Supporting representation selection to improve reasoning: The iterative design of an adaptive system

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Abstract

This thesis presents the development of an intelligent automatic information visualization system (I-AIVE), which advises users about appropriate external representation (ER) selection for a range of tasks. Factors associated with effective ER use are investigated.

It is argued that previous work on automatic information visualization generation has tended to focus on creating effective ERs, with a focus on matching ERs to information type and/or task demands. The work presented in this thesis extends earlier studies by also considering a) the user's representational 'repertoire' (graphical prior knowledge) and b) the extent to which tasks vary in their 'representational specificity' (i.e. the narrowness/diversity of representations that can be effectively used to solve them). For example, some tasks might be effectively addressed with any one of a range of ERs, whereas on other tasks only one form of representation might be effective.

The design and development of I-AIVE was informed by findings from two empirical studies. Both experiments used AIVE - a non-adaptive prototype of I-AIVE - in an iterative design approach. AIVE presented various kinds of query tasks to participants (including, for example, correlation, comparison and identification) and contained a database of information about cars. The car data included engine size, number of doors, fuel consumption, etc. Query tasks were presented to the user, who then selected from an array of buttons with iconic depictions of display representations. Participants were instructed to choose representations they thought would be most helpful to them. The user's selected display option was then instantiated with the car information needed by the user in order to respond to the query.

A first experiment investigated the effect of users' background (prior) knowledge of ERs upon their patterns of representation selection and reasoning performance across a range of different database query task types. Participants with greater prior representational knowledge successfully used a wider range of ERs and selected more appropriate representations than did participants with less prior ER knowledge. Additionally, the query tasks were observed to vary widely in their representational specificity.

A second study therefore built on the first by 1) considering a wider range of representational forms; and 2) by comparing participants' performance across tasks that differed in terms of their representational specificity. It was found that results differed extensively according to the representation specificity of the tasks. On high representation specific tasks, it was crucial to select an appropriate ER in order to deal with that task successfully. For these tasks less prior ER knowledge was associated with an inability to select an appropriate ER and poorer reasoning performance than participants with greater ER knowledge. In contrast, it was found that for low representation specific tasks, participants performed well with several different ER types regardless of their level of prior ER knowledge.

Results from the two experiments informed the design of I-AIVE. This second system extended AIVE via the addition of a user model - a Bayesian network (seeded with empirical data).

I-AIVE's user-adaptations were based on monitoring the user's performance across tasks and representations (e.g. ER-to-task matching skills). I-AIVE intervened in two ways - 1) by providing hints to the user about appropriate representation selection; and 2) by removing display forms associated with poor performance.

A summative evaluation study showed that I-AIVE improved a user's reasoning performance and that it successfully predicted a user's ER-to-task matching skill and reasoning performance via its Bayesian user model.

In conclusion, it is argued that ER effectiveness crucially depends upon a three-way interaction between user characteristics (e.g. prior knowledge), the cognitive properties of an ER, and task characteristics (e.g. representational specificity). Future developments of I-AIVE are also discussed.

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