Requirements for Modeling Collaborative Information Foraging Behavior: An Application to Emergency Response Organizations

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ABSTRACT

Collaborative information foraging refers to the collective activities of seeking and handling information in order to meet information needs. This paper delineates requirements for modeling salient factors that shape collaborative information foraging behavior of groups. Existing modeling approaches are assessed based on their adequacy for measuring identified salient factors that shape collaborative information foraging behavior. A view of information foraging behavior as a dynamic process is presented. Consequently, this paper purports that modeling methods employed to aid understanding of foraging behavior must allow for plausible explanation of the inherent dynamism in foraging activities. This work therefore provides an initial roadmap to defining salient factors that need to be addressed in order to adequately model collaborative information foraging behavior within teams that operate in extreme environments. Implications of this work in practice and research are discussed.

Keywords

Collaborative information foraging, dynamic, modeling, information foraging behavior

INTRODUCTION

Collaborative information foraging refers to the collective activities of looking for and processing information in order to meet information needs. For instance the need to gain situational awareness during emergency response operations may drive response personnel to seek and handle information from disparate sources—such as radio stations, other personnel and various information technologies—in order to make informed decisions about how best to allocate resources to meet response goals (Vieweg et al., 2008). The dependence of the output (e.g., resource allocation) on present and past values of the input (e.g., location of casualties) is a characteristic of dynamic systems. Consequently, information foraging processes are *dynamic*, a view consistent with that of prior studies (e.g., Foster, 2004, Sonnenwald and Pierce, 2000). Methods for improving understanding of this phenomenon should therefore be capable of elucidating these dynamics, which may also include articulating underlying cognitive and/or affective patterns. Because information foraging is a recognized component of sensemaking, work in this area is also expected to improve models of how groups understand and process information in their surroundings (Muhren et al., 2008).

This paper delineates a theoretical framework for modeling collaborative information foraging, followed by an assessment of three competing methods with their ability to capture key elements in the framework. It therefore stands to provide guidance for subsequent work on collaborative information foraging in the emergency response domain.

The rest of the paper is organized as follows. A background of collaborative information foraging concepts is presented, along with a discussion of salient factors that shape information foraging behavior. An example that illustrates the components of the framework is then presented. Various existing approaches to modeling collaborative information foraging are described and assessed per dimensions of the framework. The paper concludes with a discussion of the implications of the study for practice and future research.

BACKGROUND AND FRAMEWORK

To begin to understand the inherent dynamism in collaborative information foraging behavior, it is essential to identify information needs (or properties) that drive the search as well as the organization of resources and/or

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personnel that facilitate those needs in order to fulfill goals of the response operation.

Emergency Response Organizations

Typically in the event of a disaster, whether natural or man-made, sometimes referred to as emergencies, the activities of responding organizations are coordinated by emergency response organizations (EROs) (Mendonça and Wallace, 2007, Stewart and Bostrom, 2002). EROs are typically comprised of representatives from key agencies such as fire, emergency medical technicians, and police (Belardo et al., 1984). Given the high stakes, such as might be precipitated following a highly disruptive event, a premium is placed on seeking, handling and managing information in a timely fashion in order to make effective decisions (Klein et al., 1993, Perrow, 1984). Thus EROs are characterized as information hubs during emergency response (Quarantelli, 1978), where problems across organizational boundaries are addressed (Quarantelli, 1978, Scanlon, 1994) while making decisions under time constraints. These characteristics make EROs well suited for the study of collaboraitve information foraging behavior.

Collaborative Information Foraging

Information foraging is defined as the human behavior of actively seeking, gathering, and sharing information (Pirolli and Card, 1999). Whereas, collaborative information foraging is described in terms of two conceptually distinct activities—information seeking and information handling—as practiced by group members. *Information seeking* refers to "the purposive seeking for information as a consequence of a need to satisfy some goal," while *information handling* refers to "the physical and mental acts involved in incorporating found information into the group's existing knowledge base" (Wilson, 2000). Therefore, in the context of foraging processes, information may be synthesized (i.e., converted from unique to common or handled) rather than consumed iteratively throughout the response operation.

