

Knowledge Base Adaptation for Task Oriented Dialog Systems

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THESIS CERTIFICATE

This is to certify that the thesis titled **Knowledge Base Adaptation for Task Oriented Dialog**, submitted by **Nikhil Gupta**, to the Indian Institute of Technology, Delhi, for the award of the degree of **Bachelor and Master of Technology**, is a bona fide record of the research work done by him under our supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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ABSTRACT

Dialog systems or chatbots are computer programs that can interact with humans either using a speech interface or text interface. Based on the application, dialogs systems can be divided into two categories: open domain and task oriented. Dialog systems that converse with an intention to accomplish a task such as recommending a restaurant or booking a flight tickets are task oriented dialog systems. Such systems generally need to consult a Knowledge Base (KB) with stored information to accomplish the task. End-to-end neural networks trained for these task-oriented dialogs are expected to be immune to any changes in this KB which can evolve with time. However, existing approaches breakdown when asked to handle such changes. The failure is mostly due to the inability to handle Out-of-Vocabulary (OOV) words and the inability to perform simple reasoning over the knowledge base results such as suggest without repetition and sorting based on a field.

We studied the correlation between the learned language model and the knowledge base incorporation and conjectured that we must strive to create a system that learns both mutually exclusive of the other, i.e. in a disentangled manner. We propose an encoder-decoder architecture (BOSSNET) with a novel Bag-of-Sequences (BOSS) memory, which facilitates such disentangled learning. Consequently, the KB can be modified with new knowledge without a drop in interpretability. We find that BOSSNET outperforms state-of-the-art models, with considerable improvements ($>10\%$) on bAbI OOV test sets and other human-human datasets. We also systematically create adversarial attacks that introduce modifications to the KB in an attempt to measure the extent of disentanglement and show that BOSSNET remains robust to all such attacks.

Generally the training set dialogs in task-oriented systems use an explicit API for KB retrieval which must be manually annotated within the dialogs themselves. We attempt to go one step further by reducing the amount of annotations needed to train such task-oriented dialogs by predicting the correct API without it being explicitly mentioned. We generate this API using an RL-based decoder. The results from this API are then used to generate responses by our response decoder which serve as feedback (reward) to train the RL decoder. We created a novel architecture that would be capable to mitigate two critical problems: data bias (multiple APIs fetch similar KB results) and length bias (preference of the RL decoder to predict short length APIs over longer ones, despite worse results). Our system was successfully able to achieve similar performance on the unannotated dataset as compared to the fully API annotated dataset.

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Chapter 1

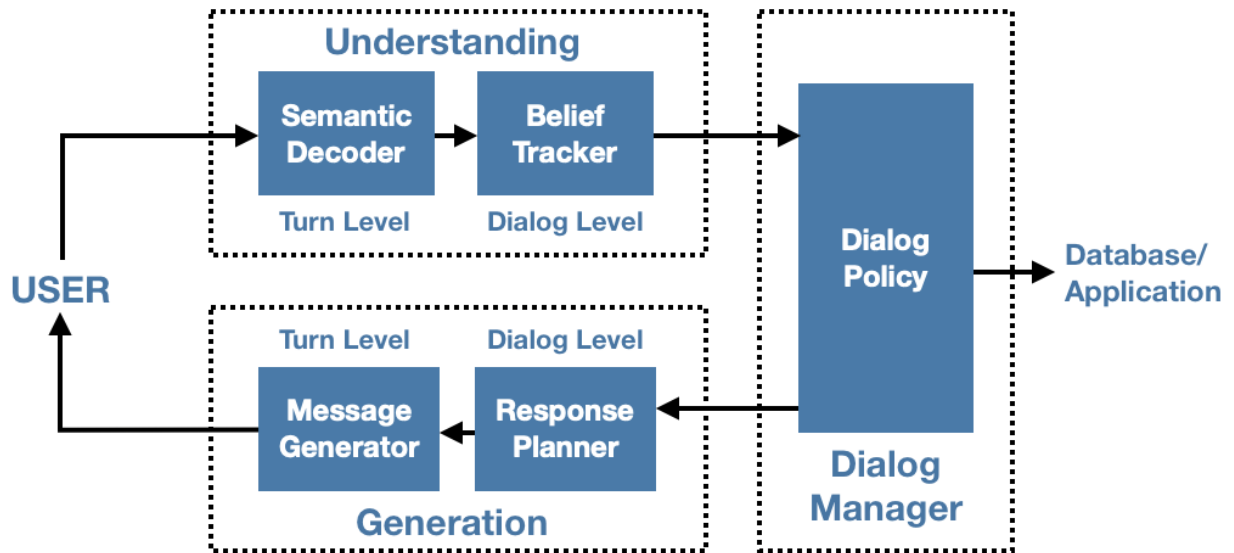
INTRODUCTION

1.1 Overview

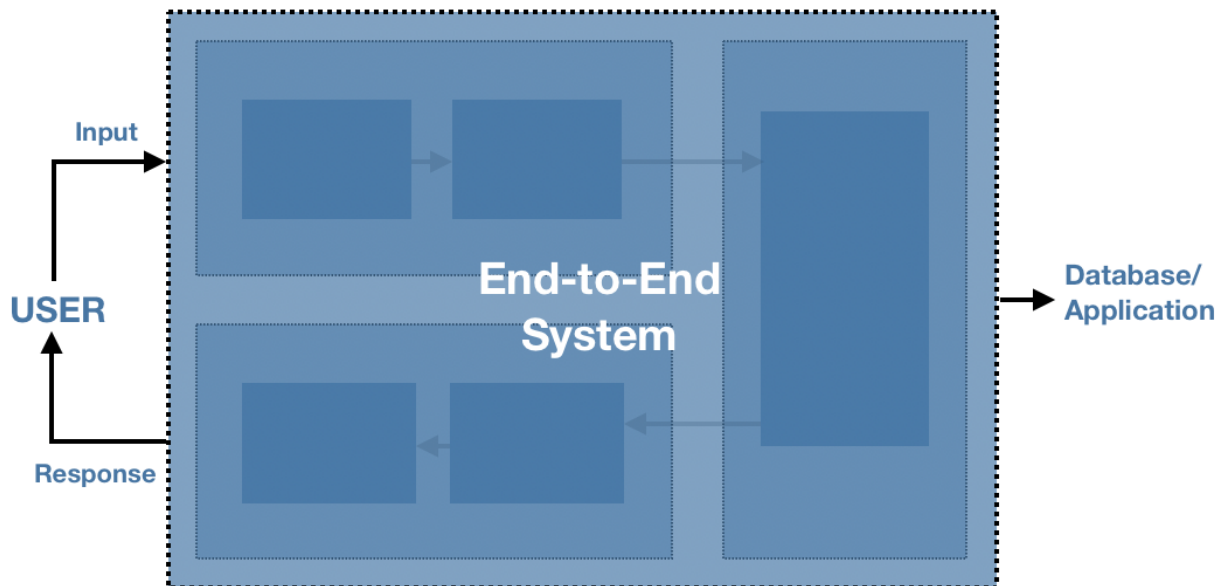
Dialog systems, also referred to as chatbots or virtual agents are systems that can converse with a human to help with their informational needs. Dialog systems are used in a wide range of applications such as personal assistants in mobile phones, technical support services, chit chat, product enquiries, IVR systems and entertainment. Some of the popular dialog systems include Apple's Siri, Google Now, Microsoft's Cortana, Amazon's Alexa and Google's Smart Reply. Most of the dialog systems that are being used for real word applications are hand crafted by a dialog designers and also very specific to a domain. Even though using such hand crafted rules provides the flexibility to build a interpretable dialog system, it requires a great amount of effort for the dialog designer to create one from scratch for a new domain. This extra effort also transcends to scenarios where the existing chatbot's capability has to be extended or improved.

End-to-End Learning: A complete dialog system is comprised of several sub-modules with different functionalities. Broadly we can classify these into three primary components: 1) natural language understanding (NLU) unit, 2) dialog manager and 3) natural language generator (NLG). The architecture is shown in Figure 1.1a. Each component can be either built using hand-crafted rules or can be a statistical machine learning model that learns from a provided set of examples. A complete dialog-system, which is a combination of these components, can then be partly hand-designed and partly data-driven. In some cases, the designer will choose to combine two or more components together because of the type of data that is available. This bypasses the need for explicitly annotating the data to serve each component separately, but in exchange, the complexity of the module increases thereby demanding a lot more data to train. The approach where all the three components are combined together and examples of (user input in natural language, expected response in natural language) pairs are used to learn a dialog model, is referred to as *end-to-end* dialog models. Note that in end-to-end learning, the intermediate output space may be defined, but examples are not annotated with expected intermediate outputs. This architecture is depicted in Figure 1.1b.

Task-Oriented: Application of dialog systems can be broadly categorized into two types: open domain (non-task-oriented) dialog systems and task-oriented dialog systems. The main difference between the two approaches is that, the objective of the former is usually broad



(a) Multi-Component Dialog System



(b) End-to-end Dialog System

Figure 1.1: Types of Dialog System Architecture

and not well defined (abstract), where as the objective of the latter is narrow and well-defined. For example, the restaurant reservation domain dialogs falls under task-oriented systems. The goal could be, given a set of options (cuisine: *Chinese*, location: *East Delhi*), the system should be able to suggest the right restaurant that is acceptable by the user. A large portion of the research in data driven approaches for dialog modeling has been around open domain systems. Some examples include chit-chat and language learning. Applications such as restaurant reservation, flight booking, travel enquiry and bus enquiry belong to the task-oriented setting. One advantage of working with task-oriented dialogs is the ease of defining evaluation techniques to measure the performance of the system. The performance of the system can be measured by the percentage of conversations where the dialog system was able to help the user achieve their goal.

