A Probability Ranking Principle for Interactive IR

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Outline

Motivation

The classical PRP
Questioning the PRP assumptions
Interactive Retrieval

The classical PRP

- Task: Retrieve relevant documents
- Relevance of a document to a query is independent of other documents
- Scanning through the ranked list is the major task of the user (and the only one considered)

Questioning the PRP assumptions

- Relevance depends on documents the user has seen before
- Relevance judgment is not the most expensive task for a user

Interactive Retrieval

- User has a rich set of interaction possibilities
  - (re)formulate query
  - selection based on summaries of various granularity
  - select related terms from list
  - follow document link
  - relevance judgment
- Information need changes during a search
- No theoretic foundation for constructing IIR systems

Approach

Requirements for an IIR-PRP
Basic Assumptions
Abstraction: Situations with Lists of Choices

Requirements for an IIR-PRP

- Consider the complete interaction process
- Allow for different costs for different activities
- Allow for changes of the information need

Basic Assumptions

- Focus on a functional level of interaction
  (usability issues disregarded here)
- System presents list of choices to the user
- Users evaluate choices in linear order
- Only positive decisions/choices are of benefit for a user

Examples of decision lists

- ranked list of documents
- list of summaries
- list of document cluster
- KWIC list
- list of expansion terms
- links to related documents
- ...

Example: Non-linear decision list

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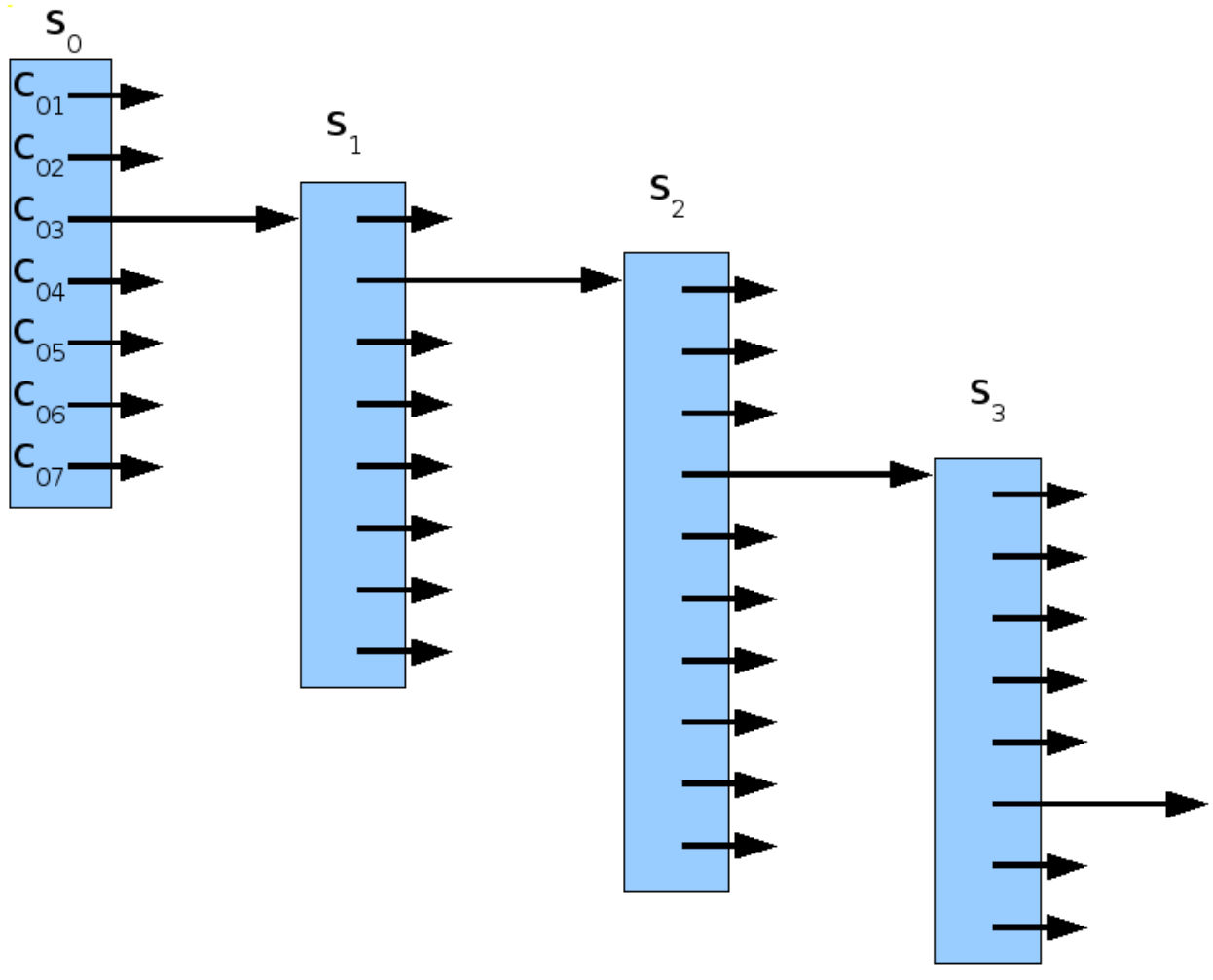
Abstraction: Situations with Lists of Choices



