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

Level 0	Level 1	Level 2	Level 3	Search terms
Treatment	–	–	–	treatment(s)
Treatment	Surgery	–	–	surgery, prostatectomy, prostate removal, remove prostate
Treatment	Surgery	Open	–	open [Surgery]
Treatment	Surgery	Laparoscopic	–	laparoscopic, minimally invasive
Treatment	Surgery	Laparoscopic	Robotic	robot, robotic, da( )vinci
Treatment	Radiation	–	–	radiation
Treatment	Radiation	Brachytherapy	–	brachytherapy, brachy, seed(s)
Treatment	Radiation	Brachytherapy	LDR	low dose [Brachytherapy], ldr
Treatment	Radiation	Brachytherapy	HDR	high dose [Brachytherapy], hdr
Treatment	Radiation	External	–	external [Radiation], external beam, ebrt
Treatment	Radiation	External	3DRT	3drt, 3dcrt, conformal
Treatment	Radiation	External	IMRT	imrt, intensity-modulated, igrt, calypso
Treatment	Radiation	External	SBRT	sbrt, stereotactic body, cyber( )knife, gamma( )knife, x-knife
Treatment	Radiation	External	Proton	proton, pencil beam
Treatment	Radiation	Drugs	Radium 223	radium 223, radium dichloride, xofigo
Treatment	Hormone therapy	–	–	hormone/hormonal therapy, hormone/hormonal treatment
Treatment	Hormone therapy	LHRH	...	*various hormone-therapeutic drugs are categorized*
Treatment	Hormone therapy	Anti-Androgen	...	*various hormone-therapeutic drugs are categorized*
Treatment	Chemotherapy	–	–	chemotherapy, chemo
Treatment	Chemotherapy	Drugs	...	*various chemotherapeutic drugs are categorized*
Treatment	HIFU	–	–	hifu, high-intensity
Treatment	Cryotherapy	–	–	cryotherapy, cryosurgery, cryoablation, cryo
Treatment	Observation	None	–	no treatment, without treatment
Treatment	Observation	Waiting	–	waiting [Treatment]
Treatment	Observation	Surveillance	–	active surveillance

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(cancer|age)P(age)
    - P(cancer|age) from Nat. Cancer Inst.
  - High match (r = .959), esp. in older

Age	Sample	Filtered	Classifed	Expected
20s	16.40%	7.30%	4.90%	0.00%
30s	17.00%	5.20%	2.80%	0.00%
40s	13.50%	9.00%	5.60%	1.40%
50s	18.80%	14.60%	12.70%	15.30%
60s	17.80%	39.10%	42.30%	43.10%
70s	8.10%	14.90%	23.90%	24.10%
80s	8.40%	9.80%	7.70%	16.10%

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

Initial Decision → Initial Preparation → Initial Post-treatment → Secondary Decision → Secondary Preparation → Secondary Post-treatment

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

Initial Decision	Initial Preparation	Initial Post-treatment	Secondary Decision	Secondary Prep.	Secondary Post.
Search queries					
prostate cancer	after prostate	after prostate	after a	adjuvant radiation	seed implants
cancer treatment	surgery for	after prostatectomy	a radical	how much	hdr treatment
proton therapy	robotic prostatectomy	prostate surgery	psa of	taking lupron	pain in
best treatment	after prostatectomy	after surgery	radical prostatectomy	seed implants	cause pain
for prostate	on the	after radical	what are	lupron injections	radiation burns
cancer treatments	da vinci	radical prostatectomy	after radical	i stop	treatment cause
treatment options	what to	psa after	are the	stop taking	lupron treatment
pros and	home on	incontinence after	radiation after	i do	after seed
and cons	the same	how to	radiation therapy	can i	not effective
surgery for	vinci prostate	sex after	cancer treatment	treatment after	psa after
active surveillance	same day	after a	adjuvant radiation	will i	flomax after
da vinci	go home	after robotic	the side	to avoid	protectomy and
surgery vs	davinci prostate	after prostectomy	radiation be	prostate seed	after lupron
watchful waiting	for radical	radical prostectomy	treatment after	with catheter	radical protectomy
vs radiation	to expect	do i	whats next	zytiga cost	enlarged abdomen
treatment for	day of	what to	treatment options	catheter in	for high
cyberknife prostate	life after	on lupron	radiation what	lupron treatment	after medications
cons of	is surgery	levels after	if radiation	radiation after	medications not
prostate treatment	cryotherapy surgery	blood in	be next	taking casodex	long will
the best	kegel exercises	long does	post psa	on lupron	i take

