CS345
Data Mining

Mining the Web for Structured Data

Our view of the web so far...

- Web pages as atomic units
- Great for some applications
  - e.g., Conventional web search
- But not always the right model

Going beyond web pages

- Question answering
  - What is the height of Mt Everest?
  - Who killed Abraham Lincoln?
- Relation Extraction
  - Find all <company,CEO> pairs
- Virtual Databases
  - Answer database-like queries over web data
  - E.g., Find all software engineering jobs in Fortune 500 companies

Question Answering

- E.g., Who killed Abraham Lincoln?
- Naïve algorithm
  - Find all web pages containing the terms “killed” and “Abraham Lincoln” in close proximity
  - Extract k-grams from a small window around the terms
  - Find the most commonly occuring k-grams

Question Answering

- Naïve algorithm works fairly well!
- Some improvements
  - Use sentence structure e.g., restrict to noun phrases only
  - Rewrite questions before matching
    - “What is the height of Mt Everest” becomes “The height of Mt Everest is <blank>”
- The number of pages analyzed is more important than the sophistication of the NLP
  - For simple questions

Reference: Dumais et al

Relation Extraction

- Find pairs (title, author)
  - Where title is the name of a book
  - E.g., (Foundation, Isaac Asimov)
- Find pairs (company, hq)
  - E.g., (Microsoft, Redmond)
- Find pairs (abbreviation, expansion)
  - (ADA, American Dental Association)
- Can also have tuples with >2 components

Relation Extraction

- Assumptions:
  - No single source contains all the tuples
  - Each tuple appears on many web pages
  - Components of tuple appear “close” together
    - Foundation, by Isaac Asimov
    - Isaac Asimov’s masterpiece, the Foundation trilogy
  - There are repeated patterns in the way tuples are represented on web pages

Naïve approach

- Study a few websites and come up with a set of patterns e.g., regular expressions

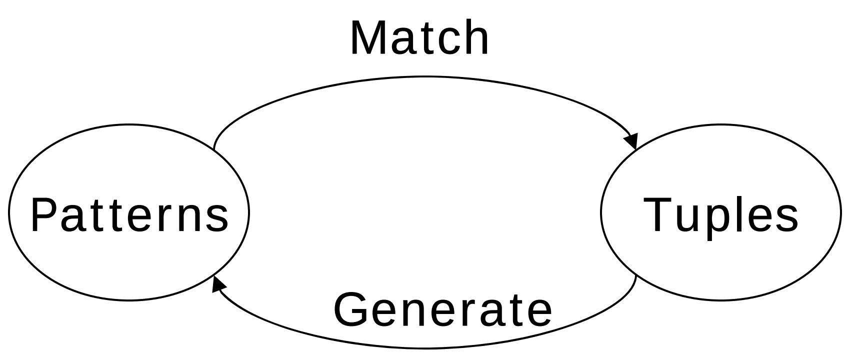
```
letter = [A-Za-z. ]
title = letter{5,40}
author = letter{10,30}
<b>(title)</b> by (author)
```

Problems with naïve approach

- A pattern that works on one web page might produce nonsense when applied to another
  - So patterns need to be page-specific, or at least site-specific
- Impossible for a human to exhaustively enumerate patterns for every relevant website
  - Will result in low coverage

Better approach (Brin)

- Exploit duality between patterns and tuples
  - Find tuples that match a set of patterns
  - Find patterns that match a lot of tuples
  - DIPRE (Dual Iterative Pattern Relation Extraction)



DIPRE Algorithm

1. R ← SampleTuples
   - e.g., a small set of <title,author> pairs
2. O ← FindOccurrences(R)
   - Occurrences of tuples on web pages
   - Keep some surrounding context
3. P ← GenPatterns(O)
   - Look for patterns in the way tuples occur
   - Make sure patterns are not too general!
4. R ← MatchingTuples(P)
5. Return or go back to Step 2

Occurrences

- e.g., Titles and authors
- Restrict to cases where author and title appear in close proximity on web page

 Foundation by Isaac Asimov (1951)

- url = http://www.scifi.org/bydecade/1950.html
- order = [title,author] (or [author,title])
  - denote as 0 or 1
- prefix = " " (limit to e.g., 10 characters)
- middle = " by "
- suffix = "(1951) "
- occurrence =

('Foundation','Isaac Asimov',url,order,prefix,middle,suffix)

Patterns

 Foundation by Isaac Asimov (1951)

<p> Nightfall by Isaac Asimov (1941)

- order = [title,author] (say 0)
- shared prefix =
- shared middle = by
- shared suffix = (19
- pattern = (order,shared prefix, shared middle, shared suffix)

URL Prefix

- Patterns may be specific to a website
  - Or even parts of it
- Add urlprefix component to pattern

http://www.scifi.org/bydecade/1950.html occurence:
 Foundation by Isaac Asimov (1951)

http://www.scifi.org/bydecade/1940.html occurence:
<p> Nightfall by Isaac Asimov (1941)

shared urlprefix = http://www.scifi.org/bydecade/19
pattern = (urlprefix,order,prefix,middle,suffix)

Generating Patterns

1. Group occurences by order and middle
2. Let O = set of occurences with the same order and middle
   - pattern.order = O.order
   - pattern.middle = O.middle
   - pattern.urlprefix = longest common prefix of all urls in O
   - pattern.prefix = longest common prefix of occurrences in O
   - pattern.suffix = longest common suffix of occurrences in O

Example

http://www.scifi.org/bydecade/1950.html occurence:

 Foundation by Isaac Asimov (1951)

http://www.scifi.org/bydecade/1940.html occurence:

<p> Nightfall by Isaac Asimov (1941)

