ \dots \\ U_1(d_{1,m_1}) = \theta_{1,m_1} \end{cases}\\
&\quad \textbf{else if}\,(c_2)\,\textbf{then}\\
&\quad\quad \begin{cases} U_2(d_{2,1}) = \theta_{2,1} \\ \dots \\ U_2(d_{2,m_2}) = \theta_{2,m_2} \end{cases}\\
&\quad \dots
\end{aligned}
$$

c_i: Condition

U_i: Utility table

$d_{i,j}$: Decision

$\theta_{i,j}$: Utility value

[2]

Instantiation

r₃: $\forall x,$

if $(a_u = RequestAction(x))$ **then**

$$\left\{ U(a'_m = Do(x)) = 5 \right.$$

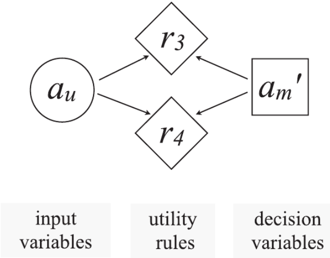
else

$$\left\{ U(a'_m = Do(x)) = -5 \right.$$

r₄: $\forall x,$

if $(a_u = RequestAction(x) \vee a_u = Ask(x))$ **then**

$$\left\{ U(a'_m = AskRepeat) = 1 \right.$$



[2]

Parameter estimation

Probabilistic **rule structure** is **hand-crafted** by system designer.

Parameters like effect probabilities and utilities are **estimated** by learning:

- Supervised learning (Wizard-of-Oz data)
- Reinforcement learning (real or simulated interactions)

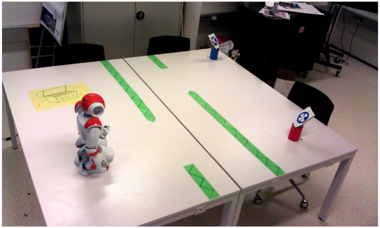
In both cases, Bayesian inference to estimate best values for parameters

Evaluation

Test scenario

Tasks:

1. Walk to the other end of the table considering walls
2. Pick up a certain object
3. Bring the object back to the start point
4. Release the object on the landmark



[2]

Evaluation

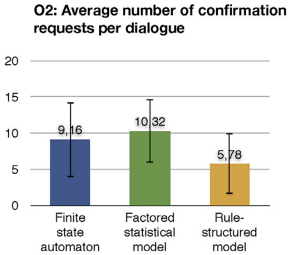
Comparison

- Finite-state automation
- Factored statistical model
- Probabilistic rule model

Evaluation

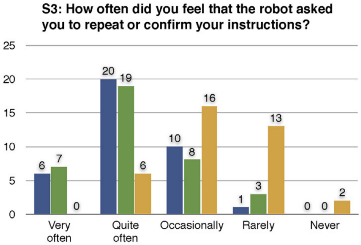
Metrics

Objective



[2]

Subjective



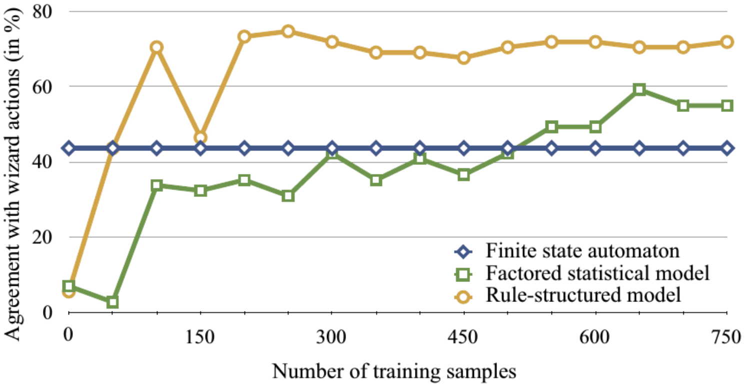
Evaluation

Results

- 15 metrics in total (9 objective, 6 subjective)
- 7 metrics show **significantly higher** results for the probabilistic rule model
- 6 metrics show **higher** results for the probabilistic model

Evaluation

Learning Curve [2]



Conclusion

Probabilistic rule model...

- ...combines advantages of hand-crafted and statistical model
- ...uses probability rules for dialogue context model
- ...uses utility rules for dialogue control
- ...partitions the state space by conditions
- ...has distributions over possible effects
- ...uses parameters estimated by learning
- ...outperforms hand-crafted and statistical model in the (simple) test scenario

[1] Kristiina Jokinen and Michael F. McTear.
Spoken Dialogue Systems, volume 5 of *Synthesis Lectures on Human Language Technologies*.
Morgan & Claypool, San Rafael, CA, 2010.

[2] Pierre Lison.
A hybrid approach to dialogue management based on probabilistic rules.
Comput. Speech Lang., 34(1):232–255, November 2015.