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Semantically Conditioned LSTM-based Natural Language Generation for Spoken Dialogue Systems

Tsung-Hsien Wen, Milica Gasic , Nikola Mrksic,
Pei-Hao Su, David Vandyke, and Steve Young

Dialogue Systems Group

Outline

- Intro
- Semantic Conditioned LSTM
- Deep Architecture
- Experiments
  - Setup
  - Corpus-based Evaluation
  - Human Evaluation
- Conclusion

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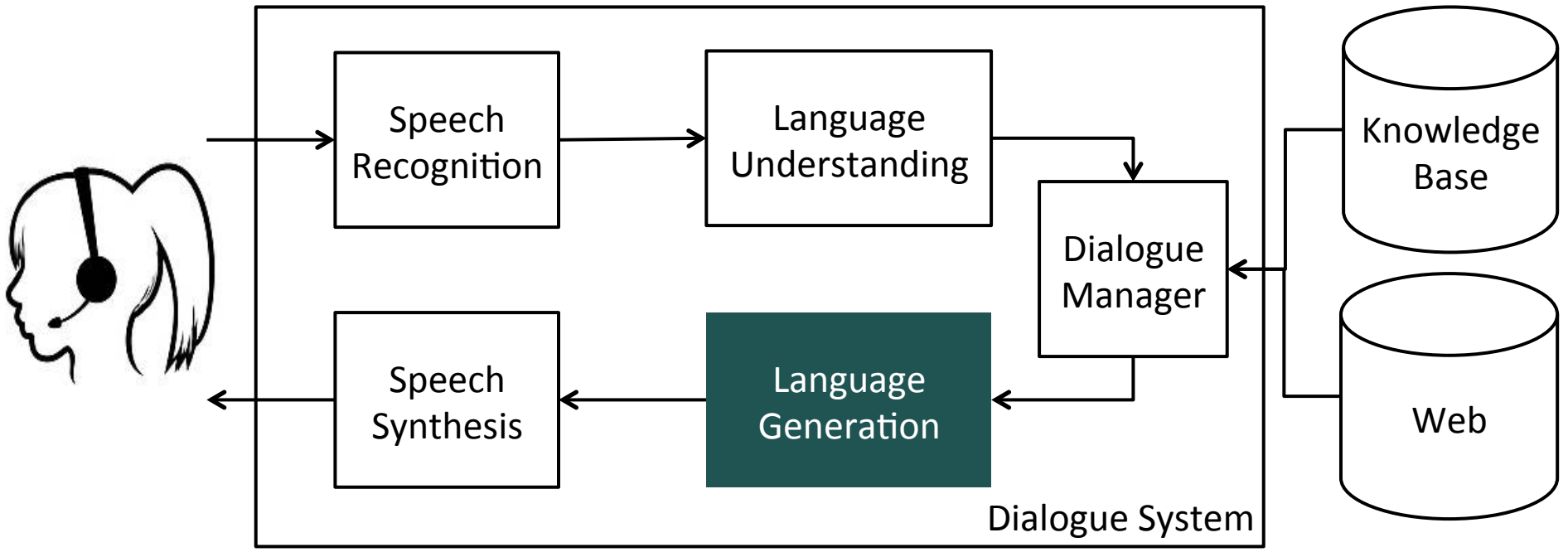
Spoken Dialogue System



NLG: Problem Definition

- Given a meaning representation, map it into natural language utterances.

Dialogue Act

Inform(restaurant=Seven_days, food=Chinese)

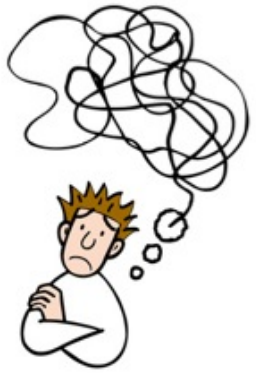
Realisations

Seven days is a restaurant serving Chinese.

Seven days is a Chinese restaurant.

- What do we care about?
  - adequacy, fluency, readability, variation (Stent et al 2005)

Traditional approaches to NLG



$$
\begin{array}{lllllllll}
A \rightarrow & mm, & \Pr(0.11) & | & mh, & \Pr(0.67) & & & \\
B \rightarrow & mm, & \Pr(0.68) & | & hm, & \Pr(0.23) & & & \\
C \rightarrow & mm, & \Pr(0.58) & | & hm, & \Pr(0.42) & & & \\
T \rightarrow & hQA, & \Pr(0.12) & | & hQB, & \Pr(0.18) & | & APm, & \Pr(0.16) \\
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W \rightarrow & BRA, & \Pr(0.10) & | & CRA, & \Pr(0.08) & | & CRB, & \Pr(0.07) \\
 & & & | & X]\{X, & \Pr(0.75) & & & \\
R \rightarrow & lWm, & \Pr(0.14) & | & mWm, & \Pr(0.22) & | & mWh, & \Pr(0.23) \\
 & & & | & hWm, & \Pr(0.17) & | & hWh, & \Pr(0.24) \\
Q \rightarrow & AVh, & \Pr(0.28) & | & BVm, & \Pr(0.55) & | & BVh, & \Pr(0.06) \\
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$$