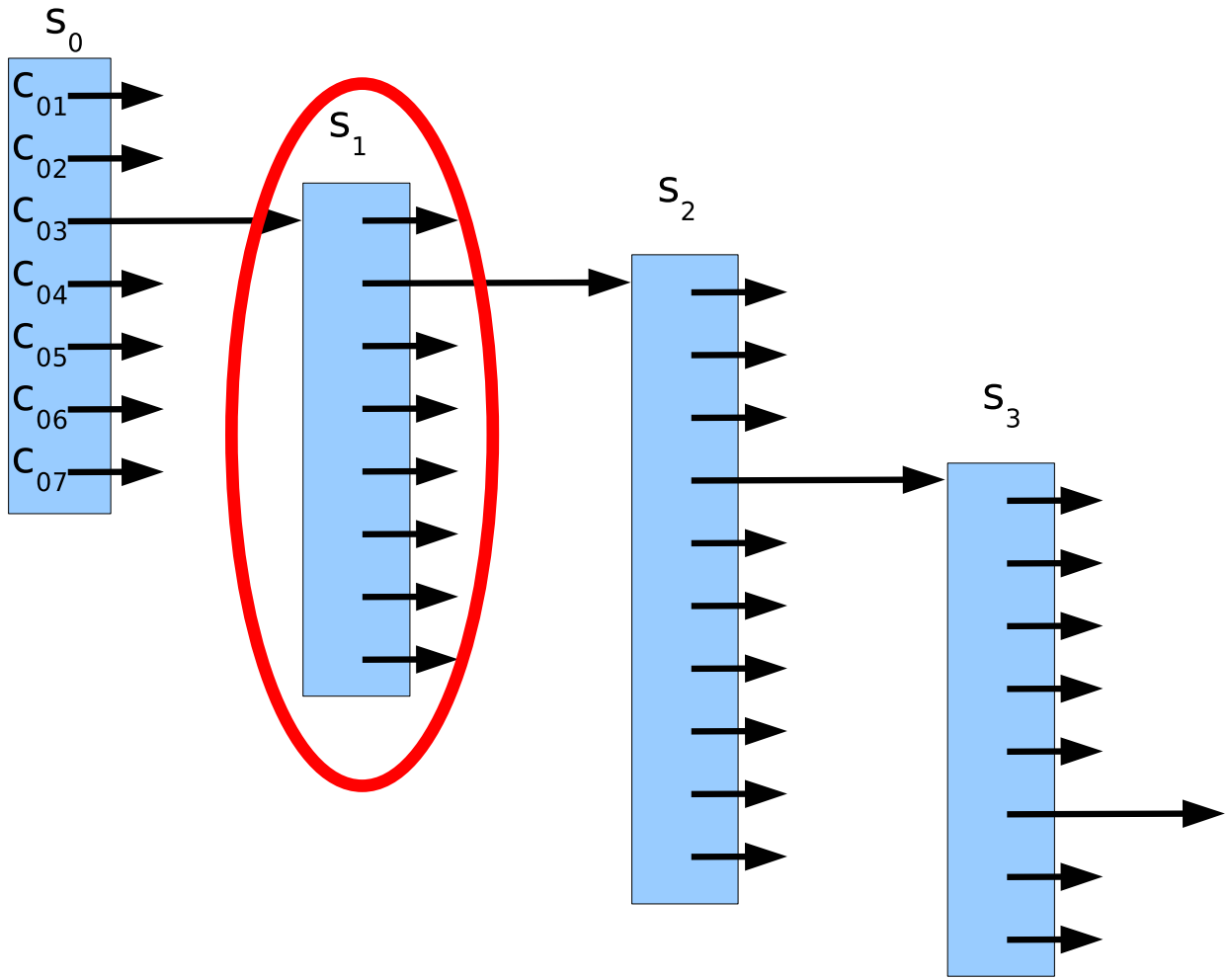
The Model

Choices
Selection lists
Ranking of choices

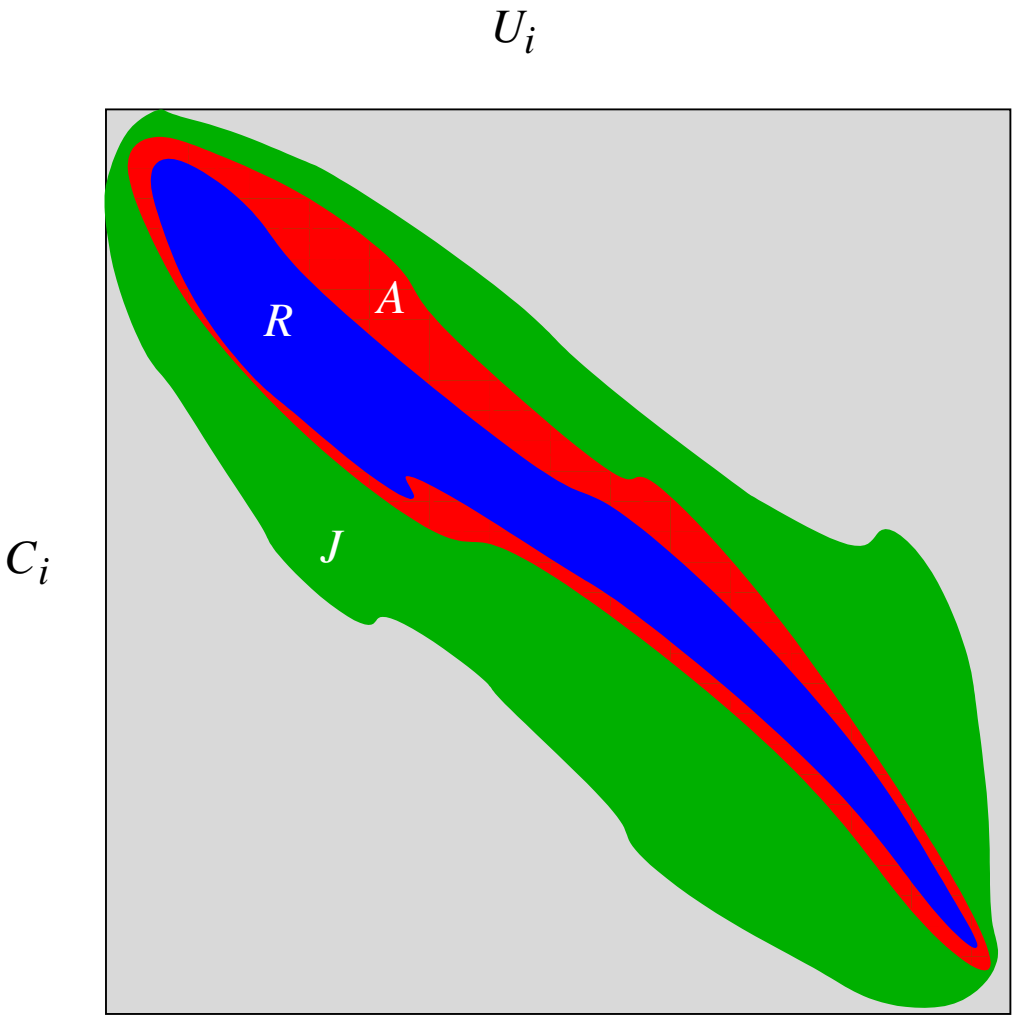
Basic ideas

- A user moves from situation to situation
- In each situation s_i, the user is presented a list of (binary) choices $< c_{i1}, c_{i2}, \ldots, c_{i,n_i} >$
- The user decides about each of these choices sequentially
- The first positive decision moves the user to a new situation s_j
- A decision may be wrong, requiring backtracking

