Formal Models in Processing of Japanese Language

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Outline

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Motivation

1. Natural language processing
   - An important application of the formal language theory
   - Many practical tasks – machine translation, information extraction...
   - Still many open problems
2. Japanese language
   - So far relatively little research in this field (such as direct translation between Japanese and Czech, for example)
   - Good relations between Japan and the Czech republic
   - Personal interest

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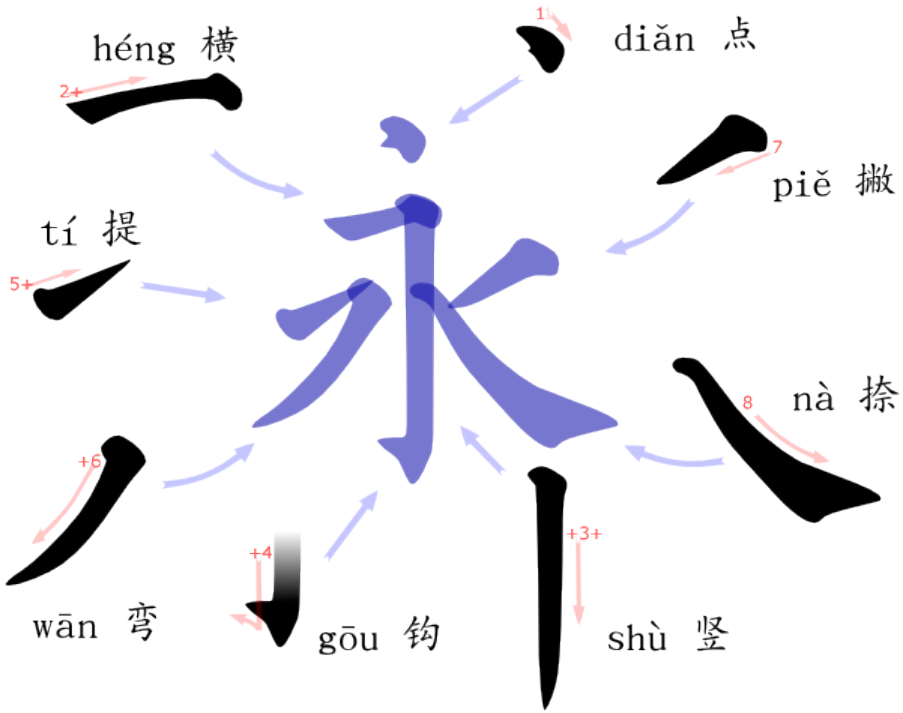
Writing *Kanji* Characters

- *Kanji* (漢字) – Chinese characters used in Japanese writing system.
- Each character composed of several strokes.
- 8 basic strokes, shown in the chinese character *yong* (eternity) below.
- Basic strokes can combine into compound strokes.
- Fixed stroke order for writing each character.



Kanji Character Recognition

- Character recognition useful in many practical applications
  - Learning applications
  - Dictionaries

Problem

- If we want to classify the character's image as a whole, there is too many classes (characters).

Solution

- If we have a vector representation of the character, we can recognize it by classifying the strokes and analyzing their relations (mainly positions) inside the character.
  - Only a small number of strokes (about 38, may vary slightly according to different sources).
  - Strokes can be relatively easily distinguished.

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Kanji Character Semantics

- A single character typically has several readings, and can have more than one meaning.
- Readings are divided into 2 groups:
  1. *On'yomi* (音読み) – Sino-Japanese reading, a Japanese approximation of a Chinese pronunciation. Used mostly for compound words (consisting of more than one *kanji*).
  2. *Kun'yomi* (訓読み) – Japanese reading, based on a native Japanese word with a similar meaning. Used mostly for stand-alone *kanji* characters.

Example

Character	*On'yomi*	*Kun'yomi*	Meanings
	KOU, GYOU	iku, yuku	to go
行	コウ，ギョウ	い(く)，ゆ(く)	

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Kanji Character Dependencies

- A sequence of *kanji* characters (usually 2, but it can be more) can form a compound word with a new meaning.
- This also determines the readings of the *kanji* in the compound word.

