

A Data Usage

Note that both single-action and multi-action data samples are used for training all the SL-based methods. The difference lies in the data used to model contextual dialog action dependency. While existing methods mimic action combination patterns from multi-action samples only, we propose to further mine conditional dependency between dialog actions from single-action dialog trajectories. Besides single-action dialog planning, the decoding module is jointly trained to further assure a valid action combination. In cases where critical dialog-acts must occur as single-action (e.g., crucial verification), our model will predict a single-action with high probability as it is trained to match the ground truth.

Due to the variety of human dialogs, we do not assume a sequential dependency priori between atomic dialog actions in a multi-action sample. Instead, we posit that a corresponding single-action dialog usually exists regardless of the sequential order of action execution. To this end, we train the single-action planning module with all the sequential order variants of expert examples. In practice, this is achieved by randomly shuffling the action sequences in each batch before the forward propagation.

B Implementation Details

All the benchmarks are implemented with Pytorch on a server equipped with one Nvidia Tesla V100 GPU with 32GB memory. All the SL-based models, including PEDP, are trained without the help of the user simulator.

We perform hyperparameter optimization for our PEDP framework using hyperopt (Bergstra, Yamins, and Cox 2013) with priors specified in Table 1. The Adam optimizer (Kingma and Ba 2014) is applied in all experiments.

Hyperparameter	Prior	Best
weight-DAP	LogUniform ($1e^{-2}$, $1e^2$)	0.23
weight-SFP	LogUniform ($1e^{-2}$, $1e^2$)	0.12
weight-SR	LogUniform ($1e^{-2}$, $1e^2$)	0.04
weight-MAP	LogUniform ($1e^{-2}$, $1e^2$)	25

Table 1: Priors on the weights of the losses for the four sub-tasks in our PEDP framework: 1) Discrete Act Prediction (DAP); 2) Stop Flag Prediction (SFP); 3) State Recovery (SR); and 4) Multi-Action Prediction (MAP).

For the fixed hyperparameters, we empirically decide the values with regard to (Li, Kiseleva, and de Rijke 2020) and report the details in Table 2.

Hyperparameter	Value	Hyperparameter	Value
Learning rate	$1e^{-3}$	Batch size	32
Dropout	0.2	Epoch	15
Hidden dim	200	State hidden dim	100
Temperature	$1e^{-3}$	Clip	0.5
TF-upper	1	TF-lower	0.25

Table 2: Fixed hyperparameter for our PEDP method.

Here, “Hidden dim” refers to the number of middle layer neurons in the Fully-connected Feed-forward Networks.

“State hidden dim” denotes the dimension of the dialog state vector (\mathbf{h}). “Temperature” is set with the same value for all the Gumbel-Softmax functions.

Note that the single-action planning module does not perform well at the early stages of dialog training and may mislead the decoder. To this end, we apply a curriculum learning strategy of Scheduled Teacher Forcing (Bengio et al. 2015) to change the training process from a fully guided scheme using the true next dialog state towards a less guided one that mostly uses the planned dialog state instead. Here, the probability of using the true next dialog state is decreased from “TF-upper” to “TF-lower” in a linear decay manner. The slope of the decay depends on the expected speed of convergence, i.e., “Epoch”.

C Hyper-parameter Sensitivity

Table 3 shows how the number of paths K affects model performance. We see that the standard deviation generally decreases with K . This is because the ensemble prediction can effectively reduce the impact of low-quality paths. Since bigger K leads to more calculation costs, we choose $K = 3$ to balance effectiveness and efficiency.

K	1	2	3	4	5	6
Success	89.1	89.3	90.6	89.7	90.2	89.9
Std. Dev.	1.74	1.19	0.68	0.73	0.62	0.57

Table 3: Hyper-parameter sensitivity.