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)

A	C		A	G		C	C
A	C	T	A	G	G	C	A
A	G	T		G	G		A

- 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)

A	C		A	G		C	C
A	C	T	A	G	G	C	A
A	G	T		G	G		A

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)

- Want to align sequences of symbols based on similarity
- Score based on how well symbols align, penalizing gaps and mismatches
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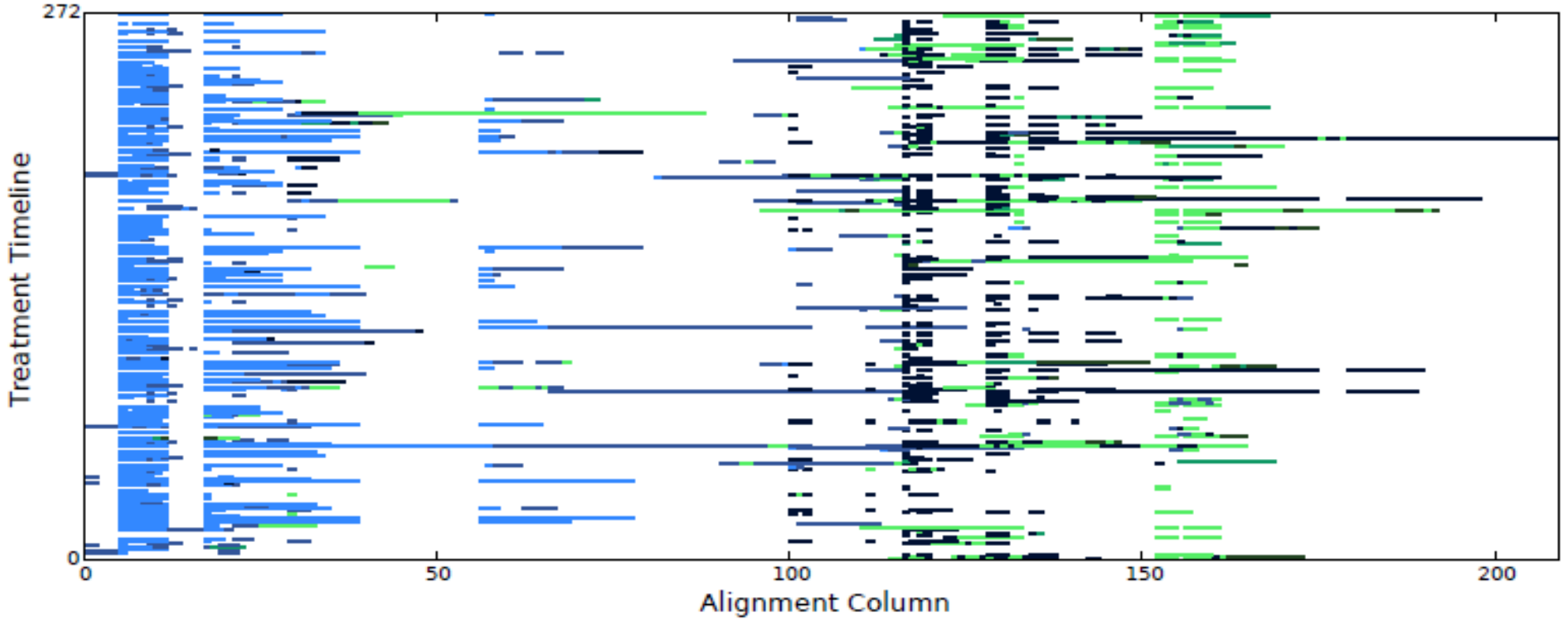
MSA of Treatment Timelines



