Diagnoses, Decisions, and Outcomes: Web Search as Decision Support for Cancer

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Decisions, Decisions

• People frequently turn to web for decision support for health issues
  • Internet is second most common information source for cancer patients
  • Majority of patients who use the internet say it influenced their decisions

• We seek to understand the use of Web search as a medical decision support system
  • Quality of information is known to be mixed
  • Little is currently known about what patients need
  • We will focus on treatment decisions
Decisions, Decisions

• Focus on **prostate cancer**
• It is the “archetypical condition" for the use of treatment decision aids
  • Many different treatments with similar outcomes
  • Choice often comes down to personal preference
Contributions

• Dataset creation
  • Create a hierarchy of treatments and associated search terms
  • Annotated corpus of 272 timelines of treatment search queries

• Characterization of different phrases of treatment over time
  • N-grams from search queries
  • Visualizations illustrating how searches evolve over time
  • Analysis of treatments searched during decision-making
Treatment Ontology

• Treatment queries range from general (“treatment options”) to specific (“low-dose radiation seed implants”)

• Created a hierarchical ontology of known treatments, moving from broad categories down to detailed therapies
  - after extensive review of literature on management of prostate cancer

• Supports:
  • Filtering for relevant logs
  • Characterizing different treatment types
  • Query specificity based on depth in hierarchy
# Treatment Hierarchy

<table>
<thead>
<tr>
<th>Level 0</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
<th>Search terms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>Surgery</td>
<td>Open</td>
<td>—</td>
<td>surgery, prostatectomy, prostate removal, remove prostate</td>
</tr>
<tr>
<td>Treatment</td>
<td>Surgery</td>
<td>Laparoscopic</td>
<td>—</td>
<td>open [Surgery]</td>
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<tr>
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<td>Surgery</td>
<td>Laparoscopic</td>
<td>Robotic</td>
<td>laparoscopic, minimally invasive</td>
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<tr>
<td>Treatment</td>
<td>Radiation</td>
<td>—</td>
<td>—</td>
<td>robot, robotic, da( )vinci</td>
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<tr>
<td>Treatment</td>
<td>Radiation</td>
<td>Brachytherapy</td>
<td>—</td>
<td>radiation</td>
</tr>
<tr>
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<td>Brachytherapy</td>
<td>LDR</td>
<td>brachytherapy, brachy, seed(s)</td>
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<tr>
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<td>HDR</td>
<td>low dose [Brachytherapy], ldr</td>
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<tr>
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<td>—</td>
<td>high dose [Brachytherapy], hdr</td>
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<tr>
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<td>External</td>
<td>3DRT</td>
<td>external [Radiation], external beam, ebrt</td>
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<tr>
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<td>External</td>
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<td>3drt, 3dcr, conformal</td>
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<td>imrt, intensity-modulated, igrt, calypso</td>
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<td>Proton</td>
<td>sbrt, stereotactic body, cyber( )knife, gamma( )knife, x-knife</td>
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<td>Drugs</td>
<td>Radium 223</td>
<td>proton, pencil beam</td>
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<tr>
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<td>Hormone therapy</td>
<td>—</td>
<td>—</td>
<td>radium 223, radium dichloride, xofigo</td>
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<td>—</td>
<td>various hormone-therapeutic drugs are categorized</td>
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<td>—</td>
<td>various hormone-therapeutic drugs are categorized</td>
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<tr>
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<td>Chemotherapy</td>
<td>Drugs</td>
<td>—</td>
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<td>various chemotherapeutic drugs are categorized</td>
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<td>—</td>
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<td>—</td>
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<td>no treatment, without treatment</td>
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<td>Observation</td>
<td>Surveillance</td>
<td>—</td>
<td>waiting [Treatment]</td>
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<tr>
<td>Treatment</td>
<td>Observation</td>
<td>None</td>
<td>—</td>
<td>active surveillance</td>
</tr>
</tbody>
</table>
Log Dataset

• Anonymized search and browsing logs
  • 18 month timeframe (Mar13 – Aug14)
  • Consenting users of Internet Explorer browser
  • Filtered users based on:
    • Searched for “prostate cancer” 3x
    • Searched for a treatment-related term (given our focus)

→ 3066 search histories related to prostate cancer treatment
Data > Experiential vs. Exploratory

• Need to identify those who were experiencing prostate cancer (experiential) vs. those who were interested in it (exploratory)
  • Want to exclude healthcare professionals who search for billing codes, etc.