D Case Study

To intuitively show the effectiveness that PEDP can incorporate contextually relevant content to enhance multi-action prediction, we present six emblematic dialog examples (from human evaluation) of various domains and dialog lengths in Fig. 1,2,3,4,5,6. **Please see the following pages.**

Please note that 1) the current language generation module does not consider the expressive order in text responses, and thus such order is not a factor for model evaluation. 2) The blank lines indicate non-actions from the policy model (or user simulator).

From the results, we observe that our PEDP model performs the best among state-of-the-art models by generating more informative and proper responses.

DiaSeq

USER: Can you help me find a restaurant? How about Asian oriental food. It just needs to be moderate. I want to find a place in the Centre.

SYSTEM: There are 1 different places that match your description. Would you like me to book it?

USER: The choice is 1.

SYSTEM: The phone number of the restaurant is 01223518111. The post code is cb11lh.

USER: The phone is 01223518111. The postcode is cb11lh.

SYSTEM: It should arrive by 06:43. Tr4391 would be your perfect fit.

USER: I want to arrive by 06:43. The id is tr4391.

SYSTEM: For how many people?

USER: What is the People of train?

SYSTEM: The trip will last 49 minutes.

DiaAdv

USER: Can you help me find a restaurant? How about Asian oriental food. It just needs to be moderate. I want to find a place in the Centre.

SYSTEM: Okay, how about yippee noodle bar? It is Asian oriental food. They are moderate.

USER: Please provide their phone number. Can i get the postcode?

SYSTEM: 01223518111 is the restaurant phone number. Their postcode is cb11lh. Did you need any further assistance today?

USER: I would like to go to Cambridge please. The train should leave on Saturday. I ' m also looking for a train from Stevenage. I want to get there by 09:15 at the latest.

SYSTEM:

USER: Can you give me the travel time please?

SYSTEM: How about 07:54 will that work for you? The trip is 49 minutes.

GDPL

USER: Can you help me find a restaurant? How about Asian oriental food. It just needs to be moderate. I want to find a place in the Centre.

SYSTEM: Okay, how about yippee noodle bar? Would you like me to book it?

USER: What is the phone number of the restaurant? I just need the postcode.

SYSTEM: 01223518111 is the restaurant phone number. Their postcode is cb11lh.

USER: I would like to go to Cambridge please. The train should leave on Saturday. I ' m also looking for a train from Stevenage. I want to get there by 09:15 at the latest.

SYSTEM:

USER: What is the travel time?

SYSTEM: The travel time is 49 minutes.

PEDP

USER: Can you help me find a restaurant? How about Asian oriental food. It just needs to be moderate. I want to find a place in the Centre.

SYSTEM: Okay, how about yippee noodle bar? Would you like me to book it?

USER: What is the phone number of the restaurant? I just need the postcode.

SYSTEM: Would you like to try yippee noodle bar? 01223518111 is the restaurant phone number. Their postcode is cb11lh. Did you need any further assistance today?

USER: I need to book a train to Cambridge. The train should leave on Saturday. Great I also need a train departs from Stevenage. Do you have a train that arrives closer to 09:15?

SYSTEM: There is a train that leaves at 05:54. The booking is for arriving in Cambridge.

USER: Can you give me the travel time please?

SYSTEM: The trip will last 49 minutes.

Figure 1: Case 1.

DiaSeq

USER: I would prefer Chinese food please. I also need a place to dine that is expensive priced. I ' m so hungry - can you find me a place to eat in the Centre?

SYSTEM: I have 4 options for you!

USER: The choice is 4.

SYSTEM: The post code is cb21tw. Is there anything else i can help you with?

DiaAdv

USER: I would prefer Chinese food please. I also need a place to dine that is expensive priced. I ' m so hungry - can you find me a place to eat in the Centre?

SYSTEM: I have 4 options for you!

USER: I would like to know the postcode of the restaurant, if possible?

SYSTEM: Would you like me to book it? Okay, how about ugly duckling? The restaurant postcode is cb21tw.

GDPL

USER: I would prefer Chinese food please. I also need a place to dine that is expensive priced. I ' m so hungry - can you find me a place to eat in the Centre?

