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# A Multidimensional and Visual Exploration Approach to Project Portfolio Management

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A MULTIDIMENSIONAL AND VISUAL EXPLORATION APPROACH TO  
PROJECT PORTFOLIO MANAGEMENT

BY

GUANGZHI ZHENG

A Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree  
of  
Doctor of Philosophy  
in the Robinson College of Business  
of  
Georgia State University

GEORGIA STATE UNIVERSITY  
ROBINSON COLLEGE OF BUSINESS  
2009

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## ACCEPTANCE

This dissertation was prepared under the direction of the candidate's Dissertation Committee. It has been approved and accepted by all members of that committee, and it has been accepted in partial fulfillment of the requirements for the degree of Doctor in Philosophy in Business Administration in the Robinson College of Business of Georgia State University.

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## **ABSTRACT**

### **A MULTIDIMENSIONAL AND VISUAL EXPLORATION APPROACH TO PROJECT PORTFOLIO MANAGEMENT**

By

**GUANGZHI ZHENG**

April 2009

Committee Chair: Dr. Vijay K. Vaishnavi

Major Department: Computer Information Systems

Managing projects in an organization, especially a project-oriented organization, is a challenging task. Project data has a large volume and is complex to manage. It is different from managing a single project, because one needs to integrate and synthesize information from multiple projects and multiple perspectives for high-level strategic business decisions, such as aligning projects with business objectives, balancing investment and expected return, and allocating resources. Current methods and tools either do not well integrate multiple aspects or are not intuitive and easy to use for managers and executives. In this dissertation project, a multidimensional and visual exploration approach was designed and evaluated to provide a unique and intuitive option to support decision making in project portfolio management. The research followed a general design science research methodology involving phases of awareness of problem, suggestion, development, evaluation and conclusion. The approach was implemented into a software system using a prototyping method and was evaluated through user interviews. The evaluation result demonstrates the utility and ease-of-use of the approach, and confirms design objectives. The research brings a new perspective and provides a new decision support tool for project portfolio management. It also contributes to the design knowledge of visual exploration systems for business portfolio management by theorizing the system.

# Chapter 1. Introduction

## 1.1 Statement of the problem and motivation

Defining projects is a very common and useful way to manage operational goals and activities within an organization or an organizational unit. It is also effective to form cross-unit project teams to carry out strategic business activities. In fact, many organizations (or their major departments overseeing organization-wide resources such as information technology) are becoming project-oriented (Arto, 2001; Gareis, 2000). A major concern in these organizations or departments is the management of their projects in an effective and efficient manner. This requires clear understanding and communication of project status, balancing 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 (McFarlan, 1981) or program management (Lycett, Rassau, & Danson, 2004; Pellegrinelli, 1997) (PPM) is adopted. In PPM, all projects are managed as a group (a portfolio or a program), which is treated as a basket of investments (activities) that can balance properties such as risks and returns. Besides following traditional single project management practices, such as defining, estimating, scheduling, tracking, and optimizing the tasks and resources required to plan and complete a project (IDC 2006), it also manages these projects at a higher portfolio level. Examples of common activities in PPM and decisions to be made are (Reddy, 2004):

- Aligning IT (Information Technology) projects with business goals (CIO level)
- Determining whether teams are working on the right projects (CIO level)
- Assessing and communicating portfolio status (program manager/director level)

- Prioritizing initiatives, resources, and assets (program manager/director level)
- Predicting project outcomes, assessing project status, and identifying inter-project dependencies (project manager level)

PPM is commonly perceived to be able to bring to an organization benefits such as cost savings, better communication, better resource allocation, and balanced risks and return (Brandon 2006, Cooper et al. 2000). However, despite such general awareness and interest, few organizations appear to maximize PPM's value in practice. In one pertinent survey (Leliveld & Jeffery, 2003), while 89% of the respondents were aware of the concept of portfolio management, only 14% of them used some kind of tool and 31% were planning to do so. In another survey (Reyck, et al., 2005), only 29% of the respondents used some kind of specialized software; 33% of them managed project diversification; and 47% of them used categorization to balance portfolio. This suggests that many organizations do not have an overall analysis and control on the portfolio level. They are missing the big picture when overloaded with all kinds of project data (Exact, 2004).

The causes to these problems lie in multiple aspects. Surveys find major reasons are related to organizational culture, data and resource availability, training, management process, analytical techniques and tools (Cardin, 2007; Exact, 2004; IDC, 2006; Leliveld & Jeffery, 2003). These problems lead to several research streams: 1) organizational structures and environments, including strategies and goals, success factors, cultures, governance structures, human factors, adoption strategies, accountability and control mechanisms (Reddy, 2004); 2) complete PPM processes, frameworks and information systems to plan, create, evaluate, monitor and communicate portfolios (Maizlish & Handler, 2005; Reyck, et al., 2005; Weistroffer & Smith, 2005); 3) techniques and tools to analyze project and portfolio information for specific tasks and

decisions from specific perspectives (Cardin, 2007; Maizlish & Handler, 2005). This dissertation chose to focus on decision support approaches and tools, because: 1) a review of current PPM techniques and tools indicates that many of these techniques and tools either do not effectively utilize multidimensional project information in the analysis process, or they are difficult to use and implement in practice (see Chapter 3.2 and 3.4); 2) the topic area is one of my research interests, and I have experience of using similar tools and techniques in other domains.

Decision support approaches and tools used in project portfolio management can be generally classified into three broad categories (R. Cooper, Edgett, & Klwinschmidt, 2001; Dickinson, Thornton, & Graves, 2001; Iamratanakul & Milosevic, 2007): 1) mathematical model based techniques, which borrow from the management science and financial management domain, usually with a focus on optimization; 2) non-mathematical model based techniques, which are less complex and do not rely on complex mathematical models. These include matrix models (Ward, 1988), scoring models and checklists (using rankings, ratings or scores, which may quantify complex project information into one or several simple numbers or categories); 3) mapping approaches, including commonly used quadrants, matrix, grid models and bubble diagrams (R. G. Cooper, Edgett, & Kleinschmidt, 2000; Ghasemzadeh & Archer, 2000). These approaches still have a number of limitations and challenges, as identified primarily in many industry surveys and white papers (R. Cooper, et al., 2001; Exact, 2004; Leliveld & Jeffery, 2003):

1. *Project portfolio managers lack necessary financial and mathematical skills to understand and make appropriate use of many mathematical model based techniques and tools.* The Leliveld and Jeffrey's survey (Leliveld & Jeffery, 2003) indicates a financial skill gap in IT personnel (46% of the respondents). The skill gap is not about knowing and calculating financial

indicators, but the ability to apply them and interpret data. Many people find mathematical model based techniques to estimate, evaluate and choose projects are not easy to understand and may not be applicable in daily practices (Archer & Ghasemzadeh, 1999).

2. *Aggregating information about each project into a single numerical value reduces the richness of information about each project to make a decision.* Scoring and matrix models are easy to use and understand, but often these scoring numbers are simply aggregated for final decision purposes. Multiple attributes may be used as inputs and contribute to the calculation process, but these attributes are transformed into one or two indicators as outputs for interpretation simplicity at the end. Such simplicity does not always satisfy the business need. The aggregated numbers may not be clear and understandable to users. In addition, these calculated final 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 & Yang, 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.

3. *Current tools focus on analytical decision making without considering the role of human intuition.* Management researchers question the effectiveness of rational decision-making as the only viable alternative (Sinclair, 2005). Many decisions are unstructured, usually involving multiple sources of information and human intuition (Kuo, 1998). Good visualization tools are able to help people to comprehend project portfolios because they can provide direct and intuitive perceptions of complex information and help users to identify patterns and trends (Grinstein & Ward, 2001; Soukup & Davidson, 2002; Tegarden, 1999). Many managers are strong supporters of diagrams, rating them as very effective decision tools and strongly



recommending their use to others (R. Cooper, et al., 2001). Unfortunately, many visualizations in mapping approaches 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 that involves human thinking. One survey shows only 8 percent of businesses rely on these visualizations as their dominant portfolio method (R. Cooper, et al., 2001). Moreover, quadrant or matrix diagrams are fundamentally constructed based on only two spatial dimensions (R. Cooper, et al., 2001). Trying to fit high dimensional information into low dimensional models often leaves out the richness of project information, and leads to a narrower understanding of project distribution.

## **1.2 Research objectives and research questions**

To address the three issues above, managers 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 (which addresses the second issue). In this dissertation, a dimension refers to an attribute of a project, such as cost, technology requirement, priority and people skill requirement. Furthermore, such a system should utilize proper interactive visualizations to effectively and intuitively handle multidimensional information for the information seeking and decision making process (which addresses the first and the third issue). Based on the synthesis of the three issues and past experiences, two major meta-requirements for a desired approach and system were proposed: 1) it needs to handle the multidimensionality of project data; 2) it needs to effectively utilize visualizations as an analytic process. Therefore, the main general research goal of this dissertation is to find out how a system can achieve the meta-requirements set above. Having adopted a design science research perspective, the research goal of this dissertation is:

*To develop and evaluate a visual exploration approach and its instantiation that well integrates multidimensional project information for various project portfolio management tasks.*

Using a research question format, the general research question of this dissertation is:

*How can a visual exploration approach and system that well integrates multidimensional project information be designed to support various project portfolio management tasks?*

More specifically:

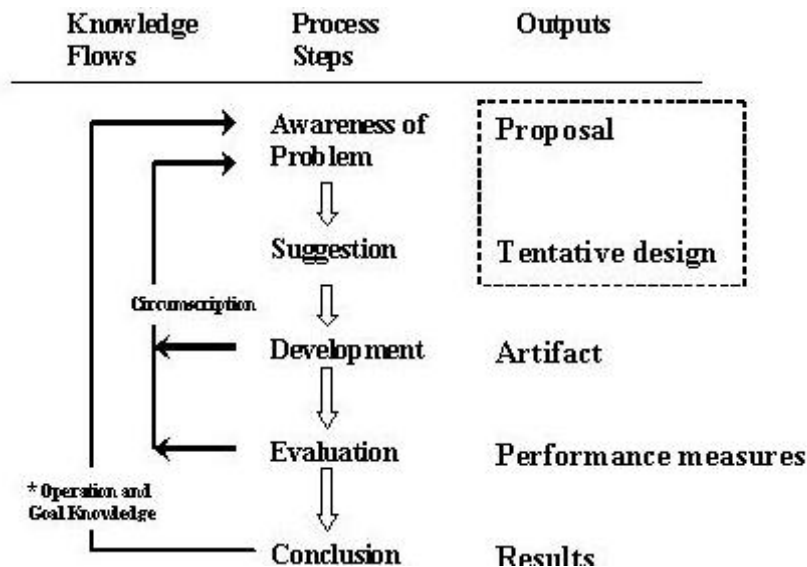
- 1. How should such a system be designed? What are the major components of it?*
- 2. How should such a system be used? What is the general process of using it?*

### **1.3 Research approach**

The primary objective of this dissertation is to develop and evaluate a software system driven approach for project portfolio management. It is believed in design science research that knowledge can be generated through the process of designing such an approach and implementing it as an IT artifact (Hevner, March, Park, & Ram, 2004; March & Smith, 1995; Vaishnavi & Kuechler, 2004). For a complete information system research life cycle (Hevner, et al., 2004), design science research plays a complementary part to explanation research, focusing on the activities of building and evaluating artifacts to solve identified problems (March & Smith, 1995) even before a complete understanding of the problem domain. Explanation research tries to theorize and justify the findings (phenomena around the artifact), and in return, can assist design research with more solid basis and reference. Compared to explanation research, design science research is usually problem driven, and seeks utility rather than truth as the research goal and outcome (Hevner, et al., 2004).

This dissertation project exercises the philosophy and principles from design science research in the Information Systems discipline (Hevner, et al., 2004; Kuechler & Vaishnavi,

2008a; March & Smith, 1995; Vaishnavi & Kuechler, 2008). I followed a general design research methodology (Figure 1) illustrated by Vaishnavi & Kuechler (2004) to conduct the research. This general design research methodology includes a series of iterative steps with an emphasis on artifact development and knowledge generation. It is very useful to guide the design science research process. More specifically, this research used a prototyping method as a vehicle to develop the artifact and to provide learning experiences for model abstraction. The prototyping resulted in a software application (the IT artifact) to help explore, understand, and evaluate the proposed approach. Through this development (prototyping) process, the approach can be further understood, refined, and tested. Knowledge then can be generated by abstracting from the prototype development experience; in this project, it is a model that describes the conceptual components and general steps of using the designed system.



**Figure 1. A General Design Science Research Methodology (Vaishnavi & Kuechler, 2004)**

I have been in contact with an IT department of a research university in the Southeastern U.S.; they provided support in a number of ways, such as providing data and participating in evaluation. The department recently adopted a system to centrally manage key project

information. This has provided the start of project data of good quality, including such data as title, abstract, begin/end date, high-level deliverable and task definition, sponsor, project participants, as well as some metrics on project status and optionally some project budget figures. The prototype was used to iteratively refine the proposed approach based on these actual (real) project data from the department.

#### **1.4 Dissertation overview**

Chapter 2 presents a research methodology and summarizes the research activities in each of the research phases. Chapter 3 provides literature review related to the problem domain (3.1 and 3.2) and related fields that provide suggestion to the design (3.3). Chapter 4 details the design outcomes from this research, explaining major conceptual components of the system (4.1), major steps of the approach with a use scenario (4.2), and the developed prototype (4.3). Chapter 5 reports the process of the evaluation (5.1) and findings from the evaluation (5.2 and 5.3). Chapter 6 provides additional discussions about the research, including a potential design theory (6.1), some learning and experiences of the design research process (6.2), contributions (6.3), limitations (6.4) and future research (6.5).

## Chapter 2. Research Methodology

This research followed a general design research methodology (Vaishnavi & Kuechler, 2004) (Figure 1). This chapter provides an overview of research activities in each phase. A summary is presented in Table 1.

<i>Research Phase</i>	<i>Research Activities</i>	<i>Related Chapters</i>
Awareness of problem	Reviewing literature of IT project portfolio management. Observing practices in an IT department.	Chapter 2 (2.1), Chapter 3 (3.1, 3.2)
Suggestion	Reviewing literature of related solution domains, such as cognitive style, visualization, visual exploration, decision support systems, data mining, information seeking, etc. Thinking creatively and incorporating past research experiences on information seeking and clustering techniques. Analyzing the problem and proposing an initial model. Determining design objectives.	Chapter 2 (2.2), Chapter 3 (3.2, 3.3)
Development	(Iterative or concurrent activities) Developing a prototype of the proposed approach. Improving and refining the approach from development experiences and user feedback. Applying the new concepts and ideas to the prototype. Abstracting concepts and components from the prototype.	Chapter 2 (2.3), Chapter 4
Evaluation	Interviewing portfolio management practitioners on their perception and acceptance of the approach. Surveying them with questionnaires. Transcribing interviews and analyzing transcripts to seek evidences to support system utility and ease-of-use.	Chapter 2 (2.4), Chapter 5
Conclusion	Summarizing research process and findings. Trying to theorize the design. Summarizing contributions, limitations and future research.	Chapter 2 (2.5), Chapter 6

**Table 1: A Summary of Research Activities and Chapters Related**

## 2.1 Awareness of Problem

This phase is the beginning of a design science research to identify and define the problem that will be addressed by the proposed research. The problem needs to be properly defined so that it is notable and worth further investigation. It also needs to be properly scoped so that the solution can be properly developed and effectively evaluated. In this phase, the problem was identified and understood mainly from the literature of IT project management and the real world experience from an IT department.

First, a literature review of project portfolio management was conducted. The literature review was focused on IT project portfolio management concepts and practices, and various methods and techniques that have been used to manage and analyze project portfolios. One of the important findings from this process is that many methods and software tools are simply borrowed from other disciplines without careful and systematic investigation. Many of these methods and tools either cannot effectively deal with project data multidimensionality, or they are too focused on mathematical and analytical functions that are difficult to understand and apply in real organizational settings. Chapter 3 (particularly section 3.1 and 3.2) reports more details of the literature review for the problem domain.

Second, an IT division of a major research university agreed to have the researcher to observe and learn its project portfolio management practices. During this process, I engaged with the department through various activities, such as participating in meetings, talking to IT staff, reading related documents and reports, and examining software applications. The purposes of these activities were (the last two purposes are more related to later research phases): 1) to have a practical understanding of the problem domain and be familiar with business needs, which would help to complete basic system requirement analysis and enhance the relevance and usefulness of

the proposed approach; 2) to identify, collect and analyze specific project data that would be used for the prototype development; 3) to find people to provide feedback and evaluate the designed approach, both during the development and evaluation phase. The evaluation results will be more convincing if participants are practitioners who are familiar with the data and daily practices of project portfolio management.

Through these activities, the problem was appropriately identified to address a gap in research and practice. Both the literature and practical experiences show the challenge of portfolio level management tasks based on multidimensional data, but many methods and tools either do not effectively support multidimensionality, or are too focused on mathematical models that are difficult to use in practice. Therefore, this project chose to focus on designing and evaluating a particular decision support approach that can analyze multidimensional project data effectively and is intuitive to use. A research framework (Figure 7) was developed to summarize typical methods and tools; it clearly positions the proposed research in a context and shows the difference from existing approaches and tools. It would be a good contribution if the approach (and system) could be designed and theorized to provide general guidelines to design similar systems. It would also be of great practical value to project portfolio management and other business domains as they would have an additional tool choice for project portfolio management.

## **2.2 Suggestion**

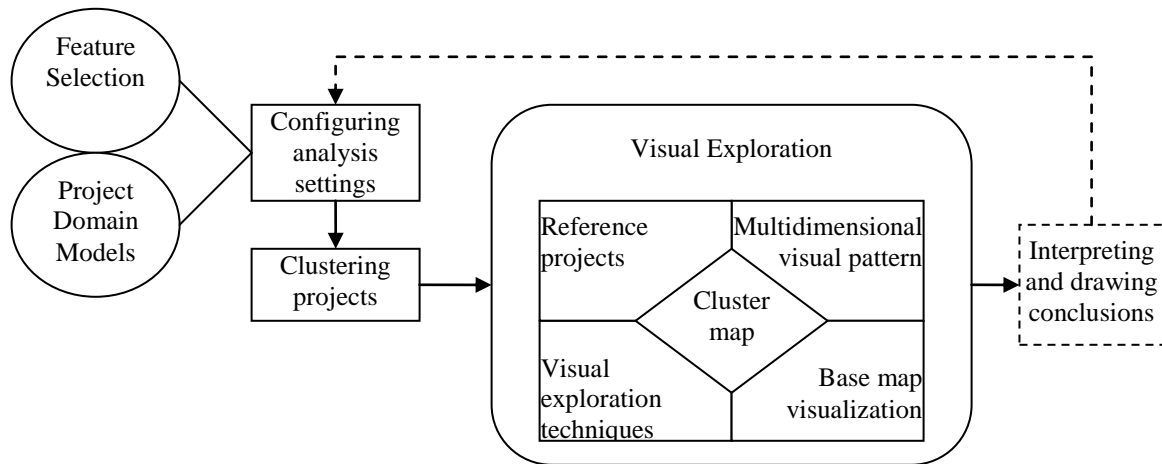
This is an exploratory phase to gain further insight into the problem domain and form a basic solution through initial analysis and design. The major sources of ideas are: 1) literature: including past published studies and relevant knowledge areas in decision making, data mining, information visualization and human information behavior (see chapter 3.3). These literatures provided good references, and at the same time the weakness and missing parts became more

clear after literature review; 2) experience: my own past research and work experience in related domains, such as the work on dealing with multidimensional data and information seeking behavior. These experiences helped to accumulate knowledge and influence the design in this project; 3) creativity: logical reasoning, integration of disparate knowledge, and sometimes imagination, generate reasonable hypotheses and potential solution ideas. These elements worked together to help me propose initial designs of a multidimensional visual exploration approach to project portfolio management.

During this stage, an initial system model of the approach was formed (Figure 2). The initial model was basically built around two major components: clustering and visualization. Clustering techniques were considered because of their well known capability to deal with multidimensional data (Wang & Yang, 2003). Another important component is visualization. Good visualizations are able to help people to comprehend project portfolios, because they can provide direct and intuitive perceptions of complex information and help users to identify patterns and trends (Grinstein & Ward, 2001; Soukup & Davidson, 2002; Tegarden, 1999). Many managers are strong supporters of diagrams, rating them as very effective decision tools and strongly recommending their use to others (R. Cooper, et al., 2001). Visualizations of multidimensional data are expected to make the analysis easier and more intuitive. The model, however, lacks the details for the two components, and is not concrete as how a software system should be built around these two components. I also envisioned typical use scenarios of how the system should be used for certain tasks, with the help of illustrational figures rather than software applications.



This initial model was a starting point for the development process, and was changed and improved based on new understandings and progress in the development process<sup>1</sup>.



**Figure 2: A Proposed Visual Exploration Process at the Early Research Phase**

Two general design objectives were also determined at this stage to guide the development and evaluation:

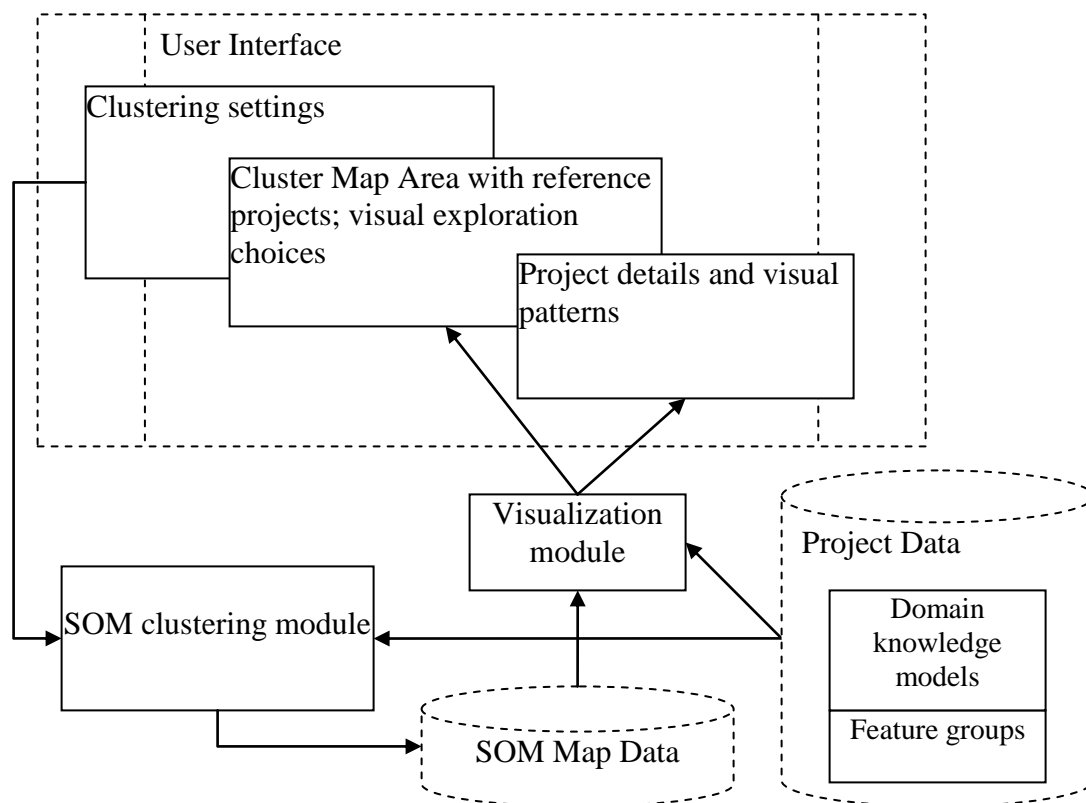
- 1) *Usefulness (Utility)*: the system is useful for users to see, explore, justify and discuss project portfolios and projects based on multiple dimensions of project data for general PPM tasks.
- 2) *Ease of Use*: the system is easy and intuitive to understand and operate.

## 2.3 Development

This stage is to implement the suggested design into a working prototype and improve the design through iterations of analysis, learning, and implementation. First, project data needed for the development was collected and analyzed. To establish the relevance of this research (Kuechler & Vaishnavi, 2008a), and to address organizational context (Baskerville, Pries-Heje,

<sup>1</sup> The final research outcome (see chapter 4) is different from the suggestion, and has much more details. This shows that the research process is a continuously changing and improving process, incorporating new discoveries and generating new ideas.

& Venable, 2007) as much as possible, all project data were collected from the IT department (see Chapter 2.1). There were two major sources of the real project data. One was “vPMO”<sup>2</sup>, a web-based project management system used by the IT department. There were about 200 active and proposed projects in the system database, either active, proposed or archived. They had 33 attributes mainly from the project charter documents. The second data source was project priority data. They were stored in off-line excel files, less organized and maintained. These data were reorganized and stored in a database as a part of the prototype. An overall conceptual architecture of the system (Figure 3) was developed to guide the actual prototyping work.



**Figure 3: Proposed System Architecture**

Based on the initial proposed approach and the conceptual architecture, the prototype was developed. Each of the features suggested was prototyped and investigated along the process of

<sup>2</sup> By Level 5 Partners, <http://www.level5partners.com>

development. Design details and new options also emerged from this process. They were carefully examined and prototyped. The major sources for these new ideas were:

1. Continuing literature search to evaluate and integrate good features and best practices.
2. Experiences gained from the prototyping work. First-hand development efforts sometimes generate good ideas.
3. External user feedback. One of the important sources of user feedback is the communication with field practitioners. During the prototype development, interviews were planned and conducted to understand user needs, discuss prototype features and design choices, and generate (or confirm) ideas. More details of interviews are reported in section 2.4 and section 5.1.
4. Creative thinking. New ideas were discovered sometimes, particularly when the three sources above were used together for synthesis of ideas.

Besides prototype development, another major process, knowledge creation, happened at the same time (see Figure 19). These two processes were concurrent and interactive. In the knowledge creation process, the work of prototyping was analyzed and summarized, and concepts and features were abstracted and defined. Then, these new or modified theoretical features were implemented in the prototype, and the prototype was modified and improved. Such a cycle iterated several times until the abstracted model matured and the prototype became functionally complete based on the design. It suggested that the development met original plans and could go to the next stage of evaluation. The outcome from the development (the approach and system) is reported in Chapter 4. Some additional discussions on the development process are discussed in Chapter 6 (6.2).

## 2.4 Evaluation

This stage is to determine how well the prototype addresses the research questions and satisfies the design objectives. The general objective of this research is to design a new decision support approach that can effectively utilize multiple dimensions of project data and visualizations for PPM tasks. The major goal of the evaluation is to seek evidence of the utility and ease-of-use of the designed system.

For design science research, there are a wide range of evaluation methods and patterns that can be used, including traditional experimentation, simulation, case study, user study, action research, etc. (Baldwin & Yadav, 1995; Hevner, et al., 2004; Vaishnavi & Kuechler, 2008; Zelkowitz & Wallace, 1998). It would be best if the designed approach can be applied in real or experimental business settings to assess its impact and utility directly, such as using an action research method or an experimentation method. However, three issues prevent such a full scale evaluation for this dissertation. First, it is difficult to find the right organization which is fully cooperative in applying the approach in a relatively short period of time. Second, the resulting system requires an extensive explanation, such as how it works and how it is used in real situations, which takes quite some time for user interaction and communication. It also requires a certain amount of domain knowledge and work experience. Thus, it is impractical to conduct a full scale experiment with a large group of people. Third, it is very difficult to determine and measure the metrics to evaluate portfolio decision success. In addition, the major purpose of the evaluation is not to seek general truth or statistical significance about the knowledge created from the design. Theorizing and full scale testing can reasonably be done following the design research project.

Therefore, in this dissertation, instead of directly measuring the utility and ease-of-use of the system, I planned to seek evidence from users' perceptions of the system. Suggested by the Technology Acceptance Model (Davis, 1989), the general evaluation objectives are to evaluate the Perceived Usefulness and the Perceived Ease-of-Use of the system. Table 2 illustrates the major objectives of the evaluation and some examples of expected evidence from user feedback. Because the sample size is limited, in order to collect rich and insightful evidence, I planned to collect qualitative data mainly through interviews. As also advocated by soft design research (Baskerville, et al., 2007), collecting qualitative data may provide deeper understanding and insights for the research domain. Especially in an early exploration phase, qualitative data may reveal something that is not considered in the original design, but is potentially useful and beneficial to the design of the system. Traditional quantitative surveys may result in limited insights because they usually constrain answers to limited and simple choices. Rich qualitative data allows us to understand in details why and how the design objectives are, or are not, satisfied; this provides us with more effective information to improve the design later – after all, this is an iterative design/evaluation process. This evaluation approach is suitable to the designed system because the approach is human centered and it needs humans to interact intensively with the system.

<i>Evaluation Objectives</i>		<i>Expected sample evidence from qualitative data analysis</i>
<i>Perceived Usefulness</i>	Users think the system is useful to see, explore, justify and discuss project portfolios and projects based on multiple dimensions of project data for general PPM tasks.	<ul style="list-style-type: none"> <li>• The approach offers a direct perception of project distributions (big picture) based on multiple dimensions (attributes).</li> <li>• The approach provides good support to compare and contrast projects and sub-portfolios based on multiple dimensions.</li> </ul>

<i>Perceived Ease of Use</i>	Users think the system is easy to understand and operate.	<ul style="list-style-type: none"> <li>• Visual elements are easy and intuitive to interpret the information they hold.</li> <li>• The exploration process is easy to operate.</li> </ul>
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**Table 2: Evaluation Objectives**

An interview approach was adopted to collect qualitative data, generally following a case-based approach (Baldwin & Yadav, 1995; Vaishnavi & Kuechler, 2008). The case-based approach uses theories to guide observations and data collection (Baldwin & Yadav, 1995). Hypotheses are defined first (in this dissertation, they are the evaluation objectives presented in Table 2), and evidence is sought to prove or disapprove hypotheses. In case-based approach, evidence is usually not obtained through controlled experiments, but from a more realistic organizational environment. In this dissertation project, the IT department and its projects present a rich organizational environment for development and evaluation. The theory (design principles and concepts) is used to guide the prototyping process and data collection. On the other hand, the prototype is used to help refine the design and the theory.

Following these ideas, I planned to utilize the collaboration with the university IT department to evaluate the developed prototype. Project managers and directors were invited to interviews<sup>3</sup> and qualitative data was collected. Interviews were semi-structured with a focus on the features and uses of the system (including regular evaluation questions and other user self-reported experience). The interviews were then transcribed; qualitative data was analyzed and coded using a template analysis method (King, 1998, 2004). Ultimately, this data was used to evaluate the utility and ease-of-use of the designed system. This data will also be analyzed to

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<sup>3</sup> Part of these people were interviewed during the development phase to discover user insights for a deeper understanding of system utility and usability; they focus more on generating (and confirming) ideas for system development, and are more open in terms of system features and design choices that can make the system more effective. See section 2.3.

seek evidence that validates design features and choices, which can be used to refine and adjust the design in the future. The details of the evaluation and results are reported in Chapter 5.

## **2.5 Conclusion**

At this stage, the findings from development and evaluation stages are analyzed, summarized and reported. It signals a periodical conclusion of the research but can inspire further work or future studies. The findings may be theorized and contribute to a mid-range design theory (Gregor & Jones, 2007; Kuechler & Vaishnavi, 2008b) that can guide the development and application of similar approaches and systems. In this dissertation, concepts of the system were theoretically defined and summarized after the development and evaluation, and a set of theoretical propositions were made to inform a mid-range theory. Chapter 6 reports some discussion on theorizing the design, contributions, research limitations and future research.

## Chapter 3. Literature Review

This chapter provides a fairly detailed literature review. Section 3.1 gives a broad background overview of the project portfolio management domain. Section 3.2 categorizes and reviews major decision support methods and tools used for PPM, and analyzes their weaknesses with respect to the current research. Section 3.3 reviews related fields and similar research work that this project can reference. Section 3.4 summarizes and compares the current research to the existing literature.

### 3.1 Project Portfolio Management

#### *3.1.1 A portfolio approach for IT project management*

Defining projects is an effective way to organize business activities and resources for an organization. A project is defined as “a temporary endeavor undertaken to create a unique product, service or result” (PMBOK, 2004). Projects are usually result-oriented, flexible and dynamic in organizational structure and resource allocation; but they usually require good support and cooperation from other functional units of the organization.

Projects and business functional units are two different dimensions of an organization structure matrix (Hobday, 2000). They constantly have conflicts in management and interest. The conflicts become more evident when organizational or cross-division project teams are formed to carry out strategic business activities. To address this challenge, many organizations, and their major departments overseeing organization-wide resources (such as information technology), are becoming project-oriented (Arto, 2001; Gareis, 2000) or project-based (Hobday, 2000). In such organizations, projects become the main elements of organizational structure,



which is usually a flat control structure and project managers have considerable autonomy (Napier, Mathiassen, & Robey, 2007). This kind of structure tends to have problems of incoherence (or project isolation), weakness in control and coordination process, and focus dilution (Hobday, 2000). Thus, a specialized central unit, such as a software coordination group (Napier, et al., 2007), or more commonly, a Project Management Office (PMO), is required to coordinate and provide support to the operations among all projects. This unit ensures that objectives of different projects comply with overall company strategies.

The growing number and complexity of projects often create management challenges for the PMO or upper management who is overseeing the organizational resources (Gareis, 2000; Kendall & Rollins, 2003) such as:

1. There are too many active projects and proposed projects. These projects are usually different in terms of their types, sizes and objectives. It is difficult for top management to get a clear big picture of what is going on.
2. Inappropriate or wrong projects (projects that will not provide value to the organization or are not linked to strategic goals)
  - a. not reflective of the organization's most important assets;
  - b. not reflective of the organization's strategic resource value;
  - c. not reflective of major product revenue opportunities, risks, etc.
3. Unbalanced projects and resource allocation. For example,
  - a. too much emphasis on the supply side, not enough on the market side;
  - b. too much emphasis on development, not enough on research;
  - c. too much emphasis on short term rather than the long term;
  - d. too many risky projects;

- e. too much contention for key resources.
4. Attention biased towards several key projects but missing the big picture.

Addressing these problems requires a clear understanding of all projects, balanced allocation of resources and their contribution to the overall organizational goals, as well as communication and collaboration across an entire business unit or an organization. Projects are not treated separately but are systematically managed as a complete entity, based on their relationships to other projects and to the whole context, with the aim of providing effective and efficient management of multiple projects at a higher level. Such approaches and practices are referred to as project portfolio management (PPM) or information systems portfolio management (McFarlan, 1981). The portfolio best represents an organization's overall strategies and intended activities.

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. It is different from a single project management perspective, which focuses on individual project success and efficiency. Although important, an individual project does not necessarily enable a firm to continue its success (Hobday, 2000). PPM's ultimate purpose is to maintain a balanced and healthy mix of projects for an organization, while effectively applying all resources across the range of projects.

Following this common strategy in financial investment, the earlier project portfolio management practice focused on investment value appraisal (Ward, 1990) and risk control (McFarlan, 1981). McFarlan elevated the concept of aggregated risk profile for a portfolio of systems and programming projects (McFarlan, 1981). In PPM, like financial investment, a

portfolio of projects can balance risks and returns. Later, other uses and benefits of the portfolio approach have been widely and generally perceived:

- Fairer decisions on resource allocation, including funding and people; avoidance of overlapping and redundant efforts (Brandon, 2006).
- Better alignment of business goals and activities (Brandon, 2006).
- Better communication and increased stakeholder (including owner, top management, customer and staff) value and confidence (Benko & McFarlan, 2003); involvement of senior management in the project management process can also ensure greater overall understanding of the organization (Hill, 2004).
- Better talent management and human resource assignment.

### ***3.1.2 PPM decisions and tasks***

There are a number of tasks performed at a portfolio level in PPM, in addition to tasks following traditional single project management practices, such as defining, estimating, scheduling, tracking, and optimizing tasks and resources required to plan and complete a project (IDC, 2006). These tasks and decisions can be at different management levels (executive, program manager, project manager, and staff) (Reddy, 2004), at different stages of the IS planning model (Ward, 1988) or portfolio management life cycle (Maizlish & Handler, 2005).

Some examples of PPM specific tasks and decisions to be made are:

- Collecting and maintaining all project related data
- Project categorization and management understanding (Ward, 1988)
- Project assessment in the context of portfolios (R. G. Cooper, et al., 2000)
- Selecting and prioritizing projects and initiatives (Hill, 2004; Reddy, 2004)
- Allocating organizational resources for project work (Hill, 2004; Reddy, 2004)

- Aligning projects with business goals/strategies (Hill, 2004; Reddy, 2004)
- Selecting and balancing portfolios
- Assessing portfolio risks and returns (Hobday, 2000; McFarlan, 1981)
- Reviewing and communicating portfolio performance and status (Hill, 2004; Reddy, 2004)
- Identifying inter-project dependencies (Reddy, 2004)

Many of these tasks or decisions are based on the understanding of the portfolio and projects from multiple aspects of projects (multiple dimensions). The understanding of projects is the first step in many process models such as the IS Planning Evolutionary Model (Ward, 1988). A good understanding of projects leads to better project selection, resource allocation, project coordination, and cross-project learning. Human learning and understanding often utilize techniques like comparison, contrasting, association, and categorization. In practice, managers also understand projects through these techniques. A good categorization leads to a good understanding of the portfolio and control of projects. Commonly, projects are classified directly by objective attributes such as size (in terms of budget or people), term, ownership, etc. For a deeper analysis and decision making perspective, more complex and abstract classification based on non-objective measures are used, such as priority, risk level, expected return, business goal, or strategic impact, etc. (Ward, 1988, 1990).

Managers often get to know unfamiliar projects by comparing them to known projects, for example, new proposed projects (unfamiliar) vs. existing projects (familiar), or their own projects (familiar) vs. others' projects (unfamiliar). They try to look for similar or related projects for guidance and to apply prior experience. They also put projects into certain groups for summarizing and reporting purposes. However, as with project definition, there is little

consistency in categorizing projects based on multiple attributes. Such association and categorization are usually based on individual key properties and intuition, which may be subjective, inconsistent, and missing the big picture. Clustering techniques are expected to address such limitations by considering more information at the same time, thus providing more objective and consistent views. However, clustering may be domain dependent in terms of what project features should be considered in a more meaningful and interpretable clustering.

When decision makers have a fairly good understanding of projects, they will exercise their understanding while performing different tasks and decisions in PPM, such as selecting proposed projects, avoiding redundant or overlapped projects, determining project priorities, aligning projects with business strategy, creating a financially or technically balanced project portfolio, etc. It also helps to foster better cross-project communication and learning if similar projects are easily identified.

Project prioritization is a common task in project portfolio management that requires consideration of multiple project properties and aspects. Organizations have limited resources (money, people, time, etc.) to conduct their unlimited business and operations, thus projects need to be prioritized. Project prioritization is usually an early project evaluation step and these priorities are commonly the basis of project selection and resource allocation in a later stage.

The importance of projects may have different interpretations and there is likely no single criterion or model to determine such importance. The criteria for determining project importance are varied and often depend on different management perspectives and business styles. Traditionally, project financial value has played a central role (Ghasemzadeh & Archer, 2000). But managers tend to comprehend project importance from multiple perspectives (risk, future, business alignment, relationship, etc.) and rank projects based on a comprehensive (holistic)

understanding. A traditional prioritization method follows 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 (R. G. Cooper, et al., 2000; Ghasemzadeh & Archer, 2000). In these models, project priority is commonly represented by one aggregated number (score) based on weighted summation of scores for each criteria in a questionnaire or checklist. Such approaches are simple to implement (even with spreadsheet tools), but such simplicity does not always satisfy business needs. There are a number of variants and enhancements to the basic technique:

- Scoring items are organized into groups/categories; each group/category is scored before final calculation (Buss, 1983; Ghasemzadeh & Archer, 2000).
- Items or categories can be assigned different weightings to reflect unequal importance.
- Projects are pre-categorized and are applied different scoring model/weightings for different categories (Ward, 1990).
- Multiple numerical indicators (usually two) are used instead of being combined into one (Weir, 2004). Section 3.2.2 provides more details on these tools.
- Many multi-attribute decision making methods (Yeh, 2002) use complex mathematical models (Weistroffer & Smith, 2005) or a lengthy comparison process (Al-Harbi, 2001) to derive user preference scores or overall priority number.

### **3.2 Decision support methods and tools for project portfolio management**

To realize PPM's full potential, not only are sound business process and management methods needed, but it is also important to have decision support methods and tools to support various portfolio level decisions and analysis tasks, including portfolio balancing, project prioritization, and strategic alignment (R. G. Cooper, et al., 2000). Innovative information

systems and tools are also needed to enable and enhance these methods and processes. This section reviews major techniques and tools used for various PPM tasks, organizing them into three categories (Dickinson, et al., 2001): mathematical models and financial indicators, non-mathematical models based methods, and visualization tools. For each category, advantages and limitations are discussed. The review is finally summarized in Table 1.

### **3.2.1 *Mathematical model based techniques***

Many mathematical model based techniques use the monetary value of projects and apply financial concepts and models from the field of financial investment management and management science. Two basic financial indicators (Brandon, 2006; R. Cooper, et al., 2001) are:

- **Cost-Benefit Analysis.** It directly compares the expected costs and benefits of projects. Return on investment (ROI) is often used as an indicator.
- **Net Present Value (NPV) or Internal Return Rate (IRR).** When projects last long and interest rate is high, time value should be considered. NPV is used to calculate the value of project at the current time. IRR is best used to compare overall return rate of a project compared to alternative investments.

Many methods and models are based on these basic indicators (Ghasemzadeh & Archer, 2000) and consider other factors that are likely to influence the accuracy of results (Reyck, Degraeve, & Gustafsson, 2003). For example, ROI or NPV rely on future estimates of return and cost, which are not guaranteed or precisely known. Risk (probability) needs to be considered in such calculations. EMV, or Expected Monetary Value (Brandon, 2006), makes use of the decision tree technique to assign probability to each estimate and calculates a value that considers all possible outcomes. (Dickinson, et al., 2001)'s Optimization Function adds the factor of project interdependencies. CURT (Denbo & Guthrie, 2003) combines ROI, NPV, and

IRR into a single model and uses the result as an indicator for projects. Other methods (Ghasemzadeh & Archer, 2000; Santhanam & Kyparisis, 1995) formulate the problem as mathematical optimization models.

Financial models and indicators are useful in evaluating a project's value and performance. They are often used to determine project priority and as a criterion for project selection (Buss, 1983; Weistroffer & Smith, 2005). They are appropriate when projects are generating clear value and have returns, such as new product/service development. The major challenge of these financial tools is their narrow focus on financial results, ignoring other aspects such as stakeholder satisfaction, portfolio balance, and strategic goals alignment (Dickinson, et al., 2001). Another challenge is a financial skill gap in IT personnel, as indicated by Leliveld and Jeffrey (2003)'s survey (46% of the respondents say IT staff lack sufficient working knowledge of financial concepts). The skill is not about knowing and calculating financial indicators, but the ability to apply them to interpret data. In some other cases, non-financial attributes are often quantified to fit in those mathematical decision models, but many people find that mathematical models are not easy to understand and apply in daily practices.

### ***3.2.2 Non-mathematical model based techniques***

Non-mathematical model based techniques are easier to understand and use in practice. The most common ones are the scoring model tools. Managers need to consider important information other than cost and return to have a more complete view of the organizational status. Besides financial aspects, other information often include risk, budget, personnel, business goal, IT resource, technology (effectiveness, interoperability, integrity, etc.), stakeholder satisfaction, timing, technical/infrastructural alignment, organizational enforcement, etc. The proliferation (or overloading) of information in the decision making process adds to the burden of decision



makers. To help managers reduce the amount of information they need to use while still supporting decision making, scoring (or rating, ranking) models, either quantitative, qualitative or mixed, are widely used primarily because they are easy to use and understand. Generally, these models provide some kind of reasoning consistency and quick comparison basis. They are often used to determine project priority level and to categorize projects.

Based on the number of final rating indicators (scores), these tools can be classified as one-dimensional, two-dimensional, and multidimensional ratings.

1. One-dimensional rating lists use a single indicator to represent projects. It is the simplest way to categorize projects. For example, (Benko & McFarlan, 2003) illustrates side analysis, which categorizes projects by stakeholder type (inside, sell-side, buy-side and multi-side). It is also the most common practice for summarizing project priority, where a single numerical score is calculated to represent the ranked importance of a project.

2. Two-dimensional rating systems use two indicators to represent projects. It is very popular to form a 2 by 2 matrix (or 3 by 3 grid) based on these two indicators. For example, (McFarlan, 1981) uses project structure and technology level; Murphy's decision model (Kesner, 2004) and (Weir, 2004) both use success and value dimensions; (Jolly, 2003) uses technology attractiveness and technology competitiveness; some other popular dimensions include risk vs. reward (Brandon, 2006; R. G. Cooper, et al., 2000), risk vs. relevance (Maio, Verganti, & Corso, 2002) and risk vs. time-to-complete (Ghasemzadeh & Archer, 2000). The advantage of using two indicators instead of one is that the additional indicator adds one more dimension of information and enriches the meaning of projects. In addition, in these models, projects are commonly and easily summarized using pivot tables, or are presented using 2D diagrams (see next section),

which give a clear impression of project distribution. But because of the limited dimensionality of information, they usually have a specific focus on project attributes, such as risk, budget, etc.

