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ABSTRACT

In project management, many decisions are made based on multiple attributes (dimensions) of project data. However, these dimensions are usually condensed into one or two indicators in the analysis process. For example, projects are commonly prioritized using a scoring approach: they are evaluated according to predefined categories, which are then aggregated into one or two priority numbers. We argue that aggregated scores may only offer a limited view of project importance. Such scores tend to hide information that may effectively distinguish projects; this often leads decision makers to ignore the possible differences masked by aggregation. This paper presents a visual exploration approach that integrates human intuition and maintains the multidimensionality of project data as a decision basis for project prioritization and selection. The approach is based on the examination of portfolio perceptual maps, generated by a clustering technique. The research provides a useful and complementary approach for decision makers to analyze project portfolios.

Keywords

Project Portfolio Management, Project Prioritization, Visual Exploration, Clustering, Self-Organizing Map, Decision Support

INTRODUCTION

Defining projects is a common and useful way to manage operational goals and activities within an organization or organizational unit. A major concern for these organizations or departments is the management of projects in an effective and efficient manner. This requires clear understanding and communication of project status, balancing the allocation of resources, and understanding a project's contribution to overall organizational goals. A Project Management Office (PMO) is usually established to take such responsibility and the concept commonly known as project portfolio management (PPM), or Project Program Management, is adopted (McFarlan 1981). Portfolio management is a business practice borrowed from the financial and investment management (Markowitz 1952) where a combination of financial investments and assets are managed as a group. In the domain of information systems, an IS portfolio or project portfolio is a combination of information systems projects with different sizes, purposes, values, etc. PPM's ultimate goal is to maintain a balanced and healthy mix of projects for an organization.

There are a number of tasks performed at a portfolio level in PPM in addition to following the traditional single project management practices. Project prioritization is one of the common portfolio management tasks. Organizations have limited resources (money, people, time, etc.) to conduct their business and operations, thus projects need to be prioritized. Project priorities are commonly the basis of project selection and also resource allocation at a later stage. The criteria for determining project priority are varied and often depend on different management perspectives and business styles. Managers tend to comprehend project importance from multiple perspectives (risk, future, business goal alignment, relationships, etc.) and rank projects accordingly.

Common prioritization methods follow an indexing or scoring approach (Dickinson et al. 2001) which evaluates projects in a set of predefined categories with an option of providing simple quadrant diagrams (Cooper et al. 2000; Ghasemzadeh et al. 2000). The project priority is commonly represented by one aggregated number (score) based on a weighted summation of scores in each criteria. There are a number of variants based on this technique:

- Scoring items are organized into groups/categories; each group/category is scored before final calculation (Buss 1983; Ghasemzadeh et al. 2000).
- Items or categories can be assigned different weightings to reflect unequal importance.
- Projects are pre-categorized and are assigned different scoring model/weightings for different categories (Ward 1990).
- Many multi-attribute decision making methods (Yeh 2002) use complex mathematical models (Weistroffer et al. 2005) or a lengthy comparison process (Al-Harbi 2001) to derive user preference scores or overall priority number.

Some other methods use two numerical indicators instead of one. For example, McFarlan (1981) uses project structure and technology level; Murphy's decision model (Weir 2004) uses success and value dimensions; Jolly (2003) uses technology attractiveness and technology competitiveness; (Ghasemzadeh et al. 2000) uses risk vs. time-to-complete; another popular model uses risk and reward (Brandon 2006; Cooper et al. 2000). The advantage of two indicators instead of one is that the additional indicator adds one more dimension of information and enrich the meaning of projects. Another advantage is that these projects are readily plotted on a two-dimensional diagram based on two indicators; in doing so, users can easily see project distributions and overall portfolio composition. Because the mapping space is often organized into 4 (2 by 2) or 9 (3 by 3) regions, the diagram is also known as a quadrant, matrix or grid diagram.

These popular approaches have several problems when dealing with multidimensional projects data:

1) The final decision relies on simple calculated numbers. Multiple attributes may be used as inputs and contribute to the calculation process, but at the end, these attributes are transformed into one or two indicators for interpretation simplicity. Such simplicity does not always satisfy business need. The calculated numbers may not be clear and understandable to users.. In addition, these calculated final indexes or scores may only offer a limited view of the project importance. An aggregated score tends to homogenize many projects, hiding useful and relevant information that may effectively distinguish them (Wang et al. 2003). That often leads decision makers to ignore the possible differences that get masked by the aggregation, and may result in decisions that are not well justified.

2) Visualization is a good mechanism to comprehend portfolio composition intuitively. Unfortunately, many visualization diagrams are more confirmatory than exploratory, where they are mere static reflections of results after the decision making process has been completed; they are not well integrated into the decision making process itself. Moreover, quadrant or matrix diagrams are fundamentally constructed based on only two dimensions. Trying to fit high dimensional information into these low dimensional models often leaves out the richness of project information, and leads to a narrower understanding of project distribution.

To address these two issues, we need a system that provides assistance in viewing, understanding and analyzing projects and project portfolios directly based on multiple dimensions of project data in the complete decision process. Furthermore, such a system should utilize proper interactive visualizations to effectively and intuitively handle multidimensional information for the information seeking process. Therefore, our main research goal is to design such a computer system driven approach that complements other methods used in project portfolio management. More specific research questions are:

1) What are the major components of such an approach/system?
2) How to use such an approach/system to understand project portfolio and prioritize projects?

Having adopted a design science research prospective (Hevner et al. 2004; Vaishnavi et al. 2008), we proposed an approach, developed a prototype system based on the approach (and iteratively refined the approach and the corresponding system), and evaluated the system using empirical qualitative data. The research outcome is a multidimensional and visual exploration approach, which directly addresses the two issues raised above. In the rest of this paper, we first describe the core design concepts and components of the approach, and illustrate the approach with the developed prototype and a scenario. Then we briefly describe evaluation work and conclude the paper.

