NPFL099 Statistical Dialogue Systems
1. Introduction

https://ufal.cz/npfl099

Ondřej Dušek, Simone Balloccu, Mateusz Lango, Ondřej Plátek, Patrícia Schmidtová

3. 10. 2023

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

Organizational: 2/1 Z+ZK – 4 Credits

- Lecture (Tue 10:40) + labs (Tue 9:50, bi-weekly, starts next week)
  - **we'll start with the lecture always**. S10 + Zoom + https://ufaldsg.slack.com/
  - Lecture: theory
  - Labs: practical projects: training 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 nets)
  - 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
- worked mostly on language generation
- also chatbots (HWU Alexa Prize team)

Simone Balloccu

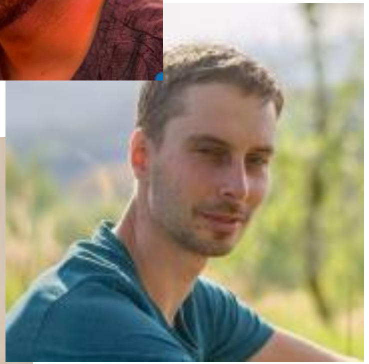
- post-doc, PhD at Uni Aberdeen, health NLG & LLMs

Mateusz Lango

- post-doc, PhD at Uni Poznań, data imbalance & accurate NLG

Ondřej Plátek

- PhD 3rd year, dialogue & NLG & TTS evaluation



Patrícia Schmidtová

- PhD 2nd year, creative NLG & accurate 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

Primary:

- Jurafsky & Martin: Speech & Language processing. 3rd ed. draft 2023, mainly Chap. 15 (https://web.stanford.edu/~jurafsky/slp3/) – basic, brief intro
- McTear: Conversational AI. Morgan & Claypool 2021. (https://doi.org/10.2200/S01060ED1V01Y202010HLT048) – bit more advanced, relatively new
- 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**

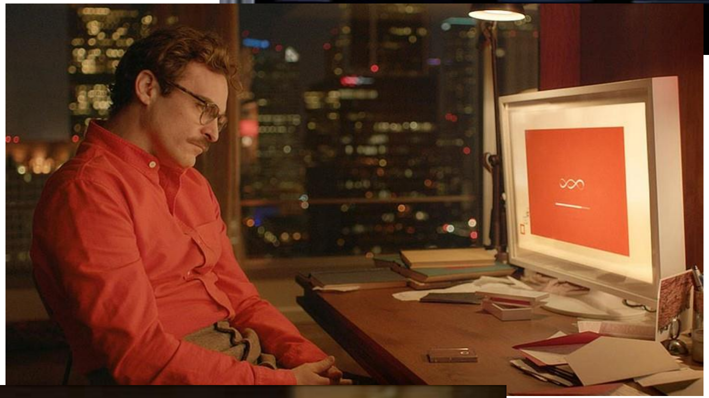
- Wide definition – covers lots of different cases
  - "smart speakers" / phone OS assistants
  - phone hotline systems (even tone-dial ones)
  - in-car systems
  - assistive technologies: therapy, elderly care, companions
  - entertainment: video game NPCs, chatbots

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 Siri/Alexa/Google
- 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 – probably for long
  - main bottleneck: understanding
    (not speech comprehension, meaning!)
  - … more like the Red Dwarf talkie toaster

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



Example – Smart Speakers

- Google, Amazon, Apple & others, Mycroft: open-source
- Really good microphones
  - and not much else – they work online only
- Huge knowledge bases
  - Google: 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 limitations)
- Can keep some context
- Conversational capabilities limited

