Statistical Dialogue Systems

NPFL099 Statistické Dialogové systémy

1. Introduction

Ondřej Dušek & Vojtěch Hudeček

http://ufal.cz/npfl099

3. 10. 2019

Organizational
NPFL099 – 2/1 Z+ZK – 5 Credits

- Lecture (Thu 10:40am S1) + labs (Thu 2pm SW1)
  - labs ~bi-weekly, starting today, mostly on Slack
- Lecture: theory
- Labs: practical examples, hands-on exercises
- To pass the course:
  - written exam – freeform questions (covered by the lectures)
  - labs projects – building some experimental systems (by agreement)
- Slides, news etc. at http://ufal.cz/npfl099
- vs. NPFL123: no ASR/TTS, more advanced
  - but also covering the basics, i.e. there's some overlap

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

Course Syllabus (1)

1. Introduction (today) ***
2. Machine learning techniques *
3. Evaluation **
4. Natural language understanding *
5. Dialogue state tracking *
6. Dialogue management *
7. Natural language generation *
8. End-to-end dialogue models

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

Course Syllabus (2)

9. Domain adaptation
10. Chatbots **
11. Multimodal/Visual Dialogue
12. Ethics & Linguistics & Problems **

Recommended Reading

Primary:

- Jurafsky & Martin: Speech & Language processing. 3rd ed. draft 2018, Chap. 24-25 (https://web.stanford.edu/~jurafsky/slp3/) – basic, brief intro
- Gao et al.: Neural Approaches to Conversational AI, 2019 (http://arxiv.org/abs/1809.08267) – more advanced

Other (see also website):

- Janarthanam: Hands-On Chatbots and Conversational UI Development. Packt 2017
- 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.
- Psutka et al.: Mluvíme s počítačem česky. Academia 2006.

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 hype, sci-fi-movie expectations
  - Star Trek – know-it-all (youtu.be/1ZXugicgn6U?t=3)
  - 2001 Space Oddyssey –mutiny (youtu.be/9W5Am-a_xWw)
  - Her – personality (youtu.be/6QRvTv_tpw0?t=27)
- We’re not there yet – probably for long
  - main bottleneck: understanding
    (not speech comprehension, meaning!)
  - problems in breadth as well as depth
  - … more like Red Dwarf talkie toaster
    (youtu.be/LRq_SAuQDec?t=71)

Example – Amazon Alexa/Google Home

- Really good microphones
- 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

https://www.lifehacker.com.au/2018/02/specs-showdown-google-home-vs-amazon-echo-vs-apple-homepod/

https://homealarmreport.com/smart-home/amazon-echo-vs-google-home/

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!**
  - 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
- “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

Johnston et al., ACL 2002

https://www.eitdigital.eu/typo3temp/assets/_processed_/a/6/csm_FURHAT_ea50ba2bf9.jpg