A MULTIDIMENSIONAL AND VISUAL EXPLORATION APPROACH

Core system design concepts

In general, the designed approach is a computer system driven visual information seeking process (Keim 2002). There are basically two parts in this approach: generation of portfolio perceptual maps based on multidimensional project data, and information visual exploration.

Generating Portfolio Perceptual Maps Using Self-Organizing Maps

A perceptual map is a high level overview visualization of the complete portfolio and it is one of the major visual elements for exploration. For our system, an unsupervised clustering technique called Self-Organizing Map (SOM) (Kohonen 2001) is used to generate such maps. Clustering is a general data mining method that groups objects based on their properties without predefined categories (Jain et al. 1999). It is one of the effective methods to analyze multi-dimensional information (Wang et al. 2003). More specifically, SOM was chosen because of its additional visualization capability. SOM inherently provides a 2D map on which complex high dimensional data can be effectively mapped. The advantage of this 2D map is that projects and portfolio distributions can be visually examined by observing the map. This is well suited to our approach with an emphasis on human intuition and visual exploration.

To apply SOM algorithm, users need to select projects, choose project attributes, and set map size (and other SOM parameters which are of less importance to business users). These settings can be flexibly configured and explored by users to get best satisfying output. The output of SOM is a cluster map, an important component for visual exploration.

Visual Exploration

The second part of the system is a visual exploration system. The overall design architecture is suggested by an information behavior model (Wilson 1981), which describes the process of how people seek information for certain needs. Part of the model is presented in Figure 1.

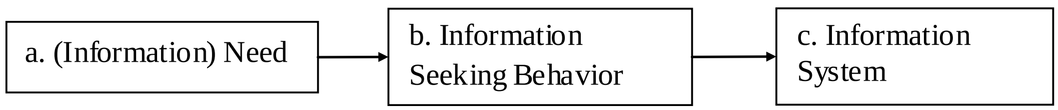

Figure 1: Information Behavior Model (Partial) (Wilson 1981)

Figure 2 shows the conceptual architecture of the current system, corresponding to the high level theoretical constructs suggested by Figure 1, with more detailed and specific designs. In Figure 2, management tasks correspond to information need (Figure 1, a). They constitute the purpose of using the system, such as general learning, understanding, decision support, and other various management tasks. Visual Exploration Actions roughly correspond to information seeking behavior (Figure 1, b); these are series of human behaviors for interacting with the visual elements for particular information needs. Visual Elements are the basic and rather static visualizations created by information systems. Conceptually, an information system (Figure 1, c) provides a set of basic visual elements as the basis, as well as functionalities to directly support visual exploration actions. The following two sections will explain in detail each component in visual elements and visual exploration actions.

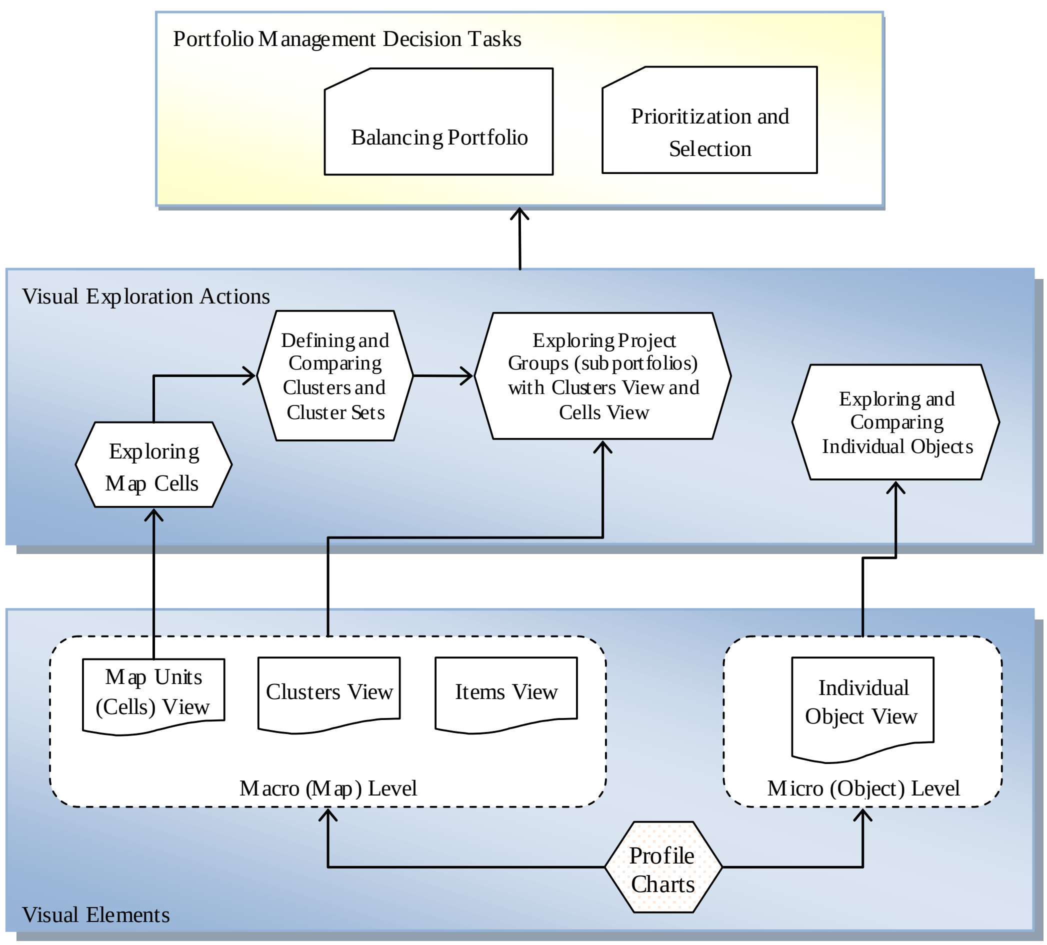

Figure 2: Conceptual Model of the Multidimensional and Visual Exploration System

Visual Elements

Visual elements are the basic visualization created by the system. There are two basic types (levels) of visual elements: micro (object) level and macro (map) level, both created around a centerpiece element called *Profile Chart.*