Google Nest

Amazon Echo

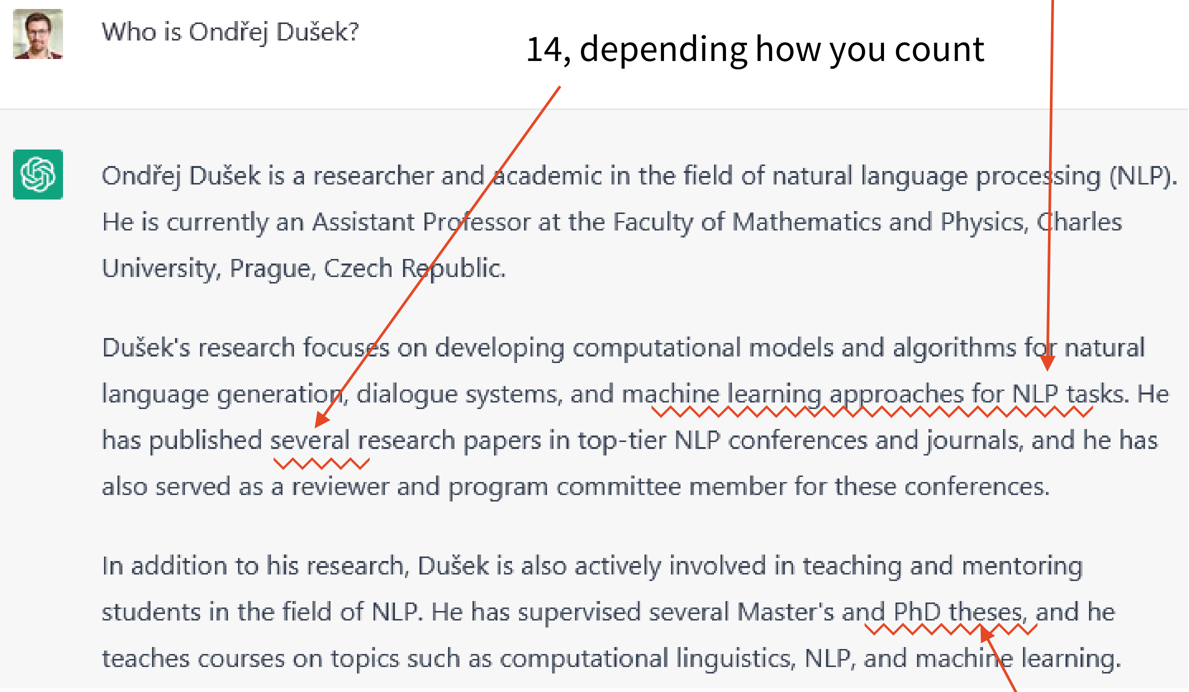
Apple HomePod

Example – 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

no other tasks than generation & dialogue

14, depending how you count



I only teach dialogue systems

no PhD graduate yet

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
  - 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

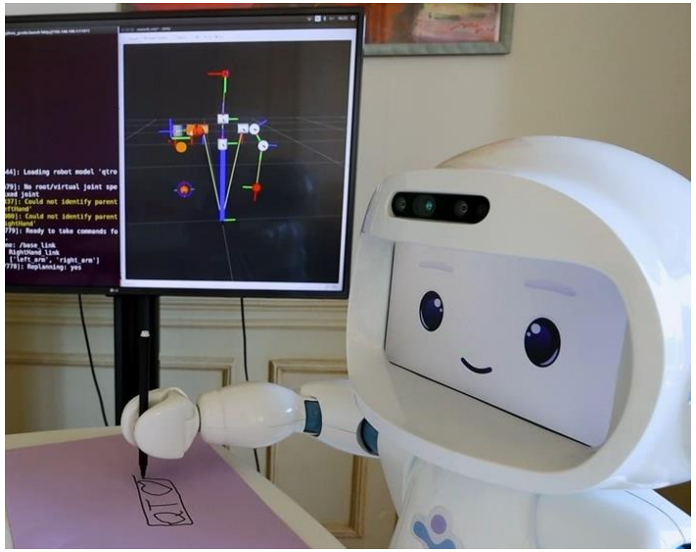
- traditional: **single/closed-domain**
  - one well-defined area, small set of specific tasks
  - e.g. banking system on a specific phone number
- **multi-domain**
  - basically joining several single-domain systems (Google/Alexa/Siri)
- **open-domain**
  - “responds to anything” – the goal, but now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