SYSTEM: I have 4 options for you!

USER: I would like to know the postcode of the restaurant, if possible?

SYSTEM: The ugly duckling is a nice place would you like to try that one? The restaurant postcode is cb21tw.

PEDP

USER: I would prefer Chinese food please. I also need a place to dine that is expensive priced. I ' m so hungry - can you find me a place to eat in the Centre?

SYSTEM: How about ugly duckling? It is Chinese food. It is located in the Centre. Would you like me to book it?

USER: What is their postcode?

SYSTEM: Their postcode is cb21nw. Is there anything else I can help you with?

Figure 2: Case 2.

DiaSeq

USER: I also need a place to dine that is expensive priced. I also would like information on a place to eat in the Centre. How about European food.

SYSTEM:

USER:

SYSTEM: How about Michaelhouse cafe? They are located at St. Michael's church trinity street city Centre.

DiaAdv

USER: I also need a place to dine that is expensive priced. I also would like information on a place to eat in the Centre. How about European food.

SYSTEM: I have 2 options for you. They are in the expensive price range. How about Eraina?

USER: May I also get the address for the restaurant?

SYSTEM: Can I make a reservation for you? How about Eraina ? Their address is free school lane city Centre.

GDPL

USER: I also need a place to dine that is expensive priced. I also would like information on a place to eat in the Centre. How about European food.

SYSTEM: How about Michaelhouse cafe?

USER: May I have the address?

SYSTEM: The restaurant address is free school lane city Centre.

PEDP

USER: I also need a place to dine that is expensive priced. I also would like information on a place to eat in the Centre. How about European food.

SYSTEM: I have 2 different restaurants I can give you some information for. they are all pretty good. Shall I try to start and book you into one? How about Eraina?

USER: May I also get the address for the restaurant?

SYSTEM: Would you like to try Eraina? They are located at free school lane city Centre. Did you need any further assistance today?

Figure 3: Case 3.

DiaSeq

USER: Can you also help me find a hotel called the Laverton house?

SYSTEM:

USER:

SYSTEM: How about Laverton house? It's located in the east. It is located at 732-734 new market road. The hotel phone number is 01223292094. The postal code for that hotel is cb58rs.

USER: I'm looking for information on a hotel called Laverton house. I need it in the east, please. The address is 732-734 new market road. The phone is 01223292094. The postcode is cb58rs.

SYSTEM: It is a guesthouse.

USER: I'd really prefer a guesthouse.

SYSTEM: Booking was successful. reference number is: ###.

USER: The reference number is ###.

SYSTEM: Is there anything else I can help you with?

USER:

SYSTEM: When would you like the train to depart?

USER: I need the departure time.

SYSTEM: The reference number is ###.

DiaAdv

USER: Can you also help me find a hotel called the Laverton house?

SYSTEM: It is a guesthouse.

USER: May I have the address for that hotel? Can I get the postcode of the hotel? Could i get the phone number of the hotel? What is the area?

SYSTEM: How about Laverton house ? The hotel address is 732-734 new market road. The hotel phone number is 01223292094. The postal code for that hotel is cb58rs. Is there anything else I can help you with?

USER: What is the area?

SYSTEM:

USER: Can you tell me what area that's in?

SYSTEM:

USER: Yeah, what area of town is it in?

SYSTEM: You are welcome. is there anything else I can help you with today?

USER: What is the area?

SYSTEM:

USER: Do you know the area the hotel is located in?

SYSTEM:

GDPL

USER: Can you also help me find a hotel called the Laverton house?

SYSTEM: It is in the east part of town.

USER: Could I get their address? Can I get the postcode of the hotel? Could I get the phone number of the hotel? What type of accommodations are they.

SYSTEM: It is located at 732-734 new market road. The phone number of the hotel is 01223292094. The postal code for that hotel is cb58rs.

USER: What type of hotel is it?

SYSTEM:

USER: What type of hotels are they?

SYSTEM:

USER: What type of accommodations are they.