• Determine based on an assessment of sustained and focused interest
  • Sustained = long-lived after initial burst
  • Focused = consumes large portion of search history

• Train a classifier on set of 100 histories to identify experiential searchers (96% precision, 78% recall)

→ 1413 experiential searchers
Data > Age Composition

- Auxiliary form of validation
- Expect to see older skew given distribution of prostate cancer in population
- Used age references in queries
  - E.g., “at/age __”, “__ year(s) old”
- 142 of 1413 users reported age

Compared:
- Sample = 2 mo of search logs
- Filtered = just 3x [prostate cancer]
- Expected = \( P(\text{cancer}|\text{age})P(\text{age}) \)
  - \( P(\text{cancer}|\text{age}) \) from Nat. Cancer Inst.
  - High match (r = .959), esp. in older

<table>
<thead>
<tr>
<th>Age</th>
<th>Sample</th>
<th>Filtered</th>
<th>Classified</th>
<th>Expected</th>
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<tr>
<td>20s</td>
<td>16.40%</td>
<td>7.30%</td>
<td>4.90%</td>
<td>0.00%</td>
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<tr>
<td>30s</td>
<td>17.00%</td>
<td>5.20%</td>
<td>2.80%</td>
<td>0.00%</td>
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<tr>
<td>40s</td>
<td>13.50%</td>
<td>9.00%</td>
<td>5.60%</td>
<td>1.40%</td>
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<tr>
<td>50s</td>
<td>18.80%</td>
<td>14.60%</td>
<td>12.70%</td>
<td>15.30%</td>
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<tr>
<td>60s</td>
<td>17.80%</td>
<td>39.10%</td>
<td>42.30%</td>
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<td>70s</td>
<td>8.10%</td>
<td>14.90%</td>
<td>23.90%</td>
<td>24.10%</td>
</tr>
<tr>
<td>80s</td>
<td>8.40%</td>
<td>9.80%</td>
<td>7.70%</td>
<td>16.10%</td>
</tr>
</tbody>
</table>
Data > Treatment Timelines

• We filtered the 1413 histories for those containing terms related to decision-making
  • e.g. “vs”, “pros and cons”, “better”

• This produced 272 search timelines
  • We annotated queries with richer information
Data > Annotation of Treatment Timelines

• Queries annotated per deliberation and treatment stage

• Deliberation
  • Decision = help searchers decide between or learn about treatment options
  • Preparation = about scheduled treatment
  • Post-treatment = after treatment commenced or completed

• Treatment stage
  • Initial = first round treatment, typically surgery or radiation
  • Secondary = any treatment that follows an initial treatment
    • E.g., adjuvant radiation, hormone therapy, chemotherapy

→ 6 different phases of treatment-related search
Phrase Characterization

- Characterize different annotated phases via n-grams from queries
- Seek **salient** phrases that are **probable** and **representative**
- Two component mixture model
  - Phase specific feature distributions and phase independent background

\[
P(\text{feature} = i | \text{phase} = k) = \lambda \theta_i^B + (1 - \lambda) \theta_i^k
\]

- Features = bigrams, trigrams from queries
## Phrase Characterization

<table>
<thead>
<tr>
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<th></th>
<th></th>
<th></th>
<th></th>
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<tbody>
<tr>
<td>prostate cancer</td>
<td>after prostate</td>
<td>after prostate</td>
<td>after a</td>
<td>adjuvant radiation</td>
<td>seed implants</td>
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<td>surgery for</td>
<td>prostate surgery</td>
<td>a radical</td>
<td>how much</td>
<td>hdr treatment</td>
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<tr>
<td>proton therapy</td>
<td>robotic prostatectomy</td>
<td>prostate surgery</td>
<td>psa of</td>
<td>taking lupron</td>
<td>pain in</td>
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<td>lupron</td>
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<td>after radical</td>
<td>injections</td>
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<td>what to home on</td>
<td>psa after</td>
<td>are the</td>
<td>i stop</td>
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<td>the same</td>
<td>incontinence after</td>
<td>radiation after</td>
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<td>after seed</td>
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<td>and cons</td>
<td>vinci prostate</td>
<td>how to</td>
<td>radiation therapy</td>
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<td>adjuvant radiation</td>
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<td>to expect</td>
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<td>radical proctom</td>
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<td>do i</td>
<td>whats next</td>
<td>with catheter</td>
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<td></td>
<td></td>
<td>long does</td>
<td>post psa</td>
<td>on lupron</td>
<td>i take</td>
</tr>
</tbody>
</table>
Progression of Phases

• Understand temporal patterns across all phases
  • What does the “average” timeline look like?

