Dialogue systems

NPFL123 Dialogové systémy

1. Introduction

Ondřej Dušek & Vojtěch Hudeček & Jan Cuřín

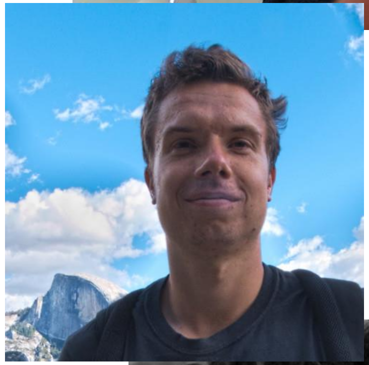
http://ufal.cz/npfl123

18. 2. 2020

Organizational
NPFL123 – 2/2 Z+ZK – 5 Credits

- Lecture (Tue 9am S1) + labs (Tue 10:40am SU1)
- Lecture: intro, theory
- Labs: practical examples, hands-on exercises
- To pass the course:
  - Written exam – 10 freeform questions, covered by the lectures
  - Lab exercises – weekly small homework
    - implementing your system for a domain
- Slides, news etc. at ufal.cz/npfl123

About Us



Ondřej Dušek: lectures, course guarantor

- PhD at ÚFAL, 2 years at Heriot-Watt Uni Edinburgh, now back
- worked mostly on language generation
- also chatbots (HWU Alexa Prize team)

Vojtěch Hudeček: some labs, a bit of lectures

- PhD student at ÚFAL (3rd year)
- working on dialogue management & language understanding
- internships at Uber AI & UC Davis on dialogue systems

Jan Cuřín: speech recognition, dialog authoring tools

- IBM – Manager at IBM Prague AI R&D Lab – IBM Watson Assistant Service
- PhD at ÚFAL in 2006 (machine translation)
- dialog systems and applications, speech recognition, machine translation

Course Syllabus (1)

1. Introduction (today)
2. What happens in a dialogue?
3. Dialogue system data & how to evaluate
4. Assistants (Alexa, Siri, Google etc.), question answering
5. Dialogue authoring/tooling systems
6. Language understanding (NLU)
7. NLU + Dialogue state tracking
8. Dialogue management (DM)
9. DM + Language generation

Course Syllabus (2)

10. Speech recognition
11. Speech synthesis
12. Chatbots

Recommended Reading

- There's nothing ideal (active research topic!)

Primary (brief):

Jurafsky & Martin: Speech & Language processing. 3rd ed. draft 2019, Chap. 26
(https://web.stanford.edu/~jurafsky/slp3/)

Other (see also website):

- Gao et al.: Neural Approaches to Conversational AI, 2019 (http://arxiv.org/abs/1809.08267)
- McTear et al.: The Conversational Interface: Talking to Smart Devices. Springer 2016.
- Janarthanam: Hands-On Chatbots and Conversational UI Development. Packt 2017.
- Skantze: Error Handling in Spoken Dialogue Systems. PhD Thesis 2007, Chap. 2 (http://www.speech.kth.se/~gabriel/thesis/chapter2.pdf)
- Jokinen & McTear: Spoken dialogue systems. Morgan & Claypool 2010.
- Psutka et al.: Mluvíme s počítačem česky. Academia 2006.
- Lemon & Pietquin: Data-Driven Methods for Adaptive Spoken Dialogue Systems. Springer 2012.
- Rieser & Lemon: Reinforcement learning for adaptive dialogue systems. Springer 2011.

What's a dialogue system?

Definition:

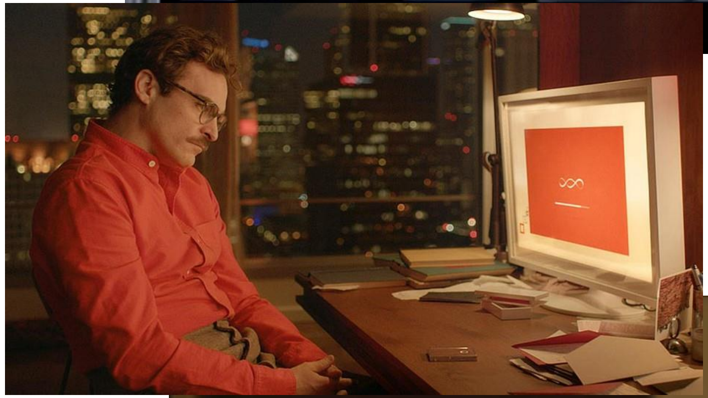
- A *(spoken)* dialogue system is a **computer system designed to interact** with users **in** *(spoken)* **natural language**