Information Distribution

Information items in extreme events such as emergencies are often differentially distributed. Prior studies strongly suggest sharp differences in patterns of human information processing and decision making when the environment in which these activities take place is characterized by dynamism (Brehmer, 1992, Gonzalez, 2004) and high stakes (Klein et al., 1993, Perrow, 1984). Each group member in an ERO typically holds information that is relevant to the task but differs from or complements information held by others. The proportion of group members who hold some information beforehand, determines initial commonality of information (Stasser and Titus, 1987, Stasser et al., 1989). A particular item of information may range from common (i.e., known by all group members) to unique (i.e., known by one group member). It is therefore appropriate to consider whether and how the pattern of this distribution can impact information foraging processes.

The *information space* is conceptualized as a pool of information items available to the group based on the idea that information is typically, unevenly distributed among group members. In other words, when information unique to a group member is shared with the entire group (synthesized from unique to common) via dialogue, the amount of information available to the group is increased. Otherwise, the information space will continue to shrink as events unfold. Thus, dynamism in the information space may shape information foraging behavior of groups in an emergency situation. It is therefore important to provide a mechanism for investigating the impact of information space on group information foraging behavior.

SALIENT FACTORS THAT SHAPE INFORMATION FORAGING BEHAVIOR

With a focus on a process view, a review of relevant literature revealed factors that shape collaborative information foraging behavior of actors. The identified factors include: individual-level factors, group-level factors, task-related factors, technology-related factors, and contextual factors. A description of each factor below illustrates its relevance and implication to emergency response organizations. Also, in the context of emergency response organizations, we reckon that other possible confounding factors such as cultural, organizational, and political may be assumed to be constant since the organization under study is homogenous. However, such factors may be included for a comparative study between organizations.

Individual-level factors

These are factors that pertain to group members, such as personality, demographics, cultural background, and expertise. Prior research has provided evidence for the impact of individual-level factors such as expertise (Bonner et al., 2002, McGrath, 1984, Mendonça and Hu, 2008), and cognitive ability (Benbasat and Taylor,

1982) on information foraging behavior. Individual roles have been identified as key conceptual unit of a team (Ilgen et al., 2005), thus important in understanding groups working together to achieve a common set of goals (Ilgen et al., 2005). In EROs, roles are typically defined before the event and filled during the response by available qualified individuals (Kreps and Bosworth, 1993). It is important to investigate whether or not roles held in an ERO have an impact on information foraging processes during a response operation.

Group-level factors

Group-level factors such as pre-discussion preferences (i.e., conflict vs. non-conflict), group composition (homogeneous vs. heterogeneous), inquiry method, counterfactual mind-set, group size, group leadership, and group history may influence information foraging behavior (Hightower and Sayeed, 1996, Kray and Galinsky, 2003, Parks and Cowlin, 1996). For our purposes, it is assumed that emergency response organizations are homogeneous, ad-hoc groups without conflict as a result of the relatively small number of representatives from the responsible agencies.

Task-related Factors

These factors pertain to the task executed by the group. Goals and complexity (Earley, 1985, Huber, 1985) attached to tasks may influence information foraging performance of responding groups. Task type may be intellective, decision making or cognitive conflicts (Saunders and Miranda, 1998). Emergency response is a complex, non-routine decision making task. As a result of the dynamic nature of the emergency environment, emergency response personnel need to access information more frequently thus increasing information load. It is therefore assumed that the tasks for emergency response groups are decision tasks with high level of complexity.

Technology-related Factors

Factors examined here relate to technologies used for collaborative information foraging processes such as communication mode—computer mediated communication systems vs. face-to-face (Hightower and Sayeed, 1996), and group support systems (GSS) treatment (Dennis, 1996). The use of computer technologies in a group setting brings changes to the patterns and efficiency of traditional information foraging processes (Ramirez Jr. et al., 2002).

Contextual Factors

Given the dynamism and uncertainty in an emergency environment, the relevant contextual factors that may impact information foraging behavior include, time constraint, characteristics of information sources and event severity. These factors may apply either to the process of information foraging, or to the consequent decisions.