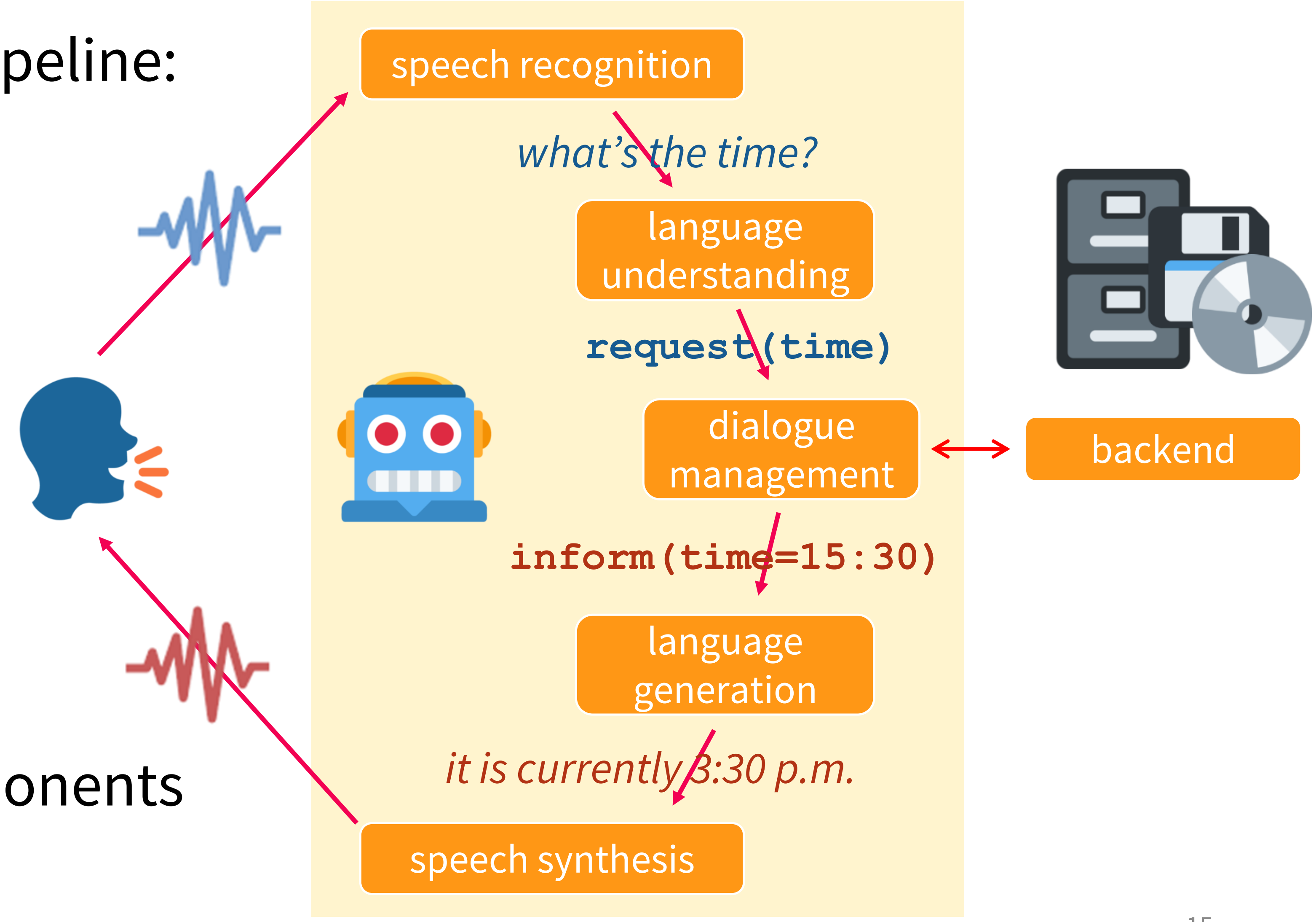
Dialogue Initiative

- **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

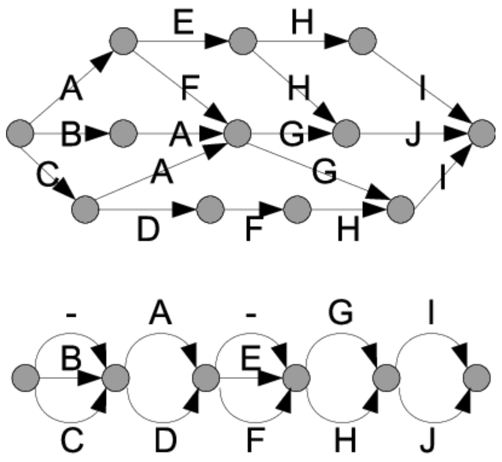
- traditional main DS pipeline:
  - voice → text
  - text → meaning
  - meaning → reaction
  - reaction → text
  - text → voice
- access to backend
  - for anything better than basic chit-chat
- multimodal systems need additional components