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

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



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

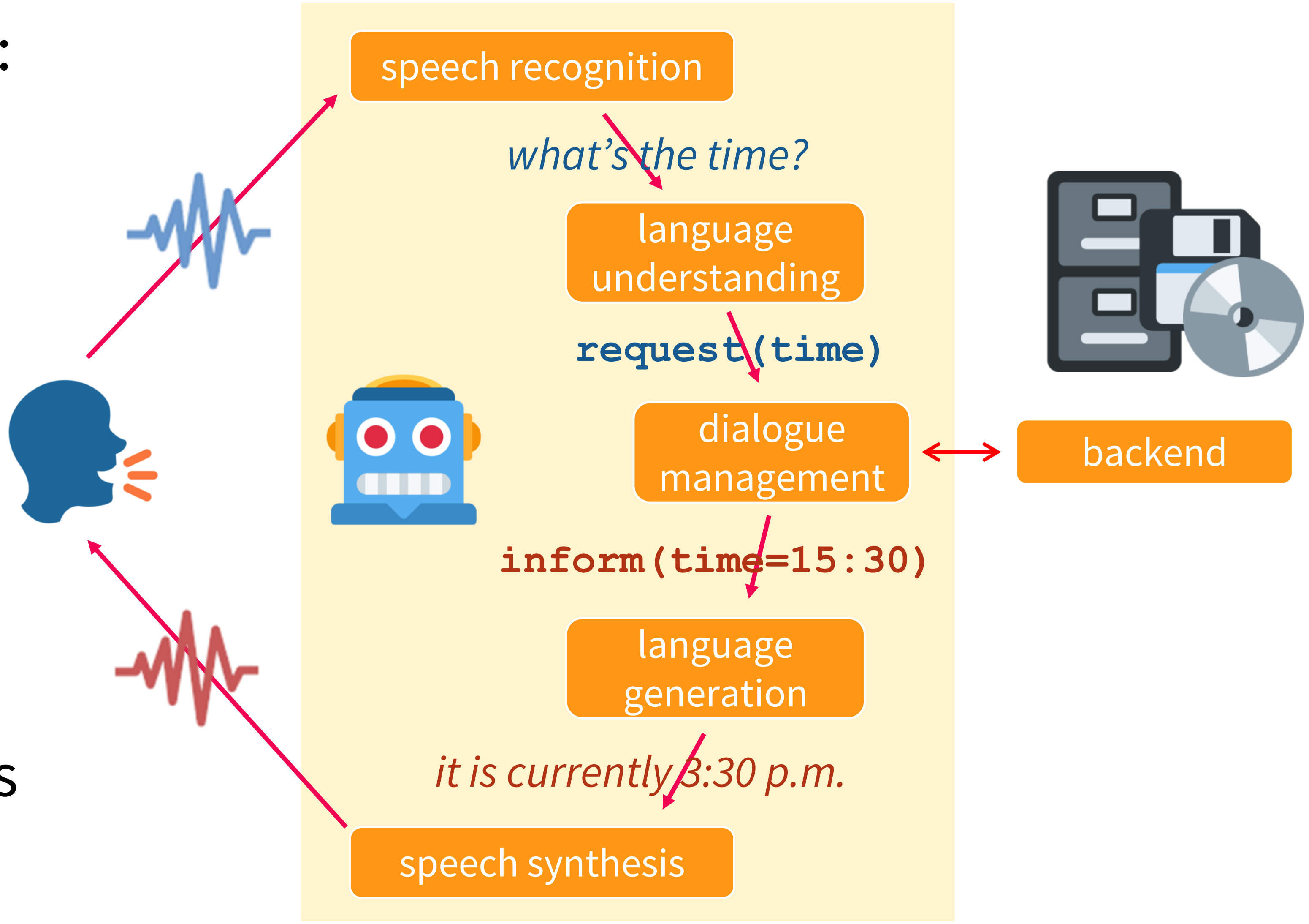
Dialogue Initiative

- **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

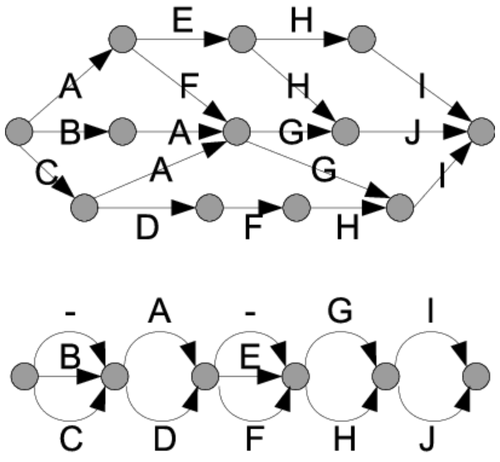
- traditional main DS pipeline:
  - voice → text
  - text → meaning
  - meaning → reaction
  - reaction → text
  - text → voice
- access to backend
  - for anything better than basic chit-chat
- multimodal systems need additional components