A profile chart is a visualization of an object based on values of attributes (dimensions) selected to represent the object; such visualization forms a representative shape pattern that can offer a strong impression of the object. It enables easy and direct visual comparison during the visual exploration process. A profile chart can be created using various types such as bar chart, line graph, area graph, or radar diagram (Jarvenpaa et al. 1988; Tegarden 1999). For example, Figure 3 shows a radar diagram for the project "Anti-Spam". The system/approach itself does not provide guidance on choosing chart types but leave that to users as options when exploring the data. For consistency and illustration purpose, this paper will use the radar diagram.

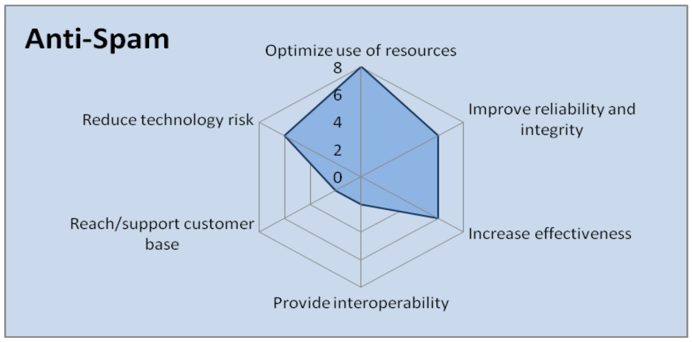

Figure 3: Profile Chart in Radar Diagram

The micro (object) level visual elements are used to visualize individual objects. At this level, the profile chart is directly used to visualize a single object, such as projects, SOM map units, and SOM map clusters. The macro (map) level visual elements generally refer to the three SOM map views (Table 1). A SOM map is a two dimensional space divided into smaller regions (map units or cells) by rows and columns. Its size (number of cells) is usually described as X by Y, where X is the number of cells per row (map width) and Y is the number of cells per column (map height). Each cell represents a certain pattern (a vector of values corresponding to selected project attributes). The three views offer different perspectives of the SOM output and can be overlapped (see Figure 7) to meet specific visual exploration needs.

Map View	Description	Example Figures
Cells View	This view is generated directly based on the SOM results. Each SOM cell, after training, is represented by a vector corresponding to the previously selected dimensions (attributes). This vector represents the characteristics of a particular map cell. In our system, each vector is visualized using the profile chart, which is embedded directly in the cell. A Cells View displays these profile charts of all cells collectively. In such a view, the changing trend/pattern of all cells can be directly observed on the map so that users can have an overall understanding of the map.	Figure 5
Clusters View	A cluster on the map is a group of nearby cells with similar patterns. A map then can be divided into more coarsely identified regions (clusters). The cluster profile is calculated based on its member cells and then visualized using the profile chart. One advantage of the cluster view is that it reduces visual complexity and suggests higher level of project grouping. Compared to cells view, the differences among clusters are more discrete.	Figure 7
Items View	This view is the result of mapping IT projects on the base map. Each project is placed into the cell with the least difference between the project and the cell based on selected dimensions. One basic difference measure is Euclidean Distance (distance $= \sqrt{\sum_{i=1}^{n}(pi - qi)^2}$). After the mapping, the distribution of projects on the map should reflect the portfolio characteristics. Projects that are closer are more similar than those further away in terms of all dimensions.	Figure 6

Table 1. Three SOM Map Views

Visual Exploration Actions

Visual exploration actions are human interactions with visual elements for a certain information seeking or decision making task. In our approach, there are two basic types of visual exploration actions: object level exploration and map level exploration. Object level exploration is viewing and comparing/contrasting individual objects. These objects mainly include projects, map cells, and clusters. The action is directly supported by the micro level visual elements. A list of more detailed exploration actions is documented, with each relating to specific exploration steps (see next section for some examples). Map level exploration is the action to explore SOM map and project portfolio based on the three map views:

1) Exploring map cells: This action is carried out directly on the Cells View. It is mainly to have an overall feeling of the complete map to comprehend map characteristics. Because the changing trend is clearly shown on the map using profile charts, users can quickly understand a new or unfamiliar map. In addition, this action is also used to support the second action of defining clusters.
2) Defining and exploring map clusters: This action is to define clusters and cluster sets (multiple ways to cluster the map based on particular needs and perspectives) by observing and comparing/contrasting cell patterns. This is a manual process to assign cells to clusters. Each cluster profile is calculated by the system on the fly and presented to users though profile charts.
3) Exploring project portfolios with Map Cells View and/or Clusters View: This action depends on the flexible combination of three map views. In addition, users can define focus groups (or sub-portfolios) for specific exploration needs. A focus group is a set of projects grouped together. Users can define various groups and compare/contrast among them, so they will better understand their similarity and differences in terms of group composition characteristics.

When using the system, a user will explore the map and projects using combinations and variations of the above basic exploring actions together with other general visual exploring techniques (such as zooming, filtering, ghosting, distortion, animation) to seek useful information.

A General Process of Using the System

The multidimensional and visual exploration approach is not merely a system providing static visualizations. It is also a series of interactions taken between human and system, hence an exploration process (Keim 2002). The approach also includes guidelines for using the system to support PPM tasks like project prioritization and selection. Figure 4 is a high level summary of the major steps of using such a system. To better understand the approach and the process, a project prioritization and selection scenario is presented in the following paragraphs, with screenshots of an actual running prototype system (for best quality, it is better to print the screenshots in color mode or to view them on computer screen).