3. Multidimensional tools use more than two indicators. Projects usually have complex and huge volumes of data with over hundreds of attributes, representing multiple perspectives. There is no consistent classification of projects and it is more of a company-specific function (Leliveld & Jeffery, 2003). There are times when more than two attributes are of equal importance and need to be considered. Fewer indicators can reduce the amount of information and simplify the decision making process, but flattening the multidimensionality of project information may fail to effectively distinguish projects (R. G. Cooper, et al., 2000). And, fewer indicators may only represent a limited perspective and focus; when multiple perspectives are needed, it is difficult to integrate those models to form a unified understanding. A good example of a multidimensional management tool is the Balanced Scorecard (BSC) (Kaplan & Norton, 1996) which evaluates performance based on four perspectives (financial, customer, internal business process, learning and growth).

The multidimensional rating system preserves the original evaluation of each major category (perspective) of projects. Thus, each project is represented by a vector of indicators. This further enriches the project meaning and understanding. However, adding more dimensions can add to decision difficulty for understanding and comparison. This approach usually needs advanced analysis and visualization tools to assist interpretation.

Another type of multidimensional analysis involves condensing multiple attributes into one preference value, found in most Multi-Criteria (attribute) Decision Making (MCDM or MADM) literature (Dyer, Fishburn, Steuer, Wallenius, & Zionts, 1992). Common methods from this literature are Simple Addictive Weighting, Weighted Product, and TOPSIS (technique for order

preference by similarity to ideal solution) (Yeh, 2002). These MCDM methods usually calculate a preference value based on multiple selected attributes (Tan & Fraser, 1998), much like a single indicator scoring model. These methods are useful to select competing options but are not helpful in understanding the complete portfolio or compare different portfolios.

These rating methods and tools are often used to prioritize and select projects for balancing purposes. The understanding based on dimensions is also the basis for other analysis such as resource allocation, relationship analysis, and project performance analysis. The major concern in priority determination is the selection and weighting of scoring criteria. There is no single way to define and organize these criteria and no standard rationale for choosing them under different situations. Having the flexibility to determine the appropriate number and weights is important.

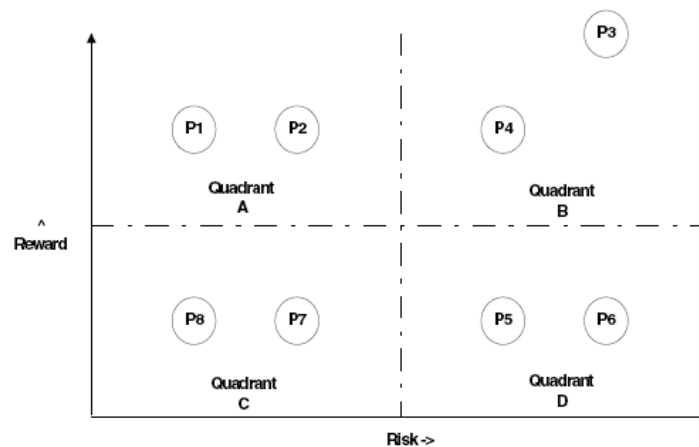
### **3.2.3 *Visualization tools***

Decisions are unstructured, usually involving multiple sources of information and human intuition. Diagramming tools usually help because they give a direct and intuitive comprehension of complex information, and can assist in discovering knowledge that is buried in numbers (Keim, 2002; Tegarden, 1999). Common tools are dashboards, Gantt charts, two-axis (quadrant, matrix, or grid) maps, and cluster maps.

Dashboards are business management tools used to visually present the status of an organization via selected metrics and key performance indicators. Dashboards offer an easy-to-understand and at-a-glance snapshot for quick comprehension and decision support. Dashboards usually make use of bar charts and pie charts to plot data with different colors. They can be used for descriptive or simple statistics reporting such as work-hour breakdown (by project types or strategic goals/core functionalities) and progress status. A Gantt chart can be viewed as a kind of complex dashboard and is widely used to show detailed schedules and progress of all project

activities. In asset management, it is also used to show portfolio composition and each asset's performance along the timeline. In project portfolio management, it can be used to show projects' resource allocations (workload, person-hours, spending, etc.) along the timeline.

Two-axis perceptual or position maps are usually used to present project distributions and portfolio composition. Very often, two perpendicular axes are plotted to represent two chosen dimensions. The scale on the axes can be quantitative and continuous (for project budget, term, or staffing size, etc.), or it can be qualitative and discrete (such as "high/low", "long term/short term", "internal/external", etc.). The projects are positioned (mapped) in the diagram with their corresponding attribute values measuring against those scales (Figure 4). Because the mapping space is often conceptually organized into four (2 by 2) or 9 (3 by 3) regions, the diagram is also known as a quadrant, matrix, or grid diagram. Common pairs of dimensions<sup>4</sup> are risk vs. reward (Brandon, 2006; R. G. Cooper, et al., 2000), success vs. value (Kesner, 2004; Weir, 2004), and risk vs. time-to-complete (Ghasemzadeh & Archer, 2000).



**Figure 4. Quadrant Diagram (Brandon, 2006)**

<sup>4</sup> More examples of axes pairs can be found in (R. Cooper, et al., 2001).

Traditional quadrant or matrix diagrams usually model only two dimensions. A third dimension can be added using a 3D visualization tool<sup>5</sup>. But more commonly, additional dimensions are directly integrated into the 2D map by using color, size, shape, and other iconic representations. For example, Figure 5 uses bubble size to represent resource requirement levels. While this technique increases the dimensions in a 2D map, the map is fundamentally constructed (positioned) based on only two dimensions. Trying to fit high dimensional information into these predefined static models often lowers the richness of project information and may require supplementary details to be annotated. In practice, this kind of mapping diagram is commonly used to comprehend the complete portfolio, understand project distributions, categorize projects, balance project portfolio, and align projects with business strategy.

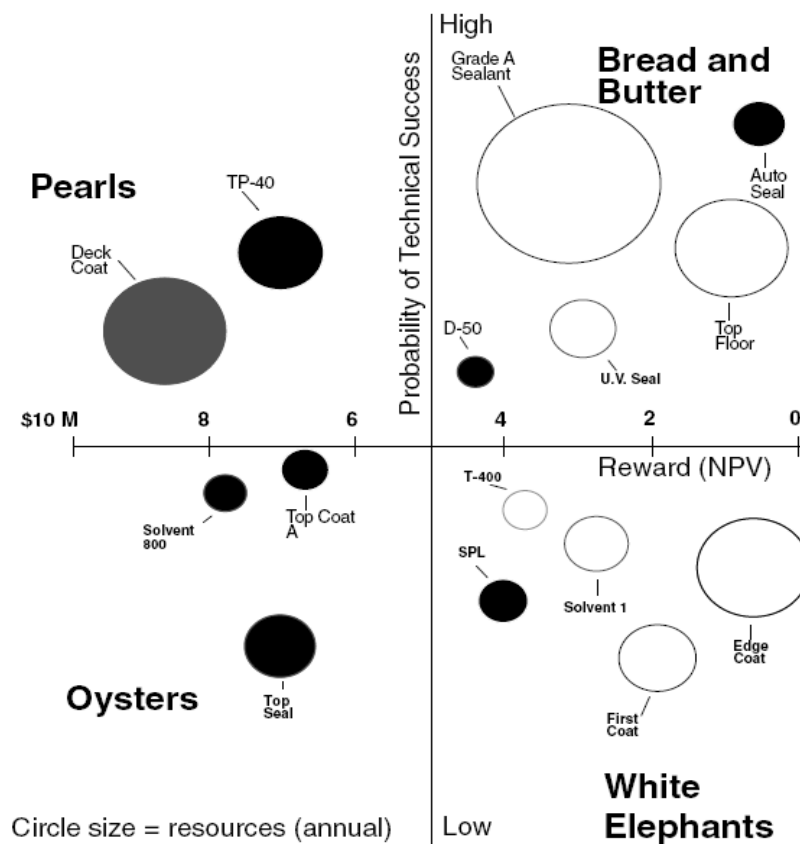


Figure 5. Example Risk-Reward Bubble Diagram (R. Cooper, et al., 2001)

<sup>5</sup> An example is the GenSight Portfolio Management Software: <http://www.gensight.com>

Some new visualization techniques seem to be promising but they have not been studied and implemented for many PPM application. For example, the Self Organizing Map (SOM) (Kohonen, 2001) provides a 2D cluster map where projects are plotted as clusters based on their similarities on multiple attributes. The SOM effectively preserves the internal associations among projects but it often lacks structure and details; additional tools and interactions need to be added to help understanding and interpretation. Another kind of visualization is the multidimensional pattern chart (profile chart) for each project in which the combined visualization of multiple project attributes may form a recognizable and interpretable visual pattern; examples include stock price chart in stock trading technical analysis, and radar (or star, spider) diagrams (Tan & Fraser, 1998). These two types of visualizations will be reviewed with more details in Chapter 3 (section 3.3.3 and 3.3.4).

### ***3.2.4 Methods and tools summary***

In practice, a mixture of tools and techniques is used in conjunction with manager's professional judgment for various portfolio management tasks and decisions. Table 3 summarizes the above discussion. Many studies have focused on mathematical and financial model based methods and tools, scoring and matrix models, and profile charts used in reporting; many 2D mapping approaches have been implemented and used in practice. Yet, little research has been done on visual exploration processes based on multidimensional perceptual maps generated by clustering techniques. The goal of this dissertation project is to investigate this idea and design a system to fill the gap.

<b><i>Methods/Tools</i></b>	<b><i>Tasks</i></b>	<b><i>Examples</i></b>
Mathematical models and financial models	Project selection, performance tracking, portfolio evaluation	NPV, IRR, ROI

Rating and scoring models	Portfolio balancing, strategic planning, project prioritization, project categorization	McFarlan (1981)'s portfolio approach, Murphy's decision model (Kesner, 2004), Balanced Scorecard (Kaplan & Norton, 1996)
One dimension diagram	Descriptive statistics, quick report, big picture view	Dashboard, Gantt chart
2D mapping	Project prioritization, portfolio balancing, portfolio composition, strategy planning	Matrix/quadrant/bubble diagram, pivot table
Cluster map	Same as above (2D diagram)	Self-Organizing Map
Profile chart	Project profile report, project comparison	Radar/star/spider diagram

**Table 3: Summary of tools for project portfolio analysis**

### 3.3 Multidimensional visualization and visual exploration

The objective of the research is to design a visual exploration approach to deal with multidimensional project data. Therefore, domains related to visualization and business intelligence (particularly multidimensional data analysis) were reviewed. Visualization has been used intensively in the business management and decision support domain to ease the information seeking and decision making process. A review of the relevant literature reveals a lot of justifiable knowledge that is useful in guiding the development of the proposed approach. This existing knowledge base is part of the forces that contribute to initial idea formulation in the suggestion phase. The following sections summarize the most relevant ones into four areas.

#### 3.3.1 *Visualization and managerial intuition*

Intuition is a psychological behavior that allows understanding without apparent efforts (such as analysis, reasoning, calculation, etc.). It is a subconscious activity based on multiple sources, including personal experiences and situational context. Intuition enables a person to

grasp the meaning, significance, or structure of a problem without explicit reliance on analytical tools; through intuition, a pattern is presented as a complete whole without explicit explanation about how it is arrived at (Isaack, 1978). Executives and managers use managerial intuition in decision making processes, and try to maintain a balance between logical/analytical reasoning and intuition (Isaack, 1978). The study on managerial intuition has a significant impact on the design of information systems (particularly decision support systems and executive information systems) to fit managerial style and support management tasks (Kuo, 1998; Robey, 1983; Vessey, 1991).

There are a number of implications of the intuition study literature to the design of a visual exploration system for PPM. First, intuition occurs in an environment with constantly moving and competing goals (Kuo, 1998). The project portfolio management is just such a field where intuition often occurs. Therefore, methods and systems need to consider how to effectively support managers to apply intuition.

Second, in the process of using intuition, perception is the key to reach immediate assessment, and then actions follow (Kuo, 1998). This perception or a feel of business data is an important starting point. Good information visualization, when used appropriately, is able to help users perceive useful and relevant information from complex and large volumes of data.

Visualization is able to (Grinstein & Ward, 2001; Jarvenpaa & Dickson, 1988; Tegarden, 1999):

- exploit the human visual system to extract information from data;
- provide a qualitative overview of complex data sets;
- identify structure, patterns, trends, anomalies, and relationships in data;
- assist in identifying the areas of “interest” and help decision-makers to use their natural sense-making abilities to determine where further exploration should be done.



Third, executives and managers are “not passive choice makers but are active sense makers”; after the initial perception, they actively interact with the environment based on their continuing perception, actions, and reasoning to arrive at conclusions (Kuo, 1998). The decision making process does not end when the visualization is presented. Further thinking occurs and actions follow after the initial perception. These actions can be interactions with the data and visualizations (such as changing, comparing, relating, attributing, etc.), or can be interactions with other people and tools (such as talking, reading, writing, meeting, etc.). The behavior of applying intuition is not independent from using logical reasoning and other tools, but an iterative and interlacing process. In this process, visualizations are not just confirmatory, but rather exploratory to directly facilitate the role of managerial intuition. They are useful in discovery tasks to generate ideas and hypothesis (Bowers, Regehr, Balthazard, & Parker, 1990). This suggests one of the important components of the proposed approach: a visual exploration process, instead of just visualizations.

### ***3.3.2 Visual information exploration/mining***

As Graphical User Interfaces have improved significantly, using dynamic and interactive visualizations as a basis for information seeking or decision support has gained popularity. There are many visual design techniques and guidelines but most of them follow a Visual Information Seeking Mantra (Shneiderman, 1996). The mantra has been widely referenced by researchers who design novel information visualization tools as a justification for their methodological approaches (Craft & Cairns, 2005). It highly abstracts the visual information seeking as a three-step process: overview, zoom and filter, and details on demand.

- 1) Overview: gaining an overview of the entire collection. The overview usually consists of a few simple and high-level data items without too many details. Patterns and themes are

often recognized to understand the big picture; major components and relationships may be more evident from this perspective. The overview visualizations allow quick perception of the big picture, and easy identification of interesting areas.

- 2) Zoom and Filter: focusing on part of the visualization and data items with more details.

Both techniques allow more focused exploration with more information provided.

Zooming is applied to portions of the overview visualization and enlarges them to include more and clearer data items, while filtering is applied to data items to exclude those of less interest. For example, the techniques of ghosting, hiding and grouping are ways to reduce the visual complexity (Herman, Melancon, & Marshall, 2000).

- 3) Details-on-demand: selecting a data item or group and getting details when needed.

Limitations of screen and visual complexity make it difficult to provide supplementary information that a data point represents directly on the overview or even zoom-in visualizations. It is impractical to provide in-depth detail about all of the displayed items. The details-on-demand technique provides this additional information on an as-needed basis, without apparent deviation from the bigger context the data item is in (Craft & Cairns, 2005). This can be achieved by a simple action, such as a mouse-over or click, and details are displayed in a stack-up layer or a separate reserved space.

The visual information seeking mantra provides descriptions of high level and abstract design concepts and guidelines for visualization systems. However, it does not provide design details for specific visual elements in different domains. Many researchers follow the mantra as a general principle to design domain specific visual exploration systems, such as a document search system for journalists (Attfield, Blandford, & Craft, 2004), a system to visualize medicine

(Chittaro, 2001), and a video exploration system (Christel & Martin, 1998). For a more complete review, see (Craft & Cairns, 2005).

Visual exploration has also been used for data mining to allow faster data exploration. The purpose of visual data exploration is not to replace good solid quantitative analysis, but instead to allow the quantitative analysis to be focused (Grinstein & Ward, 2001). It can be used as a means to gain insight into the data and to create hypotheses (Keim, 2002; Oliveira & Levkowitz, 2003). Then, the verification of the hypotheses can be accomplished by statistical analysis, or may be done through visual data exploration. In this sense, visual exploration is a good complementary, rather than a competing, approach to other methods and tools. The major advantage of this approach over other data mining techniques is the direct involvement of the user. Another advantage is that it is intuitive and requires no understanding of complex mathematical or statistical algorithms or parameters (Keim, 2002). This feature is especially helpful for business executives and managers.

### ***3.3.3 Multidimensional visualization***

In data mining, it is common to refer to data variables generally as data “dimensions” or “attributes”. A multidimensional visualization is capable of visually presenting multiple attributes of a data item or dataset. For example, many reporting charts are able to display multidimensional information, such as the bar chart, histogram and pie chart. There are some other variations of these reporting charts created for Multi-Criteria Decision Analysis problems, such as the Parallel Coordinates (Inselberg, 1985), Star and Petal (Tan & Fraser, 1998), Triple C (Angehrn, 1991) and Covariance Biplot (Losa, Honert, & Joubert, 2001). Many of these are discussed in (Hoffman & Grinstein, 2002; Soukup & Davidson, 2002; Tegarden, 1999). These

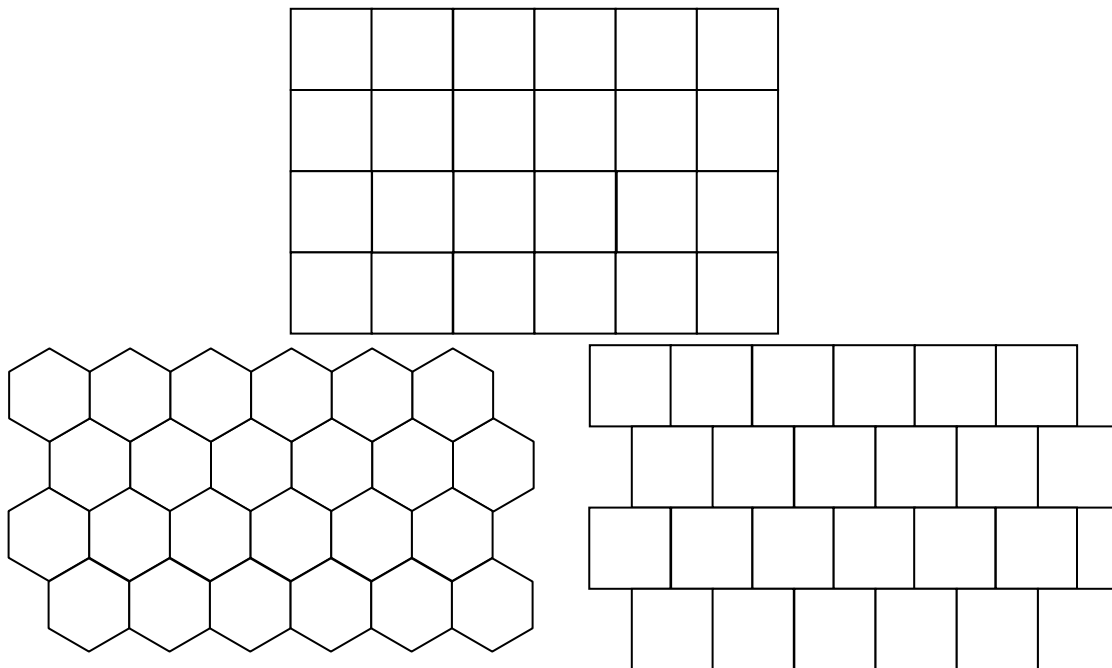
types of visualizations are able to present complete multidimensional “profiles”, avoiding the reduction of multiple dimensions to a single “number” (Kasanen, Östermark, & Zeleny, 1991).

The reporting charts above are able to display and compare individual data items as inputs, but they cannot position multiple data items in the same space based on their dimensional values because of human’s comprehension limitation of space dimensions. For example, scatter charts or quadrant diagrams are able to plot data items based on two dimensions (X- and Y-axis) for two of the attributes. A 3D chart can be built and a third dimension (Z-axis) can be added to represent a third attribute. But then it is difficult to add more dimensions to the visualization as geometric projections beyond three dimensions become difficult to convey information to people. One way to mitigate this is to project high-dimensional data to a lower dimensional space, but at the same time preserves their relative relationships. Self-Organizing Maps (SOM) (Kohonen, 2001) is such a technique.

SOM is an unsupervised clustering technique that inherently provides a 2D map on which complex high dimensional data can be effectively mapped. Clustering is a general data mining method that groups objects based on their properties without predefined categories (Jain, Murty, & Flynn, 1999). It is one of the effective analysis techniques to analyze multidimensional information (Jain, et al., 1999; Wang & Yang, 2003) and very useful in exploratory pattern analysis situations (Jain, et al., 1999). Intuitively, objects that are in a cluster are more similar to one another than those outside of the cluster. There are many options for data clustering techniques (Jain, et al., 1999), but SOM has a unique feature of presenting the output layer on a two dimensional space. Data items are projected on this map based on their relative similarities and differences in selected dimensions. This gives a high level overview of the data sets; data items’ relationships (similarities and differences) can be visually explored, and clusters can be

visually identified by observing the map. This feature makes it a first choice to the proposed approach.

SOM's output layer is a two dimensional space (map) (see Figure 6). This map is divided into small regions (cells) arranged in rows and columns. The map's size (number of cells) is usually denoted by "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). Figure 6 shows some variations of the SOM map with a size of 6 by 4 (6 columns, the width; 4 rows, the height).



**Figure 6: SOM Map Types: Rectangular (upper row) and Hexagonal (lower row)**

Each cell represents a certain pattern (a vector of values corresponding to selected attributes). Initially, these patterns are randomly generated. Then SOM uses all data items (defined by the same attributes selected previously) as a training set to train the map. Through training, each cell will become more similar to its neighbor cells; the closer the cells are, the more similar they will be (in terms of selected attributes). Then each data item will be projected on the map and is placed in a cell which it is most similar to. If all or a group of data items are projected, then their

distribution (positions) will be visualized. Consistent with the cells, data items will be more similar if they are closer to one other.

SOM map offers a natural perception of data items distribution based on multidimensional information. There are visual techniques to help humans to better comprehend the information a SOM map conveys, and to make the map exploration easier. Many of these are reviewed in (Deboeck & Kohonen, 1998; Vesanto, 1999). The most common ones are color coding and object linking techniques.

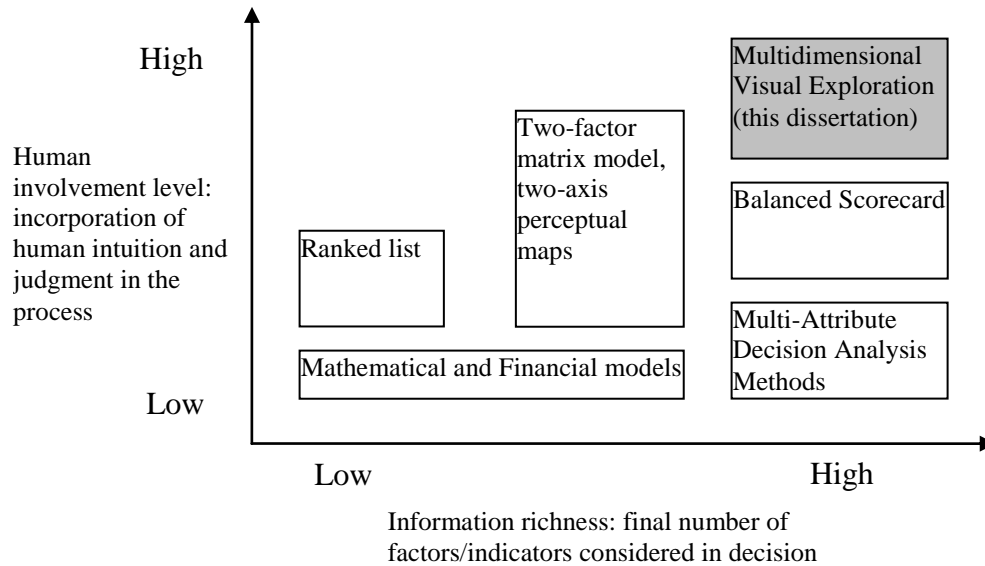
SOM has been successfully applied to many computing areas such as image analysis, optical patterns, acoustic processing, speech recognition, signal processing and robotics (Kohonen, 2001). It has also been applied to information management, such as documents organization (Kaski, Honkela, Lagus, & Kohonen, 1998), directory management (Liang, Vaishnavi, & Vandenberg, 2006), database schema (Zhao & Ram, 2004), web search results (Roussinov & Chen, 2001); and to business domain like marketing analysis, financial areas like real estate appraisal, mutual fund portfolio, etc. (Deboeck & Kohonen, 1998). It also has good potential to be applied in IT management and project portfolio management, which needs such visualization oriented multidimensional analysis tools for its project and portfolio information.

### **3.4 Summary**

Based on the literature review, together with my experience and judgment, two general techniques are chosen to be the basis of a new proposed approach: clustering and visual exploration. Clustering is an effective method to analyze multidimensional information (Wang & Yang, 2003). Further, visual representation and interaction can better incorporate human intuition and comprehension of complex information in the decision making process (Jarvenpaa & Dickson, 1988; Keim, 2002; Kuo, 1998; Meyer, 1991). A combination and integration of

clustering and visual exploration is expected to be the basis of a potential multidimensional analytic approach for project portfolio management.

A research framework (Figure 7) is developed to position the proposed research in relation to current methods and approaches. In this framework, the horizontal axis represents the number of final factors (dimensions) considered in any decision model or analytical method; the vertical axis represents the capability of incorporating human sense-making ability. In the framework, financial models usually use one or two indicators and do not require much human judgment because the financial measures are concrete numbers. Currently, the most widely used methods in PPM are one- or two-dimensional rating and scoring tools (in the form of questionnaires or checklists) in conjunction with 2D diagrams, used commonly for project prioritization, portfolio balancing, and strategic alignment. These tools require moderate human involvement to comprehend the diagram. The proposed method and system will be positioned in the upper right region. Such a tool utilizes multiple dimensions (more than 2) to include richer information and requires a high degree of human involvement to explore and interpret the system outputs. In the future, such tools are expected to play a more important role and provide additional support to PPM.



**Figure 7: Positioning the Research**

In this dissertation, SOM was chosen as an important technique to create the basic perceptual portfolio map, because it well integrates multidimensionality in the decision model, and it presents a well constructed map as a starting point for visual exploration. However, the application of SOM may be domain dependent; in addition, SOM does not define necessary elements for a visual exploration process. Further work needs to be done to define the approach and develop the system. How should SOM, and other components if necessary, be designed and used in a multidimensional and visual exploration approach for PPM? Can the proposed solution approach be implemented? Does it work? The research work in the following development stage was carried out to find the answers through iterations of system prototyping and knowledge abstraction.



## **Chapter 4. The Multidimensional and Visual Exploration Approach**

The outcome of this research is a multidimensional and visual exploration approach for project portfolio management. Such an approach consists of a set of core concepts and processes, driven by an IT artifact (a computer software application or information system). It is a method as well as an IT artifact. In this chapter, the core concepts and components of the approach are introduced first (4.1); this is followed by a detailed description of the process of using the system, presented with the help of an example scenario using the prototype developed (4.2); then the system prototype is described briefly (4.3); finally, the chapter is concluded by a discussion of the designed approach (4.4).

### **4.1 Core concepts and components of the system**

In general, the designed approach is a software driven visual information exploration process (Keim, 2002; Oliveira & Levkowitz, 2003). There are basically two parts in this approach: generating portfolio perceptual maps based on multidimensional project data, and visual information exploration.

#### ***4.1.1 Generating Portfolio Perceptual Maps with Self-Organizing Map***

A portfolio perceptual map is a high level overview visualization that shows the distribution of all projects in a project portfolio based on selected project attributes. 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 a project portfolio perceptual map. SOM is well suited to the approach because it basically satisfies the two meta-requirements (see section 1.2). First, 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 & Yang, 2003). Second, the SOM algorithm is chosen because of its added 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.

To apply the SOM algorithm, users need to prepare project data and set SOM parameters. In data preparation (pre-processing), a 2D project data table is generated as the main input (the training set) for SOM. This process generally includes selecting projects, choosing project attributes and transforming project data. The most important step is the selection of project attributes (dimensions) for later analysis and visual exploration. Typically, projects are described by attributes such as size, budget, technology, status, purpose, etc. Of these attributes, the most appropriate ones to use with the approach are those which are number-based (such as budget, project size) or can be quantified (such as priority, technology profile, skills required). What's unique of this selection in our approach is that users need to consider its impact on visualization:

- 1) The selected attributes need to make business sense and be relevant to analysis tasks. For example, conducting a technology portfolio analysis usually needs attributes of technology profiles; a human power assignment may need to select attributes related to skills requirements; in the case of project prioritization, a user usually selects attributes that are directly relevant to a particular prioritizing model adopted by his/her organization.

- 2) Project data needs to be properly quantified and scaled for the purpose of visual representation. SOM is a type of artificial neural network and depends on quantitative measures (Jain, et al., 1999). Different attributes have different domain value ranges. Some data needs to

be quantified, such as the technology profile and skills requirement. The transformation of these attribute values is sometimes subjective. But they need to be properly scaled if different types of attributes are selected together. For example, the budget attributes range is between 0 and thousands or even millions. But the technology profile for a project could just be 0 or 1 (required or not required). Such a range difference could have a big impact on SOM as well as the visual representation. Thus the data needs to be scaled to a common range, such as 1 to 10, for SOM and visualization processing. The scaling process is automatically done but is also configurable by users.

3) The number of attributes must be limited for good visual effects. Although SOM can take any number of attributes, it is best to limit the number of attributes in a certain range. Later these attributes are used to form a certain visual pattern; too few or too many attributes will impact the effectiveness of identifying and comparing/contrasting visual patterns.

4) The order of the attributes also affects visual representations. This may affect analysis and decision consistency.

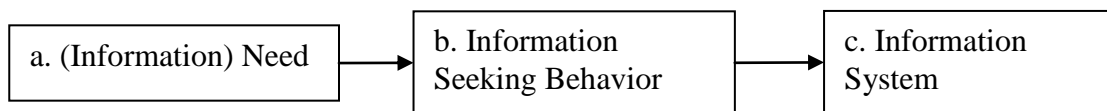
The system offers the flexibility of feature selection and configuration, which can provide users more options to utilize their expertise based on different perspectives and situations, and it allows them to do what-if analysis, a common practice in decision support systems. This flexibility could potentially lead to a generalized solution that can address the needs of different organizational and management activities. However, too much flexibility may also lead to inconsistency, confusion and interpretation difficulty. Therefore, the selection of attributes (including the number, scale and order) should follow a certain selection policy, predefined by an organization and managed by the Project Management Office. In such a way, the approach can achieve the best analytic consistency and common understanding within an organization.

The second group of settings are the SOM parameters, such as map type, map size and other algorithm parameters. Of these, the map size is the most important setting that directly affects user's visual experience. The size of SOM map can be described as X by Y. The total number of cells of a map is X multiplied by Y. Generally, the bigger the map size is, the smoother transitioning of the cell pattern change is; but, a bigger sized map may lead to visual complexity (for more details, please see the description of Cells View in section 4.1.2.1). The setting of map size should also be bound to organizational policy.

The result or output of SOM clustering is a project/portfolio distribution map (the portfolio perceptual map). This map is not just a mere static reflection of the clustering result, but also an important visual element in the exploration process that provides rich interactivity.

#### 4.1.2 Visual exploration

The second part of the system is a visual exploration system, partly based on the portfolio perceptual map generated by SOM. The overall system model is informed by an information behavior model (Wilson, 1981) and the visual information seeking mantra (Shneiderman, 1996)<sup>6</sup>. The information behavior model describes the process of how people seek information for certain needs. Part of the model is presented in Figure 8.

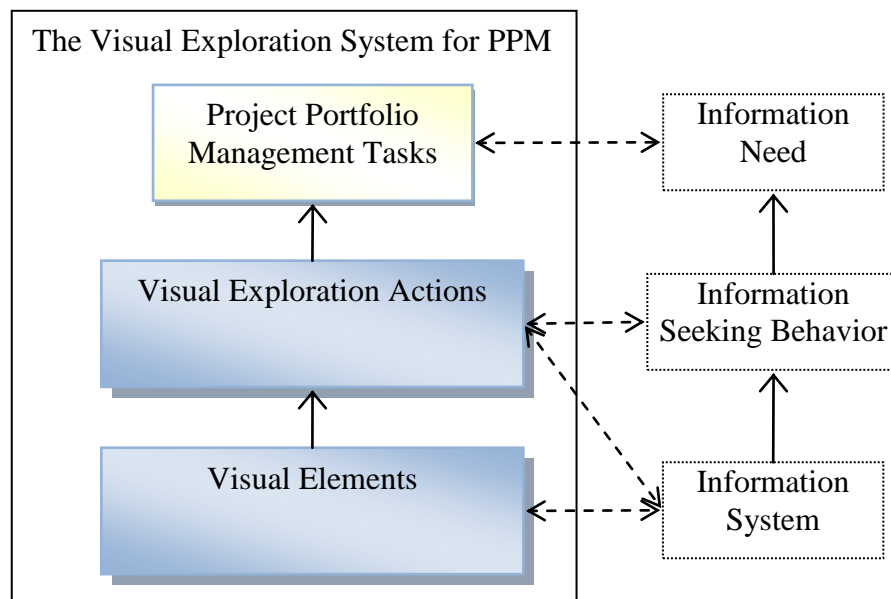


**Figure 8: Information Behavior Model (Partial) (Wilson, 1981)**

The model has a general implication on the design of the visual exploration system. Corresponding to the high level theoretical constructs suggested by Figure 8, a high level abstraction of the system can be modeled as in Figure 9. In Figure 9, management tasks

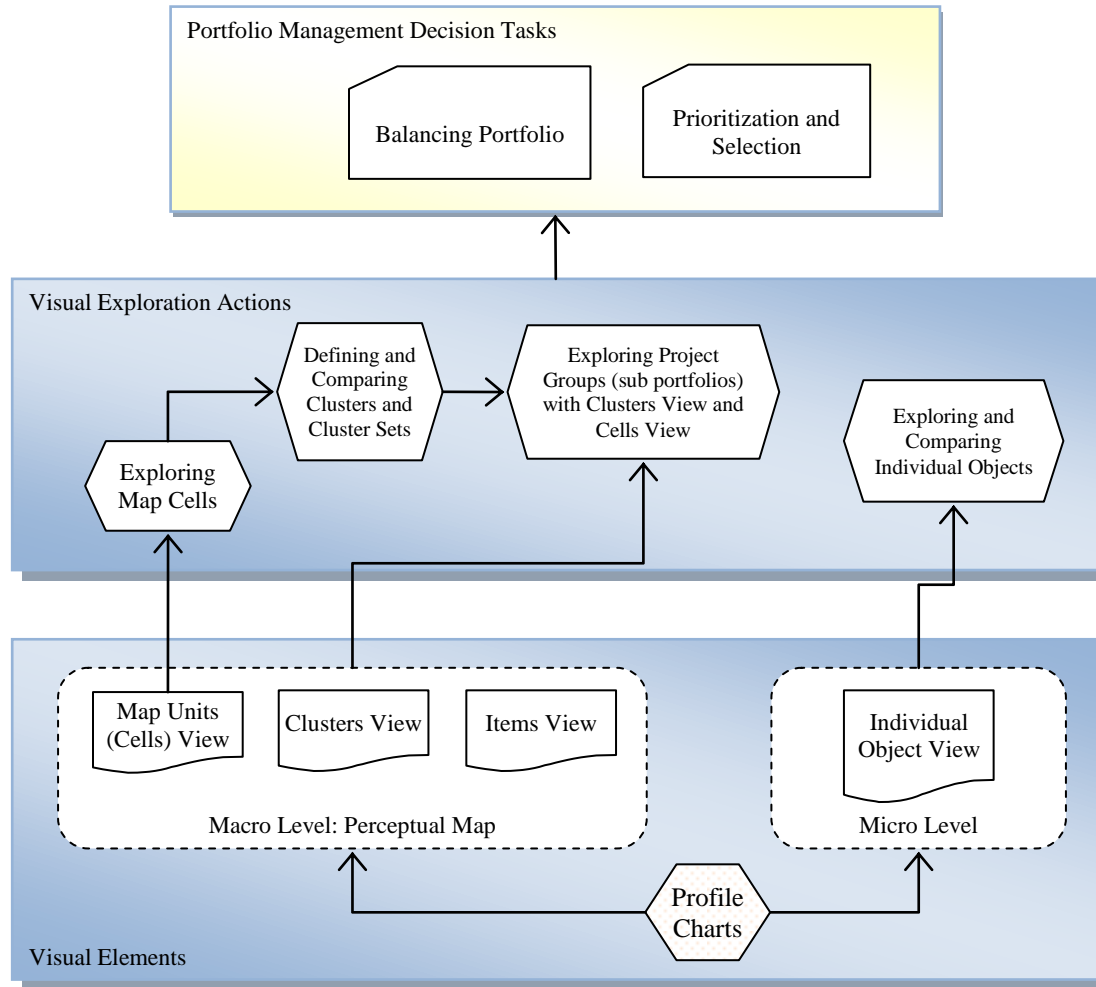
<sup>6</sup> The mantra is described in 4.4.1.

correspond to “Information Need” (Figure 8, a). They are the purposes 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 8, b); these are a series of human behaviors interacting with the visual elements for particular information needs. *Visual Elements* are the basic and static visualizations created by computer applications. Conceptually, an “Information System” (Figure 8, c) provides a set of basic visual elements as the basis, as well as functionalities to directly support visual exploration actions.



**Figure 9: High Level Abstraction of the Visual Exploration System**

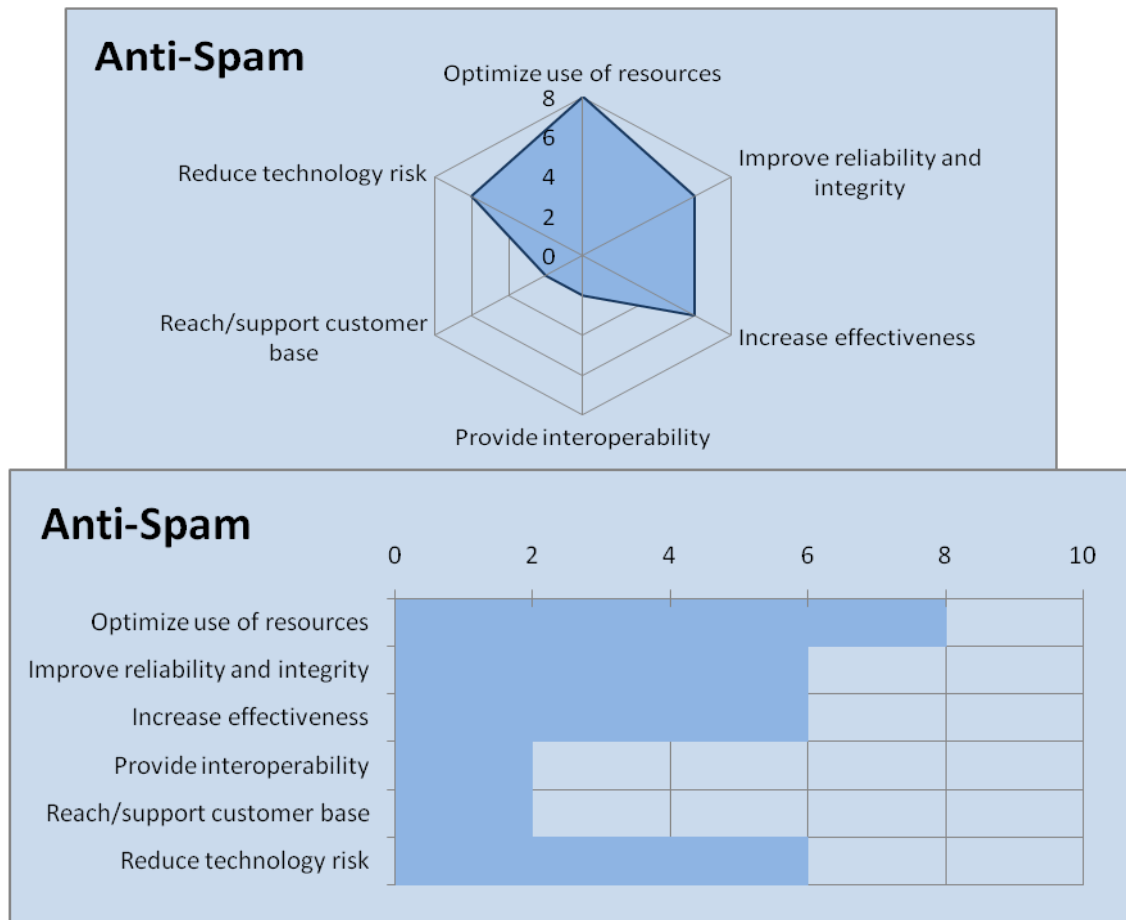
Figure 10 shows the conceptual architecture of the system with more detailed and specific designs following the high level abstraction. It includes the major components of the system. The following two sub-sections will explain each component of *Visual Elements* and *Visual Exploration Actions* in detail.



**Figure 10: Conceptual Model of the Multidimensional and Visual Exploration System**

#### 4.1.2.1 Visual elements

Visual elements are the basic visualizations 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*.



**Figure 11: Profile Chart using Radar Diagram (upper) and Gauge Bars (lower)**

A profile chart is a visualization of an object based on values of the attributes (dimensions) selected to represent the object; such a chart 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 charts, line graphs, area graphs, or radar diagrams (Jarvenpaa & Dickson, 1988; Tegarden, 1999). For example, Figure 11 shows a radar diagram and a gauge bars diagram for a project. The system/approach itself does not provide guidance on choosing chart types but leaves that to users as an option when exploring project data. For consistency and illustration purposes, this paper will use the radar diagram for examples.

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, which can be a project, a SOM map unit (cell), or a SOM map cluster. The macro (map) level visual elements generally refer to the three map views for the project portfolio perceptual map (also summarized in Table 4):

1. *Cells View* (or base map): This view is generated directly based on the SOM clustering result. Each SOM map 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 the designed 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 or pattern of all cells can be directly observed on the map so that users can have an overall understanding of the map. Figure 13 shows the prototype screenshot of such a view.
2. *Clusters View*: a cluster on the map is a group of nearby cells with similar patterns. Using clusters, a map 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 a higher level of project grouping. Compared to cells view, the differences among clusters are more discrete. Figure 15 shows the prototype screenshot of the Clusters View.
3. *Items View* (or projected map): This view is the result of mapping projects on the SOM 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<sup>7</sup>. After the mapping, the distribution of projects on the map should reflect the

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<sup>7</sup>  $Distance = \sqrt{\sum_{i=1}^n (p_i - q_i)^2}$ : p is a project, q is a cell, n is the total number of attributes, i is the counter for each attribute.



portfolio characteristics. Projects that are closer on the map are more similar than those further away in terms of all dimensions. Figure 14 shows the screenshot of such a view.

These three views offer different aspects of the map. They can be combined (overlapped) to present patterns and relationships of portfolios and projects, and meet other specific exploration needs.

<i>Map View</i>	<i>Description</i>	<i>Example Figures</i>
Cells View (or base map)	Each SOM cell, after training, is represented by a vector corresponding to the previously selected dimensions (attributes). 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.	Figure 13
Clusters View	A map can be divided into more coarsely identified regions (clusters). Clusters View reduces visual complexity and suggests a higher level of project grouping.	Figure 15
Items View (or projected map)	This view is the result of mapping projects on the SOM map. Each project is placed into the cell with the least difference between the project and the cell based on selected dimensions.	Figure 14

**Table 4: Summary of the Three Map Views**

#### 4.1.2.2 Visual exploration actions

Visual exploration actions are human actions interacting with visual elements for a certain information seeking or decision making task. In the designed approach and system, there are two basic types of visual exploration actions defined, corresponding to the two types of visual elements: object level exploration and map level exploration.

Object level exploration is viewing and comparing individual objects. These objects mainly include projects, map cells, and clusters. The action is directly supported by the micro level visual elements. Below is a list of exploration actions that can be performed at this level:

1. Viewing a single project with profile chart and all other project details;

2. Comparing and contrasting two or more projects based on their profile charts;
3. Viewing a single map cell profile;
4. Comparing and contrasting multiple SOM map cells;
5. Viewing a cluster's profile;
6. Comparing and contrasting multiple map clusters;
7. Comparing projects with cells and/or clusters;
8. Comparing map cells and clusters.

The combination of these actions can directly support information seeking tasks, or they can support other map level exploration actions. For example, action #1, #2 and #7 may be used for selecting and prioritizing projects; action #5, #6, #7 and #8 may be used to explore project distributions; action #3, #4 and #5 may be used for visual clustering.

Map level exploration is the action of exploring project portfolio perceptual maps based on the three SOM map views. There are three actions:

1. Exploring map cells: This action is carried out directly on the Cells View. Exploring map cells can let a user have an overall feeling of the complete map and 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 a map based on particular needs and perspectives) by observing and comparing/contrasting cell patterns. This is a manual process to assign cells to clusters based on a user's judgment. Each cluster profile is calculated by the system on the fly and presented to users through profile charts.

3. Exploring project groups with Cells View and/or Clusters View: This action depends on the flexible combination of three map views. In addition, users can define project groups (or sub-portfolios) for specific exploration needs. A project group is a set of projects grouped together. Users can define various groups and compare/contrast them, so they will better understand similarity and differences in terms of group composition characteristics. For example, project groups can be naturally defined based on attributes used in clustering (such as high priority projects, small budget projects, legacy technology projects, etc.); or they can be based on attributes not directly used in clustering (such as successful projects, this year's projects, new proposed projects, student related projects, etc.); or, they can be more customized and subjective (such as familiar projects, my preferred projects, etc.). The purpose of such exploration is to have an overall understanding (a big picture) of portfolio (and sub-portfolio) composition, and compare/contrast sub-portfolios.

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 techniques (such as zooming, filtering, ghosting, distortion, animation) to reduce visual complexity of the crowded map (Herman, et al., 2000).