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)…

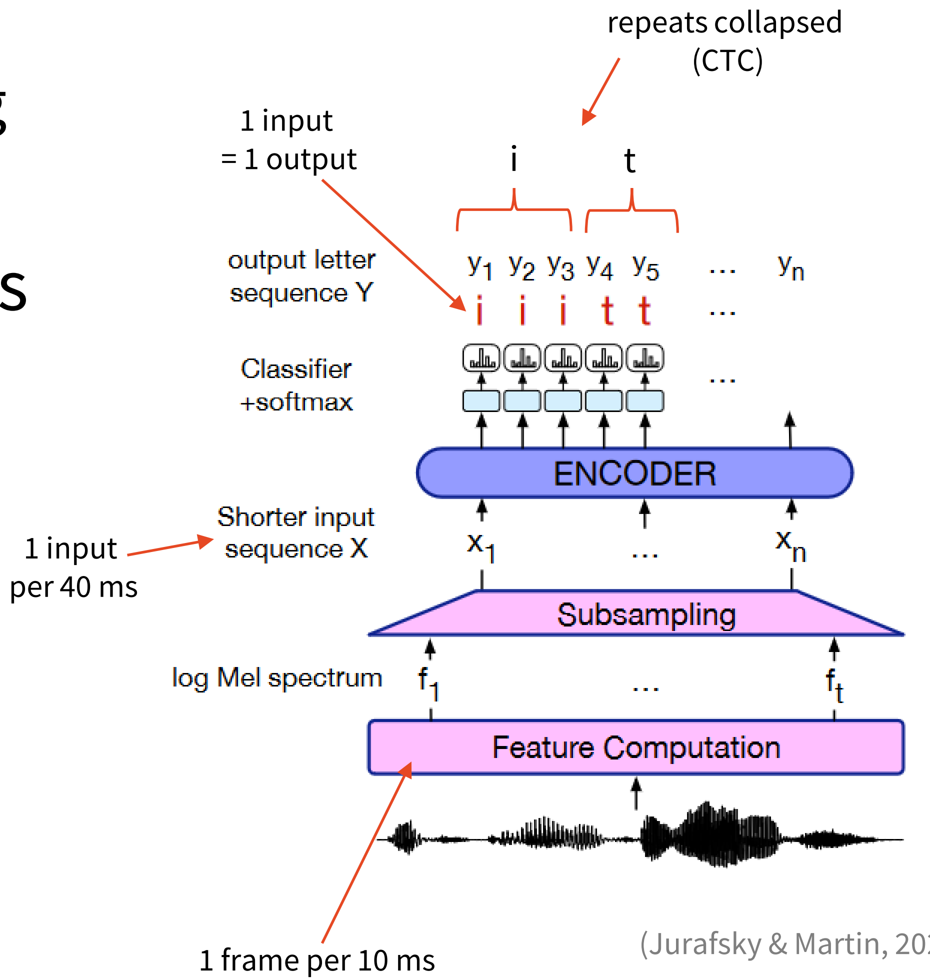
0.8 I'm looking for a restaurant
0.4 uhm looking for a restaurant
0.2 looking for a rest tour rant



(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 Friday</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

