A user interface design for consistent pairwise comparisons

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ABSTRACT

Decision Makers generally reason on several criteria, aiming to obtain a total or partial order of several alternatives. MultiCriteria analysis is based on the assumption that such ordering exists. Decision Makers are supported by several kinds of approaches or tools. One approach consists in comparing the criteria two by two, i.e. pairwise comparison, in order to find the relative importance of each criterion. This relative importance, called weight of criteria, is then used in order to find the final order of alternatives. One methodology, developed by Saaty, called Analytical Hierarchical Process (AHP) (1), is based on this principle of pairwise comparison. Having the weight of criteria, the decision makers have then to compare the alternatives two by two for each criteria. Pairwise comparisons are simple to use; however, as the number of items to compare increases, so do the effort of conducting all comparisons and the probability of introducing inconsistencies. In this article present an innovative approach to conduct pairwise comparisons based on a UI widget that resembles an interactive data plot. It uses the transitivity property of a consistent comparison matrix to infer comparisons. Our hypothesis is that this new approach is more efficient (as it reduces the number of actions the user must conduct to compare all items), more effective (as it limits the sources of inconsistencies), and yields better user satisfaction. Experimental evaluation is currently underway to compare the proposed widget to the more traditional questionnaire view, with focus on usability in terms of perceived ease of use, efficiency and efficacy.

Keywords: Pairwise comparisons, Consistency, Transitivity, UI design, Usability, AHP

INTRODUCTION

The AHP method is an analytical approach for supporting decision making following a multi-criteria approach (1). It has been used in several areas, such as transport planning, rationing of energy, risk management projects, benchmarking of logistics operations, management of quality of services in hospitals, operations management, allocation resources for product portfolio management. It was developed by Thomas Saaty in 1970 and allows the decomposition of a complex problem in a hierarchical system. Hierarchically classifying alternatives defined by the decision maker provides the relative priorities of each alternative. Then a synthesis allows decision makers to easily understand what would be the best choice. Classification is performed at several levels which are associated with different criteria. Thus, it is possible to determine the most appropriate alternative, depending on the priority given to each used criteria. Pairwise comparisons (PCs) are a central feature of AHP.

In this article we present an approach to conduct PCs that is easy to use, intuitive, reduces the number of required comparisons, and yields consistent and complete comparison matrices. A visual 2D representation of the comparable items is used to express relative preferences among items. The transitivity property of the AHP matrix is used to infer preferences thus reducing the number of required comparisons. As a result, the method yields more consistent matrices regardless of the number of alternatives considered.

Next, we motivate our work by presenting an overview of key concepts regarding consistency and transitivity in AHP comparisons, and by discussing the role of visualizations. Then, we present our approach based on an innovative pairwise comparison widget. To conclude, we offer conclusions and discuss future work.

BACKGROUND: PAIRWISE COMPARISONS IN AHP

Following the construstruction of the hierarchical model with various levels of criteria and one one level of alternatives, PCs are carried out at each level. Different scales can be used to compare items (2). In this work we focus on the original scale proposed by Saaty, using integer values in [1,9], and their reciprocals. The decision makers' judgments are kept in a matrix model called the Judgments Matrix. The main objective is to compare the relative importance of all elements belonging to the same level.

Transitivity in multiple criteria decision making is also called ordinal consistency (3). If a decision maker prefers alternative $x1$ to alternative $x2$ and $x2$ to $x3$, then transitivity requires that he/she also prefers $x1$ to $x3$, as otherwise, cycles would exist in the preferences. Tversky (4) considered transitivity to be the cornerstone of normative decision theory. Preference transitivity is a basic principle in most major rational, descriptive decision models (5).

Benitez et al. (6) propose a method to achieve consistency in AHP through optimisation. This method has the major advantage of depending on just the decision variables – the number of compared elements – and so is less computationally expensive than other optimisation methods, and can be easily implemented in virtually any existing computer environment.

Decision support software packages such as Super Decisions (7) and Expert Choice (8) offer alternative modes to elicit user preferences as PCs. A frequent strategy to elicit comparisons is to present them in a matrix. Each value in the cell compares the item represented by the row, to the item represented by the column. Entering a value in a cell, automatically updates the value if its inverse. This method requires users to get accustomed to the direction of the comparisons, and the interpretation of the values (which are both integers and fractions) . Super Decisions improves the matrix view by removing the values in the diagonal, keeping only one value for each pair (i.e., removing the inverse comparison), and introducing an arrow that indicates the direction of the comparison (see Figure 2).