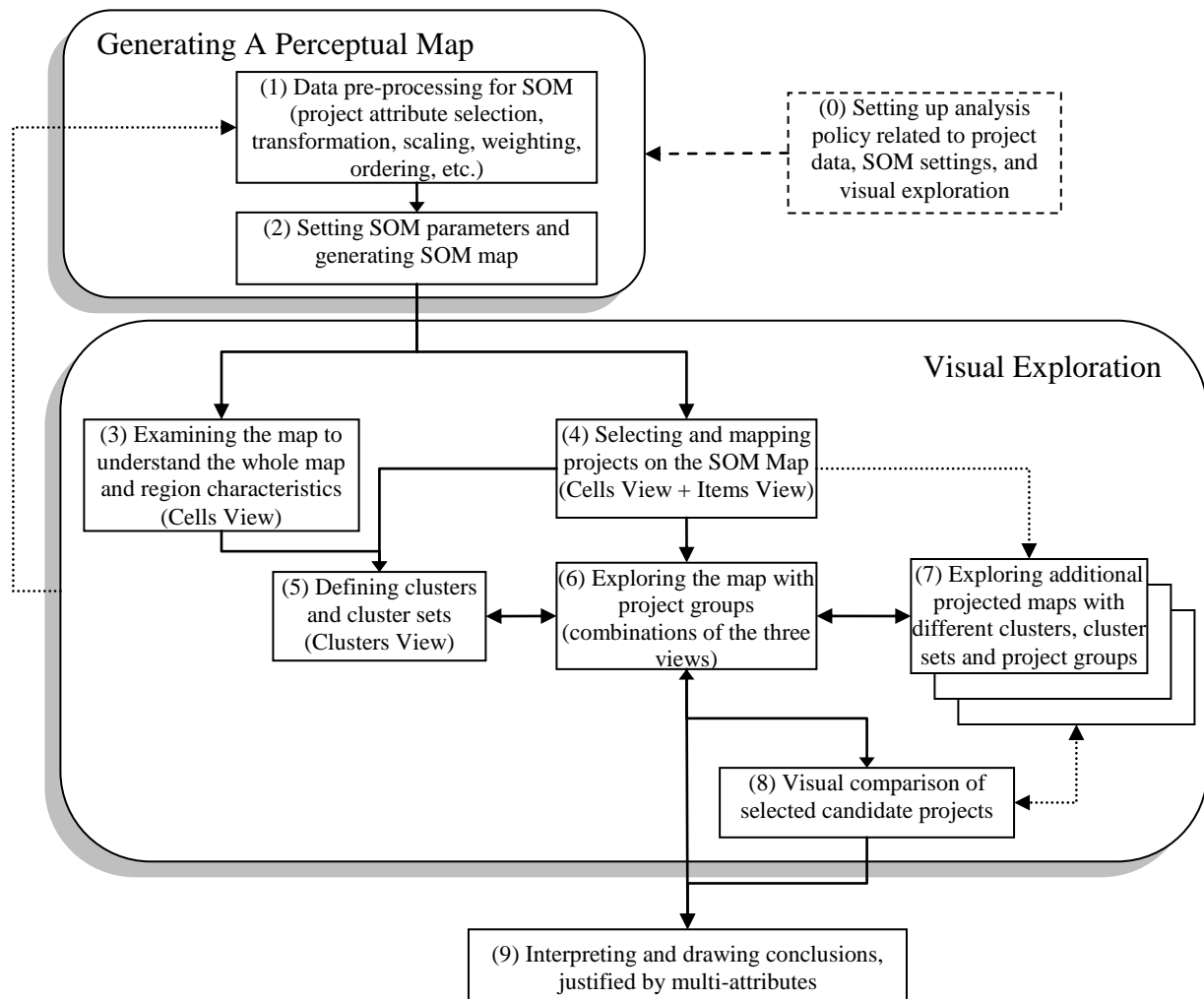
## **4.2 General processes of visual exploration**

The multidimensional and visual exploration approach is not merely a system that generates static visualizations. It is also a series of interactions taken between the human and system, hence a visual exploration process (Keim, 2002). The designed approach also includes general guidelines for using the system to support PPM tasks such as project prioritization and selection.

In this section, a general process will be explained first and then an example scenario will be illustrated following this process using the developed prototype.

#### 4.2.1 A general process and its variations

Figure 12 summarizes general steps of using the multidimensional and visual exploration system. In the visual exploration part, each step involves one or more visual elements and visual exploration actions defined earlier. The following paragraphs describe each step in detail, following the numbers in the figure. In this section, only a conceptual and abstract description is presented; a scenario using the prototype developed is presented in the next section.



**Figure 12. A General Visual Exploration Process for Project Portfolio Management**

- (0) As mentioned earlier, the system provides flexibility to configure the clustering process and adjust visual settings, but such flexibility should be bound to organizational policies. This will facilitate the consistency and common understanding if the process is used for discussion and communication by a group of users. These policies generally fall into three categories: a. those related to the project data preparation (such as data transformation, selection of attributes, weighting and scaling); b. those related to SOM settings (such as map size, type, map choice, etc.); c. those related to the visual exploration process (such as visual clustering, project groups, and profile chart comparison).
- (1) For a completely new analysis, the process generally begins with SOM clustering. Before running the SOM engine, project data needs to be pre-processed so that they are suitable for SOM. First, a set of attributes need to be selected to represent each project for a particular SOM processing. Different tasks and perspectives require different attributes. Then, each project is represented by such an attribute set with corresponding values (a vector). Last, data may be scaled or weighted to give more focus to certain attributes. The outcome of data preparation is usually a data table.
- (2) After map type, size, and other training parameters are set, SOM will be applied to generate a map based on the selected attributes. The SOM result can be directly previewed and analyzed for immediate visual exploration, or can be saved into a database for later use. The visual exploration process begins with this map.
- (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 to have a better and direct feeling of different map regions.

- (4) Now projects can be mapped (Items View) to overlay the Cells View. In this way, a user can have a quick look and feeling of project distribution. He/she may freely explore specific regions and projects that are of interest (using zooming if needed). Users can make use of this exploration action to quickly understand the relationships among projects, and get to know their similarities and differences.
- (5) To reduce visual complexity, clusters can be defined to divide the map into manageable regions (Clusters View). This is done visually by comparing cell patterns. If needed, multiple ways of clustering can be performed (cluster sets).
- (6) Now with clusters defined, users can freely switch among the three views to explore the overall map and the project portfolio. Project groups are defined and visualized for users to focus on part of the portfolio, and to compare/contrast between certain groups. These project groups are an important means to shape a user's attention. Other visualization techniques may be provided as choices to reduce visual complexity of the crowded map and provide multiple perspectives.
- (7) If necessary, users can explore the map with different settings, project groups, cluster sets, styles and visual exploration techniques to have different perspectives.
- (8) After examining the map, users may go further to visually compare individual projects head to head using the profile chart comparison tool. This is useful for the task of project selection. Users will select candidate projects directly from the map and then use the profile chart comparison tool to view their details.
- (9) Now the conclusion is better supported by the consideration of multiple attributes throughout the analysis process, and it can be better justified and communicated to others.

The above process is a general analytical process. It can be adapted to several kinds of tasks in project portfolio management, or can be varied for different situations. The process is not a linear or absolute process; rather it may be experimental, exploratory, or repeated. For example, the process does not always have to start from clustering. SOM maps can be saved and used repeatedly, for consistency and continuation reasons. So the process can start directly from step 4. Table 5 lists some more examples of the variations. In addition, it not only can be used at an individual level to seek decision support, but can also be used at a group level as a collaboration and negotiation process that facilitates discussion and common understanding.

<i>Situation</i>	<i>Sample Process</i>
Using a new map: when encountering a new situation, or new combinations of attributes need to be considered, or a map needs to be updated with significant new data.	
Complete and linear	1-2-3-4-5-6-7-8-9
Comparing project groups and have a general feeling of portfolios without going to individual projects	1-2-3-4-5-6-9
Repetition: typical in exploration and what-if analysis	1-2-3-4-5-6-7-1-2-...
Using an existing saved map: when consistency is a priority, or referring to past analysis	
Starting from a saved map	3-4-5-6-7-8-9
Without using Clusters View: if the user are conformable with the Cells View	4-6-9

**Table 5: Sample Process Variations for Different Situations**

#### **4.2.2 An example scenario**

To better understand the approach and the process, a project prioritization and selection scenario is presented here with screenshots of an actual running prototype system<sup>8</sup>.

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<sup>8</sup> 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 “Top 10” 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 issues like resource allocation and strategic planning. When one of the “Top 10” project finishes, another project will be promoted on the list. Now, three of the ten projects have been completed and the Project Management Office is asked to recommend other three projects to complete the list.

Using the designed approach and system, the following steps (corresponding to the steps in Figure 12) are taken by Randall, the PMO manager, to select the three projects:

- (1) Randall selects all 55 projects from the database, and he selects the six scoring attributes to prepare the data set for SOM (for simplicity, no data transformation, scaling, or weighting are considered).
- (2) Randall chooses the hexagon map type and sets the map size of 9 by 7. He runs the SOM and the result is ready after a few seconds.
- (3) A map with a size of 9 by 7 is generated and presented in the Cells View (Figure 13). In the figure, the six scoring components are displayed in the top region on the left panel; they represent the six axes in each radar chart, following a clock-wise order, starting from the 12 o'clock axis. Randall examines the map (Cells View) and clearly sees the changing patterns of the profile charts.



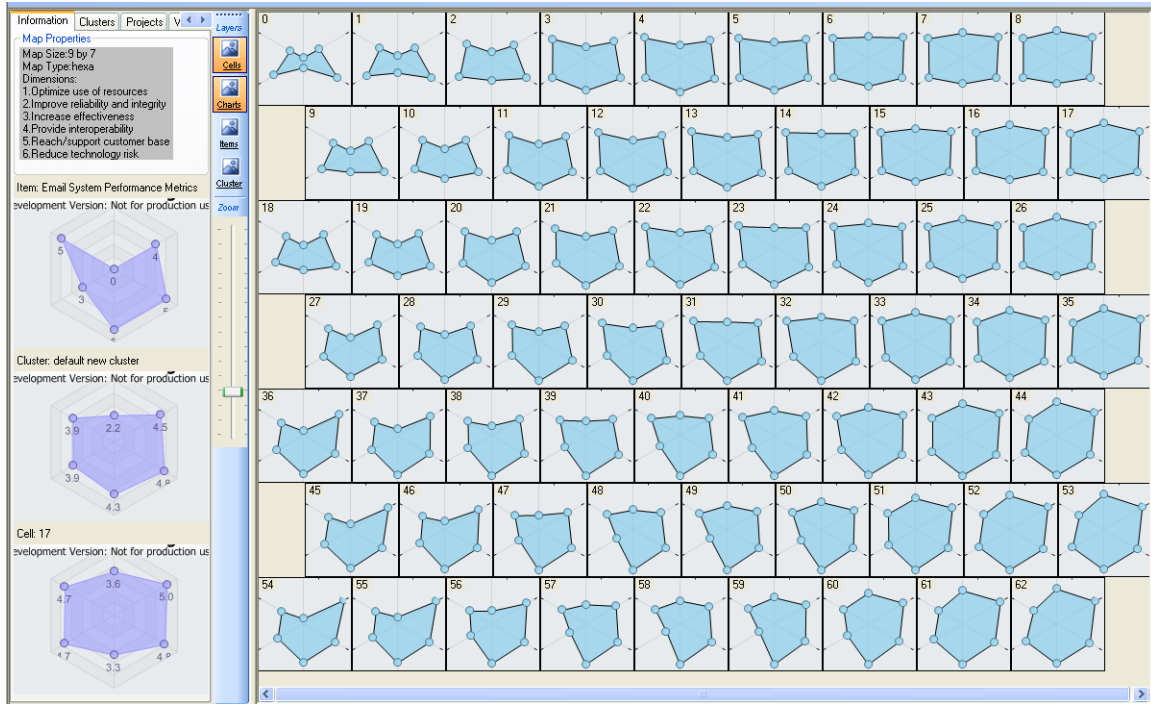


Figure 13: Prototype Screenshot: SOM Map Cells View (in hexagonal style)

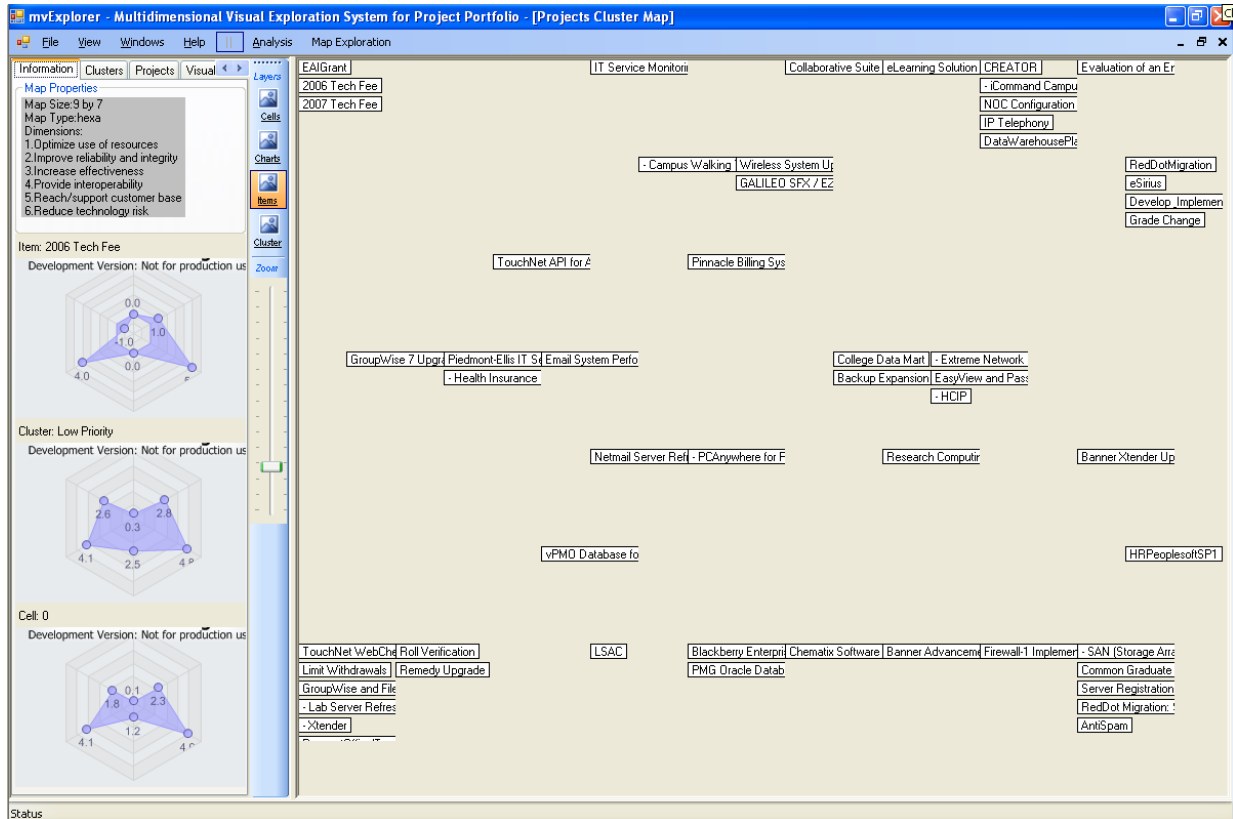


Figure 14: Prototype Screenshot: SOM Map Items View

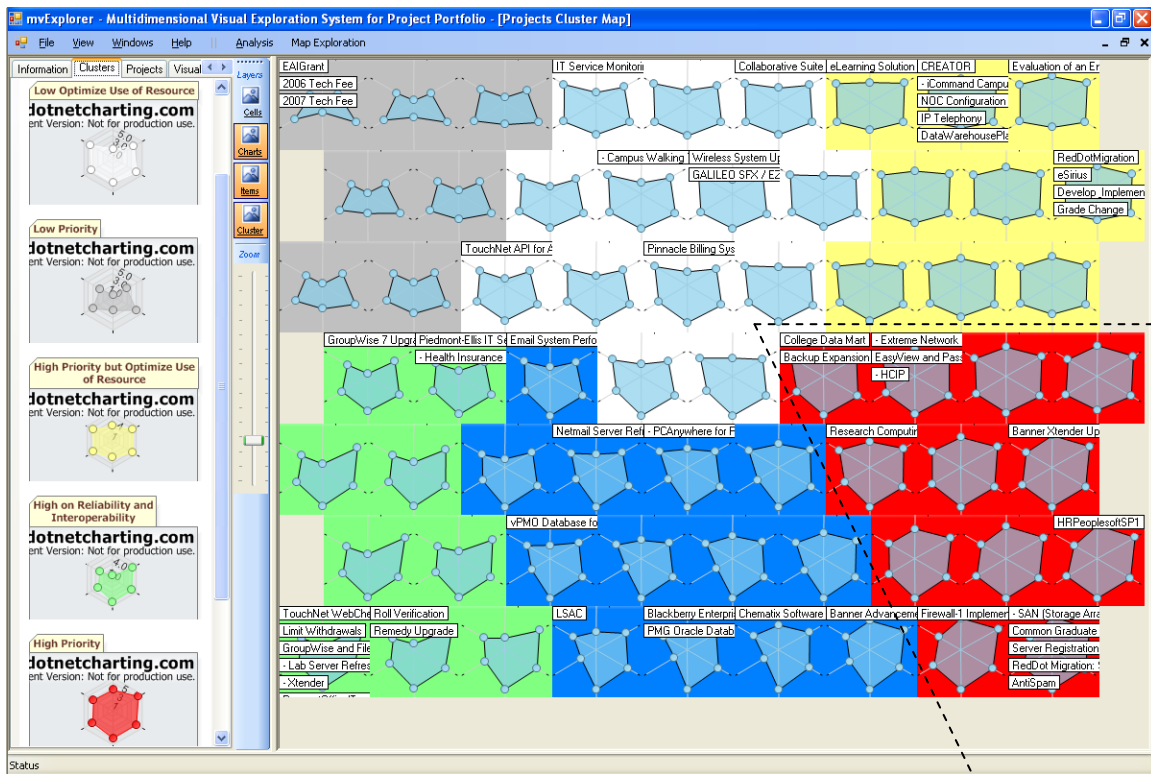


Figure 15: Prototype Screenshot: SOM Map Cells View + Clusters View + Items View

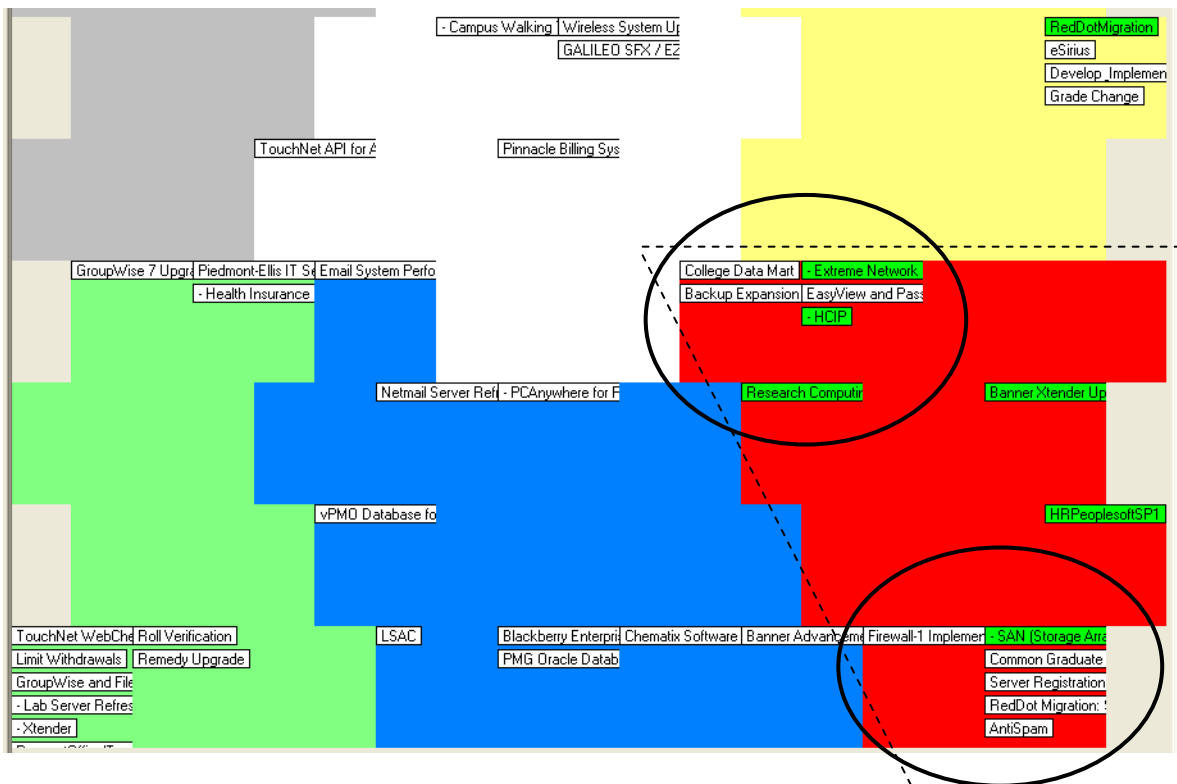
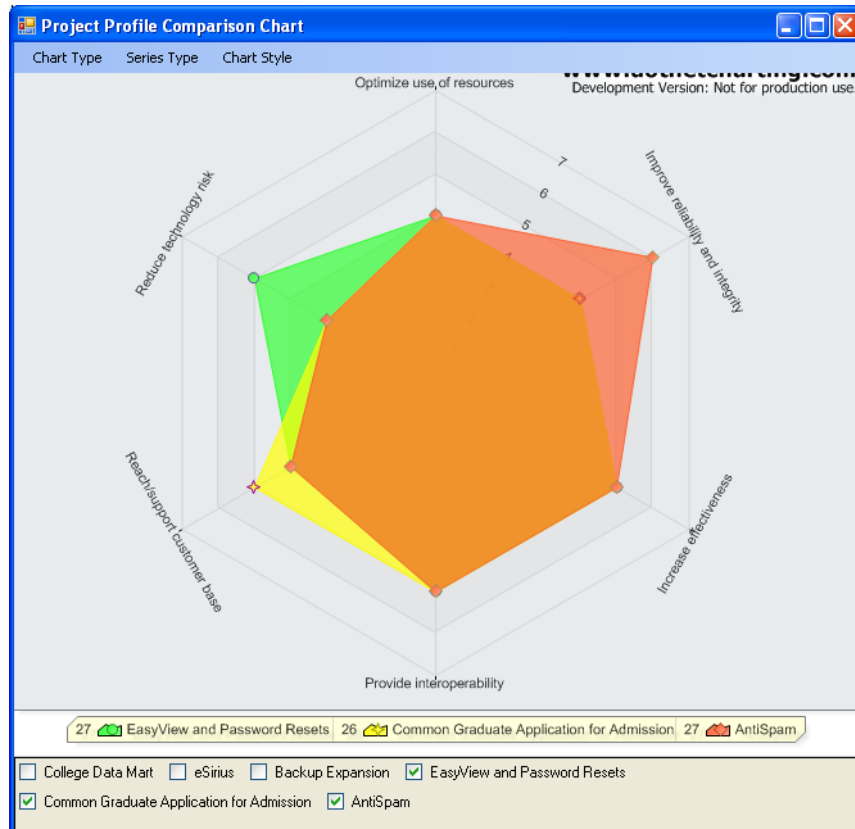


Figure 16: Prototype Screenshot (Partial): SOM Map Clusters View + Top 7 Prioritized Projects

- (4) Randall examines the project distribution using the Items View (Figure 14, projects are visualized as labels). He may overlap the Items 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 14 to Figure 13); that means, pretty intuitively, these three projects are similar to one another and to the profile chart pattern of cell #0; and they all seem to have low priorities. Randall can move the cursor on project labels in the map to get its profile chart displayed on the left panel (the first radar chart represents the profile of project “2006 Tech Fee” and the last one represents the profile of cell #0). With a quick scan of the map, Randall puts his attention to the lower right corner which seems to be the higher priority region.
- (5) To reduce map complexity, Randall decides to form clusters instead of reading cells directly. In Figure 15, 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 panel, using profile charts to preview cluster patterns. The prototype also provides a detailed report of all clusters and the projects in each cluster.
- (6) Now it’s time to look at projects and see how they are related. Randall defines a project group that consists of the seven existing projects in the “Top 10” list. He wants to find projects that are close to these seven projects on the map, so he can select those as candidates to be further examined. In Figure 16, 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 these high prioritized projects, and Randall first selects some candidate projects to focus on (Figure 16, circled).

- (7) If necessary, Randall can explore the map with different settings, project groups, cluster sets, and styles, using various visual exploration techniques, to determine other candidates.
- (8) Randall puts all 6 candidate projects in the profile chart comparison tool. He chooses the overlapping radar chart type and line-area style (Figure 17). As the figure shows, Randall switches on 3 of the selected projects and hides others (he may continue doing this with other projects). 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 department policy, Randall will choose one of them as one of his recommendations. He will repeat this process to compare and contrast other candidate projects until he decides the final three.
- (9) Now Randall can better interpret and communicate the conclusion to others. He feels it is well justified. If he needs more data or models to enhance the conclusion, he may use other tools to do so.

The scenario using the prototype developed demonstrates 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. Appendix D provides a similar scenario with different exploration settings; it complements the scenario presented here with more larger-sized screenshots and operation details.

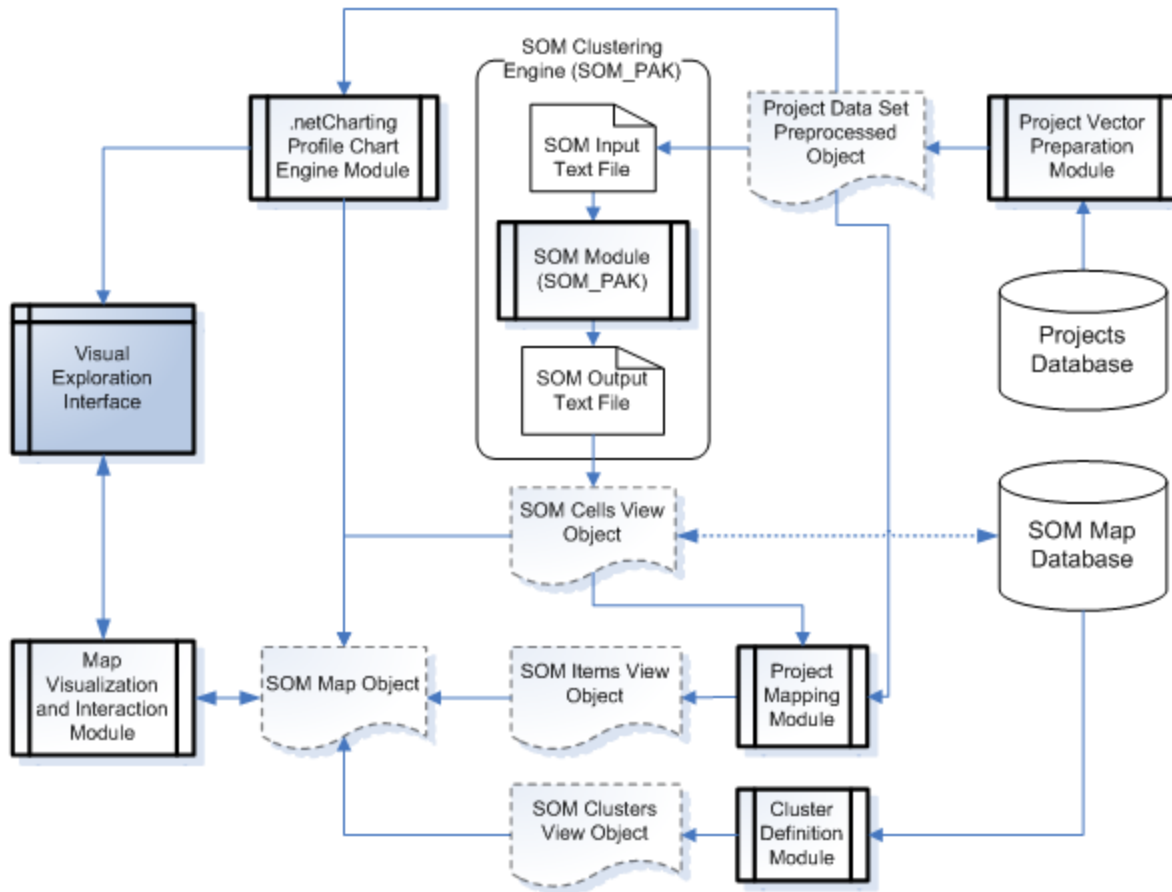


**Figure 17: Prototype Screenshot: Profile Charts**

### 4.3 System prototype

A software system was developed to implement the theoretical concepts and components presented earlier. The prototype is based on the Microsoft .Net 2.0 platform as a Windows desktop application. Figure 18 shows a conceptual architecture of the prototype. There are two 3rd party components used: 1) the original SOM\_PAK by Kohonen (Kohonen, 2001) is used as the SOM clustering engine; 2) .netCharting<sup>9</sup>, a library for diagramming and charting, is used as the visualization engine of Profile Charts. All project data is stored in a Microsoft Access database. The same database is also used to store SOM configurations and results. For a complete documentation of the prototype, please see Appendix E.

<sup>9</sup> <http://www.dotnetcharting.com/>



**Figure 18: Conceptual Architecture of the Prototype**

## 4.4 Discussion

### 4.4.1 Visual information seeking mantra

The visual information seeking mantra (Shneiderman, 1996) (see Chapter 3.3.2) has been used as a general principle for designing visual exploration systems. However, it lacks necessary details to be effectively used to guide the design and use of more specific visual exploration systems. The multidimensional and visual exploration approach also follows the mantra, and includes additional specifically defined concepts and steps for exploring multidimensional project portfolios. Table 6 shows the correspondence between the visual information seeking mantra and the multidimensional and visual exploration approach.

<i>Visual Information Seeking Mantra</i>	<i>Multidimensional and Visual Exploration Approach</i>
Overview	Generating and exploring perceptual maps: <ul style="list-style-type: none"> <li>• Exploring three views of SOM maps</li> </ul>
Zoom and Filter	Exploring cells, clusters and sub-portfolios <ul style="list-style-type: none"> <li>• Zooming on part of the map (cells or clusters)</li> <li>• Defining and examining project groups (sub-portfolios)</li> <li>• Clustering SOM map manually</li> <li>• Generating clusters report</li> </ul>
Details on Demand	Exploring and comparing individual objects <ul style="list-style-type: none"> <li>• Viewing project details with profile chart</li> <li>• Comparing objects using the profile comparison tool</li> <li>• Clusters report/summary tool</li> <li>• Previewing profile charts on the left panel</li> </ul>

**Table 6: Visual Information Seeking Mantra and Multidimensional Visual Exploration Approach**

#### **4.4.2 Advantage and disadvantage of the approach**

The major purpose of the approach is to provide a visual and intuitive system and process to support management tasks in PPM. It complements other approaches in a way that integrates managerial intuition in the process and makes complex and multidimensional information more approachable and comprehensible for decision support purposes. The major advantages of the approach are twofold:

- 1) It handles multiple dimensions of project data in a direct and flexible way. By revealing these dimensions of data, managers can have more understanding and control over the analysis process. The conclusions from the process can be well understood and justified.
- 2) It fits a certain group of people's cognitive style (Robey, 1983). Through a process of visual interactions, the perception of project portfolios and these multiple dimensions

becomes intuitive and easier. It provides a high level quick view and simple exploration of projects and portfolios. Such an approach also provides further focused areas for quantitative analysis in a quick way.

The limitation of the approach is also evident. “Overreliance on intuition can lead to systematic biases and error undetected by the user (Kuo, 1998).” Such an approach does not provide exact and clear answers based on quantitative measures; it sometimes can be subjective. This limitation is also suggested by some interviewees (see Chapter 5). It is an inherent weakness that cannot be easily addressed by the approach itself. Thus, there must be a sound understanding of the approach and its role in a bigger decision support environment.

First, the visual exploration approach is more of an exploratory approach and system, rather than a confirmatory one. It is more of a discussion/communication facilitation tool, rather than a decision making tool. It helps to quickly understand the big picture, discover potential patterns, narrow down areas of focus, and come up with hypotheses intuitively. After that, the visual exploration approach may continue to be used to confirm the conclusion, or other data oriented models can be used for further analysis. In any way, the approach is not a means of deriving final decisions, but a path to quickly form a high level overall understanding and point to a reasonable analysis direction.

Second, it does not lead to a full and complete solution for PPM. The system is designed as a complement to current approaches and systems, not a replacement. The designed approach provides additional flexibility and choices to decision makers, so they can choose the right approach and tool for the right tasks. The major purpose of the research is scoped only to investigate what and how visual exploration can provide assistance to project portfolio management. It is not intended to provide a complete and the only solution to the problem.



Last, a complete and practical solution of PPM is a complex system for a complex environment. The visual exploration approach needs to cooperate with other kinds of tools. It is a separate research question on how different kinds of tools should be selected and used for various portfolio management tasks and processes. The potential solution may largely depend on management processes and other specific management situations (Archer & Ghasemzadeh, 1999).

## Chapter 5. Evaluation and Results

This chapter reports and discusses the process and results of the evaluation. Section 5.1 gives an overview of the evaluation process. Section 5.2 reports qualitative data analysis and results. Section 5.3 summarizes questionnaire results. Section 5.4 provides some discussion of the evaluation.

### 5.1 Evaluation process overview

The major type of data collected for evaluation is qualitative data through interviews, with complementary quantitative data from post-interview questionnaires. I contacted the same IT department where I got the project data from and created a target interviewee list. The target interviewees were expected to be project managers and higher-level managers who had working experience with multi-project planning and management. These people needed to have appropriate domain knowledge so they could provide sound and relevant feedback. Nineteen of such people were then identified, including directors<sup>10</sup>, department managers and project managers. They were contacted through email and were invited to interview sessions. The recruitment result is presented in Table 7. Notably, all three people from the Project Management Office (which oversees all projects and performs portfolio level management) had participated in the evaluation. All final participants are experienced practitioners who perform project management activities daily and are familiar with project portfolio management practices. Their backgrounds, reported in the post-interview questionnaires, are summarized in Table 8.

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<sup>10</sup> Directors directly reports to the Chief Information Officer of the university.

<i>Participant Position</i>	<i>Number of People Contacted</i>	<i>Number of People Responded</i>	<i>Number of People Finally Participated</i>
Director	5	4	2
Manager/Project Manager	14	11	8
Total	19	15	10

**Table 7. Evaluation Recruitment Summary**

<i>Experience Area</i>	<i>Average experience (in years)</i>
Information system/technology	11.6
Project management	8.8
Using project management software	6.9

**Table 8. Interviewee Background Summary**

The final ten people who participated in the study were divided into two rounds. In the first round, four people were interviewed along the prototype development process, helping the researcher to generate ideas and make design choices. In the second round, six people were interviewed one-on-one after the prototype became relatively stable, with all conceptual components implemented. The interview processes were similar for both rounds. They only differed slightly on the purpose and scope. All interviews lasted about one hour. During the interview, the prototype application was projected on a big screen and was operated by the researcher; participants looked at the screen and only interacted with the screen while having a conversation. Each interview generally consisted of a mixture of the following activities<sup>11</sup>:

- Explaining and demonstrating major components and functionalities of the prototype.
- Demonstrating scenarios similar to the one presented in Chapter 4.2.2.

<sup>11</sup> See Appendix A2 for a complete interview protocol submitted to the IRB.

- Asking guided questions and getting feedback.
- Answering interviewees' questions.
- Doing small exercises with interviewees on using the prototype.
- Discussing emerging issues with participants, and exchanging ideas and thoughts.

After the interview, each participant was requested to fill out a post-interview questionnaire to respond to some assessment statements about the prototype/approach and background information. They did this on their own time. This gave interviewees more time to think about the prototype and to carefully provide their feedback. The questionnaire asks for both qualitative (optional) and quantitative data (required).

The following two sections report the data analysis and results of interviews and questionnaires in the evaluation phase.

## **5.2 Qualitative interview result**

Each interview was video recorded. After the interview, the video was reviewed and all major activities in the video were transcribed. The activities were mainly conversations between the researcher and interviewees, but also included participants' actions and emotions (for example, their actions directly interacting with the system/screen). There are about fourteen transcribed activities per interviewee on average. All data was cleaned and stored in a data file. For a complete transcript, see Appendix C1.

The analysis of these transcripts adopted a template analysis method (King, 1998, 2004). First, an initial template was developed with some pre-defined coding categories, which focused on the system components and design objectives. Then, interview transcripts were examined for their meanings and implications. Activities were coded using the initial template, seeking common themes and variations that provide rich descriptions. Each activity may be coded with

multiple codes or themes. During the process, other themes emerged, and more detailed themes were identified; these were incorporated into the initial template. The analysis template was then modified and eventually finalized, as shown in Table 9 (for a more detailed template with theme changes, see Appendix C2). Then all interview activities were coded using the final template.

<i>Coding Category</i>		<i>Codes (Themes)</i>	<i>Description</i>	
System Components	General	General	Generally about the system and the approach	
	Visual Elements	Visual Elements	Generally about visualizations	
		Profile Chart	Specifically about Profile Charts	
		SOM Map	Specifically about the SOM map and combinations of its three views	
		Cells View	Specifically about the Cells View	
		Clusters View	Specifically about the Clusters View	
		Items View	Specifically about the Items View	
	Exploration Actions	Exploration Actions	Generally about exploration actions	
		Comparing Objects	Specifically about comparing and contrasting objects	
		Comparing Project Groups	Specifically about comparing and contrasting project groups	
		Clustering	Specifically about the manual clustering process	
	Tasks	Tasks	Understand	Specifically about understanding portfolios and sub-portfolios
			Prioritize	Specifically about project prioritization
Other			Other tasks	
Design (evaluation) objectives	Usefulness	General Usefulness	Generally about the perceived usefulness of the system and the approach	
		Big Picture	Specifically about high level quick view of portfolios	

		Comparison	Specifically about comparing and contrasting projects, and portfolios
		Justification	Specifically about justifying and defending conclusions
		Awareness	Specifically about the tool's capability to help discover easy-to-ignore or hidden information
		Discussion	Specifically about the tool's capability to facilitate discussion
		Objectivity	Specifically about objectiveness of the system and the approach
	Ease-of-Use	Intuitive	Specifically about if users can easily understand the process and results delivered by the system; whether it makes sense
		Recall	Specifically about if the visualizations provided by the systems are easy to remember and recall
		Operate	Specifically about the system easiness to operate, and flexibility of the approach to meet different needs.
Tone	Positive	Positive comments	
	Negative	Negative (counter-evidence) comments	
	Neutral	Neither positive or negative; or conditionally positive or negative	
	Constructive	Providing new and effective ideas and thoughts	
Other themes	Reflecting Reality	Stating the real life situation or traditional practices in every day work	
	Self-assessment	Describing the user him/herself, such as the visual ability, work habit, etc.	
	Attitude toward using	User's attitude toward the system	
	Design suggestion	Suggesting new features, or stating design feature preferences	

**Table 9: Interview Transcript Analysis Template (Coding Categories)**

Interviewees' feedback, organized by these categories and themes, is the rich evidence to evaluate the approach and prototype developed. It gives a meaningful and insightful confirmation to the design objectives. Section 5.2.1 reports the user evaluation directly related to the prototype system as a whole and its major system components; section 5.2.2 reports user evaluation on its application to various management tasks; finally, section 5.2.3 summarizes findings around the high level evaluation objectives on perceived usefulness and perceived ease-of-use.

### ***5.2.1 The prototype system and its components***

Overall, interviewees have a positive perception toward the prototype system on dealing with multidimensional project data utilizing visualizations. Indeed, in project portfolio management, there are many tasks and decisions that need to consider multiple project attributes. These attributes are not just some kind of inputs for a decision model in which only the output is concerned; they are also the important aspects of an analytical process that provide rich information. It makes people more aware and confident of how and why they came up with their decisions (Keim, 2002). Interviewees seem to be fully aware of the importance of these attributes and the need to look at them together, as noted by one participant:

“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.”

Interviewees generally think visualization is one of the effective ways to understand multidimensional data, but they do not have the right and easy-to-use tools to help them.

“Visualization is what's missing in the current process... visualize how all of those complementary and competing dimensions aggregated together for a particular project.”

“... We have not been able to adequately visualize before.”

“I think it gives you a good representative (representation) to compare -yes. It’s not something that we do today because it is not really (an) option that we have today to do that. Today we really have just one dimensional view; I mean they go through that spreadsheet, and answer questions, and get a rank on the scale of one to a hundred. And that number becomes its rank, so it’s very one dimensional; and that’s it. It doesn’t incorporate some of the different (components) to make that number; it’s just there. You have one number and that one number doesn’t really tell you what’s high or low; it just tells you that it came out to this number.”

The prototype directly addresses this problem and provides several kinds of visual elements. Among them, the profile chart is the most fundamental visual element of the system, and it got positive feedback from interviewees. The Object Profile Detail tool and the Profile Comparison tool are directly based on the profile chart. Interviewees thought these tools are more meaningful and useful than just numbers, when reading a project and comparing projects or other objects head to head.

“Look if you can see based on what area each project’s covering the relative benefit according to your criteria and weightings of each. That’s heck a lot of meaningful than just a number vs. another number.”

“I think over time I would see more of the shape to realize that the larger the shape, the more the numbers are. ... I think, in the future, as people work more with it, look at it, (they will) get more (from the chart) ... right. ... yeah, I would look at the shape. ... [Showing the Profile Comparison tool] OK ~~~ (the user likes it).”

“You can look at it, like, OK, am I learning towards technology risk or leaning towards improving reliability. What is it that I am trying to accomplish by this? You can make a decision based upon (this).”

For flexibility, the system does not force a certain type of profile chart (such as bar chart, radar chart, pie chart), but uses the radar chart as a default type and leave others as options. After viewing other types of charts, users generally preferred the radar chart because it is easy and effective to understand.

“I suppose the radar chart as far as seeing the aggregate impact the radar chart’s a bit more helpful than serials of bars to me.”

“I like the radar because you can see where all the variables are you can make some decisions on.”



“I can understand it very well. It is easy to see, easy to understand from the six points what the priorities are for the projects. ... Yeah. I like that. ... It is easier to understand than the numbers. You know where the numbers are, right? And then you look at the pattern then you go, OK now I understand because the more you look at this the more you familiar you get of what the numbers are ... yeah that’s easier MUCH easier.”

The second major type of visual elements is the portfolio perceptual map and its three views.

All of the interviewees are foreign to this kind of visualization, and it took them some time to understand the map. Yet, they do not think it is that difficult to make sense of it after careful explanation. Some users actually picked it up fairly quickly and could follow the small exercise during the interview, and could explain it pretty well. The following feeling is common in almost all interviews:

“It makes sense to me now, now that we have gone over and explained it. But when you first look at it, it’s kind of like, you know ... (showing hesitation) ... need time to digest it and figure it out. But it does make sense to me. It is interesting.” (Participant start talking about his observation of the map compared to traditional quadrant map.)

Once they understood the SOM map (such as how it is generated and how to interpret it), they found it very interesting to look at the portfolio with this new perspective. They directly saw its advantage of providing a big picture of the portfolio in terms of project distributions, and reminding people of similar projects which people do not realize.

“That’s a real good one. It is good to have, and you can see how balanced your portfolios are.” ... “I am very visual. I like the patterns (cells view) on the map. Just because it helps me to look at where has the commons where’s not. I can see where the differences are.”

“Yeah, sure there are many projects that we do are similar in nature. I don’t think we realize it until we are really into it and we are actually working on things that are identical and many ways are pretty much the same. Whereas you put it up there, you like, wow, wait a minute, those are all pretty much the same.”

The three map views and their combinations are used to understand perceptual maps and project portfolios. The Cells View and the Clusters View provide different granularities of map regions. People generally think the Cells View is useful as it gives a direct interpretation of the map.

“Just looking at this on the right and the left (of the interface), I can see right off the bat where they are coming from (positioned). The visual benefits here show me just how close the overall project portfolio is doing in terms of meeting its goals.”

However, after seeing the use of Clusters View, a number of people began to prefer the Clusters View. They thought it is visually simpler and easier to interpret. Clusters View gives clear and explicit clusters, while Cells View gives more open and implicit map regions. People seemed to prefer more explicit clusters which are clearly differentiated. The following are pretty representative opinions:

“Having the charts (cells view) there doesn’t add anything. Especially for presenting to the executive group; all they want to see is how to cluster and what those colored regions mean.”

“I like the cluster view. Well, it also depends on your audience. I think you if you took a cluster view and explain what it is to the casual observers, it would be easier to explain the four or the six different clusters set, than explain each individual chart.”

It reflects that users, especially high level users, do not focus on details, but rather prefer visualization parsimony. They explore the map mainly for the purpose of quick understanding. For example, one interviewee mentioned it would be helpful to the ITSG group<sup>12</sup>. However, it does not mean that the Cells View is not useful. As some interviewees noted:

“You might want to just verify what you saw in the cluster. Coz when I research I look it (from) multiple sources. So I am not just gonna rely on one. But that (clusters view) would be give me a quick one sight view on what I am interested in. And then I can go to different layer.”

“I mean, if I am just comparing one to another (project), then just the map (Cells Views) is fine. But when I am looking at more than just one to one, the cluster really helps me to figure out where is this group compared to another group.”

The system just provides that flexibility and users can choose and overlay these views to their needs.

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<sup>12</sup> ITSG, or the Information Technology Strategic Group, is a university level committee to determine the plans for most important IT projects.

Interviewees also find visualizations (especially the shape pattern formed by the profile chart) more helpful because they are easier to remember, when they are familiar with the dimensions used to form those shapes.

