Visually-Driven Decision Making Using Handheld Devices

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Abstract. This paper discusses group decision making from a visual-interactive perspective. The novelty of our approach is that its major focus is on developing a collection of visual-interactive elements for group decision-making. Our research departs from a collection of representative meeting scenarios to identify common decision-making elements and behavior similarities; and to elaborate a collection of feature sets realizing those common elements and behavior into visual-interactive artifacts. The paper also describes a handled application demonstrating the proposed feature sets. This application has been extensively used to support a wide range of meetings. An important contribution of this work is that the principle behind its approach to decision-making relies almost exclusively on gestures over visual elements.

Keywords: Decision-Making Elements. Group Support Systems. Handheld Devices.

1. Introduction

Research on collaborative decision-making (CDM) is widespread and has addressed the interrelationships between decision sciences, organizational sciences, cognitive sciences, small groups research, computer supported collaborative work and information technology. Considering such a wide range, it is understandable that the interplay between CDM and the user-interface seems in general relatively unimportant. Of course, in some specific contexts it has emerged as a central problem. For instance, Decision Support / Geographical Information Systems naturally emphasize the role of the user-interface [1]. Tradeoff analysis in multiple criteria decision making also gives significant importance to the problem [2]. Other CDM areas where interest in the user-interface has emerged include information landscapes [3], strategic visualization [4], and studies on group awareness [5]. Finally, another research context emphasizing the importance of the user-interface concerns decision support using mobile technology such as Personal Digital Assistants (PDA) and mobile phones, mostly because of the different display constraints and interaction modes, pervasiveness, serendipity and wireless access [6].

One area where the interplay between CDM and the user-interface is unexplored concerns meeting support. For instance, Fjermestad and Hiltz [7] analyzed most significant research prior from 1982 to 1998 and found no experiments specifically addressing the user-interface.

Since the area is mostly unexplored, the major purpose of this paper is answering two questions: What relationships may be found between the most common meeting scenarios and CDM tasks and processes? What subsequent relationships may be found between CDM and the most commonly supported visual-interactive artifacts? These questions are addressed in a concrete setting considering the use of handheld devices (more specifically PDA) in meetings.

From this inquiry we obtained a generic and coherent collection of visual-interactive artifacts capable to support the rich requirements posed by decision making using handheld devices. These visual-interactive artifacts were implemented in an application, designated NOMAD, which has been used with success in various meetings, mostly in the educational field. The contribution of this research to CDM research consists in: a) Based on a task-process taxonomy and a collection of meeting scenarios, we identify and characterize a set of decision-making elements recurrent in meetings. b) Departing from the above elements, we define a collection of visual-interactive feature sets expressing behavior similarities, i.e. the similar ways people construct and interact with decision-making elements. And c) we present an implementation of the proposed visual-interactive feature sets.

The remaining sections of this paper are organized in the following way: in section two we start by identifying several user-interfaces requirements related with CDM; then, in section three we present the collection of meeting scenarios that have framed our research on technology support to meetings; the section four is dedicated to characterize the decision-making elements found most relevant in the adopted scenarios; the section five characterizes the common functionality associated to the decision-making elements; section six provides more details about the NOMAD application and presents results from its use in several meetings; finally, in section seven we discuss the outcomes of this research.

2. Requirements

Gray and Mandiwalla [8] reviewed the current state-of-the-art in CDM and identified the following important requirements:

Multiple group tasks. Groups develop different ways to accomplish their tasks, depending on the specific participation, context, location, problems and adopted approaches. For instance, opportunistic decisions may emerge in any time and place, and with a variable number of participants. More thorough decisions however may be result from the interaction with previous and subsequent decision processes. A meeting may be set up to resolve a problem, share information, define an action plan, brainstorm, or even to accomplish all this at the same time. This requirement stresses the importance of flexibility in information management.

Group dynamics. Often people come and go from collaborative decision-making processes, according to availability and required skills and contributions. This group dynamics has significant implications to information management, in order to avoid delays, digressions and information losses. The arrival of newcomers and latecomers should be as seamless as possible. And departures should not represent any disruptions to the remaining group. This requires seamlessly managing the group dynamics.

Visual tools for decision-making. Visual tools contribute to decision making by making information more perceptible, natural and simpler to manipulate.

Simple human-computer interfaces. Simpler human-computer interfaces contribute to free decision makers from the cognitive effort handling routine low-level activities, such as interacting with keys, menus and widgets, so they can concentrate on the task at hand.

