Cooperative Memory Network for Personalized Task-oriented Dialogue Systems with Incomplete User Profiles

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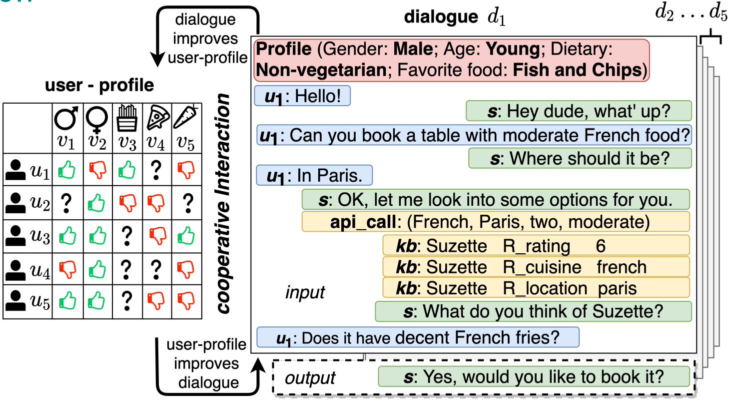
Overview

1.1 Motivation



User profiles are usually *incomplete* with lots of missing values

1. not everyone is willing to expose their profiles due to privacy concerns; and
2. user profiles involve too many aspects (e.g., gender, age, tastes), which makes it impossible to collect all these information.

1.2 Task: Personalized TDS with incomplete user profiles

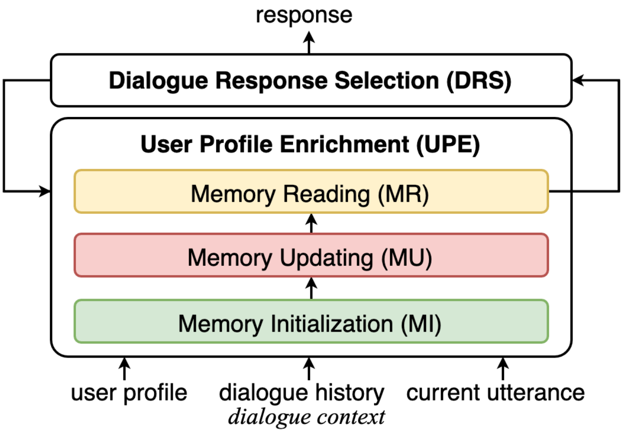
Dialogue context $(u, D_t, X_t^u) \Longrightarrow$ an appropriate response $y_t = X_t^s$ from candidates.

X_t^u	User utterance at turn t.
X_t^s	System response at turn t.
D_t	Dialogue history at turn t.
u	A user profile in the form of $\{(a_i, v_i)\}_{i=1}^m$, v_i is a candidate value of i-th attribute a_i.

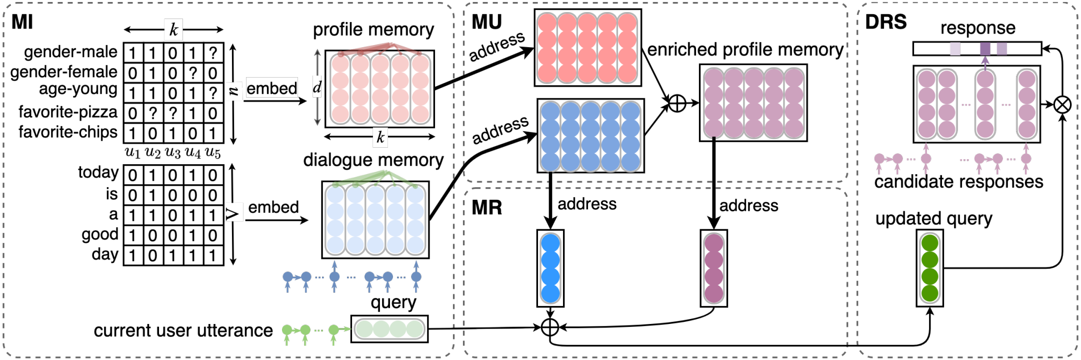
Note: it is impossible to enumerate all candidate values in a user profile!