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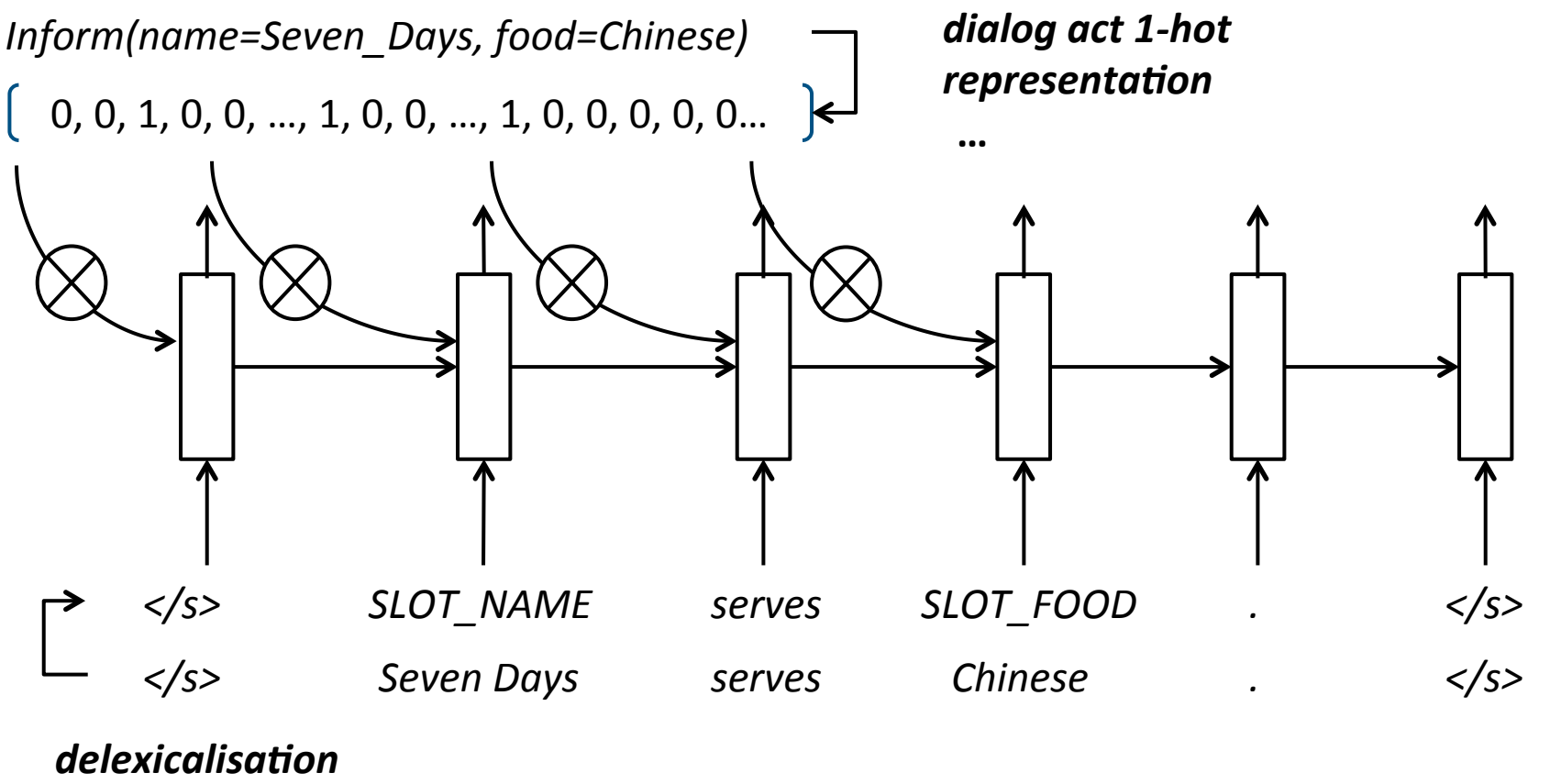
Recurrent Generation Model



RNNLM (Mikolov et al 2010)

SC-LSTM

- Original LSTM cell

$$\mathbf{i}_t = \sigma(\mathbf{W}_{wi}\mathbf{w}_t + \mathbf{W}_{hi}\mathbf{h}_{t-1})$$
$$\mathbf{f}_t = \sigma(\mathbf{W}_{wf}\mathbf{w}_t + \mathbf{W}_{hf}\mathbf{h}_{t-1})$$
$$\mathbf{o}_t = \sigma(\mathbf{W}_{wo}\mathbf{w}_t + \mathbf{W}_{ho}\mathbf{h}_{t-1})$$
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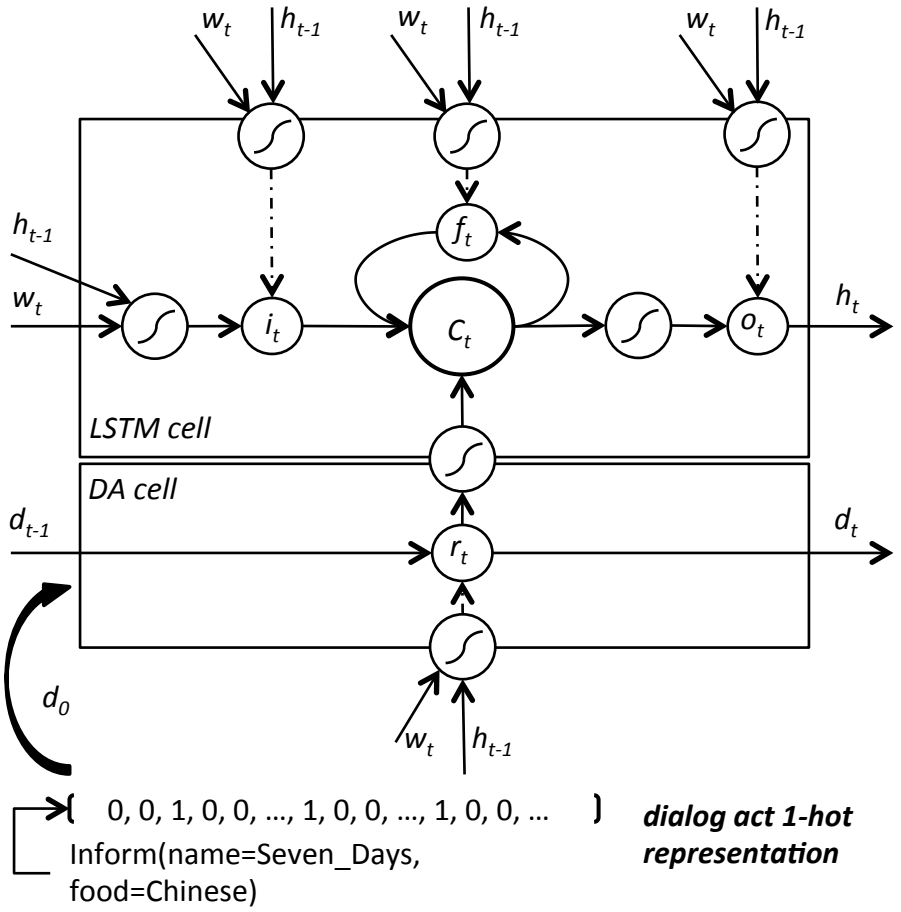
- DA cell