Question answering systems and task-oriented dialog systems are very similar to each other. The major difference between the two is that, in question answering all details necessary to achieve the task are provided in a single shot, where as in task-oriented dialog, the user conveys information spaced throughout the conversation. In the latter it is the job of the dialog system to collect the necessary information to complete the task. These architectures also provide the ability to carry over context when switching between tasks.

Knowledge Base in the Loop: These are the subset of dialog systems that require access to a knowledge base to respond to user input. Some examples of knowledge bases systems are: a bus inquiry system using a KB with bus running status, a restaurant reservation system using a KB filled with restaurant information, etc. There has been a large amount of work on using databases in systems that use hand-crafted features for modeling dialog. The community has recently (in 2017) started to explore the area of learning data-driven dialog models grounded by a knowledge base.

We interact with the Knowledge Base using specially designed APIs that are task specific. These APIs will have the ability to either retrieve information or update information in the KB. Traditionally, API calls have been simple template based responses that employ slot-filling techniques for each template entry. However, the retrieval power could be increased if the APIs would become more flexible and dynamic. This would enable the selection of more precise results and even allow simple data manipulations, such as sorting, which could aid in training the system.

Typically, to train dialog systems associated with a knowledge base, we need to annotate the knowledge base incorporation in the dialog data itself. For example, if the system is to query the KB, then the corresponding API call must be included in the dialog explicitly. This makes it difficult to create a large training corpus as general ASR systems won't be able to recognise the API call being performed and the data curator must add it manually.

1.2 Problem Definition

The focus of this thesis will be to improve the ability of task-oriented dialog systems to generalise over its KB. In real-world applications, the KB information could change over time. For example, (1) a KB associated with a movie ticket booking system gets updated every week based on new film releases, and (2) a restaurant reservation agent, trained with the knowledge of eateries in one city, may be deployed in other cities with an entirely different range of establishments. In such situations, the system should have the ability to conform to new-found knowledge unseen during its training. Ideally, the training algorithm must learn to disentangle the language model from the knowledge interface model. This separation will enable the system to generalize to KB modifications, without a loss in performance.

Moreover, for achieving good progress towards the user’s task, the agent must also retain the ability to draw inferences based on past utterances and the KB. Notably, we find that existing approaches either achieve this disentanglement or effective progress towards the task, but not both.

We will also focus on enabling the system to predict the correct API call without explicit annotations. This will help us twofold: (1) we will be able to leverage larger databanks for training end-to-end dialog systems which don’t have this additional KB annotation, and (2) we will be able to predict more efficient APIs to solve the task than those originally used.

To summarize, the goal of our research is to build a dialog system that takes as input (1) a large set of task-oriented conversation logs between a user and an agent/domain expert, (2) a knowledge base used to generate agent response and learn a dialog system that can mimic the agent to accomplish a user’s task. With this goal in mind we can broadly formulate two distinct problems as follows:

Problem 1 *Create an end-to-end dialog system that effectively disentangles the language and knowledge models.*

The system must be capable to handle changes in the database which we will simulate using systematic adversarial attacks which mutates KB information. We will test the effectiveness of the system on three standard datasets used for task-oriented dialog – bAbI [2], CamRest [22], and Stanford Multi-Domain Dataset [4]. Of these, the last two are real-world datasets. We will evaluate the responses using standard metrics in the task-oriented setting.

Problem 2 *Enable the end-to-end system to achieve comparable performance on datasets without explicit Knowledge Base API annotations.*

The mentions datasets will have to be augmented to remove the extra annotation depicting the API information and a "predict API" signal should be inserted in its exact place. The system will be evaluated using the same metrics as before and the objective will be to achieve the same performance as the model trained in the first problem definition.

1.3 Motivation

In this section, we motivate our problem by clearly defining the gap between what the state-of-the-art, data-driven approaches for dialog learning are capable of and what it takes to build a usable end-to-end task-oriented dialog system that requires a knowledge base.

Why cant already proven non-task-oriented models be used?

While end-to-end non-task-oriented (open domain) dialog systems are being used in real world applications [8], designers still prefer using hand crafted rules for modeling task-oriented dialogs. The main reason for success in non-task-oriented setting is that, models have largely been evaluated (and applied) in scenarios where, given the conversation so far the system is expected to predict just the immediate next response. Such modeling requires the system to learn a language model and a mapping from the context to the response. But in case of task-oriented settings, the requirements/expectations are much more. It is not just required to generate the next utterance based on the context, but understand the global picture of what the task is, what all details are necessary to finish the task, what is the optimal way or strategy to request for missing details, and then decide what the next utterance should be. Also, in chit chat bot (non-task-oriented) making a mistake in a single turn is not very costly, where as in flight booking system (task-oriented) making a single mistake (mis-interpreting a source city) could turn out to be very costly. Even though a large section of real world applications such flight booking, technical service support, basic medical consultations fall under this category, there has been very little focus so far.

In addition to task-oriented setting, when a knowledge base is added into the loop, the system should now also be able to learn when to query a knowledge base, how to incorporate the results from the knowledge base into the conversation. Also, such KB-centric task-oriented dialogs generally need specially annotated data which is not easily available as compared to unannotated dialogs which used to train open domain systems. This makes the problem much harder and harder to generalise. Hence models that have been proven to work on non-task-oriented systems cannot be used for task-oriented applications.

How is dialog data collected for data-driven modelling?

Most datasets used in open domain dialog systems are obtained using Automatic Speech Recognition (ASR) techniques. Here a recording of a conversation between two individuals can easily be transcribed and added to the large data corpora. This ease of data collection and large datasets has invited a lot of research interest in open domain dialog. Task-oriented dialog requires specific annotation for it to be usable, such as interaction with the Knowledge Base via an API and the results themselves. Difficulty to annotate such instances automatically has led to scarce data reserves and has forced researchers to fabricate data of their own.

Limitations of state-of-the-art task-oriented approaches

There has been very little progress made end-to-end task-oriented dialogs, as most of the proposed approaches has been around using hand crafted rules to either build the entire system, or to define the structured space of each sub-components output. The only work published so far on end-to-end task-oriented conversation has the following limitations:

1. Both the human and the agent utterances in the dataset are fabricated using rules. This simulated dataset is very simple compared to human to human conversation logs.
2. The learned model is unable to generalise over a Knowledge Base and performance suffers greatly whenever KB modifications are made. It has no support for field values that have never been encountered so far (OOVs).
3. The system performance is has acceptable accuracy on non-task-oriented evaluation metrics, but the performance is very poor on task-oriented evaluation metrics
4. The system is unable to learn simple patterns (that are exhibited in the train corpora) required to perform a task-oriented dialog, such as not repeating already suggested options and sorting based on a particular field.
5. The system proposed has a very limited view of the knowledge base. It assumes that it can only perform simple *SELECT* operation with *WHERE* clauses over the knowledge base

1.4 Contributions

To address our first problem statement, we propose BOSSNET, a novel network that effectively disentangles the language and knowledge models, and also achieves state-of-the-art performance on three existing datasets.

To achieve this, BOSSNET makes three design choices. First, BOSSNET uses an encoder-decoder architecture so that it can stitch the next utterance one word at a time as compared to a typical retrieval based model which selects a certain response from a fixed set of responses. Second, it encodes the conversational input as a *bag of sequences* (BOSS) memory, in which the input representation is built at two levels of abstraction. The *higher level* flat memory encodes the KB tuples and utterances to facilitate effective inferencing over them. The *lower level* encoding of each individual utterance and tuple is constructed via a sequence encoder (Bi-GRU). This enables the model to maintain the sequential context surrounding each token, aiding in better interpretation of unseen tokens at test time. Third, we augment the standard cross-entropy loss used in dialog systems with an additional loss term to encourage the model to only copy KB tokens in a response, instead of generating them via the language model. This combination of sequence encoding and additional loss (along with dropout) helps in effective disentangling between language and knowledge.

We find that BOSSNET is competitive or significantly better on standard metrics in all datasets as compared to state-of-the-art baselines. We also introduce *adversarial attacks* in which we systematically increase the percentage of previously unseen entities in the KB. We summarise these attacks as our *knowledge adaptability* (KA) evaluation. We find that BOSSNET is highly robust across all percentage levels in all the standard metrics. We also report a human-based evaluation and find that BOSSNET responses are frequently rated higher than other baselines.

To address the second problem statement, we extend BOSSNET and add a novel RL-decoder which generates the required API call at a fixed turn of the dialog. We train the system using a buffer containing valid API calls and do a mix of off-policy and on-policy sampling. We use a pseudo-reward for learning which is computed using a combination of precision and recall on the retrieved results and the gold system response KB entities. We were successfully able to achieve similar accuracies to the original BOSSNET model trained on the fully annotated dataset.

Overall, our contributions are:

1. We propose BOSSNET, a novel architecture to disentangle the language model from knowledge incorporation in task-oriented dialogs.
2. We introduce a *knowledge adaptability* evaluation to measure the ability of dialog systems to scale performance to unseen KB entities.
3. Our experiments show that BOSSNET is competitive or significantly better, measured via standard metrics, than the existing baselines on three datasets.
4. We extend the BOSSNET architecture and add a novel RL-based API generator which matches state-of-the-art performance on modified datasets which lack explicit API annotation.

Our work addressing the first problem statement was published as a full paper in the Proceedings of the 2019 Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies (NAACL-HLT 2019). <https://www.aclweb.org/anthology/papers/N/N19/N19-1126/>.