Probabilistic model focusing on single situation



Probabilistic Event space



U_i: Uses in situation s_i

C_i: choices in situation s_i

$J \subset U_i \times C_i$:
judged choices

$A \subset J$:
accepted choices

$R \subseteq A$: 'right' choices

Expected Benefit of a choice

- p_{ij} probability that the user will accept choice c_{ij}
- q_{ij} probability that this decision was right
- e_{ij} < 0: effort for evaluating the choice c_{ij}
- b_{ij} > 0: resulting benefit from positive, correct decision
- g_{ij} ≤ 0: cost for correcting a wrong decision

Expected benefit of choice c_{ij}

$$E(c_{ij}) = e_{ij} + p_{ij}\left(q_{ij}b_{ij} + (1 - q_{ij})g_{ij}\right)$$

Example

Web search: 'Java' $\rightarrow$ n_0=290 mio. hits

System proposes extension terms:

term	n_i	p_{ij}	b_{ij}	$p_{ij}b_{ij}$
program	195 mio	0.67	0.4	0.268
blend	5 mio	0.02	4.0	0.08
island	2 mio	0.01	4.9	0.049

benefit $b_{ij} = \log \frac{n_0}{n_i}$

Strategies for maximizing expected benefit

$$E(c_{ij}) = e_{ij} + p_{ij}\left(q_{ij}b_{ij} + (1 - q_{ij})g_{ij}\right)$$

(assume that benefit b_{ij} and corr. effort g_{ij} are given)

1. minimize effort $|e_{ij}|$ —
   but keep p_{ij} (selection prob.) and q_{ij} (success prob.) high
2. maximize p_{ij}: user should choose c_{ij} whenever it is appropriate —
   but keep success probability q_{ij} high
   $\rightsquigarrow$ increased effort e_{ij}
3. maximize q_{ij} by avoiding erroneous positive decisions
   $\rightsquigarrow$ increased effort e_{ij}

Further remarks

$$E(c_{ij}) = e_{ij} + p_{ij}\left(q_{ij}b_{ij} + (1 - q_{ij})g_{ij}\right)$$

- Expected benefit should be positive
  choices with negative values should not be presented to a user.
- Methods for estimating parameters p_{ij}, q_{ij}, b_{ij}, e_{ij}, g_{ij}:
  Issue of further research
- In the following, let $a_{ij} = q_{ij}b_{ij} - (1 - q_{ij})g_{ij}$
  ("average benefit")

$$E(c_{ij}) = e_{ij} + p_{ij}a_{ij}$$

Selection list

situation s_i with list of choices $r_i =< c_{i1}, c_{i2}, \ldots, c_{i,n_i} >$

expected benefit of choice list:

$$
\begin{aligned}
E(r_i) &= e_{i1} + p_{i1}a_{i1} + \\
&\quad (1 - p_{i1})\,(e_{i2} + p_{i2}a_{i2} + \\
&\quad (1 - p_{i2})\,(e_{i3} + p_{i3}a_{i3} + \\
&\quad \ldots \\
&\quad (1 - p_{i,n-1})\,(e_{in} + p_{in}a_{in})\ ))\\
&= \sum_{j=1}^{n} \left(\prod_{k=1}^{j-1} (1 - p_{ik}) \right) (e_{ij} + p_{ij}a_{ij})
\end{aligned}
$$

Expected benefit of a choice list

$$E(r_i) = \sum_{j=1}^{n} \left(\prod_{k=1}^{j-1} (1 - p_{ik}) \right) (e_{ij} + p_{ij} a_{ij})$$

Ranking of choices

Consider two subsequent choices c_{il} and $c_{i,l+1}$

$$E(r_i) = \sum_{\substack{j=1 \\ l \neq j \neq l+1}}^{n} \left(\prod_{k=1}^{j-1} (1 - p_{ik}) \right) (e_{ij} + p_{ij} a_{ij}) + t_i^{l,l+1}$$

where

$$t_i^{l,l+1} = (e_{il} + p_{il} a_{il}) \prod_{k=1}^{l-1} (1 - p_{ik}) + (e_{i,l+1} + p_{i,l+1} a_{i,l+1}) \prod_{k=1}^{l} (1 - p_{ik})$$

analogously $t_i^{l+1,l}$ for $< \ldots, c_{i,l+1}, c_{il}, , \ldots >$

Difference between alternative rankings

$$
\begin{aligned}
d_i^{l,l+1} &= \frac{t_i^{l,l+1} - t_i^{l+1,l}}{\prod_{k=1}^{l-1}(1-p_{ik})} \\
&= e_{il} + p_{il}a_{il} + (1-p_{il})(e_{i,l+1} + p_{i,l+1}a_{i,l+1}) - \\
&\quad \left(e_{i,l+1} + p_{i,l+1}a_{i,l+1} + (1-p_{i,l+1})(e_{il} + p_{il}a_{il})\right) \\
&= p_{i,l+1}(e_{il} + p_{il}a_{il}) - p_{il}(e_{i,l+1} + p_{i,l+1}a_{i,l+1})
\end{aligned}
$$

