Characteristics, Applications, and Architectures of Conversational Search Systems: A Systematic Literature Review

Alina Dats, 22.08.2022, Master's Thesis Final Presentation

Chair of Software Engineering for Business Information Systems (sebis)
Faculty of Informatics
Technische Universität München
wwwmatthes.in.tum.de

Outline

Background and motivation

Methodology

Results

Conclusion

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Humans increasingly use natural language interfaces

Conversational interfaces

Open-domain

Mimic conversations characteristics of human-human interaction

Examples

Microsoft Xiaolce

Insomnobot 3000

Meena

+ Other open-domain chit-chat systems

Task-based

Focus on task completion

Examples

Google Assistant

Amazon Alexa

Apple Siri

+ Other task-based agents

Information search and retrieval

Satisfy an information need

- Conversational recommendation system
- Conversational question-answering system
- **Conversational search system**

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Conversational search is emerging as one of the key technologies in fulfilling user's information needs

Conversational search *is a system for retrieving information that permits a mixed-initiative back and forth between a user and agent, where the agent's actions are chosen in response to a model of current user needs within the current conversation, using both short- and long-term knowledge of the user [1].*

Five characteristics of conversational search systems [1]

1. User Revealment
2. System Revealment
3. Set Retrieval
4. Mixed Initiative
5. Memory

…

[1] Radlinski F., and Craswell N. "A theoretical framework for conversational search." *Proceedings of the 2017 conference on conference human information interaction and retrieval*. 2017.

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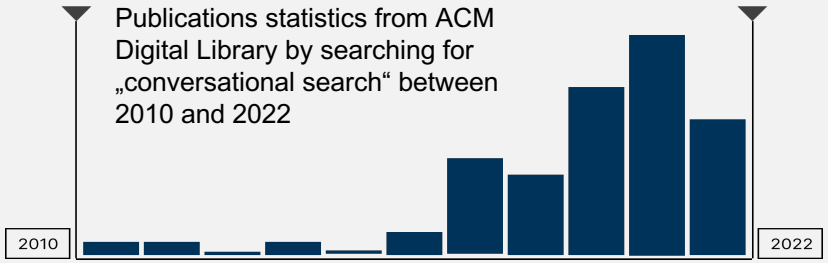
New challenges arise in the academic discussion due to increasing interest in conversational search

Rising interest



Development of new technologies and datasets in NLP

Relatively new search paradigm

Challenges

Lack of consistency in the terminology
e.g., dialog systems,
chatbots,
agents,
conversational interfaces

Lack of understanding of differences between existing information retrieval and dialog systems

No consensus on system architectures

Lack of publications that summarize existing work and consolidate findings on how to engineer conversational search systems

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The aim of this thesis is an extensive study of the conversational search systems

Main aim

How can conversational search systems be conceptualized and developed based on the findings in the academic literature?

RQ1

Which characteristics of conversational search systems are defined in the academic literature?

RQ2

What application scenarios have been investigated for conversational search systems and why?

RQ3

What architectures have been proposed for conversational search systems?

RQ4

To what extent do the system architectures depend on the scenarios?

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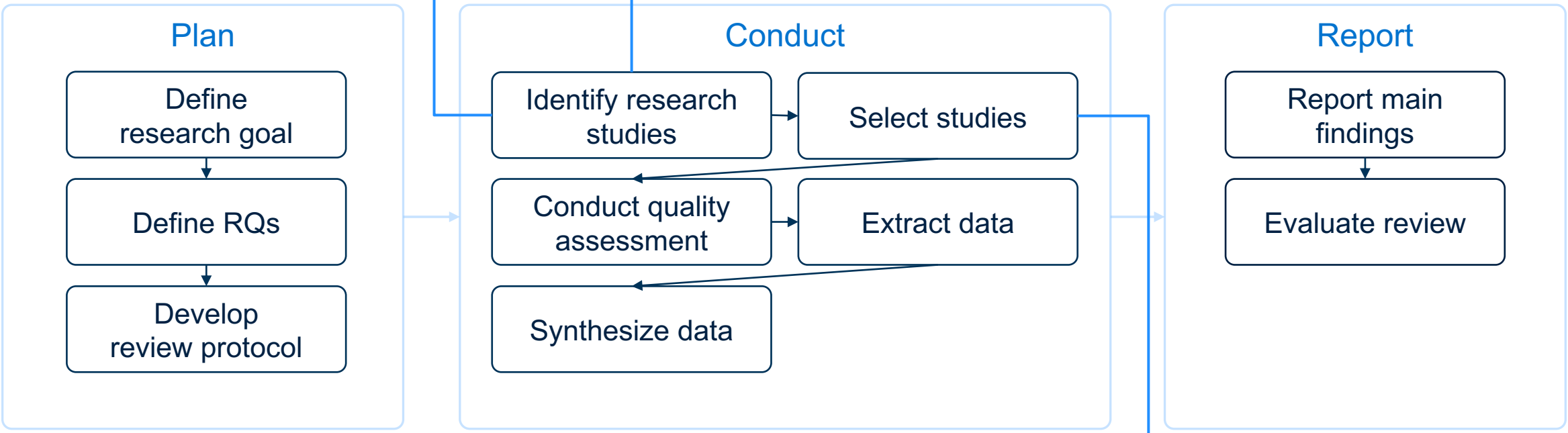
Systematic literature review method

