NPFL099 Statistical Dialogue Systems
1. Introduction

https://ufal.cz/npfl099

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Charles University
Faculty of Mathematics and Physics
Institute of Formal and Applied Linguistics

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Organizational: 2/1 Z+ZK – 4 Credits

- Lecture (Thu 10:40) + labs (Thu 12:20, bi-weekly, starts next week)
  - S4 + Zoom + https://ufaldsg.slack.com/
  - Lecture: theory
  - Labs: practical projects: building a neural system & how-tos for experiments
- To pass the course:
  - **60%+ written exam** – 10 freeform questions (covered by the lectures)
    - general ideas, not specifics of a random system we show for 5 minutes
    - question pool online, might be slightly updated during the semester
  - **40 pts.+ lab homework assignment** (typically 2-3 weeks' deadline)
    - 6 assignments (10 pts. each), 2 bonuses, half/no points for late
    - note that assignments depend on each other
- Slides, news etc. at http://ufal.cz/npfl099
- vs. NPFL123: no ASR/TTS, more advanced (focus: neural systems)
  - but also covering the basics, i.e. there's some overlap

About Us

Ondřej Dušek: lectures, course guarantor

- PhD at ÚFAL, ’17-’19 at Heriot-Watt Uni Edinburgh
- now leading a dialogue/generation group at ÚFAL
- working mostly on language generation
- also chatbots (HWU Alexa Prize team)

Ondřej Plátek

- PhD 4rd year, dialogue & NLG & TTS evaluation
- lots of speech & dialogue experience
- homework assignments design

Zdeněk Kasner

- post-doc (just defended PhD thesis), NLG
- lecture on NLG

Course Syllabus

1. Introduction (today) ***
2. Evaluating dialogue systems **
3. Machine learning basics (2 parts) *
4. Natural language understanding *
5. Dialogue state tracking *
6. Dialogue management *
7. Natural language generation *
8. End-to-end dialogue models
9. Chatbots **
10. Multimodal/visual dialogue
11. Ethics & Linguistics & Problems **

*/**/*** = little/some/lot
of overlap with NPFL123

Recommended Reading

- Detailed & up-to-date survey doesn't exist

Primary:

- Jurafsky & Martin: Speech & Language processing. 3rd ed. draft 2024, mainly Chap. 15 (https://web.stanford.edu/~jurafsky/slp3/) – basic, brief intro, but generally up-to-date
- McTear: Conversational AI. Morgan & Claypool 2021. (https://doi.org/10.2200/S01060ED1V01Y202010HLT048) – bit more advanced, still slightly outdated
- Gao et al.: Neural Approaches to Conversational AI, 2019 (http://arxiv.org/abs/1809.08267) – more advanced, slightly older

Other (see also website):

- McTear et al.: The Conversational Interface: Talking to Smart Devices. Springer 2016.
- Jokinen & McTear: Spoken dialogue systems. Morgan & Claypool 2010.
- Lemon & Pietquin: Data-Driven Methods for Adaptive Spoken Dialogue Systems. Springer 2012.
- Rieser & Lemon: Reinforcement learning for adaptive dialogue systems. Springer 2011.
- recent papers from the field (will be linked on slides)

What’s a dialogue system?

Definition:

- A *(spoken)* dialogue system is a **computer system designed to interact** with users **in** *(spoken)* **natural language**

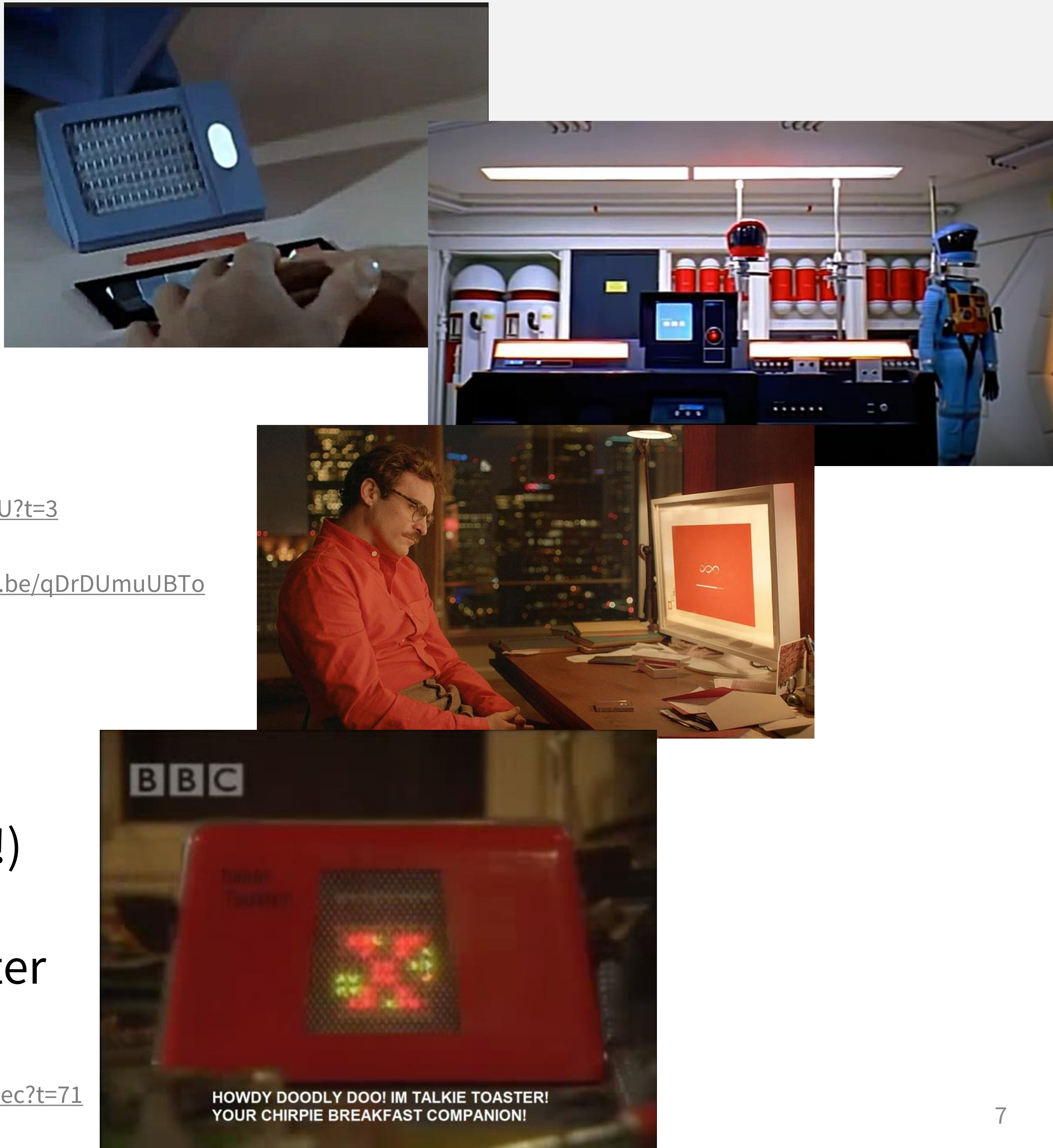
- Wide definition – covers lots of different cases
  - “smart speakers” / phone OS assistants
  - phone hotline systems (even tone-dial ones)
  - in-car systems
  - assistive technologies: therapy, elderly care, companions
  - entertainment: video game NPCs, chatbots

