Leveraging Procedural Knowledge for Task-Oriented Search

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Outline

• Background
• Problem Definition
• Proposed Approach
• Experiment
• Conclusion
Entity-centric vs. Task-oriented Search

- Entity-centric search
  - Seek for attribute, feature, related entity, action, etc.
- Task-oriented search
  - Solution seeking and decision support.

How do searchers accomplish tasks using interactive search?

- Decompose the task into required subtasks manually
- Formulate queries manually

organize a conference

- contact the publisher
- choose a hotel
- recruit volunteers
- compare banquet option

consider the number and size of conference rooms

arrange meal catering and menu plan

check for discounted rate
How do Search Engines Assist Searchers?

- Query suggestion as an example

  **Entity-centric search**
  - Suggest attribute, feature, related entity, action, etc.
  - Knowledge of attribute and features
    - Descriptive knowledge
    - Descriptive knowledge base

  **Task-oriented search**
  - Suggest required subtasks, actions, solutions, etc.
  - Knowledge exercised in the accomplishment of a task, i.e. how to do things
    - Procedural knowledge
    - Procedural knowledge base

Existing solutions

*Problem studied in this work*
Think Reversely!

- Can we learn procedural knowledge from users’ search activities and/or query suggestions, and build a PKB automatically?

*Problem also studied in this work*

Task-oriented search

- Suggest required subtasks, actions, solutions, etc.
- Knowledge of exercised in the accomplishment of a task, i.e. how to do things
- **Procedural knowledge**
- Automatically built PKB
- **Procedural knowledge base**
Related Work

• Search intent & task-oriented search
  – *Complex search task* assistant from query log [Hassan et al. 2012, 2014]
  – Task-oriented questions and *how-to Web queries* [Weber 2012]
  – IMine, Subtask Mining @ NCTIR [Liu 2014]

• Procedural knowledge acquisition
  – Ontologies proposed for structured representation of procedural knowledge [Fukazawa 2010, Pareti 2014]
  – Extraction based on structural information [Jung 2010], definition of rules or templates [Addis 2009]
  – Terminology: *goal* vs. *target* vs. *purpose*, *instruction* vs. *action sequence*, *step* vs. *action*, etc.
Outline

• Background
• Problem Definition
  – Terminology
  – Problem 1: Search Task Suggestion (STS)
  – Problem 2: Automatic Procedural Knowledge Base Construction (APKBC)
  – STS and APKBC
• Proposed Approach
• Experiment
• Conclusion
Terminology

A task

- A short and concise summary
- A detailed explanation

Is-achieved-by relation between a parent task and a list of subtasks
- Numbered “Steps”
- Bulleted substeps
- Outgoing free links

Procedural knowledge graph/base (PKB)

How to Reduce the Risk of Mosquito Infestation Around Your Residence

Mosquito infestation can be discouraged by taking simple precautions around your place of residence, in particular, paying special attention to areas that encourage water.

Steps

1. Check the yard for items and areas that permit the pooling of water. Water is the chief attractant for mosquitoes whose larvae develop in stagnant water. Water that has been allowed to stand for as little as four days can be attractive to mosquitoes.

2. Remove or regularly clean objects that permit water pooling. Bird baths should be cleaned out regularly. Avoid leaving buckets, wading pools, toys, gardening items, pots, any other form of containers, etc. to sit outside where they can gather water.

3. Keep your gutters clean. If they are clogged up, they can accumulate water and provide ideal breeding grounds.

4. Stop leaks. If you have leaking taps or pipes, get these fixed. It is likely that the leak is pooling somewhere, not to mention wasting precious water.

How to Fix a Leaky Faucet

How to Clean a Birdbath
Problem 1: Search Task Suggestion (STS)

- When users turn to search engines for information seeking and problem solving, how to leverage existing procedural knowledge to suggest sub search task (i.e. query)?

