

# A Model of Single-page Web Search: The Effect of Interdependence on Link Assessment

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## Abstract

When people search a Web page for links that are relevant to their information goal, they attend to the labels and estimate the likelihood that the link will lead to the goal. We have previously found in a simplified single-page menu search task that people sometimes, but not always, assess only a subset of the links available. Importantly, the presence of lower relevance distracters resulted in fewer items being fixated; suggesting people may adjust an independent assessment of the relevance of a link, in order to derive an estimate that is interdependent with the quality of the other links in the choice set. Recently, we have presented an ACT-R model that was inspired by Young's (1998) rational account of exploratory choice. The model makes use of ACT-R's architectural assumptions in order to produce behavior that provides both qualitative and quantitative fits across a range of performance measures including eye-movement data. The behavior of the model differs substantially from previous ACT-R models of Web navigation.

Keywords: Web navigation, single-page menu search, ACT-R cognitive modeling, eye-tracking, decision making

## Thesis Research Summary

Consider searching a newly encountered Web page for links that are relevant to the achievement of some information goal. During this activity, people focus on the labeled links in order to derive a subjective assessment of the likelihood that the selection of a given link will lead to the achievement of the current information goal. Although, people tend to select items that are highly relevant to their goal (Pirolli & Fu, 2003), eye movement protocols from a simplified single-page menu search task (Brumby & Howes, 2003) suggest that people do more than assess the *scent* of a label.

SNIF-ACT (Pirolli & Fu, 2003) makes an important contribution to the development of cognitive models that can simulate users searching the World Wide Web for information relevant to an unfamiliar information goal. The model provides a characterization of Web search behavior. Importantly, the model uses ACT-R's declarative memory module in order to derive assessments of a labels *scent* (or the relevance of the label to the information goal). The model accurately predicts that users will select Web labels that have high information scent. However, Brumby and Howes' (2003) data suggest that SNIF-ACT lacks a plausible model of how people search an individual page. This simplification is non-trivial, if people do not always assess all items on a menu page prior to selection.

In a simplified single-page Web search task, Brumby and Howes (2003) asked participants to search single-Web pages in pursuit of an information goal. Each page contained a single goal, or *target*, link and the rest of the links were *distracters*. An eye tracker recorded participant's eye movements while they searched the labeled links. The relevance of the distracter links to the goal was varied while the quality of the target link was held constant.

Brumby and Howes (2003) observed that people do not always assess all of the items available in the choice set prior to the selection of an item, and that they re-fixate a smaller and smaller subset of these items prior to selection. These signature behaviors are consistent with the search of early keyboard-driven menus in which only a single choice can be seen at a time (MacGregor, Lee, & Lam, 1986).

While some previous models do not capture the menu search behavior observed by Brumby and Howes (2003), Young (1998) has presented a rational analysis of exploratory choice. Young's model is particularly interesting because it is sensitive to the implications of the structure of the task environment in many menu search tasks. When searching a menu that contains a given choice set of menu items ( $item_1 \dots item_n$ ), typically only a single item will lead to the achievement of the information goal. Given some probability estimate of this likelihood it can be assumed that the sum of estimates across all items in the choice set must be equal to one. This *normalization assumption* "reflects real cross-relationships between the judgments about choices made by a person, and cannot be avoided ... the reality is that people are often forced to make rapid and radical revisions of their estimates of the correctness of particular options as they work their way through [the options available]" (Young, 1998, p. 474). A novel prediction to emerge from the normalization assumption is that the relevance of both the target *and* the distracters will affect the decision of whether to select or continue assessment.

Importantly, Brumby and Howes (2003) found that the presence of lower relevance distracters resulted in fewer items being fixated. This finding supports the idea that people may adjust an independent assessment of the relevance of a link, in order to derive an estimate that is interdependent with the quality of the other links in the choice set. Consequently, people may make implicit assumptions about the value of items that they *have not assessed* on the basis of generalization from those that they have assessed. More recent empirical studies have replicated this main finding.

We have presented an ACT-R model of our previous menu search data (Brumby & Howes, submitted). The model is partially constrained by Young's (1998) rational analysis of exploratory choice, and in addition is consistent with the memory constraints imposed by ACT-R (Anderson & Lebiere, 1998). More specifically, the model used ACT-R's declarative memory retrieval mechanism to model how people choose between selection of an item and further assessment of items. This approach is consistent with that employed in previous ACT-R models of Web navigation (SNIF-ACT, Pirolli & Fu, 2003) but makes a novel use of the mechanism by which source-activation models the focus of attention.

We present a brief overview of the model (but see, Brumby & Howes, submitted for more details). In the model the ACT-R goal chunk included  $n$  slots, one for each label link and each of which, initially, had a value of *unassessed*. We call these *assessment* slots. Assessment of label links was achieved by repeated attempts to retrieve chunks from declarative memory. The successful retrieval of a chunk was assumed to indicate that there was positive information linking the label and the goal, and resulted in the replacement of 'unassessed' values on the goal with the retrieved value. An unsuccessful retrieval resulted in the replacement of a slot value with "not relevant", i.e. equivalent to setting the slot value to nil. Whether or not a chunk was retrieved depended in part on its activation. Activation of a chunk was determined partly by the strength of association  $S$  between the goal and the chunk, and more crucially through the amount of *source activation*  $W$  (representing the attentional focus). Consequently, the more label links that were in the choice set (as represented by the assessment slots) the lower the amount of source activation  $W$  received by a chunk. Conversely, the fewer the number of items in the choice set the greater the amount of source activation  $W$  received by a chunk.

In other words, the model was *more likely* to make a positive assessment of an item, when the assessed distracter items were not relevant to the current goal. The model then chose to select an item if it had been judged to be highly relevant to the current information goal (indicated by retrieval of all chunk-types related to the item). Importantly, the model could sometimes retrieve some of the assessment chunks for an item, while other assessment chunks for the item would fail to be retrieved. In this case the item was judged *partially relevant* to the information goal, and given some change in the value of source activation  $W$  future assessment of the item may warrant selection.

The aim in evaluating the validity of the model was to match the models performance across a range of dependent variables used in the menu search experiment, including eye-movement data.

The model provided a good fit with the data across most of the dependent variables (the number of items fixated; percentage of trials correct; percentage of self-terminating searches; and time to selection). The model also demonstrated the observed signature behaviors: (1) the

model rarely attended all of the items available in the choice set prior to the selection of an item, and (2) reattended a smaller and smaller subset of these items prior to the selection of an item.

The model does not yet capture all of our previous data (Brumby & Howes, 2003). In particular, we have found that the history of information search moderates the local search strategy. After participants had completed trials in which they were more likely to select an incorrect item (because the distracters had been made more attractive), they were more cautious about selection. That is, they assessed more of the items in the choice set and were less likely to select an item immediately following an initial fixation of that item. Extending the current model to account for these findings should be relatively straight forward, because ACT-R's production rule learning mechanism is well suited to modeling the influence of history of successes on operator selection (Anderson & Lebiere, 1998, Chap. 8).

The idea that Web-page search is attentional focusing may seem counter-intuitive. In our model the goal of assessing unassessed items reduces the probability of retrieving information about the currently fixated item. Although, this mechanism predicts the observed behavior it seems counter-intuitive because, given that the goal is presumably under strategic control, an implication is that participants deliberately reduced the probability of retrieval of information associating an item with the goal (at least initially) in order to achieve the desired overall search strategy. Further data is required.

In summary, the current research program has used both empirical studies and cognitive modeling methods, in order to delineate how people might search a newly encountered Web page for links that are relevant to the achievement of some information goal.

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