Various interaction modes with technology. Collaboration may involve the participation of people with various degrees of proficiency with technology and these people should not feel inhibited to participate and contribute to the process outcomes. The availability of multiple interaction modes with technology, adapted to the types of users, their proficiency and roles assumed during the decision process, is fundamental to the CDM process.

Researchers noted there is an increase in the role of concepts maps, images, and other visual-interactive artefacts as mediators of collaboration, in a range of complex decision-making contexts including scientific inquiry, environmental and urban planning, resources management, and education [9]. It has also been suggested that visualisation is a powerful cognitive tool [10]. The term visualisation is used here in its familiar sense and fundamentally meaning "to form and manipulate a mental image." In this context, visual-interactive artefacts constitute physical counterparts to mental images. In everyday life, visual-interaction is essential to problem solving and decision-making, as it enables people to use concrete means to grapple with abstract information. Visual-interaction may simply entail the formation and manipulation of images, with paper and pencil, or any other technological tools, to investigate, discover, understand and explain concepts, facts and ideas. In spite of this potential, we do not find many research projects addressing group decision making from a visual-interactive perspective, in particular considering the meeting context.

3. Meeting Scenarios

Next we will mention the different meeting scenarios addressed by our research. A more detailed description can be found in [11].

Deliberate meeting: The deliberate meeting is mostly related to group problem solving and decision-making. The fundamental purpose of the deliberate meeting is to apply structured and rational procedures to systematically reduce the distance to set goals. The role of the leader/facilitator is central in deliberate meetings to focus the group on the decision process. Information management in deliberate meetings fundamentally concerns shared data.

Meeting ecosystem: The meeting ecosystem is associated to an ill-defined or unexpected reality. The most significant difference to the deliberate meeting is that advance planning is compromised. The fundamental purpose of the meeting ecosystem is thus to mobilize a group towards the identification of the best strategy to achieve the intended goals (which may also be compromised [12]). The meeting ecosystem may be regarded as an aggregate of sub-meetings with different goals. From the outset, it resembles an organized chaos, where participants flexibly move across different sub-meetings while contributing with their expertise to resolve a wide variety of problems. This type of behavior has been observed in collaboratories [13]. The critical information management role in the meeting ecosystem is situation awareness. The participants rely on shared data to deal with this organized chaos: setting up sub-groups, defining tasks, sub-tasks and to-do lists, and exchanging information between different shared contexts. Another important role to consider is integrating information produced by the sub-groups.

Creative/design meeting: This type of meeting is associated to the collaborative generation of ideas and plans. The most common structure supporting creativity and design relies on the several principles attributed to the brainstorming technique [14]: free-wheeling is welcomed, quantity is wanted, criticism is avoided and combination and improvement are sought. Considering this fairly simple structure, the most important roles associated to information management are visualization and conceptualization. Sketching affords the visual symbols and spatial relationships necessary to express ideas in a rapid and efficient way during design activities [15]. Parallel work should not only be possible but encouraged, to increase the group productivity.

Ad-hoc meeting: There is one major intention behind ad-hoc meetings: information sharing. Most meetings in organizations are ad-hoc: unscheduled, spontaneous, lacking an agenda, and with an opportunistic selection of participants [16]. In spite of an apparent informality, we identify two different motivations based on the participants' work relationships:

the need to share important information between coworkers, which is related with a horizontal type of relationship; and the need to exert management control, which is associated to a vertical type of relationship. During an ad-hoc meeting, the participants are focused on information sharing, which may be centrally moderated. Social protocols are necessary to moderate information sharing. Information synchronization may be beneficial to offer the group an overall perception of the work carried out in the meeting.

Learning meeting: This type of meeting is focused on the group exploration and structuring of knowledge with the support and guidance from a knowledgeable person. Learning meetings emphasize the role of technology supporting the teachers' goals and strategies. In this respect, information management tools help focusing the students on the information conveyed by the teacher, while facilitating the set up and conduction of parallel activities. According to [17], the degree of anonymity supported by information technology in this scenario helps reducing evaluation apprehension by allowing group members to execute their activities without having to expose themselves in front of the group; and parallelism aids reducing domination, since more persons may express their ideas at the same time.