The IS&T Department of a major university manages all of its activities based on projects. The Project Management Office has been using a scoring model to prioritize projects and reports a "Top10" prioritized project list to the upper management. Typically in the department, the scoring model consists of six components that are related to business goals. These components are "Optimize use of resources," "Improve reliability and integrity," "Increase effectiveness," "Provide interoperability," "Reach/support customer base," "Reduce technology risk." The upper management will specially focus on these top prioritized projects, when dealing with issues like resource allocation and strategic planning. When a "Top10" project finishes, another project will be promoted on the list. Now, three of the ten projects have completed and the project management office is asked to recommend other three projects to complete the list.

Using our approach, following steps (corresponding to steps in Figure 4) are taken to select the three projects:

(1) For a completely new analysis, the process generally begins with data clustering. Before a clustering process, project data needs to be prepared specifically for SOM processing. Particularly, map size needs to be determined, and project attributes needs to be selected. So in our scenario, Randall, the project manager, selects all 55 projects from the database, and selects the six scoring attributes as data input (for simplicity, no data transformation, scaling or weighting are considered).

(2) SOM will be applied to generate a cluster map, which can be directly previewed and analyzed for immediate visual exploration, or can be saved into the database for later use. So Randall runs the SOM and the result is ready after a few seconds.

(3) Starting the visual exploration process, a user first needs to understand the newly generated map. The user can do this through examining the Cells View. In the scenario, a map with size 9 by 7 is generated (Figure 5). In the figure, the six scoring components are displayed in the top left corner; they represent the six axes in each radar chart, following a clock-wise order, starting from the 12 clock axis. Randall examines the map and clearly sees the changing patterns of the profile charts.

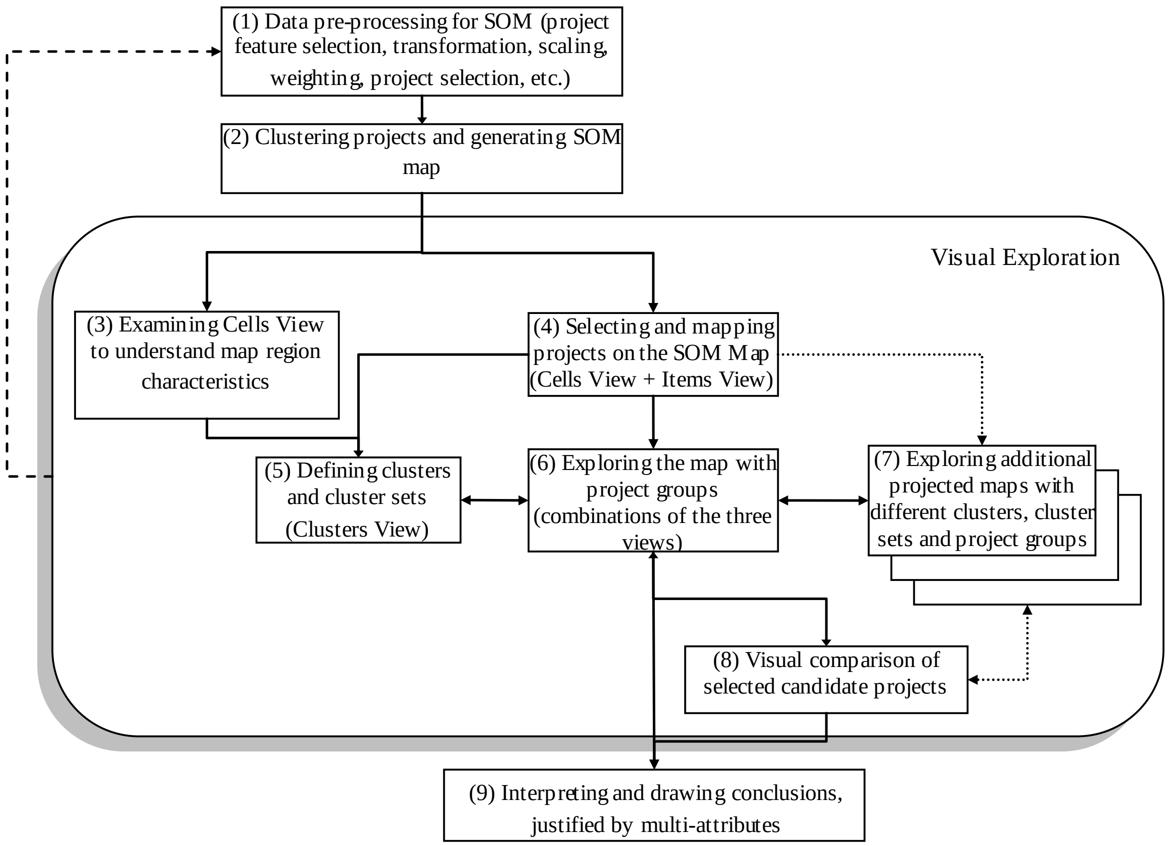

Figure 4. A Summary of Multidimensional and Visual Exploration Process for Project Portfolio Management