1.3 Research Questions

1. How well does CoMemNN perform? Does it significantly and continuously outperform state-of-the-art methods?
2. What are the effects of different components in CoMemNN?
3. Do different profile attributes contribute differently?


response
Dialogue Response Selection (DRS)
User Profile Enrichment (UPE)
Memory Reading (MR)
Memory Updating (MU)
Memory Initialization (MI)
user profile
dialogue history
dialogue context
current utterance

2.2 Dynamic Pipeline



2.3 Multiple hop CoMemNN

Input: turn t, user u_1, profile $\mathbf{p}_1$, dialogue history $\mathbf{H}_t$, query $\mathbf{q}_t$, response candidates $\{\mathbf{r}_1, \ldots, \mathbf{r}_{|Y|}\}$, max hop *HopN*, $(k-1)$ neighbors

Output: A index $\mathbf{y}_t$ of next response; An one-hot vector $\tilde{\mathbf{p}}_t^1$ presenting the enriched profile.

$\{u_2, \ldots, u_k\} \leftarrow \text{Search}(\mathbf{p}_1, k-1)$; ▷ MI

$\mathbf{M}_t^P \leftarrow [\mathbf{p}_1, \ldots, \mathbf{p}_k]$;

$\mathbf{M}_t^D \leftarrow [\mathbf{h}_t^1, \ldots, \mathbf{h}_t^k]; \mathbf{h}_t^i \leftarrow (\tilde{q}_t, \mathbf{H}_t^i), i \in [1,k]; \tilde{\mathbf{q}}_t \leftarrow \mathbf{q}_t$;

while $hop \leq HopN$ **do**

  $\tilde{\mathbf{M}}_t^D \leftarrow \mathbf{M}_t^D$; $\tilde{\mathbf{M}}_t^P \leftarrow \mathbf{M}_t^P$; ▷ MU

  $\mathbf{M}_t^D \leftarrow \tilde{\mathbf{M}}_t^D$;

  $\mathbf{M}_t^P \leftarrow \Gamma(\tilde{\mathbf{M}}_t^P, \tilde{\mathbf{M}}_t^D)$;

  $\mathbf{m}_t^D \leftarrow \mathbf{M}_t^D$; $\tilde{\mathbf{q}}_t \leftarrow \tilde{\mathbf{q}}_t + \mathbf{m}_t^D$; ▷ MR

  $\mathbf{m}_t^P \leftarrow \mathbf{M}_t^P$; $\tilde{\mathbf{q}} \leftarrow \tilde{\mathbf{q}}_t + \mathbf{m}_t^P$;

end

$\tilde{\mathbf{y}}_t \leftarrow \mathrm{Softmax}(\tilde{\mathbf{q}}_t^T \mathbf{r}_1 + \mathbf{b}_1, \ldots, \tilde{\mathbf{q}}_t^T \mathbf{r}_{|Y|} + \mathbf{b}_{|Y|})$; ▷ DRS

$y_t \leftarrow \mathrm{Argmax}_j(\tilde{\mathbf{y}}_t)$;

$\tilde{\mathbf{p}}_t^1 \leftarrow \mathrm{PiecewiseArgmax}(\mathbf{m}_t^P)$

2.4 Training Loss

- Cross entropy loss of Dialogue Response Selection (DRS)

$$\mathcal{L}_{\mathrm{drs}}(\theta) = -\frac{1}{N}\sum_{i=1}^{N}\sum_{j=1}^{|Y|}\mathbf{y}_j \log \hat{\mathbf{y}}_j \tag{1}$$

- Loss of User Profile Enrichment (UPE)

$$\mathcal{L}_{\mathrm{UPE}}(\theta) = -\frac{1}{N_2}\sum_{i=1}^{N_2}(p_i - \tilde{p}_i), \tag{2}$$

- In total,

$$\mathcal{L}(\theta) = \lambda\mathcal{L}_{\mathrm{drs}}(\theta) + (1-\lambda)\mathcal{L}_{crp}(\theta) \tag{3}$$

3.1 Dataset

- Personalized bAbI dialog dataset.
  - Four user profile attributes (gender, age, dietary preference, favorite food)
  - Statistics: a large version with 12,000 dialogues and a small version with 1,000 dialogues for train/dev/test, respectively. Vocabulary size is 14, 819 and candidate response size is 43, 863.
- Simulation of the incomplete profile with various degrees. Randomly discard some values in a user profile with probabilities of [0%, 10%, 30%, 50%, 70%, 90%, 100%].