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日	NICHI, JITSU ニチ，ジツ hi, ka ひ，か	the sun day	ある日 *aruhi* - one day 毎日 *mainichi* - everyday 今日 *kyou* (irregular) - today 日曜日 *nichiyoubi* - Sunday
学	GAKU, KAKU ガク，カク manabu まな(ぶ)	learning science to learn	科学 *kagaku* - science 学校 *gakkou* - school 数学 *suugaku* - math

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Building a *Kanji* Database

For each character, the basic information we need contains:

1. Readings
   - Distinguish between *kon'yomi* and *on'yomi*
2. Meanings
3. Relations and dependencies to other characters
   - Compounds
   - Radicals
4. Graphical representation
   - Vector-based

Character relations very important – affect the characters' readings and meanings.

- Create a relational model?
- Implement as a relational database (SQL...)?

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Natural Language Processing and Context-Free Grammars

- Formal models practically used in natural language processing (NLP) are often based on context-free grammars.

Definition

A context-free grammar (CFG) is a quadruple $G = (N, T, P, S)$, where

- N is a finite set of *nonterminal* symbols
- T is a finite set of *terminal* symbols, $N \cap T = \emptyset$
- P is a finite relation from N to $(N \cup T)^*$, usually represented as a finite set of *rules (productions)* of the form

$$A \to x,$$

  where $A \in N$ and $x \in (N \cup T)^*$
- $S \in N$ is the *start symbol*

Context-Free Grammar

Derivation

1. Let $G = (N, T, P, S)$ be a CFG. Let $u, v \in (N \cup T)^*$ and $p = A \to x \in P$. Then, *uAv directly derives uxv* according to p in G, written as $uAv \Rightarrow_G uxv\ [p]$ or simply $uAv \Rightarrow uxv$.
2. The relation $\Rightarrow^*$ *(derives)* is the reflexive transitive closure of $\Rightarrow$.

Generated language

Let $G = (N, T, P, S)$ be a CFG. The *language generated by* G, denoted as $L(G)$, is defined as

$$L(G) = \{w : w \in T^*, S \Rightarrow^* w\}$$

Beyond CFG

Problem

- CFG – insufficient generative power.
- Context-sensitive (Type-1) and general (Type-0) grammars – not suitable for practical implementation (complexity of parsing), long-distance dependencies difficult to describe.

Solution

- Increase generative power without significantly increasing implemenatation cost.
- New models often based on CFG (or context-free rules).
  - Common in NLP: CCG (using combinatory logic), PCFG/SCFG (probabilistic CFG, using statistical approach), LTAG (rewriting tree nodes instead of symbols)...
  - Other: regulated grammars (such as matrix grammar or programmed grammar), scattered context grammar...

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Matrix Grammar

Definition

A matrix grammar is a pair $H = (G, M)$, where

- $G = (N, T, P, S)$ is a context-free grammar
- M is a finite language over P ($M \subseteq P^*$)

Notation

- Let $N = A_1, \ldots, A_m$ for some $m \geq 1$
- For some $m_i = p_{i_1} \ldots p_{i_j} \ldots p_{i_{k_i}} \in M$,

$$p_{i_j} : A_{i_j} \rightarrow x_{i_j}$$

Matrix Grammar

Derivation step

For $x, y \in (N \cup T)^*$, $m \in M$,

$$x \Rightarrow y[m]$$

in H if there are $x_0, \ldots, x_n$ such that $x = x_0, x_n = y$, and

1. $x_0 \Rightarrow x_1[p_1] \Rightarrow x_2[p_2] \Rightarrow \cdots \Rightarrow x_n[p_n]$ in G, and
2. $m = p_1 \ldots p_n$

Generated language

$$L(H) = \{x \in T^* : S \Rightarrow^* x\}$$

Scattered Context Grammar

Definition

A scattered context grammar (SCG) is a quadruple $G = (N, T, P, S)$, where

- N is a finite set of nonterminal symbols
- T is a finite set of terminal symbols, $N \cap T = \emptyset$
- P is a finite set of rules of the form $(A_1, \ldots, A_n) \rightarrow (x_1, \ldots, x_n)$, where $A_1, \ldots, A_n \in N$, $x_1 \ldots, x_n \in (N \cup T)^*$
- $S \in N$ is the start symbol

Derivation step

Let $G = (N, T, P, S)$ be a SCG. For $u, v \in (N \cup T)^*$, $p \in P$, $u \Rightarrow v[p]$ in G if $u = u_1 A_1 \ldots u_n A_n u_{n+1}$, $v = u_1 x_1 \ldots u_n x_n u_{n+1}$ and $p = (A_1, \ldots, A_n) \rightarrow (x_1, \ldots, x_n)$, where $u_i \in (N \cup T)^*$ for all $1 \leq i \leq n$