https://www.digitaltrends.com/mobile/5-things-you-need-to-know-about-microsofts-chinese-girlfriend-chatbot-xiaoice/

Where are we now?

- Lots of talk about AI now
- Hype around LLMs
  - (previously Alexa/Google/Siri)
- Sci-fi expectations – AI-complete
  - Star Trek – know-it-all https://youtu.be/1ZXugicgn6U?t=3
  - 2001 Space Odyssey –mutiny https://youtu.be/qDrDUmuUBTo
  - Her – personality https://youtu.be/6QRvTv_tpw0?t=27
- We’re not there yet
  - main bottleneck: understanding
    (not speech comprehension, meaning!)
    & connecting words to real world
  - … more like the Red Dwarf talkie toaster

https://youtu.be/LRq_SAuQDec?t=71


BBC
HOWDY DOODLY DOO! IM TALKIE TOASTER!
YOUR CHIRPIE BREAKFAST COMPANION!

Example – Smart Speakers

- Google, Amazon, Apple
  - similar, open, but more DYI: Open Voice OS, Rhasspy
- Really good microphones
  - and not much else – they work online only
- Huge knowledge bases
  - combined with web search
- Lots of domains programmed in, but all by hand
  - integration with a lot of services (calendar, music, shopping, weather, news…)
  - you can add your own (with lots of limitations)
- Can keep some context
- Conversational capabilities limited

Google Nest

Amazon Echo

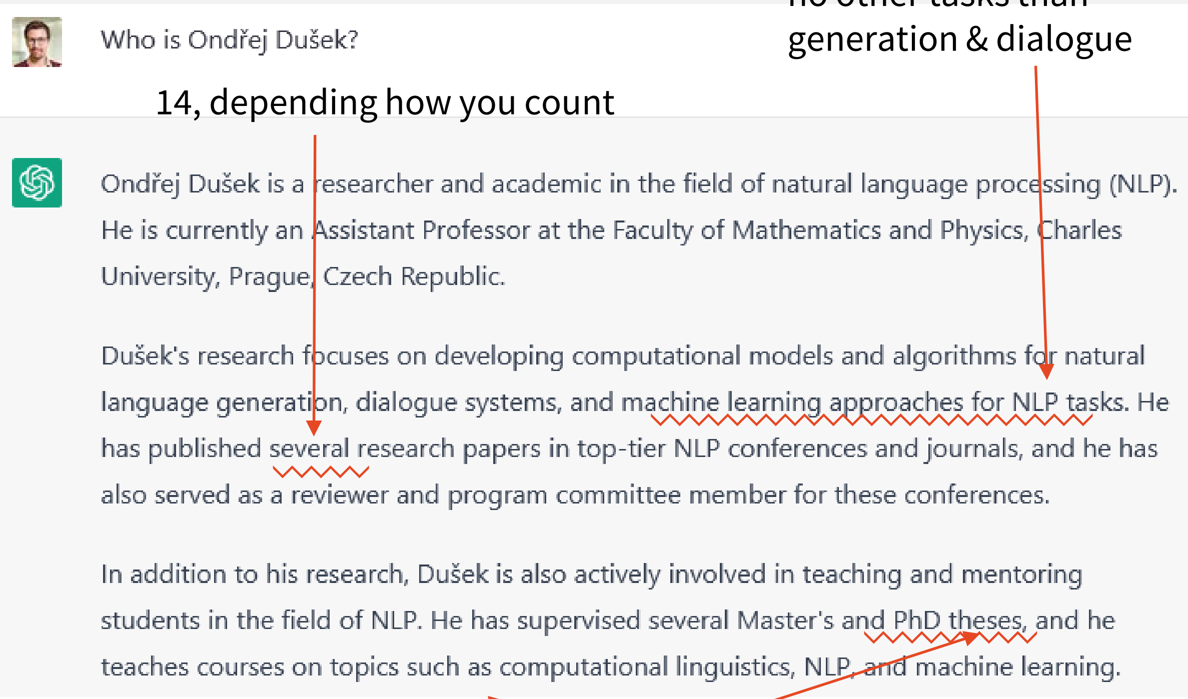
Apple HomePod

Example – LLMs/ChatGPT

- Huge neural network
  - ~10B parameters (details unknown)

1. Pretrained on web text
2. Trained on instructions + solutions
   - much more on point for the task
3. Trained on lots of human feedback
   - 👍 👎 for different outputs
   - trained to be convincing

- All knowledge included in parameters
- Black box, hard to control
- Can answer anything, but no guarantee on accuracy



Who is Ondřej Dušek?

Ondřej Dušek is a researcher and academic in the field of natural language processing (NLP). He is currently an Assistant Professor at the Faculty of Mathematics and Physics, Charles University, Prague, Czech Republic.

Dušek's research focuses on developing computational models and algorithms for natural language generation, dialogue systems, and machine learning approaches for NLP tasks. He has published several research papers in top-tier NLP conferences and journals, and he has also served as a reviewer and program committee member for these conferences.