We release our code and *knowledge adaptability* (KA) test sets for further use by the research community. <https://github.com/dair-iitd/BossNet>. We also release our extended code base along with the modified test sets. <https://github.com/NikhilGupta1997/BossNet-RL>.

Chapter 2

BACKGROUND

Compared to the traditional slot-filling based dialog [24, 21, 23], end-to-end training methods (e.g., [2], this work) do not require handcrafted state representations and their corresponding annotations in each dialog. Thus, they can easily be adapted to a new domain. We discuss end-to-end approaches along two verticals: 1) decoder: whether the response is retrieved or generated and 2) encoder: how the dialog history and KB tuples are encoded.

Most of the existing end-to-end approaches *retrieve* a response from a pre-defined set [2, 11, 17]. These methods are generally successful when they have to provide boilerplate responses – they cannot construct responses by using words in KB not seen during training. Alternatively, generative approaches are used where the response is *generated* one word at a time [5, 13]. These approaches mitigate the unseen entity problem by incorporating the ability to copy words from the input [20, 6]. The copy mechanism has also found success in summarization [14, 16] and machine translation [7]. BOSSNET is also a copy incorporated generative approach.

For encoding, some approaches represent the dialog history as a sequence [5, 7]. Unfortunately, using a single long sequence for encoding also enforces an order over the set of KB tuples making it harder to perform inferencing over them. Other approaches represent the dialog context as a bag. Original Memory Networks [2] and its extensions encode each memory element (utterance) as an average of all constituent words – this cannot point to individual words, and hence cannot be used with a copy mechanism. Mem2Seq encodes each word individually in a flat memory. Unfortunately, this loses the contextual information around a word, which is needed to decipher an unseen word. In contrast, BOSSNET uses a bag of sequences encoding, where KB tuples are a set for easier inference, and also each utterance is a sequence for effectively learning when to copy.

2.1 Related Work

BOSSNET architecture has a *multi-hop encoder*, and a *pointer network* decoder with a *hierarchical attention* over the memory. We briefly survey these three strands of related research.

Multi-hop Networks reason over a sequence of sentences fed as input. A hop refers to reading the sentences and generating an encoded-vector. Multi-hop refers to making multiple updates to the encoded-vector by iteratively reading the input. End to end memory network

(MN) [18] represents the input as a set of sentences. Here the encoded-vector is updated by adding iterative reads. Query reduction network [17] reads the sentences sequentially using an RNN like unit called the QRN unit. Dynamic memory network [10] also reads the sentences sequentially, and also updates the encoded-vector using a recurrent cell. Gated memory network [11] uses a gating mechanism to update the encoded-vector.

MN [2], gated MN and QRN have been used to learn task-oriented dialogues. BOSSNET has two key differences from such architectures. First, existing models select a response from a predefined list of candidates (retrieval model), whereas BOSSNET has a decoder that generates the response one word at a time. Second, the memory in BOSSNET is hierarchical, i.e., each memory element is a sequence of words vectors rather than just a single utterance vector. This enables the generator to copy any word from the memory during generation.

Pointer Networks are sequence to sequence (Seq2Seq) models, where each token in the output sequence corresponds to a token at a certain position in the input sequence [20]. By enabling pointing in Seq2Seq models [3, 19], the effective decode vocabulary becomes the union of the fixed decode vocabulary and the vocabulary of the input sequence. Two main methods [6, 5] exist for incorporating pointing in standard Seq2Seq models – hard decision [14, 6, 5] and soft switch [16]. The former makes a hard choice between using the pointer distribution and the decode vocabulary distribution. It usually requires the hard decision to be labeled. The latter approach learns a soft interpolation between the two distributions without explicit labels. BOSSNET employs a soft switch in its decoder.

Eric and Manning [5] use a copy augmented Seq2seq model for learning task oriented dialogues. This approach uses a hard decision to pick between the generate and pointer distributions. This model is explicitly trained to only point to words that are from the KB and generate the rest. This is the closest work to our approach, but has a flat memory and doesn't incorporate multi-hop reasoning.

Hierarchical Attention was first introduced for document classification [25]. Here, each document is represented as a set of sentences and each sentence as a set of words. For each sentence, an attention distribution is computed over words to identify informative words and compute a sentence representation. A similar approach identifies informative sentences to compute a document representation. Hierarchical attention has also been used for abstractive text summarization [14]. BOSSNET similarly computes two attention distributions over different levels of the input. A word-level distribution over the words in each utterance and an utterance-level distribution over all the input utterances. This a function of these two distributions is used when copying a word in the decode process.

2.2 Background

In this section, we briefly describe the preliminaries over which the proposed Hierarchical Pointer Memory Network (BOSSNET) is built upon. This includes (1) the multi-hop encoder in MN and (2) a standard sequence decoder with attention [1].

2.2.1 Multi-Hop Encoder in MN

The multi-hop encoder in described in end-to-end memory network [18] takes as input a query $q \in \mathbb{R}^d$ and a memory $M = \{m_i; m_i \in \mathbb{R}^d\}$ and generates a reduced query $q_r \in \mathbb{R}^d$. Here d is the embedding dimension. Augmenting the query by attending it over the memory elements, to capture relevant information necessary to generate the response, is referred to as a *hop*. A single hop reduced query is computed as follows:

$$p_i = \text{softmax}(q^T m_i) \quad (2.1)$$

$$o = W_r \sum_i p_i m_i \quad (2.2)$$

$$q_r = o + q \quad (2.3)$$

where $W_r \in \mathbb{R}^{d \times d}$. The hop step can be re-iterated, by assigning the output of the previous hop as the new input query (i.e.,) $q = q_r$. If the encoder has K hops, then the final output is represented as q_r^k . The multiple hops enable inference over multiple memory elements.

2.2.2 Sequence Decoder with Attention

The sequence decoder predicts the token y_t in the output sequence $\langle y_1 y_2 \dots y_T \rangle$, given the decoder state at time t , s_t , and a set of input contexts $Z = \{z_i; z_i \in \mathbb{R}^d\}$. For simplicity, we denote this conditional distribution of generating the next word as just $P_g(y_t)$. To compute $P_g(y_t)$, first an attention distribution α^t is computed over the input contexts z_i using Loung attention [12].

$$u_i^t = s_t W_l z_i \quad (2.4)$$

$$\alpha_i^t = \frac{\exp(u_i^t)}{\sum_k \exp(u_k^t)} \quad (2.5)$$

where $W_l \in \mathbb{R}^{d \times d}$. Then, a context vector z_t^* is generated by performing a weighed sum of the input contexts z_i using the attention distribution α_i^t . The context vector concatenated with the decoder state s_t is then used to compute the *generate distribution* over the decode

vocabulary \mathcal{V} at time t as follows:

$$P_g(y_t) = \text{softmax}(W_d[s_t; z_t^*] + b) \quad (2.6)$$

where $W_d \in \mathbb{R}^{|\mathcal{V}| \times 2d}$ and $b \in \mathbb{R}^{|\mathcal{V}|}$ are parameters to be learnt. $[\cdot]$ indicates vector concatenation along the row.

During training, the objective is to minimize the average negative log-likelihood for all the words in the response. The total loss is computed by adding the loss of all the responses in the training data.

Chapter 3

APPROACH

3.1 The BOSSNET Architecture

The proposed Bag-of-Sequences Memory Network has an encoder-decoder architecture that takes as input (1) dialog history, which includes a sequence of previous user utterances $\{c_1^u, \dots, c_n^u\}$ and system responses $\{c_1^s, \dots, c_{n-1}^s\}$, and (2) KB tuples $\{kb_1, \dots, kb_N\}$. The network then generates the next system response $c_n^s = \langle y_1 y_2 \dots y_T \rangle$ word-by-word. The simplified architecture of BOSSNET is shown in Figure 3.2.

In this section, we first describe the BOSS memory which contains the dialog history and KB tuples, followed by how the memory is consumed by the encoder and the decoder. We finally define the loss function, which, along with dropout, enables disentangled learning of language and knowledge.

3.1.1 Bag-of-Sequences Memory

The memory M contains the dialog history $\{c_1^u, c_1^s, \dots, c_{n-1}^u, c_{n-1}^s\}$ and the KB tuples $\{kb_1, \dots, kb_N\}$. Each utterance in the dialog history and each KB tuple is placed in a memory cell. As utterances and tuples are inherently a sequence, we represent each memory cell m_i as an ordered sequence of tokens $\langle w_i^1 w_i^2 \dots w_i^{|m_i|} \rangle$. For an utterance, the word tokens are followed by a temporal indicator and a speaker indicator $\{\$u, \$s\}$. For example, $\{\text{good}, \text{morning}, \#1, \$s\}$ indicates this was the first utterance by the system. For a KB tuple, the tokens are sequenced as $\{\text{subject}, \text{predicate}, \text{object}\}$ followed by temporal indicator and a kb indicator $\{\$db\}$.

