Collaborative Systems: Defining and Measuring Quality Characteristics

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Abstract: *Given the pervasiveness of collaborative systems in contemporary organizations and society, this paper aims to present several quality characteristics of collaborative systems in order to reveal the social and technological requirements that need to be met in order for such systems to provide the desired results. Furthermore, this paper defines a set of metrics for assessing the performance of collaborative systems and we propose several means for increasing their quality characteristics in use.*

Keywords: *collaborative systems, quality characteristics, quality assessment*

1. Collaborative Systems and Society

In the face of mobile, ubiquitous computing, we have witnessed the emergence of collaborative systems that bring people together to engage in common tasks and to achieve shared goals. The potential for interacting, exchanging information, joint creation, and collaborative innovation as induced by these collaborative systems is enormous, hence, we can only expect the popularity of these systems to increase.

Collaborative systems have taken on many different forms, ranging from social software—primarily web-based collaborative tools—which brings people together outside the workspace to the use of collaborative software in the workplace to enable more effective group collaboration. Therefore, the role of collaborative systems in our contemporary knowledge society is pervasive, both in people's public and private sphere.

In the realm of social software, examples of internet-based collaboration platforms abound: a web-based platform for the shared creation and revision of a free, collaborative multilingual encyclopaedia (Wikipedia); an online community platform where people plan and develop a new car along open source principles (OScar); collaborative community spaces for the collective use, modification, and redistribution of software (e.g. Linux, Symbian OS, Mozilla etc.) as well as countless social network sites for sharing ideas, documents, opinions, for networking, and for collaborating.

In the area of work-related collaborative software, we have seen widespread adoption of groupware, group support systems and collaborative project management tools that are designed to help people achieve goals, develop ideas, or create new products or services collaboratively. In this context, the value of collaborative systems is to bring together the efforts and ideas of many by providing a common means for communicating and collaborating. In general, then, collaborative systems need to support individual task, group interactions, synchronous and asynchronous communications, and multi-user editing and designing.

Given the widespread use, growing popularity, and increasing relevance of collaborative systems both to organizations and society at large, this paper aims to define a set of quality characteristics of collaborative systems as well as an array of metrics for assessing the performance of these systems building on existing models of general system quality characteristics. Furthermore, we discuss several characteristics that could enhance the quality of a system from the perspective of the user, namely tailorability, scalability, and engageability.

In what follows, we will first discuss existing models of general system quality characteristics and build upon these models to outline a set of quality characteristics of collaborative systems. Then, we will present performance metrics and evaluation criteria for assessing the quality of these systems. Finally, we conclude with a discussion of several system characteristics that could potentially enhance the quality of a collaborative system from the perspective of the user.

2. Existing Models of General System Quality Characteristics

Different ways for classifying the quality characteristics have been observed in literature [5] and a comparison between them should emphasis the strong points of each one, with considerations about which are the best to use in different situations and from which perspective should they be analyzed: (i) users, (ii) administrators or (iii) organizations.

The McCall Quality Characteristics Model is based on the life cycle of a product and the characteristics are grouped by three major categories: operations, revisions, transitions, figure 1.

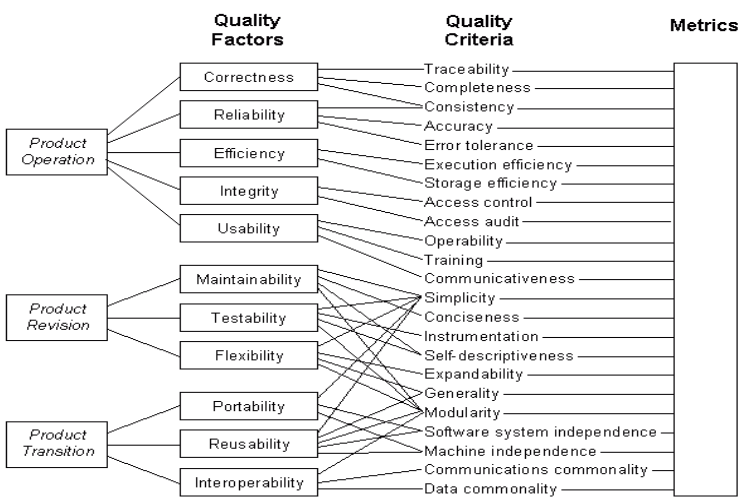

Fig. 1. McCall Quality Characteristics Model

The Boehm Quality Characteristics Model is more or less the same as the previous but he reorganized the nature of some characteristics, figure 2.