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

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

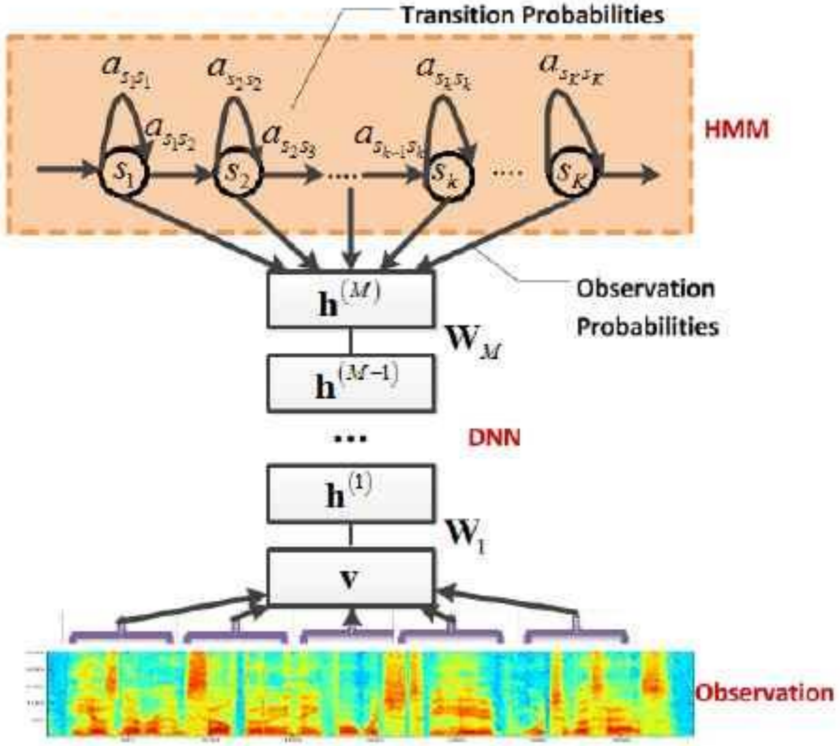


Kazemian et al., ICMR 2008
DOI 10.1145/1460096.1460112

- Very good in ideal conditions
- **Problems:**
  - noise, accents, longer distance, echo cancellation, channel (phone)…

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



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…*)
    - 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

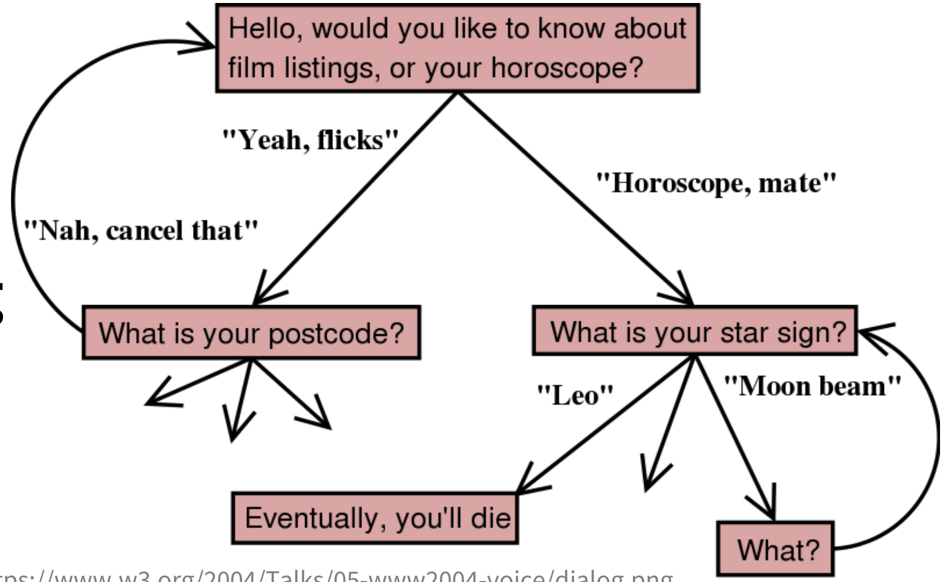
price: 0.8 cheap
0.1 moderate
0.1 <null>
food: 0.7 Chinese
0.3 Vietnamese
area: 0.5 riverside
0.3 <null>
0.2 city center

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)

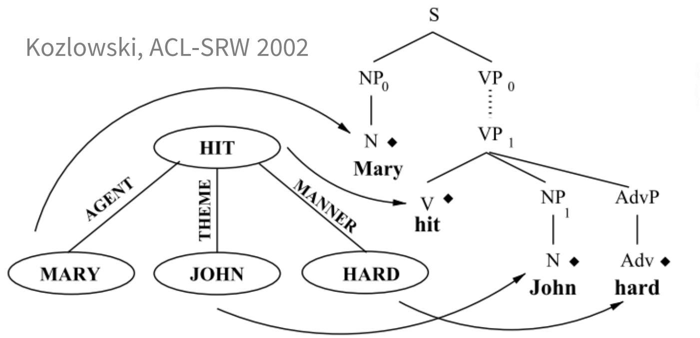
+

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

=

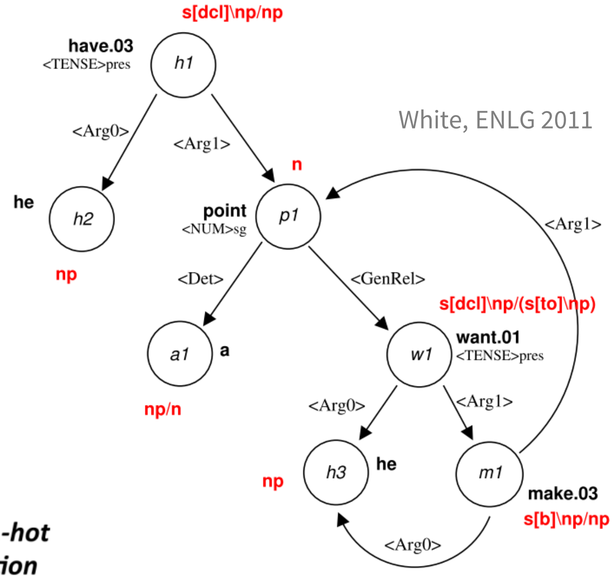
Golden Dragon is a cheaply priced restaurant serving Chinese food.