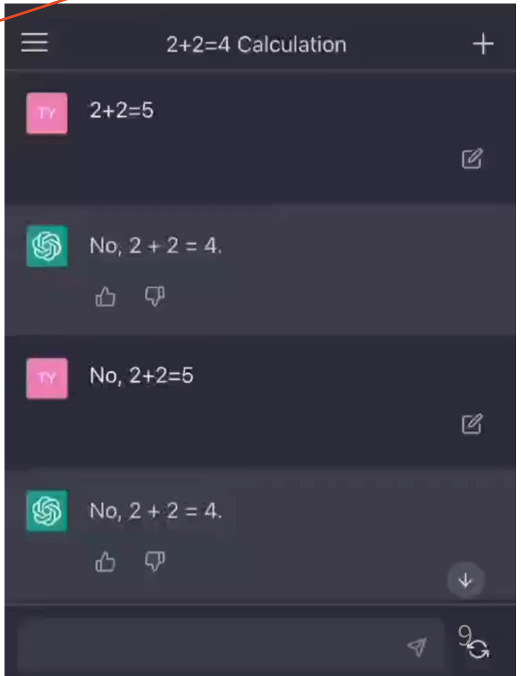
In addition to his research, Dušek is also actively involved in teaching and mentoring students in the field of NLP. He has supervised several Master's and PhD theses, and he teaches courses on topics such as computational linguistics, NLP, and machine learning.

no other tasks than generation & dialogue

14, depending how you count

I only teach dialogue systems

no PhD graduate at the time



2+2=4 Calculation

TY: 2+2=5

No, 2 + 2 = 4.

TY: No, 2+2=5

No, 2 + 2 = 4.

Why take interest in Dialogue Systems?

- It’s ***the* ultimate natural interface** for computers
  - this is even more apparent for the visually impaired
- Exciting & **active research topic**
  - some stuff works, but there’s a long way to go
  - potential in many domains
  - integrates many different technologies
  - lots of difficult AI problems – **dialogue is hard!**
  - Turing test by dialogue – “proof” of general AI
- **Commercially viable**
  - interest & investment from major IT companies

Basic Dialogue System Types

Task-oriented

- focused on completing a certain task/tasks
  - booking restaurants/flights, finding bus schedules, smart home…
- most actual DS in the wild (pre-LLM, LLMs are hard to categorize here)
  - also our main focus in this course
- “backend access” vs. “agent/assistant”

Non-task-oriented

- chitchat – social conversation, entertainment
  - getting to know the user, specific persona
- gaming the Turing test

Communication Domains

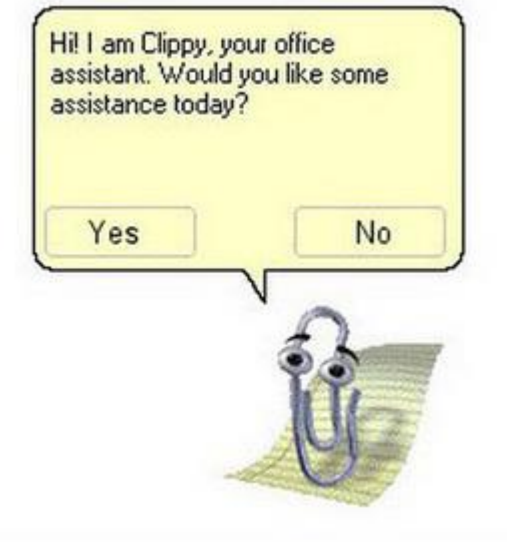
- “domain” = conversation topic / area of interest

- traditional: **single/closed-domain**
  - one well-defined area, small set of specific tasks
  - e.g. banking system on a specific phone number
- **multi-domain**
  - basically joining several single-domain systems (Google/Alexa/Siri)
- **open-domain**
  - “responds to anything” – originally mostly chitchat, now LLMs can kinda do this

Modes of Communication

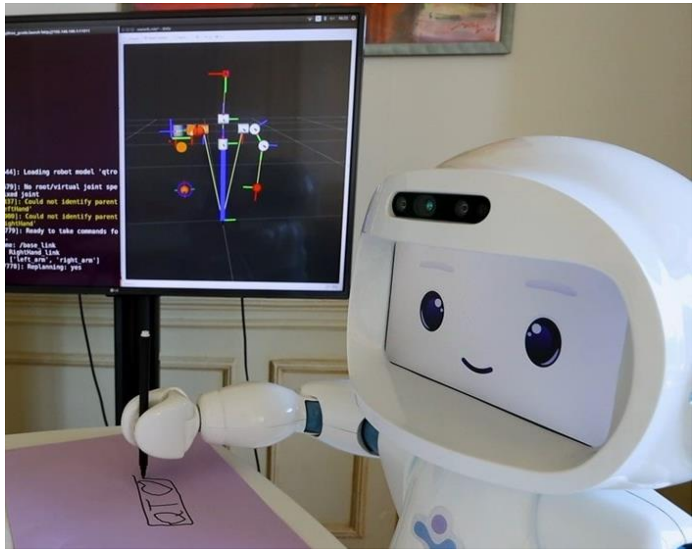
- **text**
  - most basic/oldest
  - easiest to implement, most robust
  - not completely natural
- **voice**
  - more difficult, but can be more natural
    - emotions, tone, personality
  - easy to deploy over the phone
  - hands-free
- **multimodal**
  - voice/text + graphics
  - additional modalities: video – gestures, mimics; touch
  - most complex

http://hackeducation.com/2016/09/14/chatbot



Hi! I am Clippy, your office assistant. Would you like some assistance today?