Time constraint

Time constraint, defined as the "limits on the amount of time available to complete a task" is a major characteristic of an emergency. Time constraint may impact information foraging behavior during decision making and problem solving in a number of ways (Ahituv et al., 1998, Ariely and Zakay, 2001, Durham et al., 2000, Ordóñez and Benson, 1997); decision makers may speed up their information foraging, and be more selective in choosing which information to be handled. Group members may be forced to focus on a restricted range of task-relevant cues to adopt task completion as their major interaction objective (Kelly and Loving, 2004). Thus the quality of the decisions made in such instances is potentially compromised for reaching decisions quickly.

Severity

Risk and severity are related terms used in crisis management domain. Risk is defined as a "measure of the probability and severity of the consequences of undesirable events" (Merrick et al., 2002) Severity reflects the actual magnitude of a catastrophic event. Level of severity can be described according to the type of emergency event. In this study, severity is regarded as a key indicator of loss of property and life in an emergency environment.

A scenario that calls for emergency response is described to ground the framework components described, outlining the impact of the salient factors on information foraging behavior of responders.

Scenario: Collision between two ships

Data for this illustration (see Table 1) are taken from a simulation-based training exercise with a small group of emergency response personnel consisting of a group coordinator (CO), acting as a facilitator; and four others acting as representatives of their respective emergency services (Police Department (PD), Fire Department (FD), Medical Officer (MO), and Chemical Advisor (CA)). The case concerns a collision between two ships with a resulting chemical emission. An oil slick is visible around one of the ships, and two people are trapped on it. A fire is underway on board this ship, with wind from the northwest. The group's task is to allocate resources to the incident location in order to meet the goals of the response operation.

Segment	Time	Role	Conversation
1	9:07:25AM	CO	General cargo. CO_2 fire retardant must be sprayed from 30-feet height, medical and chemical units can be dispatched from one location only, oil slick, visible around the ship. Okay, so we have 20 minutes to plan it.
…	…	…	…
2	9:44:02AM	CA	My 20 suits are at C; my 10 suits with SCBAs are at K.
3	9:44:09AM	CO	CO Okay, so you know what I'll do? This is what I'm going to do. I'll pick I to G to escort CO_2, and I'll take F to N to pick up police officers. Unless the bus, well, we can get the bus to pick up 20 police officers from N. That's better yet. Can we do that?
4	9:45:06AM	PD	Which is the bus? L?
5	9:45:08AM	CA	L is the bus.
6	9:45:09AM	CO	Yeah, okay, so we take the bus and we can pick up, like, 20 officers? L to N to F to Z. Okay? So, the bus from L will pick up 20 police officers and go to the fire. We'll send I to G, and where do we need to go from G? Straight to the fire or do we need to go somewhere else?
…	…	…	…
7	9:49:33AM	CO	All right, let me read to everybody. Fire on cargo ship and general cargo updated. Explosion occurred 10 minutes after notice of fire. Two people still trapped on the ship, wind from the Northwest due to changes.
8	9:50:33AM	MO	And the situation orders have yet been executed. There are other people injured and additionally resources are available.

Table 1: Excerpts from Response to a Simulated Emergency

Concepts discussed previously are illustrated as follows. The question posed and answered by the PD and CA respectively (segments 4 and 5), is both indicative of an *information seeking* activity. In other words, the PD attempts to find out what resources are at site L, and the CA answers by confirming that a bus is at site L. In the meantime, the CO knows that "there is one police cruiser at site I", "2200lbs of CO_2 (but no vehicles) at site G", "one police cruiser at site F", "20 police officers at site N (but no vehicles)", and "one bus for 60 people at site L". The problem then is how to deliver the CO_2 and police officers to the incident location Z as soon as possible to control of fire and remove trapped people. CO has a potential solution of assigning the cruiser at site I to escort CO_2 at site G, and assigning the cruiser at F to escort the police officers at N. But this is not the fastest way because he also knows that site L is closer to incident location Z than site F, and that there is a bus available at L, which may be used to transport the 20 police officers. So CO proposes an alternative solution (i.e., assigning the bus at site L to escort these police officers). The alternative is proposed based on the collection of information and incorporation of the information with the existing knowledge base. This act of incorporating information based on existing knowledge depicts *information handling* (in segment 6).