$$\mathbf{r}_t = \sigma(\mathbf{W}_{wr}\mathbf{w}_t + \mathbf{W}_{hr}\mathbf{h}_{t-1})$$
$$\mathbf{d}_{\boldsymbol{t}} = \mathbf{r}_t \odot \mathbf{d}_{t-1}$$

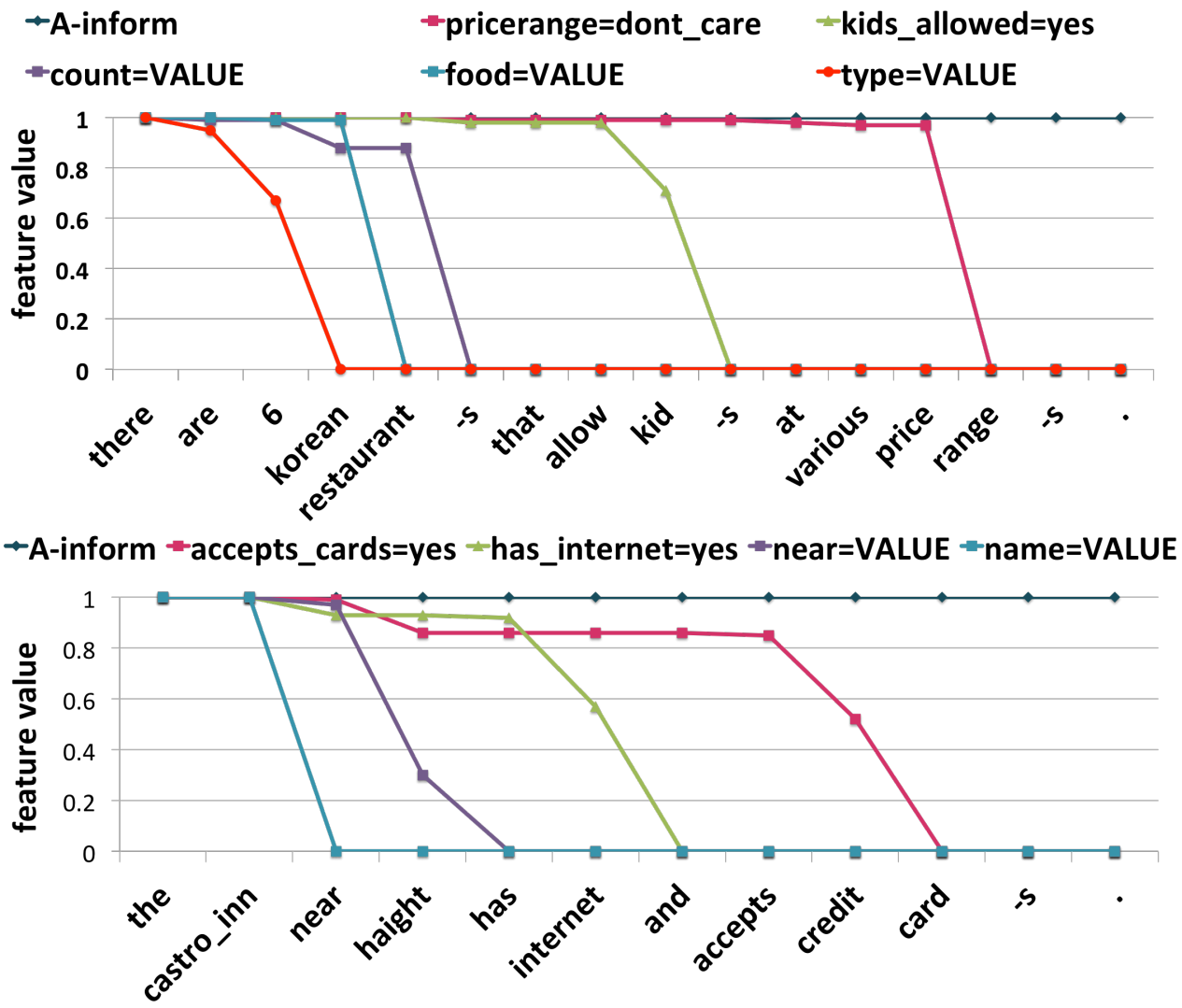
- Modify Ct

$$\mathbf{c}_t = \mathbf{f}_t \odot \mathbf{c}_{t-1} + \mathbf{i}_t \odot \hat{\boldsymbol{c}}_{\boldsymbol{t}} + \tanh(\mathbf{W}_{dc}\mathbf{d}_t)$$