Search string:
"Conversational search" OR **"conversational information retrieval"** OR **"conversational information-seeking"** OR **"information-seeking conversation"** OR **"information-seeking dialogue"** OR **"information-seeking dialog"**

1. ACM Digital Library
2. ACL Anthology
3. SCOPUS
4. Web of Science
5. IEEE Xplore
6. ScienceDirect



Exclusion criteria:
E1: Publication type: short papers, books, grey literature, etc.
E2: Papers not in English
E3: No access to full text
E4: Publications with obvious factual errors and incorrect grammar or vocabulary
E5: Papers are not related to the specified RQs

[2] B. Kitchenham. "Procedures for performing systematic reviews". In: Keele, UK, Keele University 33.2004 (2004), pp. 1–26.

[3] B. Kitchenham, D. Budgen, and P. Brereton. Evidence-Based Software Engineering and Systematic Reviews. Nov. 2015.

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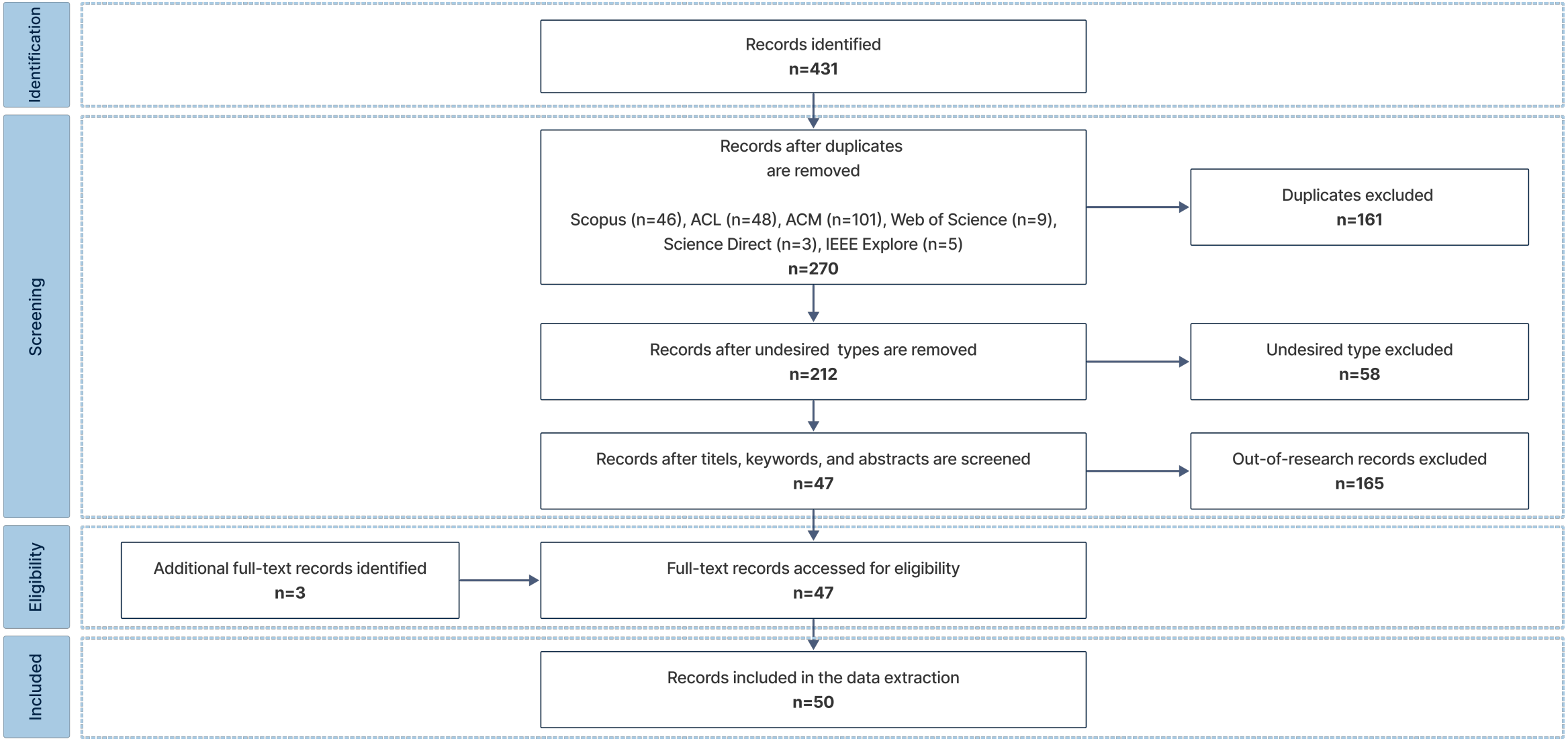
Search results with PRISMA flow diagram