Token representation is generated using a bidirectional GRU. Let the outputs of the forward and backward GRUs for the token w_i^j be denoted as \overrightarrow{h}_i^j and \overleftarrow{h}_i^j respectively. Then the token representation $\phi(w_i^j)$ is given by Eq. 3.1. Memory cell representation $\psi(m_i)$ is computed by concatenating the forward GRU output of its last token and the backward GRU output of its first token as in Eq. 3.2.

$$\phi(w_i^j) = [\overrightarrow{h}_i^j; \overleftarrow{h}_i^j] \quad (3.1)$$

$$\psi(m_i) = [\overrightarrow{h}_i^{|m_i|}; \overleftarrow{h}_i^1] \quad (3.2)$$

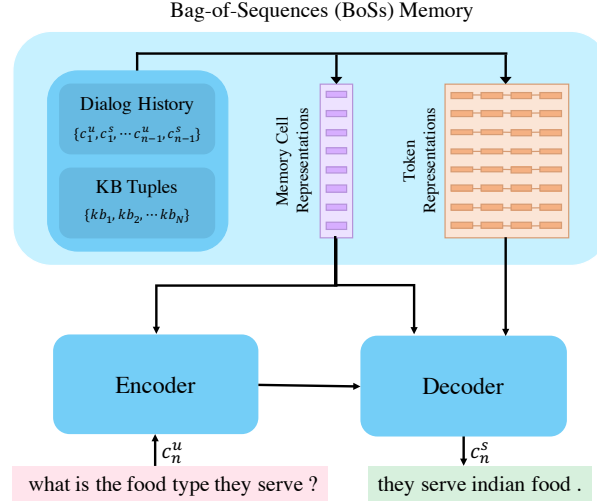


Figure 3.1: The dialog history and KB tuples stored in the memory have memory cell representations and token representations. The encoder understands the last user utterance using only the memory cell representations. The decoder generates the next response using both representations.

3.1.2 The BOSSNET Encoder

The encoder used in BOSSNET is similar to the multi-hop attention encoder with layer-wise weights proposed by (author?) ((year?)). The encoder in (author?) ((year?)) uses two different embedding matrices, whereas we use just one to reduce the number of parameters. The encoder considers the last user utterance as the query $q = \psi(c_n^u)$ and computes the reduced representation q_r using the memory M as follows:

$$p_i = \text{softmax}(q^T \psi(m_i)) \quad (3.3)$$

$$o = W_r \sum_i p_i \psi(m_i) \quad (3.4)$$

$$q_r = o + W_o q \quad (3.5)$$

where $W_r, W_o \in \mathbb{R}^{d \times d}$ are learnable parameters. The hop step can be re-iterated, by assigning the output of the previous hop as the new input query, i.e., setting $q = q_r$. The output of the encoder after K hops, q_r^k , is assigned as the initial state of the BOSSNET decoder.

3.1.3 The BOSSNET Decoder

BOSSNET models a copy-augmented sequence decoder, which generates the response one word at a time. At any decode time step t , the decoder can either *generate* a word from the decode vocabulary or *copy* a word from the memory. Consequently, the decoder computes: (1) generate distribution $P_g(y_t)$ over the decode vocabulary, and (2) copy distribution $P_c(y_t)$

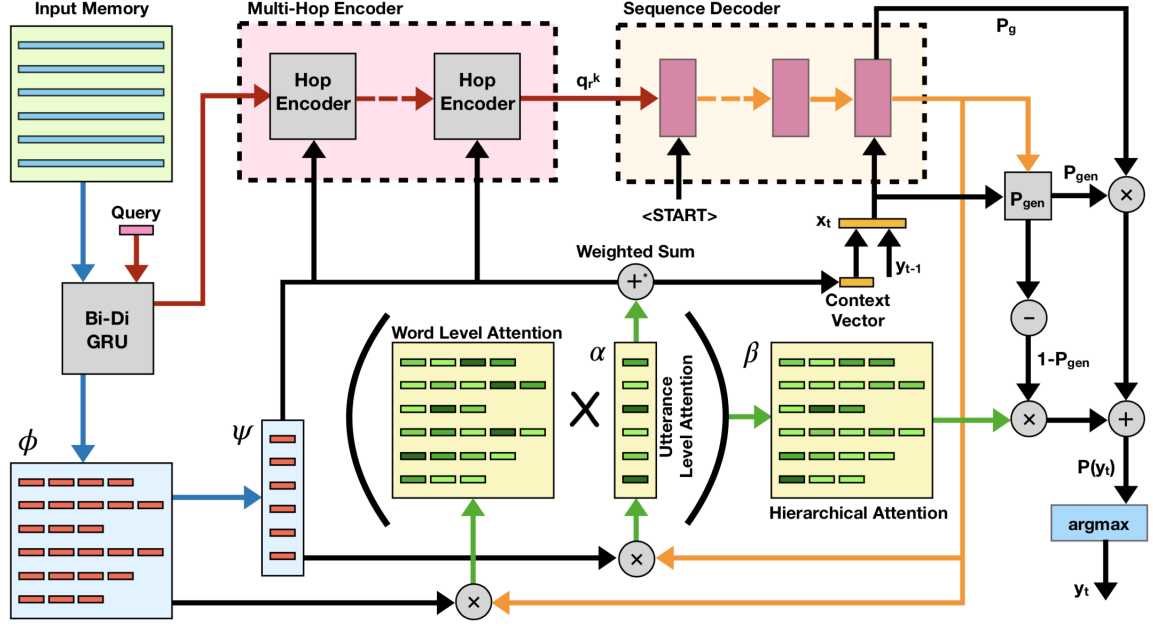


Figure 3.2: The encoder-decoder architecture of HyP-MN with hierarchical memory

over words in the memory.

The generate distribution is computed using a standard sequence decoder [19] by attending [12] over the memory cell representations ψ . The copy distribution is generated by using a *two-level attention*. Given the decoder state s_t , it first computes attention α_t over the memory cells. Then it computes attention over the tokens in each memory cell m_i . Finally it multiplies both these attentions to compute $P_c(y_t)$ as follows:

$$\alpha_i^t = \text{softmax}(s_t \psi(m_i)) \quad (3.6)$$

$$e_{ij}^t = s_t \phi(w_i^j) \quad (3.7)$$

$$\beta_{ij}^t = \alpha_i^t * \frac{\exp(e_{ij}^t)}{\sum_k \exp(e_{ik}^t)} \quad (3.8)$$

$$P_c(y_t = w) = \sum_{ij: w_i^j = w} \beta_{ij}^t \quad (3.9)$$

The copy and generate distributions are combined using a soft gate $g_s^t \in [0, 1]$ as in **(author?) ((year?))**. g_s^t is a function of the decoder state at time t and the word decoded in the previous time step.

3.1.4 Loss

The decoder is trained using cross-entropy loss. The loss per response is defined as:

$$\mathcal{L}_{ce} = - \sum_{t=1}^T \log \left(g_s^t P_g(y_t) + (1 - g_s^t) P_c(y_t) \right) \quad (3.10)$$

where T is the number of words in the sequence to be generated and y_t is the word to be generated at time step t . The decision to generate or copy is learnt implicitly by the network. However, to attain perfect disentanglement, the KB words should be copied, while the language should be generated. In other words, any word in the response that is present in the BOSS KB memory should have a low g_s . To obtain this behavior, we define a disentangle label D_l for each word in the response. This label is set to 1 if the word is present in the BOSS KB memory and 0 otherwise. We define a disentangle loss as follows:

$$\mathcal{L}_d = - \sum_{t=1}^T g_s^t \log D_l^t + (1 - g_s^t) \log(1 - D_l^t) \quad (3.11)$$

We randomly drop some words with disentangle label set to 1. This *Disentangle Label Dropout (DLD)* works in tandem with the disentangle loss and BOSS memory – it encourages the model to copy KB words whenever possible, based on their surrounding words. The overall loss is given as:

$$\mathcal{L} = \mathcal{L}_{ce} + \gamma \mathcal{L}_d \quad (3.12)$$

The relative weight of \mathcal{L}_d in the overall loss is controlled using a hyper-parameter (γ). The dropout rate is also a hyper-parameter.

Chapter 4

WORK DIVISION

Chapter 5

IMPLEMENTATION

Chapter 6

RESULTS

6.1 Setup

6.1.1 Datasets

We perform experiments on three task-oriented dialog datasets: bAbI Dialog [2], CamRest [22], and Stanford Multi-Domain Dataset [4].

bAbI Dialog consists of synthetically generated dialogs with the goal of restaurant reservation. The dataset consists of five different tasks, all grounded to a KB. This KB is split into two mutually exclusive halves. One half is used to generate the train, validation, and test sets, while the other half is used to create a second test set called the OOV test set.

CamRest is a human-human dialog dataset, collected using the Wiz-of-Oz framework, also aimed at restaurant reservation. It is typically used to evaluate traditional slot filling systems. In order to make it suitable for end-to-end learning, we stripped the handcrafted state representations and annotations in each dialog, and divided the 676 available dialogs into train, validation, and test sets (406, 135, and 135 dialogs, respectively).

Stanford Multi-Domain Dataset (SMD) is another human-human dialog dataset collected using the Wiz-of-Oz framework. Each conversation is between a driver and an in-car assistant. The other datasets consist of dialogs from just one domain (restaurant reservation), whereas SMD consists of dialogs from multiple domains (calendar scheduling, weather information retrieval, and navigation).

6.1.2 Knowledge Adaptability (KA) Test Sets

Each bAbI dialog task has an additional OOV test set, which helps to evaluate a model’s robustness to change in information in the KB. A model that perfectly disentangles language and knowledge should have no drop in accuracy on the OOV test set when compared to the non-OOV test set. To measure the degree of disentanglement in a model, we generated 10 additional test sets for each real-world corpus by varying the percentage (in multiples of 10) of unseen entities in the KB. We systematically picked random KB entities and replaced all their occurrences in the dialog with new entity names. We will refer to these generated dialogs as the *Knowledge Adaptability* (KA) test sets.

6.1.3 Baselines

We compare BOSSNET against several existing end-to-end task-oriented dialog systems. These include retrieval models, such as the query reduction network (QRN) [17], memory network (MN) [2], and gated memory network (GMN) [11].

