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Neural Approaches to Conversational AI

Question Answering, Task-oriented Dialogues and Social Chatbots

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Contents

Neural Approaches to Conversational AI

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ABSTRACT

The present paper surveys neural approaches to conversational AI that have been developed in the last few years. We group conversational systems into three categories: (1) question answering agents, (2) task-oriented dialogue agents, and (3) chatbots. For each category, we present a review of state-of-the-art neural approaches, draw the connection between them and traditional approaches, and discuss the progress that has been made and challenges still being faced, using specific systems and models as case studies.

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1

Introduction

Developing an intelligent dialogue system[1] that not only emulates human conversation, but also answers questions on topics ranging from latest news about a movie star to Einstein's theory of relativity, and fulfills complex tasks such as travel planning, has been one of the longest running goals in AI. The goal has remained elusive until recently. We are now observing promising results both in academia and industry, as large amounts of conversational data become available for training, and the breakthroughs in deep learning (DL) and reinforcement learning (RL) are applied to conversational AI.

Conversational AI is fundamental to natural user interfaces. It is a rapidly growing field, attracting many researchers in the Natural Language Processing (NLP), Information Retrieval (IR) and Machine Learning (ML) communities. For example, SIGIR 2018 has created a new track of Artificial Intelligence, Semantics, and Dialog to bridge research in AI and IR, especially targeting Question Answering (QA), deep semantics and dialogue with intelligent agents.

[1] "Dialogue systems" and "conversational AI" are often used interchangeably in the scientific literature. The difference is reflective of different traditions. The former term is more general in that a dialogue system might be purely rule-based rather than AI-based.

Recent years have seen the rise of a small industry of tutorials and survey papers on deep learning and dialogue systems. Yih *et al.* (2015b), Yih *et al.* (2016), and Gao (2017) reviewed deep learning approaches for a wide range of IR and NLP tasks, including dialogues. Chen *et al.* (2017e) presented a tutorial on dialogues, with a focus on task-oriented agents. Serban *et al.* (2015; 2018) surveyed public dialogue datasets that can be used to develop conversational agents. Chen *et al.* (2017b) reviewed popular deep neural network models for dialogues, focusing on supervised learning approaches. The present work substantially expands the scope of Chen *et al.* (2017b) and Serban *et al.* (2015) by going beyond data and supervised learning to provide what we believe is the first survey of neural approaches to conversational AI, targeting NLP and IR audiences.[2] Its contributions are:

- We provide a comprehensive survey of the neural approaches to conversational AI that have been developed in the last few years, covering QA, task-oriented and social bots with a unified view of optimal decision making.
- We draw connections between modern neural approaches and traditional approaches, allowing us to better understand why and how the research has evolved and to shed light on how we can move forward.
- We present state-of-the-art approaches to training dialogue agents using both supervised and reinforcement learning.
- We sketch out the landscape of conversational systems developed in the research community and released in industry, demonstrating via case studies the progress that has been made and the challenges that we are still facing.

[2]One important topic of conversational AI that we do not cover is Spoken Language Understanding (SLU). SLU systems are designed to extract the meaning from speech utterances and their application are vast, ranging from voice search in mobile devices to meeting summarization. The present work does encompass many Spoken Dialogue Systems – for example Young *et al.* (2013) – but does not focus on components related to speech. We refer readers to Tur and De Mori (2011) for a survey of SLU.

1.1 Who Should Read this Paper?

This paper is based on tutorials given at the SIGIR and ACL conferences in 2018 (Gao *et al.*, 2018a; Gao *et al.*, 2018b), with the IR and NLP communities as the primary target audience. However, audiences with other backgrounds (such as machine learning) will also find it an accessible introduction to conversational AI with numerous pointers, especially to recently developed neural approaches.

We hope that this paper will prove a valuable resource for students, researchers, and software developers. It provides a unified view, as well as a detailed presentation of the important ideas and insights needed to understand and create modern dialogue agents that will be instrumental to making world knowledge and services accessible to millions of users in ways that seem natural and intuitive.