[4] PRISMA framework https://prisma-statement.org/PRISMAStatement/

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We defined a conceptual framework for conversational search systems to answer the first research question

Conceptual framework for conversational search systems

Goal

Maximize the user's information gain by finding search results with maximum utility

Definitions

- System-oriented
- Dialog-oriented
- Task-oriented

Characteristics

- Conversational interaction
- Context and memory
- Search assistance
- Mutual understanding
- Learning

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We categorized the definitions into system-, dialog-, and task-oriented based on their primary focus

Conceptual framework for conversational search systems

Definitions

System-oriented	Dialog-oriented	Task-oriented
"...conversational search is the development of systems that enable information retrieval using natural language interaction, i.e., a dialogue interface." [5]	"Conversational search introduces dialog settings with flexible communication channels, such as where a screen or keyboard may be inconvenient or unavailable, where seekers may be unable to skim a search engine results page visually." [6]	"Conversational search aims at finding or recommending the most relevant information (e.g., web pages, answers, movies, products) for users based on textual- or spoken dialogs, through which users can communicate with the system more efficiently using natural language conversations." [7]

[5] S. Vakulenko, E. Kanoulas, and M. De Rijke. “A Large-scale Analysis of Mixed Initiative in Information-Seeking Dialogues for Conversational Search”.
[6] J. Kiesel, L. Meyer, M. Potthast, and B. Stein. “Meta-Information in Conversational Search”.
[7] Y. Zhang, X. Chen, Q. Ai, L. Yang, and W. Bruce Croft. “Towards conversational search and recommendation: System Ask, user respond”.

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We proposed five distinct characteristics with corresponding functionalities for conversational search systems based on the literature findings

Conceptual framework for conversational search systems

Characteristics

Conversational interaction

Description

The system and the user interact in a conversational manner, similar to human conversations.

Functionality

- Support multi-turn dialogs in natural language
- Interact with mixed-initiative or user-/system-initiative
- Off-topic chatting and negotiations

Context and memory

Description

The system maintains the context of a conversation and memorizes conversation history and user data, so a user and a system can refer to previous statements.

Functionality

- Maintain conversation history
- Retrieve and refer to past statements

Search assistance

Description

The system supports the user during the search process, retrieves the relevant results and can explain the selection.

Functionality

- Suggest, clarify and reformulate queries
- Retrieve and explain results set
- Refine the result set and its presentation to a user

Mutual understanding

Description

Through an interaction, both a user and a system perceive and constantly update each other's information needs or knowledge.

Functionality

- Reveal the capabilities of the user and system
- Understand the user's domain knowledge
- Maintain the model of the user

Learning

Description

The system can learn the information about a user and predict the best strategies to meet the user's information needs.

Functionality

- Learn dialog policy
- Track dialog state
- Capture and analyze follow-up questions