(Hochreiter and Schmidhuber, 1997)

Visualization



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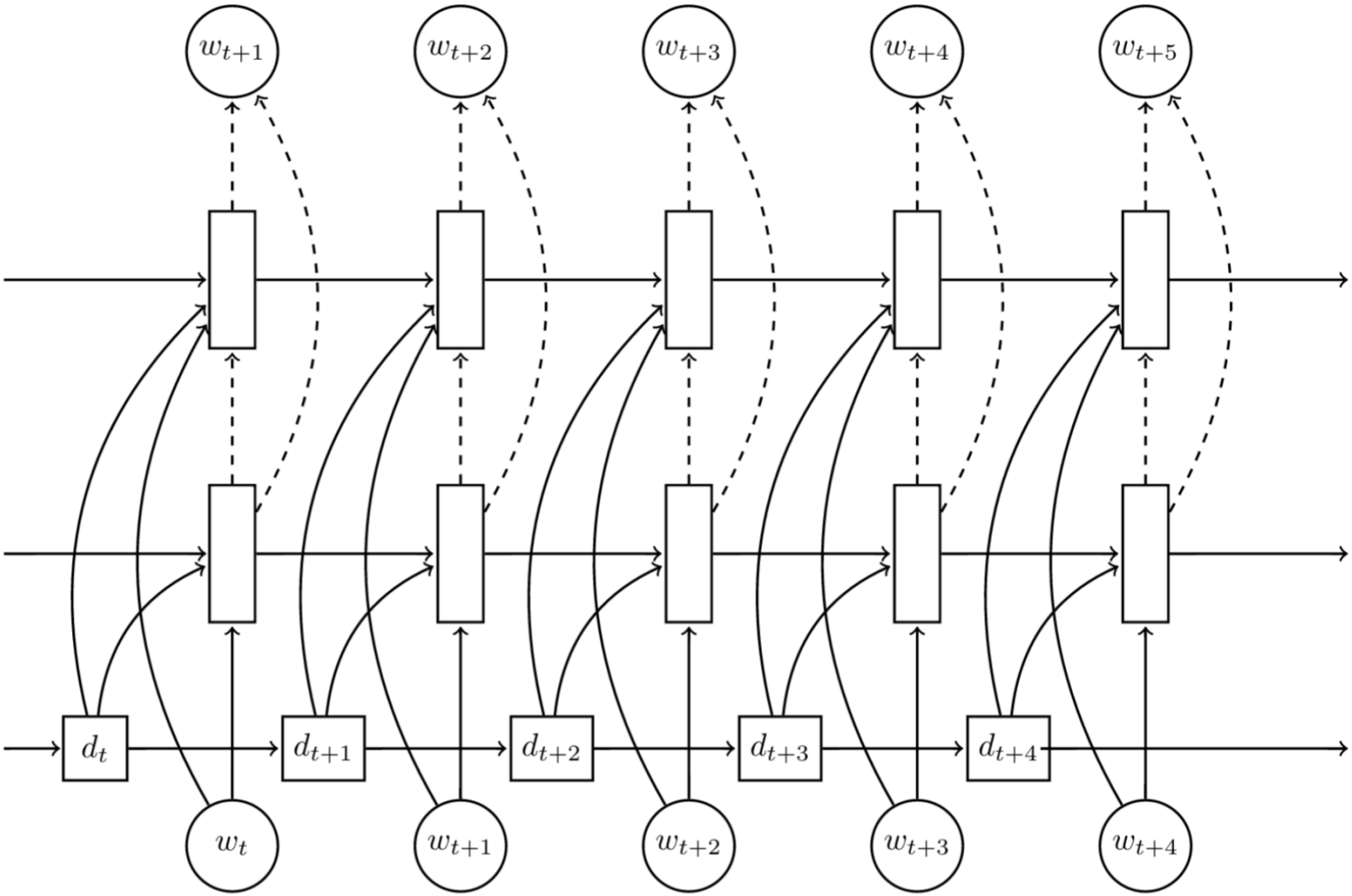
Deep Architecture



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Setup

- Data collection:
  - SFX restaurant/hotel domains

Ontologies

	SF Restaurant	SF Hotel
act type	inform, inform_only, reject, confirm, select, request, reqmore, goodbye	
shared	name, type, *pricerange, price, phone, address, postcode, *area, *near	
specific	*food *goodformeal ***kids-allowed**	***hasinternet** ***acceptscards** ***dogs-allowed**

bold=binary slots, *=slots can take "don't care" value

Setup

- Data collection:
  - SFX restaurant/hotel domains
  - Workers recruited from Amazon MT.
  - Asked to generate system responses given a DA.
  - Result in ~5.1K utterances, 228/164 distinct acts.
- Training: BPTT, L2 reg, SGD w/ early stopping.

  train/valid/test: 3/1/1, data up-sampling

Generated Examples

inform_only(name='red victorian bed breakfast',accepts_credit_cards='yes',near='haight',has_internet='yes')

red victorian bed breakfast is the only hotel near haight and accepts credit cards and has internet .

red victorian bed breakfast is the only hotel near haight and has internet and accepts credit cards .

red victorian bed breakfast is the only hotel near haight that accept credit cards and offers internet .

the red victorian bed breakfast has internet and near haight , it does accept credit cards .

the red victorian bed breakfast is the only hotel near haight that accepts credit cards , and offers internet .