We also compare against generative models such as a sequence-to-sequence model (Seq2Seq), a copy augmented Seq2Seq (Seq2Seq+Copy) [7], and Mem2Seq [13].¹ For fairness across models, we do not compare against key-value retrieval networks [4] as they simplify the dataset by canonicalizing all KB words in dialogs.

We noticed that the reported results in the Mem2Seq paper are not directly comparable, as they pre-processed² training data in SMD and bAbI datasets. For fair comparisons, we re-run Mem2Seq on the original training datasets. For completeness we mention their reported results (with pre-processing) as Mem2Seq*.

6.1.4 Evaluation Metrics

We evaluate BOSSNET and other models based on their ability to generate valid responses. The per-response accuracy [2] is the percentage of generated responses that exactly match their respective gold response. The per-dialog accuracy is the percentage of dialogs with all correctly generated responses. These accuracy metrics are a good measure for evaluating datasets with boilerplate responses such as bAbI.

To quantify performance on other datasets, we use BLEU [15] and Entity F1 [5] scores. BLEU measures the overlap of n-grams between the generated response and its gold response and has become a popular measure to compare task-oriented dialog systems. Entity F1 is computed by micro-F1 over KB entities in the entire set of gold responses.

6.1.5 Human Evaluation

We use two human evaluation experiments to compare (1) the *usefulness* of a generated response with respect to solving the given task, and (2) the *grammatical correctness* and *fluency* of the responses on a 0–3 scale. We obtain human annotations by creating Human Intelligence Tasks (HITs) on Amazon Mechanical Turk (AMT). For each test condition (percentage of unseen entities), we sampled 50 dialogs from Camrest and SMD each, and two AMT workers labeled each system response for both experiments, resulting in 200 labels

¹We thank the authors for releasing a working code at <https://github.com/HLTCHKUST/Mem2Seq>

²Mem2Seq used the following pre-processing on the data: 1) The subject (restaurant name) and object (rating) positions of the rating KB tuples in bAbI dialogs are flipped 2) An extra fact was added to the navigation tasks in SMD which included all the properties (distance, address, etc.) combined together as the subject and *poi* as the object. See Appendix.

per condition per dataset per system. We evaluate four systems in this study, leading to a total of 1600 labels per condition. The detailed setup is given in the Appendix.

6.1.6 Training

We train BOSSNET using an Adam optimizer [9] and apply gradient clipping with a clip-value of 40. We identify hyper-parameters based on the evaluation of the held-out validation sets. We sample word embedding, hidden layer, and cell sizes from $\{64, 128, 256\}$ and learning rates from $\{10^{-3}, 5 \times 10^{-4}, 10^{-4}\}$. The hyper-parameter γ in the loss function is chosen between $[0-1.5]$. The Disentangle Label Dropout rate is sampled from $\{0.1, 0.2\}$. The number of hops for multi-hop attention in the encoder is sampled from $\{1, 3, 6\}$. The best hyper-parameter setting for each dataset is reported in the Appendix.

6.2 Experimental Results

Our experiments evaluate three research questions.

1. *Performance Study*: How well is BOSSNET able to perform the tasks of our three datasets as compared to the baseline models?
2. *Disentanglement Study*: How robust are the models in generalizing on the KA test sets?
3. *Ablation Study*: What is the performance gain from each novel feature in BOSSNET?

6.2.1 Performance Study

Table ?? reports the per-response and per-dialog (in parentheses) accuracies on the bAbI dialog tasks. The multi-hop retrieval-based models such as QRN, MN and GMN perform well on the non-OOV test sets for tasks 1, 2, and 5, but fail to exhibit similar performance on the corresponding OOV test sets. This result is expected as these models are trained to retrieve from a pre-defined set of responses. Their poor non-OOV performance on tasks 3 and 4 is attributed to an error in the bAbI dataset construction, due to which, the non-OOV and OOV test conditions are the same for these tasks (see Appendix).

A simple generative model (Seq2Seq) achieves accuracies comparable to the multi-hop retrieval models. Enabling it with the ability to copy from the context (Seq2Seq+Copy) shows a considerable increase in performance, especially on the OOV test sets (and non-OOV tests for tasks 3 and 4).

The strong performance of simple sequence encoders when compared with multi-hop encoders (in retrieval models) raises a question about the value of multi-hop inference.

| | CamRest | | SMD | |
|--------------|-------------|-------------|-------------|-------------|
| | BLEU | Ent. F1 | BLEU | Ent. F1 |
| Mem2Seq* | 12.7 | 39 | 12.6 | 33.4 |
| Seq2Seq | 11.4 | 40.6 | 8.7 | 34.9 |
| Seq2Seq+Copy | 4.7 | 32.2 | 3.23 | 16.9 |
| Mem2Seq | 12.7 | 39 | 10.3 | 31.8 |
| BOSSNET | 15.2 | 43.1 | 8.3 | 35.9 |

Table 6.1: Performance of BOSSNET and baselines on the CamRest and SMD datasets

| | CamRest | | SMD | |
|--------------|-----------|-------------|-----------|------------|
| | Info | Grammar | Info | Grammar |
| Seq2Seq | 46 | 2.24 | 35 | 2.38 |
| Seq2Seq+Copy | 27 | 1.1 | 21 | 1.04 |
| Mem2Seq | 51 | 2.2 | 38 | 2.0 |
| BOSSNET | 77 | 2.28 | 36 | 2.5 |

Table 6.2: AMT Evaluations on CamRest and SMD

Mem2Seq answers this question, by obtaining improvements in several tasks, specifically on their OOV test sets. This clearly shows that multi-hop inference and the copy mechanism are essentials for task-oriented dialogs.

Despite gains from the Mem2Seq model, the performance difference between the non-OOV and OOV test sets remains large. BOSSNET succeeds to bridge this gap with its ability to better interpret unseen words, using their surrounding context. It obtains significant improvements on average of about 34% per-dialog accuracy and 10% per-response accuracy for the bAbI OOV test sets.

In Table 6.1, we report results on the real-world datasets. BOSSNET greatly outperforms other models in both Entity F1 metric and BLEU scores on CamRest. On SMD, BOSSNET achieves the best only in Entity F1. On further analysis of the generated responses we observe that BOSSNET responses often convey the necessary entity information from the KB. However, they consist of meaningful phrases with little lexical overlap with the gold response, reducing the BLEU scores. We investigate this further in our human evaluation.

Human Evaluation: We summarize the human evaluation results for real-world datasets in Table 6.2. BOSSNET shows the best performance on Camrest, and is judged useful 77 times out of 100. Also, it has the highest average grammatical correctness score of 2.28 (very close to Seq2Seq and Mem2Seq). BOSSNET performs on par with Mem2Seq and Seq2Seq in its ability to relay appropriate information to solve SMD dialog tasks, and has a slightly higher grammaticality score.

| KB (restaurant address) | |
|------------------------------------|---|
| <i>r_bangkok_overpriced_thai_8</i> | <i>r_bangkok_overpriced_thai_8_addr</i> |
| <i>r_bangkok_overpriced_thai_7</i> | <i>r_bangkok_overpriced_thai_7_addr</i> |
| <i>r_bangkok_overpriced_thai_4</i> | <i>r_bangkok_overpriced_thai_4_addr</i> |
| <i>r_bangkok_overpriced_thai_2</i> | <i>r_bangkok_overpriced_thai_2_addr</i> |
| usr-1 | may i have a table in an <i>overpriced</i> price range for <i>nine</i> people with <i>thai</i> food in <i>bangkok</i> ? |
| sys-1 | what do you think of : <i>r_bangkok_overpriced_thai_8</i> ? |
| usr-2 | can you provide the address ? |
| Gold | here it is <i>r_bangkok_overpriced_thai_8_addr</i> |
| Seq2Seq+Copy | here it is <i>r_bangkok_overpriced_thai_4_addr</i> |
| Seq2Seq | here it is <i>r_london_moderate_spanish_6_addr</i> |
| Mem2Seq | here it is <i>r_bangkok_overpriced_thai_4_addr</i> |
| BOSSNET | here it is <i>r_bangkok_overpriced_thai_4_addr</i> |

Table 6.3: Example from bAbI Task 5 KA test set with 100% OOV entities. Identifying the address of an unseen restaurant is challenging for all models.

6.2.2 Disentanglement Study

We use our generated knowledge adaptability (KA) test sets to measure the robustness of BOSSNET and the other baselines to changes in the KB. We perform this experiment on 4 different tasks, namely bAbI tasks 1 and 5, CamRest, and SMD.

Figures 6.1 and 6.2 show the per-response accuracies of the two bAbI dialog tasks plotted against the percentage of unseen entities in KA sets. From Figure 6.1 we observe that BOSSNET remains immune to any variability in the KB content, whereas the performance of Mem2Seq and Seq2Seq models drops drastically due to their inability to capture semantic representations of the injected KB entities. We see a similar trend in Figure 6.2, but here all the models show a drop in performance, with BOSSNET appearing the most steady. We explain this trend using the example dialog in Table 6.3. In the current dialog context, the system is required to provide the address of the selected restaurant, but since more than one restaurant in the KB is unseen, it becomes ambiguous for the network to identify the correct restaurant and infer its address. In the end, the system is forced to pick a random address – the probability of which being correct decreases as more restaurants become unseen.