**Search Task Suggestion:** *Given a procedural knowledge graph $G$ and a task-oriented search $q$, we aim to*

<table>
<thead>
<tr>
<th>Task-oriented search</th>
<th>Procedural knowledge base</th>
</tr>
</thead>
<tbody>
<tr>
<td>search task $q$</td>
<td>task $t$</td>
</tr>
<tr>
<td>search tasks $p_1, ..., p_k$</td>
<td>tasks $s_1, ..., s_n$</td>
</tr>
</tbody>
</table>

1(a) identify the task from $T$ the user intends to accomplish

1(b) retrieve a list of $n$ sub tasks

1(c) suggest the corresponding sub search task
Problem 2: Automatic Procedural Knowledge Base Construction (APKBC)

- Users still face *ad hoc* situations (tasks) that are not covered by an existing PKB, but other searchers may have interacted with search engines to attempt a solution.
- Can we construct a PKB using search queries and relevant documents returned from search engines?

**Automatic Procedural Knowledge Base Construction:** Given a task $t$, we aim to

<table>
<thead>
<tr>
<th>Task-oriented search</th>
<th>Procedural knowledge base</th>
</tr>
</thead>
<tbody>
<tr>
<td>search task $q$</td>
<td>2(a) identify a search task</td>
</tr>
<tr>
<td>search tasks $p_1, \ldots, p_k$</td>
<td>task $t$</td>
</tr>
<tr>
<td>2(b) collect $k$ related search tasks</td>
<td>2(c) identify $n (\leq k)$ search tasks to generate $n$ tasks that can be performed to accomplish the task $t$ with text description.</td>
</tr>
<tr>
<td>tasks $s_1, \ldots, s_n$</td>
<td></td>
</tr>
</tbody>
</table>
Outline

• Background
• Problem Definition
• Proposed Approach
  – Basic Idea
  – Three-way Parallel Corpus Construction
  – Feature Definition and Model Construction
• Experiment
• Conclusion
Queryable Phrase/Task Description Extraction: Basic Idea

- Joint learning from available artifacts

**Existing search log**
- Can reveal how to formulate queries
- Cannot cover how to search for procedural knowledge

**Existing PKBs**
- Can indicate how to accomplish tasks
- Are not optimized for interactive search

**Existing Web documents**
- Can exemplify how to describe tasks
- Do not focus on procedure

*Can we take the advantage of all the artifacts and learn from each other?*

**Three-way parallel corpus construction**

Query phrase extraction

Task description extraction
Three-way Parallel Corpus Construction

- Parallel corpus := a set of matching triples

Example: Grow Taller
http://www.wikihow.com/Grow-Taller

How to Grow Taller
Your height is largely determined by your genetics and environment. Although several factors that determine your height are out of your control, there are a few things you can do to grow to your full potential. Once your growth plates have closed, your height stays the same. Before that window closes, however, you can use the following techniques and exercises to reach your full potential.

Steps
1. Understand that most of your height will be determined by genetics of your family. Height is a polygenic trait, meaning that it's influenced by several different genes. Having two short parents doesn't necessarily mean you'll be short, just as two tall parents won't make you a towering giant. However, if most of the people on both sides of your family are short, odds are that you'll be short, too. Don't be discouraged, though. The truth is that you can't know how tall you'll be until you reach full physical adulthood in your mid twenties.
   - Calculate your projected height. Working in inches or centimetres, you can try to predict your height based on the height of your parents.
     - Add up your mom and dad's heights (in inches or cm).
     - Add 5 inches (13 cm) if you're a boy; subtract 5 inches (13 cm) if you're a girl.
Three-way Parallel Corpus Construction (cont’d)

• Step 1: Extracting seed triples from search query log
  – Scan through the entire search query log to find each query $q$ that matches the description of task $t$.
  – Extract the textual content from the top relevant documents to retrieve the context $c$.

Search queries in a session

![grow taller]

Exact matching is used in the experiment.

Task descriptions in PKBs (Grow Taller)

• If you’re from a tall family and you’re not growing by your mid-teens, or if your height hasn’t changed much from before puberty or during puberty, then it’s a good idea to see a doctor ...
• The human growth hormone (HGH) is produced naturally in our bodies, especially during deep or slow wave sleep. Getting good, sound sleep will encourage the production of HGH, which is created in the pituitary gland.
• ... There are tons of “grow taller” exercises on the Internet, which claim to help you grow ...