SYSTEM:

USER: I need the type of place it is, please.

SYSTEM:

USER: I am wondering what type of hotel, please .

SYSTEM:

PEDP

USER: Can you also help me find a hotel called the Laverton house?

SYSTEM: It is a guesthouse. It's in east. Its listed as cheap. Is there anything else I can help you with?

USER: Could I get their address? What is the postcode of the hotel? I need the phone number of the hotel.

SYSTEM: Does the Laverton house work? The hotel address is 732-734 new market road. The hotel phone number is 01223292094. The postcode is cb58rs.

USER: I would like to book it for 3 nights please. I need a room starting on Sunday. Could you book the reservation for me for 6 people?

SYSTEM: Your reference number is ###. Did you need any further assistance today?

USER: I need to find a train to Cambridge please. This will be for Sunday. I need it to depart from Peterborough. I need it to arrive by 15:15.

SYSTEM: There is a train that leaves at 08:48. Tr6183 would be your perfect fit. It should arrive by 09:38. The booking is for arriving in Cambridge.

USER: Do you have a train that arrives closer to 15:15.

SYSTEM: The id is tr0485.

USER: I would like 1 tickets please.

SYSTEM: The reference number is ###. Did you need any further assistance today?

Figure 4: Case 4.

DiaSeq

USER: I want a train leaving on Sunday.

SYSTEM: What is your destination?

USER: What is the destination of train?

SYSTEM: Where are you departing from?

USER: What is the Depart of train?

SYSTEM: When would you like to leave by? Is there a time you would like to arrive by?

USER: What is the departure time? What is the arrival time for that train?

SYSTEM: It arrives at 11:27. Tr0995 would be your perfect fit.

USER: I want to arrive by 11:27. The id is tr0995.

SYSTEM: For how many tickets?

USER: What is the People of train?

SYSTEM: The fare is 13.28 pounds per ticket.

USER: The ticket is 13.28 pounds.

SYSTEM: The reference number is ###. The ticket is 13.28 pounds

USER: The reference number is ###. The ticket is 13.28 pounds.

SYSTEM: Remind me of the area you need that in.

USER: Can you tell me which area it is in?

SYSTEM: Would you like me to book it? Wagamama looks like a good place.

USER: I am looking for details on the Wagamama restaurant.

SYSTEM: Their address is 36 saint Andrews street . The post code is cb23ar. You are welcome. is there anything else I can help you with today?

DiaAdv

USER: I want a train leaving on Sunday.

SYSTEM: What is your destination?

USER: I am going to London Liverpool street.

SYSTEM: When would you like to leave by?

USER: Great I also need a train departs from Cambridge. I need it to arrive by 14:45.

SYSTEM: The arrival time is 13:27.

USER: I 'd like to arrive by 14:45.

SYSTEM: Their id is tr7187. It arrives at 01:27. The train stop is London Liverpool street.

USER: I 'd like to arrive by 14:45.

SYSTEM: The train id is tr1163. It should arrive by 07:27.

USER: Well I want to arrive by 14:45.

SYSTEM:

USER: What 's the price?

SYSTEM: The price of those tickets are 13.28 pounds.

USER: Are there any Japanese restaurants? What restaurants are located in the Centre?

SYSTEM: How about Wagamama? There are 1 available restaurants.

USER: What is the address? What is their postcode?

SYSTEM: The restaurant address is 36 saint Andrews street. Their postcode is cb23ar. It is at 36 saint Andrews street.

GDPL

USER: I want a train leaving on Sunday.

SYSTEM: Where are you departing from? What is your destination?

USER: I am going to London Liverpool street. I ' m departing from Cambridge.

SYSTEM: When would you like to leave by? What time do you need to arrive?

USER: I need it to arrive by 14:45.

SYSTEM: Tr7187 would be your perfect fit.

USER: What is the price of a ticket, please?

SYSTEM: It would cost 13.28 pounds.

USER: I 'd like to find a Japanese restaurant, if possible. I 'd like to be in the Centre please.