“It could. It all depends on how well you define those parameters, the criteria and how meaningful those are ... If they were meaningful to me, yeah, those zones will stick to my head and I can carry around and use it.”

“Yeah, absolutely. ... Sure. Especially once you leant the six points, to me, it wouldn’t take much before you start thinking that way. You look up and then you go, hmm, that’s gonna fall into that cluster.”

Some of the interviewees had some concerns on the relative positioning of the map. As the SOM algorithm does not predefine the meaning and scale of spatial dimensions (X and Y axes), the positioning of cells are random (or semi-random, as the changing trends maintain). For example, the cell with a certain pattern could be in the lower right corner this time and could be in the upper left corner the next time (but the neighbor cells are always similar). Some people were not getting used to this kind of randomness, while some others thought it would not matter too much as they could find work-around to mitigate it.

“If I knew how it was setting all these different things and knew what they meant, then this reposition wouldn’t bother me. It shouldn’t (matter).”

“That doesn’t bother me. I understand that it is all relative. When you find the one that works for you, you stick with that one so you got a common reference point.”

“Since it s all relative ... but you got to have a common reference point for the relative mapping to make sense.”

Another flexibility of the system is the size of the map (or the resolution of the map). The bigger the map size is (with more cells), the more crowded the map is (in Cells View), but the more scattered the projects are (in Items View). When the map is bigger, the cells changing trend is smoother, but it is more difficult to cluster the map as neighboring cells are more alike. Some people preferred larger size maps:

“Well you might see the trends, the groupings, clusterings at the higher resolution that you will miss at the lower resolution. It (the high resolution) doesn’t bother me, I will take the maximum resolution and I can get to learn from it.”

Other people preferred smaller maps, but at the same time, they realized a trade-off when setting the map size.

“Yeah, for me personally, I think going with a smaller volume of cells is probably more effective as opposed to a larger volume of cells. But then you can’t go too small, because then you may lose that good overall view, there’s the trade-off. ... Having the flexibility to determine on your own what the view is gonna be, is very good.”

For the visual clustering process, people had different opinions. On one side, interviewees found the manual clustering process easy.

“That’s easy, I am visual, I am very good at dimensional things and I can see what’s close and what really seems to be not.”

On the other side, some people had concerns on its accuracy and subjectiveness. “This is kind of arbitrary”, commented by one person, and it is a common perception among interviewees. Some people thought the tool would be much more dependable if it was complemented by numbers or some kind of thresholds.

“So can you put some filters on it to say if it’s within 2% (of difference)? ... You can come up with a formula to describe that shape and then compare the numbers ... well the problem is if you gonna leave it to a manual inspection, ok, I will put these in one cluster, somebody else coming in and looking at the exactly same chart is gonna come up with a little bit different clusters.”

“To me it’s close. But, I guess at the end of the day, you have to have your threshold defined. I will probably base it on actually having a piece of threshold data that says, once it gets to this point, it’s automatically another cluster group. ... They can do it (manually), I am not a fan of doing it manually, though. Because I think it’s very important that you try to get the groups as accurate as possible, and having predefined threshold is really very helpful.”

### **5.2.2 Applications to management tasks**

The approach/system is designed to be a general tool for decision making and management tasks which involve multiple project attributes. However, in a prototyping process, the system is built step by step and cannot be built with everything considered at one time completely. In this

project, the prototype was developed with a focus for two major tasks: understanding portfolio composition and prioritizing projects. The system is expected to be useful for other tasks but needs further research (see Section 6.5). Interviewees generally agreed that the approach is applicable and improves the current practices for these tasks.

First, the approach is very suitable for understanding portfolio compositions on choosing dimensions. Based on this understanding, together with organizational policies and goals, a manager will know if too much work is being done on the inappropriate things, thus can balance a portfolio, or adjust the portfolio to meet the business goals.

“This one is, actually, you can see different areas; so I really do like this; (it) give you balanced portfolio. ... you can (realize) too much work focusing on the wrong thing. So I do like this approach to see, if this is how our projects set up, it looks like a very balanced portfolio.”

“That’s a real good one. It is good to have, and you can see how balanced your portfolios are.”

There was a small exercise during the interview asking interviewees to compare two sub-portfolios by examining their distribution pattern on the SOM map, using different views.

Generally, they could discover the portfolio characteristics and had some meaningful comparison.

For example, one interviewee explained:

“Basically, for me, right of the bat it shows that they are all over the place. [Asking finding from another sub-portfolio] They are little more closer to each other, but they are still dispersed to different clusters. ... However, I would say that these cover less; obviously they cover less at least than (the former).”

Second, as demonstrated in the interview, all interviewees thought the approach could be a viable alternative prioritization model to the ranked list. It reveals more details, and distinguishes projects that have similar aggregate priority numbers. In this way, the priorities are more reasonable and well justified.

“I could see it would be very useful. Then you don’t get just one number, you would actually see each of those dimensions that make up that number to figure out, ok, it is not just a 88,

it 's an 88 because improving reliability although optimization of resources is low. So, especially to an executive looking at it: well, they may have the same ranking, but because of the way the graph looks, really the other one is a higher priority project.”

“It could improve upon that list. That list's just taking numbers, putting them into some formula, coming up another number and sorting by that. Two projects with same exact number, you might view them very differently. That gives you a way to view them differently; it gives you the way to double check that formula you created.”

It is very interesting that one user actually thinks the process is better because of its objectiveness and transparency. He said:

“That would probably be better. It doesn't allow for as much gaming as the current process does. That's actually very helpful.”

What he meant by the “gaming” refers to a decision process that intentionally or unintentionally ignores the dimensional information behind the aggregated number. By revealing the hidden dimensional information, the process becomes transparent and trustful.

Last, interview participants were very active and mentioned potential applications of the approach to other types of management tasks, such as resource planning, business planning (goal alignment).

“The one thing I did see here that we really don't capture that data. The big issue is resource planning ... (looking at the human resources and skills) we don't look at that today; most projects require it, at least DBA and system admin, because certain projects may require more than one person. That's interesting dynamic, to say, OK, coz we do have limit resource on that.”

“Being able to display them in a diagram like this, highlight them on the chart with all the projects and showing where all of his are, then that's a good tool to say you are consuming all the resources we have up here, doing these high priority projects for you, and I can't get anything done here with some general values to the campus. Yeah that's good; helps the provost (to explain), too.”

“I can see where you would use it not just for portfolio management, but also help you plan your business; to say this looks like what's coming down, looking at these different clusters, to help underline business like who to hire, what technology to investigate, what to purchase.”

However, although all users saw its applicability to many tasks potentially, one person raised doubt about how theoretical usage could translate into actual usage in areas other than the prioritization tasks:

“Other than prioritization decisions, I am uncertain as to the practicality of using the tool. On a theoretical basis, I clearly see how one could use the tool to “explore” or “analyze” different dimensions of projects within a portfolio. However, I am uncertain as to whether these theoretical uses would translate into practical business processes routinely performed through the course of project portfolio management.”

His concern is reasonable, as the acceptance of a technology or a method is a complex process. The prototype developed here is by no means a mature, ready-to-use and comprehensive tool. Rather it separates the visual exploration part of a larger system and tries to focus on this part for the research purpose. It may be this separation that leads the user to doubt the system’s practical usefulness. The interviewee, at least, thought the tool is still applicable to project prioritization decisions. This may be related to the fact that the prototype development and evaluation both over-emphasize the prioritizing scenario.

Overall, the system is found to be more applicable to high level tasks and decisions, especially those for executives.

### ***5.2.3 Perceived usefulness and perceived ease-of-use***

The qualitative data from interviews present rich evidences that the design objectives are basically satisfied. Some interesting perspectives from the interviewees actually expand our understanding of the system utility (see Appendix C2 for analysis template changes related to design objectives). In this section, these evidences are organized and summarized as themes, according to the high level design objectives of utility and ease-of-use. Counter evidences are also discussed under corresponding themes.

### 5.2.3.1 Perceived usefulness (utility)

The biggest advantage of the approach is that it reveals the underlying dimensional information that is usually hidden from the decision makers. Because of the volume and complexity of project data, people are very easy to get lost. The visual exploration is a good way to present useful and relevant information in a very intuitive way to remind users of its value, so it is not ignored that easily. Interviewees generally agree that the designed system is useful in providing dimensional information and it can be very helpful to them. The analysis of the responses reveals a number of themes about how the system is perceived to be useful.

*Theme #1: providing overviews (big pictures) of project portfolios.*

Interviewees generally agreed that the SOM map and its three views (especially the Clusters View) give a quick, high level overview of the portfolio, on the dimensions a user chooses.

“Just looking at this on the right and the left (of the interface), I can see right off the bat where they are coming from (positioned). The visual benefits here show me just how close the overall project portfolio is doing in terms of meeting its goals.”

“The clusters definitely help, without a doubt. ... If you are gonna go with more of the cells, turning to the clustering will be very, very beneficial. Actually it will be helpful also in terms of quickly targeting. If you already know that each cluster represents, you can go straight to clusters and, (for example) I know these ones are having problems with this particular area. So you can quickly address that and take a look at that.”

One person pointed out that, for a more accurate analysis, more details may be needed than just a quick overview. One can achieve this by looking at other visual elements and conducting further explorations on individual objects.

“It’s easier in the sense that if you want to take a very quick view (snapped his finger), just take a quick look at something, you can see very quickly where the project portfolios are in terms of meeting those targets of business goals. Yes, for that, it looks good. However, I suspect that people will need to further dive into if they actually start the examination. But I think that’s the play; this is just to give you a quick look and feel of how things are going.”

*Theme #2: comparing and contrasting projects and portfolios*



The feedback shows a general preference of comparing and contrasting projects and portfolio based on multiple dimensions in a visual way. Interviewees felt visualizations are more meaningful than numbers. One interviewee reported:

“Look if you can see based on what area each project’s covering the relative benefit according to your criteria and weightings of each. That’s heck a lot of meaningful than just a number vs. another number.”

They also thought the system could reveal additional dimensional information about projects and that is more useful than just aggregate numbers in comparisons.

“It makes sense to me; a lot more than sitting there and reading a whole bunch of spreadsheets and trying to figure out the aggregates. I’d much rather do this. Once you get it and, jeez, that makes sense to me.”

“You can look at it, like, OK, am I learning towards technology risk or leaning towards improving reliability. What is it that I am trying to accomplish by this? You can make a decision based upon (this).”

### *Theme #3: justifying decisions*

Most of interviewees think the decision out of this approach is better and easier justified, and more convincing.

“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?”

“I can argue this with the boss. I can say, look, I can’t do those three (pointing to the screen); right? I can’t do all three of those at the same time. You can’t put them as the same priority -there are more possible ways we can do it - however, we can do this one, this, and ... So that’s what I am looking at.”

One interviewee added that it takes the human emotion out the process:

“This takes the human emotion out of it. When I work with people, they are very attached to the project, and they are very emotional about it. This takes all the emotion out, puts straight down: this the number, this is what it shows, this is what should be, this is why we are doing it that way. And this may help to convince some people that, yes, we realize you project is important, but this one should go first because of whatever reasons.”

*Theme #4: Drawing attention*

Exploring the visual elements is able to bring up people's attention to specific things in an intuitive way. First, it reminds people of things that are easily neglected, or things that are not sensitive enough to grab people's attention. There are hundreds of projects in an organization and it is hard to remember and relate every one of them. A lot of times, they do not realize the similarities or differences of certain projects, as one interviewee pointed out. Visualizations can make those relationships more evident to users and bring up their attention to related projects.

"Yeah, sure there are many projects that we do are similar in nature. I don't think we realize it until we are really into it and we are actually working on things that are identical and many ways are pretty much the same. Whereas you put it up there, you like, wow, wait a minute, those are all pretty much the same."

Second, it also allows people to discover interesting things which emerge from visualizations and start to ask questions. This is an important advantage of visual exploration. It is intuitive to see specific things that are usually buried in a large volume of information. It is effective for users to discover mistakes or other unusual patterns and to conduct further focused analysis.

"The conversation is: why are these are up here, and why are these are down here? So, then you bring up the individual cells, and you dive down into what the criteria were, and say OK: this why they are. Then this gives an opportunity to say, well, what if we did not rate it so high: where would it fall? Then you can probably visually say, well, it will probably flip over here, or flip down here, or just move a little bit down in the same box (cluster)."

"Oh yeah, definitely, because it immediately opens up a lot of questions: why is this like this? Just dive deeper to find out. The we keep using the views you have previously to compare each project on top of each other. See whether they meet in terms of the dimensions, the business goal."

*Theme #5: facilitating group discussions*

This theme is about how the approach and system can be used at a group level. One concern from interviewees is that the system potentially leads to multiple interpretations by different people:

“... usually it’s not one person making a decision. It might be hard you get 4 or 5 people in the room doing this, and in the beginning have to have a framework (rules) ... just one person doing it, that’s great.”

In fact, the approach is designed not only as a personal assistance tool, but also as a group level system to facilitate discussion and communication, provided that everyone understands and agrees to the dimension selected. More interviewees see its merit for group communication.

“... if the group agrees - you know, you get together and you have a group thing - and ok, this is where it should fall - how much energy you think it’s gonna take to do that? Well, here’s my number. Right? And then it’s pretty self explanatory after that one - he put the numbers in and do(es) whatever. I like it.”

“With a group of peers, we got to define some common way of negotiating. (Does the tool facilitate the seeking for such common ground?) Yes, much more so than just numbers with some secret formula behind that.”

“If everybody understood all those six criteria and agreed on them, and they understood the model, like that you just walked through, yeah. Those (dimensions) have to be meaningful for the shapes to be meaningful, (then we can) get value out of the analysis.”

“... at the staff meeting, taking this to the ITSG and have this chart coming with clusters, that would be good.”

#### *Theme #6: Being objective*

This is rather controversial in respondents. Most people were concerned about the objectivity of the system, as one interviewee said:

“The only issue I have with that is that, again, if you can’t define the thresholds, if you leave it up to the individual users to determine it, based on how objects look, that really ... lessens the objectivity. Having a specific threshold kind of makes it more objective. The group will have to agree to move in that there. I think the group would have a hard time coming to an agreement with the visual format than they would if they had actual data, because everybody sees things differently. But I like it, I like the concept and clustering is definitely useful.”

This is a legitimate concern as the system does not include accurate calculations based on mathematical formulas or models; it relies on human judgment to reach conclusions. From this perspective, the tool is subjective. However, if agreed upon by a group of people, the exploration

process is actually more transparent in revealing underlying hidden dimensions. From this perspective, the tool (noted by one interviewee)

“doesn’t allow for as much gaming as the current process does. That’s actually very helpful.”

Again, the system is not intended to be a one-serves-all tool that can immediately lead to correct decisions. It provides an additional and complementary perspective to assist decision making. It is best to incorporate the approach in a larger system, and work with other systems and approaches. In such a way, the approach can be used effectively, maximizing its advantages and minimizing its disadvantages.

### 5.2.3.2 Perceived Ease-of-Use

Utility is not the only objective for this approach. It has to be easy to use for better acceptance. As one user notes:

“If it was easy to use, I would be more inclined to use it, because this is very valuable, especially for the visual people. ... If it is an easy to use thing, I think it would be a wonderful thing to use. Any manager should have all these stuff.”

The following themes are identified from the comments made by interviewees that are relevant to people’s perception on ease of use.

#### *Theme #1: understanding visualizations*

All people agree that the visualization makes the decision process easier, especially the use of profile charts on multiple dimensions. The overall approach is also easy to understand for interviewees, as participants could actually pickup the process and the reasoning following little exercises during the interview.

“This was a very easy tool to grasp, the 6 points, the individual projects and then the map. The clustering was very simple and easy to grasp. Visualization of things we have not been able to adequately visualize before.”

“Show me, just don’t put the paper out here and make me read; don’t just talk to me, show me. This literally shows you a neutral ground based on the criteria set forward. ... The

analysis is the easy part. This is great, I love this. This would be easy, I got the whole idea - going from the cells, and clusters, making my own clusters - this is slick.”

“Yes, absolutely. I think so. I think when you look at that, and you start going around and comparing; I like that thing you just lay it down on top of it, and go where they fit it, and things you got three ways of doing it. That’s really easy! That makes total sense! It’s logical.”

“For me, being able to look at a chart like this, I can understand what the chart is trying to tell me. Whereas if I have a list of projects with numbers, you know [negative expression], coz what you are trying to show is very complex. I, as a manager, am looking for, which one is the best one? Which should I be doing? By looking it up here that gives me a smaller group to look at and say, OK, that one.”

One person had some hesitance on the randomness of SOM map. He thought a person who is getting used to the fixed position quadrant diagram will not adapt to that mindset easily. That may cause some difficulty for those people to understand the SOM map.

“From looking at any kind of chart, the zero origin is down here at the left hand corner, and everything up goes here. If you put the low value things down here, it confuses them. [The traditional orientation] is better for me; yes (I still understand), (but) positioning still important. ... If you have somebody who has never been instructed in a typical graph, then you could probably present that to them and they look at it and understand [the profile chart, cells view, SOM map]. I can see that pattern, and I don’t necessarily have to rely on [the axes].”

### *Theme #2: recalling profiles of projects and portfolios*

Interviewees found visualizations easier to remember and recognize when they are familiar with the dimensions used to form those shapes.

“It all depends on how well you define those parameters, the criteria and how meaningful those are ... If they were meaningful to me, yeah, those zones will stick to my head and I can carry around and use it.”

“Yeah, absolutely. ... Sure. Especially once you leant the six points, to me, it wouldn’t take much before you start thinking that way. You look up and then you go, hmm, that’s gonna fall into that cluster.”

“The chart you showed before (clusters summary report, and profile chart comparison) will stick with me. That will stick on my mind because it’s bigger and I can see where all these points are (dimension labels).”

For the map level visualizations, the Clusters View is generally easier than the Cells View to impress users.

“Well it is right now (imprinted in my mind) (laugh). Yeah, it has a lasting effect in terms of the groupings of the projects. For overall high level, it’s got a lasting effect; for more detail, probably it doesn’t.”

*Theme #3: Operating/using the system*

Not only are the visual elements easy to understand, the exploration actions are also easy to operate using the system.

“First of all, (describing the use process) – for that, how hard is that? I mean, you are the one that’s doing it. You know, and if the group agrees - you know, you get together and you have a group thing - and ok, this is where it should fall - how much energy you think it’s gonna take to do that? Well, here’s my number. Right? And then it’s pretty self explanatory after that one - he put the numbers in and do(es) whatever. I like it.”

“If it is an easy to use thing, I think it would be a wonderful thing to use. Any manager should have all these stuff. ... The analysis is the easy part. This is great, I love this. This would be easy, I got the whole idea - going from the cells, and clusters, making my own clusters - this is slick.”

Some users could actually use the tool quite well during the interview. In one interview, in a conversation of the potential use of the tool, the participant suddenly approached the projected screen and started to imagine/envision that he put the tool into a real case. He explored the map and at the same time explained his thoughts and analysis, on a scenario of manpower assignment and project selection.

The system is also perceived to be flexible, as there are many choices to generate the desired visualizations and multiple techniques to aid the exploration actions.

“... Having the flexibility to determine on your own what the view is gonna be, is very good.”

### **5.2.3.3 Summary**

The analysis of the previous two sections is summarized in Table 10. Following the themes identified and discussed in the previous two sections, the table summarizes the positive

evidences found to directly support design objectives and claims. These positive evidences show the utility and ease-of-use of the multidimensional and visual exploration approach and system.

The table also lists counter evidences that may motivate future investigation.

<i>Evaluation Objectives</i>	<i>Themes</i>	<i>Positive Evidence</i>	<i>Counter Evidence</i>
Perceived Usefulness (Utility)	Providing overviews (big pictures) of project portfolios	Giving a quick overview of the portfolio based on selected attributes.	Cannot be used alone to make decisions.
	Comparing and contrasting projects and portfolios	Clearly sees difference. Helpful in suggesting candidates.	
	Justifying decisions	Better justification.	
	Drawing attention	The approach helps to discover hidden information.	
	Facilitating group discussions	Facilitating discussion and communication.	
	Being objective	Less gaming.	Lack of quantitative measures and precise threshold.
Perceived Ease-of-Use	Understanding visualizations	The steps and visualizations are easy and intuitive.	SOM map randomness.
	Recalling profiles of projects and portfolios	It is easy to remember and recall project profiles and portfolio profiles in the Clusters View.	SOM map (Cells View) not easy to remember.
	Operating/using the system	Operation is easy. The system is flexible.	

**Table 10: Summary of Qualitative Data Analysis Result to Evaluation Objectives**

### 5.3 Quantitative questionnaire result

A post-interview questionnaire was designed to get participants' background information and more written words on their perceptions of the system. Participants had plenty of time to respond to the questionnaire. The first part of the questionnaire consists of six statements (Table

11) that requires an interviewee's response. These statements are based on the three TAM model constructs to evaluate user's perception and attitude of the system: Perceived Usefulness, Perceived Ease of Use and Intention to Use (Davis, 1989). The evaluations are based on the 7-point Likert scale (where "1" indicates "Strongly Disagree" and "7" indicates "Strongly Agree").

The questionnaires used for the two rounds of interviews were slightly different on the statements. The one used in the second round was modified and used specifically for evaluation (see Appendix B3). Table 12 details the responses from users in the second round (evaluation phase).

A1	A user is able to get a big picture of project portfolio compositions through exploring the cluster map with different combinations of map views.
A2	I would like to use the system to compare/contrast projects and project groups (sub-portfolios).
A3	The tool integrates multiple project attributes in analysis in a flexible way.
A4	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.
A5	The tool is easy to use and understand. A business user will be able to use it after some training.
A6	Overall, I would like to use it as a complementary support to existing tools and methods for certain portfolio management tasks and decisions.

**Table 11. Post-Interview Questionnaire Statements**

The average scores for all categories are close to "6" (Agree). The "Intention to Use" is comparably lower; this is very likely because of respondents' practitioner perspective. They value the approach more from a theoretical perspective, but for a more practical situation, they are more hesitant; because there are other complex issues in terms of adopting the system (such as organizational policy, work environment politics, system support and maintenance, etc.), and interviewees tend not to consider them separately. Because of the small sample size, it is not very meaningful, and it is not the intention, to discuss statistical significance of the results here. These



quantitative results are just to show the consistency with qualitative data analysis results, reflecting users' positive feedback to the prototype. Although the data reported here only reflects a limited perspective in a situated context (Kuechler & Vaishnavi, 2008a), it is just a starting point to more large scale experiments or user study surveys.

	Statement	User 1	User 2	User 3	User 4	User 5	User 6	Average
Perceived usefulness	A1	6	7	6	7	6	6	6.3
	A4	6	6	5	7	6	5	5.8
Perceived ease of use	A3	6	7	6	6	7	6	6.3
	A5	6	6	3	7	6	4	5.3
Intention to use	A2	4	6	5	7	6	6	5.7
	A6	4	6	4	7	7	4	5.3

**Table 12. Post-Interview Questionnaire Results from the Second Round Participants**

## 5.4 Discussion of the evaluation process and results

### 5.4.1 *How much do interviewees understand the system?*

It is important that the interviewees understand the system and the approach, so they give relevant comments and constructive suggestions. To make sure they understand the system, the following methods were used in the interview:

- During the demonstration, I periodically asked them if they understood a concept, or if a description made sense. I encouraged them to ask questions whenever they felt the need.
- I observed their facial expression and conversation style, and would repeat when I sensed something was not clear to them.
- I asked for confirmation if they agreed with me; I also guided them to speak out, or to repeat what I had just stated.

- I put up small exercises and asked them to explain their idea, describe their observations and findings, and draw conclusions from it.

All these efforts were used to make sure that interviewees have a sound understanding of the system and give thoughtful feedback. Based on their reactions during the interview, most of the interviewees seemed to have a good understanding of the system, and exchanged ideas with me smoothly.

#### **5.4.2 Interviewees' visual comprehension ability**

The approach and system designed are very visually intensive. Thus, it has a high requirement on users' visual capability. All interviewees report comfort in seeking information and doing analysis using visualizations during the interview. They describe themselves using statements such as "I am very visual", "I am very good at dimensional things", "everybody like images and visualizations"; the following statement is a good summary of people's attitude toward maps:

"You have to understand that we use maps all the time; that's how we use. We are into the mapping thing; we are into the visual thing. It makes sense to us to visualize, to map things. We use map for network, we use map for monitoring, we use map for how we put things together, and stuff like that. So this makes absolute sense to me."

A question in the post-interview questionnaire also asks how comfortable people are when doing analysis and making decisions using visualizations (such as diagrams, charts, colors, shapes, maps, etc.). Interviewees reported an average of 4.3, on a 5-point scale with 5 being the most comfortable.

This may raise the concern if it introduced the bias into interviews as all interviewees have positive attitudes toward visualizations. One weakness of the interview data is that it does not include voices and insights from people who are not visually strong. However, such weakness

should not be a problem for this research. The designed approach is targeted to people who have the strength of utilizing visualizations. In addition, it is not a replacement tool but a complementary tool for decision makers. It adds analysis flexibility and provides a choice to fit the cognitive style of a particular group of users (Robey, 1983).

## Chapter 6. Discussion and Conclusion

This chapter discusses and summarizes the work done after the evaluation. Section 6.1 discusses theory development activities and results to date. Section 6.2 summarizes the activities and relationships of two parallel processes in the development stage: prototyping and knowledge abstraction, and also discusses how these activities contribute to the overall research process. Section 6.3 discusses contributions of the research. Section 6.4 and 6.5 discusses limitations and future research. Last, Section 6.5 concludes the dissertation.

### 6.1 Design artifact, knowledge and theory

March and Smith (1995) describes the process of design research as: *Build, Evaluate, Theorize* and *Justify*. Although *Build* and *Evaluate* are the major research activities of design research projects, theorization and testing are necessary activities in a more complete research cycle to make the design work more systematically recorded and communicated. Venable (2006) also presents a design science research activity framework which includes *Theory Building* as part of the framework, in addition to Problem Diagnosis, Technology Design and Evaluation. As part of the research, this dissertation tries to abstract concepts and design models from the designed system instantiation, and tries to theorize them by making a number of theoretical propositions. This section discusses the design outcome (the IT artifact) in the form of a model, and reports the theory development to date.

The purpose of research is to generate knowledge. Design knowledge can be in several forms (Gregor & Jones, 2007; Hevner, et al., 2004; March & Smith, 1995; Vaishnavi & Kuechler, 2004) including instantiations, design principles, models, methods, constructs, and theories. The lowest abstraction level of these forms is instantiations, in which where knowledge is embedded.

For a more formal expression of knowledge, principles, models and methods are abstracted from instantiations. It is this kind of abstraction that makes the design knowledge better recorded, communicated, and accumulated. In this dissertation, a design model of a multidimensional and visual exploration system is created by abstracting concepts from the developed prototype application. The model (see Chapter 4.1 and Figure 10) depicts major components of the system and their relationships. It describes how the system is designed, what the components are and how they interact, and how the system is used for general portfolio management tasks.

A more formal form of the design knowledge is design theory. Gregor (2006) describes five types of theories in use in the field of information systems: (1) theory for analyzing, (2) theory for explaining, (3) theory for predicting, (4) theory for explaining and predicting, and (5) theory for design and action. The theory for design and action is a prescription type of theory. It gives prescriptions, in the form of models, principles or methods, for developing and using an artifact. Theory is a higher level abstraction of the artifact developed. Based on its generalization levels and focus, a grand theory or meta-theory can be very general, and a mid-range theory can be moderately abstract, more limited and relevant to a problem domain (Gregor, 2006). The development of grand or meta-theories is a long term goal, but instances may be rare; it is more practical to focus on mid-range theories, as they are also regarded as valuable (Gregor, 2008). Mid-range theories can usually emerge from a few projects, which makes it more practical as a starting point in theory development.

The outcome of this dissertation research has laid the foundation for a potential mid-range theory. Following the discussions on design theory by Gregor & Jones (2007), Walls, Widmeyer, & Sawy (1992) and Kuechler & Vaishnavi (2008b), a proposition of a mid-range design theory of the multidimensional and visual exploration system is discussed here. First, Table 13 lists

some theoretical concepts and constructs. Then, kernel theories (foundation knowledge) that inform the design theory are discussed. Third, design theory propositions for the mid-range theory are presented. Last, all components will be summarized based on formal design theory frameworks (Gregor & Jones, 2007; Walls, et al., 1992)

<i>Construct</i>	<i>Definition</i>
(Data) Dimension	A dimension is a defined property of a set of items, a defined and common attribute that applies to all data items.
Multidimensional(ity)	For a particular analysis or task, multiple dimensions (more than 2, more often more than 3 dimensions) are needed and used to describe and represent the profile of each data item.
Visual data (information) exploration	Performing a task (such as understanding a dataset, seeking additional information, drawing conclusion) through a serial of visual exploration actions.
Visualization (visual element)	Visualizations that are used to present individual data items, or patterns and relationships among all data items.
Portfolio perceptual map	A portfolio perceptual map is a high level overview visualization that shows the distribution of all projects in a project portfolio based on selected project attributes.
Profile chart	A profile chart is a visualization of an object based on values of the attributes (dimensions) selected to represent the object; such a chart forms a representative shape pattern that can offer a strong impression of the object.
Visual exploration action	A human action to directly interact with visualizations, such as observing, selecting, moving, comparing, defining and adjusting customizable components, etc.

**Table 13: Theoretical Constructs in the Proposed Theory**

Kernel theories (foundation knowledge) are the knowledge areas that inform the design theory. They are referenced to justify the design. This research references the following theories or knowledge areas mainly related to visualizations:

- 1) Cognitive style and decision making literature: these include: a) theories that explain different styles of human thinking, learning, information seeking and problem solving

(Hunt, Krzystofiak, Meindl, & Yousry, 1989; Mason & Mitroff, 1973; Robey, 1983; Vessey, 1991); b) managerial intuition in decision making (Bowers, et al., 1990; Kuo, 1998; Sinclair, 2005). These provide the theoretical basis to the current design that visualizations provide intuitive and effective understanding and communication when they fit a user's cognitive style.

- 2) Visualization techniques literature (Grinstein & Ward, 2001; Hoffman & Grinstein, 2002; Jarvenpaa & Dickson, 1988; Meyer, 1991): these techniques are not in the form of theories but they provide rich choices to visualize multidimensional data at different levels. Particularly, this dissertation heavily references the literature of Self-Organizing Maps (Deboeck & Kohonen, 1998; Kohonen, 2001; Vesanto, 1999) to produce project portfolio perceptual maps.
- 3) Visual information exploration literature (Jankun-Kelly, Ma, & Gertz, 2007; Keim, 2002; Oliveira & Levkowitz, 2003; Shneiderman, 1996; Soukup & Davidson, 2002; Wilson, 1981): these studies focus on visualization as a means for exploration process, rather than end results. The most important theory (design guideline) that informs the current design is the visual information seeking mantra (Craft & Cairns, 2005; Shneiderman, 1996), which specifies general steps in visual exploration processes.

Based on the design model abstracted from the prototype, the following propositions are made for a potential mid-range theory of a visual exploration system for business portfolio management:

- 1) A visual exploration system needs to define a set of visual elements and visual exploration actions (see Figure 9) for various decision and management tasks.

- 2) There are two levels of visual elements in the system (see Figure 10): a) at the macro level, perceptual maps (with different views) are used to present an overview of portfolios. The distribution and relationships of data items can be clearly seen on perceptual maps; b) at the micro level, profile charts are used to display and compare individual objects. Both types of visualizations are generated based on the flexible selection of multiple attributes.
- 3) Although other options are possible, SOM is used to generate perceptual maps because SOM is able to map high dimensional data on a low dimensional space effectively.
- 4) Profile charts can be of flexible styles and types that fit to a person's cognitive style.
- 5) A visual exploration process includes visual exploration actions against perceptual maps, clusters/regions of maps, sub-portfolios, and profile charts. It also includes combinations or repetitions of these exploration actions (see Figure 12).

The mid-range theory leads to several immediately testable hypotheses:

- 1) A multidimensional perceptual map (e.g. SOM map) is more effective than matrix or quadrant maps when used to understand portfolios with multiple dimensions.
- 2) Decisions will be better justified and communicated using the system because they are based on multiple dimensions and decision makers will feel more confident and find it easier to defend their decisions.
- 3) The system will better support human intuition and sense-making ability in the decision process.

Table 14 summarizes the above discussions and put them in a design theory framework suggested by (Gregor & Jones, 2007).



<i>Components</i>	<i>Description</i>
Purpose and Scope	The purpose is to develop visual exploration systems that integrate human's strength to better and more easily deal with multidimensional information for business portfolio management, where a business portfolio is a group of management targets, such as assets, projects and people.
Constructs	Visual elements (perceptual map, profile chart), visual exploration actions, visual exploration process, multidimensionality
Principles of Form and Function	The system is designed based on visual elements and visual exploration actions. There are two levels of visual elements: perceptual maps and profile charts. Visual elements directly support different exploration actions.
Testable Propositions	<ul style="list-style-type: none"> <li>• A multidimensional perceptual map (e.g. SOM map) is more effective than matrix or quadrant maps when used to understand portfolios with multiple dimensions.</li> <li>• The system will better support human intuition and sense-making ability in business portfolio management.</li> <li>• Decisions will be better justified and communicated using the system because they are based on multiple dimensions; decision makers will feel more confident and find it easier to defend their decisions.</li> </ul>
Justifiable Knowledge	Cognitive style, managerial intuition, visualization, information seeking behavior model, Visual Information Seeking Mantra, Self-Organizing Maps

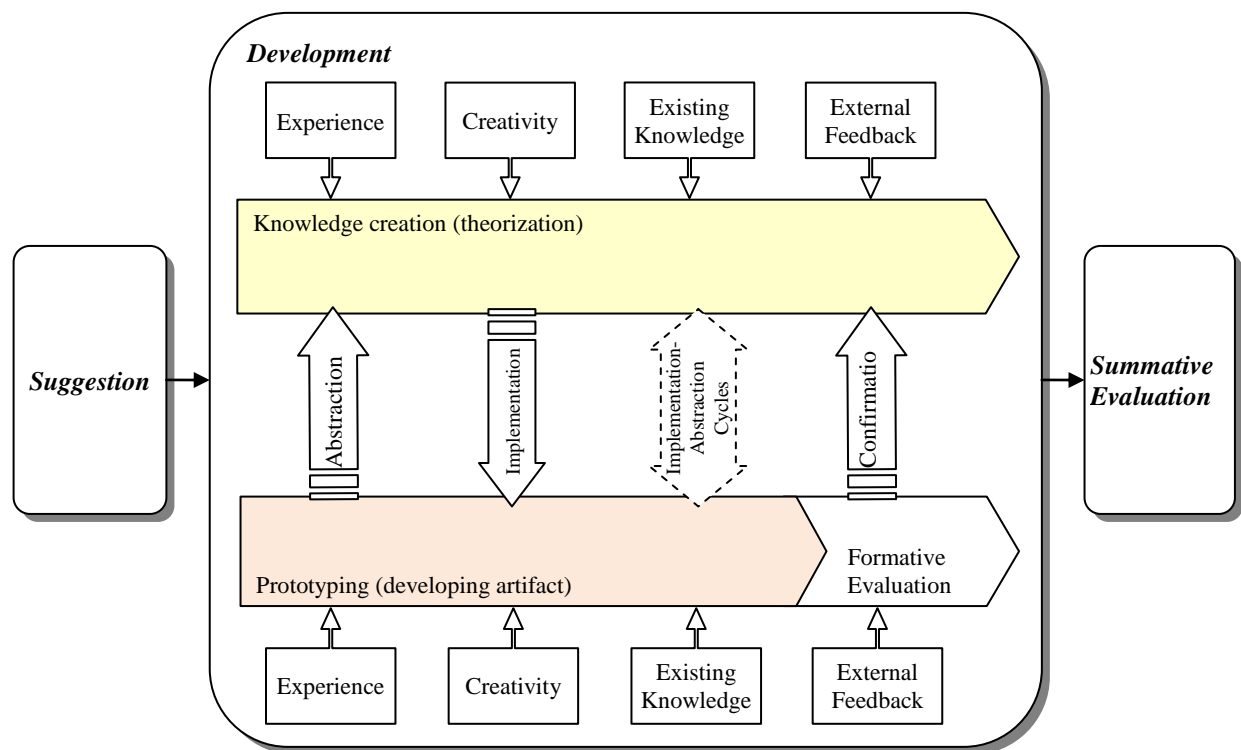
**Table 14: A Theory for Designing the Multidimensional and Visual Exploration System**

The development of the visual exploration approach and system is a continuing process based on user feedback and new learning. The theorizing process is also a continuing process that will go beyond just a single project, involving more development and abstractions from the development. March and Smith (1995) describes a research process as stages of build, evaluation, theorizing and test. The main part of this dissertation is design research, focusing on build and evaluate. It also tries to theorize the design, but the research does not stop after it is evaluated. Like any other research projects, because of a managed scope, this dissertation project may have limitations, unaddressed problems, or new questions that emerge from the research process.

Because the problem and solution investigated here is complex, a single project may not answer all questions nor directly lead to a complete theory. In such cases, this dissertation project will still provide an initial set of concepts, models and propositions that improve understanding of the research problem, and form the basis of a mid-range theory. Future research work (including more rigorous testing of the theory) is needed to incrementally refine the solution and create a more complete and generalized theory.

## 6.2 Prototyping and knowledge creation process

Design science research is a process of research based on the activities of design (development). Particularly, I adopted a prototyping method to develop an IT artifact. This section discusses some personal learning experience in the process on how prototyping can be used as a vehicle for research, and how it is different from just an application development.



**Figure 19: Development Stage Activities: Prototyping and Knowledge Creation**

There are two major activities in the development stage of the research: prototyping and knowledge creation (see Figure 19). First, being a development stage of the research process, there are a lot of normal system development activities, such as requirement analysis, design, programming, debugging, testing, etc. Second, it is also a knowledge creation process. In this process, conceptual components of the system were identified and defined; the relationships among them were also defined. The prototyping process is the underlying activity to provide raw materials for conceptual thinking and abstraction. Concepts are abstracted from the prototyping. At the same time, new theoretical developments are implemented into the prototyping process. These cycles of abstraction and implementation continue as both the knowledge and prototype are modified and improved. Eventually, the prototype becomes functionally complete and stable, and the theoretical model matures. Then formal evaluation would take place to conclude the project. During the development stage, there are multiple sources that contribute to the development of both processes: past design experience (my past projects), existing knowledge (reviewing literature), external feedback (exploratory interviews, and some other informal discussions with other people), and creativity (sudden idea popup).

For example, the three views of SOM map (see Chapter 4.1.2 and Figure 10) emerged from the prototyping and abstraction process. In the original proposal in the suggestion phase, there was only one general component and concept of SOM map (roughly corresponding to the Items View). During the prototyping process, other people (include exploratory interviewees during the development and other researchers) suggested there be more visual hints of regional map characteristics. This is an example of external feedback. Together with creativity and past experience, I developed more system components in addition to the original SOM map. I tried to describe and define them (abstraction) with the help of existing literature (for example, the

information behavior model (Wilson, 1981). Then the prototype was modified based on more specifically defined concepts. These activities were iterated several times until the concepts of the three views and other components were satisfying and finalized.

The prototyping method used in the development is not different from normal information system development methodologies in practice. What makes the prototyping work different in a research, particularly design science research, is the knowledge creation process. Here, the prototype instantiation is not the only objective of the development. The knowledge, abstracted, representative, and generalized (to a certain degree), is another important objective for research. In this sense, prototyping is used as a vehicle to learn the problem domain, seek and refine the solution, and finally create knowledge. This process usually takes a lot of time and effort. The original design could be significantly changed, incorporating new discoveries and generating new ideas. In this dissertation, I can indeed see how my prototype and model have changed from the initial suggestion phase to the end of the development phase.

### **6.3 Contributions**

The research makes contributions in three major areas:

1. This research results in a working system and approach for project portfolio management that has been empirically evaluated to be useful and easy to use.
2. This research has theoretical contributions to the design and use of the general multidimensional and visual exploration system.
3. This research contributes to the general SOM studies and applications.

*1. This research results in a working system and approach for project portfolio management that has been empirically evaluated to be useful and easy to use.* A general contribution of design science research is the creation or enhancement of IT artifacts (method, model, algorithm,

application instantiation) for a business need in an appropriate environment (Hevner, et al., 2004).

A review of the literature shows that the choices of methods and tools are limited to easily and intuitively analyze multidimensional project information at the portfolio level. This research directly addresses the challenges by prototyping and evaluating a new IT system (instantiation). It provides an alternative approach to project portfolio analysis and management. This research directly contributes to practical solutions to aid business operations in an appropriate environment. It has high relevance and value to the problem domain.

*2. This research has theoretical contributions to the design and use of the general multidimensional and visual exploration system and approach.* The research generates models and processes that explain how such a system can be designed and used for general portfolio analysis and management tasks. Here, a portfolio is a group of management targets, such as assets, projects and people. Past visual exploration research focuses more on the generation of visualization, but less effort has focused on the exploratory aspects of the visualization (Jankun-Kelly, et al., 2007). There are few formal models to describe the process and the framework to design such systems. This dissertation comes up with a model and defines a set of new theoretical concepts and constructs (Figure 10); it offers a unique design and perspective for the multidimensional and visual exploration systems. Further theoretical abstraction of the knowledge contributes to an enhanced understanding of visual information exploration. It will help build theories, rather than the empirical mantra (Shneiderman, 1996), to guide the development of visual information seeking or exploration systems. It eventually leads to the building of a mid-range design theory for a more general multidimensional and visual exploration system for general portfolio level decisions and tasks. Such research to produce mid-range theory is regarded as valuable (Gregor, 2008).

3. *This research contributes to the general SOM studies and applications.* It expands the use of SOM techniques especially from the visualization perspective. It provides a set of formalized theoretical concepts for SOM based visual exploration. Many SOM map visualization studies have a focus that is more on color coding techniques. The Cells View, on the other hand, visualizes the map using profile charts and provides a more direct and intuitive perception of the big picture. And, many SOM map are clustered based on an open clustering strategy, while this research found business managers are more comfortable if clusters are explicitly separated and cluster patterns are clearly visualized. These new discoveries will increase the flexibility of SOM and extend its use to more business domains.

#### **6.4 Limitations**

This section discusses some limitations of the research.

The first limitation is related to the IT department and its project data. The department had just adopted project portfolio management practices for about two years. The processes and systems used for portfolio management had not matured in the department. Although project data is from a real business setting, it is not of ideal quality. In fact, it has always been one of the challenges for PPM to identify and capture key organizational data, rules, policy, and objectives and criteria for prioritization (IDC, 2006). One area where the department has achieved relative success is its project prioritization model and data; this data is pretty complete and useful. Because of this, this research is focused on the project prioritization and selection task. In addition, project data from a single organization or department is very dependent on its business type and practices, and they only represent a narrow perspective of the business domain. Such a limitation restricts the development of the approach to a few specific management tasks. If more data can be used and analyzed, then the approach can be designed more generally for more tasks,

and more details can be specified to target each type of tasks. This should enrich the utility of the approach and the system.

The second limitation is the prototyping environment. Because of the complexity of visualization techniques used and the limitation of the programming software framework, the prototype could not completely implement designed features in an ideal way. This potentially affects the usability of the designed prototype, in which practitioners tend to be more aware of implementation issues. It may adversely affect the evaluation.

Another limitation lies in the limited number of people who participated in the evaluation. Two issues limit the scale of evaluation: first, the target participants need to be familiar with portfolio management concepts and practices; second, the prototype developed needs to be explained in detail and participants need to have a fairly good understanding of it. Thus, to compensate for the sample size problem, interviews were planned as the major evaluation method, and qualitative data was the major type of evaluation data to be analyzed. Although qualitative data analysis shows a positive and satisfying evaluation result, it is difficult to generalize such a result and make a convincing conclusion for a general context.

Last, the evaluation in this research only tested users' perceptions of system utility by their self-reported feelings and experiences. The objectivity of user comments may be questioned. It would be better if direct system usage and its direct impact could be measured.

## **6.5 Future research**

The limitations of the research and several emerging issues from the development and evaluation phases indicate opportunities for future research.

First, this dissertation is still at an exploration stage for a new research topic. Design is a continuing process based on user feedback and new learning. Several features of the designed

system in this research are worth further investigation based on the qualitative evaluations from interviews. For example, not all of the interviewees are completely comfortable with the randomness of SOM map. One possible improvement is to use adjustable static perceptual maps instead of clustering maps. This is possible because IT project management in a particular organization is not a constant changing domain. The attributes used to define projects are also pretty stable; project portfolios are also relatively stable compared to other domains like the web. A potential approach is to use the SOM initially, but to adjust the map with small changes subsequently using other techniques. A more aggressive effort is to design alternative methods to generate perceptual maps that enhance visual experience, for example, utilizing three dimension technologies.

The second opportunity is to design heuristics for specific portfolio management tasks based on the designed system. Currently, the system only provides a general process of using the system, with flexible exploration setting and choices. It assumes that users (or organizations) can eventually find program settings and policies to adapt the process to their needs. This may be an emerging problem and users may need more specific guidelines to follow the approach. Thus, future studies can focus on specific guidelines of using the system; for example, there may be guidelines on selecting project attributes for different analysis, on configuring system features to provide more effective and intuitive visualizations, and on preparing (quantifying, weighting and scaling) data for the system. Future studies can also focus on more specific guidelines based on the designed system for many management tasks, such as prioritizing projects, allocating resources, adjusting portfolios and creating strategic buckets.

Third, other evaluation methods may be used to provide more convincing evidence of system utility. Controlled experiments, from a traditional positivist perspective, can be designed



to get empirical data and directly measure portfolios' performance. Another potential method is action research. If some organization with sound portfolio management practices can provide research opportunities, then the system can be deployed in a real organization setting, and actual effects can be observed and analyzed.