4. Decision-Making Elements

Several taxonomies identifying decision-making elements relevant to our discussion have been proposed in the research literature. One of the earliest and mostly cited ones is the task-process taxonomy [7, 18], which differentiates between task structure, focused on the specific group conditions in focal situations such as brainstorming or voting [19]; and process structure, addressing the more general conditions under which the group accomplishes the set goals, such as anonymity and proximity. Other available taxonomies highlight the distinctions between hardware, software and people [20], coordination modes [21], collaborative services [22], facilitation support [23] and other more specific conditions. In our work we adopted the general purpose of the task-process taxonomy, however separating the task dimension in two categories:

- Task dimension
  - Macro level – Regards the task from the perspective of the group, i.e. the actions taken by the group as a whole.
  - Micro level – Regards the task from the perspective of the individual participants in the group task, addressing the conditions under which the participants communicate, coordinate and collaborate with the others to accomplish their goals.
- Process dimension
  - Adopts a broad perspective over the decision-making process, including the assumption that a collection of tasks may have to be managed to improve the group's performance.

Based on this taxonomy, we analyzed our meeting scenarios to come up with a collection of relevant decision-making elements. In Table 1 we present the several elements that were captured this way.

Scenario	**Process**	**Macro**	**Micro**
Deliberate	Lead participants Focus participants	Agenda, Discussion Wrap-up	Updating information
Ecosystem	Move between sub-meetings	Goals, Strategy, Solution Tasks/subtasks	Information exchange Information integration
Creative / Design	Free-welling Brainstorming Brainsketching	Ideas, Designs, Plans	Writing, Sketching Spatial relationships Visual symbols

Ad-hoc	Coworker Management control Moderate information sharing	Outcomes, Agreements Schedules, To-do list Deadlines	Private and public information Information sharing and synchronization
Learning	Setting activities Guidance	Structured activities, Problem solving, Ideas generation Organization of ideas Assessment	Structure knowledge Share knowledge

Table 1. Decision making elements

The next step in our approach consisted in aggregating the decision-making elements that were perceived as having similar behavior.

5. Feature Sets for Visual Decision Making

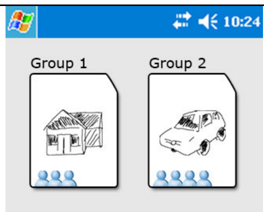
We grouped the decision-making elements shown in Table 1 according to their behavior similarity. For instance, both the agenda and wrap-up elements are usually very similar because the participants generate the same artifact: a list with topics. The functionality necessary for the group to interact with this common artifact is of course very similar and constitutes what we designate the "feature set" of these decision making elements. The several feature sets obtained this way are described below in a tabular form. Each one of these tables has three columns describing respectively the name associated to the feature set, the main behavior associated to the feature set, and additional information, restrictions or variations associated to the main behavior.

5.1 Process features

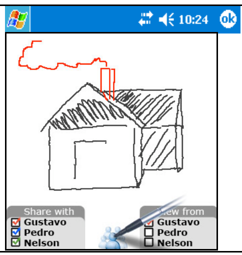
Our first feature set aims at helping the leader/facilitator setting group tasks and focusing the participants' attention in the selected tasks. In our approach this is accomplished with the notions of "pages" and "groups." Pages are associated to groups of participants by the leader/facilitator.

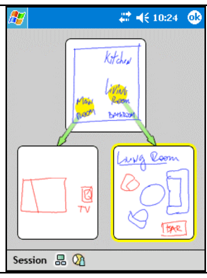
5.1a – Setting working groups and assigning activities to them. The leader/facilitator assigns participants to working sessions by dragging participant's icons into groups.		The participants linked to a certain document are restricted to work within the pages assigned to the group.

The second feature set aims at helping the leader/facilitator governing the users' focus of attention and managing shared information.

5.1b – Governing the focus of attention. The leader/facilitator organizes the users' focus of attention through the selection of pages.		The participants work collaboratively in the selected page.

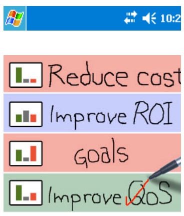
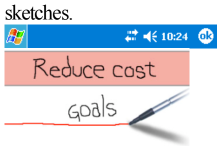
The following two features address the situations where no process management is needed, thus yielding to self-organization. These features assume respectively the collaboration restricted to one single page, thus supporting brainstorming, brainsketching and co-working situations; and collaboration supported by several pages, required e.g. by meeting ecosystems.

5.1c – Restricted self-organization. No process management is done. All participants interact freely with the system. Only one page is available.		There is one single focus of attention, which serves to coordinate the group's work.