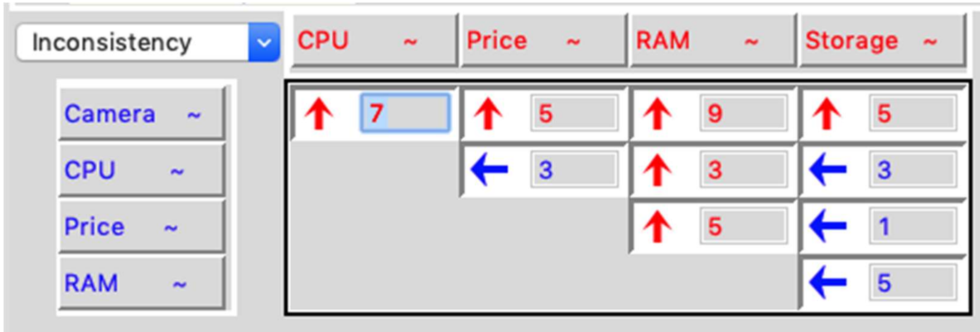

Figure 2: Matrix view in Super Decisions V3.2

The questionnaire view is another common presentation to elicit PCs . Each row represents one pairwise comparison, with the items to compare on each side. The user must place a mark closest to the item that is considered more important (or preferred). Super Decisions uses radio buttons as markers in its questionnaire view (see Figure 3), while PriEst (9) uses sliders (in PriEst, this view is called equalizer). Placing the marker in the middle indicates that items are equally important. The number of positions between items normally reflect values from 2 to 9 in each direction, plus 1 in the middle position.

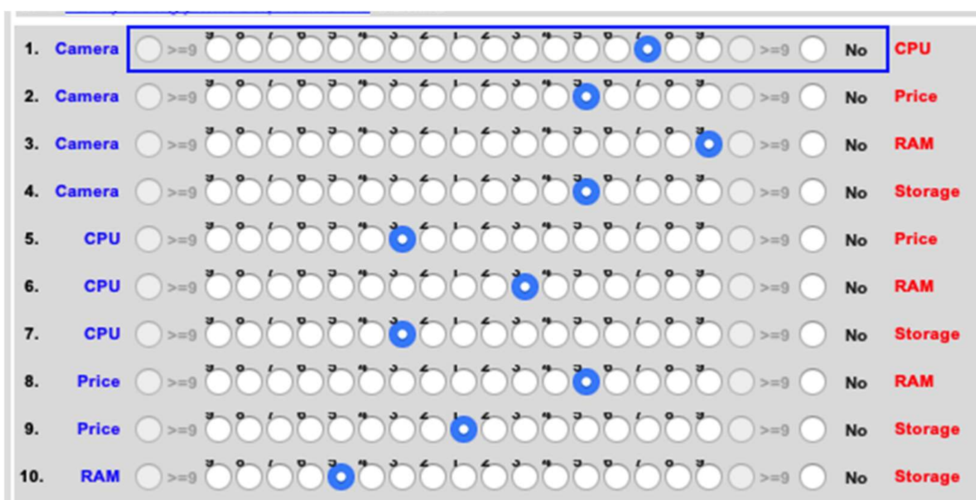

Figure 3: Questionnaire view in Super Decisions V3.2

Both, the matrix and the questionnaire presentations, offer a holistic view of all comparisons. In addition to these holistic presentations, some tools offer visual means to manipulate individual comparisons, for example in the form of an interactive bar or pie chart.

All the aforementioned strategies consider that each pairwise comparison is independent from the rest of them. Independence among comparisons directly correlates to consistency; the more liberty (and the less scaffolding) users have to independently compare items the more likely they are to introduce inconsistency. Super Decisions and PriEsT offer help to identify inconsistency. In addition, PriEsT offers visual aids to observe transitivity.

How to present and to elicit PCs is one of the challenges faced by decision support tools designers; modelling preferences is almost as important as the modelling of the logical structure of the problem (10). Abel et al. (11) compared the usability of two contrasting approaches to elicit decision priorities namely, PCs and constrained optimizations. Their work focuses on performance and usability as perceived by the user. The authors observed that PCs outperformed constraint optimizations for both efficiency and efficacy. There was little, if any, difference in terms of perceived usability. Millet (12) compared five preference elicitation models in terms of efficacy and ease of use. The results of Millet's research supports the motivation of this work to explore alternative graphical modes to elicit preferences.