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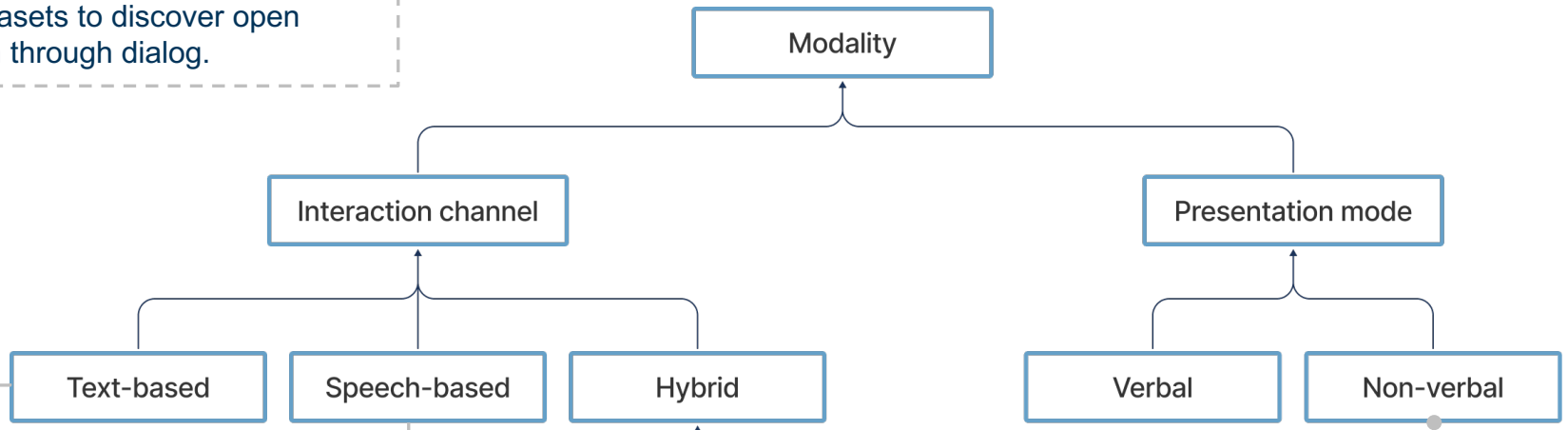
Identified taxonomy of modalities for conversational search systems

Example
Keyner et al. [8] proposed (text-based) chatbot as a conversational search application for a repository of publicly available datasets to discover open government information through dialog.



Example
Trippas et al. [9] focused on audio-only SCS excluding multi-modal or visual interactions. They stated that the CS system has to become more active and more involved in the users' search process to fulfill the audio-only channel's difficulties.

Example
Bickmore et al. [10] developed a CS avatar that speaks using synthetic speech accompanied by conversational non-verbal behavior (e.g., hand gestures, facial displays, gaze) animated in synchrony with the speech.

[8] S. Keyner, V. Savenkov, and S. Vakulenko. "Open Data Chatbot".
[9] J. Trippas, D. Spina, P. Thomas, M. Sanderson, H. Joho, and L. Cavedon. "Towards a model for spoken conversational search".
[10] T. Bickmore, D. Utami, R. Matsuyama, and M. Paasche-Orlow. "Improving access to online health information with conversational agents: A randomized controlled experiment".

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Based on the proposed scenarios from current literature, we defined four different scenario categories, depending on their focus

Scenarios

Complexity-based	Task-based	Environment-based	Domain-based
Faceted elicitation	Classic information retrieval	On-the-go search	Business
Multi-item elicitation	Learning about the topic	Longitudinal search	Tourism
Multi-item faceted elicitation	Seeking recommendation	Collaborative search	Health
			Law
			Aerospace
			Public sector

Example
Deldjoo et al. [11] provided the following example: the user is riding her bike down the road and sees a plant on the side of the road. She quickly stops, takes a picture, and continues her way. Meanwhile, she asks her earphones what kind of plant it is and if it is edible. The system considers the user's GPS location, the photo, and the input query. The system measures heart rate and recognizes that the user is cycling and therefore does not provide visual information but presents the result via speech into the earphones.

Example
Deldjoo et al. [11] stated collaborative search enables synchronous and asynchronous search with multiple participants simultaneously and continuous modality updates during the conversation.

[11] Y. Deldjoo, J. Trippas, and H. Zamani. "Towards Multi-Modal Conversational Information Seeking".