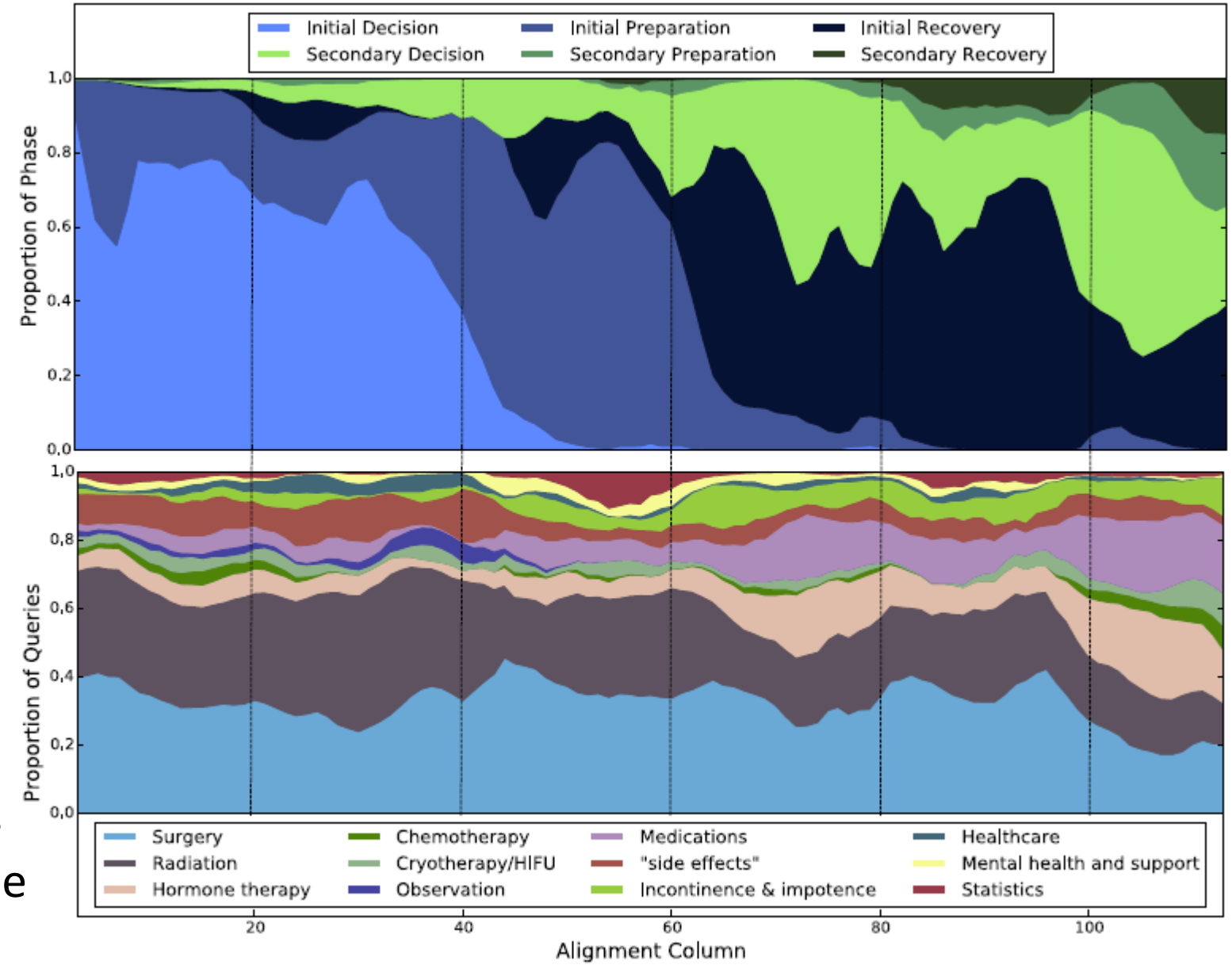
(c) Multiple sequence alignment of 272 treatment timelines. Colored dots represent the label in each row/column, using the legend at the top of (a). White space represents gaps.

