Review of Adapting Recommender Systems of E-Commerce Platforms to Deal with Cognitive Aging, written by Justyna Pawłowska-Bebel

JoNell Strough
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I have reviewed the thesis, Adapting Recommender Systems of E-Commerce Platforms to Deal with Cognitive Aging, written by Justyna Pawłowska-Bebel. My recommendation is to accept the thesis. The review follows the suggested methods and evaluation criteria for reviewers of PhD theses submitted to PJAIT.

1. What are the research problems and objectives considered in the thesis, and have they been sufficiently clearly described by the author?

The main research problem considered in this thesis is how to adapt e-commerce recommender systems to accommodate cognitive aging. This problem is important due to the growth of the proportion of the global population that is comprised by older adults and their increasing use of ecommerce systems.

There were four primary objectives, each of which was clearly described by the author: (1) evaluate age differences in ecommerce decisions to test the hypothesis that older adults make less optimal decisions than younger adults due to cognitive limitations; (2) investigate whether using decision maker's sub-optimal decisions as data to train recommender systems creates biases in recommender systems, with the hypotheses that sub-optimal decisions lead systems to make worse recommendations; (3) measure self-induced bias and evaluate how this bias operates within existing recommender systems, with the hypothesis that existing recommender systems will make sub-optimal recommendations that are biased against older adults; (4) propose an alternative recommender system that takes into account decision makers' cognitive limitations, with the hypothesis that such systems will reduce self-induced bias and yield more optimal decisions.

2. Does the thesis contain an appropriate analysis of state of the art (based on global scientific literature, current knowledge and applications in industry)? Does the analysis of related work demonstrate sufficient expertise of the author? Have the conclusions of the review of related work been sufficiently clearly stated?

This thesis is multi-disciplinary in scope. It combines psychological research on cognitive aging and behavioral decision making with a simulation-based approach from social informatics and engineering. Because my expertise lies within the areas of cognitive aging and behavioral decision making (and not social informatics or engineering), my evaluation of the thesis focuses on the state of the art in regards to cognitive aging and behavioral decision making.

In the analysis of related research, the author displayed mastery of the behavioral decision making literature in their application of research on behavioral decision making strategies such as "take the best" and "tally" to the recommender systems designed for the thesis research. The author also displayed a fundamental understanding of the key concept of "bounded rationality"

in decision making and shows how recommender systems can be applied to improve upon the limits of human cognition.

The analysis of related work demonstrated that the author understands fundamental research on cognitive aging—mainly how age-related limits in aspects of fluid intelligence such as working memory can reduce older adults' likelihood of making optimal product selections. This finding from the cognitive aging literature is foundational to the thesis rationale. In the analysis of related work, the author accurately conveyed knowledge and conclusions from this literature.

The author cited Hess's work on selective engagement of cognitive resources with age, indicating their awareness of this key theory within research on cognitive aging and decision making. From the perspective of selective engagement theory, one question for the author to consider is how consumer decisions that are personally relevant versus not might affect whether a recommender system needs to be modified to accommodate age limitations in working memory. Relatedly, a recent literature review by Tucker-Drob (citation below) suggests only a subset of older adults go on to develop cognitive limitations—highlighting that substantial individual differences exist among older adults, and that these individual differences are overlooked in studies of average age differences in cognitive functioning. Finally, a recent review of research on aging and decision making (citation below) reviews research that indicates older adults can compensate for cognitive declines by relying on their life experience and skill in regulating emotions. Together, these studies suggest that modifications to recommender systems might be most beneficial to a subset of older adults, and that recommender systems might be one of several strategies for boosting optimal decisions.