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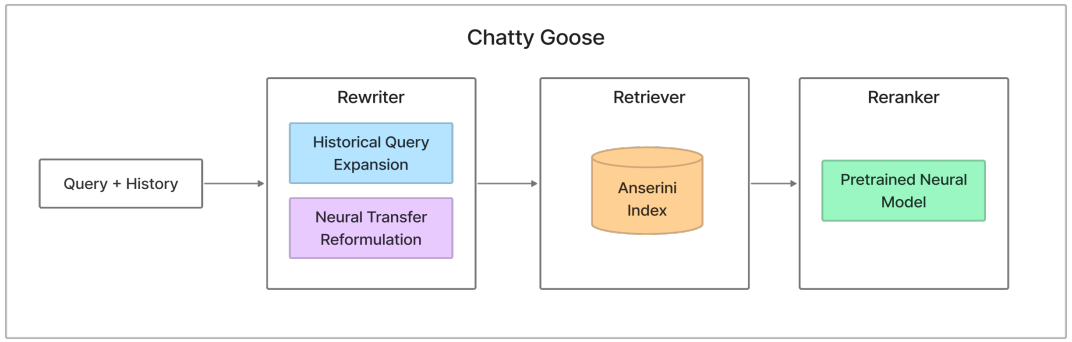
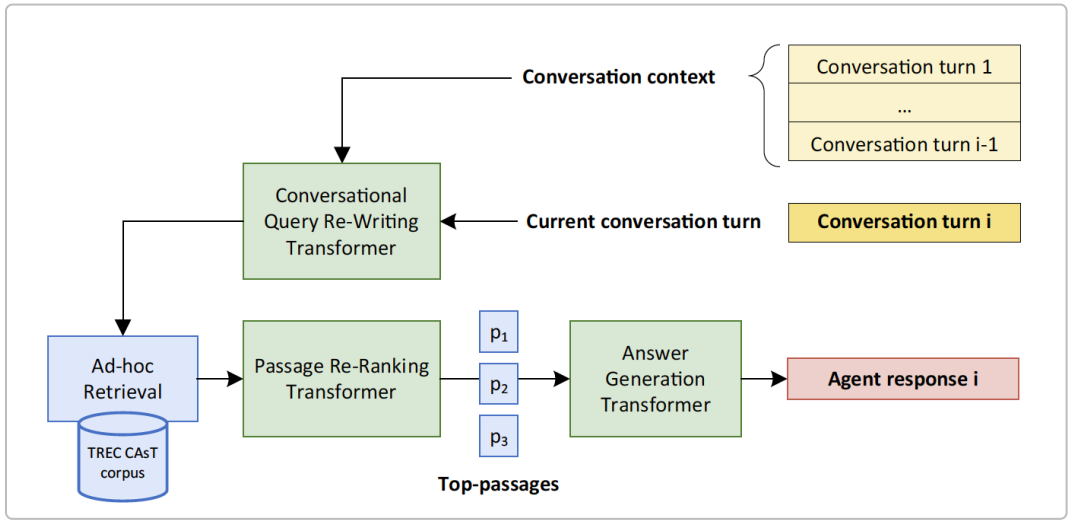
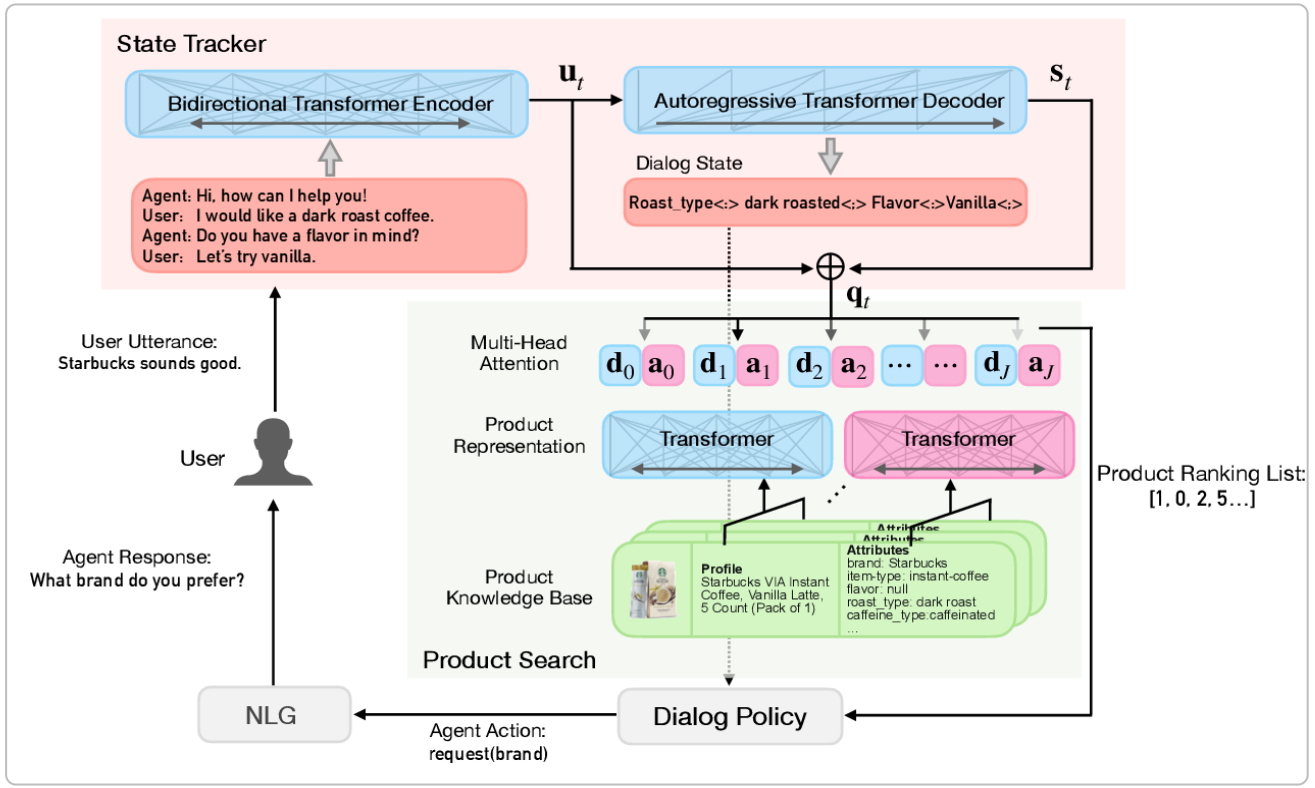
Researchers proposed architectures of varying complexity - from pipeline architectures to end-to-end interconnected transformers