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Describing Japanese Language

- Japanese sentences – SOV (subject-object-verb) form.
  - English, for example, uses SVO.
- Consider a CFG G with rules (nonterminals are in capital letters):

1:	S	$\rightarrow$	SP OP VP	5:	NP	$\rightarrow$	N
2:	SP	$\rightarrow$	NP *wa*	6:	N	$\rightarrow$	*kore* | *daigaku*
3:	OP	$\rightarrow$	NP	7:	V	$\rightarrow$	*desu*
4:	VP	$\rightarrow$	V				

- One of the possible derivations:
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Forming Questions

- To change a statement into a question, append *ka* at the end of the sentence.
- Add the following rule to G:

$$8: \quad \text{VP} \quad \rightarrow \quad \text{V } \textit{ka}$$

- Derivation example:
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- Adding the following 2 rules:

$$9: \quad \text{OP} \quad \rightarrow \quad \text{INT} \;\Big|\; 10: \quad \text{INT} \quad \rightarrow \quad \textit{nan}$$

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- But "*kore wa nan desu*" is not a well-formed sentence. We need to modify the grammar so that it does not allow this derivation.
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Describing Japanese Language Using Matrix Grammar

- Consider a matrix grammar $H = (G, M)$ with the following rules in G (nonterminals are in capital letters):

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  and $M = \{1, 2, 3, 4, 5, 6, 7, 8, 9\,8, 10\}$

- The problematic derivation in H becomes:
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More Complex Sentence – Example

1. *watashi wa konban uchi de terebi o mimasu*
   ("I am going to watch TV at home tonight")
2. *watashi wa mainichi uchi de terebi o mimasu*
   ("I watch TV at home everyday")
3. *Takeshi-san wa mainichi uchi de terebi o mimasu*
   ("Takeshi watches TV at home everyday")
4. *Takeshi-san wa mainichi uchi de terebi o mimasu ka*
   ("does Takeshi watch TV at home everyday?")
5. *Takeshi-san wa mainichi uchi de nani o mimasu ka*
   ("what does Takeshi watch at home everyday?")
6. *Takeshi-san wa konban uchi de nani o mimasu ka*
   ("what is Takeshi going to watch at home tonight?")

- Relatively small differences between the sentences in Japanese, but significantly different meaning (and translation).

SCG – Rules (1)

1:	(S)	$\rightarrow$	(SP AP OP VP)
2:	(SP, V)	$\rightarrow$	(NP_1 *wa*, V_1)
3:	(SP, V)	$\rightarrow$	(NP_2 *wa*, V_2)
4:	(SP, V)	$\rightarrow$	(NP_3 *wa*, V_3)
5:	(SP, V)	$\rightarrow$	(ϵ, V_1)
6:	(AP)	$\rightarrow$	(APTIME APPLACE)
7:	(OP)	$\rightarrow$	(NP_1)
8:	(OP)	$\rightarrow$	(NP_2)
9:	(OP)	$\rightarrow$	(NP_3)
10:	(VP)	$\rightarrow$	(V)
11:	(VP)	$\rightarrow$	(V *ka*)
12:	(OP, VP)	$\rightarrow$	(*nani*, V *ka*)

SCG – Rules (2)

13: (APPLACE) $\rightarrow$ (NP_3 *de*)
14: (APPLACE) $\rightarrow$ (ϵ)

15: (APTIME, V_1) $\rightarrow$ (APTIME_{ps}, V_{1ps})
16: (APTIME, V_1) $\rightarrow$ (APTIME_{pc}, V_{1pc})
17: (APTIME, V_1) $\rightarrow$ (APTIME_{f}, V_{1f})
18: (APTIME, V_1) $\rightarrow$ (ϵ, V_{1f})
19: (APTIME, V_2) $\rightarrow$ (APTIME_{ps}, V_{2ps})
20: (APTIME, V_2) $\rightarrow$ (APTIME_{pc}, V_{2pc})
21: (APTIME, V_2) $\rightarrow$ (APTIME_{f}, V_{2f})
22: (APTIME, V_2) $\rightarrow$ (ϵ, V_{2f})
23: (APTIME, V_3) $\rightarrow$ (APTIME_{ps}, V_{3ps})
24: (APTIME, V_3) $\rightarrow$ (APTIME_{pc}, V_{3pc})
25: (APTIME, V_3) $\rightarrow$ (APTIME_{f}, V_{3f})
26: (APTIME, V_3) $\rightarrow$ (ϵ, V_{3f})