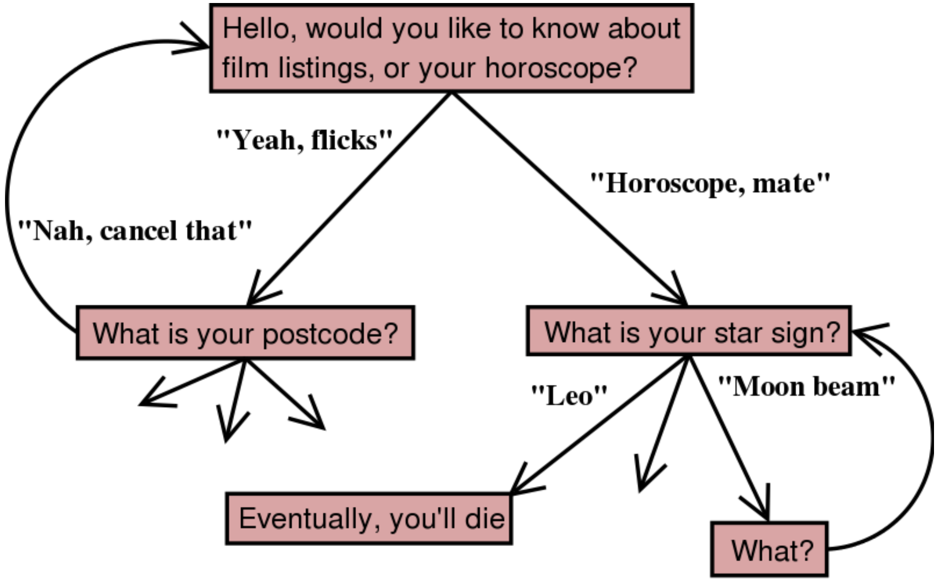
price: 0.8 cheap
0.1 moderate
0.1 <null>
food: 0.7 Chinese
0.3 Vietnamese
area: 0.5 riverside
0.3 <null>
0.2 city center

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)
  - recurrent neural networks

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)

+

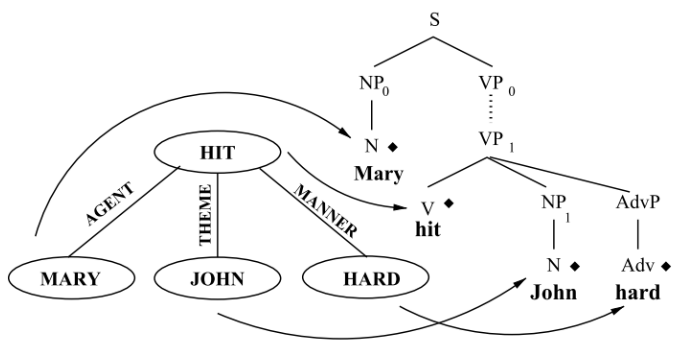
<name> is a **<price>**-ly priced restaurant serving **<food>** food

=

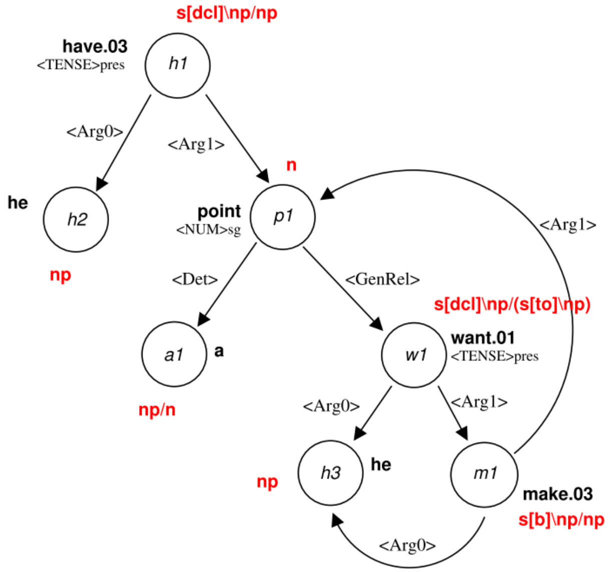
Golden Dragon is a cheaply priced restaurant serving Chinese food.