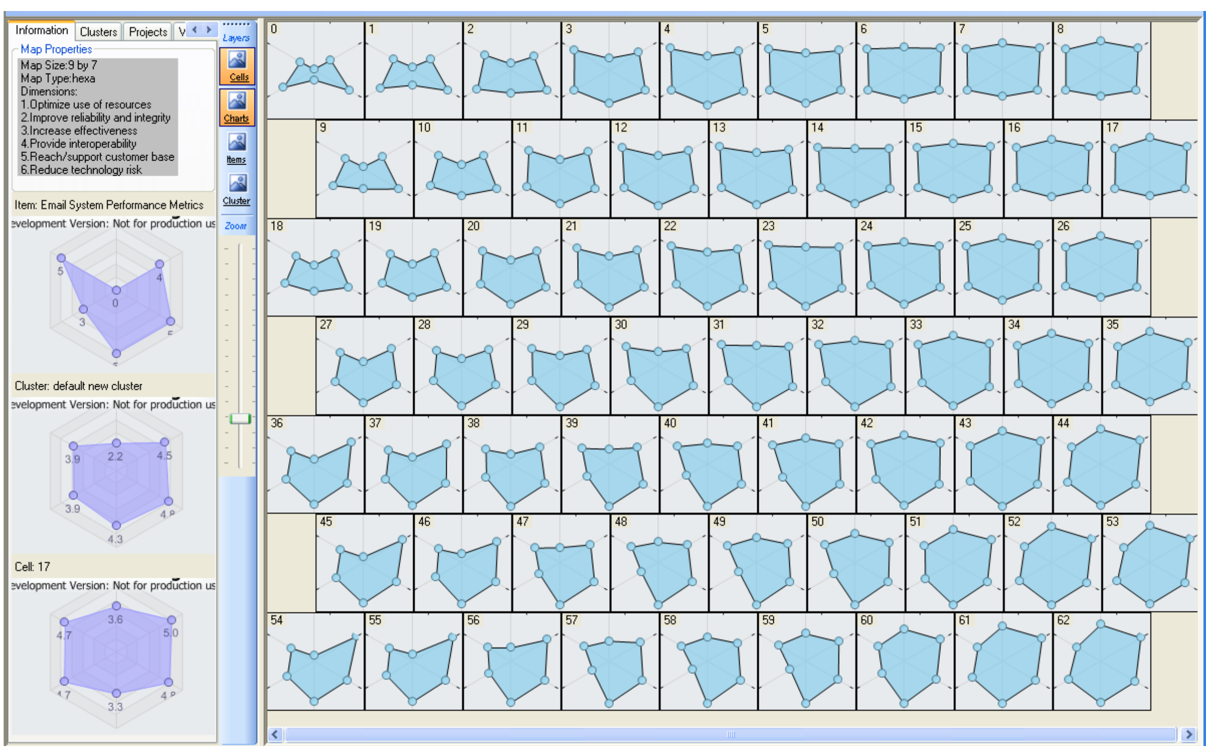

Figure 5: Prototype Screenshot: SOM Map Cells View (Hexagonal Style)

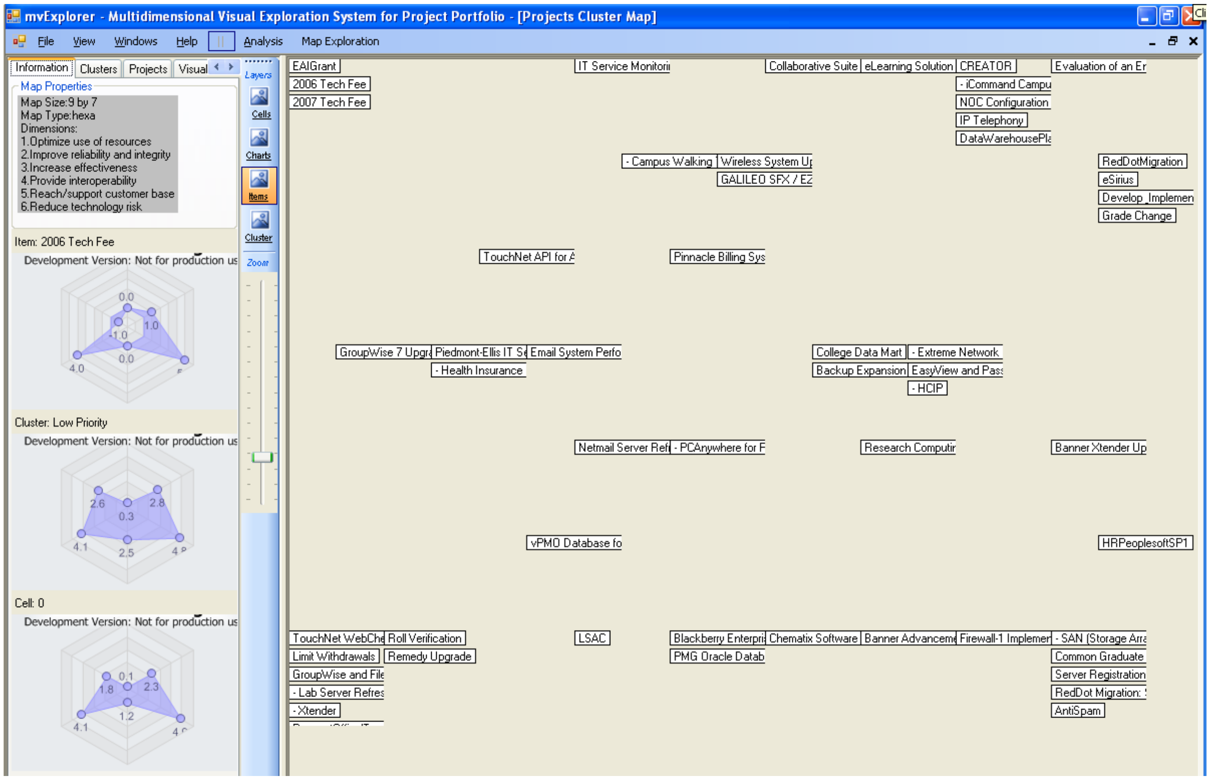

Figure 6: Prototype Screenshot: SOM Map Items View

(4) Projects are mapped and users can examine the Items View. Randall can examine the project distribution using this view (Figure 6, projects are visualized as labels). He can also overlap view with the Cells View to get more details. For example, the three projects in the upper left corner ("EAI Grant", "2006 Tech Fee", "2007 Tech Fee") are mapped to cell #0 (compare Figure 6 to Figure 5); that means, pretty intuitively, these three projects are similar to one other and to the profile chart pattern of cell #0. Randall can move the cursor to the project labels in the map to get its profile chart displayed on the left panel to the map (the first radar chart represents "2006 Tech Fee" profile and the last one represent the cell #0 profile).

