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

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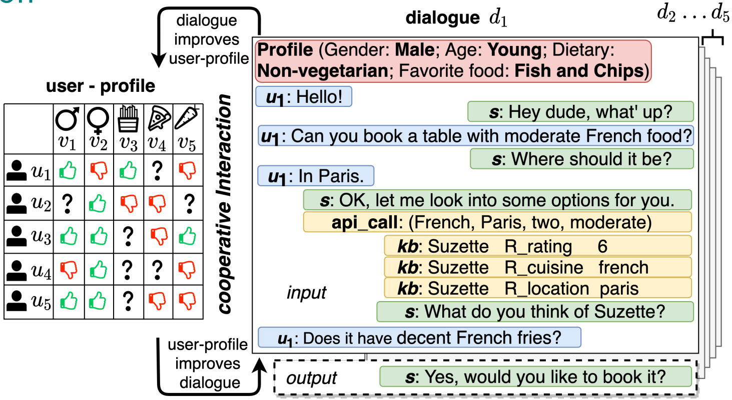
Overview

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.

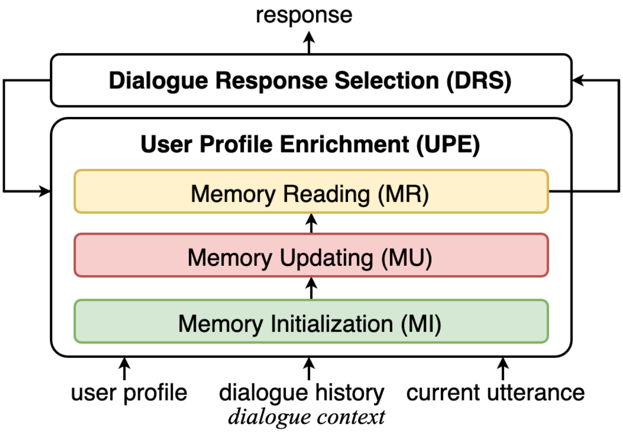
X_t^u	User utterance at turn t.
X_t^s	System response at turn t.
D_t	Dialogue history at turn t.
u	A user profile in the form of $\{(a_i, v_i)\}_{i=1}^m$, v_i is a candidate value of i-th attribute a_i.

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

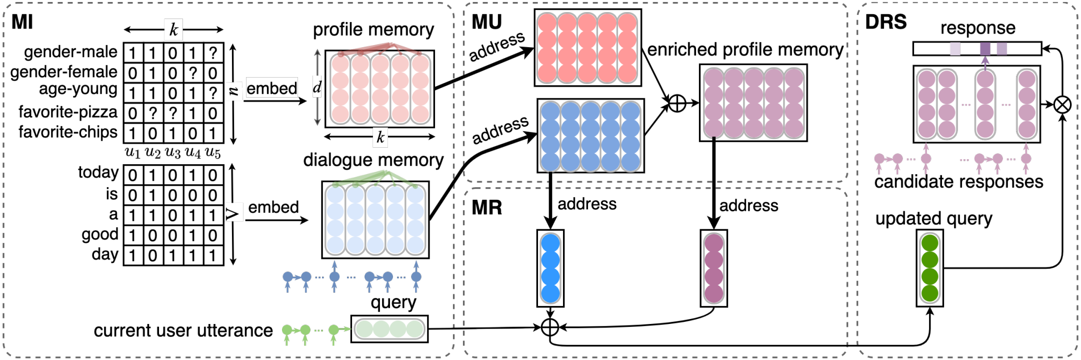
1.3 Research Questions

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?

2.1 Architecture



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

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

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

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

2.4 Training Loss

- Cross entropy loss of Dialogue Response Selection (DRS)

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

- Loss of User Profile Enrichment (UPE)

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

- In total,

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

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%].

3.2 Evaluation

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:

$$\sigma(\mathbf{z}) = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(\mathbf{z}_i - \bar{\mathbf{z}})^2}, \qquad \mathbf{z} = [z_2 - z_1, \ldots, z_{N+1} - z_N], \tag{4}$$

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
SOTAMemNN	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);Neighbor Profile (NP);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);Neighbor Profile (NP);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 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!