A Machine Learning Approach to Recipe Flow Construction

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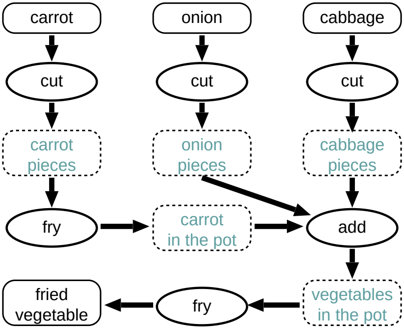
What is Recipe?

- Describing the procedures for a dish
  - submitted to the Web
  - mainly written by house chefs
- One of the successful web contents
  - search, visualization, ...
- Recipe Flow [Momouchi 80, Hamada 00]



Recipe as a Text for Natural Language Processing

- Containing general NLP problems
  - Word identification or segmentation (WS)
  - Named entity recognition (NER)
  - Syntactic analysis (SA)
  - Predicate-argument structure (PAS) analysis
  - etc.
- Simple compared with newspaper articles, etc.
  - Few modalities
  - Simple in tense and aspect
  - Mainly indicative or imperative mood
  - Only one person (Chef)

Overall Design

1. Recipe text analysis
   - State of the art in NLP area
   - Domain adaptation to recipe texts
2. Flow construction
   - Not rule-based (hopefully)
   - Graph-based approach
3. Match with movies

Recipe Text Analysis

Execute the following steps in this order

1. WS: Word segmentation (Including stemming)
   - Only required for languages without whitespace (ja, zh)
   - Some canonicalization required even for en, fr, ...
2. NER: Named entity recognition
   - **F**ood, **T**ool, **D**uration, **Q**uantity, **S**tate, **A**ction by the **c**hef or **f**oods
3. SA: Syntactic analysis
   - Grammatical relationship among NEs
4. PAS: Predicate-argument structure analysis
   - Semantic relationship among NEs

Output

煮立て (*obj.*:水-４００-ｃｃ, で:鍋)

boil(*obj.*:water 400cc, by:pot)

Step 1. Word Segmentation (word identification)

- Input: a sentence
  水４００ccを鍋で煮立て、沸騰したら中華スープの素を加えてよく溶かす 。
  (Heat 400 cc of water in a pot, and when it boils, add Chinese soup powder and dissolve it well.)

- Output: a word sequence
  水|４-０-０|ｃ-ｃ|を|鍋|で|煮-立-て|、|
  沸-騰|し|た-ら|中-華|ス-ー-プ|の|素|を|
  加-え|て|よ-く|溶-か|す|。

  where "|" and "-" mean existence and non-existence of a word boundary.

※ No dictionary form of inflectional words is needed because our standard divides them into the stem and the ending.

Pointwise WS (KyTea) [Neubig 11]

- Binary classification problem at each point between chars

$\mathbf{x_{i-2}}$ $\mathbf{x_{i-1}}$ $\mathbf{x_{i}}$ $\mathbf{x_{i+1}}$ $\mathbf{x_{i+2}}$ $\mathbf{x_{i+3}}$

Text: 鍋 で 煮 立 て 、 沸 騰 し た

↑

$\mathbf{t_i}$: Decision point

Trainable from a partially annotated corpus ⇒Flexible corpus annotation! ⇒Easy to adapt to a specific domain!

- A partially annotated corpus allows us to focus on special terms

  弱␣火␣で|煮-立-て|る

  こ␣れ␣が|煮-立|つ|ま␣で

Pointwise WS (KyTea) [Neubig 11]

- Binary classification problem at each point between chars

	$\mathbf{x_{i-2}}$	$\mathbf{x_{i-1}}$	$\mathbf{x_i}$	$\mathbf{x_{i+1}}$	$\mathbf{x_{i+2}}$	$\mathbf{x_{i+3}}$				
Text:	鍋	で	煮 ↑	立	て	、	沸	騰	し	た

$\mathbf{t_i}$: Decision point

- SVM (Support Vector Machine)

- Features
  Char (type) 1-gram feature:

  -3/鍋 (K), -2/で (H), -1/煮 (K), 1/立 (K), 2/て (H), 3/、(S)

  Char (type) 2-gram feature:

  -3/鍋で (KH), -2/で煮 (HK), -1/煮立 (KK), 1/立て (KH), 2/て、(HS)

  Char (type) 3-gram feature:

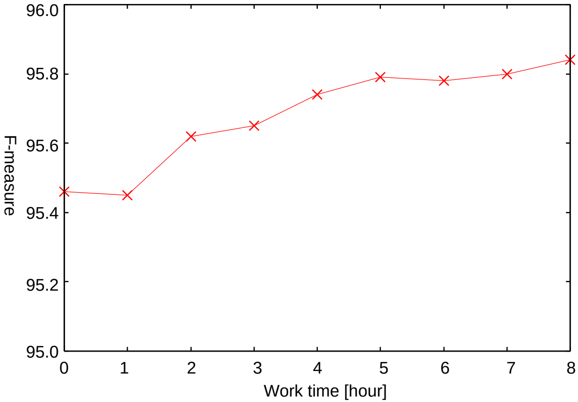
  -3/鍋で煮 (KHK), -2/で煮立 (HKK), -1/煮立て (KKH), 1/立て、(KHS)

Baseline and its Adaptation

- Baseline: BCCWJ, UniDic, etc.
- Adaptation: KWIC based partial annotation
  - 8 hours

Result

- F measure $= \{(\text{LCS}/\text{sysout}^{-1} + \text{LCS}/\text{corpus}^{-1})/2\}^{-1}$



- WS improves as the work time increases
- More work required (about 98% in the general domain)

Step 2. Named Entity Recognition (NER)

- Named entity
  - Word sequences corresponding to objects and actions in the real world
  - Highly domain dependent
- Named entity types for recipes:
  Food, **T**ool, **D**uration, **Q**uantity, **S**tate,
  Action by the **c**hef, **A**ction by **f**oods

水$_{\mathbf{F}}$ ４００ｃｃ$_{\mathbf{Q}}$ を 鍋$_{\mathbf{T}}$ で 煮立て$_{\mathbf{Ac}}$ 、沸騰し$_{\mathbf{Af}}$ たら 中華スープの素$_{\mathbf{F}}$ を 加え$_{\mathbf{Ac}}$ て よく 溶か$_{\mathbf{Ac}}$ す 。

Heat$_{\mathbf{Ac}}$ 400 cc$_{\mathbf{Q}}$ of water$_{\mathbf{F}}$ in a pot$_{\mathbf{T}}$, and when it boils$_{\mathbf{Af}}$, add Chinese soup powder$_{\mathbf{F}}$ and dissolve$_{\mathbf{Ac}}$ it well.

Pointwise NER

Trainable from a partially annotated corpus
⇒Flexible corpus annotation!
⇒Easy to adapt to a specific domain!

1. BIO2 representation (one NE tag for a word, with **O**ther)
   水/B-F ４００/B-Q ｃｃ/I-Q を/O 鍋/BT で/O
   煮立て/B-Ac 、/O 沸騰/B-Af し/I-Af たら/O
2. Train pointwise classifier (KyTea) with logistic regression from a tagged data including partially annotated corpus
   - No partially annotated corpus this time
   - Cf. A CRF requires a fully annotated sentences.

Pointwise NER (cont'd)

3. Output all the possible pairs of tag and probability to fill the Viterbi table:

P(y|w)	水	４００	ｃｃ	を	⋯
F-B	0.62	0.00	0.00	0.00	⋯
F-I	0.37	0.00	0.00	0.00	⋯
Q-B	0.00	0.82	0.01	0.00	⋯
y Q-I	0.00	0.17	0.99	0.00	⋯
T-B	0.00	0.00	0.00	0.00	⋯
⋮	⋮	⋮	⋮	⋮	⋱
O	0.01	0.01	0.00	1.00	⋯

4. Search for the best sequence satisfying the constraints
   - Ex. "**F-I Q-I**" is invalid
   - In future work we change this part into CRFs

Baseline and its Adaptation

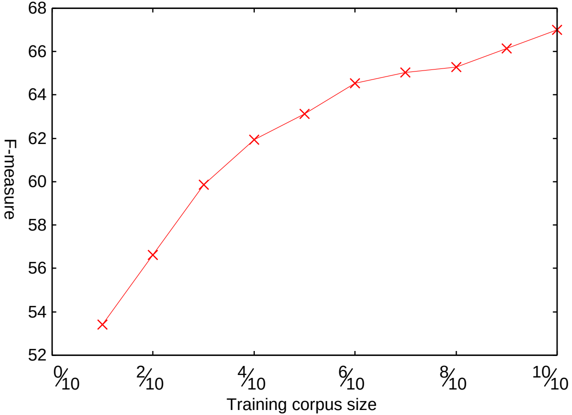
- Baseline: 1/10 of *Meet-potato* recipe text (24 sent.)
- Annotation: from 1/10 to 10/10 (about 5 hours, 242 sent.)