The case also illustrates the contextual factors discussed above. Resources at sites O, Q, L and M are alternative resources, and information about them is accessible to all group members. This information is therefore *common information*. Information about all other sites is available to the roles that control these sites and to CO. This information is therefore *unique* information. For example, "My 20 suits are at C; my 10 suits with SCBAs are at K." shows seeking for *unique* information. A reminder from the CO that the group only had 20 minutes to plan and implement a decision about the problem at hand may be referred to as *time constraint* (segment 1). *Severity* arises from the environment, as shown in segments 7 and 8 where the level of severity is increasing due to the explosion after the fire; the changed weather; the unimplemented orders; and *time constraint*.

Having defined and given examples of salient concepts in group information foraging in emergency response, we now investigate attempts to model information foraging behavior of individuals.

MODELING APPROACHES

Existing information behavior models that seek to understand seeking, handling, and/or foraging activities are reviewed using concepts identified above as well as salient factors that shape them in the context of emergency response.

In particular, three approaches for modeling information foraging behavior are discussed: Ellis's (1989) and Foster's (2004) grounded theory approach; Reddy and Jansen's (2008) ethnographic approach; and Zhang et al.'s (2009) time series model approach.

Grounded Theory

Using a grounded theory approach, Ellis (1989) posits behaviors involved in information seeking as characterized by eight features: starting, chaining, browsing, differentiating, monitoring, extracting, verifying, and ending.

Starting: the means employed by the user to begin seeking information, for example, asking some knowledgeable colleague;

Chaining: following footnotes and citations in known material or 'forward' chaining from known items through citation indexes;

> Browsing: 'semi-directed or semi-structured searching' (Ellis, 1989: 187);
>
> Differentiating: using known differences in information sources as a way of filtering the amount of information obtained;
>
> Monitoring: keeping up-to-date or current awareness searching;
>
> Extracting: selectively identifying relevant material in an information source;
>
> Verifying: checking the accuracy of information;
>
> Ending: defined as 'tying up loose ends' through a final search.

Ellis's (1989) features are indeed general enough to describe a wide range of information seeking activities. It is helpful in finding explanations for information seeking behavior. The identified features may be used as treatments to observe behavioral patterns of a target user for a potential research study. Thus it is possible to qualitatively and quantitatively discern differences in any of the features in different situations, involving different kinds of persons through successive research projects.

In the context of emergency response organization, features in Ellis's (1989) model adequately represent how information is sought and verified by a user interacting with search technologies. However, the features are not sufficient in explaining capability of task-related activities or individual-level tasks such as expertise of the information forager. Therefore we are unable to assess the impact of emergency circumstances on information foraging distribution or foraging activities. In other words, it is difficult, for instance, to compare the level of effort devoted towards handling (using sought information) unique vs. common information between a novice and an expert using this model.

Reddy and Jansen (2008) note that Ellis's (1989) model of information seeking behavior and others (e.g., Belkin & Vickery 1985a; Ellis & Haugan, 1997; Ingwersen, 1996; Marchionini 1992) "are representative of the shift from the system-centered to user-centered perspective in information science research."(Reddy and Jansen, 2008). The user-centered perspective is commonly espoused at the level of an individual user typified by the database query model of information seeking (Reddy and Jansen, 2008). The database query model is predicated on a single user's well-formulated query against an understood data repository in order to retrieve identifiable results (Robertson, 1977).

Foster (2004) presents a non-linear model to inform our understanding of the context of inter-disciplinary information seeking behavior from grounded theory approach. He represents the model with three core processes: opening, orientation, and consolidation, and three levels of contextual interaction: external, internal, and cognitive approach.

Opening was identified "as corresponding to the process of moving from a state of orientation to actually seeking, exploring and revealing information." Opening process confirmed two activities identified in Ellis (1989): monitoring and chaining.

Breadth exploration emerged under the opening process and was identified as a "conscious expansion of searching to allow exploration of every possibility"(Foster, 2004). This suggests that the user and not the context of the task or environment vary time spent in an information space, which is certainly not the case in an emergency environment where information pool shrinks as time passes.

The process of reviewing as identified under opening suggests that users synthesize known information in an area. This can be mapped to handling of a common or unique information item in a group during collaboration.