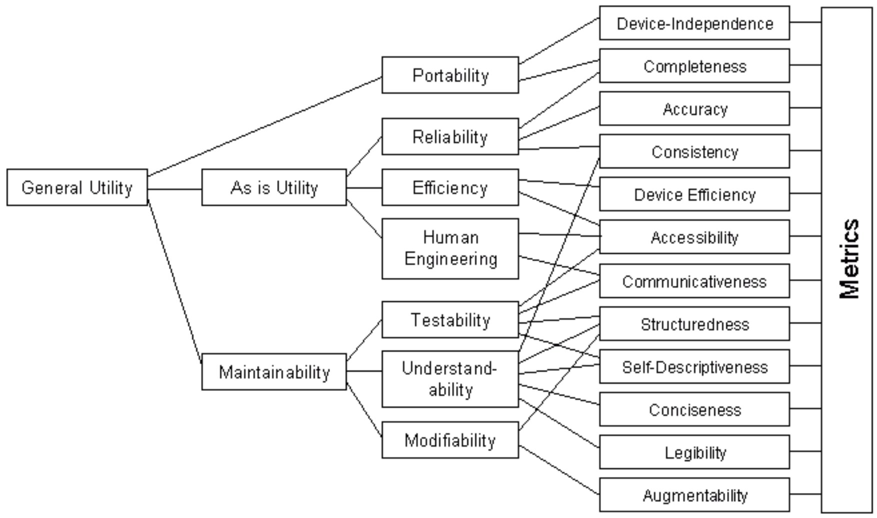

Fig. 2. Boehm Quality Characteristics Model

ISO had introduced in 1991 the following classification, figure 3 and identified six major characteristics and for each one, a set of sub characteristics based on which internal and external metrics could be developed.

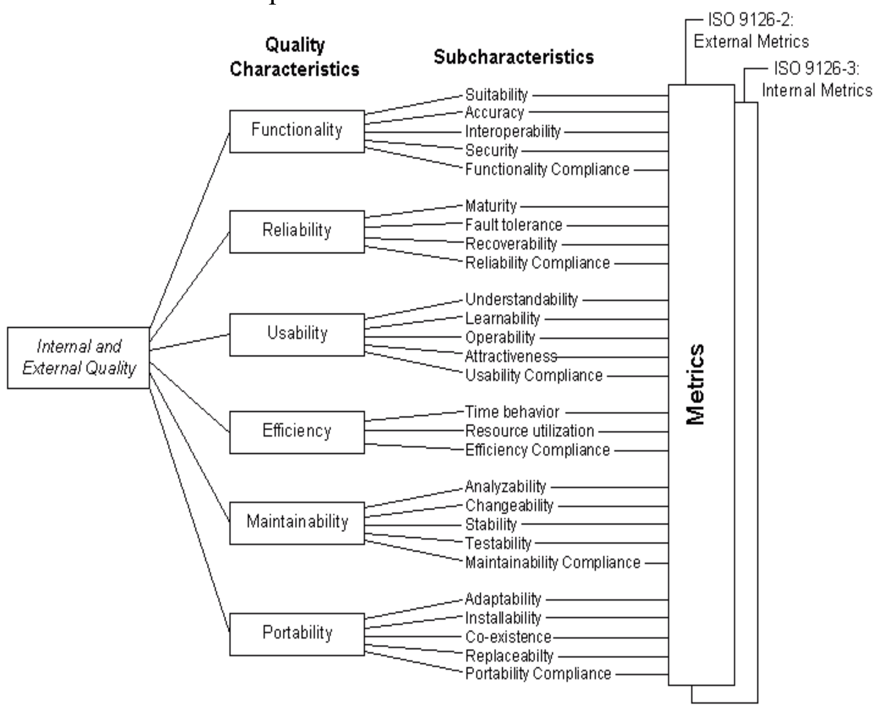

Fig. 3. ISO 9216 Quality Characteristics Model

In the next section we will build on these existing models and applied them to collaborative systems in particular.

