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# Toward Neural Symbolic Processing

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# Outline

- Overview on Natural Language Processing
- Neural Symbolic Processing
- Intelligent Information and Knowledge Management System
- Related Work
- Our Work
- Summary

# Ultimate Goal: Natural Language Understanding







### Natural Language Understanding

#### • Two definitions:

- Representation-based: if system creates proper internal representation, then we say it "understands" language
- Behavior-based: if system properly follows instruction in natural language, then we say it "understands" language, e.g., "bring me a cup of tea"
- We take the latter definition



## Five Characteristics of Human Language

- Incompletely Regular (Both Regular and Idiosyncratic)
- Compositional (or Recursive)
- Metaphorical
- Associated with Knowledge
- Interactive

# Natural Language Understanding by Computer Is Extremely Difficult

- It is still not clear whether it is possible to realize human language ability on computer
- On modern computer
  - The incomplete regularity and compositionality characteristics imply complex combinatorial computation
  - The metaphor, knowledge, and interaction characteristics imply exhaustive computation
- Big question: can we invent new computer closer to human brain?

# Reason of Challenge

- A computer system must be constructed based on math
- Open question: whether it is possible to process natural language *as humans*, using math models
- Natural language processing is believed to be AI complete





### Data-driven Approach May Work

- Hybrid is most realistic and effective for natural language processing, and AI
  - machine learning based
  - human-knowledge incorporated
  - human brain inspired
- Big data and deep learning provides new opportunity

#### AI Loop



# Fundamental Problems of Statistical Natural Language Processing

Classification: assigning a label to a string

 $s \rightarrow c$ 

• Matching: matching two strings

 $s, t \rightarrow \mathbf{R}^+$ 

Translation: transforming one string to another

 $s \rightarrow t$ 

- Structured prediction: mapping string to structure given knowledge  $s \rightarrow s'$
- Sequential decision process: continuously choosing an action in a state, where the process randomly moves between states

# Fundamental Problems of Statistical Natural Language Processing

- Classification
  - Text classification
  - Sentiment analysis
- Matching
  - Search
  - Question answering
  - Dialogue (single turn)
- Translation
  - Machine translation
  - Speech recognition
  - Handwriting recognition
  - Dialogue (single turn)

- Structured Prediction
  - Named entity extraction
  - Part of speech tagging
  - Sentence parsing
  - Semantic parsing
- Sequential Decision Process
  - Dialogue (multi turn, task dependent)

# Lower Bound of User Need vs Upper Bound of Technology



# Future Trends of Natural Language Processing

Speech recognition and machine translation are taking-off

– There are still issues to be solved, e.g., long tail challenge

- Single turn dialogue and single turn question answering will take-off
  - Task-dependent single turn dialogue will be gradually used
    Single turn question answering will be gradually used
- Multi-turn dialogue needs more research
  - Reinforcement learning can be key technology
  - Data needs to be collected first, and then the AI loop can be run

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# Combination of Neural Processing and Symbolic Processing



Neural Symbolic Processing

### Prof. Yoshua Bengio's Comment

- Injecting symbols into neural works would be difficult, even impossible
- However, externally combining symbolic processing with neural processing should work
- This particularly makes sense for question answering and dialogue



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# Intelligent Information and Knowledge Management System

Use Phase



## Intelligent Information and Knowledge Management System Learning Phase



### Characteristics and Current Status

- Continuously accumulates information and knowledge
- Properly performs question answering in natural language,
  - Answers when it knows
  - Says "I don't know", when it does not know
- Ideally, system is automatically constructed without human involvement
- Becomes intelligent assistant of human
  - Note that computer has two powerful capabilities, computing and storage
- Currently, only partially realized, cf., search engine

# Neural Symbolic Processing for Information and Knowledge Management



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### Semantic Parsing



- **Executor:** execute command based on logic form and context y = z
- **Grammar:** set of rules for creating derivations based on input D(x,c) and context
- **Model:** model for ranking derivations with parameters  $P_{\theta}(d | x, c)$
- **Parser:** find most likely derivation under learned model  $d^*$
- **Learner:** learn parameters of model  $\theta$  from data  $\{(x_i, c_i, y_i)\}_{i=1}^n$