The architecture of the conversational passage retrieval pipeline for Chatty Goose [12]



Transformer-based conversational search system proposed by [13]



Conversational end-to-end search system proposed by [14]

[12] E. Zhang, S.-C. Lin, J.-H. Yang, R. Pradeep, R. Nogueira, and J. Lin. "Chatty Goose: A Python Framework for Conversational Search".
[13] R. Ferreira, M. Leite, D. Semedo, and J. Magalhaes. "Open-domain conversational search assistants: the Transformer is all you need".
[14] L. Xiao, J. Ma, X. L. Dong, P. Martinez-Gomez, N. Zalmout, W. Chen, T. Zhao, H. He, and Y. Jin. "End-to-End Conversational Search for Online Shopping with Utterance Transfer".

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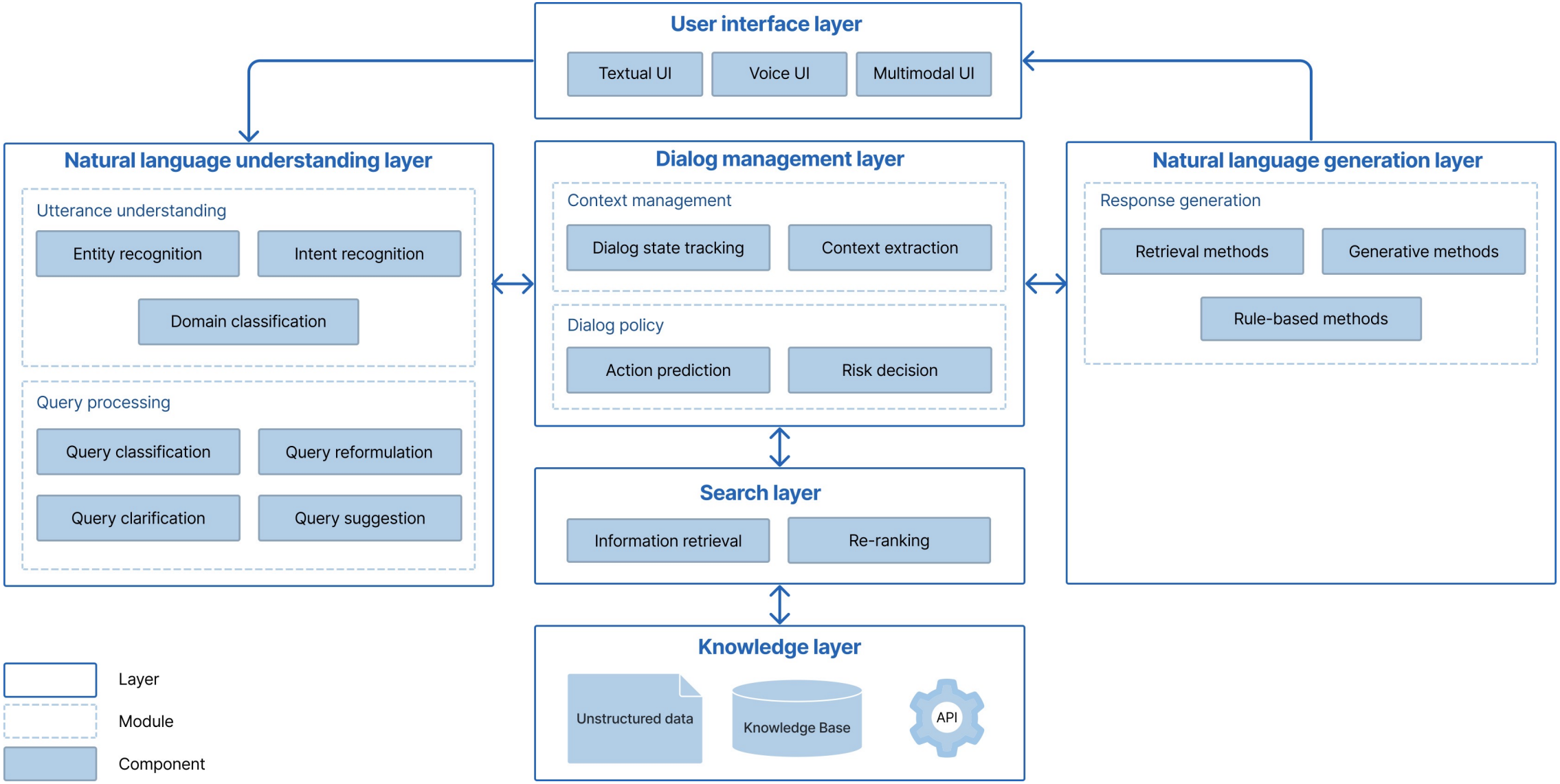
We defined a reference architecture for conversational search systems



