INTRODUCTION TO CORPUS-BASED STATISTICS-ORIENTED (CBSO) TECHNIQUES

(PART I: INTRODUCTION)

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TASKS FOR LARGE SCALE NLP

☐ Knowledge Representation
- How to organize and describe linguistic knowledge

☐ Knowledge Control Strategies
- How to use knowledge for
  —efficient analysis
  —ambiguity resolution
  —ill-formedness recovery

☐ Knowledge Acquisition
- How to systematically and cost-effectively set up knowledge bases, and
- maintain knowledge base consistency

☐ Knowledge Integration
- How to jointly consider various knowledge sources effectively

Some Observations in NLP Research

☐ Knowledge acquisition is the major engineering bottleneck for a large scale NLP/MT system.
- Required knowledge is usually huge, messy and fine-grained.
- Knowledge acquisition is a very expensive and time-consuming task.

☐ Inducing consistent knowledge with corpus-based approaches is the promising approach for NLP applications:
- Most knowledge required in NLP is inductive, not deductive.
  —Language $\rightarrow$ Linguistics
  —Linguistics $-\times\rightarrow$ Language
- Inductive knowledge can be acquired easily with statistical methods.

☐ Need a cooperative way between human and machine:
- Human is competent in abstract language modeling, but awkward in dealing with large and fine-grained knowledge.
- It is not easy for people to maintain consistency of large rule bases and guarantee global improvement by enlarging rule bases.
- Computers are good at processing large corpora.

Knowledge Acquisition

☐ **Induction by human**: Rule-based approaches

☐ **Automatic Induction**:
- Statistical Modeling
  —Pure statistical approach
  —CBSO approach
- Symbolic Learning
- Connectionist

RULE-BASED APPROACHES

☐ Have a strict sense of well-formedness in mind

☐ Impose linguistic constraints on syntactic or semantic constructs to satisfy well-formedness

☐ Mostly based on linguistic knowledge that is linguistically interesting or *ad hoc* heuristics

☐ Example: (lexical disambiguation)

- Heuristics: a "determiner" cannot be followed by a "verb"
- Rule: if C_{i-1} = "det" then $C_i \neq$ "verb"

Rule-Based Systems: Advantages and Disadvantages

☐ Advantages:

- Easy to incorporate existing linguistic knowledge.
- Have better generalization (deduction) capacity.

☐ Disadvantages:

- Hard to handle uncertainty (lack of objective preference measure).
- Hard to deal with complex and irregular knowledge (exception).
- Hard to maintain consistency among different persons at different time.
- Knowledge acquisition is costly and time consuming.
- Lack of systematic and automatic ways for learning rules in large-scale applications.
- Not easy to obtain high coverage (completeness) even for a given domain.
- Not easy to avoid redundancy.

PURELY STATISTICAL APPROACHES

☐ No strict sense of well-formedness in mind

☐ Assume language generation to be a Markov chain

☐ Treat translation as a decoding process, no traditional linguistic knowledge is used in modeling

☐ Example I: (lexical disambiguation)

- To discover the fact that p(v|det) = 0, one need to find p(y|x) = 0 for all x $\in$ "det" and all y $\in$ "verb"

x	y	p(y|x)
the	ate	0
a	took	0
an	walks	0
	buy	0

☐ Have a large parameter space: for example

- 100,000 words + Tri-gram word model
  => number of parameters is $10^5 \cdot 10^5 \cdot 10^5 = 10^{15}$

☐ Example II: [Brown et. al, 89, 90]

- find possible translation lexicon for all words in source language
- English-to-French translation
  - —cut a sentence into words
  - —find corresponding French words
  - —place the words in a bag
  - —try to recover the sentence by rearranging all possible sequences and using tri-gram source model, fertility probability and distorsion probability to find the preferred one
- assume free word order:
  - —"John likes Mary." is as good as
  - —"Mary likes John."

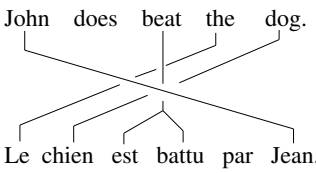
☐ Example II: [Brown et. al, 89, 90] (cont'd)

- Regard "Translation Mechanism" as a Decoding Process

  —Find max P(t|s), where (s,t) is a source language and target language sentence pair.

- Translation Model:

$$
\begin{aligned}
P(s \mid t) = & P(f_1 = 1 \mid John) \cdot P(Jean \mid John) \cdot \\
& P(f_2 = 0 \mid does) \cdot \\
& P(f_3 = 2 \mid beat) \cdot P(est \mid beat) \cdot P(battu \mid beat) \cdot \\
& P(f_4 = 1 \mid the) \cdot P(le \mid the) \cdot \\
& P(f_5 = 1 \mid dog) \cdot P(chien \mid dog) \cdot \\
& P(f_6 = 1 \mid null) \cdot P(par \mid null)
\end{aligned}
$$



Purely Statistical Approaches: Advantages and Disadvantages

☐ Advantages:

- Do not need to establish linguistic models.
- Computation is easy.

☐ Disadvantages:

- The parameter space is too large.
- A very large training corpus is required due to the large number of parameters.
- Only local dependency can be handled.

  —Noam Chomsky's Debate (1956):
  No finite-state Markov Process can serve as an English grammar.

  Example:

  —If S1, then S2.
  —Either S3, or S4.
  —The man who said that S5, is arriving today.

- Cannot make use of prior existing knowledge induced by linguists

WHAT IS A CBSO APPROACH?

☐ Use Corpus as the Main Information Source

- Only a Few Well-Justified Linguistic Rules are Used

  —mechanical induction processes are performed by computers

- Most Knowledge is Obtained from Corpora

  —Except modeling

☐ Language model is proposed by human which is, in general, more complex than the simple Markov chain.