Contexts retrieved from the Web

• ... If you’re from a tall family and you’re not growing by your mid-teens, or if your height hasn’t changed much from before puberty to during puberty, then it’s a good idea to see a doctor.
• The growth hormone (HGH) is produced naturally in the pituitary gland during deep or slow wave sleep.
Step 2 (optional): Manually creating search tasks for tasks in the PKB

- Use the summary of the task \( t \) to form a search query \( q \) and issue it to the search engine to extract context \( c \).
- Exclude this triple due to “artificiality”!

Task descriptions in PKBs (Grow Taller)

- If you’re from a tall family and you’re not growing by your mid-teens, or if your height hasn’t changed much from before puberty or during puberty, then it’s a good idea to see a doctor …
- The human growth hormone (HGH) is produced naturally in our bodies, especially during deep or slow wave sleep. Getting good, sound sleep will encourage the production of HGH, which is created in the pituitary gland.
- … There are tons of “grow taller” exercises on the Internet, which claim to help you grow …

Contexts retrieved from the Web

- … If you’re from a tall family and you’re not growing by your mid-teens, or if your height hasn’t changed much from before puberty to during puberty, then it’s a good idea to see a doctor.
- The growth hormone (HGH) is produced naturally in the pituitary gland during deep or slow wave sleep.
Three-way Parallel Corpus Construction (cont’d)

• Step 3: Collecting related queries
  – Combine the user-issued queries from the same session (from Step 1) and the list of queries suggested by the search engine (from Steps 1 and 2).

Search queries in a session
- grow taller
- human growth hormone
- grow taller exercises
- ...

Task descriptions in PKBs (Grow Taller)
- If you’re from a tall family and you’re not growing by your mid-teens, or if your height hasn’t changed much from before puberty or during puberty, then it’s a good idea to see a doctor …
- The human growth hormone (HGH) is produced naturally in our bodies, especially during deep or slow wave sleep. Getting good, sound sleep will encourage the production of HGH, which is created in the pituitary gland.
- … There are tons of “grow taller” exercises on the Internet, which claim to help you grow …

Contexts retrieved from the Web
- … If you’re from a tall family and you’re not growing by your mid-teens, or if your height hasn’t changed much from before puberty to during puberty, then it’s a good idea to see a doctor.
- The growth hormone (HGH) is produced naturally in the pituitary gland during deep or slow wave sleep.
Three-way Parallel Corpus Construction (cont’d)

• **Step 4: Expanding parallel corpus**
  – For each related query $p$, find the subtasks $s_1, ..., s_n$ that contains $p$ in its summary or explanation, and retrieve its context $d$.
  – Discard unmatched related queries or task descriptions.

---

**Search queries in a session**
- grow taller
- human growth hormone
- grow taller exercises
- ...

**Task descriptions in PKBs (Grow Taller)**
- **Exact matching is used in the experiment.**
- If you’re from a tall family and you’re not growing by your mid-teens, or if your height hasn’t changed much from before puberty or during puberty, then it’s a good idea to see a doctor...
- The human growth hormone (HGH) is produced naturally in our bodies, especially during deep or slow wave sleep. Getting good, sound sleep will encourage the production of HGH, which is created in the pituitary gland.
- There are tons of “grow taller” exercises on the Internet, which claim to help you grow...

**Contexts retrieved from the Web**
- If you’re from a tall family and you’re not growing by your mid-teens, or if your height hasn’t changed much from before puberty to during puberty, then it’s a good idea to see a doctor.
- The growth hormone (HGH) is produced naturally in the pituitary gland during deep or slow wave sleep.
Three-way Parallel Corpus Construction (cont’d)

• Step 5: Annotating BIO
  – Find the contiguous sequence of words from the task \(t\) (context \(c\)) that is most relevant to the query \(q\) (task \(t\)’s summary or explanation).

Search queries in a session

- grow taller
- human growth hormone
- grow taller exercises
- ...