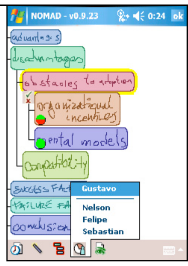
5.1d – Self-organization. Multiple pages are available, but no process management is done to regulate how participants move between them. The pages are organized hierarchically, allowing participants to develop different working areas where they may work in parallel.		Participants may freely switch between pages (double-clicking and other methods are available for switching between pages).

5.2 Task-Macro features

The first feature set considered in this category supports a varied collection of meeting activities which fundamental purpose is to generate a list of items. This includes activities such as agenda building, brainstorming, producing a list of meeting outcomes, a to-do list, meeting wrap-up, and defining goals and solutions. The adopted approach organizes these items in one single page. More complex uses of list items can be supported with additional sketches (discussed in 5.3b). For instance, in the example below we illustrate how a SWAT analysis page was defined by combining writing with several lines forming the typical SWAT 2x2 matrix.

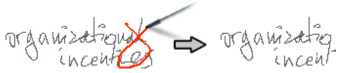
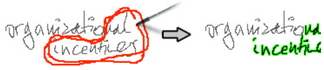
5.2a – Generate list items. Organized lists allow several group-oriented tasks (such as voting and prioritizing).		Free-hand inputs may be turned into list items by drawing a line between two sketches.  Sketches may be integrated with lists to support more complex decision situations (e.g. SWAT).

The second feature set addresses the activities requiring more complex information structures than the simple list defined above. Examples include planning activities, organizing ideas and problem solving situations. In our approach this functionality is supported with hierarchical pages. An overview page is also supplied, allowing the participants to take a glance at the whole information structure and navigate to a specific page. Note that SWAT analysis may also be implemented this way.

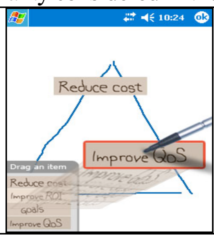
5.2b – Manage hierarchical items. Hierarchical structure of pages. There is an overview page showing all pages and their structural relations.		The overview page may be navigated and zoomed in and out. The participants may navigate to a page from the overview.

5.3 Task-Micro features

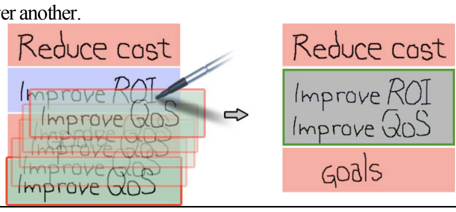
The first feature set considered in this category supports the production of writing and sketching using freehand input. Keyboard input is also considered as an alternative for writing. Common functionality such as selecting and moving elements is supported.

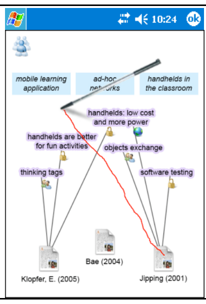
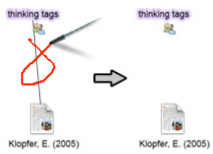
5.3a – Managing text and sketches with pen-based gestures. Collaborative or individual contents may be created based on freehand and keyboard inputs. Sketches may be done over backdrops or recently taken photographs in camera-enabled devices.		Several pen-based gestures are available to facilitate content management. Some examples:  Drawing a connected cross implements "erase"  Drawing a double closed shape allows selecting complex areas. Simple tapping allows selecting single items. Rotation, resizing and other advanced editing features are available as well.

Sketching affords establishing spatial, visual and conceptual relationships between visual elements, a type of functionality considered in the following feature set.

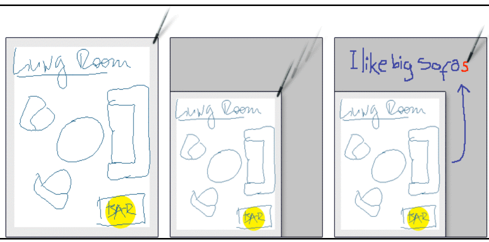
5.3b – Conceptual relationships. Sketches allow organizing concepts on implicit-meaning distribution.		Gestures used for sketching are also used for spatial relationships.

The following two feature sets concern additional ways to structure knowledge. The first one concerns managing list items, while the second one addresses managing links to pages. In the later case links are visually represented as icons and may be followed by double-clicking.