Dominated by **Initial Phases** Dominated by **Secondary Phases**

- Initial post-treatment and secondary decision phases often interleaved

Phase Distribution

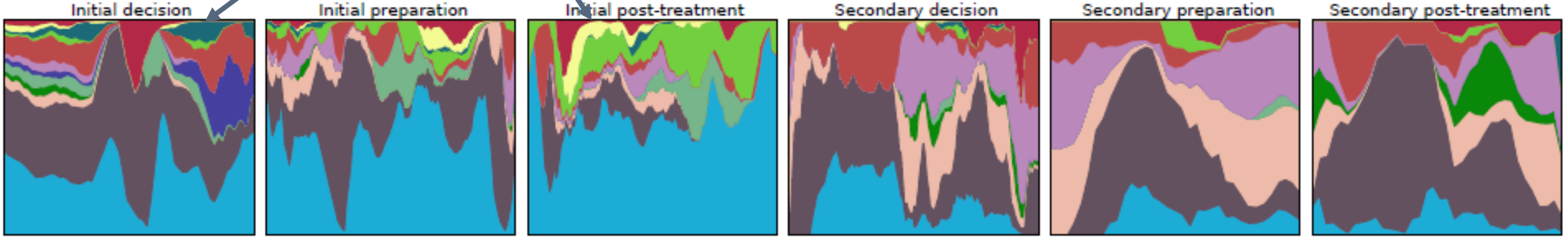
- More clearly see phase progression over time
- Do this by:
  - Removing gaps from each column
  - Excluding columns with < 10 non-gap symbols
- Computed distribution of categories over time
- Patterns, e.g.,
  - Hormone and prostate cancer medications increase over time
  - General interest in side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



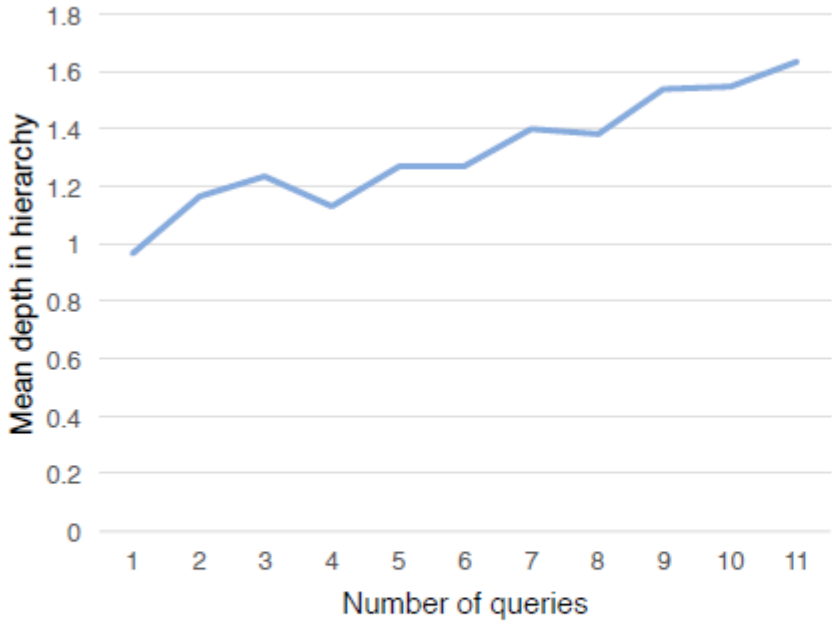
Analyzing Treatment Decisions

- Want to understand the sequential patterns of information-gathering about treatments and outcomes during decision making
- Focus on “initial decision” phase

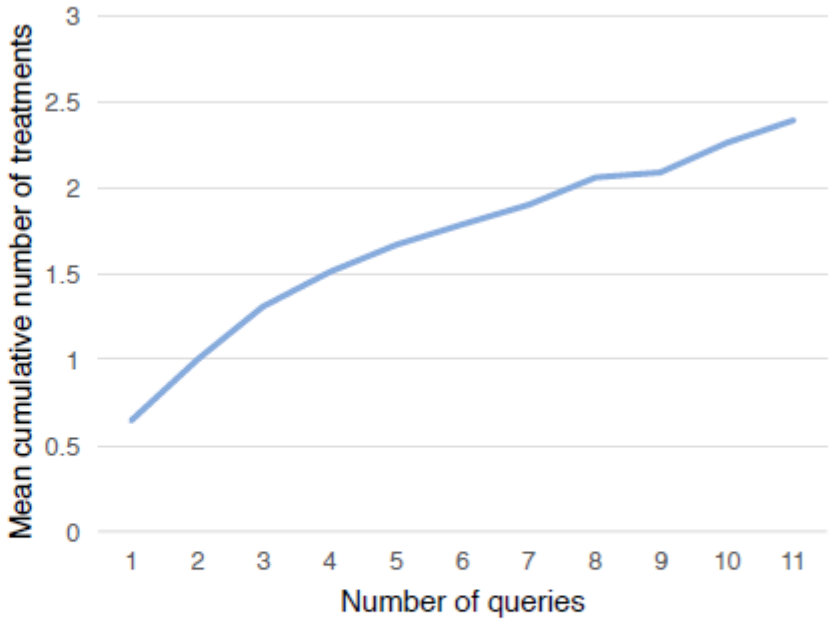
- Target
  - Number and Specificity of Treatments
  - Treatment Comparisons