Task descriptions in PKBs (Grow Taller)

- If you’re from a tall family and you’re not growing by your mid-teens, or if your height hasn’t changed much from before puberty during puberty, then it’s a good idea to see a doctor ...
- The human growth hormone (HGH) is produced naturally in our bodies, especially during deep or slow wave sleep. Getting good, sound sleep will encourage the production of HGH, which is created in the pituitary gland.
- ... There are tons of “grow taller” exercises on the Internet, which claim to help you grow ...

Exact matching is used for annotating task in the experiment.

Selected the sentences from context that contain all the tokens in the task summary and 70%+ of the tokens in the task explanation, and annotated the minimal span that contains those overlapping tokens.

Contexts retrieved from the Web

- ... If you’re from a tall family and you’re not growing by your mid-teens, or if your height hasn’t changed much from before puberty during puberty, then it’s a good idea to see a doctor ...
- The growth hormone (HGH) is produced naturally in the pituitary gland during deep or slow wave sleep.
## Feature Definition

- Feature list for both **context** and **task**

<table>
<thead>
<tr>
<th>Category</th>
<th>Description / Motivation</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location (LOC)</td>
<td>Appears in the task summary and explanation</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>“Skimmable information that readers can quickly understand” should be provided in the title and the beginning sentence of each step.</td>
<td></td>
</tr>
<tr>
<td>Part of speech (POS)</td>
<td></td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>Both the article title and the first sentence in each step begin with a verb in bare infinitive form.</td>
<td></td>
</tr>
<tr>
<td>Parse (PAR)</td>
<td>Basic Stanford dependency types</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Named entity, noun phrase, verb phrase</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td><em>Identify the task facets (subsidiary resources or constraints, etc.)</em></td>
<td></td>
</tr>
<tr>
<td>Word, context</td>
<td>Surface, stem, TF-IDF score</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Surface, stem, TF-IDF score, POS tags of previous/next word</td>
<td>78</td>
</tr>
</tbody>
</table>
# Model Construction

- Word sequence labeling for **query** construction, **task** summary and explanation construction

<table>
<thead>
<tr>
<th>Problem</th>
<th>Word sequence labeling problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>$M^Q$</td>
</tr>
<tr>
<td></td>
<td>$M^{TS}$</td>
</tr>
<tr>
<td></td>
<td>$M^{TE}$</td>
</tr>
<tr>
<td>Features</td>
<td>The same feature set, except that location is only used for query</td>
</tr>
<tr>
<td>Training set</td>
<td>Features $X^t$, labels $Y^t$ extracted from task description</td>
</tr>
<tr>
<td>Feature set</td>
<td>Features $X^c$, labels $Y^c$ extracted from context</td>
</tr>
<tr>
<td>Prediction objective</td>
<td>$y^t*$ = argmax $p(y^t</td>
</tr>
<tr>
<td></td>
<td>$y^c*$ = argmax $p(y^c</td>
</tr>
<tr>
<td></td>
<td>$y^c*$ = argmax $p(y^c</td>
</tr>
<tr>
<td>Output</td>
<td>$y^t*$ = 0...0BQTQIQ0...0</td>
</tr>
<tr>
<td></td>
<td>$y^c*$ = 0...0BSTSTSTST0...0BTEITEITE0...0</td>
</tr>
</tbody>
</table>

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STS and APKBC

Task-oriented search

1(a) identify task
2(a) identify search task

Procedural knowledge base

1(b) retrieve subtasks
2(b) collect related search tasks

Search task $q$

Task $t$

Search tasks $p_1, \ldots, p_k$

Tasks $s_1, \ldots, s_n$

Need a search intent model to retrieve task-oriented search tasks (future work)

Generate queryable phrases/task descriptions using an algorithm that learns how searchers formulate queries/editors describe procedural knowledge

Exact matching or retrieval based method

Refer to PKB to retrieve related subtasks
Outline

• Background
• Problem Definition
• Proposed Approach
• Experiment
  – Data Preparation
  – Experiment Settings
  – Search Task Suggestion Result
  – Procedural Knowledge Base Construction Result
• Conclusion
Data Preparation