- order = [title,author]
- middle = “ by ”
- urlprefix = http://www.scifi.org/bydecade/19
- prefix = “<b> ”
- suffix = “ (19”

Example

http://www.scifi.org/bydecade/1950.html occurence:
Foundation, by Isaac Asimov, has been hailed…

http://www.scifi.org/bydecade/1940.html occurence:
Nightfall, by Isaac Asimov, tells the tale of…

- order = [title,author]
- middle = “, by ”
- urlprefix = http://www.scifi.org/bydecade/19
- prefix = “”
- suffix = “, ”

Pattern Specificity

- We want to avoid generating patterns that are too general
- One approach:
  - For pattern p, define specificity = |urlprefix||middle||prefix||suffix|
  - Suppose n(p) = number of occurences that match the pattern p
  - Discard patterns where $n(p) < n_{min}$
  - Discard patterns p where specificity(p)n(p) < threshold

Pattern Generation Algorithm

1. Group occurences by order and middle
2. Let O = a set of occurences with the same order and middle
3. p = GeneratePattern(O)
4. If p meets specificity requirements, add p to set of patterns
5. Otherwise, try to split O into multiple subgroups by extending the urlprefix by one character
   - If all occurences in O are from the same URL, we cannot extend the urlprefix, so we discard O

Extending the URL prefix

Suppose O contains occurences from urls of the form

http://www.scifi.org/bydecade/195?.html

http://www.scifi.org/bydecade/194?.html

urlprefix = http://www.scifi.org/bydecade/19

When we extend the urlprefix, we split O into two subsets:

urlprefix = http://www.scifi.org/bydecade/194

urlprefix = http://www.scifi.org/bydecade/195

Finding occurrences and matches

- Finding occurrences
  - Use inverted index on web pages
  - Examine resulting pages to extract occurrences
- Finding matches
  - Use urlprefix to restrict set of pages to examine
  - Scan each page using regex constructed from pattern

Relation Drift

- Small contaminations can easily lead to huge divergences
- Need to tightly control process
- Snowball (Agichtein and Gravano)
  - Trust only tuples that match many patterns
  - Trust only patterns with high “support” and “confidence”

Pattern support

- Similar to DIPRE
- Eliminate patterns not supported by at least n_{min} known good tuples
  - either seed tuples or tuples generated in a prior iteration

Pattern Confidence

- Suppose tuple t matches pattern p
- What is the probability that tuple t is valid?
- Call this probability the confidence of pattern p, denoted conf(p)
  - Assume independent of other patterns
- How can we estimate conf(p)?

Categorizing pattern matches

- Given pattern p, suppose we can partition its matching tuples into groups p.positive, p.negative, and p.unknown
- Grouping methodology is application-specific

Categorizing Matches

- e.g., Organizations and Headquarters
  - A tuple that exactly matches a known pair (org,hq) is positive
  - A tuple that matches the org of a known tuple but a different hq is negative
    - Assume org is key for relation
  - A tuple that matches a hq that is not a known city is negative
    - Assume we have a list of valid city names
  - All other occurrences are unknown

Categorizing Matches

- Books and authors
  - One possibility...
  - A tuple that matches a known tuple is positive
  - A tuple that matches the title of a known tuple but has a different author is negative
    - Assume title is key for relation
  - All other tuples are unknown
- Can come up with other schemes if we have more information
  - e.g., list of possible legal people names

Example

- Suppose we know the tuples
  - Foundation, Isaac Asimov
  - Startide Rising, David Brin
- Suppose pattern p matches
  - Foundation, Isaac Asimov
  - Startide Rising, David Brin
  - Foundation, Doubleday
  - Rendezvous with Rama, Arthur C. Clarke
- |p.positive| = 2, |p.negative| = 1, |p.unknown| = 1

Pattern Confidence (1)

pos(p) = |p.positive|

neg(p) = |p.negative|

un(p) = |p.unknown|

conf(p) = pos(p)/(pos(p)+neg(p))

Pattern Confidence (2)

- Another definition – penalize patterns with many unknown matches

$$conf(p) = pos(p)/(pos(p)+neg(p)+un(p)\alpha)$$

where $0 \cdot \alpha \cdot 1$

Tuple confidence

- Suppose candidate tuple t matches patterns p_1 and p_2
- What is the probability that t is an valid tuple?
  - Assume matches of different patterns are independent events

Tuple confidence

- Pr[t matches p_1 and t is not valid] = 1-conf(p_1)
- Pr[t matches p_2 and t is not valid] = 1-conf(p_2)
- Pr[t matches $\{p_1, p_2\}$ and t is not valid] = (1-conf(p_1))(1-conf(p_2))
- Pr[t matches $\{p_1, p_2\}$ and t is valid] = 1 - (1-conf(p_1))(1-conf(p_2))

- If tuple t matches a set of patterns P
  conf(t) = 1 - $\Pi_{p \in P}$(1-conf(p))

Snowball algorithm

1. Start with seed set R of tuples
2. Generate set P of patterns from R
   - Compute support and confidence for each pattern in P
   - Discard patterns with low support or confidence
3. Generate new set T of tuples matching patterns P
   - Compute confidence of each tuple in T
4. Add to R the tuples t2T with conf(t)>threshold.
5. Go back to step 2

Some refinements

- Give more weight to tuples found earlier
- Approximate pattern matches
- Entity tagging

Approximate matches

- If tuple t matches a set of patterns P

$$conf(t) = 1 - \Pi_{p2P}(1-conf(p))$$

- Suppose we allow tuples that don't exactly match patterns but only approximately

$$conf(t) = 1 - \Pi_{p2P}(1-conf(p)match(t,p))$$