SYSTEM:

USER: May I also get the address for the restaurant? Can I get the postcode for the restaurant?

SYSTEM: Their address is 36 saint Andrews street. Their postcode is cb23ar.

PEDP

USER: I 'm looking for a train leaving on Sunday please.

SYSTEM: What time would you like to leave? Where will you be departing from? Where will you be arriving at?

USER: I need to book a train to London Liverpool street. I also need a train departing from Cambridge.

SYSTEM: It leaves at 21:59. The train id is tr3256.

USER: Do you have a train that arrives closer to 14:45.

SYSTEM: There is a train that leaves at 05:59. Tr1163 would be your perfect fit.

USER: Can you give me the price?

SYSTEM: The cost of the one-way journey is 13.28 pounds.

USER: This restaurant should serve Japanese food too. I also would like information on a place to eat in the Centre.

SYSTEM: I have 1 option for you. That is a Japanese restaurant.

USER: May I have the address for the restaurant please? Can I get the postcode for it please?

SYSTEM: Would you like to try Wagamama? The restaurant address is 36 saint Andrews street. The restaurant postcode is cb23ar.

Figure 5: Case 5.

DiaSeq

USER: A college type of attraction. I would like to visit on in town Centre please.

SYSTEM: There are 13, anything in particular you are looking for?

USER: The choice is 13.

SYSTEM: How about saint john's college? Here is the attraction phone number, 01223338600.

USER: Hello, I'm looking for the saint john's college, could you tell me more about it? The phone is 01223338600.

SYSTEM: Would you like for me to try and make a reservation? How about Kirkwood house? It's in north. It is moderate. The hotel is 4 stars.

USER: I'm looking for information on a hotel called Kirkwood house. Would you be able to help me find a place to stay in the north? I would like to keep it in the moderate range, please. Do you have any hotels with a 4-star rating?

SYSTEM: There is Wi-Fi available at the hotel. The hotel address is 172 Chesterton road.

DiaAdv

USER: A college type of attraction. I would like to visit on in town Centre please.

SYSTEM: Would you be interested in visiting a college?

USER: Please get me their phone number.

SYSTEM: Here is the attraction phone number, 01223338600.

USER: I am looking for a hotel call Kirkwood house.

SYSTEM: Would you like for me to try and make a reservation? How about Kirkwood house? It's in north. It is moderate. The hotel is 4 stars. Okay! glad I could help. enjoy your stay.

USER: Could I get their address? Does it have internet?

SYSTEM: Would you like me to book it? How about Kirkwood house? They are located at 172 Chesterton road.

USER: Can you tell me if the hotel has internet available?

SYSTEM: There is Wi-Fi available at the hotel.

GDPL

USER: A college type of attraction. I would like to visit on in town Centre please.

SYSTEM:

USER: Can you give me the phone number of the attraction?

SYSTEM: Here is the attraction phone number, 01223338300.

USER: I am also looking for the Kirkwood house.

SYSTEM: It is in the north.

USER: Could you give me the address of the hotel, please? Do you have a price range for that hotel? Do any of them offer internet?

SYSTEM: It is in the moderate price range. They are located at 172 Chesterton road.

USER: Can you tell me if they have free internet?

SYSTEM: It has free Wi-Fi.

PEDP

USER: A college type of attraction. I would like to visit on in town Centre please.

SYSTEM: Sidney Sussex college looks good. Sure, there are 13 in that area. I recommend Sidney Sussex college.

USER: Can you give me their phone number please?

SYSTEM: Here is the attraction phone number, 01223331100. Is there anything else I can help you with today?

USER: I'm looking for information on a hotel called Kirkwood house.

SYSTEM: How about Kirkwood house?

USER: What's the address of the hotel? Do you have a price range for that hotel? Do they also have internet available?

SYSTEM: Okay, how about Kirkwood house? It is a guesthouse. Its listed as moderate. It has free Wi-Fi. They are located at 172 Chesterton road.

Figure 6: Case 6.

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