• English wikiHow data dump
• AOL search query log
• Queries suggested by search engines
• Context extracted from search engines
## Experiment Settings

- **Sequence labeling vs. end-to-end evaluation**

<table>
<thead>
<tr>
<th></th>
<th>Sequence labeling evaluation</th>
<th>End-to-end evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gold standard</strong></td>
<td>Automatically labeled parallel corpus</td>
<td>Manual judgment</td>
</tr>
<tr>
<td><strong>Test set</strong></td>
<td>10-fold cross validation</td>
<td>50 randomly sampled triples</td>
</tr>
<tr>
<td><strong>Evaluation methods</strong></td>
<td>Precision, Recall, F-1, averaged on all test instances (macro-averaged) and on each task then across all tasks (micro-averaged), F-1 based ROUGE-2 and -S4</td>
<td>Macro-averaged and micro-averaged Precision@8, MAP</td>
</tr>
<tr>
<td><strong>Baseline methods</strong></td>
<td>CRF (proposed), HMM (surface), LR, SVM, feature ablation</td>
<td>Google, Bing, wikiHow</td>
</tr>
<tr>
<td><strong>Feature extractors, learners</strong></td>
<td>Stanford CoreNLP: sentence, token, stem, POS, dependency parse, chunk, named entity</td>
<td>MALLET: CRF, HMM; LibLinear: LR, SVM</td>
</tr>
</tbody>
</table>
Search Task Suggestion Result

• Query construction result
  – The proposed CRF-based approach outperforms other classifiers*, esp. independent classifiers (max. SVM).
  – Also outperforms each feature category** (max. W/ WORD), and LOU studyns (max. W/O POS).

![Graph showing performance metrics for different classifiers and feature categories.](image-url)
## Search Task Suggestion Result (cont’d)

- **End-to-end example**
  - Slim down
  - Play red alert2

<table>
<thead>
<tr>
<th>PROPOSED</th>
<th>GOOGLE</th>
<th>BING</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Task: slim down</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>weight loss</td>
<td>slim down diet</td>
<td>the slim down club</td>
</tr>
<tr>
<td>heavy food</td>
<td>7 day slim down</td>
<td>how to slim down fast</td>
</tr>
<tr>
<td>junk food</td>
<td>weight loss</td>
<td>slim down challenge</td>
</tr>
<tr>
<td>keep up the mood</td>
<td>slim down thighs</td>
<td>how to slim down legs</td>
</tr>
<tr>
<td><strong>Task: play red alert2</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>build a barracks</td>
<td>red alert 2 complete (iso) original 2 disc</td>
<td>play red alert 2 game</td>
</tr>
<tr>
<td>build a war factory</td>
<td>play red alert 2 free</td>
<td>play ra2 online</td>
</tr>
<tr>
<td>radar should</td>
<td>play red alert 2 online free</td>
<td>red alert 2 download</td>
</tr>
<tr>
<td>build a power plant/tesla reactor</td>
<td>play red alert 3</td>
<td>free red alert 3</td>
</tr>
</tbody>
</table>
Search Task Suggestion Result (cont’d)

• End-to-end evaluation
  – Proposed approach is tailored for task-oriented search.
  – Current general-purpose commercial search engines are designed for entity-centric search.
  – Current search engines tend to suggest queries by appending keywords such as product, image, logo, online, free, etc.
Automatic Procedural Knowledge Base Construction Result

- Task summary generation result
  - All scores are lower than in the query construction task.
  - CRF outperforms other classifiers* (max. SVM), each feature category\textsuperscript{ns} (max. W/ POS), and LOU study\textsuperscript{ns} (max. W/O WORD).
Automatic Procedural Knowledge Base Construction Result (cont’d)

• Task explanation generation result
  – CRF outperforms other classifiers* (max. HMM, implying the importance of surface forms and sequence labeling nature).
  – Also outperforms each feature category ns (max. W/ WORD).
  – LOU study shows W/O PAR performs the best in terms of ROUGE.
Automatic Procedural Knowledge Base Construction Result (cont’d)

- **End-to-end example**
  - Search engine would suggest “sign up for airbnb coupon” for “sign up for airbnb”, which implies an important resource for the task.