This survey is structured as follows:

- The rest of this chapter introduces dialogue tasks and presents a unified view in which open-domain dialogue is formulated as an optimal decision making process.

- Chapter 2 introduces basic mathematical tools and machine learning concepts, and reviews recent progress in the deep learning and reinforcement learning techniques that are fundamental to developing neural dialogue agents.

- Chapter 3 describes question answering (QA) agents, focusing on neural models for knowledge-base QA and machine reading comprehension (MRC).

- Chapter 4 describes task-oriented dialogue agents, focusing on applying deep reinforcement learning to dialogue management.

- Chapter 5 describes social chatbots, focusing on fully data-driven neural approaches to end-to-end generation of conversational responses.

- Chapter 6 gives a brief review of several conversational systems in industry.

- Chapter 7 concludes the paper with a discussion of research trends.

Turn	Dialogue
1	*usr:* Good morning!
	agt: Good morning, I hope you had a great weekend.
2	*usr:* not really.
	agt: You sound depressed. What can I do for you?
3	*usr:* I'd like to know where sales are lagging behind our forecast?
	agt: The worst region is [country], where sales are 15% below projections.
4	*usr:* Do you know why?
	agt: The forecast for [product] growth was overly optimistic.
5	*usr:* How can we turn this around?
	agt: Here are the 10 customers in [country] with the most growth potential, per our CRM model.
6	*usr:* Can you set up a meeting with the CTO of [company]?
	agt: Yes, I've set up a meeting with [person name] for next month when you are in [location].
7	*usr:* Thanks!

Figure 1.1: A human-agent dialogue during the process of making a business decision. (*usr*: user, *agt*: agent) The dialogue consists of multiple segments of different types. Turns 1 and 2 are a social chat segment. Turns 3 to 5 are a QA segment. Turns 6 and 7 are a task-completion segment.

1.2 Dialogue: What Kinds of Problems?

Fig. 1.1 shows a human-agent dialogue during the process of making a business decision. The example illustrates the kinds of problems a dialogue system is expected to solve:

- **question answering**: the agent needs to provide concise, direct answers to user queries based on rich knowledge drawn from various data sources including text collections such as Web documents and pre-compiled knowledge bases such as sales and marketing datasets, as the example shown in Turns 3 to 5 in Fig. 1.1.
- **task completion**: the agent needs to accomplish user tasks ranging from restaurant reservation to meeting scheduling (e.g., Turns 6 to 7 in Fig. 1.1), and to business trip planning.
- **social chat**: the agent needs to converse seamlessly and appropriately with users — like a human as in the Turing test — and provide useful recommendations (e.g., Turns 1 to 2 in Fig. 1.1).

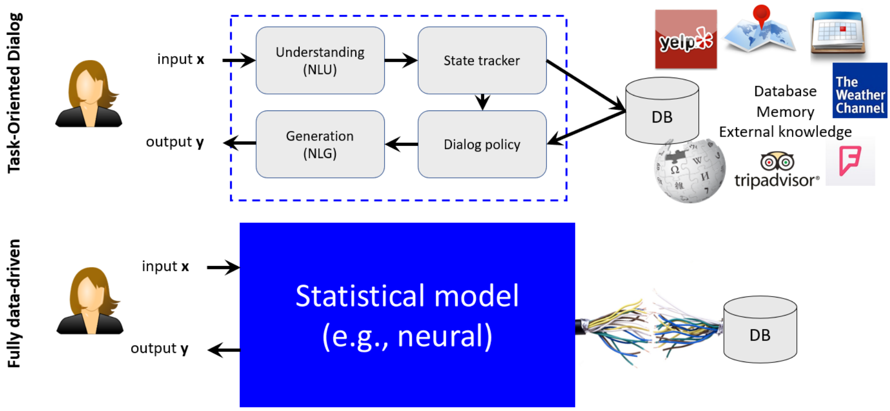

Figure 1.2: Two architectures of dialogue systems for (Top) traditional task-oriented dialogue and (Bottom) fully data-driven dialogue.