The performance on the CamRest KA test sets is illustrated in Figures ?? and 6.3. BOSSNET has the best performance with even a slight increase in both BLEU and Entity F1 metrics as more OOV content is injected in the dialog, probably because it is clear that it needs to copy when processing unseen entities. Seq2Seq+Copy is unable to perform well in CamRest as the length of the input (dialog history + KB tuples) is long and the size of the training set is also small. We believe that Seq2Seq+Copy works best in an environment with an abundance of short dialog training data (e.g., bAbI task 1 in Figure 6.1).

SMD consists of dialogs with a large KB and a highly varying response pattern. This makes it very difficult to learn the language model – reflected in the low BLEU scores for all

| | CamRest | | SMD | |
|--------------|-----------|-------------|-----------|-------------|
| | Info | Grammar | Info | Grammar |
| Seq2Seq | 26 | 2.28 | 22 | 2.44 |
| Seq2Seq+Copy | 22 | 1.22 | 16 | 1.04 |
| Mem2Seq | 35 | 2.06 | 26 | 1.9 |
| BoSSNET | 80 | 2.44 | 51 | 2.28 |

Table 6.4: AMT Evaluations on CamRest and SMD (50% unseen) KA datasets

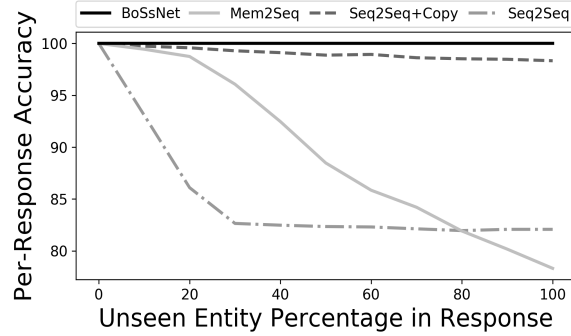


Figure 6.1: bAbI Task 1: Per-response accuracy comparison on KA sets

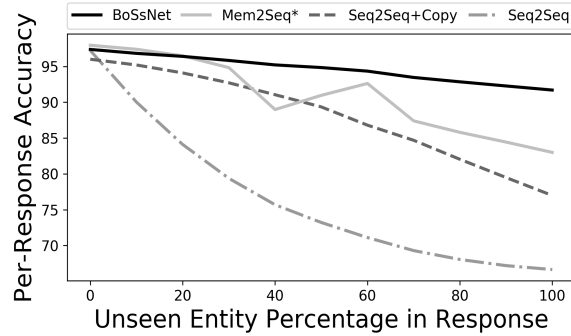


Figure 6.2: bAbI Task 5: Per-response accuracy comparison on KA sets

the systems. BOSSNET still provides the best F1 entity score due to its ability to inference efficiently on the large KB (Figure 6.4). Mem2Seq shows the best BLEU score performance on the original test set, but its performance drop of 42.5%, from 10.3 at 0% unseen to 5.93 at 100% unseen, is a lot heavier than that of BOSSNET which only drops 7.6% – 8.27 at 0% unseen to 7.64 at 100% unseen.

Human Evaluation: We summarize the human evaluation results for real-world datasets on the 50% unseen KA test set in Table 6.4. BOSSNET again outperforms the baselines and is labeled *successful* twice more often than the next best model on both Camrest and SMD. Seq2Seq appears to produce better sentence structures on the SMD dataset, primarily because it does not attempt to learn inference on the KB, allowing it to solely focus on learning the language model better.

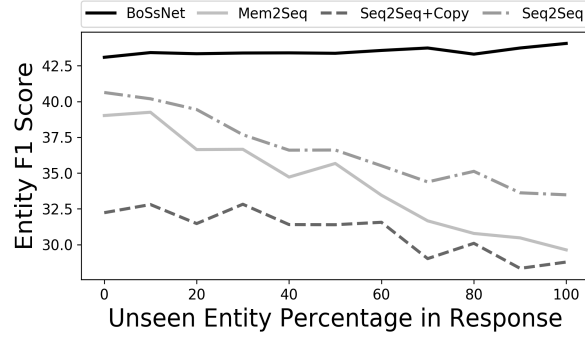


Figure 6.3: CamRest: Entity F1 comparison on KA sets

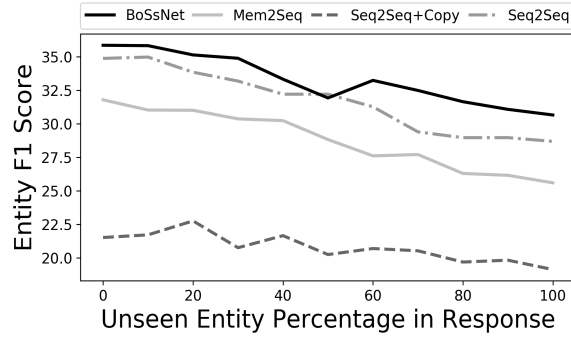


Figure 6.4: SMD: Entity F1 comparison on KA sets

6.2.3 Ablation Study

| | bAbI Dialog Tasks | | | | | bAbI Dialog Tasks (OOV) | | | | | CamRest | |
|-----------------------------|-------------------|-----|------|------|------|-------------------------|------|------|-----|------|---------|---------|
| | T1 | T2 | T3 | T4 | T5 | T1 | T2 | T3 | T4 | T5 | BLEU | Ent. F1 |
| BoSSNET w/o BoSS Memory | 100 | 100 | 74.9 | 57.2 | 95.6 | 93.5 | 78.9 | 74.9 | 57 | 81.4 | 10.13 | 29 |
| BoSSNET w/o \mathcal{L}_d | 100 | 100 | 91.7 | 100 | 94.3 | 83.2 | 78.9 | 92.7 | 100 | 66.7 | 15.5 | 40.1 |
| BoSSNET w/o DLD | 100 | 100 | 93.4 | 100 | 95.3 | 79.2 | 84.6 | 90.7 | 100 | 78.1 | 12.4 | 40.45 |
| BoSSNET | 100 | 100 | 95.2 | 100 | 97.3 | 100 | 100 | 95.7 | 100 | 91.7 | 15.2 | 43.1 |

Table 6.5: Ablation study: impact of each model element on BOSSNET

| | bAbI Dialog | bAbI Dialog (OOV) | CamRest |
|-----------------------------|--------------------|--------------------|---------|
| | Avg. Response Acc. | Avg. Response Acc. | Ent. F1 |
| BoSSNET w/o BoSS Memory | 85.54 | 77.14 | 29 |
| BoSSNET w/o \mathcal{L}_d | 97.2 | 84.3 | 40.1 |
| BoSSNET w/o DLD | 97.74 | 86.52 | 40.45 |
| BoSSNET | 98.5 | 97.48 | 43.1 |

Table 6.6: Ablation study: impact of each model element on BOSSNET

We assess the value of each model element, by removing it from BOSSNET. Table 6.6 reports the per-response accuracy scores for various configurations of BOSSNET on bAbI

dialog tasks. It also reports the BLEU and entity F1 metric of various configurations on CamRest.

Without BoSs Memory: This configuration uses the Bag-of-Bags (BoB) Memory rather than BoSs memory. The BoB memory is a simplified representation, similar to the one in the original Memory Networks. Here the token representation is the vector embedding of the token with no influence from the surrounding words and the memory cell representation is the sum of all its token embeddings. As a result, each word w representation is influenced equally by all words in a memory cell, irrespective of its distance from w . This makes capturing context in the immediate neighbourhood harder. Inability to capture the correct context prevents the configuration from generalizing to OOV test sets.

Without Disentangled Loss: Disentangled Loss (\mathcal{L}_d) plays an important role in enforcing that KB words be copied and other language be generated. By removing this loss component, it achieves better BLEU score in CamRest, but with a drop in Entity F1. Without the disentangled loss, the model sometimes learns to generate KB words. This severely affects OOV performance. As described earlier, an error in bAbI dataset construction tasks 3 and 4 effectively injects the validation set with a lot of OOVs. This anomaly in conjunction with the dropout (DLD), helps the configuration in achieving an acceptable performance for those tasks.

Without Disentangled Label Dropout: BOSSNET learns to generate language and copy KB words. Without DLD, the model learns to memorize words to be copied rather than learning the context under which a word should be copied. Hence, the performance on OOV test sets is much inferior compared to the non-OOV setting.

Overall, we notice that combining all three model elements is necessary in obtaining the best performance across all tasks.

6.2.4 Qualitative Evaluation

We qualitatively compare the performance of BOSSNET with other baselines using examples.

Table 6.7, demonstrates the ability of BOSSNET to copy entities (restaurant name and address) in its response. The other baselines either generate unwanted or irrelevant entities in their response, or fail to copy altogether. BOSSNET also best captures the language model effectively with a slight paraphrasing of the gold response.