Number and Specificity of Treatments

- Analyze average depth of treatments (in hierarchy) and average number of different treatments searched



Specificity of treatments over time during initial decision phase



Cumulative number of different treatments searched over time by average user

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 →

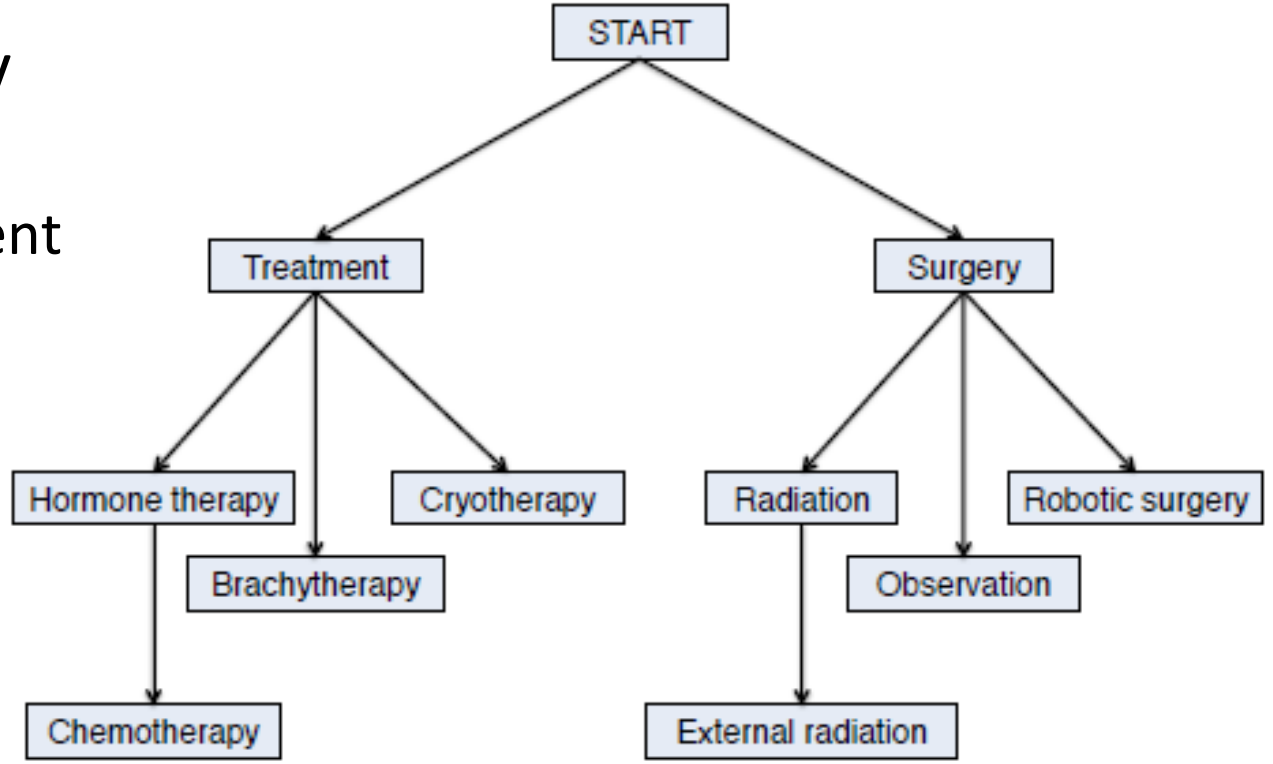


Figure 2: Maximum directed spanning tree induced from the treatment query transition graph.

- Better understand which treatments are searched after an initial treatment

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!