(5) To reduce visual complexity, clusters can be defined to divide the map into manageable clusters. In Figure 7, Randall defines six clusters based on his examination of cells and projects. He also labels each cluster and uses colors for visual differentiation. All clusters are summarized in the left pane, using profile chart to quickly preview the pattern of a cluster. The prototype also provides a detailed report of all clusters and the projects in each cluster.

(6) Now with clusters defined, users can freely switch among the three views to explore the overview map and project portfolio. Project groups can be defined to focus on part of the portfolio, and compare/contrast between certain project groups. In our scenario, Randall defines a project group that consists of the seven existing projects in the "Top10" list. He wants to look for projects that are close to these seven projects on the map, so he can selects those as candidates to be further examined. In Figure 8, these seven projects are highlighted in green. It is clear to see that 6 of them fall in the cluster "High Priority" (red colored, lower right cluster, marked by the broken line). There are a number of projects close to the project group, and Randall first selects some projects from those within the circles as candidates (Figure 8).

(7) If necessary, users can explore the map with different setting, project groups, cluster sets, and styles, using various visual exploration techniques to determine further candidates.

(8) Now users can further visually compare selected candidate projects head to head using the profile chart comparison tool. In the scenario, Randall first puts 6 projects together and compares them using the overlapping radar chart type and line-area style (Figure 9). Other chart types and styles can be chosen flexibly per user's need and cognitive style. In the figure, Randall switches on 3 of the selected project and hides others. The difference is clear: "EasyView and Password Resets" scores higher on "Reduce technology risk"; "Common Graduate Application for Admission" scores higher on "Reach customer base"; "Anti-Spam" scores higher on "Improve reliability and integrity." Now, depending on Randall's perspective or the department policy, Randall will choose one of them as one of his recommendation. Randall will repeat this process to compare and contrast other candidate projects until he decides the final three.

(9) Now the user can better justify and communicate the decision to others.