Last, as mentioned earlier, it is an opportunity for theoretical development for the visual exploration systems for business portfolio management. The theorizing will be based on more similar future projects, as well as analysis of the literature. A general framework for visual exploration system and process is expected from future research.

## **6.6 Conclusion**

The concept of project portfolio management has been developing in recent years and has gained wide awareness. However, PPM tools and systems have not achieved what has been promised by the concept. One of the reasons is likely the lack of methods and tools that can assist managers and executives to analyze multidimensional project information in an intuitive way. This research project identified the challenge and designed the multidimensional and visual exploration approach. The approach is driven by a computer application based on SOM clustering analysis and visual explorations. The research follows a general design science research methodology (Vaishnavi & Kuechler, 2004) going through research phases of awareness of the problem, suggestion, development, evaluation and conclusion. A prototype system was developed to implement the approach. To evaluate the utility and the ease-of-use of the designed artifact, interviews and post-interview questionnaires were used to get both qualitative and quantitative data. After analysis, both qualitative and quantitative data show the utility and the ease-of-use of the multidimensional and visual exploration approach and system. This confirms the design objective and answers the research question. The knowledge generated

from this research contributes to the domain of project portfolio management, as well as to the design of general visual exploration systems for business portfolio management.

## Appendix A. Research Process

### 1. Dissertation Timeline

The table below lists research progress and activities of this dissertation. The complete duration is about 32 months.

<i>Time</i>	<i>Activity</i>	<i>Duration</i>
Sept 2006 - Jan 2007	Awareness of the problem	5 months
Oct 2006 - July 2007	Initial literature review	10 months
April 2007 - Dec 2007	Field study and data collection in the IT department on PPM practices.	9 months
April 2007 - Jan 2008	Suggestion: initial analysis and design	10 months
Aug 2007 - Jan 2008	Dissertation proposal writing	5 months
Feb 29, 2008	Passed dissertation proposal defense	
Dec 2007 - Nov 2008	Prototype development	12 months
Aug 2008 - Dec 2008	Evaluation	3 months
July 2008 - Feb 2009	Knowledge generation (abstraction)	7 months
Jan 2009 - Feb 2009	Data transcription and analysis	2 months
Dec 2009 - Apr 2009	Writing dissertation	5 months
April 24, 2009	Dissertation defense	

**Table 15: Dissertation Timeline**

## 2. Research outcomes and funding

- Research paper accepted to the 15th Americas Conference on Information Systems (mini-track of business intelligence), 2009, San Francisco, CA
- Prototype demonstration in the Eighteenth Annual Workshop on Information Technologies and Systems (WITS), 2008, Paris, France
- Short paper presentation in the Third International Conference on Design Science Research in Information Systems and Technology (DESRIST), 2008, Atlanta, GA
- Georgia State University Dissertation Grant from the University Research Services & Administration, 2008
- Accepted to the doctoral consortium in the 13th Americas Conference on Information Systems, 2007, Keystone, CO
- Georgia State University Scholarly Support Grant from the University Research Services & Administration, 2007

## Appendix B: Evaluation Documents

### 1. IRB interview protocol

#### General Procedure

1. Explaining system purposes and features
2. Demonstrating software application with 2 or 3 predefined use cases
3. Asking users questions regarding the utility and usability of software application.

#### Data collection

##### 1. Interview:

The interview is trying to discover user insights and comments for deeper understanding of system utility and usability. The interview will be of open and free style but will be focus on the features of the system and design choices that will make the system more effective. Some examples of these questions (not in order) are:

- Is the clustering process easy to configure and execute?
- Is the clustering process flexible to reflect multiple perspectives?
- Is the cluster map easy to understand and interpret?
- Is the visual exploration method is easy to understand and operate
- Is the cluster map meaningful? And does it provide insights of projects?
- Do the visual patterns give a stronger impression of project characteristics?
- Is priority pattern more meaningful than aggregated priority number?
- Can you get a more comprehensive big picture of the portfolio?
- Would you like to use the system to compare and contrast projects?
- Would you like to use the system to understand unfamiliar projects?
- Would you like to use the system to look at project priorities?
- Would you like to use the system to help making other decisions?

##### 2. Questionnaire:

Interviewees will be asked to fill a questionnaire to complement the qualitative comments.

## 2. Guided questions for interviews

Steps: following the steps below, explaining each one first and getting feedback.

### A. Clustering and multidimensionality

#### 1. Demo selecting project features

- Do you need to analyze projects from multiple perspectives (dimensions)? How?
- Would you explore the different combinations of dimensions?
- How many features (dimensions) do you usually select in an analysis?

### B. Visual elements and exploration

#### 1. The basic profile (pattern) chart for individual object and objects comparison

- How useful/meaningful to use the chart to represent a dimensional pattern of an object? And to compare dimensions of different object items? Is the pattern more meaningful than aggregated number?
- Is it easy to compare and contrast object patterns visually? Does the visual pattern give a stronger impression of object characteristics?
- How important is the chart type/style for visualization effectiveness? Is there a dominant (preferred) chart type/style that you use to represent and compare such patterns?

#### 2. The SOM cluster map and three views + project groups

- What do you think about the SOM cluster map (base map and projected map view)?
- Do you get a big picture of project distribution through the exploration of these map views?
- How useful to use the map to understand and compare project groups (sub-portfolios)?
- Does the cluster view simplify the understanding of SOM map? How? Is it useful?
- Is the base map view useful when exploring the portfolio?
- How compatible are you with the overlapping of all three views?

#### 3. Defining cluster sets and clusters

- What do you think about the process of assigning clusters based on cell patterns?
- What do you think about the multiple ways to cluster the map? Would you like to explore the map using different cluster sets?
- Is it necessary to manually adjust and name clusters?

#### 4. Overall

- SOM map may be different in terms of cluster position (thus affecting object item positions on the map) with different settings (selection of projects, dimensions, weights, scaling, SOM parameters, etc.); does that matter to you (assuming you fully understand how to interpret the map)?
- How likely would you reference/recall the chart and the map for future portfolio related decision tasks, once you have used it?
- Does the size of SOM map (number of cells) increase visual complexity and affect your understanding of the map?
- Is the SOM map (with flexible combinations of three views) easy to understand and interpret after some training?

### C. Prioritization and selection

- Does priority pattern provide richer information than aggregated priority number?
- Is it better and easier to justify and communicate your decision using multiple priority dimensions?
- Is better to compare and select projects based on priority patterns, instead of aggregated numbers?
- How likely do you think that the cluster-based prioritization can be practically implemented?

### 3. Post-interview questionnaire

#### A. Evaluation Questions

Please use 1 to 7 point scale to evaluate the following statements (you may provide details as much as possible).

1	2	3	4	5	6	7
Strongly Disagree	Disagree	Slightly Disagree	Natural	Slightly Agree	Agree	Strongly Agree

- 1. A user is able to get a big picture of project portfolio compositions through exploring the cluster map with different combinations of map views.
- 2. I would like to use them to compare/contrast projects and project groups (sub-portfolios).
- 3. The tool integrates multiple project attributes in analysis in a flexible way.
- 4. 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.
- 5. The tool is easy to use and understand. A business user will be able to use it after some training.
- 6. Overall, I would like to use it as a complementary support to existing tools and methods for certain portfolio management tasks and decisions.

B. Considering the time constraint, how much do you think that the familiarity of the system affect the above evaluations? Will you change your assessment if you have more experience with the system?

- A. I understand the tool very well; I will not change my evaluations.
- B. I still have some questions in mind; I may change my evaluations but not significantly.
- C. I am still not comfortable with the tool; I may change my evaluations significantly.
- D. Other (please explain).

C. Do you have additional comments?

#### D. Background Information

- 1. Experience in the field of information systems and technology (years)
- 2. Experience of project management and related activities (years)
- 3. Experience of overseeing and coordinating multiple projects (years)
- 4. Experience using (any) project management software (years)
- 5. Generally, how comfortable are you when doing analysis and making decisions using visualizations (such as diagrams, charts, colors, shapes, maps, etc.)?

1	2	3	4	5
Ineffective	Somewhat Ineffective	Neutral	Somewhat Effective	Very Effective

## Appendix C: Interview Data Analysis

### 1. Interview Transcripts

#	Time	Activity (comment)
1	4.00	Visualization is what's missing in the current process... visualize how all of those complementary and competing dimensions aggregated together for a particular project.
1	4.35	[Do you feel the need to look at multiple dimensions at the same time, rather than aggregated measures?] 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.
1	6.14	[Do you think visually compare projects useful? - showing the profile chart, project comparison window.] To me it is. Look if you can see based on what area each project's covering the relative benefit according to your criteria and weightings of each. That's heck a lot of meaningful than just a number vs. another number.
1	7.30	[Do you prefer any particular chart type? – when show different profile chart types.] No not me personally ... I suppose the radar chart as far as seeing the aggregate impact the radar chart's a bit more helpful than serials of bars to me.
1	11.05	[Can you see a big picture of portfolio in terms of how they are distributed? Does make it sense to you?] Sure undoubtedly. ... Yes.
1	11.30	[Showing Cells View - visually complex to you?] It is pretty complex.
1	11.40	[Does that affect your understanding of it (Cells View)] Me, no. it doesn't overwhelm or intimidate me.
1	14.05	[Showing cluster view] That one makes (more) sense than the previous (Cells View)
1	14.25	[Showing cells view + clusters view – asking if necessary] They are equal. About the same.
1	23.15	[About clustering process] This is kind of arbitrary.
1	24.05	[Is the clustering process easy?] Oh yeah, as far as defining clusters.
1	26.40	[Is the visualization has a lasting effect? Are you more likely to reference them in future.] It could. It all depends on how well you define those parameters, the criteria and how meaningful those are ... If they were meaningful to me, yeah, those zones will stick to my head and I can carry around and use it.



1	30.50	[SOM map randomness/difference, relative positioning.] Since it s all relative ... but you got to have a common reference point for the relative mapping to make sense.
1	32.00	[SOM map randomness/difference, relative positioning.] That doesn't bother me. I understand that it is all relative. When you find the one that works for you, you stick with that one so you got a common reference point.
1	34.10	[About the size of the map] Well you might see the trends, the groupings, clusterings at the higher resolution that you will miss at the lower resolution. It (the high resolution) doesn't bother me, I will take the maximum resolution and I can get to learn from it.
1	36.00	[Will you use the tool to communicate and discuss?] With the common understanding, yes. If everybody understood all those six criteria and agreed on them, and they understood the model, like that you just walked through, yeah. Those (dimensions) have to be meaningful for the shapes to be meaningful, (then we can) get value out of the analysis.
1	47.20	[About prioritizing model] It could improve upon that list. That list's just taking numbers, putting them into some formula, coming up another number and sorting by that. Two projects with same exact number, you might view them very differently. That gives you a way to view them differently; it gives you the way to double check that formula you created.
1	48.10	[Ease to use to prioritize project] I could use that to prioritize. It wouldn't be that difficult to me.
1	49.15	[For group common ground] With a group of peers, we got to define some common way of negotiating. (Does the tool facilitate the seeking for such common ground?) Yes, much more so than just numbers with some secret formula behind that.
2	4.27	[Profile chart and comparison] I can understand it very well. It is easy to see, easy to understand from the six points what the priorities are for the projects. ... Yeah. I like that.
2	5.32	[Profile chart and comparison] It is easier to understand than the numbers. You know where the numbers are, right? And then you look at the pattern then you go, OK now I understand because the more you look at this the more you familiar you get of what the numbers are ... yeah that's easier MUCH easier.
2	9.05	[Cells view - Do you see a pattern of the cells view?] Yeah. It starts out here ... slowly (changes) ... continues its moves around ... finally comes into 4 variations (4 other patterns).
2	13.00	[Cluster view and cells view -Which one do you prefer?] With the clusters, it is much easier to figure out ... (self explain what he can learn from the map)
2	16.00	[See and compare example sub-portfolios] It is not as spread out well as the rest (), yeah. ...
2	16.50	[See and compare example sub-portfolios] That's a real good one. It is good to have, and you can see how balanced your portfolios are.

2	22.15	[See step 6 – overlapping 3 views] I am very visual. I like the patterns (cells view) on the map. Just because it helps me to look at where has the commons where's not. I can see where the differences are. I have a feeling once if this was something you use on a regular basis, you will quickly know where the 6 points were, quickly figure out ... after some training, make quick decisions based on that look. ... You will learn those six points (profile charts) pretty quick ... I like it.
2	23.08	[Compare cells view and cluster view] Yes. Certainly it matters. ... Those six points mean something. ... It is more direct.
2	26.15	[compare individual projects] Right. You can look at it, like, OK, am I learning towards technology risk or leaning towards improving reliability. What is it that I am trying to accomplish by this? You can make a decision based upon (this).
2	28.39	[compare the priority model to ranked list] 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 gonna 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?
2	29.50	[about project dimensions] That's really good. It is another one of those things you might want to fine tune later on, maybe another one or two ... we talked about manpower those kind of things.
2	30.30	[ask whether the visualization has a lasting effect.] Yeah, absolutely. ... Sure. Especially once you leant the six points, to me, it wouldn't take much before you start thinking that way. You look up and then you go, hmm, that's gonna fall into that cluster.
2	31.15	[general comments] I am very visual, and it makes sense to me; a lot more than sitting there and reading a whole bunch of spreadsheets and trying to figure out the aggregates. I'd much rather do this. Once you get it and, jeez, that makes sense to me. ... You have to understand that we use maps all the time; that's how we use. We are into the mapping thing; we are into the visual thing. It makes sense to us to visualize, to map things. We use map for network, we use map for monitoring, we use map for how we put things together, and stuff like that. So this makes absolute sense to me.
2	32.30	[about getting a big picture] Yes, absolutely. I think so. I think when you look at that, and you start going around and comparing; I like that thing you just lay it down on top of it, and go where they fit it, and things you got three ways of doing it. That's really easy! That makes total sense! It's logical.
2	33.35	[practical use of prioritization] Yeah, sure there are many projects that we do are similar in nature. I don't think we realize it until we are really into it and we are actually working on things that are identical and many ways are pretty much the same. Whereas you put it up there, you like, wow, wait a minute, those are all pretty much the same.

2	34.00	[observation] In the conversation of the potential use of the tool, the participant suddenly approaches the screen projection and starts to imagine/envision he put the tool into a real case. He explores the map and at the same time explains his analysis and think process, using the tool, on a scenario of manpower assignment and project selection.
2	36.30	[Is it easy to justify?] I can argue this with the boss. I can say, look, I can't do those three (pointing to the screen); right? I can't do all three of those at the same time. You can't put them as the same priority - there are more possible ways we can do it - however, we can do this one, this, and ... So that's what I am looking at.
2	37.00	[Is it easy?] First of all, (describing the use process) – for that, how hard is that? I mean, you are the one that's doing it. You know, and if the group agrees - you know, you get together and you have a group thing - and ok, this is where it should fall - how much energy you think it's gonna take to do that? Well, here's my number. Right? And then it's pretty self explanatory after that one - he put the numbers in and do(es) whatever. I like it.
3	7.2	[On multiple attributes] I think it gives you a good representative (representation) to compare -yes. It's not something that we do today because it is not really (an) option that we have today to do that. Today we really have just one dimensional view; I mean they go through that spreadsheet, and answer questions, and get a rank on the scale of one to a hundred. And that number becomes its rank, so it's very one dimensional; and that's it. It doesn't incorporate some of the different (components) to make that number; it's just there. You have one number and that one number doesn't really tell you what's high or low; it just tells you that it came out to this number. Looking at the graph, it shows me all of them are high and that's why (it) has a high score; or all of them are fairly low, that may be why's low. You may have outliers for one or two.
3	8.5	[On other dimensions] The one thing I did see here that we really don't capture that data. The big issue is resource planning ... (looking at the human resources and skills) we don't look at that today; most projects require it, at least DBA and system admin, because certain projects may require more than one person. That's interesting dynamic, to say, OK, coz we do have limit resource on that.
3	19.05	[One profile chart] I could see it would be very useful. Then you don't get just one number, you would actually see each of those dimensions that make up that number to figure out, ok, it is not just a 88, it 's an 88 because improving reliability although optimization of resources is low. So, especially to an executive looking at it: well, they may have the same ranking, but because of the way the graph looks, really the other one is a higher priority project.
3	20	[Number vs. shape] Well I see the numbers but I guess it's because I'm new. I think over time I would see more of the shape to realize that the larger the shape, the more the numbers are. ... I think, in the future, as people work more with it, look at it, (they will) get more (from the

		chart) ... right. ... yeah, I would look at the shape. ... [Showing the profile chart comparison tool] OK ~~~ (the user likes it).
3	25.15	[Cells View] It makes sense to me, now, now that we have gone over and explained it. But when you first look at it, it's kind of like, you know ... (showing hesitation) ... need time to digest it and figure it out. But it does make sense to me. It is interesting. (Participant start talking about his observation of the map compared to traditional quadrant map.)
3	28.5	[Clusters View – easier?] Yes, I think so. It does, they got some interesting shapes but yes.
3	31.5	[Clusters View vs. Cells View] I like the cluster view. Well, it also depends on your audience. I think you if you took a cluster view and explain what it is to the casual observers, it would be easier to explain the four or the six different clusters set, than explain each individual chart.
3	40.2	[three views for sub-portfolio balance] Yeah, that makes a lot of sense, coz if all of your projects are in the purple one, which is higher priority, that would be too much. ... I can take that further ... (describing a scenario on resources allocation) ... so, there's a lot of different ways I can see you can actually use that. ... I can see that to be valuable information. (describing more scenarios) ... I can see where you would use it not just for portfolio management, but also help you plan your business; to say this looks like what's coming down, looking at these different clusters, to help underline business like who to hire, what technology to investigate, what to purchase.
3	44.5	[Cluster View vs. Cells View] I think the cluster really does help a lot. ... I mean, if I am just comparing one to another (project), then just the map (Cells Views) is fine. But when I am looking at more than just one to one, the cluster really helps me to figure out where is this group compared to another group.
3	52	[application to prioritization] The concern is that usually it's not one person making a decision. It might be hard you get 4 or 5 people in the room doing this, and in the beginning have to have a framework (rules) ... just one person doing it, that's great. ... I like this because you can see comparison of each dimension of the total versus just looking at the total number. You can compare them overlapped. So I really do like this.
3	55.45	[applied to portfolio balance] This one is, actually, you can see different areas; so I really do like this; (it) give you balanced portfolio. ... you can (realize) too much work focusing on the wrong thing. So I do like this approach to see, if this is how our projects set up, it looks like a very balanced portfolio.
4	7.4	[profile chart] I think that's where you can really see ... this would be a good thing to look at. Like say if you ... so it's gonna be low cost and high people, this would show me what I need. ... I like charts and graphs.

4	9	[Chart types] That would be helpful for something. But ... I cannot do that as easily as the spider web (Radar Chart).
4	17.15	[clusters view] The clusters view makes more sense. It is easier to interpret. That's cool idea, I think, by the way.
4	18	[cluster view vs. cells view] You might want to just verify what you saw in the cluster. Coz when I research I look it (from) multiple sources. So I am not just gonna rely on one. But that (clusters view) would be give me a quick one sight view on what I am interested in. And then I can go to different layer.
4	28	[clustering process] That's easy, I am visual, I am very good at dimensional things and I can see what's close and what really seems to be not.
4	31.3	[SOM map randomness] If I knew how it was setting all these different things and knew what they meant, then this reposition wouldn't bother me. It shouldn't (matter).
4	33.48	[ease of use, usefulness, intention to use] If it was easy to use, I would be more inclined to use it, because this is very valuable, especially for the visual people. ... Show me, just don't put the paper out here and make me read; don't just talk to me, show me. This literally shows you a neutral ground based on the criteria set forward. ... If it is an easy to use thing, I think it would be a wonderful thing to use. Any manager should have all these stuff. ... The analysis is the easy part. This is great, I love this. This would be easy, I got the whole idea - going from the cells, and clusters, making my own clusters - this is slick.
4	39.19	That's a very flexible tool.
4	46.15	[prioritization] This takes the human emotion out of it. When I work with people, they are very attached to the project, and they are very emotional about it. This takes all the emotion out, puts straight down: this the number, this is what it shows, this is what should be, this is why we are doing it that way. And this may help to convince some people that, yes, we realize you project is important, but this one should go first because of whatever reasons.
4	48.18	[applicability] Yeah, visualizing it and pulling out different reports and different displays, I think it's great. It's got a lot applicability.
5	6	[profile chart] It gives me a visualization of where one (dimension) over here might stand out [user pointing the screen] and say I want to focus on that one because appears to have more (higher) value than others. ... If you know what the purpose is, you are gonna map different potential projects together to visually pick one; yeah, that's easier.
5	8.2	[profile chart type] I like the radar because you can see where all the variables are you can make some decisions on.
5	11.3	(Items View) I can see that these up here because their values have smallest variations (with the cell they are in).

5	17.25	[clusters view + items view] I think a visual representation like this to the ITSG (IT Strategic Group, a university level committee to determine the most important project plan) is helpful. So they understand ... [starting to explain how projects in each cluster should be treated and why].
5	19.5	[clusters view + cells view] Having the charts there doesn't add anything. Especially for presenting to the executive group; all they want to see is how to cluster and what those colored regions mean.
5	21.4	[sub-portfolio] Yeah that's good; that would help the decisions. [describing a scenario] Being able to display them in a diagram like this, highlight them on the chart with all the projects and showing where all of his are, then that's a good tool to say you are consuming all the resources we have up here, doing these high priority projects for you, and I can't get anything done here with some general values to the campus. Yeah that's good; helps the provost (to explain), too.
5	26	[clusters view] This is important ... at the staff meeting, taking this to the ITSG and have this chart coming with clusters, that would be good.
5	30.15	[clustering process, finding similar cells] So can you put some filters on it to say if it's within 2% (of difference)? ... You can come up with a formula to describe that shape and then compare the numbers ... well the problem is if you gonna leave it to a manual inspection, ok, I will put these in one cluster, somebody else coming in and looking at the exactly same chart is gonna come up with a little bit different clusters.
5	34.32	[memorizing the chart] the chart you showed before (clusters summary report, and profile chart comparison) will stick with me. That will stick on my mind because it's bigger and I can see where all these points are (dimension labels). [clusters view] Your mind is already saying that everything up here is high value on everything, everything down here is low value, and everything here is between.
5	37.2	[sub-portfolios and views] For me, being able to look at a chart like this, I can understand what the chart is trying to tell me. Whereas if I have a list of projects with numbers, you know [negative expression], coz what you are trying to show is very complex. I, as a manager, am looking for, which one is the best one? Which should I be doing? By looking it up here that gives me a smaller group to look at and say, OK, that one.
5	38.3	[communication] I think it gives you a good ... the conversation is: why are these are up here, and why are these are down here? So, then you bring up the individual cells, and you dive down into what the criteria were, and say OK: this why they are. Then this gives a opportunity to say, well, what if we did not rate it so high: where would it fall? Then you can probably visually say, well, it will probably flip over here, or flip down here, or just move a little bit down in the same box (cluster). I think it's a useful tool for discussion at a very high level. Discussion of things that maybe we decide not to do, it is an effective tool; to decided we do do, I don't think so. ... yeah, that would give more basis for some discussion. You got a representation, that's good, that helps.

5	42	[relative position] Yeah it does, coz I am looking for the low stuff at lower left hand corner. From looking at any kind of chart, the zero origin is down here at the left hand corner, and everything up goes here. If you put the low value things down here, it confuses them. [The traditional orientation] is better for me; yes (I still understand), (but) positioning still important. ... If you have somebody who has never been instructed in a typical graph, then you could probably present that to them and they look at it and understand [the profile chart, cells view, som map]. I can see that pattern, and I don't necessarily have to rely on [the axes].
5	46	[ease to use] The final product (map) is easy to understand.
5	51.2	[priority model] That would probably be better. It doesn't allow for as much gaming as the current process does. That's actually very helpful.
6	9.35	[profile charts using bar chart] This is more effective.
6	10.2	[visualization] Well the graphical presentation of data is definitely powerful tool. It's a powerful way of presenting the data, without a doubt, I like to see that. It definitely serves its purpose.
6	18.4	[cells view] Just looking at this on the right and the left (of the interface), I can see right off the bat where they are coming from (positioned). The visual benefits here show me just how close the overall project portfolio is doing in terms of meting its goals.
6	20.2	[easy to interpret the map] It's easier in the sense that if you want to take a very quick view (snapped his finger), just take a quick look at something, you can see very quickly where the project portfolios are in terms of meeting those targets of business goals. Yes, for that, it looks good. However, I suspect that people will need to further dive into if they actually start the examination. But I think that's the play; this is just to give you a quick look and feel of how things are going.
6	23.5	[map size] Yeah, for me personally, I think going with a smaller volume of cells is probably more effective as opposed to a larger volume of cells. But then you can't go too small, because then you may lose that good overall view, there's the trade-off. ... Having the flexibility to determine on your own what the view is gonna be, is very good.
6	26.1	[clusters view] The clusters definitely help, without a doubt. Right off the bat, I can tell you it's gonna be helpful. That's good mechanism to use, if you are gonna go with more of the cells, turning to the clustering will be very, very beneficial. Actually it will be helpful also in terms of quickly targeting. If you already know that each cluster represents, you can go straight to clusters and, (for example) I know these ones are having problems with this particular area. So you can quickly address that and take a look at that.
6	29.55	[visual compare in clustering process] To me it's close. But, I guess at the end of the day, you have to have your threshold defined. I will probably base it on actually having a piece of threshold data that says, once it gets to this point, it's automatically another cluster group. ... They can do it (manually), I am not a fan of doing it manually, though. Because I

		think it's very important that you try to get the groups as accurate as possible, and having predefined threshold is really very helpful.
6	35.3	[asking finding from a sub-portfolio] Basically, for me, right of the bat it shows that they are all over the place. [Asking finding from another sub-portfolio] They are little more closer to each other, but they are still dispersed to different clusters. ... However, I would say that these cover less; obviously they cover less at least than (the former).
6	47.05	[justification] Definitely, because the value here is that you base the decision, the priority, on the six dimensions, those dimensions, as oppose to the number generated.
6	48.05	[communication, discussion] Oh yeah, definitely, because it immediately opens up a lot of questions: why is this like this? Just dive deeper to find out. The we keep using the views you have previously to compare each project on top of each other. See whether they meet in terms of the dimensions, the business goal.
6	54	[lasting effect: profile chart of individual project] well it is right now (laugh). [map, clusters view] Yeah, it has a lasting effect in terms of the groupings of the projects. For overall high level, it's got a lasting effect; for more detail, probably it doesn't.
6	56.05	[easy to use] I think it is pretty straight forward. ... The only issue I have with that is that, again, if you can't define the thresholds, if you leave it up to the individual users to determine it, based on how objects look, that really ... lessens the objectivity. Having a specific threshold kind of makes it more objective. The group will have to agree to move in that there. I think the group would have a hard time coming to an agreement with the visual format than they would if they had actual data, because everybody sees things differently. But I like it, I like the concept and clustering is definitely useful.



## 2. Analysis Template Details

<i>Initial Template</i>		<i>Final Template</i>		<i>Description</i>	<i>Example</i>
<i>Coding Category</i>	<i>Codes (Themes)</i>	<i>Coding Category</i>	<i>Codes (Themes)</i>		
System Components	General	General	General	Generally about the system and the approach	Yeah, visualizing it and pulling out different reports and different displays, I think it's great. It's got a lot of applicability.
	Visual Elements	Visual Elements	Visual Elements	Generally about visualizations	Well the graphical presentation of data is definitely powerful tool. It's a powerful way of presenting the data, without a doubt, I like to see that. It definitely serves its purpose.
	Profile Chart		Profile Chart	Specifically about Profile Charts	I suppose the radar chart as far as seeing the aggregate impact the radar chart's a bit more helpful than serials of bars to me.
	SOM Map		SOM Map	Specifically about the SOM map and combinations of its three views	That doesn't bother me. I understand that it is all relative. When you find the one that works for you, you stick with that one so you got a common reference point.
	Cells View		Cells View	Specifically about the Cells View	It makes sense to me, now, now that we have gone over and explained it. But when you first look at it, it's kind of like, you know ... (showing hesitation) ... need time to digest it and figure it out. But it does make sense to me. It is interesting. (Participant start talking about his observation of the map compared to traditional quadrant map.)

	Clusters View		Clusters View	Specifically about the Clusters View	The clusters definitely help, without a doubt. Right off the bat, I can tell you it's gonna be helpful. That's good mechanism to use, if you are gonna go with more of the cells, turning to the clustering will be very, very beneficial. Actually it will be helpful also in terms of quickly targeting. If you already know that each cluster represents, you can go straight to clusters and, (for example) I know these ones are having problems with this particular area. So you can quickly address that and take a look at that.
	Items View		Items View	Specifically about the Items View	It is not as spread out well as the rest (), yeah. ...
	Exploration Actions	Exploration Actions	Exploration Actions	Generally about exploration actions	I think when you look at that, and you start going around and comparing; I like that thing you just lay it down on top of it, and go where they fit it, and things you got three ways of doing it. That's really easy! That makes total sense! It's logical.
	Comparing Objects		Comparing Objects	Specifically about comparing and contrasting objects	[compare individual projects] Right. You can look at it, like, OK, am I learning towards technology risk or leaning towards improving reliability. What is it that I am trying to accomplish by this? You can make a decision based upon (this).
	Comparing Project Groups		Comparing Project Groups	Specifically about comparing and contrasting project groups	[Asking finding from another sub-portfolio] They are little more closer to each other, but they are still dispersed to different clusters. ... However, I would say that these cover less; obviously they cover less at least than (the former).
	Clustering		Clustering	Specifically about the manual clustering process	[About clustering process] This is kind of arbitrary.

Tasks	Understand	Tasks	Understand	Specifically about understanding portfolios and sub-portfolios	This one is, actually, you can see different areas; so I really do like this; (it) give you balanced portfolio. ... you can (realize) too much work focusing on the wrong thing.
	Prioritize		Prioritize	Specifically about project prioritization	So, especially to an executive looking at it: well, they may have the same ranking, but because of the way the graph looks, really the other one is a higher priority project.”
			Other	Other tasks	I can see where you would use it not just for portfolio management, but also help you plan your business.
Design (evaluation) objectives	General	Usefulness	General Usefulness	Generally about the perceived usefulness of the system and the approach	It makes sense to me; a lot more than sitting there and reading a whole bunch of spreadsheets and trying to figure out the aggregates.
	Big Picture		Big Picture	Specifically about high level quick view of portfolios	Just looking at this on the right and the left (of the interface), I can see right off the bat where they are coming from (positioned). The visual benefits here show me just how close the overall project portfolio is doing in terms of meeting its goals.
	Comparison		Comparison	Specifically about comparing and contrasting projects, and portfolios	You can look at it, like, OK, am I learning towards technology risk or leaning towards improving reliability. What is it that I am trying to accomplish by this? You can make a decision based upon (this).
	Justification		Justification	Specifically about justifying and defending conclusions	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: ...

			Awareness	Specifically about the tool's capability to help discover easy-to-ignore or hidden information	Yeah, sure there are many projects that we do are similar in nature. I don't think we realize it until we are really into it and we are actually working on things that are identical and many ways are pretty much the same. Whereas you put it up there, you like, wow, wait a minute, those are all pretty much the same.
			Discussion	Specifically about the tool's capability to facilitate discussion	... at the staff meeting, taking this to the ITSG and have this chart coming with clusters, that would be good.
			Objectivity	Specifically about objectiveness of the system and the approach	The only issue I have with that is that, again, if you can't define the thresholds, if you leave it up to the individual users to determine it, based on how objects look, that really ... lessens the objectivity.
	Intuitive	Ease-of-Use	Intuitive	Specifically about if users can easily understand the process and results delivered by the system; whether it makes sense	This was a very easy tool to grasp, the 6 points, the individual projects and then the map. The clustering was very simple and easy to grasp. Visualization of things we have not been able to adequately visualize before.
	Recall		Recall	Specifically about if the visualizations provided by the systems are easy to remember and recall	Well it is right now (imprinted in my mind) (laugh). Yeah, it has a lasting effect in terms of the groupings of the projects. For overall high level, it's got a lasting effect; for more detail, probably it doesn't.
	Operate		Operate	Specifically about the system easiness to operate, and flexibility of the approach to meet different needs.	First of all, (describing the use process) – for that, how hard is that? I mean, you are the one that's doing it. You know, and if the group agrees - you know, you get together and you have a group thing - and ok, this is where it should fall - how much energy you think it's gonna take to do that? Well, here's my number. Right? And then it's pretty self explanatory after that one.

Tone	Positive	Tone	Positive	Positive comments	I can understand it very well. It is easy to see, easy to understand from the six points what the priorities are for the projects. ... Yeah. I like that.
	Negative		Negative	Negative (counter-evidence) comments	[About clustering process] This is kind of arbitrary.
	Neutral		Neutral	Neither positive or negative; or conditionally positive or negative	Since it's all relative ... but you got to have a common reference point for the relative mapping to make sense.
			Constructive	Providing new and effective ideas and thoughts	So can you put some filters on it to say if it's within 2% (of difference)? ... You can come up with a formula to describe that shape and then compare the numbers ...
		Other themes	Reflecting Reality	Stating the real life situation or traditional practices in every day work	The one thing I did see here that we really don't capture that data. The big issue is resource planning ... (looking at the human resources and skills) we don't look at that today; most projects require it, at least DBA and system admin.
			Self-assessment	Describing the user him/herself, such as the visual ability, work habit, etc.	You have to understand that we use maps all the time; that's how we use. We are into the mapping thing; we are into the visual thing. It makes sense to us to visualize, to map things.
			Attitude toward using	User's attitude toward the system	This is great, I love this. This would be easy, I got the whole idea - going from the cells, and clusters, making my own clusters - this is slick.
			Design suggestion	Suggesting new features, or stating design feature preferences	I suppose the radar chart as far as seeing the aggregate impact the radar chart's a bit more helpful than serials of bars to me.

## **Appendix D. Prototype Demonstration in WITS 2008**

The following scenario and screenshots are demonstrated in the prototype session of the Eighteenth Annual Workshop on Information Technologies and Systems (WITS), 2008, Paris, France. The scenario provides more configuration details and demonstrates more operational features of the prototype. It can be used as a complement to the scenario demonstrated in Chapter 4.2.2. The screenshots are also larger with more details.

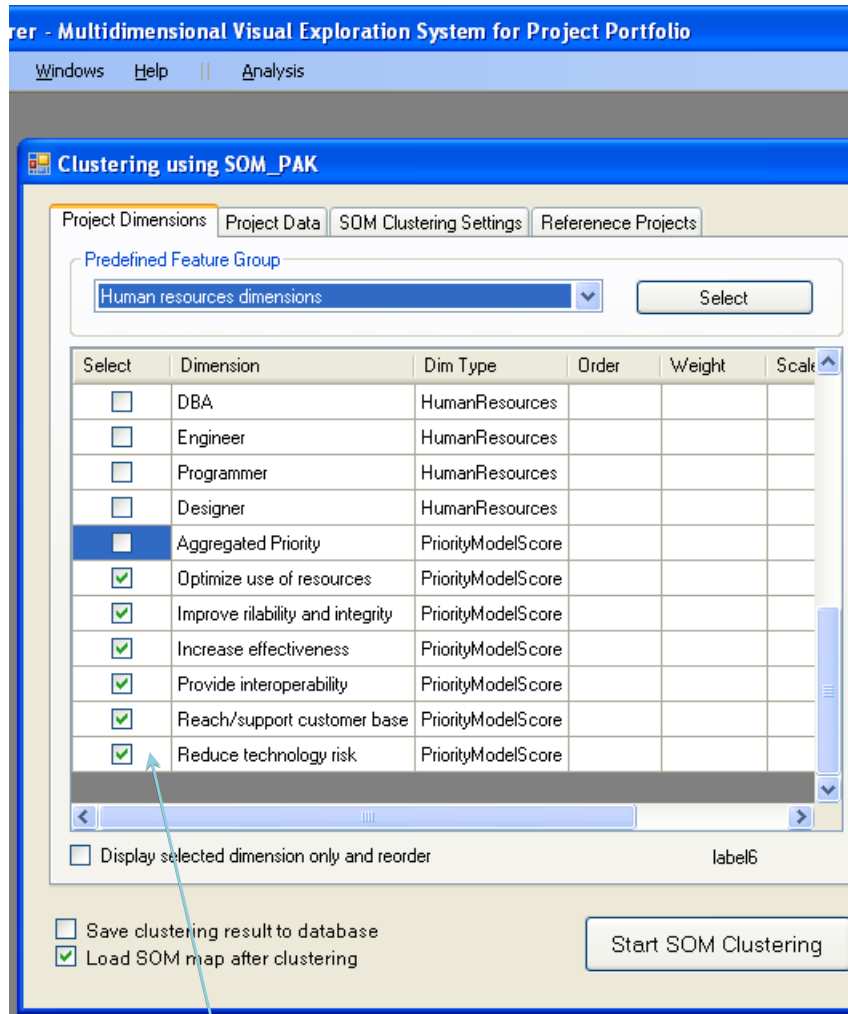
Section 1 presents the scenario and section 2 provides more screenshots for more system functions.

### **1. Scenario**

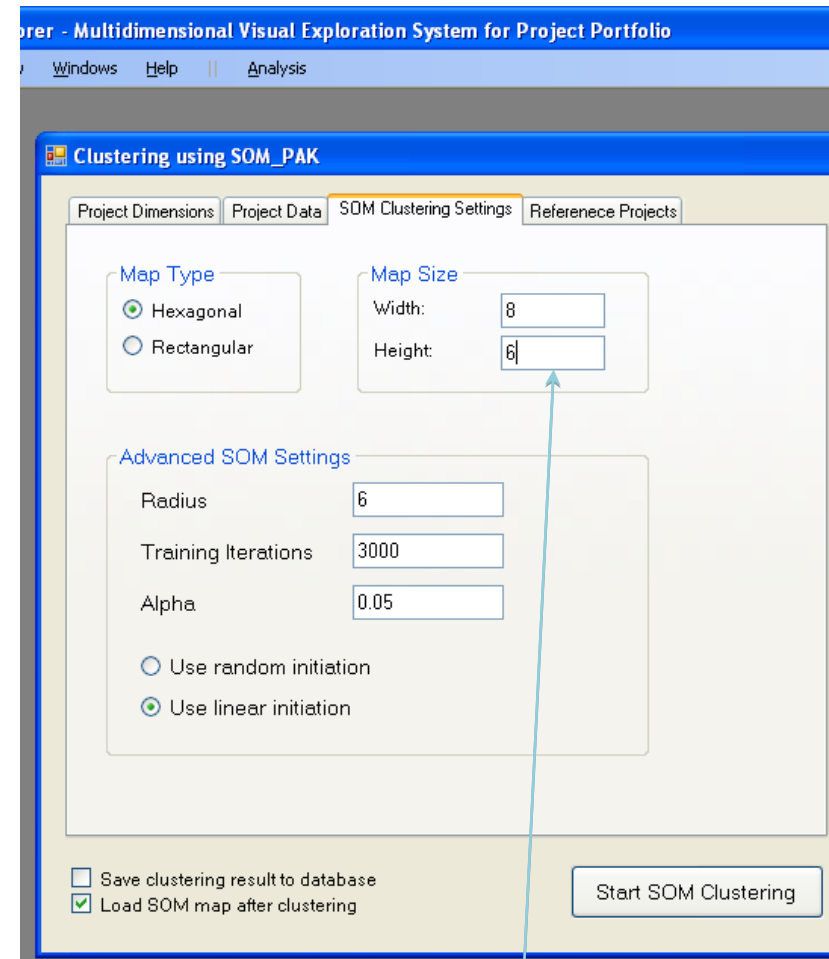
The process is configurable and involves only part of the steps and their sequences. The following use scenario illustrates the basic process when prioritizing projects based on this system (with screenshots).

Task: selecting 3 more highly prioritized projects to add to the current existing current highest priority 7 projects and make a Top 10 List, based on the pattern of 6 scoring dimensions (note: the system allows flexible configuration of dimensions, such as dimension selection, weighting and scaling – here it is just one most basic example). Please follow the “Scenario Screenshots #” for the scenario.

Scenario Screenshots #1, #2: Selecting dimensions for SOM, using default dimension order, weight and scale; and specifying map settings.

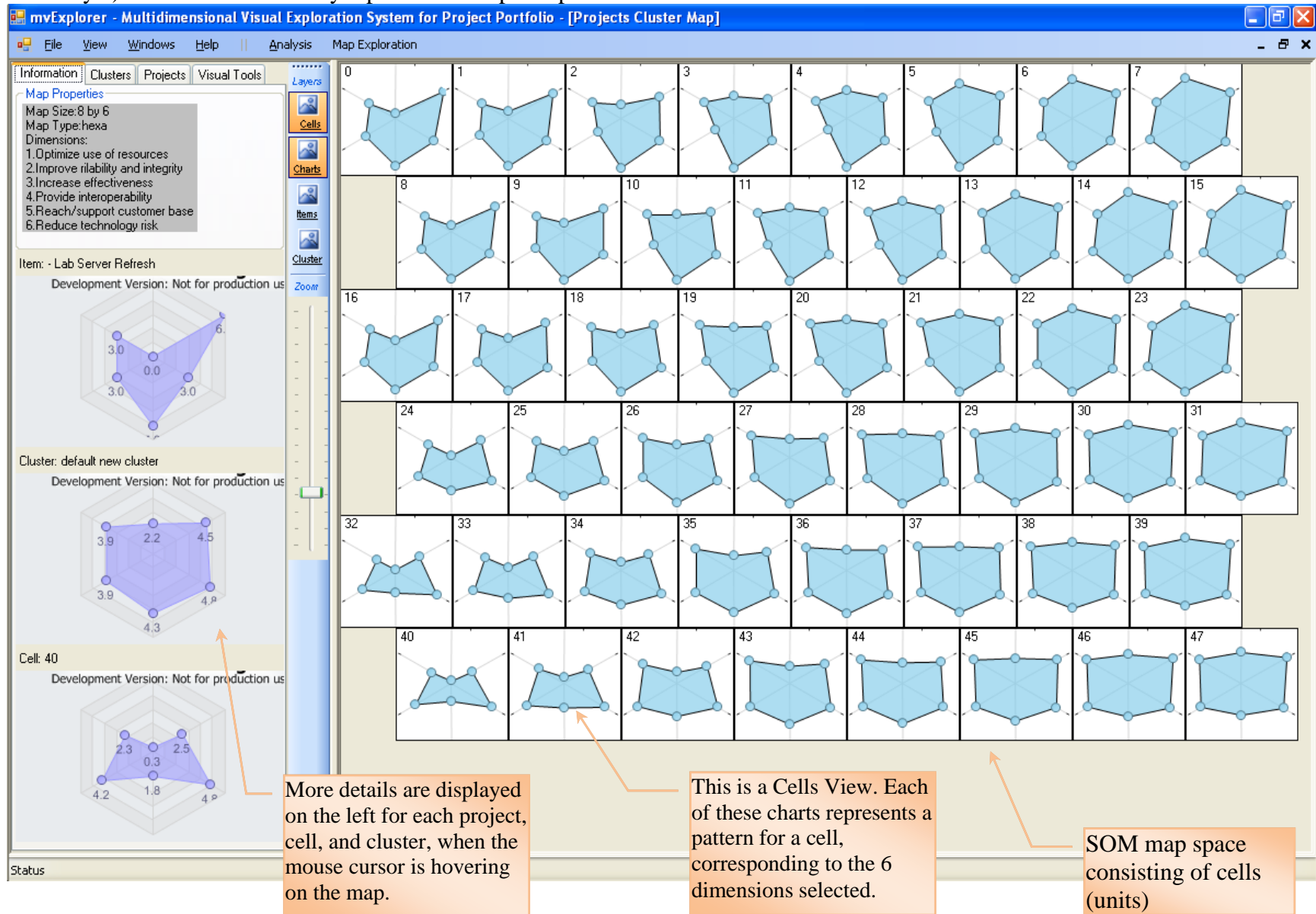


Selecting 6 priority score dimensions



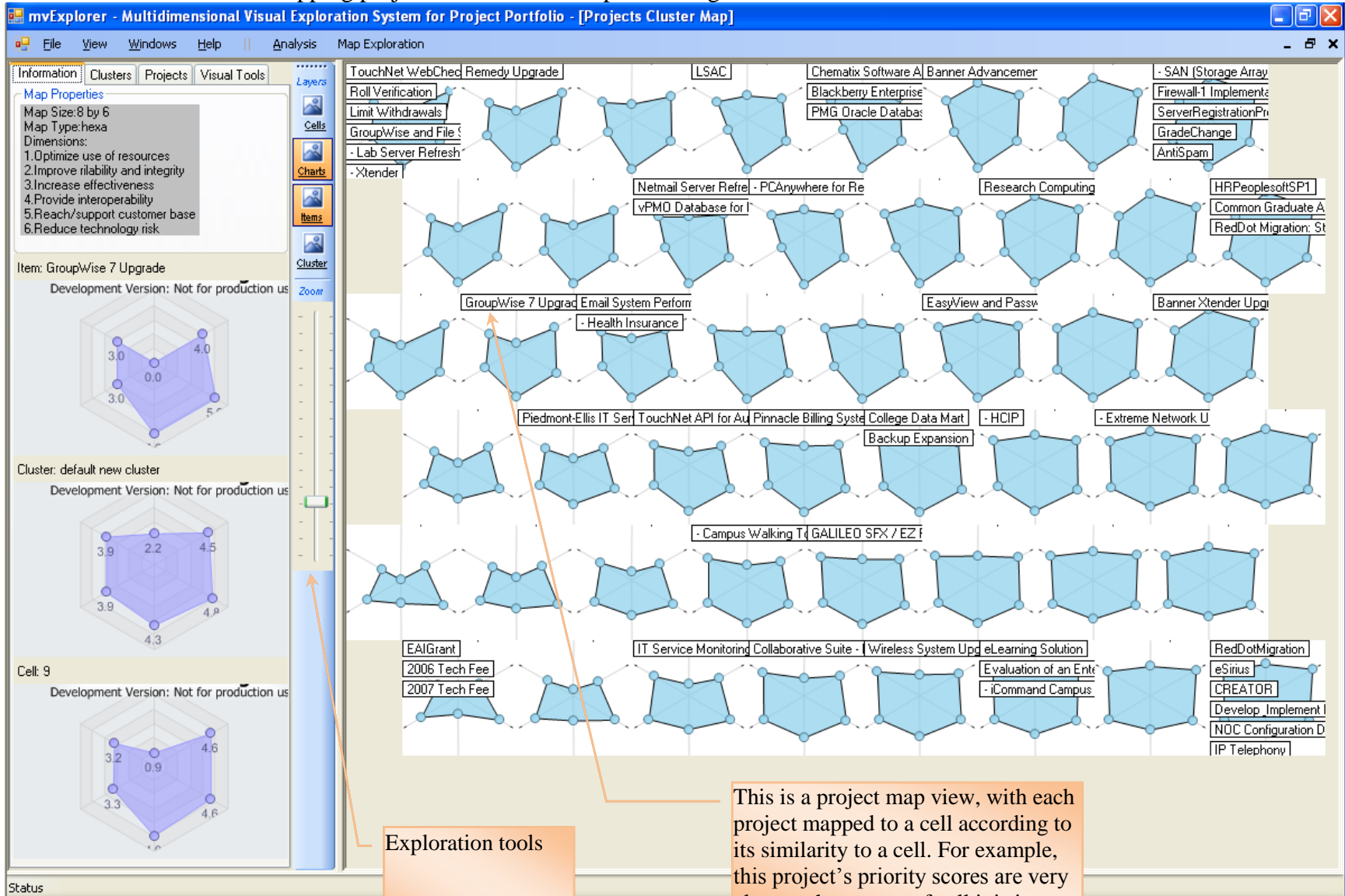
Setting map size:  
number of cells (units)  
of the SOM map.