  Not randomly selected recipes ... (bad setting)

Meet potato

Result

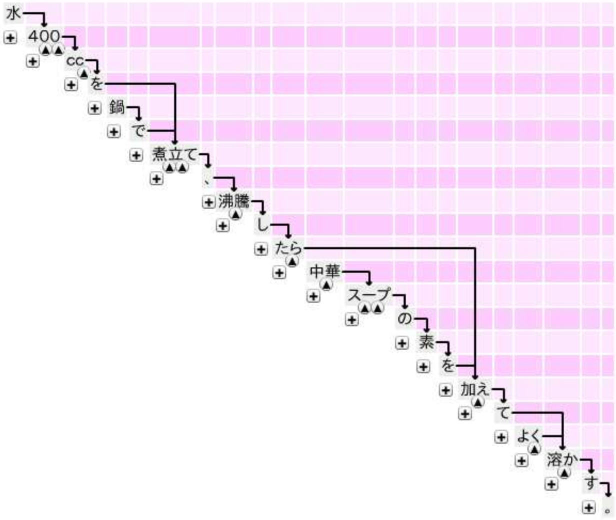
- F measure



- Very low F measure compared with the general domain (around 80%)
- NER improves rapidly as the work time increases

Step 3. Syntactic Analysis

- Dependency among the words (and NEs) in a sentence



Pointwise SA

- Pointwise MST (EDA) [Flannery 11]

> Trainable from a partially annotated corpus
> ⇒Flexible corpus annotation!
> ⇒Easy to adapt to a specific domain!

1. Estimate dependency scores of all the possible pairs in a sentence

$$\boldsymbol{\sigma}(\langle \mathbf{i}, \mathbf{d_i} \rangle, \vec{\mathbf{w}}), \qquad \text{where } \mathbf{w_i} \text{ depends on } \mathbf{w_{d_i}}$$

2. Select the Spanning Tree which Maximizes the total score (MST)

$$\hat{\vec{\mathbf{d}}} = \underset{\vec{\mathbf{d}} \in \mathbf{D}}{\mathbf{argmax}} \sum_{\mathbf{i}=1}^{\mathbf{n}} \boldsymbol{\sigma}(\langle \mathbf{i}, \mathbf{d_i} \rangle, \vec{\mathbf{w}})$$

Pointwise SA (cont'd)

- Features for dependency score of a word pair

		oyster	*obj.*	Hiroshima	to	eat	to	go	*infl.*
		牡蠣	を	広島	に	食べ	に	行	く
$\mathbf{w_{i-3}}$	$\mathbf{w_{i-2}}$	$\mathbf{w_{i-1}}$	$\mathbf{w_i}$	$\mathbf{w_{i+1}}$	$\mathbf{w_{i+2}}$	$\mathbf{w_{i+3}}$			
			$\mathbf{w_{d_i-3}}$	$\mathbf{w_{d_i-2}}$	$\mathbf{w_{d_i-1}}$	$\mathbf{w_{d_i}}$	$\mathbf{w_{d_i+1}}$	$\mathbf{w_{d_i+2}}$	$\mathbf{w_{d_i+3}}$

F1 The distance between a dependent word $\mathbf{w_i}$ and its candidate head $\mathbf{w_{d_i}}$.

F2 The surface forms of $\mathbf{w_i}$ and $\mathbf{w_{d_i}}$.

F3 The parts-of-speech of $\mathbf{w_i}$ and $\mathbf{w_{d_i}}$.

F4 The surface forms of up to three words to the left of $\mathbf{w_i}$ and $\mathbf{w_{d_i}}$.

F5 The surface forms of up to three words to the right of $\mathbf{w_i}$ and $\mathbf{w_{d_i}}$.

F6 The parts-of-speech of the words selected for F4.

F7 The parts-of-speech of the words selected for F5.

Baseline and its Adaptation

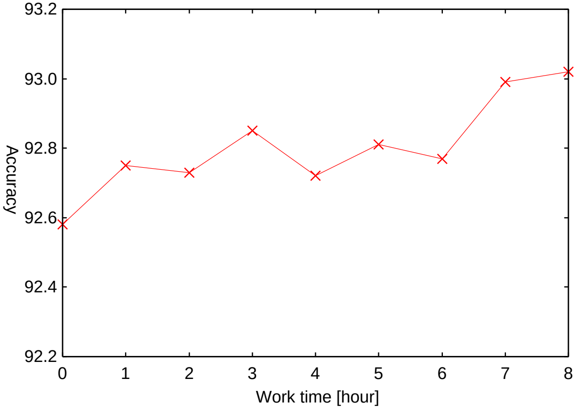
- Baseline: about 20k sent.
  - EHJ (Dictionary example sentences):
    11,700 sentences, 145,925 words
  - NKN (*Nikkei* newspaper articles):
    9,023 sentences, 263,425 words

- Adaptation: Annotate new pairs of a noun and a postposition with the dependency
  1. Find a pair of a noun and a postposition not appearing in the traing corpus
  2. Annotate the dependencies from the noun to its head verb

     c c $\rightarrow$ を (*obj.*) $\rightarrow$ (… 煮立て (**boil**))
  3. 8 hours

Result

- Accuracy

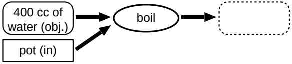


- Low accuracy compared with the in-domain data (96.83%)
- SA improves slowly as the work time increases