5.3c –Structuring knowledge with list items. List item may be moved and merged to afford organizing concepts (e.g. combining ideas).	Example illustrating the selection and merging of two list items by dragging and dropping one list item over another. 

5.3d – Structuring knowledge with links. Managing links affords structural knowledge.		Selecting, moving and deleting links is done with the same gestures for general sketches manipulation. 

In the context of the micro perspective, many participants' activities require managing private and public information. In our approach, private information is created and managed in special private pages, which may be created by a participant whenever it is necessary. Also, in many situations the participants may have to transfer information between private pages and between private and public spaces. The following category concerns the functionality necessary to transfer information between pages using an "offer area."

5.3e – Managing private and public information. The participants may create and work individually on private or public pages.	

5.3f – Governing information exchange. Moving items between two participants' private spaces and between private and public spaces.	One participant drags a visual element to an offer area. The other participant drags the offered element from the offer area into his/her private page. 

6. Application

The whole collection of feature sets described in the previous section has been implemented in a mobile application designated NOMAD. This application runs on Personal Digital Assistants utilizing the Windows Mobile operating system. The technical details about the implementation of low-level functionality, including ad-hoc networking, information exchange between multiple devices, synchronization, and in particular the implementation of the special interactions required by the features sets are described in detail in another paper [24]. In this paper we will instead focus on demonstrating how the combination of the visual-interactive features built into the application could effectively support group decision-making in the adopted meeting scenarios. To recap, the implemented visual-interactive features include:

- Setting work groups and assigning activities
- Governing the focus of attention
- Setting self-organization
- Structuring knowledge with list items and hierarchical items
- Managing text and sketches with pen-based gestures
- Creating conceptual relationships
- Managing private and public information
- Governing information exchange between private and public spaces

Screen dumps showing the implementation of these visual-interactive features have been given above. In particular, figures shown along with feature sets 5.2a, 5.2b 5.3d and 5.3f provide a good view of the application. These visual-interactive features have been utilized to accomplish many traditional decision-making tasks. For instance, the typical brainstorming activity has been supported by one single page with list items using the 5.2a feature set. The planning activity has been supported with hierarchical pages (5.1d for creation and 5.2b for navigation). Two well-known meeting artifacts, the agenda and meeting report, have also been implemented with pages and list items described in 5.2a. Besides these simple decision-making cases, more complex meeting situations have also been implemented with NOMAD:

- Supporting creative design meetings in the field, where participants have to generate ideas, discuss them, refine them, and select a subset of ideas to be further refined in the office. The feature set 5.3a has been used to sketch design ideas over a photograph of the subject being discussed taken on site. These design ideas were then recursively refined on new pages, linked to the previous one using the feature set 5.1d. The feature set 5.1a was used to differentiate between the group of people working in the field and in the office. The feature set 5.3f was used to exchange private information among the field participants, as well as to distribute work among the office participants, so they could offline work on the design ideas.
- Meeting ecosystems and ad-hoc meetings have also been well supported by NOMAD. The mobile nature of the application makes it possible to start a meeting anytime and anyplace. For a certain meeting participant, to move among sub-meeting has been as easy as moving among different shared pages hierarchically organized. This was achieved with feature set 5.1d, allowing different working spaces to be shared, and with 5.2b, allowing a swift and easy change between the working areas. The feature set 5.1a has been used whenever more formal working groups were needed, restricting the users' access to particular working areas. The flexible nature of meeting ecosystems and ad-hoc meetings was well in line with the developed functionality, since there is no workflow modeling activities and restricting users' participation. Members could decide which specific features they would like to adopt, ranging from totally free-willing to chauffeured and guided situations.
- More structured meetings, especially those oriented to take decisions according to the classical decision-making steps of setting and agenda, brainstorming, groan, voting, selecting and follow-up have also been experimented with NOMAD. Feature sets 5.1c, 5.2a and 5.3c were used to define the agenda, brainstorm, merge several ideas after the brainstorming session, and finally vote. In order to keep flexibility, NOMAD does not guide or impose the meeting members to go through the different stages of a structured meeting. Instead, NOMAD supports different configurations adapted to the different stages in decision-making. We think members take benefits from a structured meeting only if they beforehand understand the necessity of a particular set of stages and agree

to follow them. Having such an agreement, the participants may then adopt the NOMAD configuration that best fits their choice.