Scenario Screenshots #3: Examining the generated SOM Base Map (Cells View) to understand map region characteristics (no clusters defined yet). A radar chart directly represents a map cell pattern.





Scenario Screenshots #4: Mapping projects on the SOM map according to the least Euclidean Distance of all 6 dimensions.



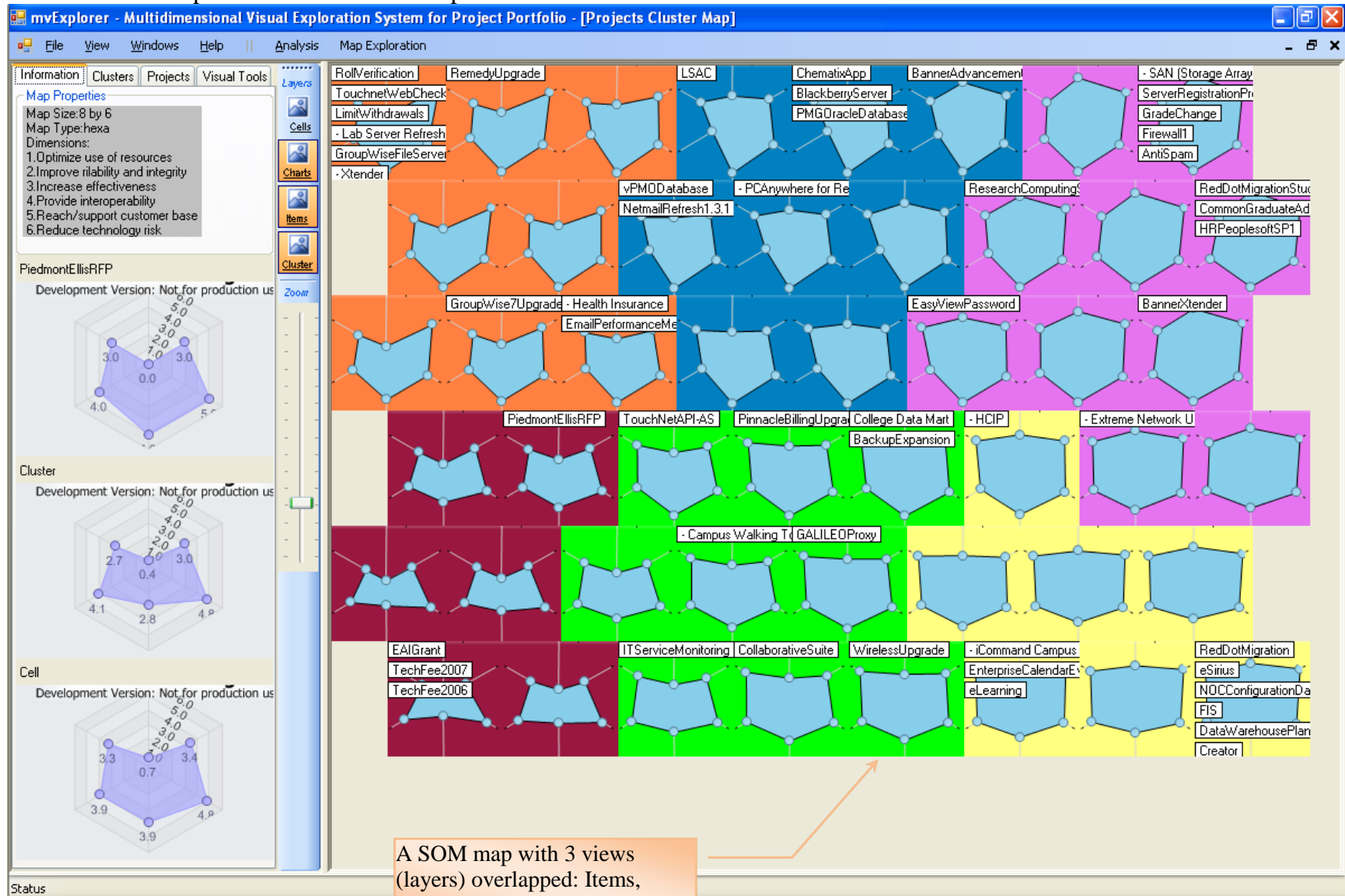
Scenario Screenshots #5-1: defining clusters based on the exploration of cells and projects.

The screenshot displays the mvExplorer interface for defining clusters. The main window shows a grid of cells, some of which are highlighted in blue, green, and magenta. An 'Edit Cluster' dialog box is open, allowing users to modify cluster settings. The dialog includes fields for 'Cluster Name' and 'Cluster Color', along with buttons for 'Update', 'Reset', 'View', and 'Hide'. A 'Cluster Suggestion' section is also visible. Callout boxes provide additional context: one points to the 'Cluster Information' section of the dialog, stating 'Cluster information and pattern are dynamically updated and displayed', and another points to the magenta-highlighted cells, stating 'Users can use mouse to assign cells to a cluster'.

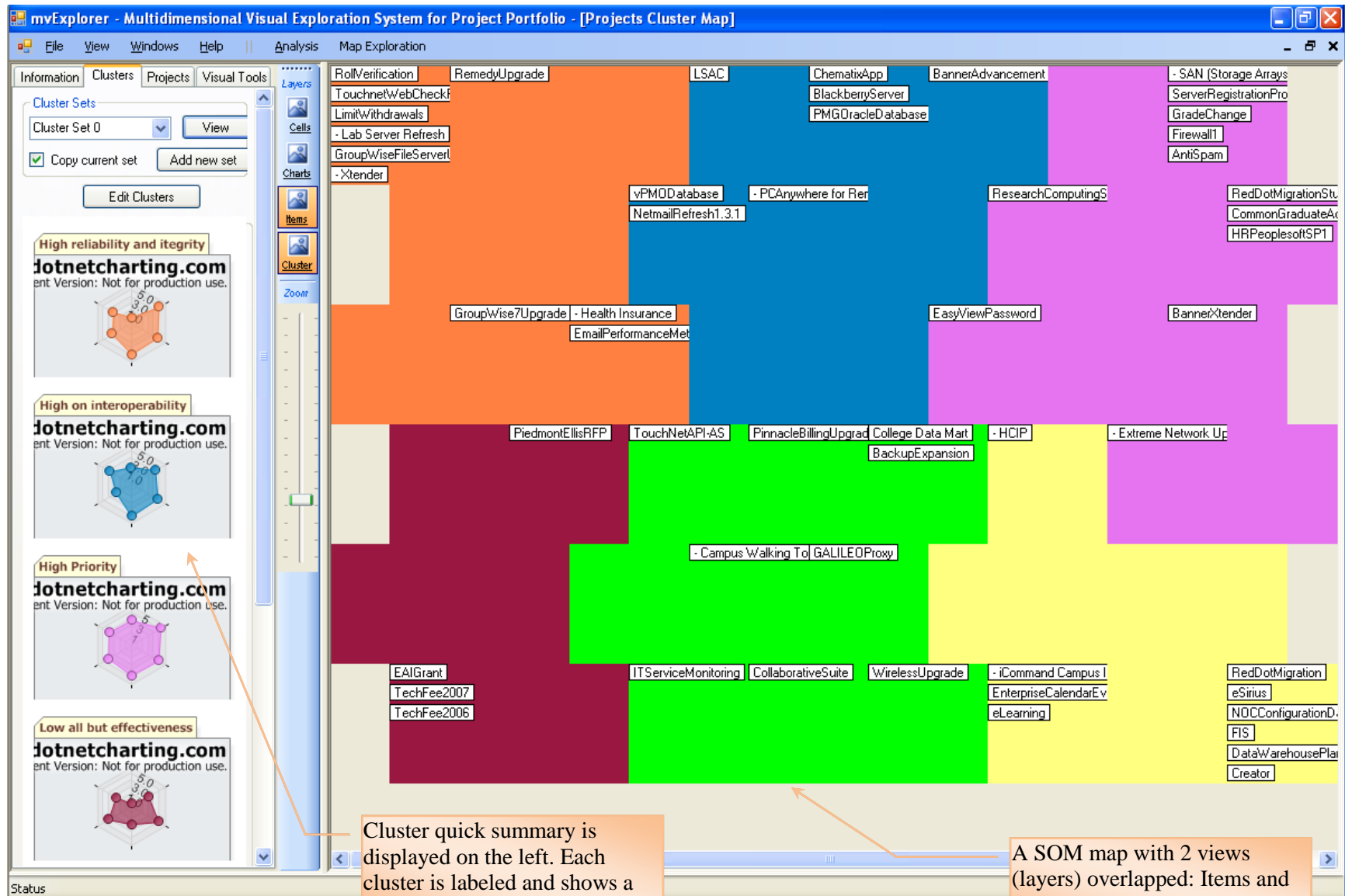
Cluster information and pattern are dynamically updated and displayed

Users can use mouse to assign cells to a cluster

Scenario Screenshots #5-2: a final defined acceptable cluster map on the right panel (three map level views overlapped); detail information and exploration tools on the left panel.



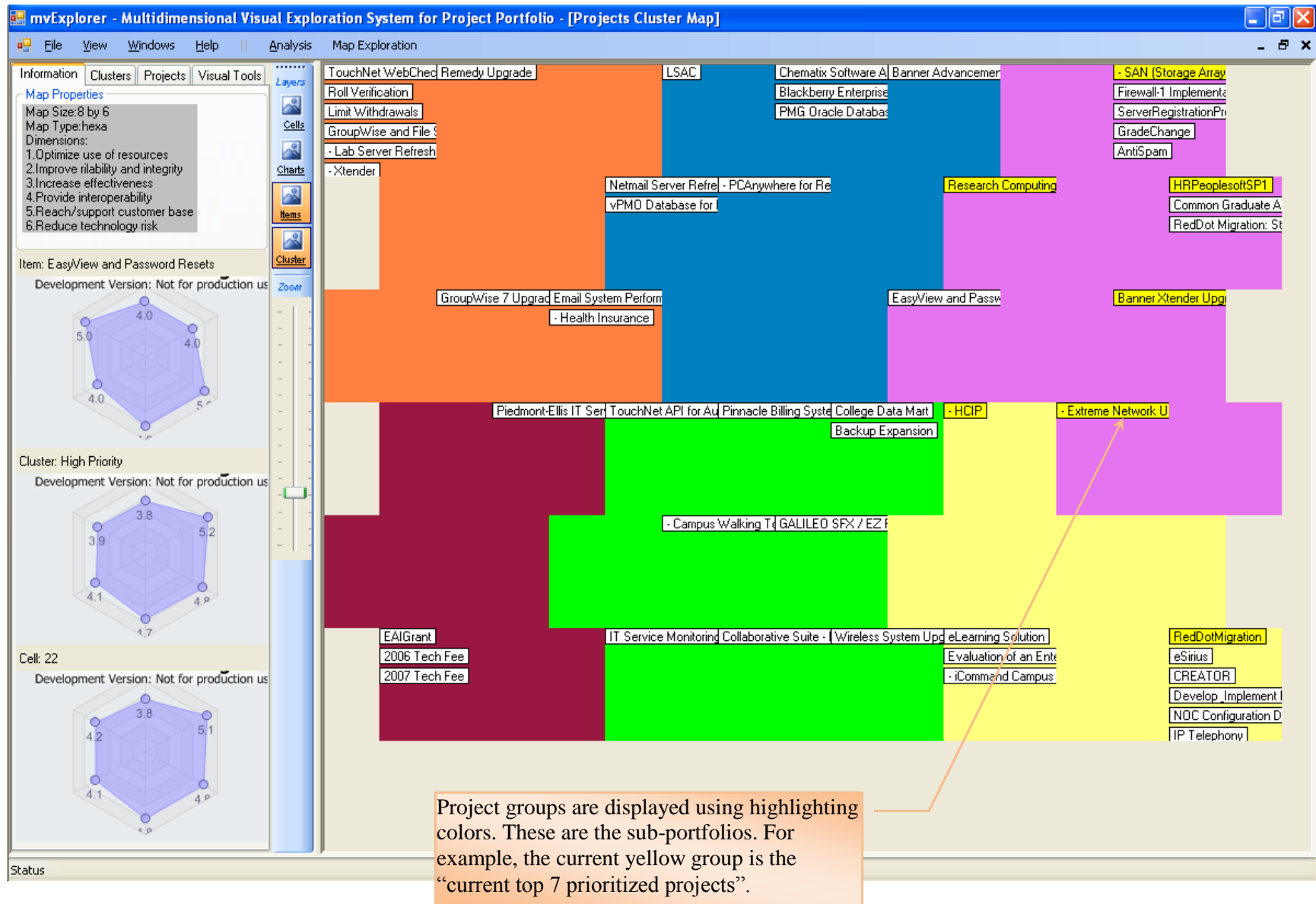
Scenario Screenshots #5-3: A better view of clusters and projects; cluster pattern summary on the left.



Cluster quick summary is displayed on the left. Each cluster is labeled and shows a cluster pattern using charts.

A SOM map with 2 views (layers) overlapped: Items and Clusters.

Scenario Screenshots #6: exploring projected map with a project group (yellow colored for “the top 7 projects”).



Scenario Screenshots #7: exploring an alternative cluster set with a project group; users can compare this set with others (see screenshot #6)

The screenshot displays the mvExplorer interface, titled "mvExplorer - Multidimensional Visual Exploration System for Project Portfolio - [Projects Cluster Map]". The main window shows a map of project clusters, with various project names and descriptions displayed within colored regions. The sidebar on the left contains a "Cluster Sets" section with a dropdown menu set to "Cluster Set 1" and a "View" button. Below this, there are four cluster set definitions, each with a "dotnetcharting.com" logo and a "ent Version: Not for production use." note. The definitions are:

- High reliability, effectiveness and interoperability**: dotnetcharting.com
- High Priority**: dotnetcharting.com
- Low all but effectiveness**: dotnetcharting.com
- High but lack optimization**: dotnetcharting.com

An orange arrow points from the "Low all but effectiveness" definition to the main map area. At the bottom, a text box states: "Users can explore the map with a different definition of cluster set. This reflects different perspectives and needs. Again, cluster names and patterns are displayed on the left."

Scenario Screenshots #8: visual comparison of selected candidate projects; different chart types are available. Conclusions can be made. (For example, I would choose “AntiSpam”, “ServerRegistrationProcess” and “EasyView and Password Resets”)

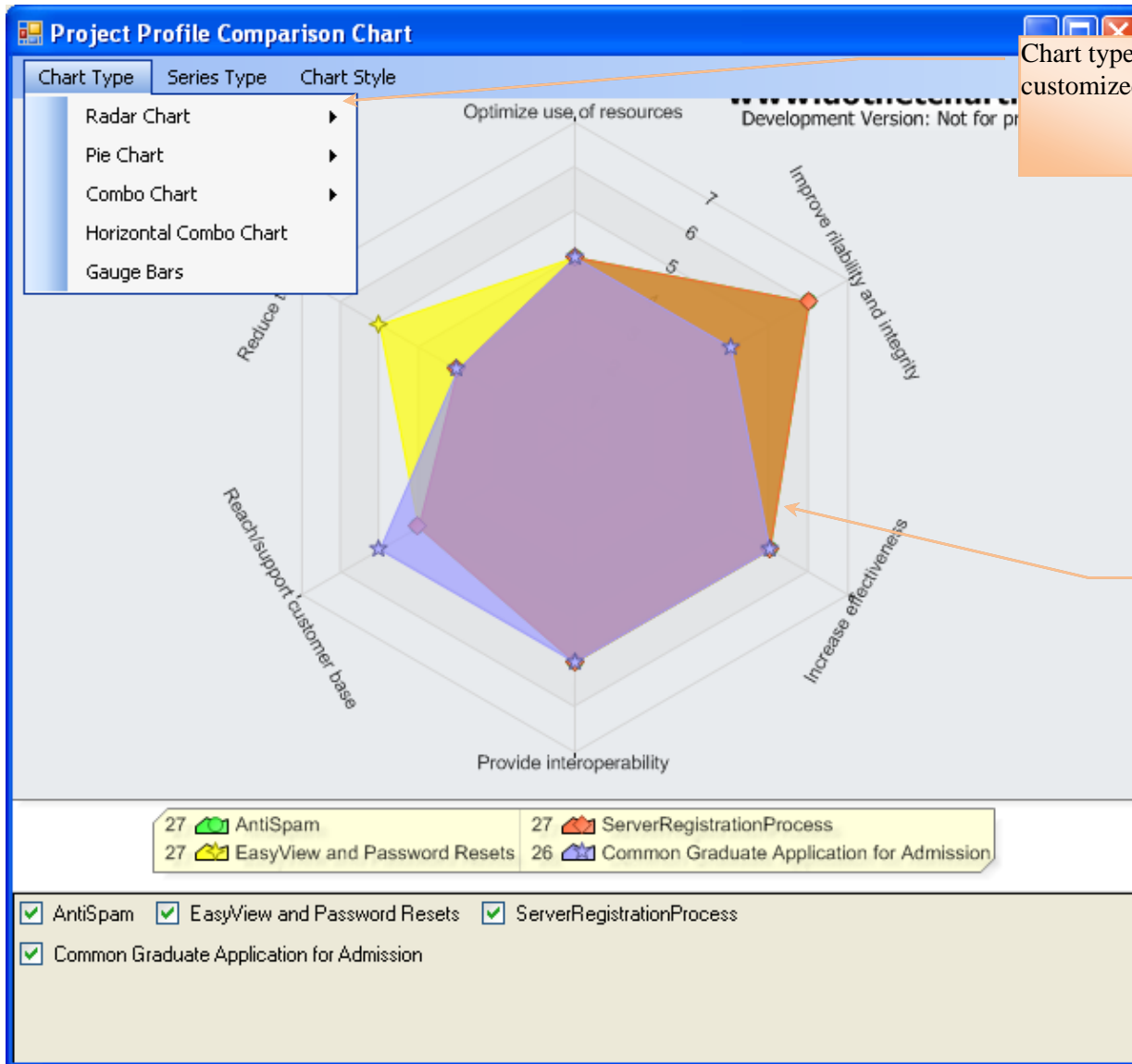
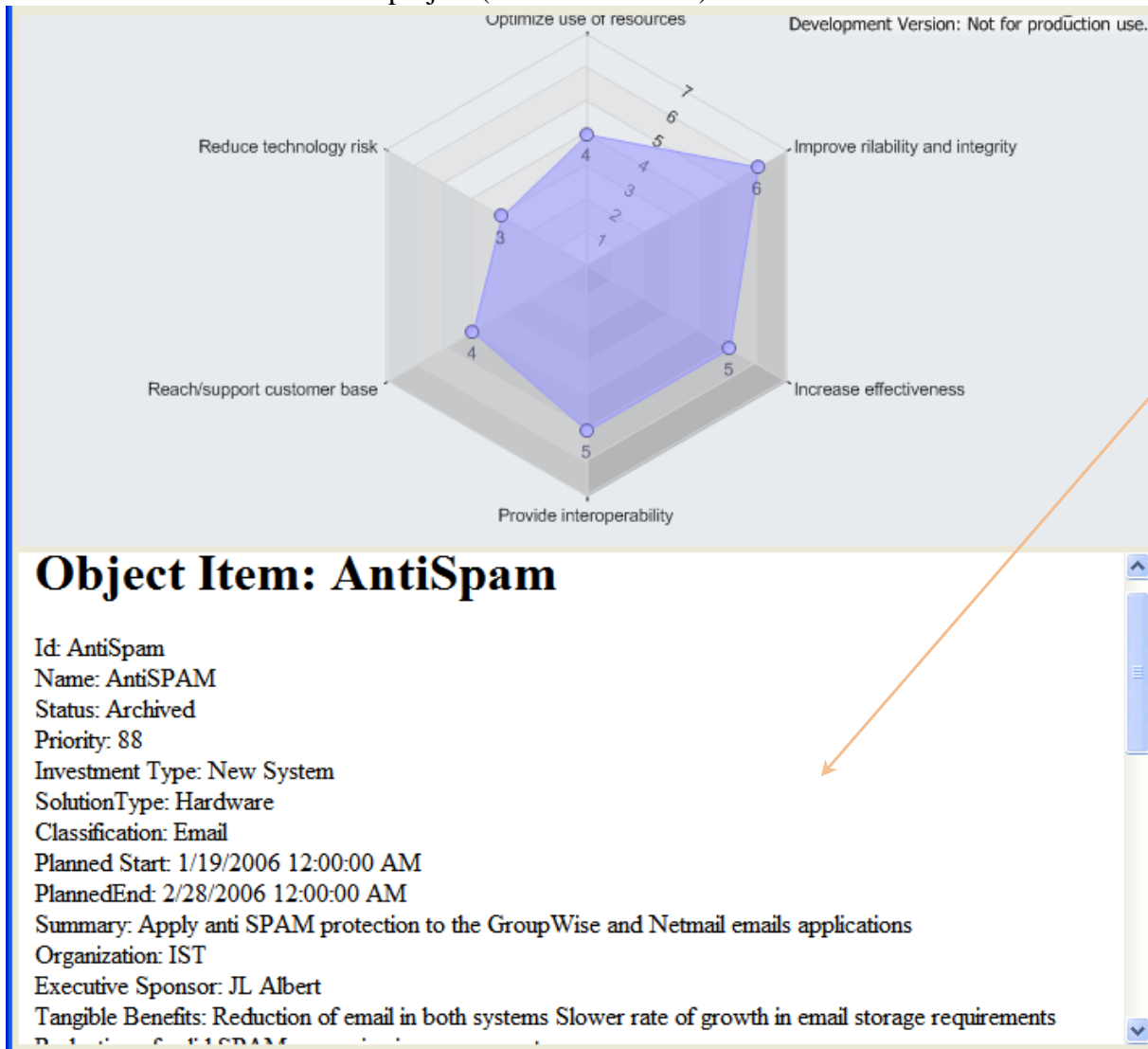


Chart type and style can be customized.

Visual profile comparison is very direct and intuitive.

## 2. Other system function screenshots

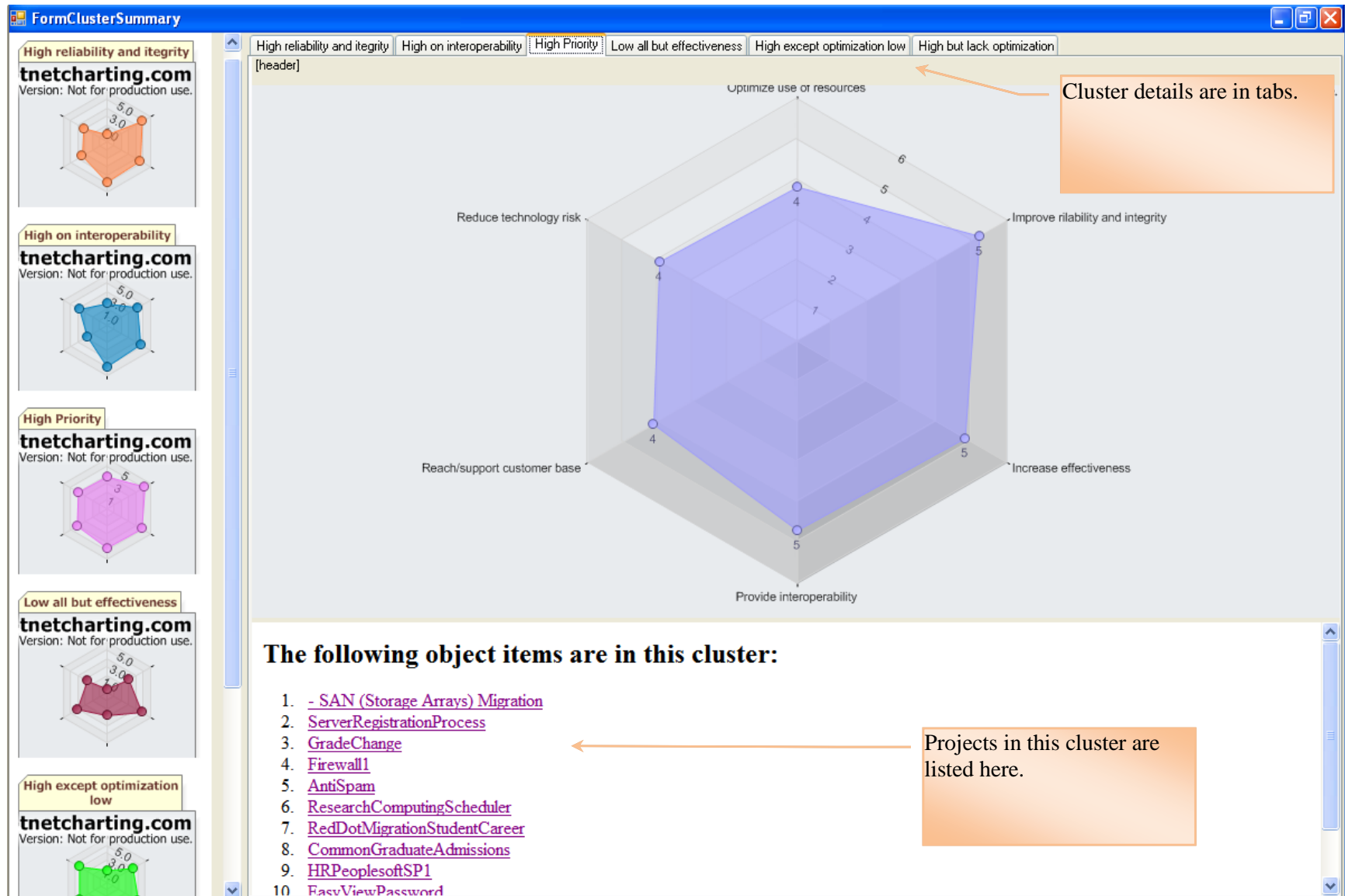
Detailed view for an individual project (detail on demand)



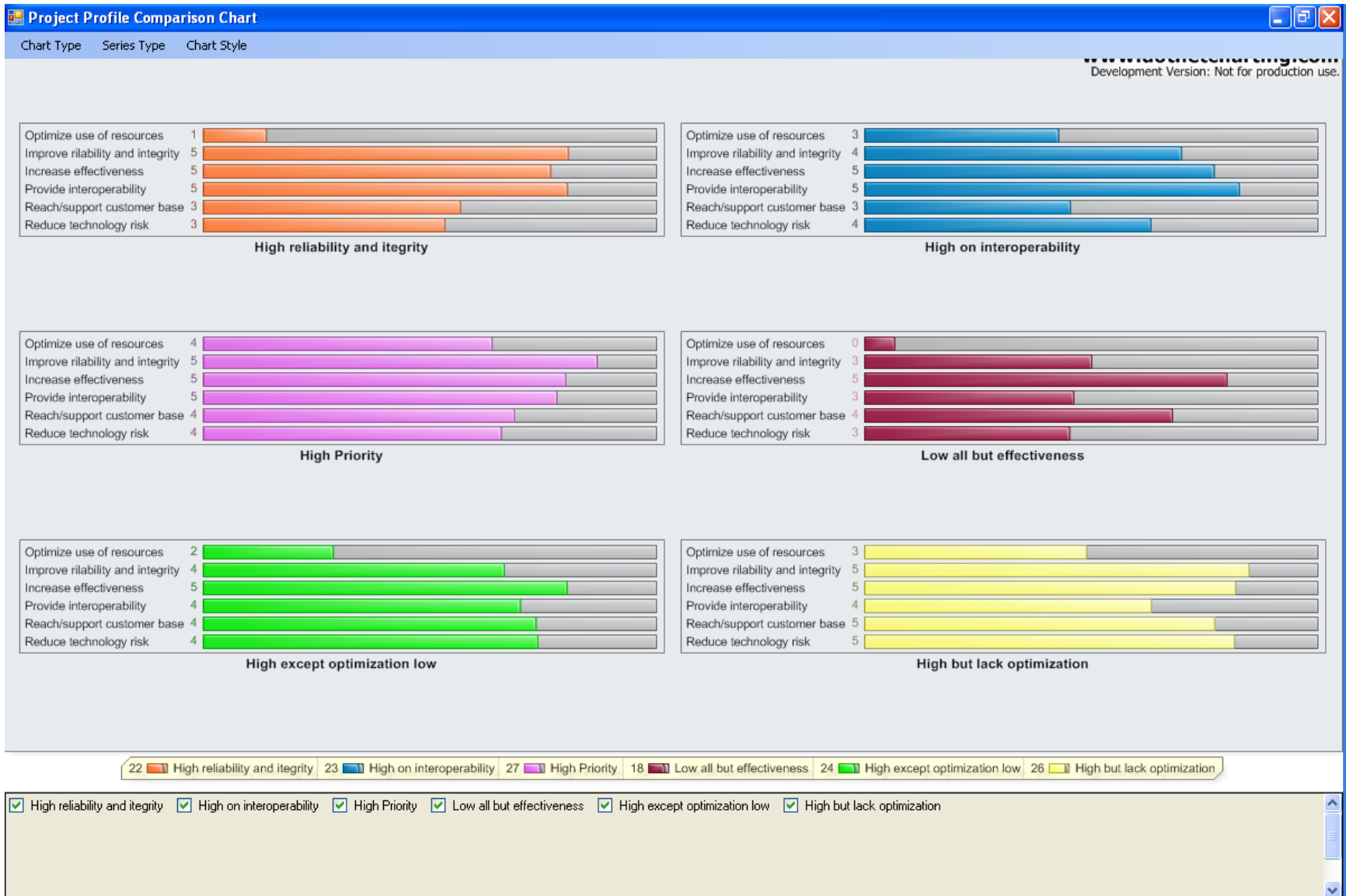
Detailed information of a project is read from the database.



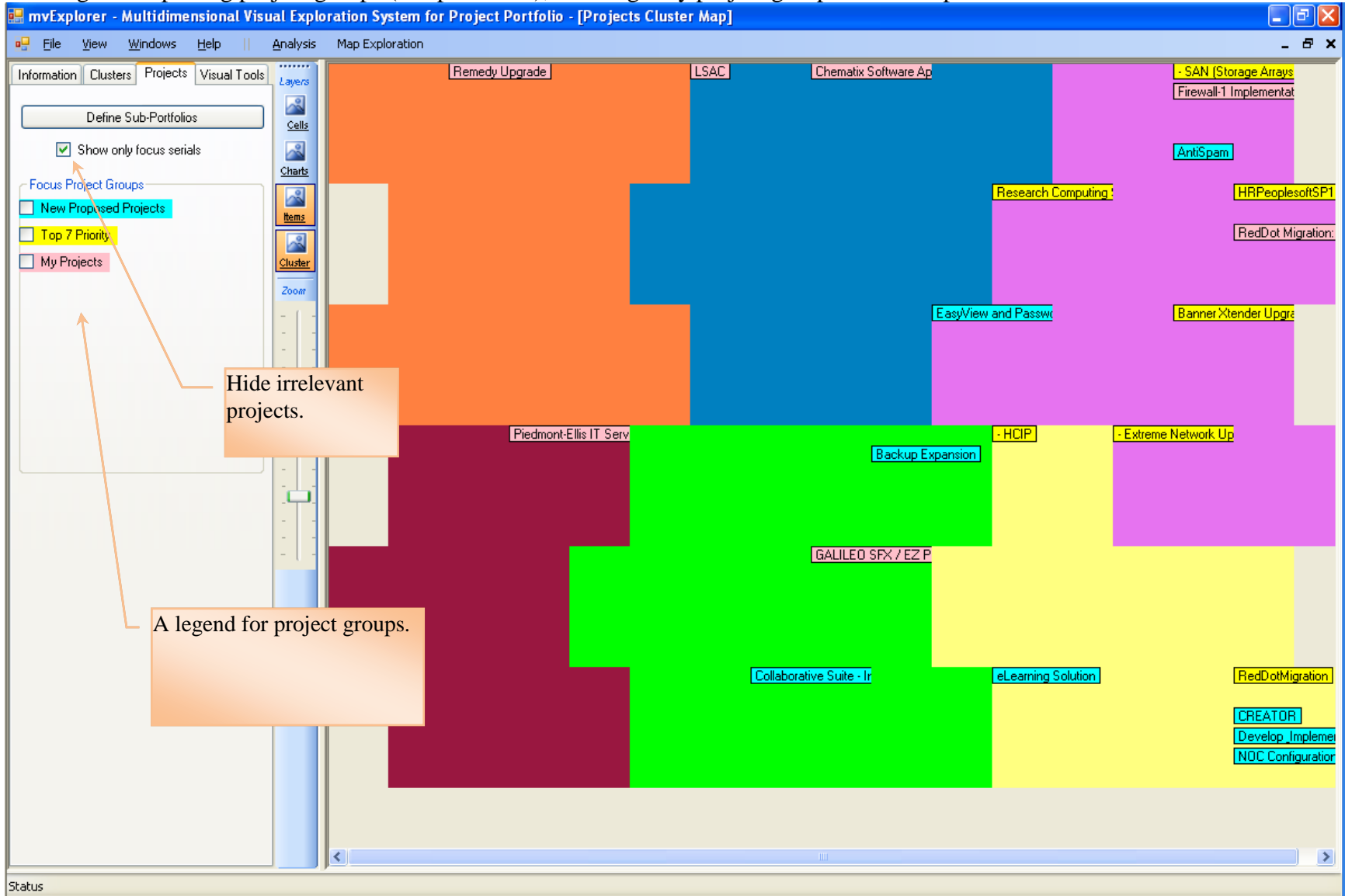
## Cluster summary report



Visual comparisons of individual objects (clusters) using separate gauge charts (there are more types of charts)



Defining and exploring project groups (sub portfolios); showing only project groups on the map.



## Appendix E: Prototype Documentation

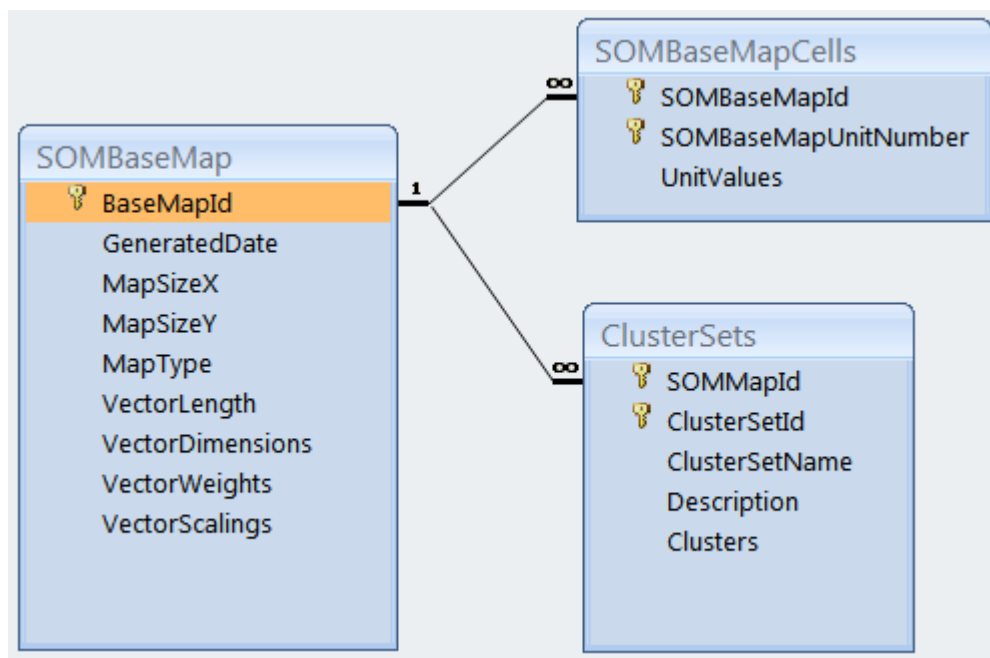
### 1. Programming environment

Platform: Intel Pentium 4, Windows XP Professional, Microsoft.NET 2.0

Development Software: Microsoft Visual Studio 2005, C# 2.0, Microsoft Access 2007

Third Party Component: SOM\_PAK 1.0, dotnetCharting 5.0

### 2. Database



DataDimensions			
DimensionN	DimensionType	DimensionFullName	DataMax
Budget0	Budget	Total Budget	150000
Budget1	Budget	Hardware Cost	50000
Budget2	Budget	Software Cost	50000
Budget3	Budget	People Cost	50000
Labor0	HumanResources	Total Labor	750
Labor1	HumanResources	Analyst	150
Labor2	HumanResources	DBA	150
Labor3	HumanResources	Engineer	150
Labor4	HumanResources	Programmer	150
Labor5	HumanResources	Designer	150
Priority0	PriorityModelScore	Aggregated Priority	36
Priority1	PriorityModelScore	Optimize use of resources	6
Priority2	PriorityModelScore	Improve reliability and integrity	6
Priority3	PriorityModelScore	Increase effectiveness	6
Priority4	PriorityModelScore	Provide interoperability	6
Priority5	PriorityModelScore	Reach/support customer base	6
Priority6	PriorityModelScore	Reduce technology risk	6

### 3. Namespaces defined in the program

<i>Namespace</i>	<i>Description</i>
ProjectPortfolio.Clustering	Classes for SOM processing, and data structures of SOM map objects
ProjectPortfolio.Utility	Utility classes for data transformations
ProjectPortfolio.UI	User interfaces, including visual elements

### 4. Classes in the “ProjectPortfolio.Clustering” namespace

<i>Class Name</i>	<i>Description</i>	<i>Source File Name</i>
SOMBaseMap	This class models SOM map and the Cells View	SOMBaseMap.cs
SOMMapCluster	This class models the Clusters View	SOMMapCluster.cs
SOMMapDataItem	This class models project items	SOMMapDataItem.cs
SOMMapUnit	This class models each cell of the map	SOMMapUnit.cs

SOMObjectMapper	This class maps data items on the Cells View	SOMObjectMapper.cs
SOMPak	This class wraps the SOM_PAK C program	SOMPak.cs
SOMProjectedMap	This class models the Items View	SOMProjectedMap.cs
SOMVectorDimension	This class models a project dimension (attribute) with its options in SOM	SOMVectorDimension.cs
SOMVectorEngine	This class prepares a group of project attributes with settings to use in SOM clustering and visual exploration.	SOMVectorEngine.cs

### *SOMBaseMap.cs*

```

using System;
using System.Collections.Generic;
using System.Text;
using System.Collections;
using System.Data;
using System.Data.OleDb;

namespace ProjectPortfolio.Clustering
{
    public class SOMBaseMap
    {
        public String MapType;
        public SOMMapUnit[] MapUnits;    //array of map units of type "SOMMapUnit"
        public int MapSizeX;            //x is the number of columns, map width
        public int MapSizeY;            //y is the number of rows, map height
        public DateTime GenerationDate;
        public SOMVectorDimension[] VectorMetadata; // vector metadata: attribute name, corresponding column in database,
weight and scale
        public ArrayList ClusterSets = new ArrayList(); // user defined map clusters

        private String mapId;
        public String MapId
        {
            get { return mapId; }
        }
        public int NumberOfMapUnits
        {
            get { return MapSizeX * MapSizeY; }
        }

        public SOMBaseMap() //new SOM base map with a new map id
        {
            DateTime now = DateTime.Now;
            mapId = "SOMsx" + MapSizeX + "y" + MapSizeY + "dt" + now.Year + now.DayOfYear + (now.Hour * 3600 + now.Minute *
60 + now.Second);
            GenerationDate = now;
        }

        public SOMBaseMap(String mid) //existing som base map with an existing map id
        {

```

```

        this.mapId = mid;
    }

    public void SetMap(int mapx, int mapy, String type, SOMVectorDimension[] meta) //constructing an empty map - units
    without values
    {
        MapSizeX = mapx;
        MapSizeY = mapy;
        MapType = type;
        VectorMetadata = meta;

        MapUnits = new SOMMapUnit[NumberOfMapUnits];
        for (int i = 0; i < NumberOfMapUnits; i++)
            MapUnits[i] = new SOMMapUnit(i, VectorMetadata.Length);
    }

    public int AddDefaultClusterSet()
    {
        SOMMapCluster c = new SOMMapCluster(0, "default new cluster", -1);
        ArrayList cset = new ArrayList();
        cset.Add(c);
        this.ClusterSets.Add(cset);
        AssignMapUnitsToDefaultCluster();
        return this.ClusterSets.Count-1;
    }

    public void BuildMapCluster(int clusterSetId) //build "SOMMapCluster"s in a given cluster set
    {
        ArrayList set = ClusterSets[clusterSetId] as ArrayList;
        //get the cluster id for each map units, reorganize them and build "SOMMapCluster"
        foreach (SOMMapCluster c in set)
        {
            c.ClusterItems.Clear();
        }
        for (int i = 0; i < MapUnits.Length; i++)
        {
            int c = MapUnits[i].ClusterNumber;
            SOMMapCluster cluster = set[c] as SOMMapCluster;
            cluster.AddItem(MapUnits[i]);
        }
        this.CalculateClusterVector(clusterSetId);
    }

    public void CalculateClusterVector(int clusterSetId)
    {
        //calculate cluster vector value, based on even average
        ArrayList set = ClusterSets[clusterSetId] as ArrayList;
        for (int m = 0; m < set.Count; m++)
        {
            SOMMapCluster c = set[m] as SOMMapCluster;
            c.CalculateVectorValues();
        }
    }

    public void CalculateAllClusterVector()
    {
        //calculate all cluster vector value, based on even average
        for (int m = 0; m < ClusterSets.Count; m++)
    }

```

```

    {
        CalculateClusterVector(m);
    }
}

public double getDimMaxValue() //get the max value from all data items values
{
    double max = 0;
    for (int i = 0; i < VectorMetadata.Length; i++)
    {
        max=Math.Max(max,VectorMetadata[i].Max * VectorMetadata[i].Weight * VectorMetadata[i].Scale);
    }
    return max;
}

public void AssignMapUnitsToCluster(int clusterSetNo)
{
    ArrayList set = ClusterSets[clusterSetNo] as ArrayList;
    for (int i = 0; i < set.Count; i++)
    {
        SOMMapCluster cluster = set[i] as SOMMapCluster;
        for (int j = 0; j < cluster.ClusterItems.Count; j++)
        {
            SOMMapUnit unit = cluster.ClusterItems[j] as SOMMapUnit;
            unit.ClusterNumber = i;
        }
    }
}

public void AssignMapUnitsToDefaultCluster()
{
    for (int i = 0; i < MapUnits.Length; i++)
    {
        MapUnits[i].ClusterNumber = 0;
    }
}
}
}
}
}

```

### ***SOMMapCluster.cs***

```

using System;
using System.Collections.Generic;
using System.Text;
using System.Collections;

namespace ProjectPortfolio.Clustering
{
    public class SOMMapCluster
    {
        public int ClusterId;
        public String ClusterName;
        public int ClusterColor;
        public ArrayList ClusterItems = new ArrayList();
        public double[] VectorValues;
        //public int VectorLength;
    }
}

```



```

public SOMMapCluster(int len)
{
    // VectorLength = len;
}

public SOMMapCluster(int id, String name, int color)
{
    ClusterId = id;
    ClusterName = name;
    ClusterColor = color;
    //VectorLength = len;
}

public void AddItem(SOMMapUnit item)
{
    ClusterItems.Add(item);
}

public void CalculateVectorValues()
{
    if (ClusterItems.Count > 0) // if not items in the current cluster
    {
        int VectorLength = ((SOMMapUnit)ClusterItems[0]).VectorValues.Length;
        VectorValues = new double[VectorLength];
        foreach (SOMMapUnit item in ClusterItems)
        {
            for (int i = 0; i < VectorLength; i++)
            {
                VectorValues[i] += item.VectorValues[i];
            }
        }
        for (int i = 0; i < VectorLength; i++)
        {
            VectorValues[i] = VectorValues[i] / ClusterItems.Count;
        }
    }
}

public override string ToString()
{
    return ClusterName;
}
}
}