Step 4. Predicate-argument structure analysis

- Rule-based (as far as it is)
  - Should be based on a machine learning
  - Have to guess zero-pronouns
- Correspond to the smallest units in the recipe flow

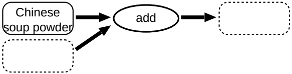
1. **boil** **water** *obj.* **pot** **in**
   煮立て$_{\mathbf{Ac}}$ (Chef, 水$_{\mathbf{F}}$ ４００ ｃｃ$_{\mathbf{Q}}$ を, 鍋$_{\mathbf{T}}$ で)

2. **boils**
   沸騰-し$_{\mathbf{Af}}$ (Food)

3. **add** **Chinese soup powder** *obj.*
   加え$_{\mathbf{Ac}}$ (Chef, 中華 スープ の 素$_{\mathbf{F}}$ を, 水$_{\mathbf{F}}$ に)

4. **dissolve**
   溶か-す$_{\mathbf{Ac}}$ (Chef, 中華 スープ の 素$_{\mathbf{F}}$ を)

Experimental Setting

1. Test data: randomly selected 100 recipes in Japanese

#recipes	#sent.	#words	#NEs
100	724	13,150	3,797

2. Training data
   - WS: (BCCWJ + etc.) + partial annotation
   - NER: *Meet-potato* 1/10 + 9/10 (bad setting ...)
   - SA: (EHJ + NKN) + partial annotation
   - PAS: on going
   - Recipe Flow: on going

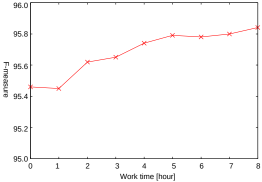
Evaluation 1: Each Step (summary)

Step 1. WS: Word segmentation

Baseline: 95.46%

⇓ (8 hours)

Adaptation: 95.84%

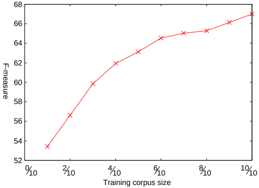


Step 2. NER: Named entity recognition

Baseline: 53.42%

⇓ (5 hours)

Annotation: 67.02%

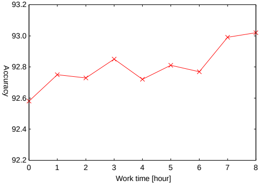


Step 3. SA: Syntactic analysis

Baseline: 92.58%

⇓ (8 hours)

Adaptation: 93.02%



Evaluation 2: Overall

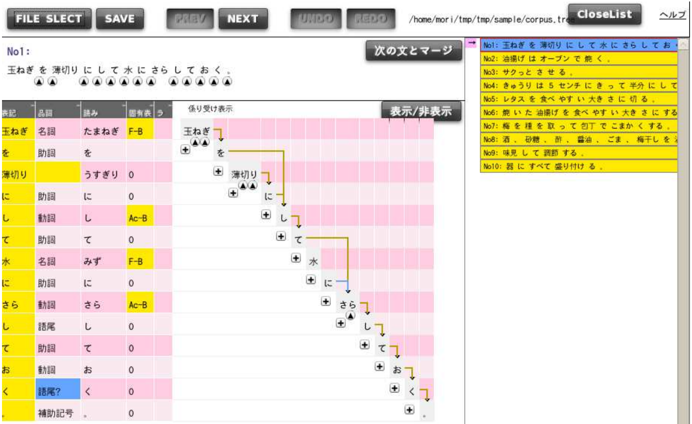
1. Predicate-argument structure
   - PA pair as an evaluation unit
     - 〈煮立て, *obj.*:水-４００-ｃｃ〉
       ⟨boil, *obj.*:400 cc of water⟩
     - 〈煮立て, で:鍋〉
       ⟨boil, by:pot⟩
   - F measure
     Baseline 42.01%
     $\Downarrow$ (8 + 5 + 8 hours) 28.0% error elimination!
     Adaptation 58.27%
   - F measure is still low
     - Because of NER? (67.02% $\ll$ 90%)
     - More annotation required (21 hours $\ll$ ∞)
     - Strict criterion (word boundary incl., etc.)
2. Flow Accuracy

Conclusion

- Recipe Text Analysis
  - Word segmentation, Named entity recognition
  - Syntactic analysis, Predicate-argument structure analysis
- A Machine Learning Approach
  - Systematic domain adaptation
  - Easily trainable to achieve the required accuracy
- Future work
  - Improvement^3
  - Recipe flow construction (search, visualization, ...)
  - Matching with movies to understand the real world
  - Spoken dialog system to help a chef (Smart kitchen)
    - equipped with the recipe flow as the database

PNAT: Pointwise NLP Annotation Tool

- Word segmentation
- Part-of-speech tag
- Pronunciation
- Named entity tag
- Syntactic structure



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