Performance:

- *Response Selection Accuracy (RSA)*: the fraction of correct responses out of all candidate responses.
- *Profile Enrichment Accuracy (PEA)*: we define this metric as the fraction of correct profile values out of all discarded profile values.

Stability: Given a list of evaluation values $[z_1, \ldots, z_{N+1}]$, either RSA or PEA, σ is computed as follows:

$$\sigma(\mathbf{z}) = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(\mathbf{z}_i - \bar{\mathbf{z}})^2}, \qquad (4)$$

$$\mathbf{z} = [z_2 - z_1, \ldots, z_{N+1} - z_N],$$

where $\bar{z}$ is the mean of the values in performance difference list $\mathbf{z}$.

4.1 Results without discarding user profiles

	Small Set (%)	Large Set (%)
MemNN	77.74	85.10
Split MemNN	78.10	87.28
Retrieval MemNN	83.94	87.33
Personalized MemNN	88.07	95.33
NPMemNN	87.91	97.49
CoMemNN	**91.13***	**98.13***

- **MemNN**. Profile as the first user utterance + standard MemNN model.
- **Split MemNN**. Profile MemNN + dialogue MemNN.
- **Retrieval MemNN**. Encoder-encoder MemNN + Response Candidates Retrieval.
- **Personalized MemNN**. MemNN (current user profile, current dialogue history, dialogue history of all users with the same gender and age, user bias towards different KB entries).
- **NPMemNN**. Our implementation. Dialogue history from nearest $(k-1)$ neighbors.

4.2 Results with different profile discard ratios

Discard Ratio	0%	10%	30%	50%	70%	90%	100%
NPMemNN	87.91	86.11	86.56	85.79	83.93	84.08	**84.83**
CoMemNN	**91.13***	**89.90***	**88.69***	**87.80***	**86.35***	**84.83***	82.85
Small Set/Diff.	3.22	3.79	2.13	2.01	2.42	0.75	-1.98
NPMemNN	97.49	97.01	96.05	95.52	95.40	90.96	90.50
CoMemNN	**98.13***	**97.94***	**97.68***	**97.53***	**96.98***	**96.63***	**92.73***
Large Set/Diff.	0.64	0.93	1.63	2.01	1.58	5.67	2.23

- CoMemNN significantly outperforms NPMemNN on both datasets.
- CoMemNN steadily decreases with the increase of the profile discard ratio.
- Model stability: NPMemNN has higher deviations; CoMemNN is more stable.

5.1 Ablation study on Profile Enrichment Accuracy (PEA)

	10%	30%	50%	70%	90%	100%
CoMemNN	99.99	99.93	99.82	99.83	99.38	98.98
-PEL	85.71 (↓14.28)	87.85 (↓12.08)	91.34 (↓8.48)	89.19 (↓10.64)	90.04 (↓9.34)	90.60 (↓8.38)
-NP	99.87 (↓0.12)	99.85 (↓0.08)	99.24 (↓0.58)	99.15 (↓0.68)	99.13 (↓0.25)	98.86 (↓0.12)
-NP-CP	98.89 (↓1.10)	99.09 (↓0.84)	99.16 (↓0.66)	99.20 (↓0.63)	99.14 (↓0.23)	98.92 (↓0.06)
-ND	99.72 (↓0.26)	99.87 (↓0.06)	99.80 (↓0.02)	99.46 (↓0.37)	98.72 (↓0.66)	97.23 (↓1.75)
-ND-CD	99.99 (||0.00)	99.86 (↓0.07)	99.68 (↓0.14)	99.69 (↓0.14)	99.19 (↓0.19)	34.78 (↓64.2)
-ND-NP	99.09 (↓0.90)	98.98 (↓0.95)	97.95 (↓1.87)	97.69 (↓2.14)	97.06 (↓2.32)	97.23 (↓1.75)

- PEL: Profile Enrichment Loss.
- Input of UPE: Neighbor Profile (NP);Current Profile (CP);Neighbor Dialogue (ND); Current Dialogue (CD).