Generated Examples

inform_no_match(area=tenderloin)

there are no restaurants in the tenderloin area .

there are 0 restaurants in the tenderloin area .

unfortunately there are 0 restaurants in the tenderloin area .

i could not find any restaurants in tenderloin .

there are no restaurants in tenderloin .

Generated Examples

?request(food)
what type of food are you looking for ?
what type of food would you like ?
what kind of food are you looking for ?
what type of food are you interested in ?
what kind of food would you like ?

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Corpus-based Evaluation

- Test set: ~1K utterances each domain
- Metrics: BLEU-4 (against multiple references), ERR(slot error rates)
- Averaged over 5 random initialised networks.
- Over-gen 20, evaluate on top-5
- Baselines:
  - handcrafted generator (hdc)
  - kNN example-based generator (kNN)
  - class-based LM generator (classlm, O&R 2000)
  - rnn-based generator (rnn, Wen et al 2015)

Corpus-based Evaluation

Selection scheme : 5/20

Corpus-based Evaluation

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Human Evaluation

- Setup
  - Judges (~60) recruited from Amazon MT.
  - Asked to evaluate two system responses pairwise.
  - Comparing *classlm*, *rnn*, *sc-lstm*, and *+deep*

- Metrics:
  - Informativeness, Naturalness (rating out of 3)
  - Preference

Human Evaluation

Method	Informativeness	Naturalness
+deep	2.58	**2.51**
sc-lstm	**2.59**	2.50
rnn	2.53	2.42*
classlm	2.46**	2.45

* $p < 0.05$ ** $p < 0.005$

Human Evaluation

Pref.%	classlm	rnn	sc-lstm	+deep
classlm	-	46.0	40.9^{**}	37.7^{**}
rnn	54.0	-	43.0	35.7^{*}
sc-lstm	59.1^{*}	57	-	47.6
+deep	62.3^{**}	64.3^{**}	52.4	-

$^{*}p < 0.05$ $^{**}p < 0.005$

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Conclusion

- Train NLG N2N using LSTM.
- Learn LM & slot gating control signal jointly
- Deep architecture helps.
- Corpus-based/Human evaluation.
- Achieve best performance.
- Potential for open domain SDS.

Papers

- Tsung-Hsien Wen, Milica Gasic , Dongho Kim, Nikola Mrksic, Pei-Hao Su, David Vandyke, and Steve Young. Stochastic language generation in dialogue using recurrent neural networks with convolutional sentence reranking. In *Proceedings of SIGdial 2015*.
- Tsung-Hsien Wen, Milica Gasic , Nikola Mrksic, Pei-Hao Su, David Vandyke, and Steve Young. Semantically Conditioned LSTM-based Natural Language Generation for Spoken Dialogue Systems. To be appear in *Proceedings of EMNLP 2015*.

Selected References

- Amanda Stent, Matthew Marge, and Mohit Singhai. 2005. Evaluating evaluation methods for generation in the presence of variation. In Proceedings of CICLing 2005.
- Alice H. Oh and Alexander I. Rudnicky. 2000. Stochastic language generation for spoken dialogue systems. In Proceedings of the 2000 ANLP/NAACL Workshop on Conversational Systems.
- Tomas Mikolov, Martin Karafit, Lukas Burget, Jan Cernocky, and Sanjeev Khudanpur. 2010. Recurrent neural network based language model. *In Proceedings on InterSpeech*.
- Nal Kalchbrenner, Edward Grefenstette, and Phil Blunsom. 2014. A convolutional neural network for modelling sentences. Proceedings of the 52nd Annual Meeting of ACL.
- Sepp Hochreiter and Jurgen Schmidhuber. 1997. Long short-term memory. *Neural Computation*.

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Thank you! Questions?

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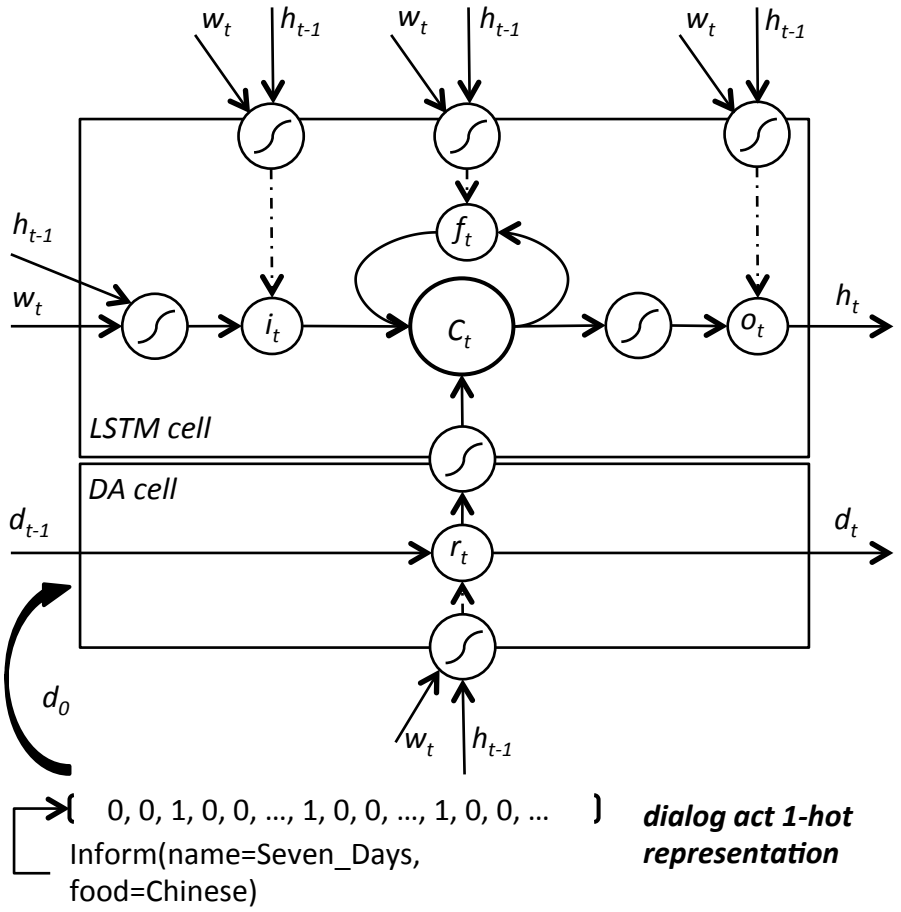
SC-LSTM