- Wide definition – covers lots of different cases

“AI”: sci-fi vs. reality

- 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 Oddyssey –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

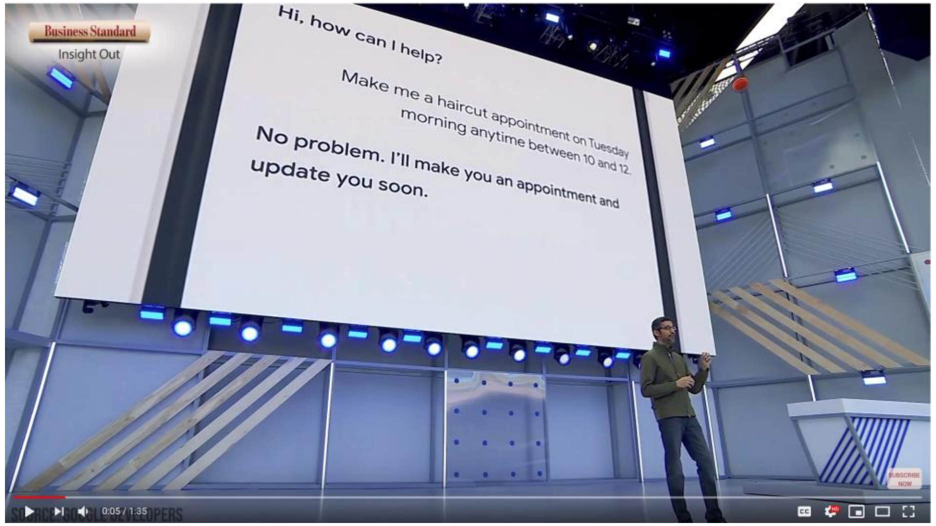
https://youtu.be/LRq_SAuQDec?t=71



Example: Google Assistant

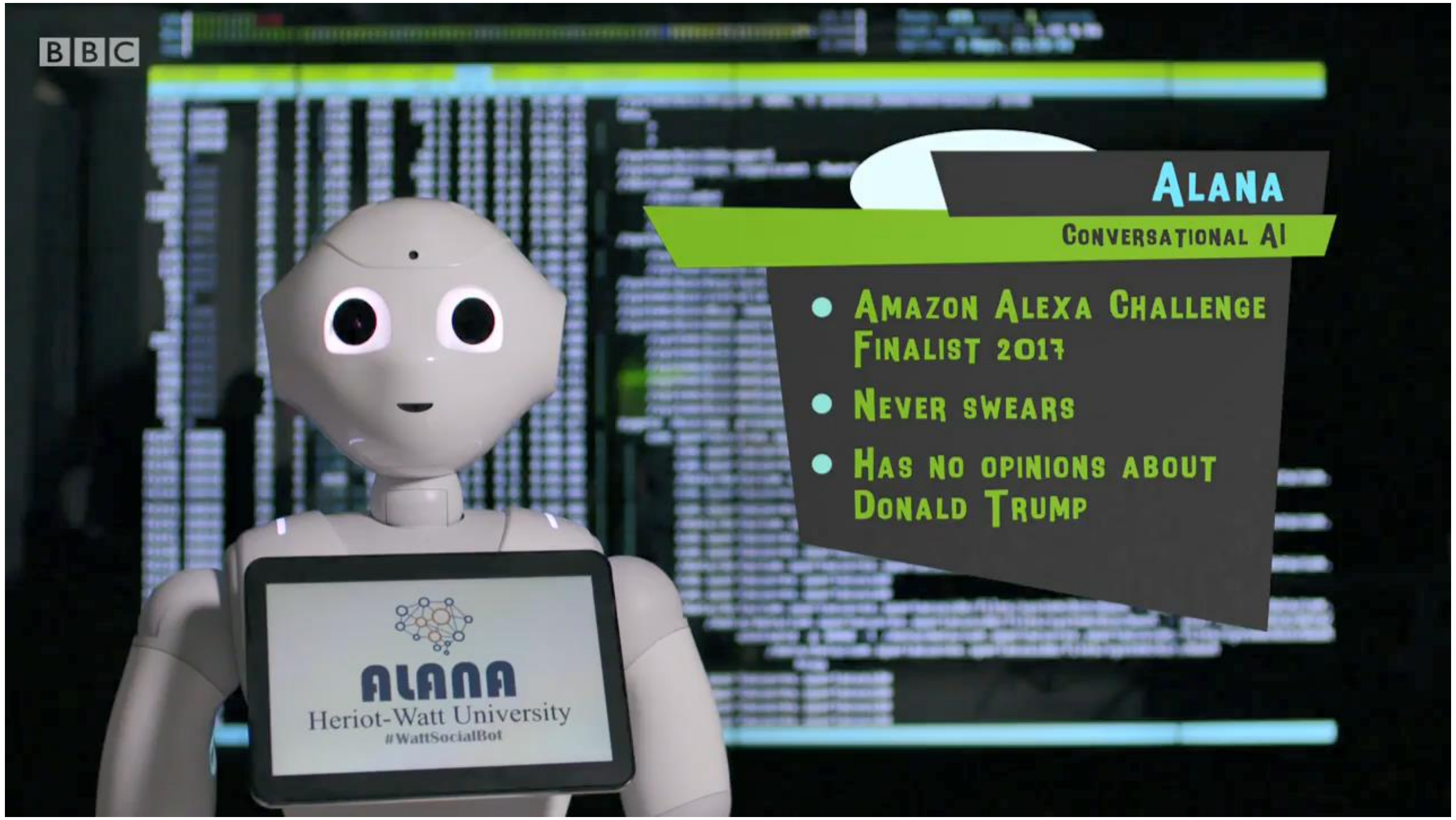
- Handling call for a client (Google IO 2018 demo)
  - very natural speech
  - show's what's possible now **in a limited domain**
  - redirects to a human if it can't handle a shop's request

https://youtu.be/d40jgFZ5hXk



Example: Alana Chatbot (Heriot-Watt University)

- Open-domain



https://www.bbc.co.uk/programmes/b0bhwhw1
(the Alana section starts at 47:38)

Why take interest in Dialogue Systems?

- It’s ***the*** **ultimate natural interface** for computers
- 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!**