- In structured as well as non-structured meetings it is important to generate information about the outcomes, for instance to implement a follow-up. For this, we realized that a concise information structure is of paramount importance. Feature set 5.3b and 5.3b have been used to support this, since they can relate different pieces of information in a simple yet meaningful way.

Collaborative decision-making using NOMAD typically starts with the creation of the first page of a new project. The subsequent activities (such as creating groups, linking pages, etc.) as well as the order they are performed depend on what the users may need or want to do. Overall, we have observed very significant flexibility implementing most meeting arrangements falling within the limits of the scenarios described in section 3. We have also observed very significant flexibility relative to the presence or absences of the leader/facilitator. NOMAD is not highly dependent on the leader/facilitator to prepare and conduct the technology, as only feature sets 5.1a and 5.1b require one.

Although NOMAD has been used in multiple situations, it has not yet been subject to a "formal" evaluation process. We have several reasons for currently avoiding such an evaluation. The fundamental one is founded on the observations by Gray and Mandiwalla [8] that experimental research with this type of technology is tied to the particular characteristics of individual prototype systems, which can be insightful but is difficult to generalize and predict. Experimental research requires a relatively stable context that we do not find in our prototype neither in the currently available mobile technology. Furthermore, the research literature on experiments with this types of technology has shown very inconclusive and sometimes conflicting results [7]. We believe that in the current context performing laboratory experiments with our prototype would contribute with more inconclusive results. From our point of view, research with this technology is still in a state where design ideas must be evaluated in a qualitative insightful way.

7. Discussion

Our decision-making approach is organized in twelve feature sets, where four sets were classified as process, two as task-macro and six as task-micro. The most commonly used visual-interactive artifact is the "page", that serves multiple purposes and is supported with very rich functionality, such as setting groups and sub-groups, focusing the groups' attention, allowing the participants to move between different tasks, supporting private and public activities, and organizing more complex information with multiple pages and links.

Another important visual-interactive artifact is the list item. Apparently, many different decision-making activities evolve around creating and modifying information organized as lists, which gives this simple information structure a powerful role in visual decision making. Rich functionality is also associated to list items, allowing the participants to create items by sketching, to move, drag and collapse items using the pencil, and to turn them private or public.

The smallest visual-interactive artifacts considered in our approach are the written text, sketches and sketches expressing conceptual relationships. Again, very rich functionality is available to facilitate interaction between the meeting participants, including the selection of multiple artifacts using specific movements with the pencil.

One interesting characteristic of our approach is that it clearly parts away from the traditional group decision support approach. We will discuss why in some detail. Although many different group decision support tools have already been developed, they seem to fall into one of the two following categories: the technology-driven and the model-driven [25]. The former shows strong concerns for the role and impact of the technology on the group decision process [7]. A central focus is the development of various tools supporting specific group tasks (e.g. brainstorming, categorizing and voting [26]) and their orchestration, mostly often conducted by a human facilitator [23]. Antunes et al. [27] point out the general-purpose nature of technology-driven tools generates a major organizational problem, since decision making is always performed in specific organizational contexts that are well known to participants but ignored by the technology.

The model-driven approach regards decision modeling as the fundamental requirement to support group participants articulating and structuring complex problems [25]. The emphasis is thus on utilizing decision models and methodologies capable to help eliciting and reconciling the participants' doubts, concerns and different views over the problem at hand. Morton et al. [25] point out the model-driven approach essentially works as a problem consultation tool, basically supporting strategy consultants performing their work with organizations and thus highly dependent on them. Therefore the target population for this type of tools is very narrow.

We share the view of Gray and Mandiwalla [8], who advocate a rethinking of decision-making technology, moving away from tools like brainstorming and voting, which are hardly used in organizations, and also less dependent on champions such as facilitators or strategy consultants. We believe our approach falls neither in the technology-driven nor the model-driven approaches. We may classify our approach as visually-driven: essentially focused on managing information artifacts that we commonly observe in meetings: pages with various types of information, lists with topics, and multiple pages when necessary. Our approach provides the basic visual elements necessary to make decisions, including complex strategic decisions such as SWAT, but does not make any assumptions about the specific tasks at hand.

Also, our approach does not make any assumptions about decision models and methodologies. The developed feature sets are sufficiently generic to be independent from such decision models and methodologies. The process features are also sufficiently generic to avoid any preconceptions about decision processes, be they more rational or more convoluted. In summary and in our view, the proposed visually-driven approach supports group decision-making using less assumptions about what decision-making should be, and how it should be organized from the information systems and process perspectives.

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