5.2 Ablation study on Response Selection Accuracy (RSA)

	0%	10%	30%	50%	70%	90%	100%
CoMemNN	91.13	89.90	88.69	87.80	86.35	84.83	82.85
-PEL	90.84 (↓0.29)	90.29 (↑0.39)	89.07 (↑0.38)	87.18 (↓0.62)	85.42 (↓0.93)	80.54 (↓4.29)	81.23 (↓1.62)
-PEL-UPE	87.91 (↓3.22)	86.11 (↓3.79)	86.56 (↓2.13)	85.79 (↓2.01)	83.93 (↓2.42)	84.08 (↓0.75)	<u>84.83</u> (↑1.98)
-NP	91.06 (↓0.07)	<u>91.23</u> (↑1.33)	89.17 (↑0.48)	85.26 (↓2.54)	83.30 (↓3.05)	82.10 (↓2.73)	82.83 (↓0.02)
-NP-CP	86.60 (↓4.53)	86.10 (↓3.80)	84.56 (↓4.13)	83.53 (↓4.27)	82.48 (↓3.87)	81.95 (↓2.88)	81.35 (↓1.50)
-ND	90.91 (↓0.22)	87.33 (↓2.57)	89.06 (↑0.37)	87.49 (↓0.31)	86.59 (↑0.24)	85.38 (↑0.55)	<u>85.41</u> (↑2.56)
-ND-CD	87.70 (↓3.43)	90.44 (↑0.54)	85.79 (↓2.90)	84.90 (↓2.90)	83.56 (↓2.79)	82.57 (↓2.26)	<u>85.38</u> (↑2.53)
-ND-NP	90.04 (↓1.09)	91.08 (↑1.18)	89.23 (↑0.54)	87.38 (↓0.42)	85.76 (↓0.59)	85.46 (↑0.63)	<u>85.41</u> (↑2.56)

- PEL: Profile Enrichment Loss.
- UPE: User Profile Enrichment module.
- Input of UPE: Neighbor Profile (NP);Current Profile (CP);Neighbor Dialogue (ND); Current Dialogue (CD).

5.3 Effect of different profile attributes

Discard	none	gender	age	dietary	favorite	all
gender	/	*93.05*	*91.94*	88.86	*91.95*	/
age	/	/	*92.26*	89.37	91.04	/
dietary	/	/	/	86.74	86.42	/
favorite	/	/	/	/	90.25	/
Remain	<u>82.85</u>	87.46	87.93	90.57	87.37	**91.13**

	RSA (Diff.)
CoMemNN /wo neighbors	**90.34**
CoMemNN /wo neighbors-gender	88.25 (↓2.09)
CoMemNN /wo neighbors-age	85.62 (↓4.72)
CoMemNN /wo neighbors-gender-age	83.73 (↓6.61)

- Each attribute works well in isolation.
- Different types of attributes depend on each other differently.

6 Conclusion

- **Contribution**:
  - A novel, practical task, i.e., personalized Task-oriented Dialogue System (TDS) with incomplete user profiles.
  - A CoMemNN model with cooperative interactive modules, which can enrich user profiles gradually as dialogues go on, and to promote response selection based on enriched profiles simultaneously.
  - Extensive experiments to demonstrate that CoMemNN significantly outperforms SOTA methods especially in incomplete user profile settings.
- **Limitation**: CoMemNN is tested on the only available personalized TDS dataset PbAbI.
- **Future work**: Experiment on more datasets and explore whether we can further improve the performance by leveraging non-personalized TDS datasets.

Thanks for your attention!

- **Paper**: Jiahuan Pei, Pengjie Ren, Maarten de Rijke. "A Cooperative Memory Network for Personalized Task-oriented Dialogue Systems with Incomplete User Profiles". In Proceedings of the 30th The Web Conference 2021 (WWW '21)
- **Email**: j.pei@uva.nl
- **Code**: https://github.com/Jiahuan-Pei/CoMemNN