- Cost function

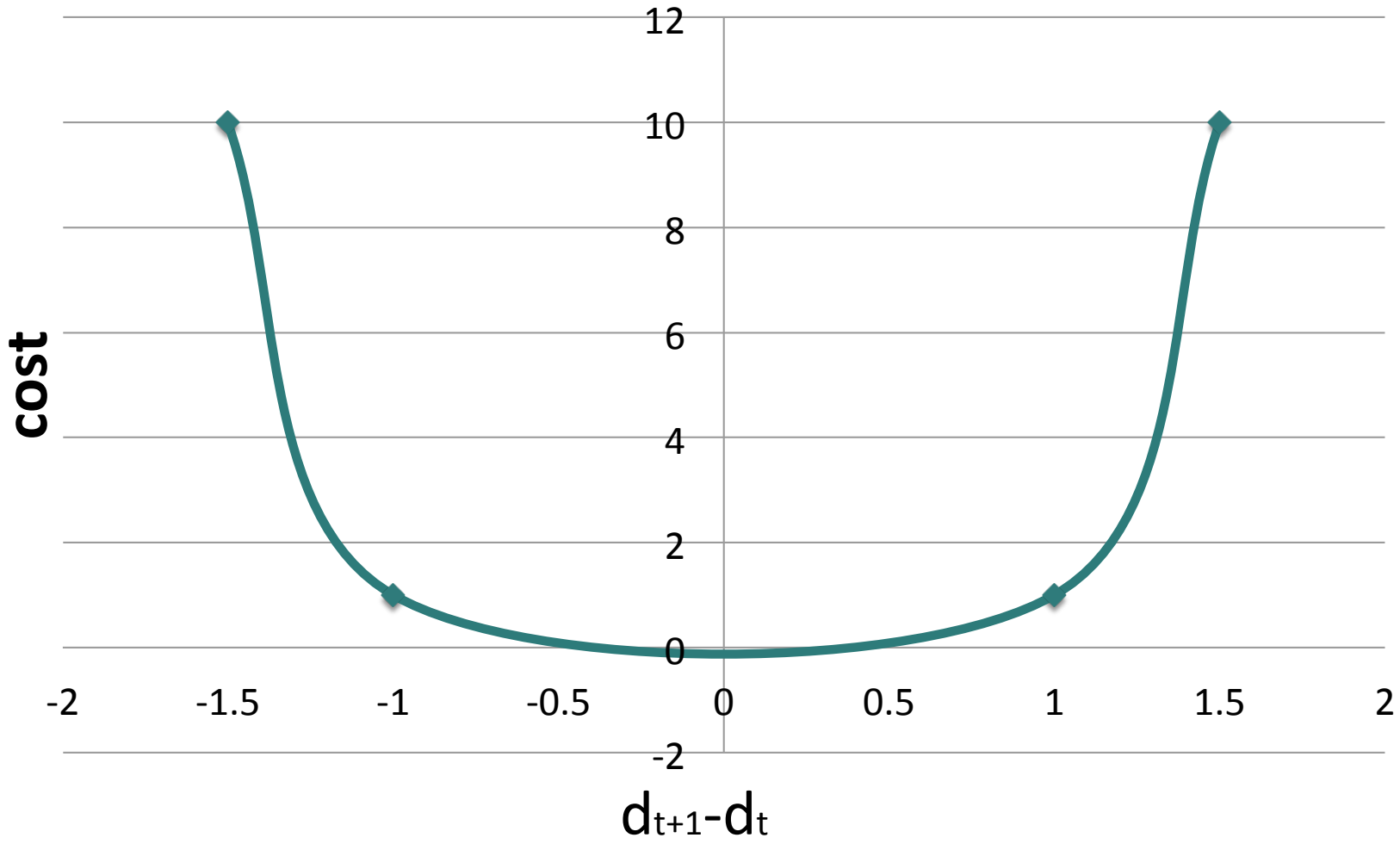
$$F(\theta) = \sum_t \mathbf{p}_t^\intercal log(\mathbf{y}_t) + \|\mathbf{d}_T\| + \sum_{t=0}^{T-1} \eta\xi\|\mathbf{d}_{t+1} - \mathbf{d}_t\|$$

- 1st term : Log-likelihood
- 2nd term: make sure rendering all the information needed
- 3rd term: close only one gate each time step.