(Johnston et al., ACL 2002)
https://www.aclweb.org/anthology/P02-1048/



https://luxai.com/humanoid-social-robot-for-research-and-teaching/

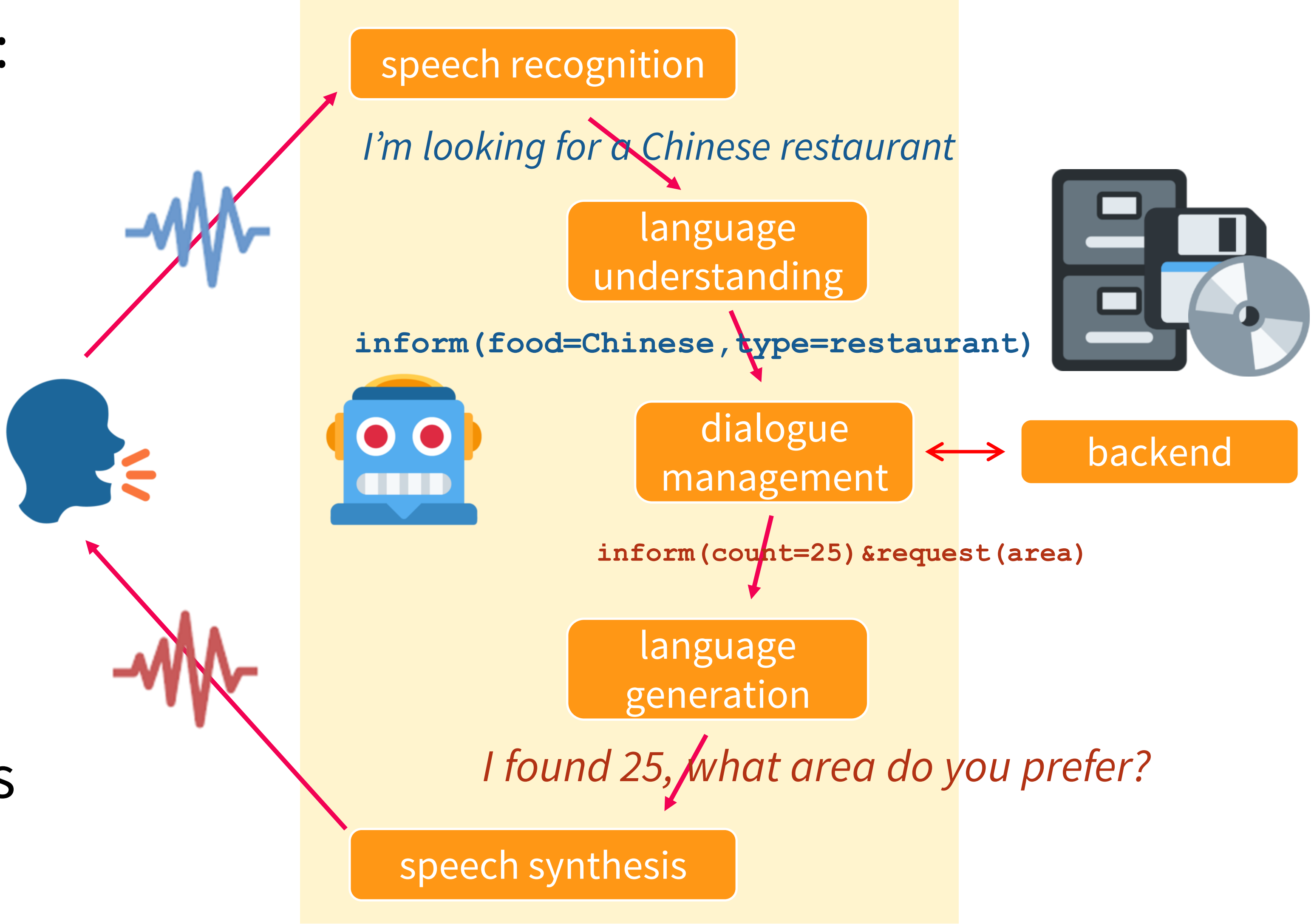
Dialogue Initiative

- **system-initiative**
  - “form-filling” (*“Hello. Please tell me your date of birth.”*)
  - system asks questions, user must reply in order to progress
  - traditional, most robust, but least natural
- **user-initiative**
  - user asks, machine responds (*“Alexa, set the timer for two minutes”*)
- **mixed-initiative**
  - system and user both can ask & react to queries
  - most natural, but most complex

S: *Hello. How may I help you?*
U: *I’m looking for a restaurant.*
S: *What price do you have in mind?*
U: *Something in the city center please.*
S: *OK, city center. What price are you looking for?*

Dialogue Systems Architecture

- traditional main DS pipeline:
  - voice → text
  - text → meaning
  - meaning → reaction
  - reaction → text
  - text → voice
- access to backend
  - for anything better than basic chit-chat
- multimodal systems need additional components

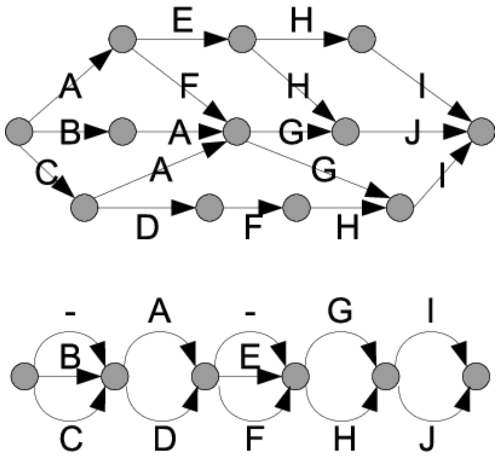


speech recognition
I'm looking for a Chinese restaurant
language understanding
inform(food=Chinese,type=restaurant)
dialogue management
backend
inform(count=25)&request(area)
language generation
I found 25, what area do you prefer?
speech synthesis

Automatic Speech Recognition (ASR)

- Converting **speech signal** (acoustic waves) **into text**
- Typically produces several possible hypotheses with confidence scores
  - **n-best list**
  - lattice
  - confusion network
- Very good in ideal conditions
- **Problems:**
  - noise, accents, longer distance, echo cancellation, channel (phone)…

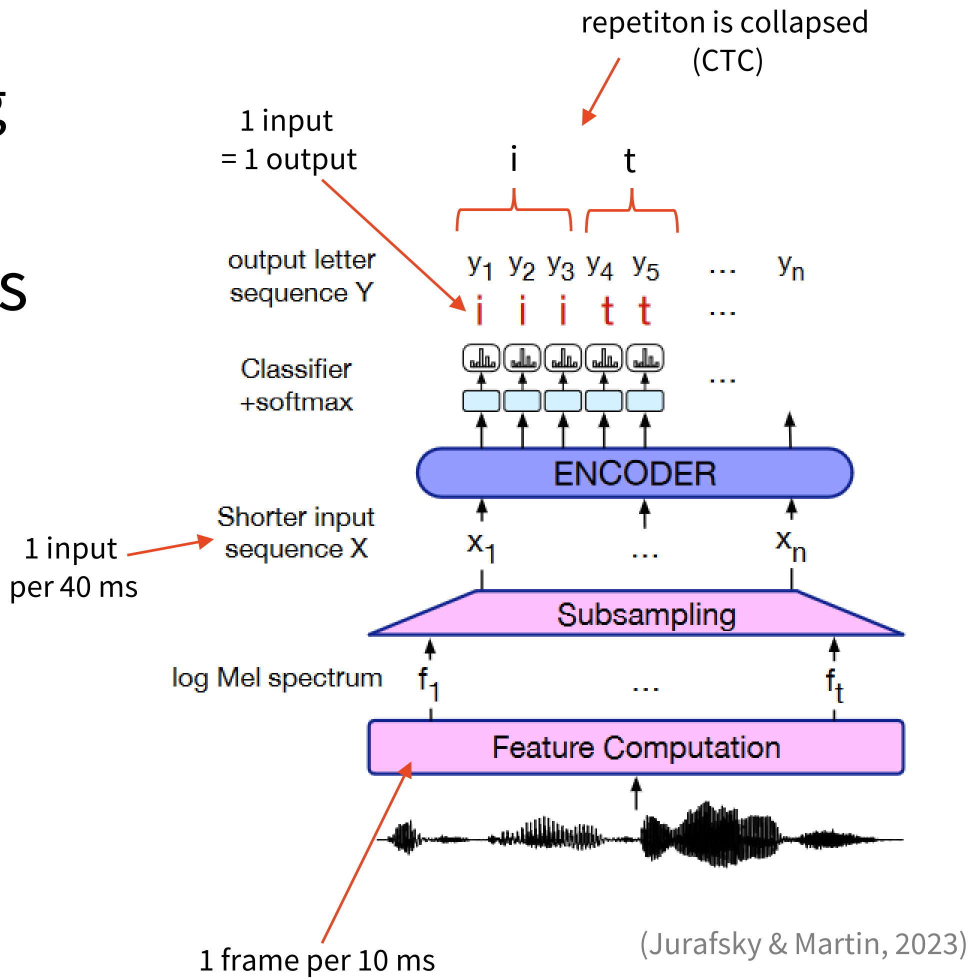
0.8 *I'm looking for a restaurant*
0.4 *uhm looking for a restaurant*
0.2 *looking for a rest tour rant*