☐ Use Statistical Method to Acquire Knowledge

- Knowledge is Interpreted in Statistical Sense
- Parameters are Automatically Learned from Corpus

Characteristics of the CBSO Approaches

☐ CBSO = Statistical Language Model + Language Parameters

☐ No strict sense of well-formedness in mind

☐ Assume that a language generation process has stochastic behavior when a proper language model is used

☐ Make use of well-justified linguistic knowledge to construct high-level stochastic language models

☐ A promising paradigm for integrating linguistic and statistic knowledge

☐ Example: (lexical disambiguation)

- use the known lexical knowledge to drastically reduce the parameter space and the required training data

$$\left.\begin{array}{l} w_1\ w_2\ w_3\ w_4\ \ldots \\ c_1\ c_2\ c_3\ c_4\ \ldots \\ \\ w_1\ w_2\ w_3\ w_4\ \ldots \\ c_1\ c_2\ c_3\ c_4\ \ldots \end{array}\right\} \quad p(\text{verb}|\text{det}) = 0$$

☐ Have a moderate and manageable parameter space:

- e.g., 100 parts of speech + Tri-gram model in part of speech
  => number of parameters is $10^2 \cdot 10^2 \cdot 10^2 = 10^6$

☐ Why linguistic models are needed?

- Linguistic models group words into equivalent classes (e.g., parts of speech, phrase elements, words with the same semantic features), and hence reduce the number of required parameters drastically.

CBSO: Advantages and Disadvantages

☐ Disadvantages:

- It is sometimes hard to couple with some existing linguistic theories.
- Generalization (deduction) capability is poor with small database.
- Large corpora are required to get reliable statistics.

☐ Advantages:

- Uncertainty or preference is interpreted objectively and consistently.
- Consistency can be easily maintained even in large scale systems.
- Well-established statistical theories and techniques are available.
- (Semi-)automatic training is possible with least human intervention.
- Remove the burden of rule induction from linguists to machine.
- Long distance dependency is manageable:
  - —more contextual information can be used;
  - —syntactic and semantic information could be consulted.

- It is suitable for feedback training because of the parameterized modeling.
- Sparse data problem is less severe:
  - —intermediate forms are introduced to reduce the parameter space;
  - —parameter space is small with respect to purely statistical approaches.
- It is usually robust to the ill-formed cases.

☐ The CBSO approaches manipulate stochastic behavior on top of nonterminal symbols. Hence, long distance dependency can be easily handled, and the size of the parameter space can be limited to a manageable scale.

CBSO DESIGN PHILOSOPHY

☐ **Cooperative approach**:

- Admit the facts that
  - —general linguistic knowledge has better generalization for unseen domain
  - —uncertain knowledge can be more objectively quantified by statistic models
  - —large and fine-grained language parameters can be acquired more cost-effectively by machine
  - —human is competent in language modeling while machines are suitable for massive data processing
- Principles of cooperative approach
  - —take advantages of well-recognized linguistic phenomena
  - —setup probabilistic language model by humans
  - —acquire language parameters from corpora (semi-) automatically

☐ **Systematic approach**:

- knowledge acquisition & integration should be done with systematic approach
- least human intervention should be involved via parameter learning

WHY CBSO APPROACHES BECOME POPULAR?

☐ An appropriate integration of symbolic and statistical approaches can enhance both of the individual processing [Meteer 94].

- "Traditionally, symbolic and statistical approaches have been kept separate and applied to very different problems."
- Symbolic techniques apply best:
  - —"when we have well-developed knowledge of the language or the domain."
  - —"when the application of a theory or study of selected examples can help leverage and extend our knowledge."
- Statistical approaches apply best:
  - —when the randomness of existing linguistic theory is observed.
  - —"when the results of decisions can be represented in a statistical model."
  - —"when we have sufficient training data to accurately estimate the parameters of the model."

☐ The demand for large scale practical NLP applications is increasing. Thus, corpus-based research is required to reflect the real usage of the languages and provide the real world view for daily encountered linguistic problems.

- Wide coverage toward unrestricted domain is required in real NLP applications; practically encountered phenomena must be resolved even if they are not theoretically interesting.
- Robustness: NLP systems must show good performance both in laboratory and real environment (avoid over-tuning).

☐ Justification of various theoretical frameworks against a large and possibly common text corpus is required to evaluate all frameworks.

☐ Human intervention is costly and time consuming; corpus processing techniques are required to reduce the cost of knowledge acquisition

A COMPARATIVE REVIEW

☐ Rule-Based Approaches

- Heuristic Rule: a "determiner" cannot be followed by a "verb"

☐ Purely Statistical Approach

x	y	p(y|x)
the	ate	0
a	took	0
an	walks	0
	buy	0

- Conclusion: a word in x cannot be followed by a word in y

☐ CBSO Approach

$$\left.\begin{array}{l} w_1\ w_2\ w_3\ w_4\ \ldots \\ c_1\ c_2\ c_3\ c_4\ \ldots \\ \\ w_1\ w_2\ w_3\ w_4\ \ldots \\ c_1\ c_2\ c_3\ c_4\ \ldots \end{array}\right\} \; p(\text{verb}|\text{det}) = 0$$

WHEN TO ADOPT A CBSO APPROACH?

☐ When we should adopt rule-based approach

- Not easy to establish a large-scale database
- The size of rule-base needed is not large (Phenomena can be governed by a small number of rules, which have been well justified.)
- Rules with large coverage exist
- Extensional knowledge is important to the system

☐ When should we adopt corpus based statistics oriented approach

- Establishing a large-scale database is affordable
- Knowledge needed to solve the problem is huge and intricate, not easy to acquire by human.
- Intensional knowledge is enough for the system
- A good model or formulation can be found