TRANSITIVE SPACIAL COMPARISONS

Our approach to support PCs while maintaining consistency builds on two pillars. Firstly, it proposes a new visual tool (a User Interface widget) to express relative preferences. Secondly, all PCs are updated on every preference update using the transitivity property of an (assumed) consistent AHP matrix. The design of the widget conveys the transitivity of comparisons

The proposed widget is depicted in Figure 4. It resembles a 2D, continuous data plot. The vertical axis is labeled with the expressions that are normally given to the values in Saaty's scale. All items to compare are placed on the horizontal axis. The plot line includes a handle (a small circle) for the value corresponding to each item. The first handle (in this case, Price) is "anchored" to the middle value (representing 1, or equally important) . All other handles can be moved upwards or downwards.

At first, all handles are anchored at the middle position indicating that they are equally important. The user moves handles to indicate how a given item compares to the anchored one. For example, Figure 4 shows that the handle for RAM has been moved upwards to indicate that RAM is strongly better than Price (the anchored item). Moreover, moving a handle to express how the item compares to the anchored one, also indicates how it compares to all other items.

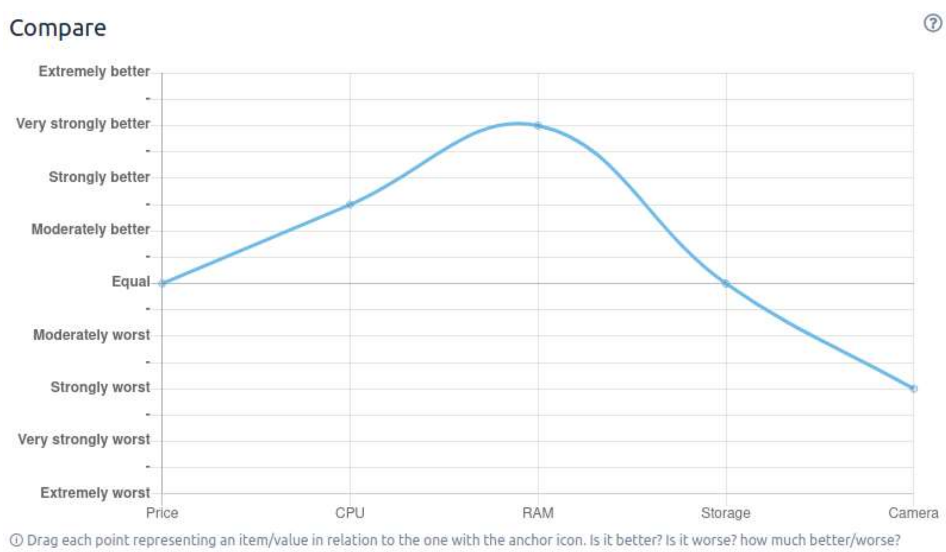

Figure 4: UI widget to present and elicit PCs

The widget offers a complete picture of how items compare to one another; however, labels in the vertical axis are expressed only in relation to the anchored item. Double clicking on a handle, anchors it to the left, updating the position of all other handles to reflect the change. This feature lets users explore the comparison space from the perspective of each item.

The visual representation of the comparisons helps maintain transitivity. By plotting all preferences in a 2D space, they inherit the transitivity properties of the comparison function in real numbers. Moving one handle simultaneously expresses how the item compares to the anchored one, and to all other items. This feature of the widget reduces the number of actions (e.g., clicks) that the user must make to compare all items.

PCs are stored in a matrix using Saaty's scale; rows and columns represent the handles (i.e., the items that handles stand for). The widget is divided in the middle by a line labeled "equally important". In addition, each half is divided by eight lighter lines (that correspond to the labels in the vertical axis).

When the user moves a handle h, the widget computes which line it is closest to. Then it computes the vertical distance d_i (rounded to the next integer) from that line, to the horizontal axis. The distance d_i is used to update the value in the cell that corresponds to the comparison between h and the anchored item. If h is above the horizontal axis, the cell takes the value $1 / (d_i + 1)$; otherwise, it takes $(d_i + 1)$.