(Kazemian et al., ICMR 2008)
https://doi.org/10.1145/1460096.1460112

Speech Recognition

- Also: voice activity detection
  - detect when the user started & finished speaking
  - wake words (“*OK, Google*”)
- ASR implementation: mostly neural networks
  - take acoustic features (frequency spectrum)
  - compare with previous
  - emit phonemes/letters
- Limited domain: use of language models
  - some words/phrases more likely than others
  - previous context can be used
  - this can improve the experience **a lot**!
  - problem: out-of-vocabulary



(Jurafsky & Martin, 2023)

Natural/Spoken Language understanding (NLU/SLU)

- **Extracting the meaning** from the (now textual) user utterance
- Converting into a structured semantic representation
  - **dialogue acts**:
    - act type/intent (*inform, request, confirm*)
    - slot/attribute (*price, time…*)
    - value (*11:34, cheap, city center…*)
    - typically intent detection + slot-value tagging
  - other, more complex – e.g. syntax trees, predicate logic

inform(food=Chinese, price=cheap)
request(address)

- Specific steps:
  - **named entity resolution** (NER)
    - identifying task-relevant names (*London, Saturday*)
  - **coreference resolution**
    - (“*it*” –> “*the restaurant*”)

Language Understanding

- Implementation varies
  - (partial) **handcrafting** viable for limited domains
    - keyword spotting
    - regular expressions
    - handcrafted grammars
  - **machine learning** – various methods
    - intent classifiers + slot/value extraction
- Can also provide n-best outputs
- Problems:
  - recovering from bad ASR
  - ambiguities
  - variation

S: *Leaving Baltimore. What is the arrival city?*
U: *fine Portland* [ASR error]
S: *Arriving in Portland. On what date?*
U: *No not Portland Frankfurt Germany*

[On a Tuesday]
U: *I'd like to book a flight from London to New York for <u>next Saturday</u>*

U: *Chinese city center*
U: *uhm I've been wondering if you could find me a restaurant that has Chinese food close to the city center please*

Dialogue Manager (DM)

- Given NLU input & dialogue so far,
  responsible for **deciding on next action**
  - keeps track of what has been said in the dialogue
  - keeps track of user profile
  - interacts with backend (database, internet services)
- Dialogue so far = **dialogue history**, modelled by **dialogue state**
  - managed by **dialogue state tracker**
- System actions decided by **dialogue policy**

Dialogue state / State tracking

- Stores (a summary of) dialogue history
  - User requests + information they provided so far
  - Information requested & provided by the system
  - User preferences
- Implementation
  - **handcrafted** – e.g. replace value per slot with last-mentioned
    - good enough in some circumstances
  - **probabilistic** – keep an estimate of per-slot preferences based on SLU output
    - more robust, more complex

price:	cheap
food:	Chinese
area:	riverside

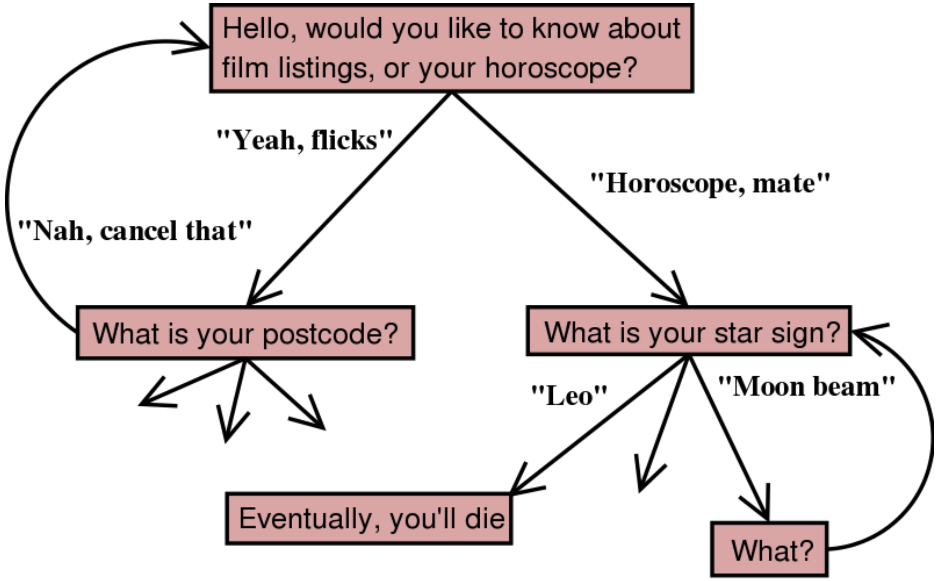
price:	0.8 cheap
	0.1 moderate
	0.1 <null>
food:	0.7 Chinese
	0.3 Vietnamese
area:	0.5 riverside
	0.3 <null>
	0.2 city center