• No single user searched all phases, but we can stitch these together
  • Computed multiple sequence alignment of the timelines
Multiple Sequence Alignment (MSA)

<table>
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<tr>
<th>A</th>
<th>C</th>
<th>A</th>
<th>G</th>
<th>C</th>
<th>C</th>
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</thead>
<tbody>
<tr>
<td>A</td>
<td>C</td>
<td>T</td>
<td>A</td>
<td>G</td>
<td>G</td>
</tr>
<tr>
<td>A</td>
<td>G</td>
<td>T</td>
<td>G</td>
<td>G</td>
<td>A</td>
</tr>
</tbody>
</table>

- Want to align sequences of symbols based on similarity
- Score based on how well symbols align, penalizing gaps and mismatches
  - Want to pick alignment with highest score
- Commonly used to align biological sequences
  - A lot of software exists that we can use off the shelf
Multiple Sequence Alignment (MSA)

Want to align sequences of symbols based on similarity
Score based on how well symbols align, penalizing gaps and mismatches
  • Want to pick alignment with highest score
Commonly used to align biological sequences
  • A lot of software exists that we can use off the shelf

Our version:
• Each timeline is a sequence
• Each phase label is a symbol (6 total)
• Special symbol for start of timeline (to encourage beginnings to align)
• Initial post-treatment and secondary decision phases often interleaved

(c) Multiple sequence alignment of 272 treatment timelines. Colored dots represent the label in each row/column, using the legend at the top of (a). White space represents gaps.
Phase Distribution

- More clearly see phase progression over time
- Do this by:
  - Removing gaps from each column
  - Excluding columns with < 10 non-gap symbols
- Computed distribution of categories over time
- Patterns, e.g.,
  - Hormone and prostate cancer medications increase over time
  - General interest in side effects → Specific concerns

(a) Distribution over non-gap phases and content categories in each alignment column.
Content Distribution within Treatment Phase

• Computed content distribution within each of the treatment phases
• Only excluded non-gap values (no minimum)
• Differences per phase, e.g.,
  • Searches for **healthcare** appear mostly in initial decision phase
  • Searches for **mental health** appear mostly in the initial post-treatment phase
  • More reference to **surgery** in initial; more to **hormone/chemotherapy** in secondary
Analyzing Treatment Decisions

• Want to understand the sequential patterns of information-gathering about treatments and outcomes during decision making

• Focus on “initial decision” phase

• Target
  • Number and Specificity of Treatments
  • Treatment Comparisons
Number and Specificity of Treatments

- Analyze average depth of treatments (in hierarchy) and average number of different treatments searched.
Transitions among Treatments

• Examined transition structure by comparing consecutive queries
  • Better understand query refinement during exploring

• Broken down as:
  • 68.8% of time, same treatment as previous query
  • 12.7% of time more specific
  • 9.5% of time more general
  • 9.0% of time different branch

• Built query transition graph →
  • Better understand which treatments are searched after an initial treatment

Figure 2: Maximum directed spanning tree induced from the treatment query transition graph.
Treatment Comparisons

• Analyzed queries with multiple treatments in the same query
• Likely to have a comparative intent (e.g., “surgery vs radiation”)
• 9.6% of initial decision queries contain multiple treatments
• 43.6% of (272) users issued such queries
• Broken down as:
  • Surgery and radiation (75%)
  • Different types of surgery (7.3%)
  • Surgery and observation (7.3%)
  • Radiation and hormone therapy (6.3%)
  • Different types of radiation (4.2%)

  65.3% for most general terms (e.g. “surgery vs radiation”)
  34.7% for specific types (e.g. “robotic surgery or seed implants”)
Summary

• Analyzed timelines of prostate cancer searchers seeking treatment info.
  • Identified clear temporal patterns and shifting interests / foci over time

• Search engines need to better serve as decision support systems
  • E.g., searcher making a decision may benefit from comparison support

• Next step:
  • Obtain additional context that affects information searching
  • Engage direction with patients and understand their clinical situations

• Other directions: Adapt methods to other illnesses, improve search and retrieval for other healthcare needs, e.g., selecting care providers
Thank you!