Natural Language Generation

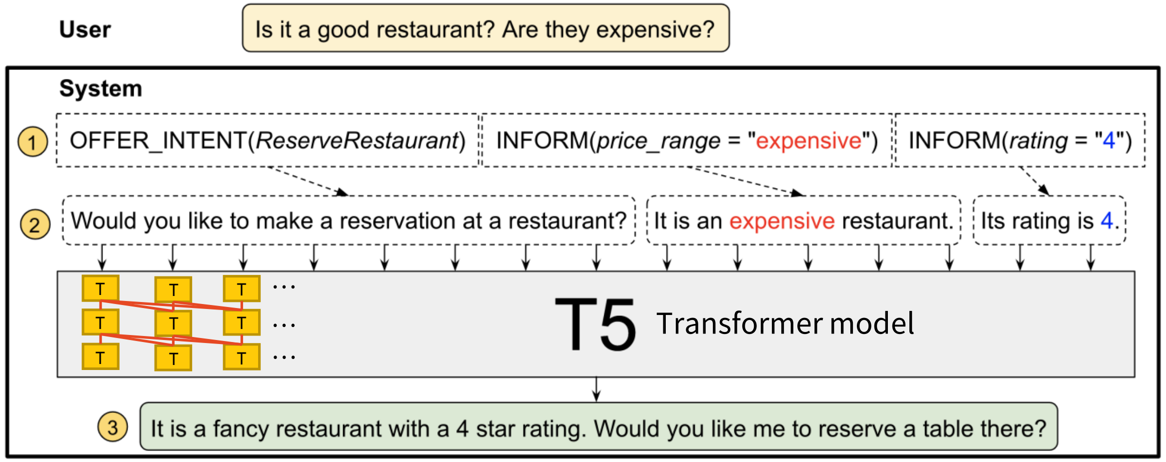
- Grammar-based approaches
  - grammar/semantic structures instead of templates
  - NLG **realizes** them (=converts to linear text) by applying syntactic transformation rules
- Statistical approaches
  - most prominent: **neural networks (RNN/Transformer)**
  - generating word-by-word
  - input: encoded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



(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

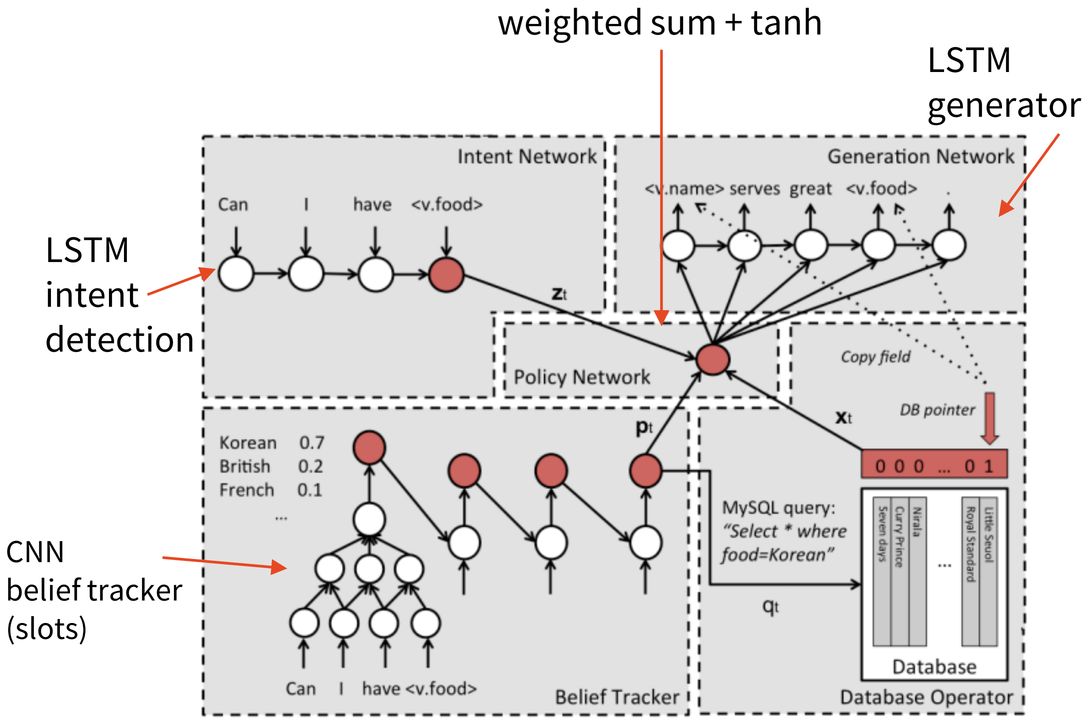
- TTS Methods:
  - **Formant**-based: phoneme-specific frequencies http://www.festvox.org/history/klatt.html (example 35)
    - oldest, not very natural, but works on limited hardware
  - **Concatenative** https://en.wikipedia.org/wiki/MBROLA
    - record a single person, cut into phoneme transitions (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
    - also 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
- typically still needs annotation
  - same as individual modules
  - can be less predictable
- connecting the database is a problem