As described previously, weights in an AHP matrix are consistent if they are transitive. That is, $a_{ik} = a_{ij}a_{jk}$ for all i, j, and k. The widget forces the transitivity property, using it to compute all cell values for rows different from that of the anchored item. Listing 1 outlines the algorithm used to transitively update cells. It iterates only over the cells that are above the diagonal and not in the row that corresponds to the anchored item. For each cell, it sets the expected value (according to the transitivity formula), and it sets the value of its inverse. To deal with rounding errors and extreme values (smaller than 1/9 or higher than 9), the algorithm adjusts values to the closest in Saaty's scale.

```
for i = 1 to n
  for j = i to n
      if (i != anchored) & (i != j)
         trasitively_update(i,j);
         set(j, i, 1 / get(i,j));
```

Listing 1: Using the transitive property to update cells not corresponding to the anchored item

In combination, the widget design and the update function limit the sources of inconsistencies to only those cases that reflect extreme comparisons (i.e. the transitive distance between two items is larger than what Saaty's scale can express).

CONCLUSIONS

PCs are a central feature of AHP. They are simple to use; however, as the number of items to compare increases, so do the effort of conducting all comparisons and the probability of introducing inconsistencies. We presented an innovative approach to conduct PCs based on a UI widget that resembles an interactive data plot. It uses the transitivity property of a consistent comparison matrix to infer comparisons. Our hypothesis is that this new approach is more efficient (as it reduces the number of actions the user must conduct to compare all items), more effective (as it limits the sources of inconsistencies), and yields better user satisfaction.

Experimental evaluation is currently underway to compare the proposed widget to the more traditional questionnaire view, with focus on usability in terms of perceived ease of use, efficiency and efficacy. The design of the experiments is similar to the one used by Anel et al. (11) and Millet (12). Participants are asked to produce a model to represent a problem statement (a decision scenario) either using the traditional view or the new widget. Perceived ease of use is assessed via a survey adapted from the SUS (System Usability Scale). Efficiency is measured in terms of time and number of actions required to complete a task. Efficacy is measured in terms of the consistency index of the resulting matrix, and the similarity of the produced ranking to the real one for a set of tangible values. We aim to conduct the experiments with Master and PhD students from at least two countries.

Pairwise comparison tools frequently present each comparison independently. In contrast our widget presents multiple pairwise comparisons at once, visually suggesting how they relate to one another (especially via transitivity). Presenting comparisons this way may hinder (psychological) independence of comparisons. Moreover, the curve that connects handles may misguide users to believe that there is something between items (taking intermediate values). Studying the impact of these potential drawbacks is the focus of future work.

REFERENCES

1. Saaty TL. Fundamentals of Decision Making and Priority Theory. 1st edition. Pittsburgh, PA: RWS Publications; 2000. 477 p.
2. Triantaphyllou E. Multi-criteria Decision Making Methods: A Comparative Study [Internet]. Boston, MA: Springer US; 2000. (Pardalos PM, Hearn D, editors. Applied Optimization; vol. 44).
3. Tanino T. Fuzzy preference orderings in group decision making. Fuzzy Sets and Systems. 1984 Feb 1;12(2):117–31.
4. Tversky A. Intransitivity of preferences. Psychological Review. 1969;76(1):31–48.
5. Regenwetter M, Dana J, Davis-Stober CP. Transitivity of preferences. Psychological Review. 2011 Jan;118(1):42–56.
6. Benítez J, Delgado-Galván X, Izquierdo J, Pérez-García R. Improving consistency in AHP decision-making processes. Applied Mathematics and Computation. 2012 Nov 15;219(5):2432–41.
7. Saaty TL. Super Decisions [Internet]. 2004. Available from: https://superdecisions.com/
8. Expert Choice. Expert Choice; 2021. Available from: https://www.expertchoice.com
9. Siraj S, Mikhailov L, Keane JA. PriEsT: an interactive decision support tool to estimate priorities from pairwise comparison judgments. International Transactions in Operational Research. 2015;22(2):217–35.
10. Kämpke T, Radermacher FJ, Wolf P. Supporting preference elicitation: The FAW preference elicitation tool. Decision Support Systems. 1993 Jun 1;9(4):381–91.
11. Abel E, Galpin I, Paton NW, Keane JA. Pairwise comparisons or constrained optimization? A usability evaluation of techniques for eliciting decision priorities. International Transactions in Operational Research
12. Millet I. The Effectiveness of Alternative Preference Elicitation Methods in the Analytic Hierarchy Process. Journal of Multi-Criteria Decision Analysis. 1997;6(1):41–51.