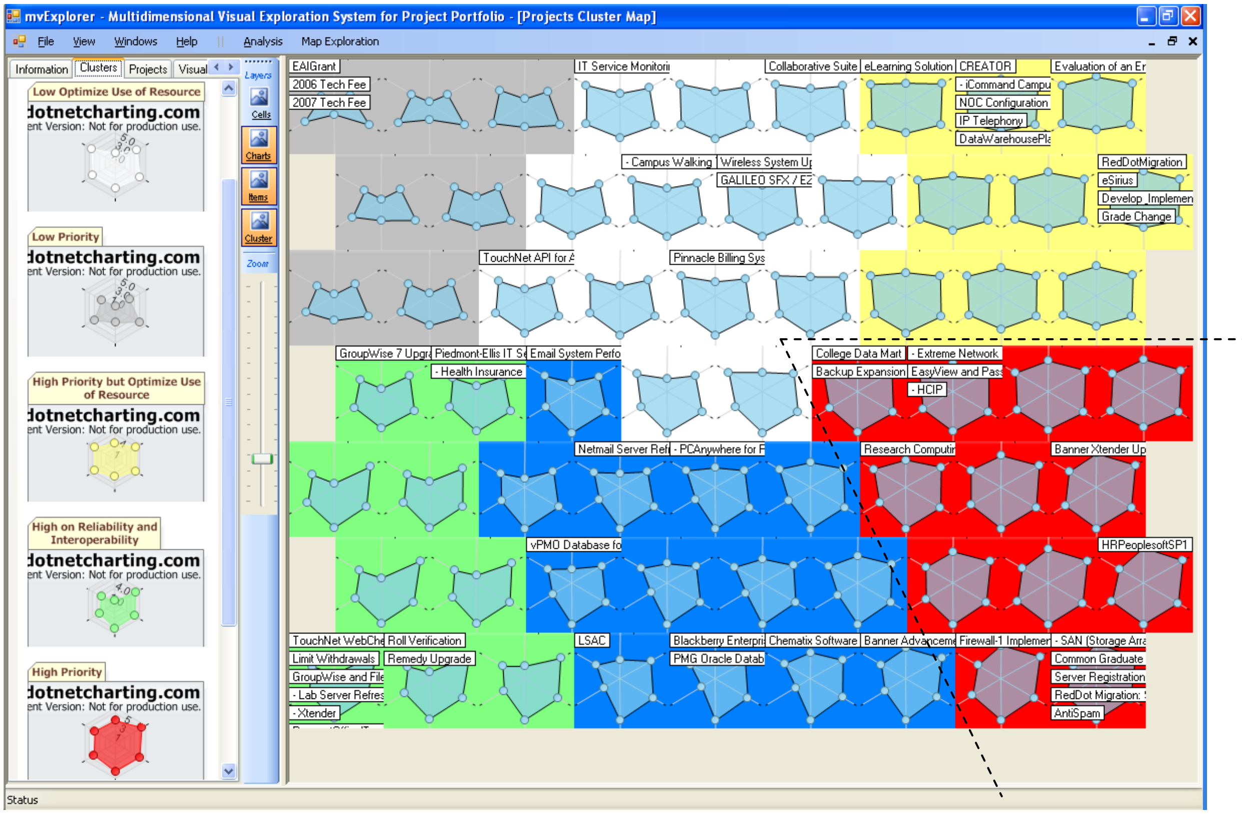

Figure 7: Prototype Screenshot: SOM Map Cells View + Clusters View + Items View

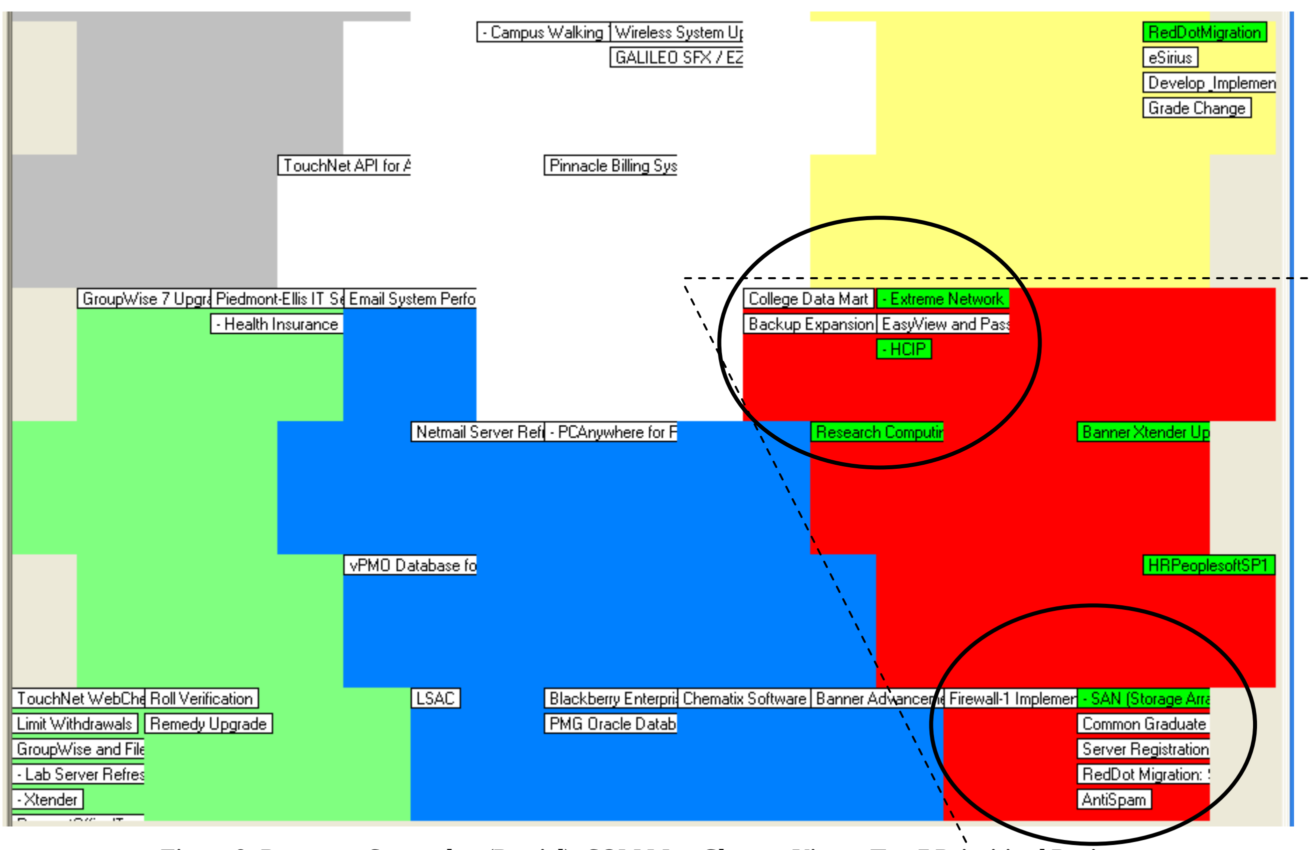

Figure 8: Prototype Screenshot (Partial): SOM Map Clusters View + Top 7 Prioritized Projects