3. Collaborative Systems Quality Characteristics

In order for collaborative systems to behave according to the requirements and needs of people and contemporary organizations, stringent quality characteristics and sub-characteristics need to be met. Quality characteristics are defined by [3] as being a set of attributes of a software product by which its quality is described and can be evaluated. The way in which these systems are designed must reflect the quality characteristics needed for usage and need to be carefully managed throughout the entire system life cycle. During all stages of the lifecycle—that is from starting to develop a collaborative system using modelling languages, doing a back stage analysis upon the characteristics that are required in order to achieve the purposes for which the system is being built, through to the final stage of the life cycle in which the system is removed from use or replaced—quality characteristics inevitably influence all the components with which the system interacts. By understanding better the underlying processes that constitute the collaborative system's GUI and identifying the aspects that are relevant in providing useful and reliable results an analysis upon the quality characteristics at different levels for collaborative systems must be made.

The quality characteristics and sub characteristics should be treated from several different perspectives to get a good understanding of how these can influence the overall performance of the system.

The purpose of collaborative systems can be unfolded as follows:

- increase efficiency by means of better interactions between participants;
- share resources to achieve a higher level of collaboration;
- dividing tasks for obtaining reliable results more effectively and efficiently;

Depending on the perspective we adopt, different characteristics can be identified for a collaborative system. These perspectives can be categorized according to the following criteria:

- target group criteria – the users for which a collaborative system is designed and who have their own opinions about how such a system must react when dealing with their requests;
- technological aspect criteria – from a technological perspective collaborative systems must enclose all the characteristics of a distributed system much more;
- social or economic area of activating – depending on the type of jobs collaborative systems are performing they must meet different characteristics, some more important than others; e.g., in the military field, the collaborative systems of defence [1] has a stronger need for security than informal collaborative systems such as Wikipedia;
- the nature of activities it serves: informing, negotiating, collaborating or cooperating; based on the nature of the activity that the system needs to support, certain characteristics are required.

In what follows, we will discuss these four criteria in more detail.

Regarding the first criteria we can identify some important characteristics that a collaborative system must have, defined also in [2,3], in order to satisfy the designated target group for which it is built; these are important characteristics viewed from a user perspective:

- accessibility – is a general term used to describe the degree to which a collaborative system is accessible by as many people as possible, with as less of assistance or none, preferable;
- availability – is the characteristic which reflects the time in which a system is fully operational and users can access its processes without interference;
- usability – describes the extent to which a collaborative system can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context without any kind of impediments;

- reliability – refers to the capacity of collaborative systems to perform tasks given a certain stressful setting without any unpredictable stops;
- efficiency – determines the relationship between the level of performance of a collaborative system and the amount of resources used for generating results.

The second topic contains characteristics that must be met during the design stage but also after the collaborative system is put into production. These kinds of characteristics are defined in [3] as quality software characteristics without which parts of a collaborative system cannot serve its purposes:

- functionality;
- portability;
- maintainability.

The third aspect will require that specific characteristics are more rigorously treated than others depending on the domain in which collaborative systems are integrated:

- scalability – geographical collaborative systems rely heavily on two elements, one is the algorithms that are needed to compute all the data and the other one is a database in which attributes of the geographical elements are stored. From this point of view scalability—the power and easiness with which data or new elements can be added and the system's ability to handle these growing amounts of data—requires careful management;
- security – collaborative systems of defence have a greater need for security characteristics like confidentiality, integrity and authenticity due to the nature of the tasks for which these systems are implemented;
- accurateness – collaborative medical systems must work with efficient algorithms and high precision otherwise situations in which doctors are performing remote procedures on patients could lead to dramatic results;
- completeness – informing collaborative systems need to have huge databases filled with different types of data and they must cover as much as possible in relation to the specific subject domains for which these are employed.