For $d_i^{l,l+1} \overset{!}{\geq} 0$, we get

$$
a_{il} + \frac{e_{il}}{p_{il}} \geq a_{i,l+1} + \frac{e_{i,l+1}}{p_{i,l+1}}
$$

PRP for Interactive IR

$$a_{il} + \frac{e_{il}}{p_{il}} \geq a_{i,l+1} + \frac{e_{i,l+1}}{p_{i,l+1}}$$

$\rightsquigarrow$ **Rank choices by decreasing values of**

$$\varrho(c_{ij}) = a_{il} + \frac{e_{il}}{p_{il}}$$

Expected benefit: single choices vs. list

$$\text{expected benefit:} \quad E(c_{ij}) = p_{ij} a_{ij} + e_{ij}$$

$$\text{ranking criterion:} \quad \varrho(c_{ij}) = a_{il} + \frac{e_{il}}{p_{il}}$$

Example:

choice	p_{ij}	a_{ij}	e_{ij}	$E(c_{ij})$	$\varrho(c_{ij})$
c_1	0.5	10	-1	4	8
c_2	0.25	16	-1	3	12

$$E(< c_1, c_2 >) = 4 + 0.5 \cdot 3 = 5.5$$

$$E(< c_2, c_1 >) = 3 + 0.75 \cdot 4 = 6$$

IIR-PRP vs. PRP

$$a_{il} + \frac{e_{il}}{p_{il}} \geq a_{i,l+1} + \frac{e_{i,l+1}}{p_{i,l+1}}$$

Let $e_{ij} = -\bar{C}$, $\bar{C} > 0$ and $a_{il} = C$:

$$\begin{aligned} C - \frac{\bar{C}}{p_{il}} &\geq C - \frac{\bar{C}}{p_{i,l+1}} \\ \Rightarrow p_{il} &\geq p_{i,l+1} \end{aligned}$$

$\rightsquigarrow$ Classic PRP still holds!

IIR-PRP: Observations

$$\text{Rank choices by} \quad a_{ij} + \frac{e_{ij}}{p_{ij}}$$

- p_{ij} 'probability of relevance' still involved
- tradeoff between effort e_{ij} and benefit a_{ij}
- difference between PRP and IIR-PRP due to variable values for e_{ij} and a_{ij}
- IIR-PRP looks only for the first positive decision

Towards application

Parameter estimation
Saved effort

Parameter estimation

1. Selection probability p_{ij}:
   focus of many IR models,
   but models for dynamic info needs required
2. Effort parameters e_{ij}, g_{ij} +success probability q_{ij}:
   most research needed
3. Benefit b_{ij}:
   - information value ?
   - saved effort (see below)

Saved effort

- methods for estimating number r_q of relevant documents for query q
- linear recall-precision curve: $P(R) := P^0 \cdot (1 - R)$
- position of the first relevant document: $n_q = \frac{r_q}{P^0(r_q - 1)}$
- user's choice transforms current query q' to optimum query q
- $P(q|q')$: probability that a random document from the result list of q also occurs in the result list of q'
- $n_{q'} = \frac{r_q}{P(q|q')P^0(r_q - 1)}$
- benefit for moving from q' to q: $n_{q'} - n_q$.

Saved effort: Example

term	n_i	p_{ij}	b_{ij}	$p_{ij}b_{ij}$	$n_{q'}$	ϱ_{ij}
program	195m	0.67	0.4	0.268	3	-0.5
blend	5m	0.02	4.0	0.08	116	56
island	2m	0.01	4.9	0.049	290	145

Conclusion and Outlook

Conclusion and Outlook

- Current IIR systems lack theoretic foundation
- Interactive IR as decision making
- user works on linear list of choices
- positive choices move user to new situation, with (possibly) new choice list
- IIR-PRP is generalization of classical PRP
- introduced new parameters
- parameter estimation is issue of further research