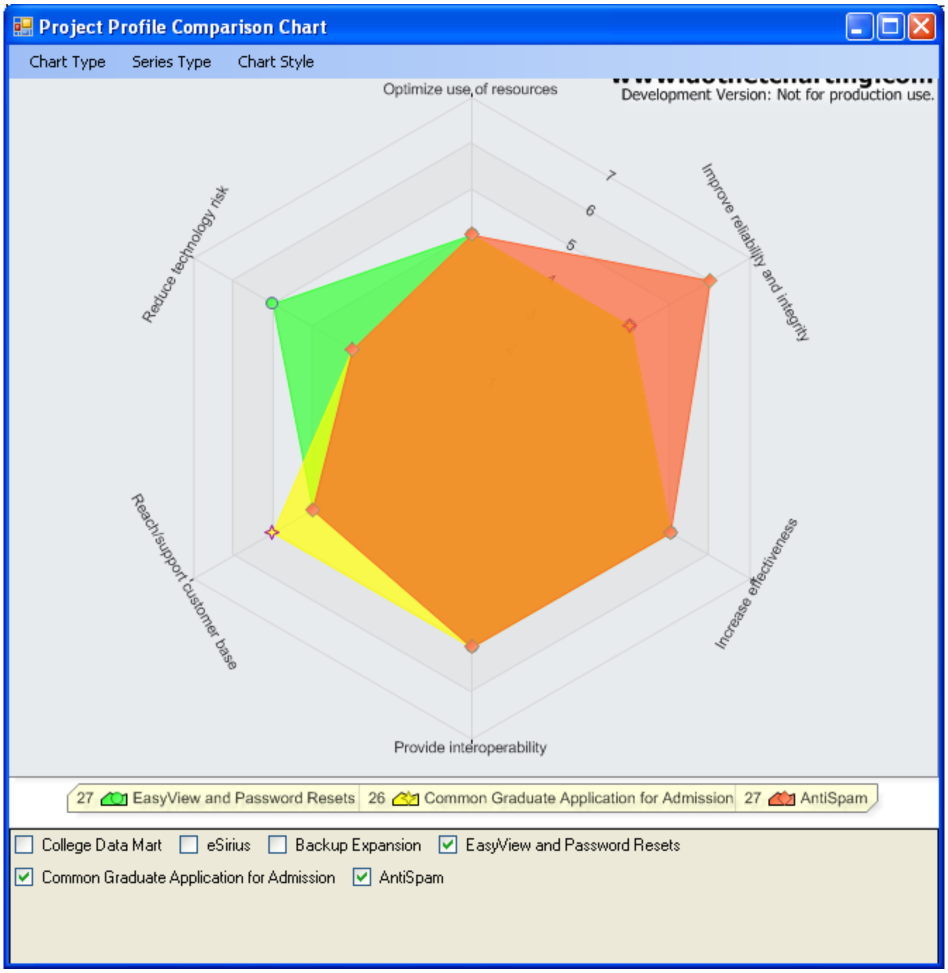

Figure 9: Prototype Screenshot: Profile Charts

The above scenario and prototype demonstrate the core concepts described earlier. Such a process to prioritize and select projects is easy to explain and discuss. It successfully differentiates projects with similar aggregate scores, and makes sure the selected projects are aligned with the business goals as closely as possible. The scenario described above is only one typical process of using the approach and system. This process or its variations could be repeated until fully satisfied. In addition, the approach is not only an individual level analysis tool to seek decision support but is also a group level tool to facilitate the collaborative and negotiation process to achieve common understanding.

EVALUATION

To evaluate the approach we conducted interviews to see how project management practitioners react to the prototype based on the approach. We invited six people from an IT department in a major university to evaluate the prototype.

Each interview lasted about an hour. Participants were presented with the prototype and walked through major functionalities of the prototype with the help of use scenarios. Efforts were made to make sure that participants understand each component of the prototype system and each step of using the system. A prepared list of guided question was used to guide the interview; interviewees could also raise questions and provide their comment freely. After the interview, participants were requested to fill out a post-interview questionnaire to report some quantitative data at their own time. This gave the participants to think about the prototype and to carefully provide their feedback.

All of the participants are experienced practitioners in project management. Of these six participants, two are at the director /assistant director level (directors directly report to the CIO), two are from the Project Management Office, and two are departmental project managers. Their backgrounds are shown in Table 2.

Experience Area	*Average experience (in years)*
Information system/technology	13.8
Project management	11.3
Project management software	8.5

Table 2. Interviewee Backgrounds Summary

The main objectives of the evaluation is to seek evidences from the interview data to confirm the perceived usefulness and perceived ease-of-use (Davis 1989) of the system. Interviews were transcribed and analyzed using a template analysis method (King 2004). Evidences were identified and organized as themes that provide more details of perceived usefulness and ease-of-use (Table 3). These themes show the utility and ease-of-use of the system. Because of page limitations, only some samples of such qualitative comments are shown in Table 3.

Evaluation Objectives	*Identified Themes of Positive Evidences*	*Example Comments*
Perceived Usefulness	Giving a quick overview of the portfolio based on selected attributes.	"If you want to make an intelligent and informed decision, yes, you have to look at them together, coz otherwise you are just trusting whatever algorithms translating all those into a number, right? If you want to take a simple and easy way out, just let them show you the number and ride your project, fine; but if you want to understand the interplay between all those dimensions and all those projects visualizations is the right way to happen."
	Clearly sees difference. Helpful in suggesting candidates.	
	Better justification.	
	The approach helps to discover hidden information.	
	Facilitating discussion and communication.	
	Less gaming.	
Perceived Ease-of-Use	The steps and visualizations are easy and intuitive.	"I like it. It makes sense to me, and it is easy to argue, too. Because you can throw it up there and you go, look … if you are goanna defend your position for what you are thinking about. Here's my reason behind it … well, there's your argument, there's nothing to argue about. There it is. It is pretty cut and dry, to me. It is really easy to throw it up there and go: what you guys want to do?"
	It is easy to remember and recall project profiles and portfolio profiles in the Clusters View.	
	Operation is easy. The system is flexible.	

Table 3. Selected Qualitative Results

Participants also responded to the questionnaire questions (statements) based on the 7-point Likert scale, where 1 indicates "Strongly Disagree" and 7 indicates "Strongly Agree". Table 4 details the user answers to these statements.

Statement		*Average Rating*
Perceived usefulness	The tool provides a good model of prioritizing projects based on priority patterns, instead of aggregate numbers; and it is effective to communicate and justify them.	6.3
Perceived ease of use	The tool is easy to use and understand. A business user will be able to use it after some training.	5.3

Table 4. Post-Interview Questionnaire Results

The quantitative results from the questionnaire are consistent with their qualitative comments, reflecting users' positive feedback to the prototype. Although the data reported here points to design principles only in a situated context (Kuechler et al. 2008), it is only a starting point to more large scale experiments or user study surveys. We will continue the design research cycle to theorize the design.

CONCLUSION

In this research, we tried to look for an alternative approach to address some current decision support limitations in project portfolio management. Adopting a design science research perspective, we designed the multidimensional and visual exploration approach, created a prototype system, and evaluated it. The initial evaluation results are very encouraging and positive, meeting our expectation that such an approach is able to integrate multidimensional analysis and human comprehension of visualizations into project portfolio management. Further research will utilize user comments from the evaluation to improve the approach and the prototype.

There are two major contributions of this work, both to the problem domains and to the visual exploration system. First, a general design science research contribution is the creation or enhancement of IT artifacts for a business need in an appropriate environment (Hevner et al. 2004). In this research, we designed a new analytical approach and system (IT artifact) that enriches the analytical choices in project portfolio management (environment). It can be generalized to be applicable in other business domains which need to process structured multidimensional data as well as to utilize human intuition and judgment, such as asset management, talent management and performance evaluation. Second, the design work of this research abstracts the basic elements of the approach/system (see Figure 2 and Figure 4). This is the basis of a potential mid-range design theory (Kuechler et al. 2008) that can guide the development and application of similar approaches and systems. With further work, the research could lead to a more general design theory or framework for visual information exploration systems for business portfolios.

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