One may envision that the above dialogue can be collectively accomplished by a set of agents, also known as *bots*, each of which is designed for solving a particular type of task, e.g., QA bots, task-completion bots, social chatbots. These bots can be grouped into two categories, *task-oriented* and *chitchat*, depending on whether the dialogue is conducted to assist users to achieve specific tasks, e.g., obtain an answer to a query or have a meeting scheduled.

Most of the popular personal assistants in today's market, such as Amazon Alexa, Apple Siri, Google Home, and Microsoft Cortana, are task-oriented bots. These can only handle relatively simple tasks, such as reporting weather and requesting songs. An example of a chitchat dialogue bot is Microsoft XiaoIce. Building a dialogue agent to fulfill complex tasks as in Fig. 1.1 remains one of the most fundamental challenges for the IR and NLP communities, and AI in general.

A typical task-oriented dialogue agent is composed of four modules, as illustrated in Fig. 1.2 (Top): (1) a Natural Language Understanding (NLU) module for identifying user intents and extracting associated information; (2) a state tracker for tracking the dialogue state that captures all essential information in the conversation so far; (3) a dialogue policy that selects the next action based on the current state; and (4) a Natural Language Generation (NLG) module for converting agent actions to natural language responses. In recent years there has been a trend towards developing fully data-driven systems by unifying these modules using a deep neural network that maps the user input to the agent output directly, as shown in Fig. 1.2 (Bottom).

Most task-oriented bots are implemented using a modular system, where the bot often has access to an external database on which to inquire about information to accomplish the task (Young *et al.*, 2013; Tur and De Mori, 2011). Social chatbots, on the other hand, are often implemented using a unitary (non-modular) system. Since the primary goal of social chatbots is to be AI companions to humans with an emotional connection rather than completing specific tasks, they are often developed to mimic human conversations by training DNN-based response generation models on large amounts of human-human conversational data (Ritter *et al.*, 2011; Sordoni *et al.*, 2015b; Vinyals and Le, 2015; Shang *et al.*, 2015). Only recently have researchers begun to explore how to ground the chitchat in world knowledge (Ghazvininejad *et al.*, 2018) and images (Mostafazadeh *et al.*, 2017) so as to make the conversation more contentful and interesting.

1.3 A Unified View: Dialogue as Optimal Decision Making

The example dialogue in Fig. 1.1 can be formulated as a decision making process. It has a natural hierarchy: a top-level process selects what agent to activate for a particular subtask (e.g., answering a question, scheduling a meeting, providing a recommendation or just having a casual chat), and a low-level process, controlled by the selected agent, chooses primitive actions to complete the subtask.

Such hierarchical decision making processes can be cast in the mathematical framework of *options* over Markov Decision Processes (MDPs) (Sutton *et al.*, 1999b), where options generalize primitive actions to higher-level actions. In a traditional MDP setting, an agent chooses a primitive action at each time step. With options, the agent can choose a "multi-step" action which for example could be a sequence of primitive actions for completing a subtask.

If we view each option as an action, both top- and low-level processes can be naturally captured by the reinforcement learning framework. The dialogue agent navigates in a MDP, interacting with its environment over a sequence of discrete steps. At each step, the agent observes the current state, and chooses an action according to a policy. The agent then receives a reward and observes a new state, continuing the cycle until the episode terminates. The goal of dialogue learning is to find optimal policies to maximize expected rewards. Table 1.1 formulates an sample of dialogue agents using this unified view of RL, where the state-action spaces characterize the complexity of the problems, and the rewards are the objective functions to be optimized.

The unified view of hierarchical MDPs has already been applied to guide the development of some large-scale open-domain dialogue systems. Recent examples include Sounding Board [3], a social chatbot that won the 2017 Amazon Alexa Prize, and Microsoft XiaoIce [4], arguably the most popular social chatbot that has attracted more than 660 million users worldwide since its release in 2014. Both systems use a hierarchical dialogue manager: a master (top-level) that manages the overall conversation process, and a collection of skills (low-level) that handle different types of conversation segments (subtasks).