Orientation process is generally geared towards problem solving as it encompasses "a diverse range of activities covering the identification of existing research, key themes, disciplinary communities, latest opinion, sources, keywords, and picture building" (Foster, 2004).

A main concept of consolidation was termed *knowing enough*, which emerged as an iterative process of questioning of whether or not sufficient material had been acquired to meet the present information need.

Overall, the model offers a complex multilayered tool to explain and further explore inter-disciplinary information behavior of emergency response personnel. Although the range of activities in the model is described from an individual user perspective; hence the model falls short on providing details on how the core processes and contextual factors will play out in a group environment.

Ethnography

Reddy and Jansen (2008) used ethnographic techniques in two field studies to investigate information seeking behavior of medical practitioners.

Findings from these studies, confirmed "collaborative information behavior differs from individual information behavior with respect to how individuals interact with each other, the complexity of the information need, and the role of information technology" (Reddy 2008). They also found that certain characteristics, called *triggers* to be responsible for transitioning from individual to collaborative information foraging behavior. The triggers identified are (Reddy and Jansen, 2008):

> Complexity of information need: complex information problems initiate much of the collaborative information behavior activities.
> Fragmented information resources: Work environments where information resources reside in multiple and dispersed systems can trigger CIB occurrence.
> Lack of domain expertise: When an individual does not have the prerequisite knowledge to answer a question, s/he will turn to people with the necessary knowledge to help him or her find the correct answer.
> Lack of immediately accessible information: When information is not easily accessible, people often collaborate to find the information.

Technology-related factors, in this case information retrieval technologies used, were found to enhance collaborative information behavior. Based on results from these field studies and prior work, a logical model of collaborative information behavior was developed along the axes of participant behavior, situational elements, and contextual triggers.

Time Series Analysis

Time series analysis approach deals with analyzing the correlation between time series variables and discovering the causal relationships. Causal analysis in time series has been widely studied and used in many applications, e.g., stock market analysis and rainfall forecast (Naill and Momani, 2009). Given the inherent dynamism embedded in information foraging behavior, the idea of measuring the impact of passage of time is therefore plausible. To this end, research is underway to explore and model the amount of variability explained by the passage of time on information foraging behavior of groups in extreme events. The argument for understanding the impact of time in an extreme environment is also predicated on the assumption that time spent on sharing common information is time taken away from implementation with a potential risk of information overload.

Zhang et al., (2009) proposed a time series approach to understand information-seeking behavior of web users over time. Zhang et al (2009) found evidence for patterns in how users interacted with the search engine as well as explanations for the observed patterns. This approach captured task-related factors (e.g., preference for informational rather than transactional or navigational needs); technology-related factors (e.g., the use of a search engine); contextual factor (i.e., the effect of time of passage of time on information seeking behavior) at the individual level of analysis. Although the level of analysis is at that of a solitary user, this approach provides prospects for estimating and evaluating circumstances that shape information foraging in extreme events.

ANALYSIS

Based on the review of modeling approaches presented in the previous section, salient information characteristics (dynamic information space and synthetic nature of information) as well as factors that shape collaborative information foraging behavior in an emergency situation are summarized into a conceptual framework (see Table 2).

Cells in the table are used for assessing the adequacy of approach (row) employed in measuring dynamics of the salient factors and information properties (column) that shape information foraging behavior in dynamic, uncontrolled environments. An assessment value of either *yes, no, or partial* is assigned in each cell based on how well an approach explains information foraging behavior in the context of the salient factors.

Dynamic: Information space

Two triggers, fragmented information resources and lack of immediately accessible information, observed in the ethnographic studies are a potential metric for investigating the influence of dynamic information space on foraging behavior. Ethnographic approach is therefore adequate for specifying and measuring dynamic information space during foraging processes. Time series and the grounded theory approaches on the other hand, do not provide explanation or potential capability of estimating the dynamism in information space during foraging process.

Synthesizable: Information

Models derived from grounded theory and ethnographic technique hint on when, why, and how foragers share information during foraging processes but unclear as to what information item is shared. Although it is not clearly stated, there is an implied notion that information is assumed to be a non-consumable entity. Time series model however, provided no explanation as to how an information item is synthesized from being unique to common.