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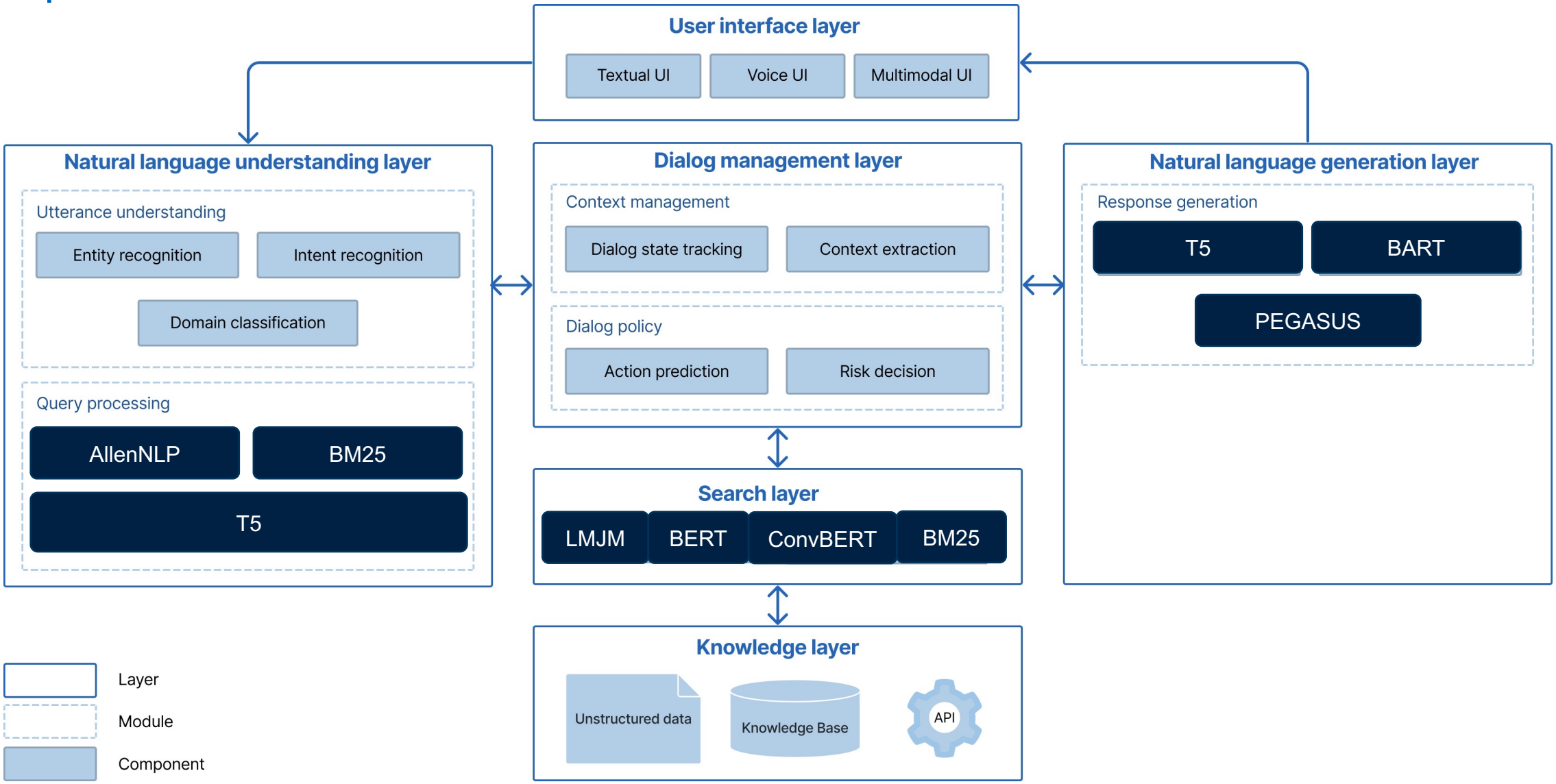
We identified example techniques for conversational search system components



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With regards to selected studies, we concluded that architectural characteristics partially depend on application scenarios