<table>
<thead>
<tr>
<th>Task: sign up for airbnb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airbnb is no longer running the $50 OFF $200 promo but you can still save $25 OFF Your First Airbnb Stay of $75 or more by copying and pasting this link into your browser…</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Task: make blueberry banana bread</th>
</tr>
</thead>
<tbody>
<tr>
<td>Please don’t use regular whole wheat in this recipe – the loaf will turn out very dense</td>
</tr>
<tr>
<td>Add the wet ingredients – the egg mixture to the flour mixture and stir with a rubber spatula until just combined</td>
</tr>
<tr>
<td>If you’re in need of a quick, easy and delicious way to use up the ripe bananas in your house … definitely</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Task: become a cell phone dealer</th>
</tr>
</thead>
<tbody>
<tr>
<td>However, the cell phone provider may place restrictions on the manner in which you can use its company name, phone brands and images</td>
</tr>
<tr>
<td>Visit the state’s business licensing agency’s website and your city’s occupational/business licensing department’s website to determine if you need a license for your prepaid cell phone business</td>
</tr>
</tbody>
</table>
Automatic Procedural Knowledge Base Construction Result (cont’d)

• End-to-end evaluation
  – Automatic approach performs worth than manual curation in building a new PKB from scratch.
  – But still discover relevant subtasks that are not covered in the current PKB, which delivers the freshest information that is hardly added and updated instantly in a manual process.
Outline

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Conclusion

• Investigated two problems
  – Search task suggestion using procedural knowledge
  – Automatic procedural knowledge base construction from search activities
• Proposed to create a three-way parallel corpus of queries, query contexts, and task descriptions.
• Applied CRF-based sequence labeling models for query construction and task description generation.
• Future work
  – User study
  – Joint ranking
  – APKBC using a natural language generation approach
Thanks! Questions?

**Related Workshop Talk**

Answering Task-Oriented Questions from the Web
*WebQA Workshop*,
Thursday 11am

**Code & Resources**

[http://github.com/ziy/pkb](http://github.com/ziy/pkb)

**Acknowledgement**

Travel is sponsored by SIGIR Student Travel Grant!

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Parallel Corpus Construction Result

• Related query to subtask mapping
  – Identified 1,182 query-task pairs using exact matching.

• Task to context mapping
  – Selected the sentences that contain all the tokens in the task summary and 70%+ of the tokens in the task explanation.
  – Annotated the minimal span that contains those overlapping tokens.
How Do Search Engines and Users Response to Task-Oriented Queries?

• The number (and percentage) of suggested queries (or queries issued in the same session) that are mentioned within the description of some subtask.
  – “New Words”: E.g. slim down -> slim down diet
  – Low quality maybe due to an over-simplified session detection method
Search Task Suggestion

Given a task-oriented search task represented by query $q$

(a) Identify task

- Retrieve a list of candidate tasks from PKB that mention the query $q$ in either the summary or explanation.
- Select the task $t$ that maximizes the likelihood of each candidate occurrence, i.e. $p(y^t = B^{q\top^q\cdots\top^q} | x^t; M^Q)$.

(b) Retrieve subtasks

- Retrieve the first-level subtasks $s_1, \ldots, s_n$ of task $t$.

(c) Suggest and create sub search task

- Extract query candidates for each subtask $s_i$ using $M^Q$ again.
- Rank by $p(y^{s_i} = B^{q\top^q\cdots\top^q} | x^{s_i}; M^Q)$.
Automatic Procedural Knowledge Base Construction

Given a task $t$,

(a) Identify search task
   - Apply $M^Q$ to extract a task-oriented search query $q$.

(b) Collect related search tasks
   - Identify the queries $p_i$ related to $q$ in both search logs and suggested queries.

(c) Identify and generate sub tasks
   - Extract relevant document snippets for each related query $p_i$ from search engines.
   - Apply $M^{TS/E}$ to extract task summary and explanation.