SCG – Rules (3)

27: $(NP_1) \rightarrow (watashi) \mid (boku)$
28: $(NP_2) \rightarrow (anata) \mid (kimi)$
29: $(NP_3) \rightarrow (kare) \mid (Takeshi\text{-}san) \mid (terebi) \mid (uchi)$
30: $(APTIME_{ps}) \rightarrow (mainichi) \mid (maiban) \mid (tokidoki)$
31: $(APTIME_{pc}) \rightarrow (ima)$
32: $(APTIME_f) \rightarrow (konban) \mid (ashita)$
33: $(V_{1ps}) \rightarrow (o\ mimasu)$
34: $(V_{1pc}) \rightarrow (o\ mimasu)$
35: $(V_{1f}) \rightarrow (o\ mimasu)$
36: $(V_{2ps}) \rightarrow (o\ mimasu)$
37: $(V_{2pc}) \rightarrow (o\ mimasu)$
38: $(V_{2f}) \rightarrow (o\ mimasu)$
39: $(V_{3ps}) \rightarrow (o\ mimasu)$
40: $(V_{3pc}) \rightarrow (o\ mimasu)$
41: $(V_{3f}) \rightarrow (o\ mimasu)$

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$\Rightarrow$ SP APTIME APPLACE OP VP

$\Rightarrow$ SP APTIME APPLACE NP_3 VP

$\Rightarrow$ SP APTIME APPLACE NP_3 V

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$\Rightarrow$ NP_1 *wa* APTIME NP_3 *de* NP_3 V_1

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$\Rightarrow$ *watashi wa* $APTIME_f$ NP_3 *de* NP_3 V_{1f}

$\Rightarrow$ *watashi wa konban* NP_3 *de* NP_3 V_{1f}

$\Rightarrow$ *watashi wa konban uchi de* NP_3 V_{1f}

$\Rightarrow$ *watashi wa konban uchi de terebi* V_{1f}

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("I am going to watch TV at home tonight")

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Transformational SCG

Definition

A transformational scattered context grammar (TSCG) is a quadruple $G = (V, T, P, I)$, where

- V is the total vocabulary
- $T \subset V$ is the set of terminals (output vocabulary)
- P is a finite set of scattered context rules
- $I \subset V$ is the input vocabulary

Transformation

The transformation T that G defines from from $K \subseteq I^*$ is defined as

$$T(G, K) = \{(x, y) : x \Rightarrow_G^* y, x \in K, y \in T^*\}$$

Transformational SCG – Example

1:	(*watashi*, *mimasu*)	$\rightarrow$	(I, watch)
2:	(*Takeshi-san*, *mimasu*)	$\rightarrow$	(Takeshi, watches)
3:	(*terebi*)	$\rightarrow$	(TV)
4:	(*mainichi*)	$\rightarrow$	(everyday)
5:	(*wa*)	$\rightarrow$	(ϵ)
6:	(*o*)	$\rightarrow$	(ϵ)

watashi wa mainichi terebi o mimasu

$\Rightarrow$ I *wa mainichi terebi o* watch

$\Rightarrow$ I *wa mainichi* TV *o* watch

$\Rightarrow$ I *wa* everyday TV *o* watch

$\Rightarrow$ I everyday TV *o* watch

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Takeshi-san wa mainichi terebi o mimasu

$\Rightarrow$ Takeshi-san *wa mainichi terebi o* watches

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...

Outline

Specific Problems

- Besides *kanji*, the Japanese writing system also uses 2 syllabaries:
  1. *Hiragana* (ひらがな) – used for particles, suffixes, words that have no *kanji*.
  2. *Katakana* (カタカナ) – used mainly for transcribing words from foreign languages (including names).
- Modern Japanese writing sometimes also includes Latin alphabet (mostly abbreviations such as CD, DVD) and Arabic numerals.
- The transcription of Japanese text using Latin alphabet is called *romaji* (ローマ字) (several different standards).
- In Japanese sentences, it is not customary to separate words by spaces.

Specific Problems

Example

- A typical Japanese sentence might look like this:
  日本とチェコスロバキア間の外交関係は
  1919年に樹立されました。
  ("The diplomatic relations between Japan and Czechoslovakia started in 1919.")
- Written in *hiragana* only:
  にほんとちぇこすろばきあかんのがいこうかんけいは
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1. Separating the sentence into words (syntactic units).
2. Many different ways to write the same sentence.

Solution

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