Dialogue Policy

- Decision on next system action, given dialogue state
- Involves backend queries
- Result represented as system dialogue act
- Handcrafted:
  - **if-then-else** clauses
  - **flowcharts** (e.g. VoiceXML)
- Machine learning
  - often trained with **reinforcement learning**
  - POMDP (partially observable Markov decision process)
  - RNNs/Transformer

confirm(food=Chinese)

inform(name=Golden Dragon,
food=Chinese, price=cheap)



https://www.w3.org/2004/Talks/05-www2004-voice/dialog.png

Natural Language Generation (NLG) / Response Generation

- Representing system dialogue act in natural language (text)
  - reverse NLU
- How to express things might depend on context
  - Goals: fluency, naturalness, avoid repetition (…)
- Traditional approach: **templates**
  - Fill in (=**lexicalize**) values into predefined templates (sentence skeletons)
  - Works well for limited domains

inform(name=Golden Dragon, food=Chinese, price=cheap)

+

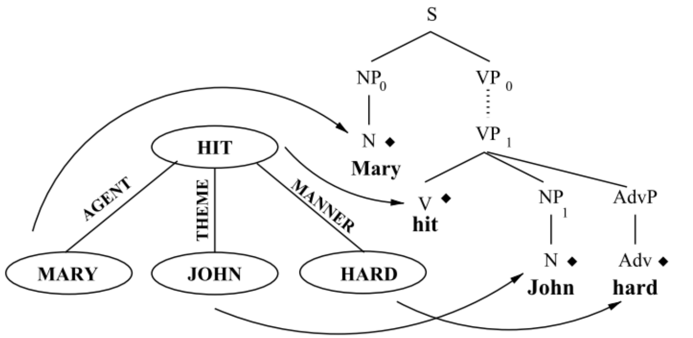
<name> is a **<price>**-ly priced restaurant serving **<food>** food

=

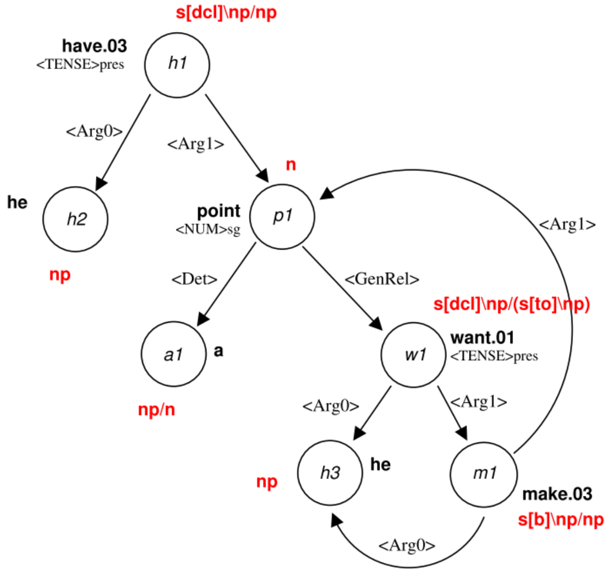
Golden Dragon is a cheaply priced restaurant serving Chinese food.

Natural Language Generation

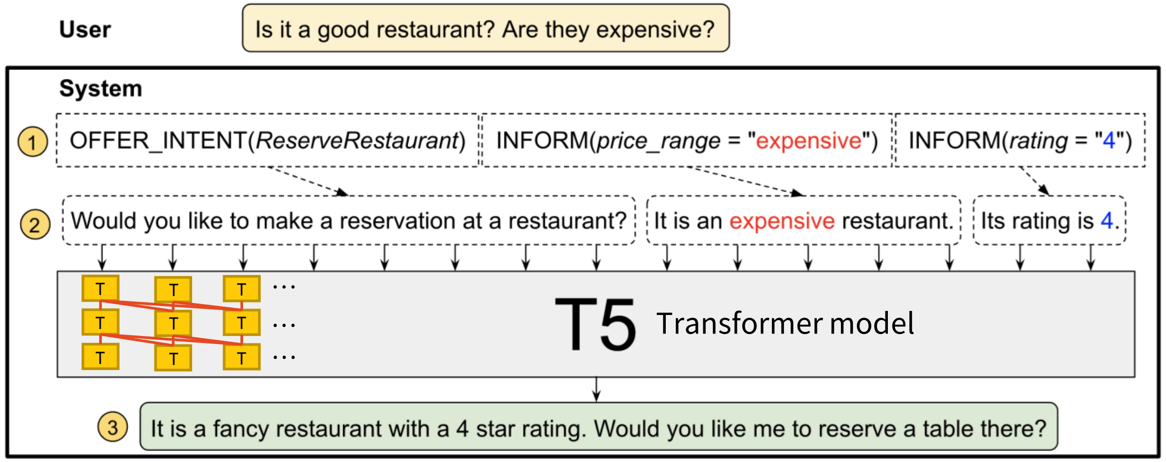
- Grammar-based approaches
  - grammar/semantic structures instead of templates
  - NLG **realizes** them (=converts to linear text) by applying syntactic transformation rules
- Statistical approaches
  - most prominent: **neural networks (RNN/Transformer)**
  - generating word-by-word
  - input: encoded semantics + previous words



(Kozlowski, 2002)
http://www.eecis.udel.edu/~mccoy/publications/2002/Kozlowski-ACL-Stu.ps



(White, 2011)
https://www.aclweb.org/anthology/W11-2827/


User

Is it a good restaurant? Are they expensive?

System

1 OFFER_INTENT(*ReserveRestaurant*) | INFORM(*price_range* = "expensive") | INFORM(*rating* = "4")

2 Would you like to make a reservation at a restaurant? | It is an expensive restaurant. | Its rating is 4.

3 It is a fancy restaurant with a 4 star rating. Would you like me to reserve a table there?

(Kale & Rastogi, 2020)
https://aclanthology.org/2020.emnlp-main.527/

Text-to-speech (TTS) / Speech Synthesis

- Generate a speech signal corresponding to NLG output
  - text → sequence of **phonemes**
    - minimal distinguishing units of sound (e.g. [p], [t], [ŋ] “ng”, [ə] “eh/uh”, [iː] “ee”)
  - + pitch/intonation, speed, pauses, volume/accents
- Standard pipeline:
  - text normalization
    - abbreviations
    - punctuation
    - numbers, dates, times
  - pronunciation analysis (**grapheme → phoneme conversion**)
  - intonation/stress generation
  - waveform synthesis

take bus number 3 at 5:04am
take bus number three at five o four a m
t eɪ k b ʌ s n ʌ m b ə θ r iː æ t f aɪ v ə ʊ f ɔː r eɪ ɛm