Layer-based dependencies

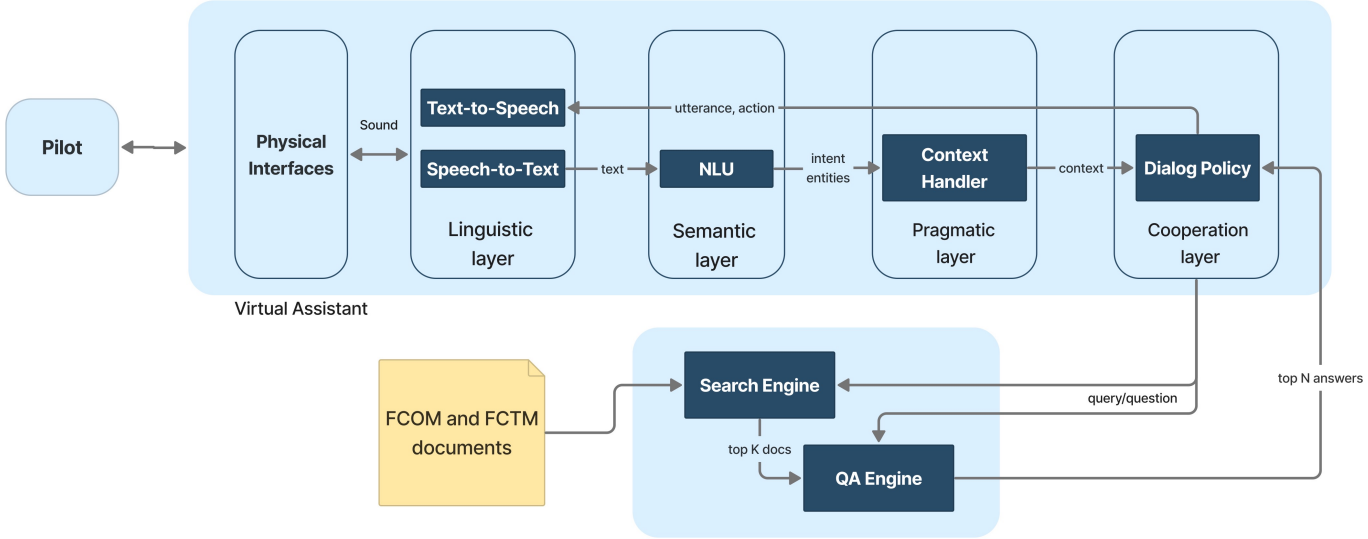
UI layer

- Architectural elements in most cases depend on the modality of UI
- For the multi-modal CS system a introduction of new components, like **request dispatcher** and **output modality selection component** needed

NLU layer

- Architecture may depend on special scenarios, like conversational search for people with low literacy [15]. Bickmore et al. defined that users can only enter input from the multiple-choice selection.

In general, often was proposed, that the proposed CS systems could be extended to new domains.



Architecture for a conversational search system architecture for document exploration for pilots [16].

[15] T. Bickmore, D. Utami, R. Matsuyama, and M. Paasche-Orlow. “Improving access to online health information with conversational agents: A randomized controlled experiment”.
[16] Y.-H. Liu, A. Arnold, G. Dupont, C. Kobus, and F. Lancelot. “Evaluation of conversational agents for aerospace domain”.

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Conversational search remains an attractive area of research with many future areas for researchers to explore

Conclusion

In this research, we:

✓ Conducted a systematic literature review on the conversational search systems
✓ Approached the overall problem in four directions, formulated as research questions

For RQ1:

✓ Introduced a conceptual framework for the CS paradigm
✓ Analyzed the characteristics of conversational search and proposed five characteristic properties

For RQ2:

✓ Examined the application scenarios and summarized them

For RQ3:

✓ Explored architectures and identified various architectural elements, techniques, and algorithms that compile the CS architecture
✓ Proposed a reference architecture for conversational search systems based on six layers

For RQ4:

✓ Observed dependencies between the scenarios suitable for CS and its architectural elements

Future work

- Do an in-depth analysis of algorithms and datasets for different architectures
- Evaluate the performance and robustness between end-to-end and pipeline architectures in real-world scenarios
- Further validate SLR results with insights from industry through expert interviews
- Investigate different domains and their real-word scenario implementation

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Thank you for your attention! Do you have any questions?

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Alina Dats
Master Thesis in Informatics

Technische Universität München
Faculty of Informatics
Chair of Software Engineering for Business Information Systems

Boltzmannstraße 3
85748 Garching bei München

Tel +49.89.289. 17132
Fax +49.89.289.17136

matthes@in.tum.de
wwwmatthes.in.tum.de