Individual-level factor

Models developed from grounded theory and ethnographic studies adequately addressed individual-level factors. A common denomination used to assess this factor in both approaches is the impact of individual expertise on their foraging behavior. Time series approach however, provided no explanation for a distinction between individual levels of expertise for instance, of users or how that may have impacted their foraging behavior.

Group-level factor

Although the models derived from grounded theory approach captured individual level factors such as expertise of a user, it failed to extend the consequential effect of such factors in a group setting.

The ethnographic approach on the other hand, shows potential in controlling for when and why participants switch from solitary to collaborative behavior in the foraging process. This suggests that ethnographic approach is adequate for measuring group-level factors that affect information foraging behavior.

Time series approach provides neither explanation nor capability for measuring any sort of group-level characteristics of the information forager.

Task-related factor

Since all the approaches are aimed at formalizing behavioral patterns of individuals performing a particular task, it is assumed that they possess the potential for investigating information foraging behavior of participants either at the individual or group level.

Technology-related factor

None of the approaches treated for technology-related factors on information foraging behavior. Although, foraging characteristics captured in the models developed from all of the approaches are subsumed in the interaction of users with information retrieval technologies.

Contextual Factor

Models developed from the grounded theory approach acknowledge the impact of time constraint (a contextual factor) on unique or common information item that is sought or handled during the search process. This therefore translates to a potential ability of grounded theory approach to capture and explain foraging activities under the treatment of a contextual factor such as time constraint.

Time series approach investigates, by default, the impact of the passage of time on information foraging behavior, hence it is adequate for that purpose.

Models derived from ethnographic approach did not explain treatment for time constraint or severity level on information foraging processes.

None of the approaches treated for or provide insights as to how to estimate severity levels during a foraging process.

Approach	Information properties		Factors that shape collaborative information foraging				
	Dynamic	Synthesizable	Individual-level	Group-level	Task-related	Technology-related	Time constraint/ Severity
Grounded Theory Ellis (1989); Foster (2004)	No	Partial	Yes	No	Yes	No	Partial/No
Ethnography Reddy and Jansen (2008)	Yes	Partial	Yes	Yes	Yes	No	No/No
Time Series Zhang et al (2009)	No	No	No	No	Yes	No	Yes/No

Table 2. Conceptual Framework

This framework immediately provides a standard for assessing models and approaches that seek to investigate or promote understanding of group dynamics in collaborative or collective information foraging behavior in an environment characterized by time constraint, variable severity level, decision-making or problem solving. It is important to note that the focus of a research study on investigating the influence of a factor of interest may be independent of the approach employed.

IMPLICATIONS

Approaches reviewed for modeling information seeking and handling in this paper were all developed to understand an individual user's behavior, which partly explains why most of the approaches turn out to be inadequate for measuring group dynamics. This speaks to the scarcity of models that explain group information foraging behavior in the Information Sciences, and Emergency Management fields as well as the contribution of this work in provoking research in this area. We therefore encourage researchers in these fields to consider the expansion of knowledge in the area of collaborative information foraging behavior as an integrative transition from the individual user focus of the current models.

Although the models reviewed were single-user specific, the conceptual framework is found to be a useful tool for assessing the requirements needed in order to modify existing models into group level models with a roadmap of behavioral patterns to investigate. The conceptual framework will be useful as a guide for a research study that is aimed at investigating one or more phenomenon that influences group information foraging behavior of teams collaborating to solve a problem.

CONCLUSION

This paper synthesized a conceptual framework that defines requirement for modeling collaborative information foraging behavior in an emergency response domain. With a focus on a process view of collaborative information foraging behavior that holds on a variety of contexts, situations, and domains, it is believed that this work will inform our understanding of requirements that need to be brought to bear for systems designers as well as researchers in a variety of environments. We hope that findings from this work will be used among researchers to formalize requirements for modeling collaborative information foraging behavior in groups in environments characterized by dynamism, time constraint and varying severity. It is also hoped that this work encourages fellow researchers to critically explore and expand the understanding of collaborative information foraging behavior so that future researchers can work more effectively (Bechky, 2003). System designers can leverage insights from this study by designing tools that will allow for the measurement and assessment of the identified salient factors that facilitate collaboration among response groups in emergency situations.

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