Natural Language Generation

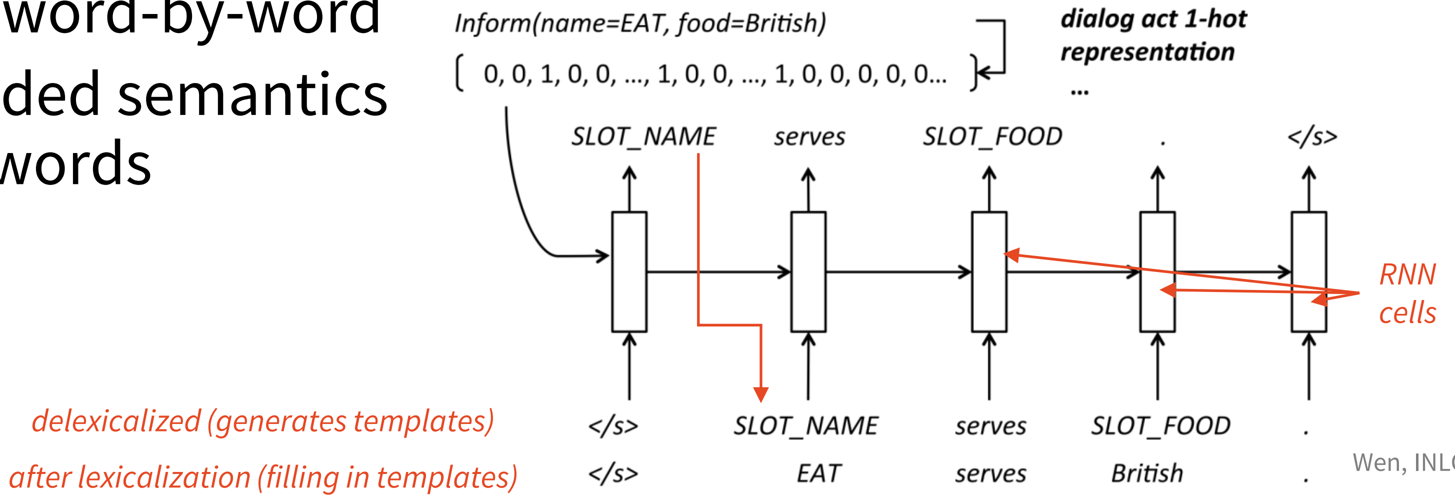


Kozlowski, ACL-SRW 2002

- 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 https://youtu.be/9Avlhm55kvg?t=379
    - 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

End-to-End Systems

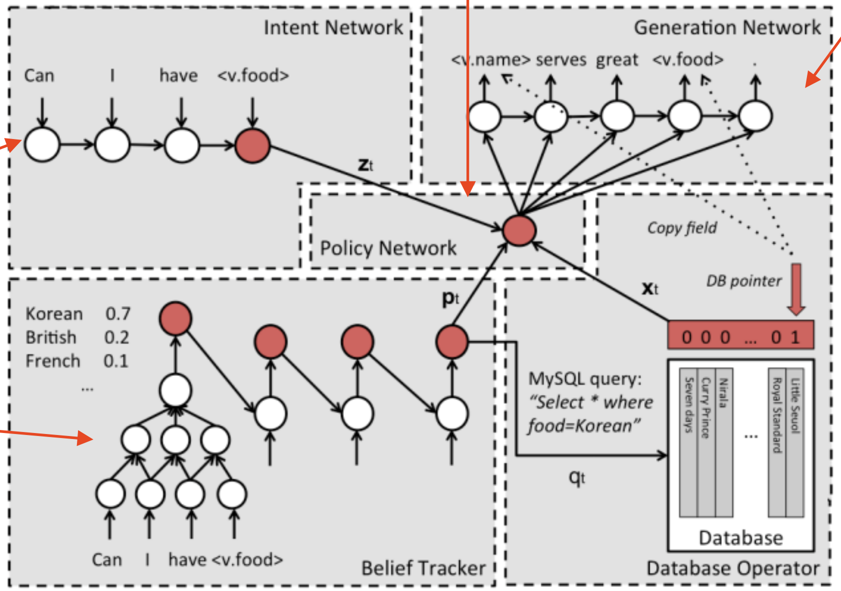
- now typical for non-task-oriented
  - single network, trained e.g. on movie subtitles
- task oriented – very experimental
- the whole system (NLU/DM/NLG) is a single neural network
  - joint training ("end-to-end")
  - more elegant
  - potentially easily retrainable
- typically still needs annotation
  - same as individual modules
  - can be less predictable
- connecting the database is a problem