Liang 2016

# Never Ending Language Learning (NELL)

- Task
  - Initial ontology, few examples of each category predicate, the web, occasional interaction from humans
  - Extract more facts from web
  - Learn to read better than before
- System
  - KB with 15 million candidate beliefs
- Technologies

 Coupled semi-supervised learning, automatic discovery of new coupling constraints, automatic extending of ontology, staged curriculum



#### Mitchell et al. 2015

# Memory Networks

- Long term memory + inference
- Model is learned
- Can answer factoid
   questions
- Acc = 40%+

- Example
  - John is in the playground.
  - Bob is in the office.
  - John picked up the football.

Weston et al. 2014

- Bob went to the kitchen.
- Q: where is the football?
- A: playground



# **Differentiable Neural Computers**

- DNC = neural network + external memory (matrix)
- Memory represents complex data structures
- Neural network, learned from data and supervised learning, controls access to memory
- Memory heads use three forms of differentiable attention
- Resembling mammalian
   hippocampus



#### Graves et al. 2016

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# Researchers



Zhengdong Lu



Xin Jiang



Lifeng Shang

### Question Answering from Knowledge Graph

Q: How tall is Yao Ming? A: He is 2.29m tall and is visible from space. (Yao Ming, height, 2.29m)

Q: Which country was Beethoven from?A: He was born in what is now Germany.(Ludwig van Beethoven, place of birth, Germany)

Learning System

Knowledge Graph

(Yao-Ming, spouse, Ye-Li) (Yao-Ming, born, Shanghai) (Yao-Ming, height, 2.29m)

(Ludwig van Beethoven, place of birth, Germany)

**Q:** How tall is Liu Xiang?

Question Answering System Answer is generated

A: He is 1.89m tall





Encoder creates question representation, decoder generates answer

Matches and retrieves most relevant answer representation Triples in symbolic representations (indexed) & neural representation

## Question Answering from Relational Database

Q: How many people participated in the game in Beijing? A: 4,200 SQL: select #\_participants, where city=beijing

Q: When was the latest game hosted?
A: 2012
SQL: argmax(city, year)

Learning System

#### **Relational Database**

year	city	#_days	#_med als
2000	Sydney	20	2,000
2004	Athens	35	1,500
2008	Beijing	30	2,500
2012	London	40	2,300

**Q**: Which city hosted the longest Olympic game before the game in Beijing?

Question Answering System

A: Athens



Encoder creates question representation, decoder simply returns answer Matches question representation to table representations to find answer Feature and values are in symbolic representations and neural representation

# Summary

- Intelligent Information and Management System
  - Can automatically acquire information and knowledge
  - Can accurately answer questions from humans
- Should be most important topic for research in AI
- Neural Symbolic Processing should be most promising approach
- Recent research is making progress
- Many open questions and challenges

# References

- 李航,迎接自然语言处理新时代,计算机学会通讯,2017年第2期
- 李航,简论人工智能,计算机学会通讯,2016年第3期
- 李航,对于AI我们应该期待什么,计算机学会通讯,2016月第11期
- 李航,技术的上界与需求的下界,新浪博客,2014年
- Jun Yin, Xin Jiang, Zhengdong Lu, Lifeng Shang, Hang Li, Xiaoming Li. Neural Generative Question Answering. Proceedings of the 25th International Joint Conference on Artificial Intelligence (IJCAI'16), 2972-2978, 2016.
- Pengcheng Yin, Zhengdong Lu, Hang Li, Ben Kao. Neural Enquirer: Learning to Query Tables with Natural Language. Proceedings of the 25th International Joint Conference on Artificial Intelligence (IJCAI'16), 2308-2314, 2016.
- Lili Mou, Zhengdong Lu, Hang Li, Zhi Jin. Coupling distributed and symbolic execution for natural language queries. To appear in ICML, 2017.

# Thank You!