```

### *SOMMapDataItem.cs*

```

using System;
using System.Collections.Generic;
using System.Text;
using System.Collections;
using System.Data;

namespace ProjectPortfolio.Clustering
{
    public class SOMMapDataItem
    {

```

```

    public String DataItemGroups;
    public double[] SOMVector;
    //public ProjectObject project;
    public String ItemId;
    public String ItemName;

    public DataRow BusinessObject;
}
}

```

### *SOMMapUnit.cs*

```

using System;
using System.Collections;
using System.Text;

namespace ProjectPortfolio.Clustering
{
    public class SOMMapUnit
    {
        public int UnitNumber;
        public int ClusterNumber;
        public double[] VectorValues;

        public SOMMapUnit(int number, int size)
        {
            UnitNumber = number;
            ClusterNumber = 0;
            VectorValues = new double[size];
        }

        public void SetVectorValues(double[] values)
        {
            VectorValues = values;
        }
    }
}

```

### *SOMObjectMapper.cs*

```

using System;
using System.Collections.Generic;
using System.Text;
using System.Collections;

namespace ProjectPortfolio.Clustering
{
    public class SOMObjectMapper
    {
        public static SOMProjectedMap CreateProjectedMap(SOMBaseMap baseMap, Hashtable DataItems) //mapping processing
        {
            SOMProjectedMap ProjectedMap = new SOMProjectedMap(baseMap);
            foreach (String key in DataItems.Keys)
            {
                SOMMapDataItem item = (SOMMapDataItem)DataItems[key];
                double[] itemValues = item.SOMVector;
                int len = itemValues.Length;
            }
        }
    }
}

```

```

//double[] mapCellValues = new double[len];
double minDistance = 100000; //initial value needs to be large enough
int minCell=0;

//for each unit in the base map
for (int x = 0; x < ProjectedMap.NumberOfMapUnits; x++)
{
    double distance = CalculateDistance(itemValues, ProjectedMap.BaseMap.MapUnits[x].VectorValues);
    if (minDistance > distance)
    {
        minDistance = distance;
        minCell = x;
    }
}

//record the item position to SOMProjectedMap
ProjectedMap.AddDataItem(item,minCell);
}
return ProjectedMap;
}

private static double CalculateDistance(double[] source, double[] target)
{
    double distance = 0;
    for (int i = 0; i < source.Length; i++)
    {
        distance += Math.Pow(source[i] - target[i], 2);
    }
    distance = Math.Sqrt(distance);
    return distance;
}
}
}

```

### ***SOMPak.cs***

```

using System;
using System.Collections.Generic;
using System.Text;
using System.IO;
using System.Data;
using System.Data.OleDb;

namespace ProjectPortfolio.Clustering
{
    // This is a class wrapping the original C based SOM_PAK program
    class SOMPak
    {
        public double[][] TrainingData; //input training data in 2d array

        // SOM settings: SOM_PAK command parameters of randinit.exe/lininit.exe, vsom.exe
        public String Radius;
        public String Iteration;
        public String Neighbor;
        public String Alpha;

        // SOM map settings
        public SOMBaseMap map;
    }
}

```

```

// environment settings
public String WorkingDirectory;
public String FileDirectory;
public String InputDataFile;
public String InitialMapFile;
public String TrainedMapFile;

public SOMPak()
{
    WorkingDirectory = "SOM_PAK/";
    FileDirectory = WorkingDirectory+"Files/";
    InputDataFile = "som_datavector.txt";
    InitialMapFile = "basemap_init.txt";
    TrainedMapFile = "basemap_trained.txt";
}

//read data from database and generate an input text file for my_som_pak.
public void GenerateSOMPakTrainingDataFile()
{
    StreamWriter writer = new StreamWriter(FileDirectory+InputDataFile);
    writer.WriteLine(map.VectorMetadata.Length); //number of dimensions/vector length

    StringBuilder sb = new StringBuilder();
    foreach (double[] vector in TrainingData)
    {
        String line="";
        for (int i=0; i<vector.Length;i++)
            line+=vector[i] + " ";
        // if fixed
        // line+="fixed=1,1"
        sb.AppendLine(line.TrimEnd());
    }

    writer.Write(sb.ToString());
    writer.Close();
}

//Load SOMPAK trained base map(a text file) to the data model of SOMBaseMap
public SOMBaseMap LoadSOMBaseMap()
{
    StreamReader reader = new StreamReader(FileDirectory + TrainedMapFile);
    String s = reader.ReadLine();
    String[] separator = { " " };
    String[] mapSetting=s.Split(separator, StringSplitOptions.RemoveEmptyEntries);
    //int mapSizeX = Int32.Parse(mapSetting[2]);
    //int mapSizeY = Int32.Parse(mapSetting[3]);
    //int vectorLength=Int32.Parse(mapSetting[0]);

    int counter = 0;
    //map.InitializeCells();
    while (!reader.EndOfStream)
    {
        s=reader.ReadLine(); //read a line of values (one cell)
        String[] cellValues = s.Split(separator, StringSplitOptions.RemoveEmptyEntries);
        // assign value
    }
}

```

```

    for (int j = 0; j < cellValues.Length;j++)
    {
        map.MapUnits[counter].VectorValues[j] = Double.Parse(cellValues[j]);
    }

    counter++;
}

return map;
}

public SOMBaseMap RunSOMPak() // run the SOM_PAK exe file lininit.exe/randinit.exe and vsom.exe
{
    this.GenerateSOMPakTrainingDataFile();
    this.RunSOMPakInit();
    this.RunSOMPakVsom();

    return this.LoadSOMBaseMap();
}

public void RunSOMPakInit()
{
    String cmdArgs = this.PrepareInitArgs();
    System.Diagnostics.Process process1 = new System.Diagnostics.Process();
    process1.StartInfo.FileName = this.WorkingDirectory+"randinit.exe";
    process1.StartInfo.Arguments = cmdArgs;
    process1.StartInfo.WindowStyle = System.Diagnostics.ProcessWindowStyle.Minimized;
    process1.Start();
    process1.WaitForExit();
}

public void RunSOMPakVsom()
{
    String cmdArgs = this.PrepareVSOMArgs();
    System.Diagnostics.Process process1 = new System.Diagnostics.Process();
    process1.StartInfo.FileName = this.WorkingDirectory + "vsom.exe";
    process1.StartInfo.Arguments = cmdArgs;
    process1.Start();
    process1.WaitForExit();
}

public String PrepareInitArgs()
{
    String initArgs = "-xdim "+this.map.MapSizeX+" -ydim " + map.MapSizeY+" -din "+ FileDirectory+InputDataFile+" -cout "+
FileDirectory+InitialMapFile
        + " -neigh bubble -topol "+map.MapType;
    return initArgs;
}

public String PrepareVSOMArgs()
{
    String vsomArgs = "-din " + FileDirectory + InputDataFile + " -cin " + FileDirectory + InitialMapFile + " -cout " +
FileDirectory+TrainedMapFile
        + " -rlen " + this.Iteration + " -alpha " + this.Alpha + " -radius " + this.Radius;
    return vsomArgs;
}
}

```

```
}

```

### *SOMProjectedMap.cs*

```
using System;
using System.Collections.Generic;
using System.Text;
using System.Collections;
using System.Data;
using ProjectPortfolio.Utility;

namespace ProjectPortfolio.Clustering
{
    public class SOMProjectedMap: SOMBaseMap
    {
        //public ArrayList MapItems;
        public SOMBaseMap BaseMap; //base map component
        public ArrayList[] ProjectedMapUnits; //map units of the projected map, corresponding to the base map units, holder of
        SOMMapDataItem
        public SOMMapDataItem[] DataItems; // data items to be mapped

        public String ProjectedMapId;

        public SOMProjectedMap(SOMBaseMap baseMap)
        {
            BaseMap = baseMap;
            MapSizeX = BaseMap.MapSizeX;
            MapSizeY = BaseMap.MapSizeY;
            MapType = BaseMap.MapType;
            DataItems = new SOMMapDataItem[BaseMap.MapSizeX * BaseMap.MapSizeY];

            // build up projected map units
            ProjectedMapUnits = new ArrayList[this.NumberOfMapUnits];
        }

        public void AddDataItem(SOMMapDataItem project, int position)
        {
            if (ProjectedMapUnits[position] == null)
                ProjectedMapUnits[position] = new ArrayList();
            ProjectedMapUnits[position].Add(project);
        }

        public double GetDataItemsMaxValue() //get the max value from all data items values
        {
            double max=0;
            for (int i = 0; i < DataItems.Length;i++ )
                for (int j=0;j<DataItems[i].SOMVector.Length;j++)
                    max=Math.Max(max, DataItems[i].SOMVector[j]);
            return max;
        }
    }
}

```

### *SOMVectorDimension.cs*

```
using System;

```

```

using System.Collections.Generic;
using System.Text;

namespace ProjectPortfolio.Clustering
{
    public class SOMVectorDimension
    {
        public String DimensionName;
        public String DatabaseColumn;
        public double Weight;
        public double Scale;
        public double Max;
        public double Min;

        public SOMVectorDimension() { }

        public SOMVectorDimension(String name, String dbCol, double weight, double scale, double max)
        {
            this.DimensionName = name; //full name
            this.DatabaseColumn = dbCol; //database column
            this.Weight = weight;
            this.Scale = scale;
            this.Max = max;
        }
    }
}

```

### *SOMVectorEngine.cs*

```

using System;
using System.Collections.Generic;
using System.Text;
using System.Data;
using System.Collections;

namespace ProjectPortfolio.Clustering
{
    // this class will transform source data into SOM vectors, applying the definition in vector dimension metadata
    class SOMVectorEngine
    {
        public SOMVectorDimension[] VectorMetadata;

        public SOMVectorEngine(SOMVectorDimension[] dimensions)
        {
            VectorMetadata=dimensions;
        }

        // return a vector table for SOM data input
        public double[][] CreateSOMTrainingDataVectors(DataSet sourceData)
        {
            DataTable dt = sourceData.Tables[0];
            double[][] trainingSet = new double[dt.Rows.Count][];

            //Construct each item
            for (int i = 0; i < dt.Rows.Count;i++) //construct each item value vector
            {
                trainingSet[i]=this.CreateASOMVector(dt.Rows[i]);
            }
        }
    }
}

```

```

        return trainingSet;
    }

    public void CreateASOMVector(SOMMapDataItem item)
    {
        item.SOMVector = new double[VectorMetadata.Length];
        for (int i=0;i<VectorMetadata.Length;i++)
        {
            Object o=item.BusinessObject[VectorMetadata[i].DatabaseColumn];
            item.SOMVector[i] = Double.Parse(o.ToString()) * VectorMetadata[i].Weight * VectorMetadata[i].Scale;
        }
    }

    public double[] CreateASOMVector(DataRow row)
    {
        double[] vector = new double[VectorMetadata.Length];
        for (int i = 0; i < VectorMetadata.Length; i++)
        {
            String value = row[VectorMetadata[i].DatabaseColumn].ToString();
            vector[i] = Double.Parse(value) * VectorMetadata[i].Weight * VectorMetadata[i].Scale;
        }
        return vector;
    }
}
}
}

```

## 5. Classes in the “ProjectPortfolio.Utility” namespace

<i>Class Name</i>	<i>Description</i>	<i>Source File Name</i>
DatabaseUtility	This class servers as the layer to between the database and generic data table structures	SOMBaseMap.cs
ORMDataTransformer	This class transforms the generic database tables to specific business objects	SOMMapCluster.cs

### *DatabaseUtility.cs*

```

using System;
using System.Collections.Generic;
using System.Text;
using System.IO;
using System.Data;
using System.Data.OleDb;
using ProjectPortfolio.Clustering;

namespace ProjectPortfolio.Utility
{
    class DatabaseUtility
    {
        public static String DBConnectionString = "Provider=Microsoft.Jet.OLEDB.4.0;Data Source=ProjectPortfolio.mdb;User
Id=admin;Password=";
    }
}

```



```

// SOM data -----
#region SOM Data methods

public static DataTable GetSOMBaseMapTable(String MapId)
{
    DataTable BaseMapTable = new DataTable();
    String CommandText = "select * from SOMBaseMap where BaseMapId = '" + MapId + "'";
    OleDbDataAdapter adapter = new OleDbDataAdapter(CommandText, DBConnectionString);
    adapter.Fill(BaseMapTable);

    return BaseMapTable;
}

public static DataTable GetSOMBaseMapCellsDataTable(String mapId)
{
    DataTable BaseMapCellsTable = new DataTable();
    String CommandText = "select * from SOMBaseMapCells where SOMBaseMapId='" + mapId + "' order by SOMBaseMapUnitNumber";
    OleDbDataAdapter adapter = new OleDbDataAdapter(CommandText, DBConnectionString);
    adapter.Fill(BaseMapCellsTable);

    return BaseMapCellsTable;
}

public static DataTable GetSOMBaseMapClusterSetsDataTable(String mapId)
{
    DataTable BaseMapClusterSetsTable = new DataTable();
    String CommandText = "select * from ClusterSets where SOMMapId='" + mapId + "' order by ClusterSetId";
    OleDbDataAdapter adapter = new OleDbDataAdapter(CommandText, DBConnectionString);
    adapter.Fill(BaseMapClusterSetsTable);

    return BaseMapClusterSetsTable;
}

public static DataTable GetAllBaseMapsDataTable() //get all base maps basic information from database
{
    DataTable BaseMapsTable = new DataTable();
    String ConnectionString = DBConnectionString;
    String CommandText = "select * from SOMBaseMap order by GeneratedDate";
    OleDbDataAdapter adapter = new OleDbDataAdapter(CommandText, ConnectionString);
    adapter.Fill(BaseMapsTable);

    return BaseMapsTable;
}

//store the base map to database
public static void StoreSOMBaseMap(SOMBaseMap baseMap)
{
    String columns="";
    String weights="";
    String scalings="";

    foreach (SOMVectorDimension dim in baseMap.VectorMetadata)
    {
        columns += dim.DatabaseColumn+",";
        weights+=dim.Weight+",";
        scalings+=dim.Scale+",";
    }
}

```

```

OleDbConnection con = new OleDbConnection();
con.ConnectionString = DBConnectionString;
OleDbCommand cmd = new OleDbCommand();
cmd.CommandText = "insert into SOMBaseMap values (" + baseMap.MapId + "," +
    + baseMap.GenerationDate + "," + baseMap.MapSizeX + "," + baseMap.MapSizeY + "," + baseMap.MapType + "," +
    + baseMap.VectorMetadata.Length + "," + columns + "," + weights + "," + scalings + ")";
cmd.Connection = con;
con.Open();
cmd.ExecuteNonQuery();

for (int i = 0; i < baseMap.NumberOfMapUnits; i++)
{
    double[] values = baseMap.MapUnits[i].VectorValues;
    String value="";
    for (int k = 0; k < values.Length; k++)
    {
        value += values[k] + " ";
    }
    cmd.CommandText = "insert into SOMBaseMapCells values (" + baseMap.MapId + "," + i + "," + value.Trim() + ")";
    cmd.ExecuteNonQuery();
}
con.Close();
}
#endregion SOM Data methods

// business data -----

#region Business Data methods

public static DataSet GetProjectDataset() //read selected projects data from database to mamory(a DataSet)
{
    DataSet ds = new DataSet();
    OleDbConnection con = new OleDbConnection();
    con.ConnectionString = DBConnectionString;
    String cmd = "select * from ObjectItems order by ItemId";

    OleDbDataAdapter da = new OleDbDataAdapter(cmd, con);
    da.Fill(ds);

    return ds;
}

public static DataTable GetDimensionsDataTable()
{
    DataTable DimensionsTable = new DataTable();
    String CommandText = "select * from DataDimensions";
    OleDbDataAdapter adapter = new OleDbDataAdapter(CommandText, DBConnectionString);
    adapter.Fill(DimensionsTable);

    return DimensionsTable;
}

public static String GetProjectDetails(String pname)
{

```

```

DataTable pTable = new DataTable();
String CommandText = "select * from Projects where Name='"+pname+"'";
OleDbDataAdapter adapter = new OleDbDataAdapter(CommandText, DBConnectionString);
adapter.Fill(pTable);

string html="";
if (pTable.Rows.Count > 0)
{
    for (int i = 0; i < pTable.Columns.Count; i++)
    {
        html+=pTable.Columns[i].ColumnName + ": " + pTable.Rows[0][i].ToString() + "<br />";
    }
}
else
    html = "<p>Detailed project information will be here: title, budget, description, status, etc. - from database</p>";
return html;
}

#endregion Business Data methods
}
}

```

### *ORMDataTransformer.cs*

```

using System;
using System.Collections.Generic;
using System.Collections;
using System.Text;
using System.Data;
using ProjectPortfolio.Clustering;
using System.Xml;
using ProjectPortfolio.Clustering;

namespace ProjectPortfolio.Utility
{
    public class ORMDataTransformer
    {
        public static Hashtable CreateSOMMapDataItemHashtable(DataSet ds)
        {
            Hashtable hs = new Hashtable();
            SOMMapDataItem data;

            foreach (DataRow dr in ds.Tables[0].Rows)
            {
                data = new SOMMapDataItem();
                data.BusinessObject = dr;
                data.ItemName = dr[0].ToString(); //assuming project id (primary key) to be the first column.
                hs.Add(data.ItemName,data);
            }
            return hs;
        }

        // construct a SOMBaseMap object from relational data
        public static SOMBaseMap CreateSOMBaseMap(String MapId)
        {
            SOMBaseMap baseMap;
            DataRow dr = DatabaseUtility.GetSOMBaseMapTable(MapId).Rows[0];

```

```

int sizeX = Int32.Parse(dr["MapSizeX"].ToString());
int sizeY = Int32.Parse(dr["MapSizeY"].ToString());
String maptype = dr["MapType"].ToString();
int len = Int32.Parse(dr["VectorLength"].ToString());
String dimensions = dr["VectorDimensions"].ToString();
String weight = dr["VectorWeights"].ToString();
String scaling = dr["VectorScalings"].ToString();

String[] dimCols = dimensions.Split(',');
String[] weights = weight.Split(',');
String[] scalings = scaling.Split(',');

DataTable dimTable=DatabaseUtility.GetDimensionsDataTable();
DataView dimView = dimTable.DefaultView;
dimView.Sort = "DimensionName";

//construct dimensions
SOMVectorDimension[] meta = new SOMVectorDimension[len];
for (int i = 0; i < len; i++)
{
    int rownumber=dimView.Find(dimCols[i]);
    meta[i] = new SOMVectorDimension(dimView[rownumber]["DimensionFullName"].ToString(), dimCols[i],
Double.Parse(weights[i]), Double.Parse(scalings[i]), Double.Parse(dimView[rownumber]["DataMax"].ToString()));
}

baseMap = new SOMBaseMap(MapId);
baseMap.SetMap(sizeX, sizeY, maptype, meta);

//load map unit values

DataTable dt = DatabaseUtility.GetSOMBaseMapCellsDataTable(MapId);
foreach (DataRow dr2 in dt.Rows)
{
    int location = Int32.Parse(dr2["SOMBaseMapUnitNumber"].ToString());
    String value = dr2["UnitValues"].ToString();

    String[] separator ={ " " };
    String[] values = value.Split(separator, StringSplitOptions.RemoveEmptyEntries);
    for (int i = 0; i < values.Length; i++)
        baseMap.MapUnits[location].VectorValues[i] = Double.Parse(values[i]);
}

//build cluster sets

DataTable dtClusterSets = DatabaseUtility.GetSOMBaseMapClusterSetsDataTable(MapId);
foreach (DataRow dr3 in dtClusterSets.Rows)
{
    ArrayList clusterSet = new ArrayList();
    String clustersXML=dr3["Clusters"].ToString();
    XmlDocument xml = new XmlDocument();
    xml.LoadXml(clustersXML);
    XmlElement root = xml.DocumentElement;
    foreach (XmlNode clusterXML in root.ChildNodes)
    {
        int clusterId=Int32.Parse(clusterXML.Attributes["id"].Value);
        String clusterName = clusterXML.Attributes["name"].Value;
        int clusterColor = Int32.Parse(clusterXML.Attributes["color"].Value);
    }
}

```

```

String units = clusterXML.FirstChild.InnerText; //units in a cluster
SOMMapCluster cluster = new SOMMapCluster(clusterId, clusterName,clusterColor);

String[] unitsArray = units.Split(',');
for (int i = 0; i < unitsArray.Length; i++)
{
    int unit = Int32.Parse(unitsArray[i]);
    cluster.AddItem(baseMap.MapUnits[unit]);
}
clusterSet.Add(cluster);
}
baseMap.ClusterSets.Add(clusterSet);
}

baseMap.CalculateAllClusterVector();

return baseMap;
}

public static String GetClusterSetXML(ArrayList set)
{
    XmlDocument xml = new XmlDocument();
    xml.AppendChild(xml.CreateElement("ClusterSet"));
    XmlElement root = xml.DocumentElement;
    foreach (SOMMapCluster cluster in set)
    {
        XmlElement clusterElement = xml.CreateElement("cluster");
        clusterElement.SetAttribute("id",cluster.ClusterId.ToString());
        clusterElement.SetAttribute("name", cluster.ClusterName);
        clusterElement.SetAttribute("color", cluster.ClusterColor.ToString());

        String units="";
        foreach (SOMMapUnit unit in cluster.ClusterItems)
        {
            units += unit.UnitNumber + ",";
        }
        if (units.Length>0)
            units = units.Substring(0, units.Length - 1);

        XmlElement unitsElement = xml.CreateElement("units");
        unitsElement.AppendChild(xml.CreateTextNode(units));

        clusterElement.AppendChild(unitsElement);
        root.AppendChild(clusterElement);
    }
    return xml.InnerXml;
}
}
}

```

## 6. Classes in the “ProjectPortfolio.UI” namespace

<i>Source File Name</i>	<i>Description</i>
FormChangeCluster.cs	The interface to manually assign clusters

FormClustering.cs	The interface to prepare data and settings to execute SOM clustering
FormClusterSummary.cs	The interface to give a summary of clusters with details
FormComparison.cs	The interface to compare individual objects based on profile charts
FormFocusGroup.cs	The interface to define project groups (sub-portfolios)
FormItemDetail.cs	The interface to display details of a project
FormNewProjection.cs	The interface to selected saved SOM map
FormVisualExploration.cs	The main interface to explore the SOM map and three views
ItemInfoPreviewChart.cs	The interface component to display a preview of a selected object
PanelFocusGroup.cs	The interface component to display selected project group legend on the left
PanelItemDetail.cs	The interface component to display a project's details
PanelSOMMap.cs	The interface component to display the SOM map and three views
ProjectPortfolioMDI.cs	The basic interface to manage the whole program

### ***FormChangeCluster.cs***

```

using System;
using System.Collections;
using System.Collections.Generic;
using System.ComponentModel;
using System.Data;
using System.Drawing;
using System.Text;
using System.Windows.Forms;
using ProjectPortfolio.Clustering;

namespace ProjectPortfolio.UI
{
    public partial class FormChangeCluster : Form
    {
        public FormChangeCluster()
        {
            InitializeComponent();
        }

        PanelSOMMap MainMapPanel;
        ArrayList clusterSet;
        int currentSetNumber;
        public FormVisualExploration formVisualExploration;
    }
}

```

```

private void btnNewCluster_Click(object sender, EventArgs e)
{
    colorDialog1.ShowDialog();
    Color co = colorDialog1.Color;
    SOMMapCluster c = new SOMMapCluster(comboClusters.Items.Count, "[new cluster]", co.ToArgb());
    clusterSet.Add(c);

    this.ShowClusterInfo(c);
    this.comboClusters.Items.Add(c);
    this.comboClusters.SelectedItem = c;
    this.comboClusters.Refresh();
}

private void FormChangeCluster_Load(object sender, EventArgs e)
{
}

public void LoadClusters(int clusterSetNo, PanelSOMMap panel)
{
    MainMapPanel = panel;
    currentSetNumber = clusterSetNo;
    clusterSet = MainMapPanel.BaseMap.ClusterSets[currentSetNumber] as ArrayList;

    foreach (SOMMapCluster cluster in clusterSet)
    {
        this.comboClusters.Items.Add(cluster);
    }
    comboClusters.SelectedIndex = 0;
    ShowClusterInfo(comboClusters.SelectedItem as SOMMapCluster);

    MainMapPanel.ClusterDrawingMode = clusterSet[0] as SOMMapCluster;
}

private void comboClusters_SelectedIndexChanged(object sender, EventArgs e)
{
    SOMMapCluster c = comboClusters.SelectedItem as SOMMapCluster;
    MainMapPanel.ClusterDrawingMode = c;
    ShowClusterInfo(c);
}

private void ShowClusterInfo(SOMMapCluster cluster)
{
    lblColor.BackColor = Color.FromArgb(cluster.ClusterColor);
    textClusterName.Text = cluster.ClusterName;
}

private void btnUpdateCluster_Click(object sender, EventArgs e)
{
    SOMMapCluster c = comboClusters.SelectedItem as SOMMapCluster;
    c.ClusterName = textClusterName.Text;
    c.ClusterColor = lblColor.BackColor.ToArgb();

    //update cluster members
    MainMapPanel.BaseMap.BuildMapCluster(currentSetNumber);
    MainMapPanel.ColorCellByCluster(currentSetNumber);
    formVisualExploration.PreviewClusters(currentSetNumber);
    MainMapPanel.ShowColorCodedMap(true);
}

```

```

}

private void btnReset_Click(object sender, EventArgs e)
{
    MainMapPanel.ColorCellByCluster(currentSetNumber);
    MainMapPanel.ShowColorCodedMap(true);
}

private void FormChangeCluster_FormClosed(object sender, FormClosedEventArgs e)
{
    MainMapPanel.ClusterDrawingMode = null;
}

private void btnViewClusterHint_Click(object sender, EventArgs e)
{
    if (comboClusterHint.SelectedIndex == 0)
        MainMapPanel.ColorCellByScale();
    else if (comboClusterHint.SelectedIndex == 1)
        MainMapPanel.ColorCellBySum();
    MainMapPanel.ShowColorCodedMap(true);
}
}
}

```

### *FormClustering.cs*

```

using System;
using System.Collections.Generic;
using System.ComponentModel;
using System.Data;
using System.Drawing;
using System.Text;
using System.Windows.Forms;
using ProjectPortfolio.Utility;
using ProjectPortfolio.Clustering;
using System.Collections;

namespace ProjectPortfolio.UI
{
    public partial class FormClustering : Form
    {
        public FormClustering()
        {
            InitializeComponent();
            sompak1 = new SOMPak();
        }

        SOMPak sompak1;
        SOMBaseMap basemap;
        SOMBaseMap TrainedBaseMap;
        DataSet SourceData;

        private void FormClustering_Load(object sender, EventArgs e)
        {
            comboPredefinedGroup.SelectedIndex = 0;

            DataTable dt = DatabaseUtility.GetDimensionsDataTable();

```



```

dt.Columns.Add("DimensionSelection");
dt.Columns.Add("DimensionOrder");
dt.Columns.Add("DimensionWeight");
dt.Columns.Add("DimensionScale");

dgvDimensions.AutoGenerateColumns = false;
this.dgvDimensions.DataSource = dt.DefaultView;
}

private void chkDisplayDim_CheckedChanged(object sender, EventArgs e)
{
    dgvDimensions.CurrentCell = null;
    DataView dv = (DataView)dgvDimensions.DataSource;
    if (chkDisplayDim.Checked)
        dv.RowFilter = "DimensionSelection = 'true'";
    else
        dv.RowFilter = null;
    dv.Sort = "DimensionSelection desc, DimensionOrder";
}

private void btnStartSOM_Click(object sender, EventArgs e)
{
    this.PrepareSOMPakSetting(); // 1. prepare SOMPak settings
    this.PrepareSOMBaseMap(); // 2. initialize a base map
    this.LoadDataVector(); // 3. load data into SOM vector

    // 5. start clustering process: including a) generate input file; b) call commandline program c) load output file into
    memory
    TrainedBaseMap = sompak1.RunSOMPAK();
    TrainedBaseMap.AddDefaultClusterSet();
    TrainedBaseMap.BuildMapCluster(0);

    if (chkSaveToDatabase.Checked) //5. save to database
        this.SaveToDatabase();

    MessageBox.Show("Done! Click OK to continue.");

    //6. optional: load clustering map visualization
    if (chkDisplayMap.Checked)
    {
        Hashtable dataItemTable = ORMDataTransformer.CreateSOMMapDataItemHashtable(SourceData);
        SOMVectorEngine engine1 = new SOMVectorEngine(TrainedBaseMap.VectorMetadata);
        foreach (String item in dataItemTable.Keys)
        {
            engine1.CreateASOMVector((SOMMapDataItem)dataItemTable[item]);
        }

        FormVisualExploration mapForm = new FormVisualExploration(TrainedBaseMap);
        mapForm.MdiParent = this.ParentForm;
        mapForm.SetDataItemPool(dataItemTable);
        mapForm.Show();
    }
}

private void PrepareSOMPakSetting()
{
    sompak1.Iteration = txtIteration.Text.Trim();
    sompak1.Neighbor = "bubble";
}

```

```

sompak1.Alpha = txtAlpha.Text.Trim();
sompak1.Radius = txtRadius.Text.Trim();
}
private void PrepareSOMBaseMap()
{
    String type = radioTypeHex.Checked?"hexa":"rect";
    basemap = new SOMBaseMap();

    DataView dv = (DataView)dgvDimensions.DataSource;
    dv.RowFilter = "DimensionSelection = true";
    int len = dv.Count;

    // prepare dimension meta data
    SOMVectorDimension[] dim = new SOMVectorDimension[len];
    for (int i=0; i<len; i++)
    {
        double weight = dv[i]["DimensionWeight"].ToString().Equals("")?1:Double.Parse(dv[i]["DimensionWeight"].ToString());
        double scale = dv[i]["DimensionScale"].ToString().Equals("") ? 1 : Double.Parse(dv[i]["DimensionScale"].ToString());
        dim[i] = new SOMVectorDimension(dv[i][2].ToString(), dv[i][0].ToString(), weight, scale,
Double.Parse(dv[i]["DataMax"].ToString()));
    }
    basemap.SetMap(Int32.Parse(txtSizeX.Text.Trim()), Int32.Parse(txtSizeY.Text.Trim()), type, dim);
    sompak1.map = basemap;
}
private void LoadDataVector()
{
    SourceData=DatabaseUtility.GetProjectDataset();
    SOMVectorEngine engine = new SOMVectorEngine(basemap.VectorMetadata);
    sompak1.TrainingData = engine.CreateSOMTrainingDataVectors(SourceData);
}
private void SaveToDatabase()
{
    DatabaseUtility.StoreSOMBaseMap(TrainedBaseMap);
}

#region testing functions
private void btnTest1_Click(object sender, EventArgs e)
{
    this.PrepareSOMBaseMap();
    this.LoadDataVector();
    sompak1.GenerateSOMPakTrainingDataFile();
}
private void btnTest2_Click(object sender, EventArgs e)
{
    this.PrepareSOMPakSetting();
    this.PrepareSOMBaseMap();
    this.LoadDataVector();
    MessageBox.Show(sompak1.PrepareInitArgs());
    sompak1.RunSOMPakInit();
    MessageBox.Show(sompak1.PrepareVSOMArgs());
    sompak1.RunSOMPakVsom();
}
private void btnTest3_Click(object sender, EventArgs e)
{
    this.PrepareSOMBaseMap();
    this.LoadDataVector();
    TrainedBaseMap = sompak1.LoadSOMBaseMap();
    String s="";

```

```

for (int i=0;i<TrainedBaseMap.MapUnits.Length;i++)
    for (int j=0;j<TrainedBaseMap.VectorMetadata.Length;j++)
        s+=TrainedBaseMap.MapUnits[i].VectorValues[j].ToString()+" ";
MessageBox.Show(s);
}
private void btnTest4_Click(object sender, EventArgs e)
{
    String s = "";
    foreach (DataGridViewRow row in dgvDimensions.Rows)
    {
        if (row.Cells[0].FormattedValue.ToString().Equals("True"))
        {
            s += row.Cells["colDimDBCol"].Value.ToString() + " ";
        }
    }
    MessageBox.Show(s);
}

```

#endregion

```

private void btnSelectGroup_Click(object sender, EventArgs e)
{
    dgvDimensions.CurrentCell = null;
    DataView dv = (DataView)dgvDimensions.DataSource;

    switch (comboPredefinedGroup.SelectedIndex)
    {
        case 0: dv.RowFilter = null; break;
        case 1: dv.RowFilter = "DimensionType = 'PriorityModelScore'"; break;
        case 2: dv.RowFilter = "DimensionType = 'Technology'"; break;
        case 3: dv.RowFilter = "DimensionType = 'Budget'"; break;
        case 4: dv.RowFilter = "DimensionType = 'HumanResources'"; break;
    }
    dv.Sort = "DimensionSelection desc, DimensionOrder";
}
}
}

```

### ***FormClusterSummary.cs***

```

using System;
using System.Collections;
using System.Collections.Generic;
using System.ComponentModel;
using System.Data;
using System.Drawing;
using System.Text;
using System.Windows.Forms;

using ProjectPortfolio.Clustering;
using dotnetCHARTING.WinForms;

namespace ProjectPortfolio.UI
{
    public partial class FormClusterSummary : Form
    {

```

```

public FormClusterSummary()
{
    InitializeComponent();
}

//SOMBaseMap map;
//SOMProjectedMap map;

private void FormClusterSummary_Load(object sender, EventArgs e)
{ }

public void LoadSummary(SOMProjectedMap map, int clusterSetId)
{
    InitializeClusterIndex(map.BaseMap, clusterSetId);
    InitializeClusterTabs(map, clusterSetId);
}

private void InitializeClusterTabs(SOMProjectedMap map, int clusterSetId)
{
    ArrayList set = map.BaseMap.ClusterSets[clusterSetId] as ArrayList;
    for (int i = 0; i < set.Count; i++)
    {
        SOMMapCluster c = set[i] as SOMMapCluster;
       TabPage tp1 = new TabPage();
        PanellItemDetail panellItemDetail = new PanellItemDetail();
        tp1.Controls.Add(panellItemDetail);
        panellItemDetail.Dock = DockStyle.Fill;
        panellItemDetail.VisualizeProfile( c.VectorValues, map.BaseMap.VectorMetadata);

        tp1.Text = c.ClusterName;
        String html="<h2>The following object items are in this cluster:</h2><ol>";
        foreach (SOMMapUnit u in c.ClusterItems)
        {
            if (map.ProjectedMapUnits[u.UnitNumber] != null)
            {
                foreach (SOMMapDataItem d in map.ProjectedMapUnits[u.UnitNumber])
                    html += "<li><a href=""> + d.ItemName + "</a></li>\n";
            }
        }
        html += "</ol>";

        panellItemDetail.SetDetails(c.ClusterName, html);
        tabControl1.TabPages.Add(tp1);
    }
}

private void InitializeClusterIndex(SOMBaseMap map, int clusterSetId)
{
    ArrayList set = map.ClusterSets[clusterSetId] as ArrayList;
    int numberOfClusters = set.Count;
    Chart[] ClusterPatternCharts = new Chart[numberOfClusters];
    for (int x = 0; x < numberOfClusters; x++)
    {
        SOMMapCluster cluster1 = set[x] as SOMMapCluster;
        double[] mapUnitVector = cluster1.VectorValues;

        ClusterPatternCharts[x] = new Chart();
        SeriesCollection chartDataSerials = new SeriesCollection();
    }
}

```

```

Series s = new Series();//s.Name = item.ItemName;
for (int i = 0; i < mapUnitVector.Length; i++)
{
    Element e = new Element();
    e.Name = "";
    e.YValue = mapUnitVector[i];
    s.Elements.Add(e);
}
chartDataSeries.Add(s);
ClusterPatternCharts[x].SeriesCollection.Add(chartDataSeries);
// chart settings
ClusterPatternCharts[x].Type = ChartType.Radar;
ClusterPatternCharts[x].YAxis.ClearValues = true;
ClusterPatternCharts[x].YAxis.Maximum = map.getDimMaxValue();
ClusterPatternCharts[x].DefaultElement.LabelTemplate = "<%=YValue,{0:#0.0}>";
ClusterPatternCharts[x].Height = 220;
ClusterPatternCharts[x].Width = 200;
ClusterPatternCharts[x].Top = x * (ClusterPatternCharts[x].Height - 36);
ClusterPatternCharts[x].Left = 0;
ClusterPatternCharts[x].LegendBox.Visible = false;
ClusterPatternCharts[x].DefaultElement.Color = Color.FromArgb(cluster1.ClusterColor);
ClusterPatternCharts[x].Title = cluster1.ClusterName;
ClusterPatternCharts[x].Anchor = (AnchorStyles.Top | AnchorStyles.Left | AnchorStyles.Right);

splitContainer1.Panel1.Controls.Add(ClusterPatternCharts[x]);
ClusterPatternCharts[x].BringToFront();
}
}

private void InitializeComparisonTab(SOMBaseMap map)
{
}
}
}

```

### *FormComparison.cs*

```

using System;
using System.Collections.Generic;
using System.ComponentModel;
using System.Data;
using System.Drawing;
using System.Text;
using System.Windows.Forms;
using System.Collections;

using dotnetCHARTING.WinForms;
using ProjectPortfolio.Clustering;
using ProjectPortfolio;

namespace ProjectPortfolio.UI
{
    public partial class FormComparison : Form
    {
        public FormComparison()
        {

```

```

InitializeComponent();
}

private void FormProjectDetailChart_Load(object sender, EventArgs e)
{
    chart1.DefaultSeries.GaugeType = GaugeType.Bars;
    chart1.DefaultSeries.DefaultElement.Transparency = 30;
    chart1.DefaultElement.LabelTemplate = "<%YValue,{0:#0.0}>";
}

SeriesCollection chartDataSeries;
ArrayList checkBoxItems = new ArrayList();
String[] dimCaptions;

public void SetDimensionCaption(SOMVectorDimension[] dims)
{
    //dimension names
    dimCaptions = new String[dims.Length];
    for (int i = 0; i < dims.Length; i++)
        dimCaptions[i] = dims[i].DimensionName;
}

public void ClearAllSeries()
{
    chart1.SeriesCollection.Clear();
}

public void AddDataSeries(String serialName, double[] serialValues, Color color)
{
    chartDataSeries = new SeriesCollection();

    //creating a serial
    Series s = new Series();
    s.Name = serialName;
    if (color != Color.Empty)
        s.DefaultElement.Color = color;

    for (int b = 0; b < serialValues.Length; b++)
    {
        Element e = new Element();
        e.Name = dimCaptions[b];
        e.YValue = serialValues[b];
        e.XValue = 1;
        //e.BubbleSize = myR.Next(50);
        s.Elements.Add(e);
    }
    // Set Different Colors for our Series
    //chartDataSeries[0].DefaultElement.Color = Color.FromArgb(49, 255, 49);

    CheckBox cb = new CheckBox();
    cb.Text = s.Name;
    cb.AutoSize = true;
    cb.Tag = s;
    cb.Checked = true;
    cb.CheckedChanged += new EventHandler(cb_CheckedChanged);

    checkBoxItems.Add(cb);
}

```

```

        this.flowLayoutPanel1.Controls.Add(cb);
        chart1.SeriesCollection.Add(s);

        this.RenderChart();
    }

    void cb_CheckedChanged(object sender, EventArgs e) //re-render chart based on data serials change
    {
        chart1.SeriesCollection.Clear();
        foreach (Object ob in checkBoxItems)
        {
            CheckBox cb=(CheckBox)ob;
            if (cb.Checked)
            {
                chart1.SeriesCollection.Add((Series)cb.Tag);
            }
        }
        this.RenderChart();
    }

    private void RenderChart()
    {
        chart1.RefreshChart();
    }

    private void checkedListBox1_SelectedIndexChanged(object sender, EventArgs e)
    {
        this.RenderChart();
    }

    public void ChangeChartType(ChartType type)
    {
        this.chart1.Type = type;
        this.RenderChart();
    }

    public void ChangeRadarLabelMode(RadarLabelMode mode)
    {
        this.chart1.RadarLabelMode = mode;
        this.RenderChart();
    }

    public void ChangeSeriesType(object type)
    {
        this.chart1.DefaultSeries.Type = type;
        this.RenderChart();
    }
}

#region: menu item clicks
// Menu item events -----
private void overlapRadarToolStripMenuItem_Click(object sender, EventArgs e)
{ this.ChangeChartType(ChartType.Radar); }
private void separateRadarToolStripMenuItem_Click(object sender, EventArgs e)
{ this.ChangeChartType(ChartType.Radars); }
private void overlappingPieToolStripMenuItem_Click(object sender, EventArgs e)
{ this.ChangeChartType(ChartType.PiesNested); }
private void separatePieToolStripMenuItem_Click(object sender, EventArgs e)
{ this.ChangeChartType(ChartType.Pies); }
private void groupByDimMenuItem_Click(object sender, EventArgs e)
{ this.ChangeChartType(ChartType.Combo); }

```

```

private void groupByObjectItemMenuItem_Click(object sender, EventArgs e)
{ this.ChangeChartType(ChartType.ComboSideBySide); }
private void horizontalBarChartTypeMenuItem_Click(object sender, EventArgs e)
{ this.ChangeChartType(ChartType.ComboHorizontal); }
private void gaugeBarsToolStripMenuItem_Click(object sender, EventArgs e)
{ this.ChangeChartType(ChartType.Gauges); }

private void normalToolStripMenuItem_Click(object sender, EventArgs e)
{ this.ChangeRadarLabelMode(RadarLabelMode.Normal); }
private void insideToolStripMenuItem_Click(object sender, EventArgs e)
{ this.ChangeRadarLabelMode(RadarLabelMode.Inside); }
private void outsideToolStripMenuItem_Click(object sender, EventArgs e)
{ this.ChangeRadarLabelMode(RadarLabelMode.Outside); }
private void angleToolStripMenuItem_Click(object sender, EventArgs e)
{ this.ChangeRadarLabelMode(RadarLabelMode.Angled); }

private void lineSeriesTypeMenuItem_Click(object sender, EventArgs e)
{ this.ChangeSeriesType(SeriesType.Line); }
private void lineAreSeriesTypeMenuItem_Click(object sender, EventArgs e)
{ this.ChangeSeriesType(SeriesType.AreaLine); }
private void barSeriesTypeMenuItem_Click(object sender, EventArgs e)
{ this.ChangeSeriesType(SeriesType.Bar); }

private void use3DToolStripMenuItem_Click(object sender, EventArgs e)
{ this.chart1.Use3D = use3DToolStripMenuItem.Checked; chart1.Refresh(); }

#endregion: menu item clicks
}
}

```

## *FormFocusGroup.cs*

```

using System;
using System.Collections.Generic;
using System.ComponentModel;
using System.Data;
using System.Drawing;
using System.Text;
using System.Windows.Forms;
using System.Collections;

using ProjectPortfolio.Visualization;

namespace ProjectPortfolio.UI
{
    public partial class FormFocusGroup : Form
    {
        public FormFocusGroup()
        {
            InitializeComponent();
        }

        public ArrayList PredefinedFocusGroups;
        public ArrayList SelectedFocusGroups;
        private FocusGroup currentGroup;
    }
}

```



```

private void FormFocusGroup_Load(object sender, EventArgs e)
{
    PredefinedFocusGroups = new ArrayList();
    this.LoadPredefinedFocusGroups();

    foreach (object o in SelectedFocusGroups)
    {
        this.listSelectedGroups.Items.Add(o);
    }
}

private void btnSelectGroup_Click(object sender, EventArgs e)
{
    this.listSelectedGroups.Items.Add(this.listPredefinedGroups.SelectedItem);
}

private void btnRemoveGroup_Click(object sender, EventArgs e)
{
    this.listSelectedGroups.Items.Remove(listSelectedGroups.SelectedItem);
}

private void listPredefinedGroups_SelectedIndexChanged(object sender, EventArgs e)
{
    currentGroup = (FocusGroup)this.listPredefinedGroups.SelectedItem;
    this.LoadGroupSetting(currentGroup);
}

private void listSelectedGroups_SelectedIndexChanged(object sender, EventArgs e)
{
    currentGroup = this.listSelectedGroups.SelectedItem as FocusGroup;
    this.LoadGroupSetting(currentGroup);
}

private void lblColor_Click(object sender, EventArgs e)
{
    colorDialog1.ShowDialog();
    lblColor.BackColor = colorDialog1.Color;
    currentGroup.Color = lblColor.BackColor;
}

private void btnOK_Click(object sender, EventArgs e)
{
    this.SelectedFocusGroups.Clear();
    foreach (object o in this.listSelectedGroups.Items)
    {
        this.SelectedFocusGroups.Add(o);
    }
    this.Hide();
}

private void LoadPredefinedFocusGroups()
{
    FocusGroup fg1 = new FocusGroup();
    fg1.GroupName = "Top 7 Priority";
    fg1.Color = Color.Yellow;

    String[] s = { "Banner Xtender Upgrade", "- Extreme Network Upgrade", "- HCIP",
        "- SAN (Storage Arrays) Migration", "Research Computing Scheduler",
        "RedDotMigration", "HRPeoplesoftSP1"};
}