- **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
- "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
- **open-domain**
  - “responds to anything” – mostly chitchat

Application Areas

- **phone** (traditional)
  - users call a phone number, a dialogue system picks up
  - even DTMF systems belong here (e.g. banks, phone operators)
  - information – buses (Let's Go), restaurants/tourist info

http://www.speech.cs.cmu.edu/letsgo/example.html

https://youtu.be/lHfLr1MF7DI

- **apps**
  - assistant apps for your phone/computer
  - language learning, navigation (Spacebook)
  - companions (XiaoIce)

https://youtu.be/qQZnwrOyeTE?t=65

- **smart speakers**
  - home automation, assistants (Alexa/Google Home)

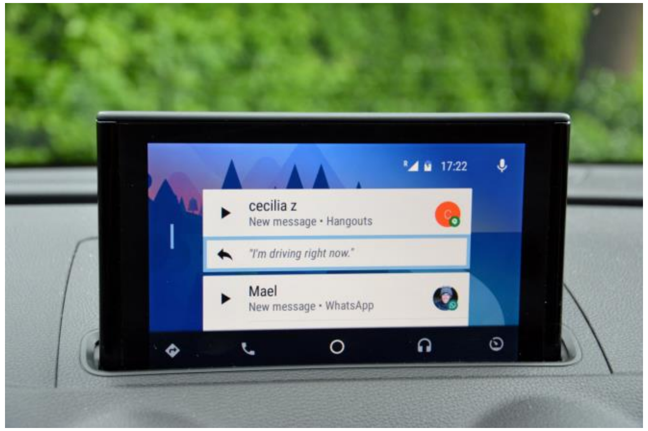
https://www.digitaltrends.com/mobile/5-things-you-need-to-know-about-microsofts-chinese-girlfriend-chatbot-xiaoice/