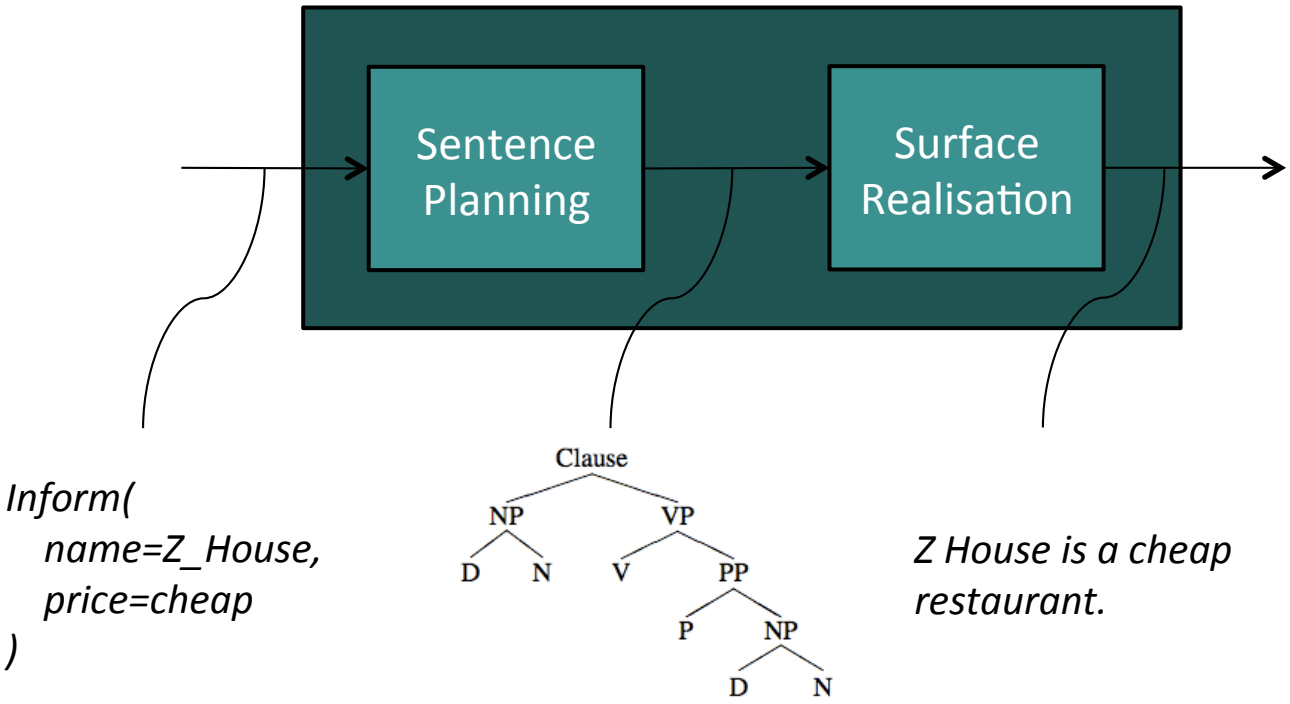
(Hochreiter and Schmidhuber, 1997)

Intuition behind the 3rd term



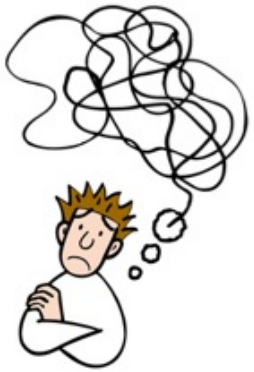
$$\eta = 0.01, \xi = 100$$

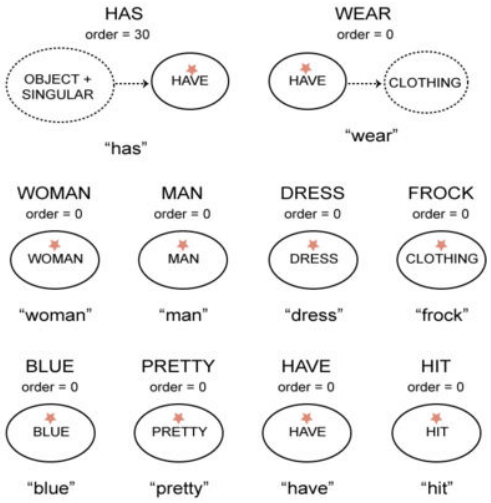
Traditional pipeline approach



Problems

- Scalability
  - Grammars are handcrafted.
  - Require expert knowledge.





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V \rightarrow & ARA, \Pr(0.16) \mid ARB, \Pr(0.66) \mid CRB, \Pr(0.08) \\
 & \quad \mid hQA, \Pr(0.10) \\
W \rightarrow & BRA, \Pr(0.10) \mid CRA, \Pr(0.08) \mid CRB, \Pr(0.07) \\
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R \rightarrow & lWm, \Pr(0.14) \mid mWm, \Pr(0.22) \mid mWh, \Pr(0.23) \\
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O \rightarrow & ATA, \Pr(0.86) \mid CTC, \Pr(0.14) \\
\\
X \rightarrow & xX, \Pr(0.35) \mid \epsilon, \Pr(0.65) \\
S \rightarrow & [XTX\}, \Pr(1.00)
\end{array}
$$

Problems

- Boring
  - Frequent repetition of outputs.
  - Non-colloquial, awkward utterances.

Seven Days is a nice restaurant in the expensive price range, in the north part of the town, if you don't care about what food they serve.