The reward functions in Table 1.1, which seem contradictory in CPS (e.g., we need to minimize CPS for efficient task completion but maximize CPS for improving user engagement), suggest that we have to balance the long-term and short-term gains when developing a dialogue system. For example, XiaoIce is a social chatbot optimized for user engagement, but is also equipped with more than 230 skills, most of which are QA and task-oriented. XiaoIce is optimized for *expected* CPS which corresponds a long-term, rather than a short-term, engagement. Although incorporating many task-oriented and QA skills can reduce CPS in the short term since these skills help users accomplish tasks *more efficiently* by minimizing CPS, these new skills establish XiaoIce as an efficient and trustworthy personal assistant, thus strengthening the emotional bond with human users in the long run.

[3] https://sounding-board.github.io/
[4] https://www.msxiaobing.com/

Table 1.1: Reinforcement Learning for Dialogue. CPS stands for Conversation-turns Per Session, and is defined as the average number of conversation-turns between the bot and the user in a conversational session.

dialogue	**state**	**action**	**reward**
QA	understanding of user query intent	clarification questions or answers	relevance of answer, (min) CPS
task-oriented	understanding of user goal	dialogue-act and slot/value	task success rate, (min) CPS
chitchat	conversation history and user intent	responses	user engagement, measured in CPS
top-level bot	understanding of user top-level intent	options	user engagement, measured in CPS

Although RL provides a unified ML framework for building dialogue agents, applying RL requires training the agents by interacting with real users, which can be expensive in many domains. Hence, in practice, we often use a hybrid approach that combines the strengths of different ML methods. For example, we might use imitation and/or supervised learning methods (if there is a large amount of human-human conversational corpus) to obtain a reasonably good agent before applying RL to continue improving it. In the paper, we will survey these ML approaches and their use for training dialogue systems.

1.4 The Transition of NLP to Neural Approaches

Neural approaches are now transforming the field of NLP and IR, where symbolic approaches have been dominating for decades.

NLP applications differ from other data processing systems in their use of language knowledge of various levels, including phonology, morphology, syntax, semantics and discourse (Jurafsky and Martin, 2009). Historically, much of the NLP field has organized itself around the architecture of Fig. 1.3, with researchers aligning their work with one component task, such as morphological analysis or parsing. These tasks can be viewed as resolving (or realizing) natural language ambiguity (or diversity) at different levels by mapping (or generating) a natural language sentence to (or from) a series of human-defined, unambiguous, symbolic representations, such as Part-Of-Speech (POS) tags, context

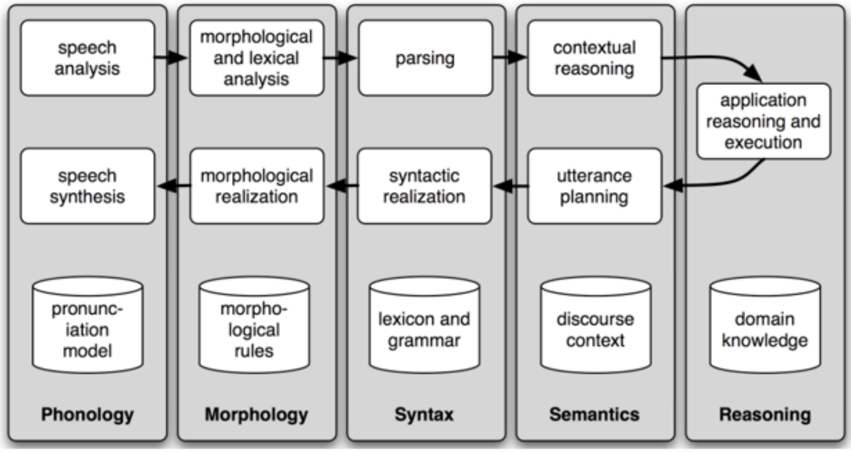

Figure 1.3: Traditional NLP Component Stack. Figure credit: Bird *et al.* (2009).

free grammar, first-order predicate calculus. With the rise of data-driven and statistical approaches, these components have remained and have been adapted as a rich source of engineered features to be fed into a variety of machine learning models (Manning *et al.*, 2014).