- **appliances**
  - voice operated TVs
  - other devices connect to smart speakers

Application Areas

- **cars**
  - hands-free car-specific functions
  - Android Auto, Apple CarPlay, vendor-specific solutions
- **web**
  - search assistants (IKEA, research)
  - Facebook Messenger chatbots
  - chit-chat chatbots (Pandorabots)
- **embodied (robots)**
  - information assistants
- **virtual characters**
  - computer games
  - therapy, elderly care

https://www.digitaltrends.com/cars/what-is-android-auto/



https://skylar.speech.cs.cmu.edu/

https://www.ikea.com/ms/cs_CZ/customer_service/contact_us/ask_anna.html

https://robots.nu/en/robot/Pepper

(DeVault et al., 2014) https://dl.acm.org/doi/10.5555/2615731.2617415

Modes of Communication

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

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

(Skantze & Al Moubayed, 2012)
https://doi.org/10.1145/2388676.2388698

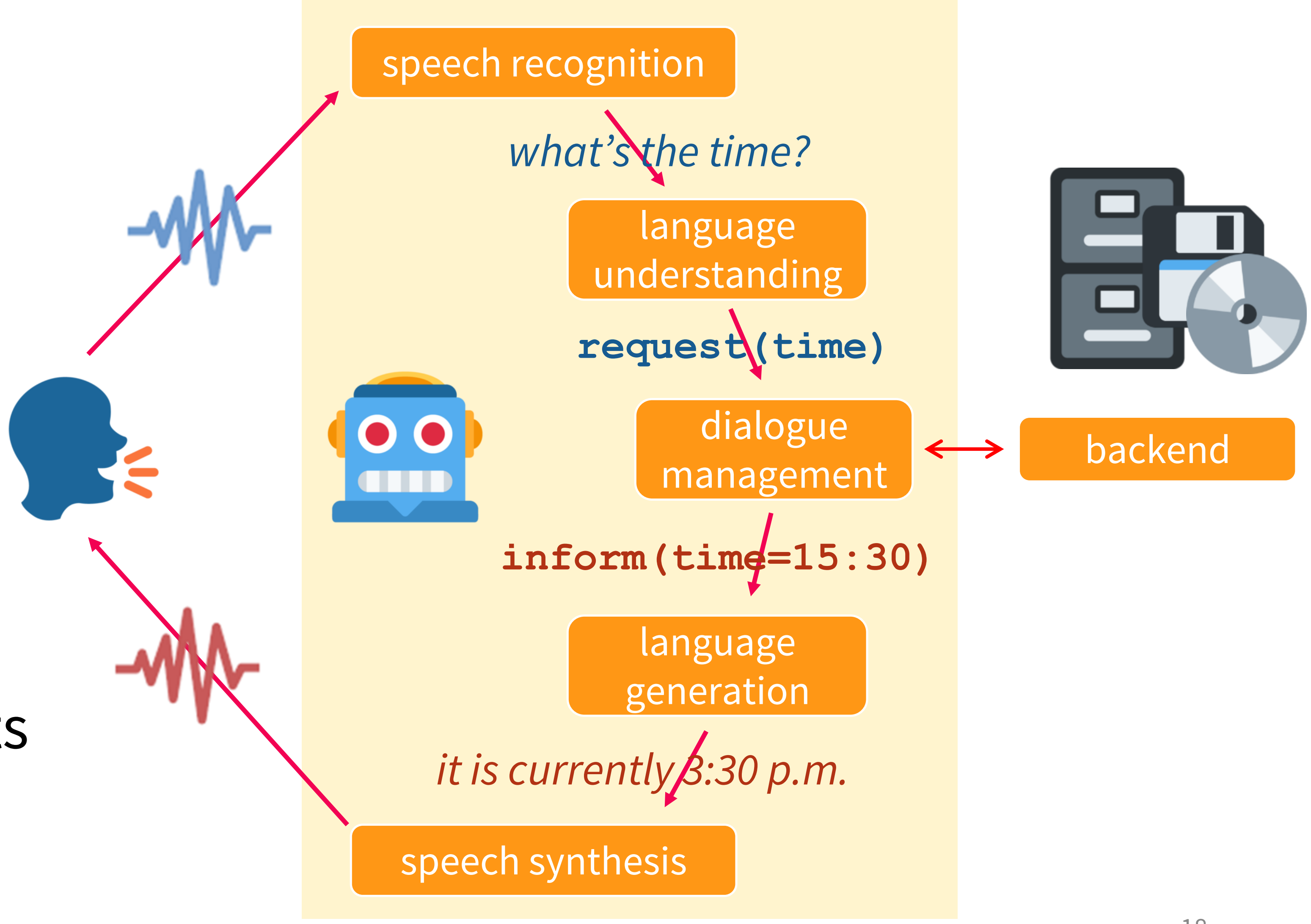
Dialogue Initiative

- **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

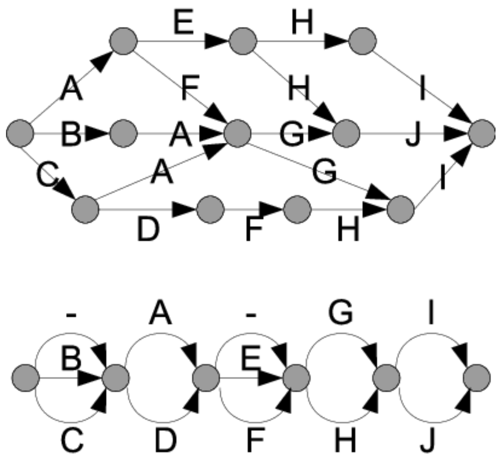
- main loop:
  - voice → text
  - text → meaning
  - meaning → reaction
  - reaction → text
  - text → voice
- access to backend
- multimodal systems: additional components



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, distance, channel (phone)…

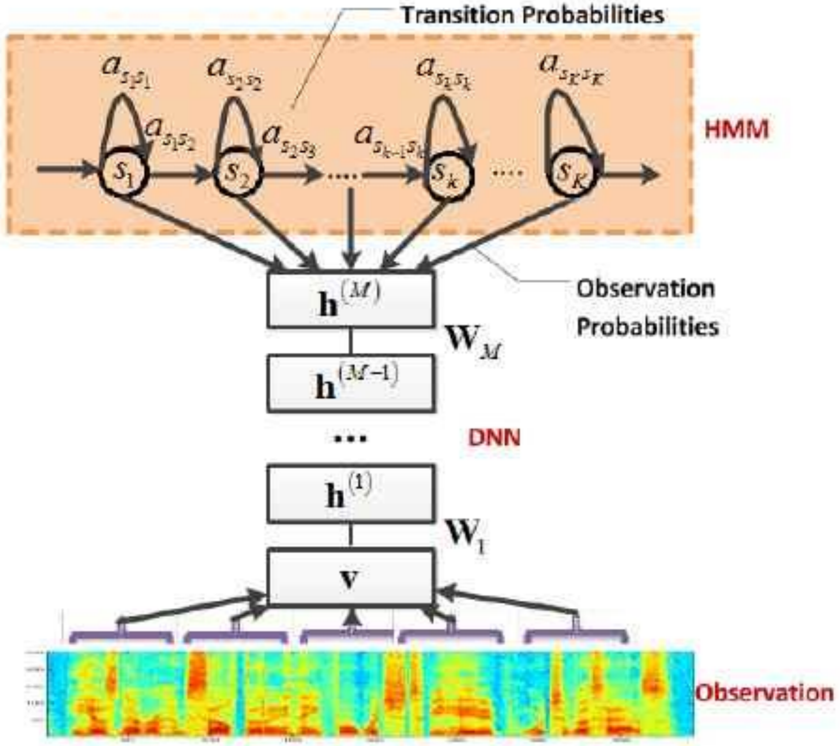
0.8 I'm looking for a restaurant
0.4 uhm looking for a restaurant
0.2 looking for a rest tour rant