Speech Synthesis

- TTS Methods:
  - **Formant**-based: phoneme-specific frequencies http://www.festvox.org/history/klatt.html (example 35)
    - oldest, not very natural, but works on limited hardware
  - **Concatenative** https://en.wikipedia.org/wiki/MBROLA
    - record a single person, cut into phoneme transitions (diphones), glue them together
  - **Hidden Markov Models** http://homepages.inf.ed.ac.uk/jyamagis/
    - phonemes in context modelled as hidden Markov models
    - Model parameters estimated from data (machine learning)
  - **Neural networks** https://google.github.io/tacotron/
    - HMMs swapped for a recurrent neural network
    - or fully neural architectures: adapted Transformers + CNNs (predict spectrum/wave in time)
    - can go directly from text, no need for phoneme conversion

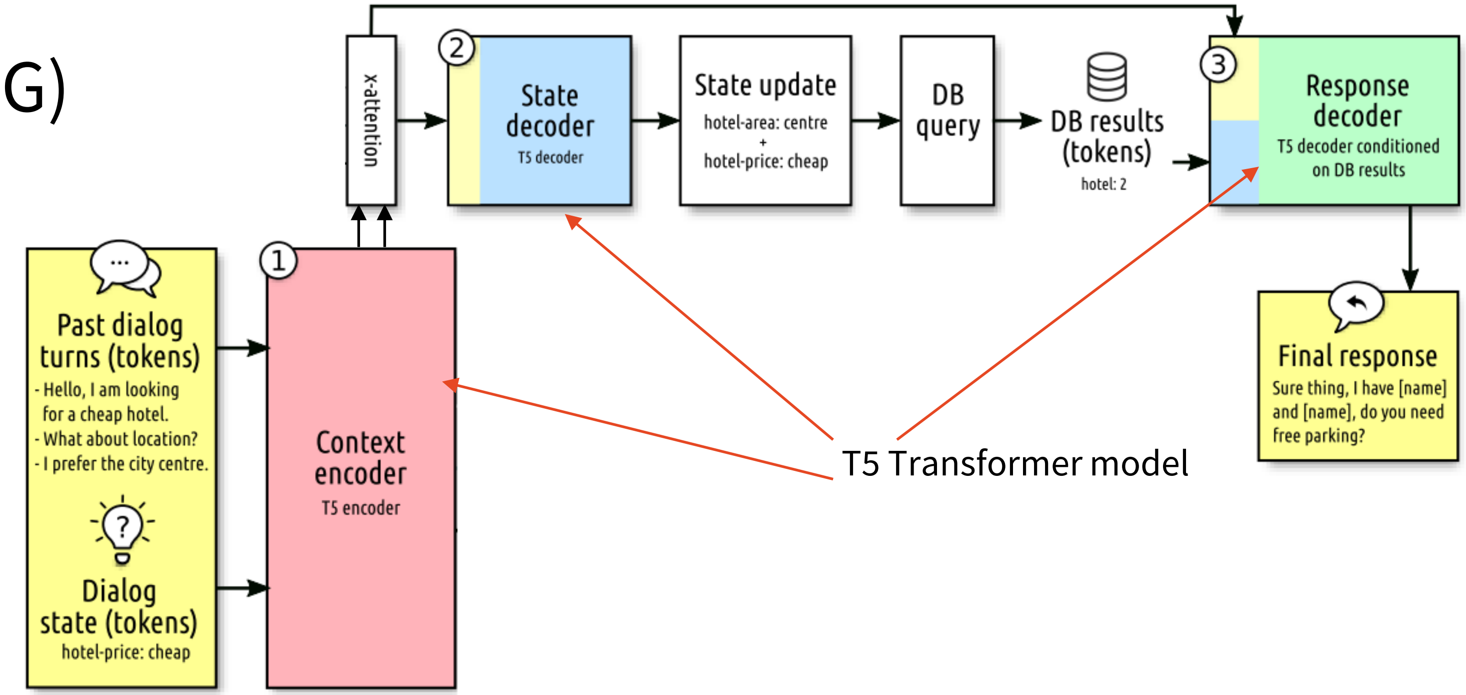
Organizing the Components

- Basic: pipeline
  - ASR → NLU → DM → NLG → TTS
  - components oblivious of each other
- Interconnected
  - read/write changes to dialogue state
  - more reactive (e.g. incremental processing), but more complex
- Joining the modules (experimental)
  - ASR + NLU
  - NLU + state tracking
  - NLU & DM & NLG

End-to-End Systems

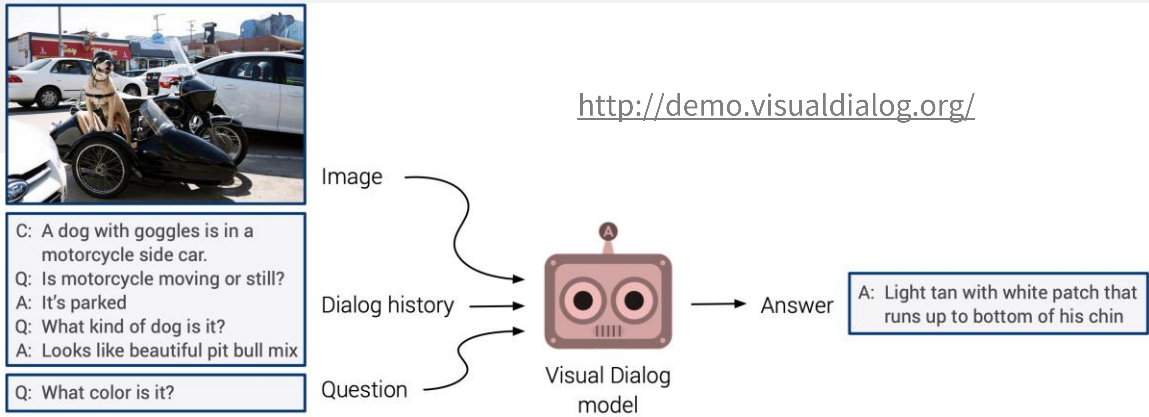
- typical for non-task-oriented
  - single network, trained e.g. on movie subtitles
- task oriented – experimental
- the whole system (NLU/DM/NLG) is a single neural network
  - joint training (“end-to-end”)
  - more elegant
  - potentially easily retrainable
- still needs annotation
  - same as individual modules
  - can be less predictable
- database stays external (predict DB query first, then response)

(Nekvinda & Dušek, 2022)
https://aclanthology.org/2022.sigdial-1.29



Multimodal/Visual Dialogue

- adding other modalities
- specific components
  - parallel to NLU
    - vision – image classification networks
    - face identification/tracking
  - parallel to NLG
    - mimics/gesture generation
    - gaze
    - image retrieval/generation
  - vision – typically CNN
    - often off-the-shelf stuff
  - specific classifiers/rules
- or end-to-end neural
  - mostly combining multiple NNs



C: A dog with goggles is in a motorcycle side car.
Q: Is motorcycle moving or still?
A: It's parked
Q: What kind of dog is it?
A: Looks like beautiful pit bull mix

Q: What color is it?