Neural approaches do not rely on any human-defined symbolic representations but learn in a *task-specific* neural space where task-specific knowledge is *implicitly* represented as semantic concepts using low-dimensional continuous vectors. As Fig. 1.4 illustrates, neural methods in NLP tasks (e.g., machine reading comprehension and dialogue) often consist of three steps: (1) *encoding* symbolic user input and knowledge into their neural semantic representations, where semantically related or similar concepts are represented as vectors that are close to each other; (2) *reasoning* in the neural space to generate a system response based on input and system state; and (3) *decoding* the system response into a natural language output in a symbolic space. Encoding, reasoning and decoding are implemented using neural networks of different architectures, all of which may be stacked into a deep neural network trained in an end-to-end fashion via back propagation.

End-to-end training results in tighter coupling between the end application and the neural network architecture, lessening the need for traditional NLP component boundaries like morphological analysis and

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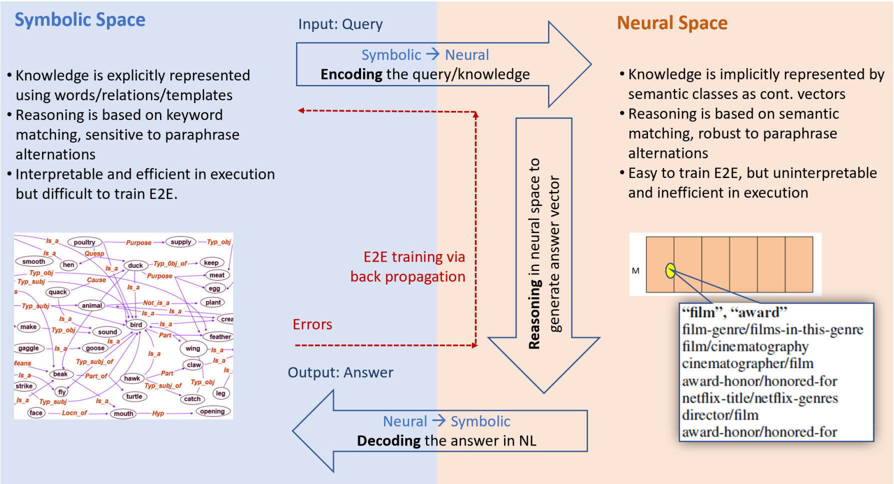

Figure 1.4: Symbolic and Neural Computation.

parsing. This drastically flattens the technology stack of Fig. 1.3, and substantially reduces the need for feature engineering. Instead, the focus has shifted to carefully tailoring the increasingly complex architecture of neural networks to the end application.

Although neural approaches have already been widely adopted in many AI tasks, including image processing, speech recognition and machine translation (e.g., Goodfellow *et al.*, 2016), their impact on conversational AI has come somewhat more slowly. Only recently have we begun to observe neural approaches establish state-of-the-art results on an array of conversation benchmarks for both component tasks and end applications and, in the process, sweep aside the traditional component-based boundaries that have defined research areas for decades. This symbolic-to-neural shift is also reshaping the conversational AI landscape by opening up new tasks and user experiences that were not possible with older techniques. One reason for this is that neural approaches provide a consistent representation for many modalities, capturing linguistic and non-linguistic (e.g., image and video (Mostafazadeh *et al.*, 2017)) features in the same modeling framework.

There are also works on hybrid methods that combine the strengths of both neural and symbolic approaches e.g., (Mou *et al.*, 2016; Liang *et* *al.*, 2016). As summarized in Fig. 1.4, neural approaches can be trained in an end-to-end fashion and are robust to paraphrase alternations, but are weak in terms of execution efficiency and explicit interpretability. Symbolic approaches, on the other hand, are difficult to train and sensitive to paraphrase alternations, but are more interpretable and efficient in execution.

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