Kazemian et al., ICMR 2008
DOI 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 letters
- Limited domain: use of language models
  - some words/phrases more likely than others
  - previous context can be used



https://www.i-programmer.info/images/stories/News/2011/AUG/DNNspeech.jpg

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…*)

    inform(food=Chinese, price=cheap)
    request(address)
  - other, more complex – e.g. syntax trees, predicate logic
- 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 next Friday*

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

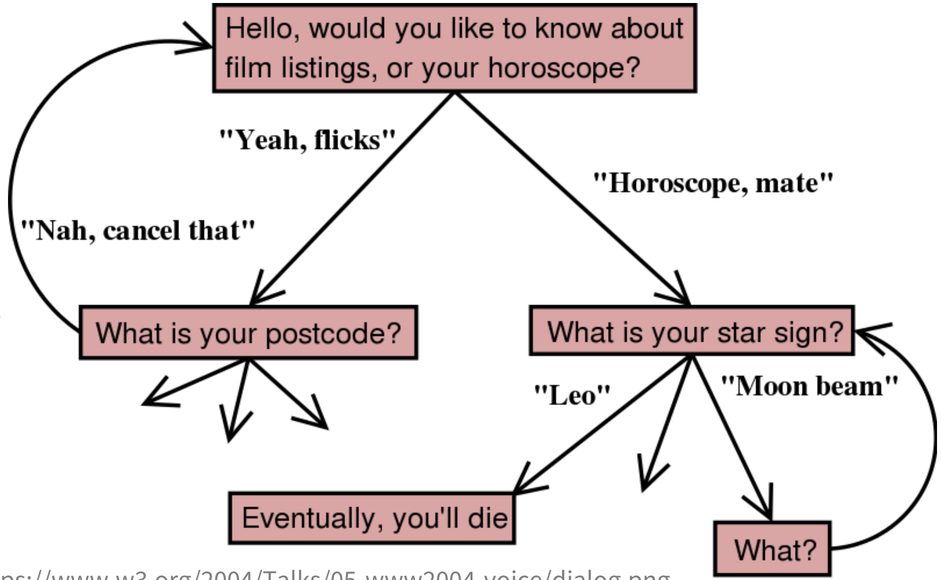
price: 0.8 cheap
0.1 moderate
0.1 <null>
food: 0.7 Chinese
0.3 Vietnamese
area: 0.5 riverside
0.3 <null>
0.2 city center

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)

+

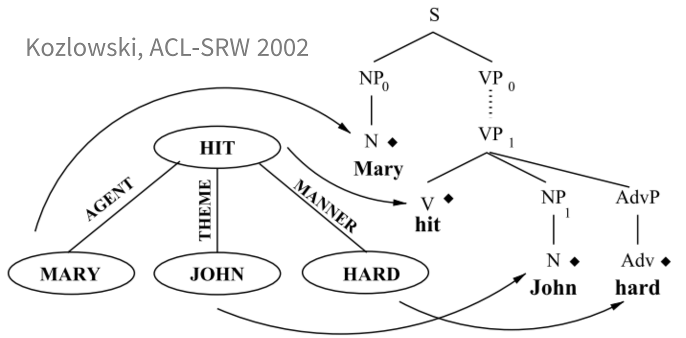
<name> is a **<price>**-ly priced restaurant serving **<food>** food

=

Golden Dragon is a cheaply priced restaurant serving Chinese food.