```

```

fg1.AddItem(s);
PredefinedFocusGroups.Add(fg1);

FocusGroup fg2 = new FocusGroup();
fg2.GroupName = "Prioritized runner-ups";
fg2.Color = Color.Pink;
String[] s2 = {"CREATOR", "AntiSpam", "DataWarehousePlanning", "EasyView and Password Resets",
    "Develop & Implement FIS (Faculty Information System)", "NOC Configuration Database", "Server Registration Process",
    "IP Telephony", "eSirius"};
fg2.AddItem(s2);
PredefinedFocusGroups.Add(fg2);

FocusGroup fg3 = new FocusGroup();
fg3.GroupName = "JL's Projects";
fg3.Color = Color.Pink;
String[] s3 = {"Blackberry Enterprise Server", "AntiSpam", "Collaborative Suite - Investigation", "Server Registration
Process",
    "2007 Tech Fee", "GroupWise and File Server Storage Upgrades"};
fg3.AddItem(s3);
PredefinedFocusGroups.Add(fg3);

FocusGroup fg4 = new FocusGroup();
fg4.GroupName = "Classroom Support Projects";
fg4.Color = Color.Pink;
String[] s4 = {"Firewall-1 Implementation", "NOC Configuration Database", "Blackberry Enterprise Server", "Server
Registration Process",
    "Backup Expansion", "IP Telephony", "Wireless System Upgrade/Replacement"};
fg4.AddItem(s4);
PredefinedFocusGroups.Add(fg4);

foreach (object o in PredefinedFocusGroups)
{
    this.listPredefinedGroups.Items.Add(o);
}
this.listPredefinedGroups.SelectedIndex = 0;
}

private void LoadGroupSetting(FocusGroup group)
{
    if (group != null)
    {
        this.lblGroupName.Text = "Group Name: " + group.GroupName;
        this.lblColor.BackColor = group.Color;
        listMembers.Items.Clear();
        listMembers.Items.AddRange(group.Items.ToArray());
    }
}
}
}

```

### ***FormItemDetail.cs***

```

using System;
using System.Collections.Generic;
using System.ComponentModel;

```

```

using System.Data;
using System.Drawing;
using System.Text;
using System.Windows.Forms;

using ProjectPortfolio.Clustering;

namespace ProjectPortfolio.UI
{
    public partial class FormItemDetail : Form
    {
        public FormItemDetail()
        {
            InitializeComponent();
        }

        private void FormItemDetail_Load(object sender, EventArgs e)
        {
        }

        public void ShowDetails(SOMMapDataItem item, SOMVectorDimension[] dims)
        {
            panelDetail.SetDetails(item.ItemName, "<h1>Object Item: " + item.ItemName
+ "</h1>" + Utility.DatabaseUtility.GetProjectDetails(item.ItemName));
            panelDetail.VisualizeProfile(item.SOMVector, dims);
        }

        public void ShowDetails(SOMMapUnit item, SOMVectorDimension[] dims)
        {
            String content="";
            for (int i=0;i<item.VectorValues.Length;i++)
                content += item.VectorValues[i]+" ";

            panelDetail.SetDetails("Cell #" + item.UnitNumber, "<h1>Unit (Cell) #" + item.UnitNumber + "</h1><p>Unit pattern: " +
content + "<p>This unit has the following object items: ...");
            panelDetail.VisualizeProfile(item.VectorValues, dims);
        }

        public void ShowDetails(SOMMapCluster item, SOMVectorDimension[] dims)
        {
            panelDetail.SetDetails(item.ClusterName, item.ClusterItems.Count.ToString());
            panelDetail.VisualizeProfile(item.VectorValues, dims);
        }
    }
}

```

### ***FormNewProjection.cs***

```

using System;
using System.Collections.Generic;
using System.Collections;
using System.ComponentModel;
using System.Data;
using System.Drawing;
using System.Text;
using System.Windows.Forms;

```

```

using ProjectPortfolio.Clustering;
using ProjectPortfolio.Utility;

namespace ProjectPortfolio.UI
{
    public partial class FormNewProjection : Form
    {
        public FormNewProjection()
        {
            InitializeComponent();
        }

        private void FormNewProjection_Load(object sender, EventArgs e)
        {
            //load som base map list
            DataTable dt = DatabaseUtility.GetAllBaseMapsDataTable();
            dgvBaseMaps.DataSource = dt;
        }

        private void btnOK_Click(object sender, EventArgs e)
        {
            // 1. load base map from database
            String mapid=dgvBaseMaps.SelectedRows[0].Cells[0].Value.ToString();
            SOMBaseMap baseMap = Utility.ORMDataTransformer.CreateSOMBaseMap(mapid);
            // 2. load selected projects
            DataSet SourceData = DatabaseUtility.GetProjectDataset();
            Hashtable dataItemTable = ORMDataTransformer.CreateSOMMapDataItemHashtable(SourceData);

            // 3. generate vector data based on the SOM base map
            SOMVectorEngine engine1 = new SOMVectorEngine(baseMap.VectorMetadata);
            foreach (String item in dataItemTable.Keys)
            {
                engine1.CreateASOMVector((SOMMapDataItem)dataItemTable[item]);
            }
            // 4. display map
            FormVisualExploration mapForm = new FormVisualExploration(baseMap);
            mapForm.MdiParent = this.ParentForm;
            mapForm.SetDataItemPool(dataItemTable);
            mapForm.Show();
        }

        private void tbtnGenerateNewBaseMap_Click(object sender, EventArgs e)
        {
        }
    }
}

```

### ***FormVisualExploration.cs***

```

using System;
using System.Collections.Generic;
using System.ComponentModel;
using System.Data;
using System.Drawing;
using System.Text;

```

```

using System.Windows.Forms;
using System.Collections;

using ProjectPortfolio;
using ProjectPortfolio.Visualization;
using ProjectPortfolio.Clustering;
using dotnetCHARTING.WinForms;

namespace ProjectPortfolio.UI
{
    public partial class FormVisualExploration : Form
    {
        public FormVisualExploration(SOMBaseMap map) //a base map has to be set
        {
            InitializeComponent();
            this.MainMapPanel.BaseMap = map;
        }

        FormClusterSummary formClusterSummary;

#region: init methods

        private void FormVisualExploration_Load(object sender, EventArgs e)
        {
            this.DisplayMapInfo();           //display basic map info on the top left
            this.MainMapPanel.InitializeSOMMap(); //init som map on the right
            this.PopulateClusterSetCombo();
            this.PreviewClusters(0);        //load default cluster set info

            //init visual tool bar objects
            this.toolStripExploration.Items.Add(new ToolStripControlHost(this.barZoomMap));
        }
        private void DisplayMapInfo()
        {
            String info = "Map Size:\t"+MainMapPanel.BaseMap.MapSizeX + " by " +MainMapPanel.BaseMap.MapSizeY;
            info += "\nMap Type:\t"+MainMapPanel.BaseMap.MapType;
            info += "\nDimensions:";

            SOMVectorDimension[] dims = MainMapPanel.BaseMap.VectorMetadata;
            for (int i = 0; i < dims.Length; i++)
                info += "\n"+(i+1)+". "+dims[i].DimensionName;

            this.lblMapInfo.Text = info;

            //this.panellItemProfile.SetChartElementNames(panelMap.BaseMap.VectorMetadata);

            this.ProjectInfoPreviewChart.SetTitle("Project Profile");
            this.ClusterInfoPreviewChart.SetTitle("Cluster Profile");
            this.CellInfoPreviewChart.SetTitle("Map Unit Profile");
        }
        private void PopulateClusterSetCombo()
        {
            comboClusterSets.Items.Clear();
            for (int i=0;i<MainMapPanel.BaseMap.ClusterSets.Count;i++)
                this.comboClusterSets.Items.Add("Cluster Set "+i);
            comboClusterSets.SelectedIndex = 0;
        }
    }
}

```

#endregion: init methods

#region: preview object, unit, cluster info methods

```

    public void PreviewItemProfile(SOMMapDataItem item)
    {
        this.ProjectInfoPreviewChart.DisplayChart("Item: "+item.ItemName,
item.SOMVector,MainMapPanel.BaseMap.getDimMaxValue());
    }
    public void PreviewCellProfile(SOMMapUnit item)
    {
        this.CellInfoPreviewChart.DisplayChart("Cell: " + item.UnitNumber, item.VectorValues,
MainMapPanel.BaseMap.getDimMaxValue());
    }
    public void PreviewClusterProfile(int clusterNo)
    {
        ArrayList al= MainMapPanel.BaseMap.ClusterSets[comboClusterSets.SelectedIndex] as ArrayList;
        SOMMapCluster c = al[clusterNo] as SOMMapCluster;
        this.ClusterInfoPreviewChart.DisplayChart("Cluster: " + c.ClusterName, c.VectorValues,
MainMapPanel.BaseMap.getDimMaxValue());
    }

```

#endregion: preview object, unit, cluster info methods

```

//-----
private void DisplayFocusGroupsLegend() //display focus group legend on the left
{
    this.groupBoxFocusGroups.Controls.Clear();
    int i = 0;
    foreach (FocusGroup rg in MainMapPanel.FocusGroups)
    {
        System.Windows.Forms.CheckBox lbl=new System.Windows.Forms.CheckBox();
        lbl.BackColor=rg.Color;
        lbl.Text = rg.GroupName;
        lbl.AutoSize = true;
        lbl.Margin = new Padding(1,3,1,3);
        lbl.Top = i * lbl.Height + 20;
        this.groupBoxFocusGroups.Controls.Add(lbl);
        i++;
    }
}

```

//-----

#region: toolbar and menu methods

```

private void checkGridline_CheckedChanged(object sender, EventArgs e)
{
    MainMapPanel.ShowGridLines(checkGridline.Checked);
}
private void checkBasemap_CheckedChanged(object sender, EventArgs e)
{
    MainMapPanel.ShowBaseMap(this.checkBasemap.Checked);
}
private void checkProjectedmap_CheckedChanged(object sender, EventArgs e)
{
    MainMapPanel.ShowMapDataItem(this.checkProjectedmap.Checked);
    chkShowOnlyFocusSerials.Checked = false;
}

```

```

private void chkShowMapRegion_CheckedChanged(object sender, EventArgs e)
{
    //automatically divide map into regions/clusters
    MainMapPanel.ShowColorCodedMap(chkShowMapRegion.Checked);
}
private void chkShowOnlyFocusSerials_CheckedChanged(object sender, EventArgs e)
{
    if (toolStripButtonItems.Checked)
    {
        if (chkShowOnlyFocusSerials.Checked)
        {
            MainMapPanel.ShowMapDataItem(false);
            MainMapPanel.RenderFocusGroups();
        }
        else
            MainMapPanel.ShowMapDataItem(true);
    }
}

private void toolStripButtonItems_Click(object sender, EventArgs e)
{
    if (!this.toolStripButtonItems.Checked)
        MainMapPanel.ShowMapDataItem(false);
    else
    {
        if (chkShowOnlyFocusSerials.Checked)
        {
            MainMapPanel.ShowMapDataItem(false);
            MainMapPanel.RenderFocusGroups();
        }
        else
            MainMapPanel.ShowMapDataItem(true);
    }
}

private void toolStripButtonCells_Click(object sender, EventArgs e)
{
    MainMapPanel.ShowGridLines(this.toolStripButtonCells.Checked);
}
private void toolStripButtonCharts_Click(object sender, EventArgs e)
{
    MainMapPanel.ShowBaseMap(this.toolStripButtonCharts.Checked);
}
private void toolStripButtonClusters_Click(object sender, EventArgs e)
{
    MainMapPanel.ShowColorCodedMap(this.toolStripButtonClusters.Checked);
}
private void barZoomMap_Scroll(object sender, EventArgs e)
{
    MainMapPanel.ResizeMap(barZoomMap.Value);
}

private void menuItemShowExplorationTools_Click(object sender, EventArgs e)
{
    splitContainer_1.Panel1Collapsed = !menuItemShowExplorationTools.Checked;
}
private void saveMapToolStripMenuItem_Click(object sender, EventArgs e)
{
}
private void saveClustersToolStripMenuItem_Click(object sender, EventArgs e)
{
Clipboard.SetText(Utility.ORMDataTransformer.GetClusterSetXML(MainMapPanel.BaseMap.ClusterSets[comboClusterSets.SelectedIndex] as ArrayList));
    MessageBox.Show("The XML is copied to the clipboard!");
}
}

```

#endregion: toolbar and menu methods

```
//-----
#region additional form window methods
private void clustersToolStripMenuItem_Click(object sender, EventArgs e)
{
    PrepareClustersSummaryForm();
}

private void PrepareClustersSummaryForm()
{
    formClusterSummary = new FormClusterSummary();
    formClusterSummary.LoadSummary(MainMapPanel.ProjectMap, 0);
    formClusterSummary.Show();
}

private void btnFocusGroupForm_Click(object sender, EventArgs e)
{
    FormFocusGroup form = new FormFocusGroup();
    form.SelectedFocusGroups = MainMapPanel.FocusGroups;
    form.ShowDialog();

    MainMapPanel.RenderFocusGroups();
    this.DisplayFocusGroupsLegend();
}
#endregion additional form window methods

#region cluster exploration methods

public void PreviewClusters(int clusterSetId) //display all clusters info in the tool panel, cluster tab, for a given cluster set
{
    groupBoxClusters.Controls.Clear();
    ArrayList set = MainMapPanel.BaseMap.ClusterSets[clusterSetId] as ArrayList;
    int numberOfClusters = set.Count;
    Chart[] ClusterPatternCharts = new Chart[numberOfClusters];
    for (int x = 0; x < numberOfClusters; x++)
    {
        SOMMapCluster cluster1 = set[x] as SOMMapCluster;
        double[] mapUnitVector = cluster1.VectorValues;

        ClusterPatternCharts[x] = new Chart();
        SeriesCollection chartDataSeries = new SeriesCollection();
        Series s = new Series();//s.Name = item.ItemName;
        for (int i = 0; i < mapUnitVector.Length; i++)
        {
            Element e = new Element();
            e.Name = "";
            e.YValue = mapUnitVector[i];
            s.Elements.Add(e);
        }
        chartDataSeries.Add(s);
        ClusterPatternCharts[x].SeriesCollection.Add(chartDataSeries);
        // chart settings
        ClusterPatternCharts[x].Type = ChartType.Radar;
        ClusterPatternCharts[x].Height = 180;
        ClusterPatternCharts[x].Width = 200;
        ClusterPatternCharts[x].Top = x * (ClusterPatternCharts[x].Height - 36);
        ClusterPatternCharts[x].Left = 0;
        ClusterPatternCharts[x].LegendBox.Visible = false;
        ClusterPatternCharts[x].DefaultElement.Color = Color.FromArgb(cluster1.ClusterColor);
    }
}

```



```

        ClusterPatternCharts[x].Title = cluster1.ClusterName;

        groupBoxClusters.Controls.Add(ClusterPatternCharts[x]);
        ClusterPatternCharts[x].BringToFront();
    }
}

private void btnViewClusterSet_Click(object sender, EventArgs e)
{
    this.ShowSelectedClusterSet();
}

private void btnEditClusters_Click(object sender, EventArgs e)
{
    this.ShowSelectedClusterSet();

    FormChangeCluster form = new FormChangeCluster();
    form.formVisualExploration = this;
    form.LoadClusters(comboClusterSets.SelectedIndex, MainMapPanel);
    form.Show();
}

private void ShowSelectedClusterSet()
{
    int index = comboClusterSets.SelectedIndex;
    this.PreviewClusters(index);
    MainMapPanel.ColorCellByCluster(index);
    MainMapPanel.ShowColorCodedMap(true);
    MainMapPanel.CurrentClusterSet = index;
}

private void btnAddNewSet_Click(object sender, EventArgs e)
{
    int index=MainMapPanel.BaseMap.AddDefaultClusterSet();
    MainMapPanel.BaseMap.BuildMapCluster(index);
    PopulateClusterSetCombo();
    comboClusterSets.SelectedIndex = index;
}

#endregion cluster exploration methods

public void SetDataItemPool(Hashtable itemPool)
{
    this.MainMapPanel.DataItemPool = itemPool;
}

private void compareClustersToolStripMenuItem_Click(object sender, EventArgs e)
{
    ArrayList cset = MainMapPanel.BaseMap.ClusterSets[comboClusterSets.SelectedIndex] as ArrayList;
    for (int x = 0; x < cset.Count; x++)
    {
        SOMMapCluster cluster1 = cset[x] as SOMMapCluster;
        MainMapPanel.ComparePatterns(cluster1.ClusterName, cluster1.VectorValues,
Color.FromArgb(cluster1.ClusterColor));
    }
}

private void comboClusterSets_SelectedIndexChanged(object sender, EventArgs e)

```

```

    {
        MainMapPanel.CurrentClusterSet = comboClusterSets.SelectedIndex;
        MainMapPanel.BaseMap.AssignMapUnitsToCluster(comboClusterSets.SelectedIndex);
    }
}
}

```

### *ItemInfoPreviewChart.cs*

```

using System;
using System.Collections.Generic;
using System.ComponentModel;
using System.Drawing;
using System.Data;
using System.Text;
using System.Windows.Forms;

using dotnetCHARTING.WinForms;

namespace ProjectPortfolio.UI
{
    public partial class ItemInfoPreviewChart : UserControl
    {
        public ItemInfoPreviewChart()
        {
            InitializeComponent();
            this.chartProjectPreview.LegendBox.Visible = false;
            chartProjectPreview.YAxis.ClearValues = true;
        }

        public void SetTitle(String title)
        { this.labelHeader.Text = title; }

        public void DisplayChart(String header, double[] data, double max)
        {
            if (data != null)
            {
                Series defaultSeries = new Series();
                defaultSeries.Name = "";
                for (int b = 0; b < data.Length; b++)
                {
                    Element e = new Element();
                    e.Name = "";
                    defaultSeries.Elements.Add(e);
                }

                for (int b = 0; b < data.Length; b++)
                {
                    defaultSeries.Elements[b].YValue = data[b];
                }
                //chartDataSeries[0].DefaultElement.Color = Color.FromArgb(49, 255, 49);

                chartProjectPreview.SeriesCollection[0] = defaultSeries;
                chartProjectPreview.YAxis.Maximum = max;
                chartProjectPreview.DefaultElement.LabelTemplate = "<%=YValue,{0:#0.0}>";
                this.chartProjectPreview.Refresh();
            }
        }
    }
}

```

```

    }
    this.labelHeader.Text = header;
  }
}

```

### *PanelFocusGroup.cs*

(No significant code.)

### *PanelItemDetail.cs*

```

using System;
using System.Collections.Generic;
using System.ComponentModel;
using System.Drawing;
using System.Data;
using System.Text;
using System.Windows.Forms;

using dotnetCHARTING.WinForms;
using ProjectPortfolio.Clustering;

namespace ProjectPortfolio.UI
{
    public partial class PanelItemDetail : UserControl
    {
        public PanelItemDetail()
        {
            InitializeComponent();
        }

        Series defaultSerial;

        private void PanelItemDetail_Load(object sender, EventArgs e)
        {
            chartItem.LegendBox.Visible = false;
        }

        public void VisualizeProfile(double[] values, SOMVectorDimension[] dims)
        {
            defaultSerial = new Series();
            defaultSerial.Name = "";

            for (int b = 0; b < values.Length; b++)
            {
                Element e = new Element();
                e.Name = dims[b].DimensionName;
                e.XValue = 1;
                e.YValue = values[b];
                defaultSerial.Elements.Add(e);
            }
            // Set Different Colors
            //chartDataSeries[0].DefaultElement.Color = Color.FromArgb(49, 255, 49);
            chartItem.DefaultElement.LabelTemplate = "<math>\%YValue, \{0:\#0.0\}>";
        }
    }
}

```

```

        chartItem.SeriesCollection[0] = defaultSerial;
        chartItem.Refresh();
    }

    public void SetDetails(String header, String details)
    {
        this.lblHeader.Text = header;
        this.browserDetails.DocumentText = details;
    }

    public void Enlarge()
    {
        chartItem.RadarLabelMode = RadarLabelMode.Normal;
    }

    private void browserDetails_Navigating(object sender, WebBrowserNavigatingEventArgs e)
    {
        e.Cancel = true;
        FormItemDetail form = new FormItemDetail();
        form.Show();
    }
}

```

### *PanelSOMMap.cs*

```

using System;
using System.Collections.Generic;
using System.ComponentModel;
using System.Drawing;
using System.Data;
using System.Text;
using System.Windows.Forms;
using dotnetCHARTING.WinForms;
using System.Collections;

using ProjectPortfolio;
using ProjectPortfolio.Visualization;
using ProjectPortfolio.Clustering;

namespace ProjectPortfolio.UI
{
    public partial class PanelSOMMap : UserControl
    {
        public PanelSOMMap()
        {
            InitializeComponent();
        }
        // local default visual settings
        int panelMapWidth;
        int panelMapHeight;
        int panelCellSize;

        // map visual objects
        Panel[,] panelMapCells; // a visualized map is a panel (panelMap) with x*y map cells (smaller panels, a 2D array of panels)
        Chart[,] CellPatternCharts; // these are the visualization layer of the base map units: a small chart in each cell
        System.Windows.Forms.Label[,] CellIds;
    }
}

```

```

Color[,] CellColors;
Hashtable DataItemIconPool = new Hashtable(); // visualizing data items using icons

// other visual components
FormComparison formChart;
public SOMMapCluster ClusterDrawingMode; // -1 means off.
public int CurrentClusterSet;

// public associated map objects
public SOMBaseMap BaseMap;
public SOMProjectedMap ProjectedMap;
public Hashtable DataItemPool = new Hashtable(); // represents all data items to be displayed
public ArrayList FocusGroups = new ArrayList();

// -----

private void PanelSOMMap_Load(object sender, EventArgs e)
{
}

#region: map init

public void InitializeSOMMap()
{
    // 0.set visual parameters for the map
    this.panelMapWidth = BaseMap.MapSizeX;
    this.panelMapHeight = BaseMap.MapSizeY;
    this.panelCellSize = ProgramConfig.DefaultSOMMapCellSize;
    this.CellColors = new Color[panelMapHeight, panelMapWidth];
    this.CurrentClusterSet = 0;

    this.InitializeCells(); // 1. initializing map cell panels
    this.InitializeBaseMap(); // 2. preparing cell charts, projected items, and clusters
    this.InitializeClusters(); // 3. prepare clusters in the default cluster set
    this.InitializeDefaultProjectedMap(); // 4. prepared object items on the map

    //final default visual layer settings, configurable
    this.ResizeMap(this.panelCellSize);
    this.ShowMapDataItem(true);
}

private void InitializeCells()
{
    panelMapCells = new Panel[panelMapHeight, panelMapWidth];
    CellIds = new System.Windows.Forms.Label[panelMapHeight, panelMapWidth];
    for (int i = 0; i < panelMapHeight; i++)
    {
        for (int j = 0; j < panelMapWidth; j++)
        {
            panelMapCells[i, j] = new Panel();
            panelMapCells[i, j].Margin = new Padding(0);
            this.Controls.Add(panelMapCells[i, j]);
            panelMapCells[i, j].Tag = BaseMap.MapUnits[BaseMap.MapSizeX * i + j];
            panelMapCells[i, j].ContextMenuStrip = this.contextMenuStrip1;
            panelMapCells[i, j].MouseMove += new MouseEventHandler(DrawingMouseMoveEventHandler);
            panelMapCells[i, j].MouseEnter += new EventHandler(MapCell_MouseEnter);

            CellIds[i, j] = new System.Windows.Forms.Label();
            CellIds[i, j].Text = "" + (BaseMap.MapSizeX * i + j);
        }
    }
}

```

```

        CellIds[i, j].Visible = false;
        CellIds[i, j].AutoSize = true;
        panelMapCells[i, j].Controls.Add(CellIds[i, j]);
    }
}
} // initialize each cell with an ID label

private void InitializeBaseMap() // initialize each small charts in cells
{
    CellPatternCharts = new Chart[panelMapHeight, panelMapWidth];
    for (int x = 0; x < panelMapHeight; x++)
    {
        for (int y = 0; y < panelMapWidth; y++)
        {
            double[] mapUnitVector = BaseMap.MapUnits[BaseMap.MapSizeX * x + y].VectorValues;

            Chart chart1 = new Chart();
            SeriesCollection chartDataSeries = new SeriesCollection();
            Series s = new Series();//s.Name = item.ItemName;
            for (int i = 0; i < mapUnitVector.Length; i++)
            {
                Element e = new Element();
                e.Name = "";
                e.YValue = mapUnitVector[i];
                s.Elements.Add(e);
            }
            chartDataSeries.Add(s);
            chart1.SeriesCollection.Add(chartDataSeries);
            // chart settings
            chart1.Type = ChartType.Radar;
            chart1.Top = -40;
            chart1.Left = -55;
            chart1.LegendBox.Visible = false;
            chart1.YAxis.ClearValues = true;
            chart1.YAxis.Maximum = BaseMap.getDimMaxValue();
            chart1.YAxis.AlternateGridBackground.Color = Color.Transparent;
            chart1.DefaultElement.Transparency = 30;
            chart1.DefaultElement.Color = Color.SkyBlue;
            chart1.DefaultSeries.Line.Color = Color.Black;
            chart1.YAxis.ShowGrid = false;
            chart1.Tag = BaseMap.MapUnits[BaseMap.MapSizeX * x + y];
            chart1.ContextMenuStrip = this.contextMenuStrip1;

            chart1.MouseMove += new MouseEventHandler(DrawingMouseMoveEventHandler);
            chart1.MouseEnter += new EventHandler(MapCell_MouseEnter);
            chart1.ContextMenuStrip = contextMenuStrip1;

            CellPatternCharts[x, y] = chart1;
            panelMapCells[x, y].Controls.Add(chart1);
        }
    }
}

private void InitializeClusters()
{
    BaseMap.AssignMapUnitsToCluster(0);
    ColorCellByCluster(0);
}

```

```

private void InitializeDefaultProjectedMap() // build ProjectMap object; project each data item on the map and visualize
them
{
    // create a projected map object
    ProjectedMap = SOMObjectMapper.CreateProjectedMap(BaseMap, DataItemPool);

    // display projected map: 1. create a visual representation icon (Label) for each dataitem
    //2. add icon to the IconPool
    foreach (String key in DataItemPool.Keys)
    {
        SOMMapDataItem dataItem = (SOMMapDataItem)DataItemPool[key];
        System.Windows.Forms.Label itemIcon = new System.Windows.Forms.Label();//temp using Label
        itemIcon.AutoSize = true;
        itemIcon.Text = dataItem.ItemName;
        itemIcon.BackColor = ProgramConfig.DefaultMapItemBgColor;
        itemIcon.BorderStyle = BorderStyle.FixedSingle;
        itemIcon.Tag = dataItem;
        itemIcon.MouseEnter += new EventHandler(itemIcon_MouseEnter);
        itemIcon.MouseLeave += new EventHandler(itemIcon_MouseLeave);
        itemIcon.MouseClick += new MouseEventHandler(itemIcon_MouseClick);
        itemIcon.ContextMenuStrip = this.contextMenuStrip1;
        DataItemIconPool.Add(dataItem.ItemName, itemIcon);
    }
    //3. add icons to corresponding cell
    for (int m = 0; m < ProjectedMap.ProjectedMapUnits.Length; m++)
    {
        if (ProjectedMap.ProjectedMapUnits[m] != null)
        {
            foreach (SOMMapDataItem item in ProjectedMap.ProjectedMapUnits[m])
            {
                int x = m / ProjectedMap.MapSizeX;
                int y = m % ProjectedMap.MapSizeX;
                System.Windows.Forms.Label l = (System.Windows.Forms.Label)DataItemIconPool[item.ItemName];
                l.Location = new Point(0, (panelMapCells[x, y].Controls.Count - 2) * (l.Height-5));
                panelMapCells[x, y].Controls.Add(l);
            }
        }
    }
}

```

#endregion: map init

// -----

#region: coloring cells methods

```

public void ColorCellByCluster(int clusterSetId) // set color code for each cell
{
    //display clusters
    for (int x = 0; x < panelMapHeight; x++)
    {
        for (int y = 0; y < panelMapWidth; y++)
        {
            int number=BaseMap.MapUnits[BaseMap.MapSizeX * x + y].ClusterNumber;
            ArrayList set = BaseMap.ClusterSets[clusterSetId] as ArrayList;
            SOMMapCluster c = set[number] as SOMMapCluster;
            CellColors[x, y] = Color.FromArgb(c.ClusterColor);
        }
    }
}

```

```

    }
  }
}

public void ColorCellByScale() // gray colored
{
  double[] distances = new double[BaseMap.NumberOfMapUnits];
  int[] itemCount = new int[BaseMap.NumberOfMapUnits];

  for (int x = 0; x < panelMapHeight; x++)
  {
    for (int y = 0; y < panelMapWidth; y++)
    {

      //temp: static solution
      int currentUnitLocation = BaseMap.MapSizeX * x + y;
      double[] mapUnitVector = BaseMap.MapUnits[currentUnitLocation].VectorValues;
      itemCount[currentUnitLocation] = ProjectedMap.ProjectedMapUnits[currentUnitLocation] == null ? 1 :
ProjectedMap.ProjectedMapUnits[currentUnitLocation].Count * 2;

      for (int xx = -1; xx <= 1; xx++)
      {
        for (int yy = -1; yy <= 1; yy++)
        {
          int location = BaseMap.MapSizeX * (x + xx) + (y + yy);
          double sum = 0;
          if (location >= 0 && location < BaseMap.NumberOfMapUnits)
          {
            double[] neighborUnitVector = BaseMap.MapUnits[location].VectorValues;
            for (int i = 0; i < mapUnitVector.Length; i++)
              sum += Math.Abs(mapUnitVector[i] - neighborUnitVector[i]);

            itemCount[currentUnitLocation] += ProjectedMap.ProjectedMapUnits[location] == null ? 0 :
ProjectedMap.ProjectedMapUnits[location].Count;
          }
          distances[currentUnitLocation] += sum;
        }
      }
    }
  }

  //find out distance range
  double max = 0;
  double min = 10000;
  int average = 0;

  for (int i = 0; i < distances.Length; i++)
  {
    max = distances[i] > max ? distances[i] : max;
    min = distances[i] < min ? distances[i] : min;
  }
  double range = max - min;

  //find out average

  for (int i = 0; i < itemCount.Length; i++)

```



```

    {
        average += itemCount[i];
    }
    average = average / itemCount.Length;

    for (int x = 0; x < panelMapHeight; x++)
    {
        for (int y = 0; y < panelMapWidth; y++)
        {
            int color = (int32)((255 * (distances[BaseMap.MapSizeX * x + y] - min) / range) * average /
itemCount[BaseMap.MapSizeX * x + y]);
            color = color > 255 ? 255 : color;
            CellColors[x,y] = Color.FromArgb(color, color, color);
        }
    }
}

public void ColorCellBySum()
{
    double[] sums = new double[BaseMap.NumberOfMapUnits];
    int[] itemCount = new int[BaseMap.NumberOfMapUnits];

    for (int x = 0; x < panelMapHeight; x++)
    {
        for (int y = 0; y < panelMapWidth; y++)
        {
            //temp: static solution
            double[] mapUnitVector = BaseMap.MapUnits[BaseMap.MapSizeX * x + y].VectorValues;
            double sum = 0;
            for (int i = 0; i < mapUnitVector.Length; i++)
                sum += mapUnitVector[i];

            sums[BaseMap.MapSizeX * x + y] = sum;
        }
    }

    //find out distance range
    double max = 0;
    double min = 10000;

    for (int i = 0; i < sums.Length; i++)
    {
        max = sums[i] > max ? sums[i] : max;
        min = sums[i] < min ? sums[i] : min;
    }
    double range = max - min;

    //find out break points
    double[] breakpoints = new double[3];
    breakpoints[0] = range / 4 + min;
    breakpoints[1] = min + range / 4 * 2;
    breakpoints[2] = min + range / 4 * 3;

    //color coding
    for (int x = 0; x < panelMapHeight; x++)
    {
        for (int y = 0; y < panelMapWidth; y++)

```

```

    {
        if (sums[BaseMap.MapSizeX * x + y] > breakpoints[2])
            CellColors[x, y] = Color.LightGreen;
        else if (sums[BaseMap.MapSizeX * x + y] > breakpoints[1])
            CellColors[x, y] = Color.LightCoral;
        else if (sums[BaseMap.MapSizeX * x + y] > breakpoints[0])
            CellColors[x, y] = Color.LightSkyBlue;
        else
            CellColors[x, y] = Color.LightSalmon;
    }
}
}

```

**#endregion:** coloring cells methods

// -----

**#region:** visual exploration methods: display map layers (objects), zooming

```

public void ShowGridLines(bool line)
{
    for (int i = 0; i < panelMapHeight; i++)
    {
        for (int j = 0; j < panelMapWidth; j++)
        {
            CellIds[i, j].Visible = line;
            CellIds[i, j].BringToFront();
            if (line)
                panelMapCells[i, j].BorderStyle = BorderStyle.FixedSingle;

            else
                panelMapCells[i, j].BorderStyle = BorderStyle.None;
        }
    }
}

public void ShowBaseMap(bool isDisplayed)
{
    for (int x = 0; x < panelMapHeight; x++)
        for (int y = 0; y < panelMapWidth; y++)
            this.CellPatternCharts[x, y].Visible = isDisplayed;
}

public void ShowMapDataItem(bool isVisible)
{
    foreach (String key in DataItemIconPool.Keys)
    {
        System.Windows.Forms.Label itemIcon = (System.Windows.Forms.Label)DataItemIconPool[key];
        itemIcon.Visible = isVisible;
        itemIcon.BringToFront();
    }
}

public void ShowColorCodedMap(bool vis)
{
    for (int x = 0; x < panelMapHeight; x++)
    {
        for (int y = 0; y < panelMapWidth; y++)

```

```

    {
        if (vis) //&& panelMapCells[x,y].Controls.Count >1
            panelMapCells[x, y].BackColor = CellColors[x, y];
        else
            panelMapCells[x, y].BackColor = this.BackColor;

        CellPatternCharts[x, y].ChartArea.Background.Color = panelMapCells[x, y].BackColor;
        CellPatternCharts[x, y].Refresh();
    }
}

public void RenderFocusGroups()
{
    foreach (String k in DataItemIconPool.Keys)
    {
        Control c = DataItemIconPool[k] as Control;
        c.BackColor = ProgramConfig.DefaultMapItemBgColor;
    }

    foreach (FocusGroup rg in this.FocusGroups)
    {
        foreach (String s in rg.Items)
        {
            System.Windows.Forms.Label lbl = (System.Windows.Forms.Label)DataItemIconPool[s];
            lbl.BackColor = rg.Color;
            lbl.Visible = true;
        }
    }
}

public void ResizeMap(int size) // resize and display all cells, zoom in, zoom out, fit
{
    this.panelCellSize = size;

    for (int i = 0; i < panelMapHeight; i++)
    {
        for (int j = 0; j < panelMapWidth; j++)
        {
            panelMapCells[i, j].Width = panelCellSize;
            panelMapCells[i, j].Height = panelCellSize;
            int x = 0;
            if (BaseMap.MapType.Equals("hexa") && i % 2 == 1)
                x = panelCellSize / 2 + (j) * panelCellSize - 1;
            else
                x = (j) * panelCellSize - 1;
            int y = i * panelCellSize - 1;

            panelMapCells[i, j].Location = new Point(x, y);

            CellPatternCharts[i, j].Width = panelMapCells[i, j].Width + 110;
            CellPatternCharts[i, j].Height = panelMapCells[i, j].Height + 90;
        }
    }
}

```

**#endregion:** visual exploration methods: display map layers (objects), zooming

#region: context menu events

```

private void contextMenuStrip1_Opening(object sender, CancelEventArgs e)
{
    Control c=((ContextMenuStrip)sender).SourceControl;
    contextMenuStrip1.Tag = c;
}

private void menuItemCompare_Click(object sender, EventArgs e)
{
    if (contextMenuStrip1.Tag.GetType() == typeof(System.Windows.Forms.Label))
    {
        SOMMapDataItem item = ((Control)contextMenuStrip1.Tag).Tag as SOMMapDataItem;
        ComparePatterns(item.ItemName, item.SOMVector, Color.Empty);
    }
    else
    {
        SOMMapUnit item = ((Control)contextMenuStrip1.Tag).Tag as SOMMapUnit;
        ComparePatterns("Map Cell " + item.UnitNumber, item.VectorValues, Color.Empty);
    }
}

public void ComparePatterns(String name, double[] values, Color color)
{
    if (formChart == null || formChart.IsDisposed)
    {
        formChart = new FormComparison();
        formChart.SetDimensionCaption(BaseMap.VectorMetadata);
    }

    formChart.AddDataSeries(name, values, color);
    formChart.Show();
    formChart.BringToFront();
}

private void menuItemViewMoreDetails_Click(object sender, EventArgs e)
{
    FormItemDetail form = new FormItemDetail();
    if (contextMenuStrip1.Tag.GetType() == typeof(System.Windows.Forms.Label))
    {
        SOMMapDataItem item = ((Control)contextMenuStrip1.Tag).Tag as SOMMapDataItem;
        form.ShowDetails(item, BaseMap.VectorMetadata);
    }
    else
    {
        SOMMapUnit item = ((Control)contextMenuStrip1.Tag).Tag as SOMMapUnit;
        form.ShowDetails(item, BaseMap.VectorMetadata);
    }
    form.Show();
}

private void menuItemCompareItems_Click(object sender, EventArgs e)
{
}

```

#endregion: context menu events

#region: mouse events

```

void DrawingMouseMoveEventHandler(object sender, EventArgs e)
{
    if (Control.ModifierKeys == Keys.Control && ClusterDrawingMode != null)
    {
        if (sender.GetType() == typeof(Panel))
        {
            Control c = (Control)sender;
            c.BackColor = Color.FromArgb(ClusterDrawingMode.ClusterColor);
            Chart ch = c.Controls[0] as Chart;
            ch.ChartArea.Background.Color = Color.FromArgb(ClusterDrawingMode.ClusterColor);
            ((SOMMapUnit)c.Tag).ClusterNumber = ClusterDrawingMode.ClusterId;
            //chart.ChartArea.Background.Color = ClusterDrawingMode.ClusterColor;
        }
        else if (sender.GetType() == typeof(dotnetCHARTING.WinForms.Chart))
        {
            //assign the cell to a cluster
            //render the cell and chart
            dotnetCHARTING.WinForms.Chart chart = sender as dotnetCHARTING.WinForms.Chart;
            chart.ChartArea.Background.Color = Color.FromArgb(ClusterDrawingMode.ClusterColor);
            chart.Parent.BackColor = Color.FromArgb(ClusterDrawingMode.ClusterColor);
            ((SOMMapUnit)chart.Parent.Tag).ClusterNumber = ClusterDrawingMode.ClusterId;
            chart.Refresh();
        }
    }
}

void itemIcon_MouseLeave(object sender, EventArgs e)
{
    System.Windows.Forms.Label l = (System.Windows.Forms.Label)sender;
    l.BringToFront();
}

void itemIcon_MouseEnter(object sender, EventArgs e)
{
    Control l = (Control)sender;
    l.BringToFront();
    FormVisualExploration form = (FormVisualExploration)this.ParentForm;
    form.PreviewItemProfile( (SOMMapDataItem)(((System.Windows.Forms.Label)sender).Tag) );
}

void MapCell_MouseEnter(object sender, EventArgs e)
{
    FormVisualExploration form = (FormVisualExploration)this.ParentForm;
    Control c = (Control)sender;
    SOMMapUnit u;
    if (sender.GetType() == typeof(Panel))
    {
        u = c.Tag as SOMMapUnit;
    }
    else
    {
        u = c.Parent.Tag as SOMMapUnit;
    }
    form.PreviewCellProfile(u);
    form.PreviewClusterProfile(u.ClusterNumber);
}

```

```

void itemIcon_MouseClick(object sender, MouseEventArgs e)
{

}

```

#endregion: mouse events

```

}
}

```

### *ProjectPortfolioMDI.cs*

```

using System;
using System.Collections.Generic;
using System.ComponentModel;
using System.Data;
using System.Drawing;
using System.Text;
using System.Windows.Forms;
using ProjectPortfolio.Clustering;

namespace ProjectPortfolio.UI
{
    public partial class ProjectPortfolioMDI : Form
    {
        private int childFormNumber = 0;

        public ProjectPortfolioMDI()
        {
            InitializeComponent();
        }

        private void OpenFile(object sender, EventArgs e)
        {
            OpenFileDialog openFileDialog = new OpenFileDialog();
            openFileDialog.InitialDirectory = Environment.GetFolderPath(Environment.SpecialFolder.Personal);
            openFileDialog.Filter = "Text Files (*.txt)|*.txt|All Files (*.*)|*.*";
            if (openFileDialog.ShowDialog(this) == DialogResult.OK)
            {
                string fileName = openFileDialog.FileName;
            }
        }

        private void SaveAsToolStripMenuItem_Click(object sender, EventArgs e)
        {
            SaveFileDialog saveFileDialog = new SaveFileDialog();
            saveFileDialog.InitialDirectory = Environment.GetFolderPath(Environment.SpecialFolder.Personal);
            saveFileDialog.Filter = "Text Files (*.txt)|*.txt|All Files (*.*)|*.*";
            if (saveFileDialog.ShowDialog(this) == DialogResult.OK)
            {
                string fileName = saveFileDialog.FileName;
            }
        }

        private void ExitToolStripMenuItem_Click(object sender, EventArgs e)
        {
            Application.Exit();
        }
    }
}

```

```

}

private void StatusBarToolStripMenuItem_Click(object sender, EventArgs e)
{
    statusBarStrip.Visible = statusBarToolStripMenuItem.Checked;
}

private void CascadeToolStripMenuItem_Click(object sender, EventArgs e)
{
    LayoutMdi(MdiLayout.Cascade);
}

private void TileVerticalToolStripMenuItem_Click(object sender, EventArgs e)
{
    LayoutMdi(MdiLayout.TileVertical);
}

private void TileHorizontalToolStripMenuItem_Click(object sender, EventArgs e)
{
    LayoutMdi(MdiLayout.TileHorizontal);
}

private void ArrangIconsToolStripMenuItem_Click(object sender, EventArgs e)
{
    LayoutMdi(MdiLayout.ArrangeIcons);
}

private void CloseAllToolStripMenuItem_Click(object sender, EventArgs e)
{
    foreach (Form childForm in MdiChildren)
    {
        childForm.Close();
    }
}

private void viewMapToolStripMenuItem_Click(object sender, EventArgs e)
{
}

private void ProjectPortfolioMDI_Load(object sender, EventArgs e)
{
}

private void newProjectionToolStripMenuItem_Click(object sender, EventArgs e)
{
    FormNewProjection viewmap = new FormNewProjection();
    viewmap.MdiParent = this;
    viewmap.Show();
}

private void sOMPAKToolStripMenuItem_Click(object sender, EventArgs e)
{
    FormClustering f = new FormClustering();
    f.MdiParent = this;
    f.Show();
}

```

```
private void sOMMapManagerToolStripMenuItem_Click(object sender, EventArgs e)
{
    FormMapManager manager = new FormMapManager();
    manager.MdiParent = this;
    manager.Show();
}
}
```



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### Work Experience

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 Courses Taught: CIS3730 Database Management Systems (1 semester), Internet  
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### Publications, Conference Proceedings and Book Chapters

1. "A Multi-dimensional and Visual Exploration Approach to Project Prioritization and Selection", with Vijay Vaishnavi, the 15th Americas Conference on Information Systems, San Francisco, CA, Aug 2009
2. "The Influence of Checklists and Roles on Software Practitioner Risk Perception and Decision-Making", with Mark Keil, Lei Li, Lars Mathiassen, Journal of Systems and Software, vol 81(6), pp.908-919, June 2008
3. "A Historical Perspective of Web Engineering", in Encyclopedia of Networked and Virtual Organizations, edited by Goran Putnik and Maria Chunha, the Information Science Reference, 2008
4. "A Multi-dimensional and Visual Exploration Approach to Project Prioritization", with Vijay Vaishnavi and Art Vandenberg, short paper presentation for the third international conference on design science research in information systems and technology, Atlanta, GA, May 2008

5. "TQN: A Novel Approach to Generating Information Security Data", with Vijay Vaishnavi, Art Vandenberg, Richard Baskerville, Proceedings of the 16th Workshop on Information Technologies and Systems (WITS), Milewaukee, Wisconsin, 2006
6. "TQN Prototype: A Novel Approach to Generating Information Security Data", with Tony Vance, Robert Sainsbury, Art Vandenberg, Vijay Vaishnavi, Richard Baskerville, prototype demo presented at the 16th Workshop on Information Technologies and Systems (WITS), Milewaukee, Wisconsin, 2006
7. "ZWebNav: Integrated Web Navigation Manager", prototype demo presented at the 16th Workshop on Information Technologies and Systems (WITS), Milewaukee, Wisconsin, 2006
8. "The Influence of Checklists and Roles on Software Practitioner Risk Perception and Decision-Making", with Mark Keil, Lei Li, Lars Mathiassen, Proceedings of the 39th Annual Hawaii International Conference on System Sciences (HICSS'06)
9. "Semantic Heterogeneity: Problem and Solution Frameworks", with Vijay Vaishnavi, Art Vandenberg, Roop Singh, Computing Letters, 1(2), 2005, page 75-82
10. "A Methodology for Semantic Integration of Metadata in Bioinformatics Data Sources", with Lei Li, Roop Singh, Art Vandenberg, Vijay Vaishnavi, Sham Navathe, proceedings of ACMSE 2005
11. "Critical Themes in Electronic Commerce Research: A Meta-Analysis", with Jonathan Wareham, Detmar Straub, Journal of Information Technology, Volume 20, Number 1, February 2005

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