Search engines are able to correctly suggest related tasks to the user, rather than related entities or attributes.

Search logs reveal how a specific user works to accomplish a task.
Data Preparation

• English wikiHow data dump
  – Used a modified version of WikiTeam tool.
  – Obtained 149,975 articles that are *non-redirect*, *in namespace “0”*, *non-stub*, *with “Introduction” and “Steps”*.
  – Created a PKB of 1,488,587 tasks, 1,439,217 relations.

• AOL search query log
  – 21M (10M unique) queries in total.
  – After downcase and remove non-alphanumeric characters, 639 unique queries match 619 task summaries after whitespace and punctuation marks ignored.
  – Identified 33,548 related query candidates by collecting the queries that were issued by the same user within 30 minutes after issued each the matching query.
Data Preparation (cont’d)

• Queries suggested by search engines
  – Randomly sampled 1,000 non-primitive tasks from PKB that do not appear in the query log.
  – Collected 9,906 related queries suggested by Google (avg. 6.11, max. 8) and 9,715 (avg. 5.99, max. 13) related queries suggested by Bing for the 1,639 queries.

• Context extracted from search engines
  – Extracted URLs from Google’s first search result page and excluded wikihow.com domain (for generalizability), google.com domain, URLs that have no subpaths (navigational search results), and downloaded 7,440 context documents.
  – Used Boilerpipe to extract 7,437 documents as contexts, and additional 3,512 documents for end-to-end evaluation.
Search Task Suggestion Result (cont’d)

• 5 most contributing non-word features
  – Query phrases are more likely extracted from the summary part of a description due to its clarity and conciseness.
  – Singular nouns and verbs are indicators to begin a query.
  – Verb phrase is used to decide whether to continue a query.

<table>
<thead>
<tr>
<th></th>
<th>0 → B^Q</th>
<th>B^Q → I^Q</th>
<th>I^Q → I^Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(POS: NNP)</td>
<td>POS^-1: VB</td>
<td>(LOC: sum)</td>
</tr>
<tr>
<td>2</td>
<td>(LOC: sum)</td>
<td>(LOC: sum)</td>
<td>POS^-1: IN</td>
</tr>
<tr>
<td>3</td>
<td>DEP: ccomp</td>
<td>POS^-1: VBP</td>
<td>VP</td>
</tr>
<tr>
<td>4</td>
<td>(POS: VB)</td>
<td>POS^-1: NNP</td>
<td>DEP: dobj</td>
</tr>
<tr>
<td>5</td>
<td>DEP: nsubjpass</td>
<td>POS^-1: NN</td>
<td>POS^{+1}: JJ</td>
</tr>
</tbody>
</table>
Automatic Procedural Knowledge Base Construction Result (cont’d)

• 5 most contributing non-word features
  – Nouns and verbs are crucial for construction task description.
  – Verbs are more preferred to begin the summary than nouns.
  – To begin an explanation, it prefers the “begin” of a sentence and/ a dependency label of nsubj.
  – Verb phrases are also important.

<table>
<thead>
<tr>
<th></th>
<th>Summary</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><strong>POS</strong>: VB</td>
<td><strong>POS</strong>&lt;sup&gt;−1&lt;/sup&gt;: VB</td>
</tr>
<tr>
<td>2</td>
<td><strong>POS</strong>: VBP</td>
<td><strong>POS</strong>&lt;sup&gt;−1&lt;/sup&gt;: VBP</td>
</tr>
<tr>
<td>3</td>
<td><strong>POS</strong>: NN</td>
<td><strong>POS</strong>&lt;sup&gt;−1&lt;/sup&gt;: NNP</td>
</tr>
<tr>
<td>4</td>
<td><strong>DEP</strong>: appos</td>
<td><strong>POS</strong>&lt;sup&gt;−1&lt;/sup&gt;: NN</td>
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<tr>
<td>5</td>
<td><strong>POS</strong>: NNP</td>
<td><strong>DEP</strong>: case</td>
</tr>
</tbody>
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