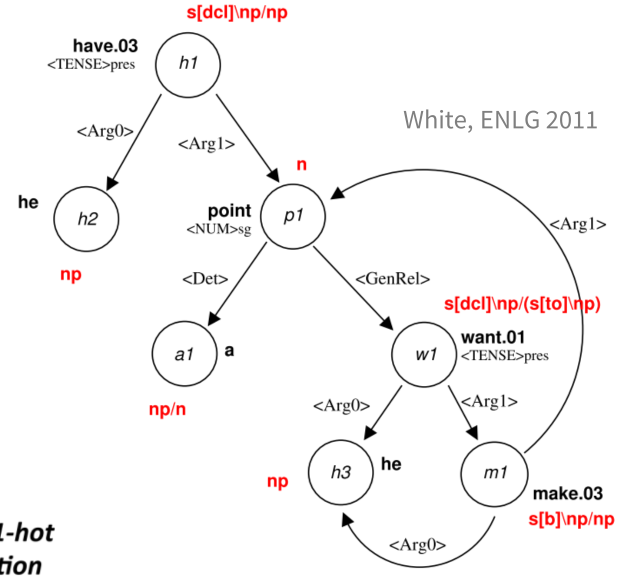
Natural Language Generation

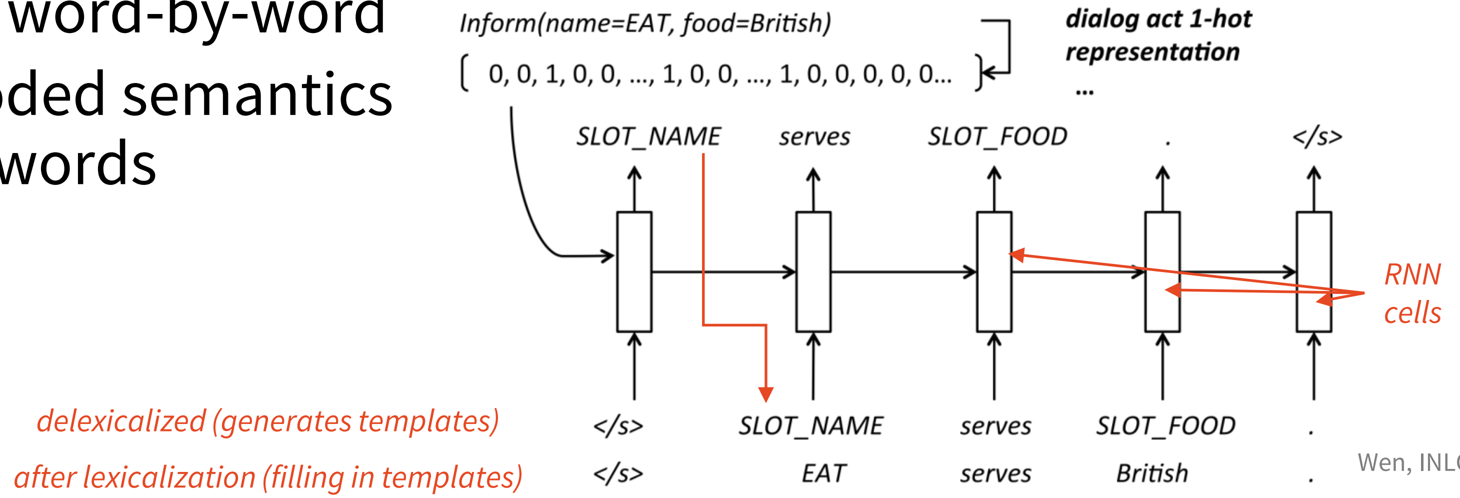
Kozlowski, ACL-SRW 2002



- 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: **recurrent neural networks**
  - generating word-by-word
  - input: encoded semantics + previous words

White, ENLG 2011





Wen, INLG 2016

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”, [i:] “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
teɪk bʌs nʌmbə θriː æt faɪv əʊ fɔːr eɪ ɛm

Speech Synthesis

- TTS Methods:
  - **Formant**-based: phoneme-specific frequencies http://www.festvox.org/history/klatt.html (example 33)
    - 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
    - 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 sometimes)

Dialogue Systems Research

- Multi/open domains
  - reusability, domain transfer
- Joint models (“end-to-end”, all in one neural network)
- Multimodality
  - adding video (input/output)
- Context dependency
  - understand/reply in context (grounding, speaker alignment)
- Incrementality
  - don’t wait for the whole sentence to start processing

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, multi vs. open domain**
  - system vs. user initiative
- Main components: **ASR → NLU → DM → NLG → TTS**
  - implementation varies
- It's an active and interesting research topic!
- Next week: what happens in dialogue and why it's hard

Thanks

Contact us:

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Slack – will send out invites
room 424 (but email me first)

Come to labs!
Today 10:40 SU1

Get the slides here:

http://ufal.cz/npfl123

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/