weighted sum + tanh

LSTM generator

LSTM intent detection

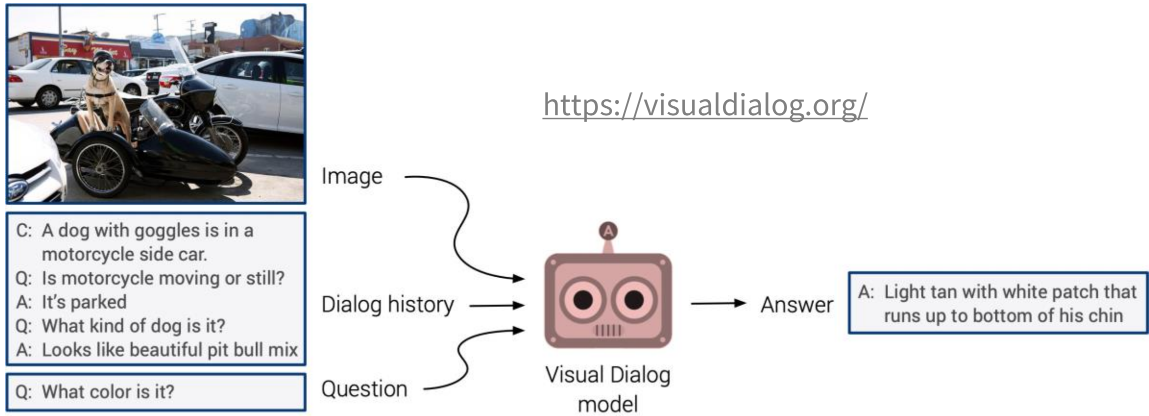
CNN belief tracker (slots)



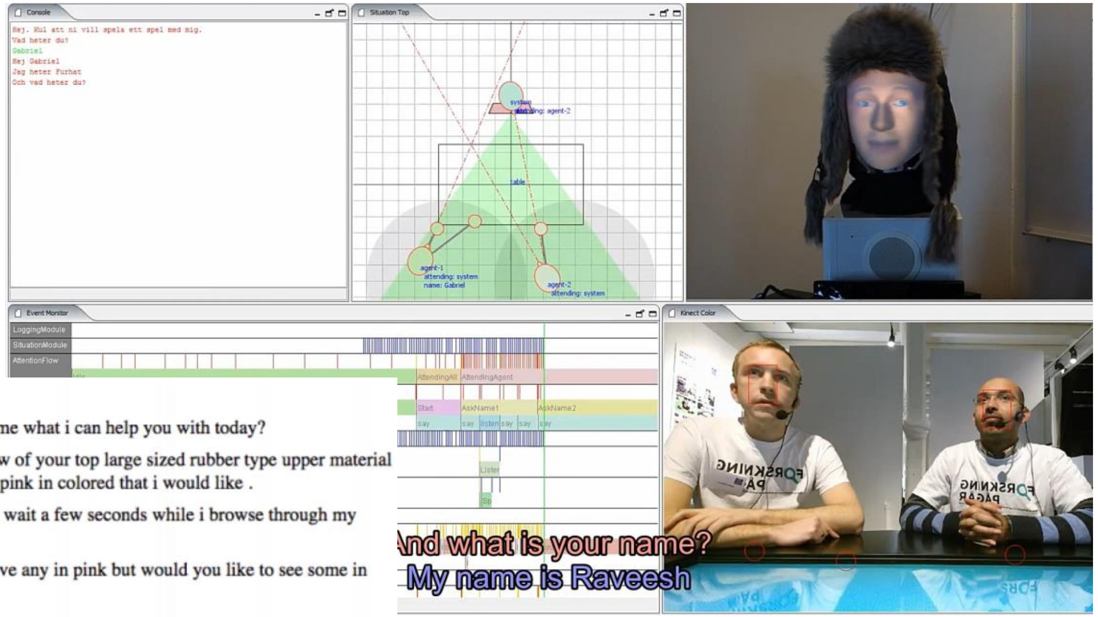
(Wen et al., 2017)
https://www.aclweb.org/anthology/E17-1042/

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



https://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
- 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: machine learning bits and pieces

Thanks

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room 424 (but email me first)

Labs

Today 14:00 SW1

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/