Table 6.8 contains only unseen entities. This example highlights the shortcomings of the Seq2Seq model as it ends up predicting a restaurant encountered during training. Mem2Seq copies a restaurant name without learning to sort the restaurants based on rating. BOSSNET, with its efficient memory addressing, is seen to be able to solve both issues.

| KB (restaurant cuisine address phone) | |
|--|--|
| <i>pizza_hut_fen_ditton italian cambridge_retail_park_newmarket_road_fen_ditton 01223_323737</i> | |
| usr-1 | may i have information for an <i>italian</i> restaurant in the <i>east</i> part of town ? |
| sys-1 | yes sure . there is only on <i>italian</i> restaurant called <i>pizza_hut_fen_ditton</i> in the <i>east</i> . what else do you want to know ? |
| usr-2 | what is their address please ? |
| Gold | the address for <i>pizza_hut_fen_ditton</i> is <i>cambridge_retail_park_newmarket_road_fen_ditton</i> . can i help you with anything else ? |
| Seq2Seq+Copy | their address is at |
| Seq2Seq | <i>curry_prince</i> is at <i>451_newmarket_road_fen_ditton</i> |
| Mem2Seq | <i>pizza_hut_fen_ditton</i> is located at <i>7_barnwell_road_fen_ditton</i> is <i>7_barnwell_road_fen_ditton</i> and the phone number is <i>01223_244955</i> |
| BOSSNET | <i>pizza_hut_fen_ditton</i> is located at <i>cambridge_retail_park_newmarket_road_fen_ditton</i> is there anything else i can help you with |

Table 6.7: An example of responses generated by BOSSNET and baselines on the CamRest test set. Thia example has no unseen entities.

| KB (restaurant cuisine price_range location rating) | |
|---|---|
| <i>resto_tokyo_affordable_vietnamese_8stars vietnamese affordable tokyo 8</i> | |
| <i>resto_tokyo_affordable_vietnamese_7stars vietnamese affordable tokyo 7</i> | |
| <i>resto_tokyo_affordable_vietnamese_6stars vietnamese affordable tokyo 6</i> | |
| <i>resto_tokyo_affordable_vietnamese_5stars vietnamese affordable tokyo 5</i> | |
| usr-1 | can you book a table in <i>tokyo</i> with <i>vietnamese</i> food in a <i>affordable</i> price range ? |
| sys-1 | what do you think of this option : <i>resto_tokyo_affordable_vietnamese_8stars</i> ? |
| usr-2 | no this does not work for me . |
| sys-2 | what do you think of this option : <i>resto_tokyo_affordable_vietnamese_7stars</i> ? |
| usr-3 | do you have something else ? |
| Gold | what do you think of this option : <i>resto_tokyo_affordable_vietnamese_6stars</i> |
| Seq2Seq+Copy | what do you think of this option : what ? |
| Seq2Seq | what do you think of this option : <i>resto_london_moderate_british_2stars</i> ? |
| Mem2Seq | what do you think of this option : <i>resto_tokyo_affordable_vietnamese_5stars</i> ? |
| BOSSNET | what do you think of this option : <i>resto_tokyo_affordable_vietnamese_6stars</i> ? |

Table 6.8: An example of responses generated by BOSSNET and baselines on bAbI dialog Task-5. This example is from the KA test set with 100% unseen entities.

Appendix A

CODE SNIPPETS

A.1 Two-Level attention on BoSs Memory

To visualize the benefit of two-level attention used on BOSS memory by the decoder, we compare attention weights for two models: our proposed *two-level attention* and a variant with just *one-level attention* (over all the words in the memory). In the example of a sample dialog from bAbI Task 3, shown in Figure A.1, the decoder is aimed at predicting the second best restaurant *3 stars*, given that the restaurant with rating *8 stars* has already been suggested and rejected. We show attention only on the KB entries for brevity.

The models share some similarities in their distribution of attention. First, the attention weights are localized over the restaurant names, indicating the preference of the system to point to a specific restaurant. This is supported by the g_s values, 3.14×10^{-5} and 1.15×10^{-4} for two-level attention and one-level attention respectively, i.e., both models prefer to copy rather than generate. Moreover, entries with the same restaurant name have similar attention weights, reflecting the robustness of the distribution.

We also observe that two-level attention is able to perform the difficult task of *sorting* the restaurant entries based on decreasing order of rating (number of stars). It gives more weight to entries with a high rating (*3 stars* > *2 stars* > *1 star*) and suppresses the weights of any previously suggested restaurant.

The attention over memory cells provides BOSSNET with the ability to infer over multiple sets of tuples. The ability to sort the restaurants and reject a previously seen restaurant can be observed by the attention heat map of Memory cells. Attention over tokens on the other hand can push the attention weights towards either the subject or object in the KB tuple, based on the query’s request. Thus using both in conjunction helps BOSSNET perform significantly better than the baselines and illustrates the importance of the BOSS memory in comparison to a flat memory layout.

A.2 Reproducibility

We list out the complete set of hyperparameters used to train BOSSNET for the various datasets in Table A.1. Our code will be made publically accessible for future research purposes. Our trained models and evaluation scripts will also be provided. We will also

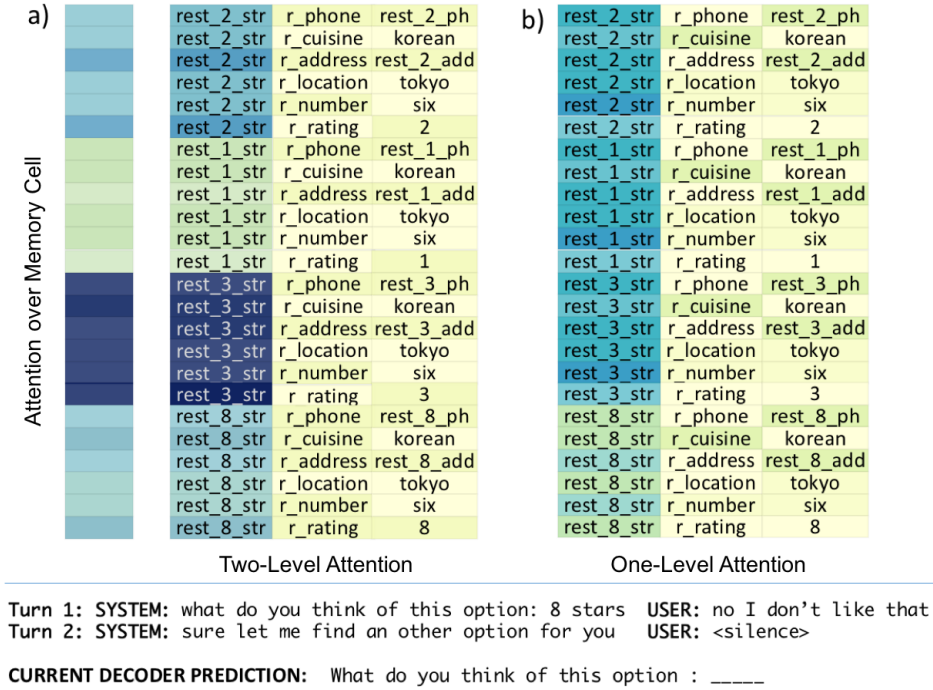


Figure A.1: Visualization of attention weights on selected portions of memory in (a) BOSSNET with two-level attention vs (b) BOSSNET with one-level attention

make our end-to-end reconstructed Camrest dataset along with our whole batch of knowledge adaptability test sets available.

| Task | Learning Rate | Hops | Embedding Size | Disentangle Loss Weight | DLD |
|---------|---------------|------|----------------|-------------------------|-----|
| T1 | 0.001 | 1 | 128 | 1.0 | 0.2 |
| T2 | 0.001 | 1 | 128 | 1.0 | 0.2 |
| T3 | 0.0005 | 3 | 128 | 1.5 | 0.2 |
| T4 | 0.001 | 1 | 128 | 1.0 | 0.2 |
| T5 | 0.0005 | 3 | 256 | 1.0 | 0.2 |
| CamRest | 0.0005 | 6 | 256 | 1.0 | 0.2 |
| SMD | 0.0005 | 3 | 256 | 1.0 | 0.1 |

Table A.1: The hyperparameters used to train BOSSNET on the different datasets

A.3 Example Predictions of BOSSNET and Baselines

Examples from SMD is shown in Table A.4 respectively. Examples from KA test set with percentage of unseen entites set to 50 from CamRest and SMD are shown in Table A.3 and Table A.5 respectively. Examples from KA test set with percentage of unseen entites set to 100 from bAbI dialog Task 1 is shown in Table A.2.

| | |
|---------------------|---|
| usr-1 | good morning |
| sys-1 | hello what can i help you with today |
| usr-2 | can you book a table with <i>korean</i> cuisine for <i>five</i> in <i>beijing</i> |
| sys-2 | i ' m on it . which price range are looking for ? |
| usr-3 | i am looking for a <i>overpriced</i> restaurant |
| Gold | api_call <i>korean beijing five overpriced</i> |
| Seq2Seq+Copy | api_call <i>korean beijing five overpriced</i> |
| Seq2Seq | api_call <i>french london four moderate</i> |
| Mem2Seq | api_call <i>overpriced korean korean overpriced</i> |
| BOSSNET | api_call <i>korean beijing five overpriced</i> |

Table A.2: Example from bAbI dialog Task 1 with 100% OOV.

| KB (restaurant cuisine address phone postcode) | |
|--|--|
| <i>prezzo ethiopian 22_atlantis_road 01799_521260 cb30ad</i> | |
| usr-1 | i want a <i>moderately_expensive ethiopian</i> restaurant in the <i>south</i> side of town |
| sys-1 | i ' m sorry . i can not find a <i>moderately_expensive ethiopian</i> restaurant in the <i>south</i> side of town |
| usr-2 | i would like to find a <i>moderately</i> priced restaurant in the <i>west</i> part of town |
| sys-2 | <i>prezzo</i> is a moderately priced <i>ethiopian</i> restaurant in the <i>west</i> part of town . there is also <i>indian</i> and <i>british</i> food available in that area and price range . would you like more info ? |
| usr-3 | yes can i get thier address and postcode ? |
| Gold | of course , <i>prezzo</i> ' s address is <i>22_atlantis_road</i> and postcode is <i>cb30ad</i> |
| Seq2Seq+Copy | postcode a is is <i>01223350688</i> UNK there get i for for today |
| Seq2Seq | the address is <i>83_regent_street</i> and their postcode is <i>cb58aq</i> |
| Mem2Seq | the phone address is <i>cb21uj</i> |
| BOSSNET | the address is <i>22_atlantis_road</i> at <i>22_atlantis_road</i> the postcode is <i>cb30ad</i> is there anything else i can help you with |