SC-LSTM

- Original LSTM cell

$$\mathbf{i}_t = \sigma(\mathbf{W}_{wi}\mathbf{w}_t + \mathbf{W}_{hi}\mathbf{h}_{t-1})$$
$$\mathbf{f}_t = \sigma(\mathbf{W}_{wf}\mathbf{w}_t + \mathbf{W}_{hf}\mathbf{h}_{t-1})$$
$$\mathbf{o}_t = \sigma(\mathbf{W}_{wo}\mathbf{w}_t + \mathbf{W}_{ho}\mathbf{h}_{t-1})$$
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- DA cell

$$\mathbf{r}_t = \sigma(\mathbf{W}_{wr}\mathbf{w}_t + \mathbf{W}_{hr}\mathbf{h}_{t-1})$$
$$\mathbf{d}_{\boldsymbol{t}} = \mathbf{r}_t \odot \mathbf{d}_{t-1}$$

- Modify Ct

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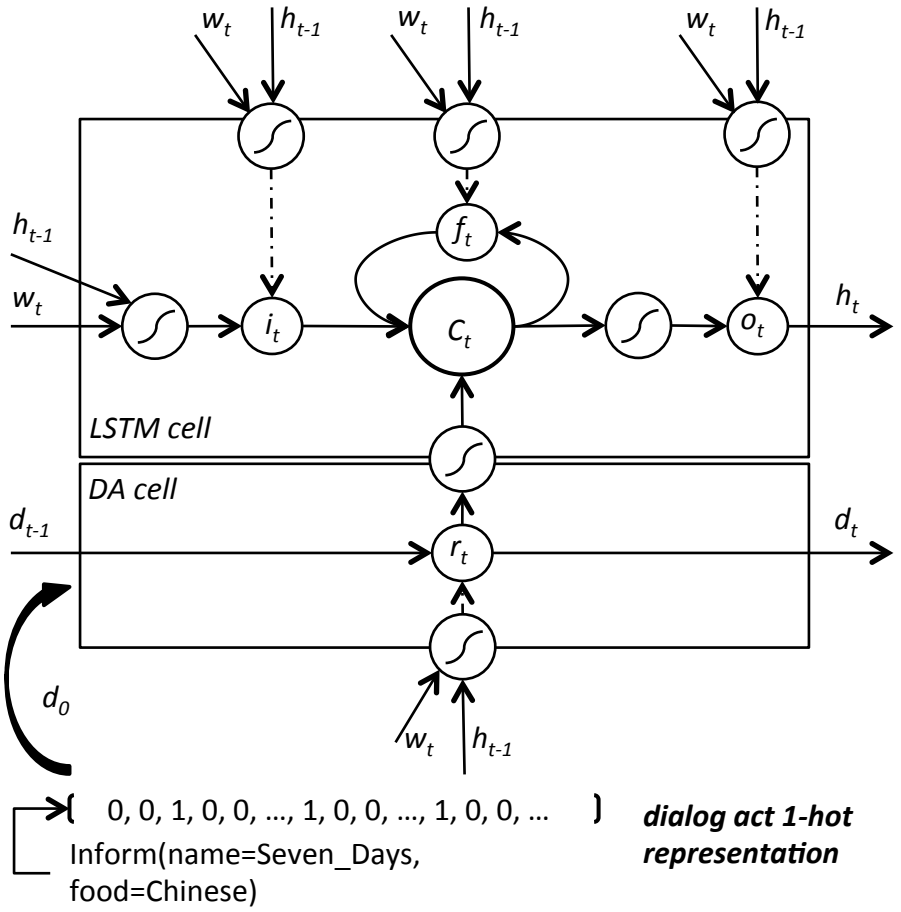
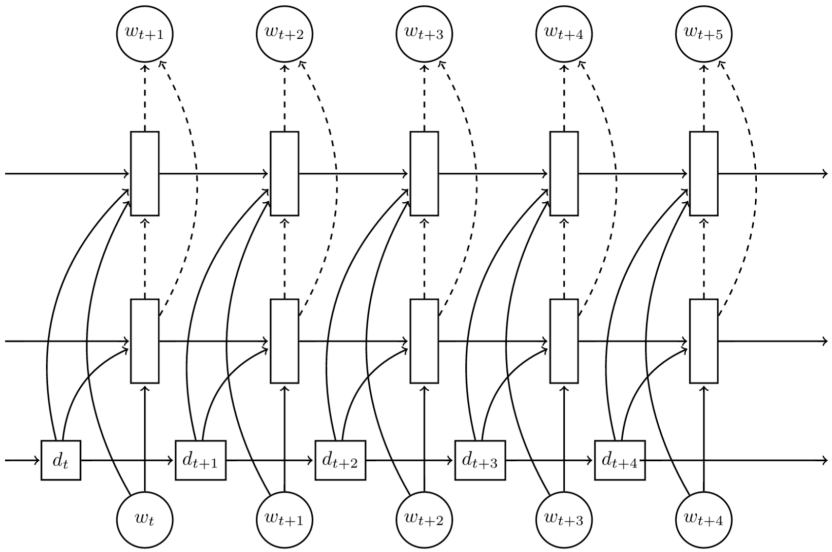


(Hochreiter and Schmidhuber, 1997)

Deep Architecture

- Techniques applied
  - Skip connection (Graves et al 2013)
  - RNN dropout (Srivastava et al 2014)



- Gating Equation is modified from

$$\mathbf{r}_t = \sigma(\mathbf{W}_{wr}\mathbf{w}_t + \alpha\mathbf{W}_{hr}\mathbf{h}_{t-1})$$

- To

$$\mathbf{r}_t = \sigma(\mathbf{W}_{wr}\mathbf{w}_t + \sum_l \alpha_l \mathbf{W}^l_{hr}\mathbf{h}^l_{t-1})$$