Image

Dialog history

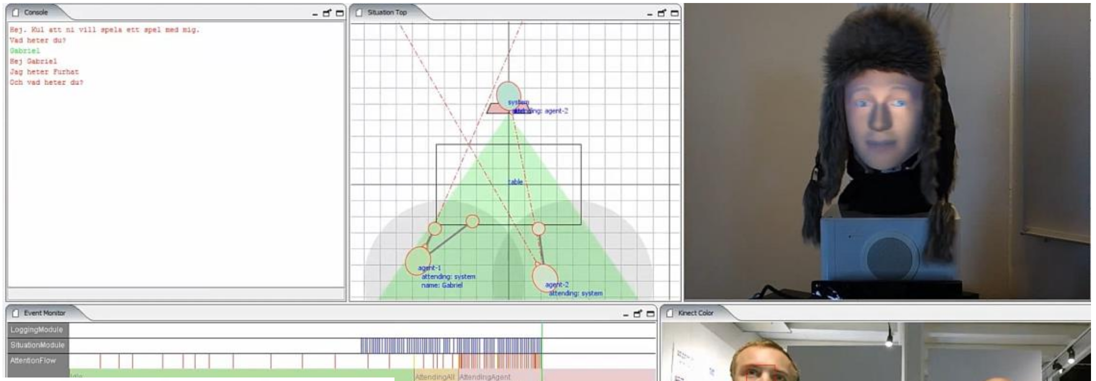
Question

Visual Dialog model

Answer

A: Light tan with white patch that runs up to bottom of his chin

http://demo.visualdialog.org/

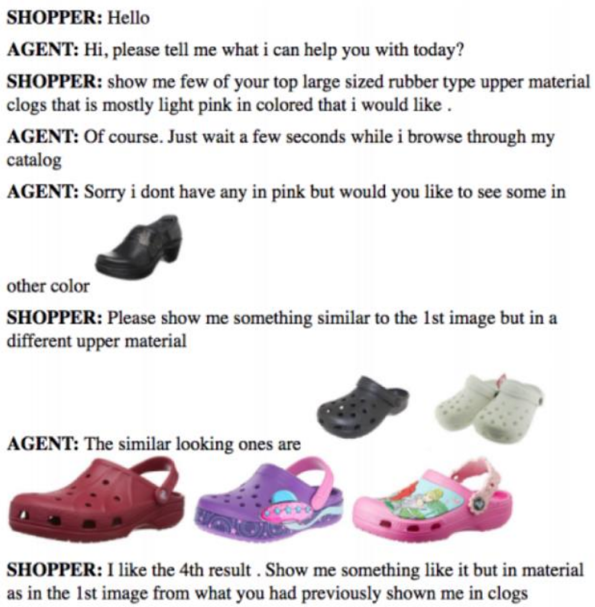


```
Hej. Kul att ni vill spela ett spel med mig.
Vad heter du?
Gabriel
Hej Gabriel
Jag heter Furhat
Och vad heter du?
```

And what is your name?
My name is Raveesh

https://youtu.be/5fhjuGu3d0I?t=137

https://vimeo.com/248025147



SHOPPER: Hello

AGENT: Hi, please tell me what i can help you with today?

SHOPPER: show me few of your top large sized rubber type upper material clogs that is mostly light pink in colored that i would like .

AGENT: Of course. Just wait a few seconds while i browse through my catalog

AGENT: Sorry i dont have any in pink but would you like to see some in other color

SHOPPER: Please show me something similar to the 1st image but in a different upper material

AGENT: The similar looking ones are

SHOPPER: I like the 4th result . Show me something like it but in material as in the 1st image from what you had previously shown me in clogs

(Agarwal et al., 2018)
http://aclweb.org/anthology/W18-6514

Further Research Areas

- Multi/open domains
  - reusability, domain transfer
  - training from little (or no) data
  - joining task-oriented and chitchat dialogue
- Context dependency
  - understand/reply in context (grounding, speaker adaptation)
- Incrementality
  - don’t wait for the whole sentence to start processing
  - allow more natural flow than regular turns
- Evaluation
  - checking if the system does well is actually non-trivial

Summary

- We’re far from AI sci-fi dreams, but it still works a bit
  - dialogue is hard
- DSs have many forms & usage areas
  - **task-oriented vs. non-task-oriented**
  - **closed vs. open domain**
  - system vs. user initiative
- Main components: **ASR → NLU → DM → NLG → TTS**
  - implementation varies
  - sometimes things are joined together
- It’s an active and interesting research topic!
- Next week: evaluation methods

Thanks

Next Thu:
lecture 10:40
1st lab 12:20

Contact us:

https://ufaldsg.slack.com/
odusek@ufal.mff.cuni.cz
Zoom/Slack/Troja (by agreement)

Get the slides here:

http://ufal.cz/npfl099

References/Inspiration/Further:

Apart from materials referred directly, these slides are based on slides and syllabi by:

- Pierre Lison (Oslo University): https://www.uio.no/studier/emner/matnat/ifi/INF5820/h14/timeplan/index.html
- Oliver Lemon & Verena Rieser (Heriot-Watt University): https://sites.google.com/site/olemon/conversational-agents
- Filip Jurčíček (Charles University): https://ufal.mff.cuni.cz/~jurcicek/NPFL099-SDS-2014LS/
- Milica Gašić (University of Cambridge): http://mi.eng.cam.ac.uk/~mg436/teaching.html
- David DeVault & David Traum (Uni. of Southern California): http://projects.ict.usc.edu/nld/cs599s13/schedule.php
- Luděk Bártek (Masaryk University Brno): https://is.muni.cz/el/1433/jaro2018/PA156/um/
- Gina-Anne Levow (University of Washington): https://courses.washington.edu/ling575/