Hess TM. 2014. Selective engagement of cognitive resources: motivational influences on older adults' cognitive functioning. *Perspect. Psychol. Sci.* 9:388–407. **https://doi.org/10.1177/1745691614527465**

Strough, J. & Bruine de Bruin, W. (2020). Aging and decision making. *Annual Review of Developmental Psychology,* 345–363 **https://doi.org/10.1146/annurev-devpsych-051120-010038**

Tucker-Drob EM. 2019. Cognitive aging and dementia: a life-span perspective. *Annu. Rev. Dev. Psychol.* 1:177–96. **https://doi.org/10.1146/annurev-devpsych-121318-085204**

Finally, I think that is important to note that although recommendation algorithms are not my area of expertise, the author's description of these algorithms was sufficiently clear to allow me to understand how such systems work and the problems they pose when considering aging decision makers.

3. Does the research described in the thesis use a correct scientific methodology?

The thesis research uses scientific methodology correctly. First, data were collected to show that older adults make non-optimal decisions and that the difficulty of decisions affects performance. Next, agents were designed to make decisions that resembled those of real participants and the effectiveness of different recommender systems was tested and a new recommender system was designed and tested. The measures used were appropriate. Statistics were used appropriately. The results were clearly explained.

4. What are the original and innovative contributions of the author, and what is the position of these contributions compared to the state of the art?

A key contribution of the author's research is the incorporation of user bias (e.g., heuristics) and cognitive limitations (e.g., working memory) into simulations of recommender systems.

a. How do you evaluate the publication record of the candidate?

On page 11, the author lists five publications upon which the thesis is based. One of these is a manuscript in preparation. Of the other four listed publications, the author is listed as first author for two of the four —one of which appears to be a peer-reviewed journal (Journal of Artificial Intelligence and Soft Computing research), the other first-author publication is a conference paper that was also included in a book series. In addition to these publications, the author list a co-authored chapter in an edited book and another conference paper that was included in a book series. The author's productivity during their doctoral training is good. In the future, the author should strive to publish their research in peer-reviewed journals,

5. Did the author present his results correctly and convincingly? (Please evaluate the clarity, conciseness, correctness of the thesis or presented research articles).

The author presented their results correctly and convincingly. The presentation of the results was concise and clear. Tables and figures were used effectively to summarize the main research findings. The approach to the issue investigated by the thesis was logical and each new study built systematically on the preceding study.

6. What are the weak and strong points of presented research results?

The strong points of the research is that it addresses a key gap in the field by showing the need for a recommender system that can facilitate more optimal decisions among those who have cognitive limitations. The simulation models are also a strong point because they allow different simulations and recommender systems to be compared to a baseline. Another strong point was using different distributions of product utility when testing the new recommendation system to show how different recommendation systems perform depending on the situation.

A weak point of the presented research is that it is unclear how the new recommendation systems would be implemented if they were to be used in the real world. The decision maker's cognitive abilities would need to be tested to determine which, if any, algorithm to use. The author acknowledges this barrier in the conclusion section. Another weakness is that the thesis rests on the assumption that older adults make less optimal decisions due to age-related cognitive declines. Although it is certainly true that age-related cognitive declines can impair decisions for some older adults, it is not necessarily the case that all older adults make less optimal choices, or that less than optimal choices are limited to older adults. Indeed, as the author notes, younger adults also have limitations in working memory that can curtail their ability to make optimal choices. Another issue that I did not think was sufficiently addressed is that from the decision

maker's perspective, there may be a relative lack of concern with making the so-called optimal choice. That is, especially for consumer decisions, decision makers may only be concerned with choosing an option that is "good enough" (satisficing). Indeed, there is research that shows older adults are more likely to satisfice. Thus, the author could take a more nuanced approach to the need for modified recommender systems by clarifying the conditions under which (types of products, what cost) and for whom (those with cognitive limitations irrespective of their age, those who care about making the "best" choice) new algorithms are most beneficial.

7. What is the contribution of the thesis to the discipline of information technology.

The thesis contributes to information technology by proposing and testing new algorithms that aim to improve decision quality by acknowledging and correcting for cognitive limitations of some users.