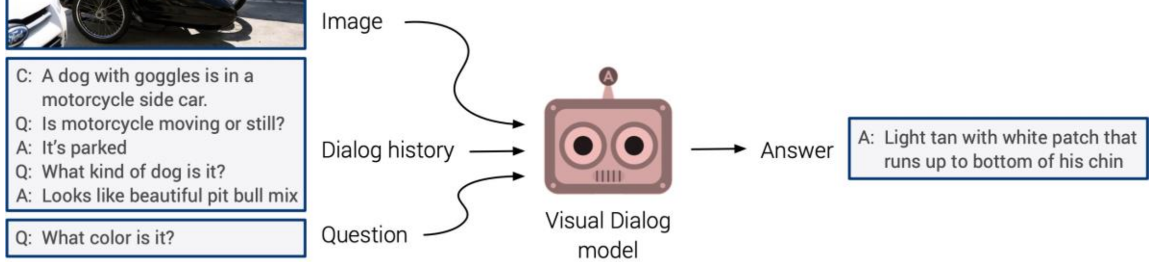


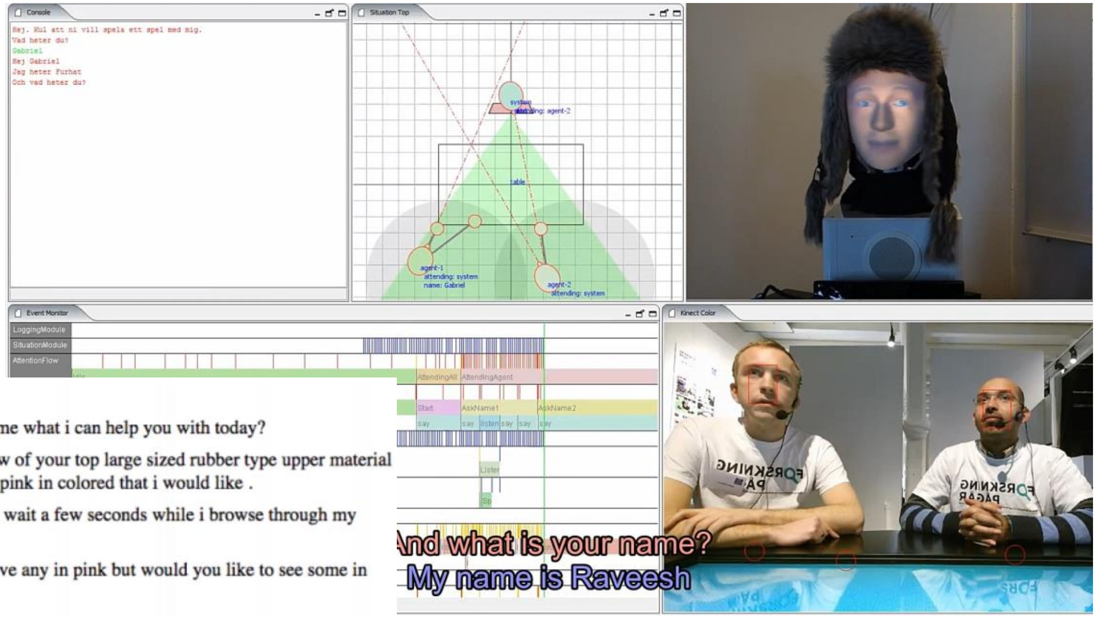
(Wen et al., 2017)
https://www.aclweb.org/anthology/E17-1042/

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
  - vision – typically CNN
    - often off-the-shelf stuff
  - specific classifiers/rules

http://demo.visualdialog.org/





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

https://vimeo.com/248025147

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

Further Research Areas

- Multi/open domains
  - reusability, domain transfer
  - training from little data
  - pretraining with “generic” data
  - connecting task-oriented systems and chatbots
- Context dependency
  - understand/reply in context (grounding, speaker alignment)
- Incrementality
  - don’t wait for the whole sentence to start processing
  - not much stuff going on at the moment, but would help
- 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

Contact us:

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

Next Tue:
lecture 9:50
1st lab 11:30

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/