Table A.3: Example from Camrest with 50% OOV. The OOV entities present in the dialog are {*ethiopian*, *22_atlantis_road*}

| KB (location distance traffic info address) | |
|---|---|
| <i>teavana 4_miles no_traffic 145_amherst_st</i> | |
| <i>cafe_venetia 5_miles moderate_traffic 269_alger_dr</i> | |
| <i>town_and_country 3_miles moderate_traffic 383_university_ave</i> | |
| usr-1 | where can i get tea ? |
| sys-1 | there is 2 tea shops near you <i>teavana</i> is <i>4_miles</i> away and <i>cafe_venetia</i> is <i>5_miles</i> away which one do you want ? |
| usr-2 | which one is the quickest is there any traffic ? |
| Gold | <i>teavana</i> is the fastest journey because there is <i>no_traffic</i> on the way there . <i>cafe_venetia</i> has <i>moderate_traffic</i> should we go to <i>teavana</i> |
| Seq2Seq+Copy | there is |
| Seq2Seq | there is <i>moderate_traffic</i> on the way to <i>palo_alto_medical_foundation</i> |
| Mem2Seq | there is <i>moderate_traffic</i> on our way |
| BOSSNET | <i>teavana</i> there is a <i>moderate_traffic</i> nearby but i might find another route to <i>town_and_country town_and_country</i> address is <i>383_university_ave</i> i sent it on your screen |

Table A.4: Example from SMD

| KB (location day weather) | |
|--------------------------------------|--|
| <i>mountain_view sunday foggy</i> | |
| <i>mountain_view monday overcast</i> | |
| <i>pittsburgh sunday overcast</i> | |
| <i>pittsburgh monday warm</i> | |
| <i>downtown_chicago sunday foggy</i> | |
| <i>downtown_chicago monday warm</i> | |
| <i>today monday</i> | |
| usr-1 | is the weather <i>cloudy</i> right now ? |
| sys-1 | what city do you want the weather for ? |
| usr-2 | <i>pittsburgh</i> |
| Gold | there are no clouds in <i>pittsburgh</i> right now |
| Seq2Seq+Copy | which is no |
| Seq2Seq | it is currently raining in <i>san_francisco</i> right now |
| Mem2Seq | it will not be cloudy in in |
| BOSSNET | it will be <i>cloudy</i> on <i>sunday</i> in <i>pittsburgh</i> |


Table A.5: Example from SMD with 50% OOV. The OOV entity present in the dialog is {*pittsburgh*}

A.4 Dataset Preprocessing and Faults

A.4.1 Mem2Seq Preprocessing

(a) Original bAbI Data

| Subject | Predicate | Object |
|--------------------------------|------------|--|
| resto_rome_cheap_indian_6stars | R_phone | resto_rome_cheap_indian_6stars_phone |
| resto_rome_cheap_indian_6stars | R_cuisine | indian |
| resto_rome_cheap_indian_6stars | R_address | resto_rome_cheap_indian_6stars_address |
| resto_rome_cheap_indian_6stars | R_location | rome |
| resto_rome_cheap_indian_6stars | R_number | eight |
| resto_rome_cheap_indian_6stars | R_price | cheap |
| resto_rome_cheap_indian_6stars | R_rating | 6 |
| resto_rome_cheap_indian_7stars | R_phone | resto_rome_cheap_indian_7stars_phone |
| resto_rome_cheap_indian_7stars | R_cuisine | indian |
| resto_rome_cheap_indian_7stars | R_address | resto_rome_cheap_indian_7stars_address |
| resto_rome_cheap_indian_7stars | R_location | rome |
| resto_rome_cheap_indian_7stars | R_number | eight |
| resto_rome_cheap_indian_7stars | R_price | cheap |
| resto_rome_cheap_indian_7stars | R_rating | 7 |



| Subject | Predicate | Object |
|--------------------------------|------------|--|
| resto_rome_cheap_indian_6stars | R_phone | resto_rome_cheap_indian_6stars_phone |
| resto_rome_cheap_indian_6stars | R_cuisine | indian |
| resto_rome_cheap_indian_6stars | R_address | resto_rome_cheap_indian_6stars_address |
| resto_rome_cheap_indian_6stars | R_location | rome |
| resto_rome_cheap_indian_6stars | R_number | eight |
| resto_rome_cheap_indian_6stars | R_price | cheap |
| 6 | R_rating | resto_rome_cheap_indian_6stars |
| resto_rome_cheap_indian_7stars | R_phone | resto_rome_cheap_indian_7stars_phone |
| resto_rome_cheap_indian_7stars | R_cuisine | indian |
| resto_rome_cheap_indian_7stars | R_address | resto_rome_cheap_indian_7stars_address |
| resto_rome_cheap_indian_7stars | R_location | rome |
| resto_rome_cheap_indian_7stars | R_number | eight |
| resto_rome_cheap_indian_7stars | R_price | cheap |
| 7 | R_rating | resto_rome_cheap_indian_7stars |

(a) Pre-Processed bAbI Data


Figure A.2: Pre-processing of bAbI dialog data used in Mem2Seq paper

Mem2Seq paper used the following pre-processing on the data:

1. The subject (restaurant name) and object (rating) positions of the rating KB tuples in bAbI dialogs are flipped, while the order remains the same for other tuples remains the same. This pre-processing is illustrated in Figure A.2
2. an extra fact was added to the navigation tasks in In-Car Assistant with all the properties (such as distance, address) combined together as the subject and *poi* as the object. This pre-processing is illustrated in Figure A.3

(a) Original SMD Navigate Data

| Subject | Predicate | Object |
|------------|--------------|--------------------|
| the_westin | distance | 2_miles |
| the_westin | traffic_info | moderate_traffic |
| the_westin | poi_type | rest_stop |
| the_westin | address | 329_el_camino_real |
| toms_house | distance | 1_miles |
| toms_house | traffic_info | heavy_traffic |
| toms_house | poi_type | friends_house |
| toms_house | address | 580_van_ess_ave |



| Subject | Predicate | Object |
|-------------------------------------|--------------|--------------------|
| 2_miles moderate_traffic rest_stop | poi | the_westin |
| the_westin | distance | 2_miles |
| the_westin | traffic_info | moderate_traffic |
| the_westin | poi_type | rest_stop |
| the_westin | address | 329_el_camino_real |
| 1_miles heavy_traffic friends_house | poi | toms_house |
| toms_house | distance | 1_miles |
| toms_house | traffic_info | heavy_traffic |
| toms_house | poi_type | friends_house |
| toms_house | address | 580_van_ess_ave |

(a) Pre-Processed SMD Navigate Data

Figure A.3: Pre-processing of SMD Navigate data used in Mem2Seq paper

The pre-processing has major impact on the performance of Mem2Seq, as it can only copy objects of a KB tuple, while the subject and relation can never be copied.

A.4.2 bAbI Dataset Faults

The KB entities present in validation and non-OOV test sets for task 3 and 4 do not overlap with those in the train set. This effectively means that non-OOV and OOV test conditions are the same for tasks 3 and 4. This explains the low performance of baseline models on task 3 and 4 non-OOV test sets.

A.5 AMT Setup

Response Relevance Test We show a sample of an Human Intelligence Task (HIT) on Amazon Mechanical Turk in Figure A.4a. We randomize the responses generated by the

| | bAbI Dialog Tasks | | | | | bAbI Dialog Tasks (OOV) | | | | | CamRest | |
|--------------------------------|-------------------|-----|------|-----|------|-------------------------|-----|------|-----|------|---------|---------|
| | T1 | T2 | T3 | T4 | T5 | T1 | T2 | T3 | T4 | T5 | BLEU | Ent. F1 |
| BOSSNET with 1-Hop Encoder | 100 | 100 | 92.3 | 100 | 90.5 | 100 | 100 | 91.4 | 100 | 89 | 10.5 | 36.9 |
| BOSSNET with Multi-Hop Encoder | 100 | 100 | 95.2 | 100 | 97.3 | 100 | 100 | 95.7 | 100 | 91.7 | 15.2 | 43.1 |

Table A.6: Ablation study: impact of hops in BOSSNET encoder

three baseline models and BOSSNET on the same dialog and ask the user to tick all those response options that seem to capture the relevant information of the given sample response. A total of 200 such annotations were collected for Camrest and SMD each.

Response Grammar Test We show a sample of an Human Intelligence Task (HIT) on Amazon Mechanical Turk in Figure A.4b. We randomize the responses generated by the three baseline models and BOSSNET on the same dialog and ask the user to rate each response based on the grammatical correctness and natural flow of the sentence. The rating ranges from 0-3 where 0 being the worst and 3 being the best. Note) the sentences were not asked to be rated with respect to each other, but instead as individual occurrences. A total of 200 such annotations were collected for Camrest and SMD each.

A.6 Multi-Hop vs 1-Hop Encoders

Table A.6 shows the performance of bAbI tasks and CamRest on two BOSSNET encoder settings. Multi-hops in encoder helps in bAbI task 3 and 5, as they require inferencing over the KB tuples (sorting restaurants by rating) to recommend a restaurant. We also see substantial improvements on CamRest in both BLEU and entity F1 metric.

(a)

(b)

Figure A.4: A sample HIT on Amazon Mechanical Turk to (a) validate useful responses based on the given dialog context, and (b) validate grammatical correctness of different responses on a scale of 0-3

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