For the fourth category—the purpose of a collaborative system— we can identify several characteristics that are worth mentioning. Every category stresses certain of the aforementioned aspects while ignoring others, as follows:

- informative purpose – these types of collaborative systems aim to gather and store information under a common aegis, helping people share their knowledge, hence, these systems must offer among other characteristics, the intrinsic characteristics of information: (i)*accuracy*, (ii)*relevancy* and (iii)*updated*; e.g. Wikipedia;
- negotiating purposes – such collaborative systems play a vital role in the negotiation process and therefore (i)the *fault tolerance* and (ii)*non time consuming* characteristics must persist; e.g. BidRivals negotiation system;
- the collaboration aspect is presented here as a group that is working towards a single goal but at an individual level different tasks are assigned in order to accomplish the common goal; such an approach must rely on a complex (i)*document* and (ii)*process management* system; e.g. Office SharePoint server;
- the cooperation captures the aspects of a collaborative system used by a group of people who are trying to achieve the same goal, therefore having a common objective plus, using and sharing the same resources and working simultaneously and collectively like brainstorming activities; the characteristics which must emphasis in such systems are (i)*atomicity* and a (ii)*boundless framework* together with a (iii)*low level of interference*; e.g. Google Wave an open system which has a strong and well defined atomic structure in the presence of waves and a framework that allow users to

add external components and expand the functionalities of the entire system without trails of interfering between these atomic structures, in other words a low level of redundancy.

We can conclude that, as DeMarco was saying in [5], a product's quality is a function of how much it changes the world for the better.

4. Collaborative Quality Characteristics Metrics

In the spirit of DeMarco, for better assessing the way how quality characteristics can influence the overall results of a collaborative system, we can formalize this as follows:

$$F: M_{1,n} \rightarrow M_{11}$$

$F(x) = y,$

where:

- F – the function of product's quality defined by DeMarco;
- x – the vector of quality characteristics and sub characteristics with n values;
- y – the output in terms of how much a product can influence the world for the better.

For maximizing this model we can apply the following system and determine the *m* points in which the output gets its highest value:

$$(S)\begin{cases} \frac{\partial F}{\partial x_i} = 0 \\ F(x_{0j} - \varepsilon) > 0 \\ F(x_{0j} + \varepsilon) < 0 \end{cases}, \forall i = \overline{1,n}, j = \overline{1,m}$$

Epsilon represents a vector of minimum variation having $\varepsilon \rightarrow 0$. This model can be used also for determining the total and local influence of input upon output. By adding different types of constraints such as costs used for increasing the input's level, we can determine the input combination which assures a predetermined level of output.

For doing a correct and relevant assessment upon the implications of the input material-the quality characteristics and sub characteristics-on the qualitative and quantitative changes that can be brought to the output we don't have to analyse just the bound between the factors and the result, but also we have to synthesize metrics that can measure the dynamics and the behaviour of each and every input factor.

In the following debate we identify six important characteristics that will be analysed and metrics will be developed for a better understanding of how the final output of a collaborative system could be improved.

Based upon them six major characteristics that can be used for defining (i) internal or (ii) external metrics:

- usability;
- portability;
- functionality;
- maintainability;
- reliability;
- efficiency.

Usability describes the extent to which a collaborative system can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context without any kind of impediments, is the characteristic of being intuitive and can be measured by the following formula:

$$UM = \frac{\sum_{i=1}^{n}(1-p_i)}{m},$$

where:

- UM – usability metric;
- n – the number of user's successful operations with or without assistance;
- m – the number of user's total operations;
- p_i – the degree in which a user was assisted for completing the *i* operation.

The metric will take values between:

$UM \in [0;1]$

If a user completed all operations successfully, than n will be equal to m and further more if it didn't had need of any kind of assistance, $p_i = 0, \forall i = \overline{1,m}$, than UM = 1, which means that the system has maximum usability.

Another characteristic that can be also measured is portability which defines the degree of changing the environment in which a collaborative system is functioning without being forced to spend extra costs for these modifications. The metric used could be determined by the following formula:

$$PM = 1 - {C_{integration}}/{C_{develope}},$$

where:

- PM – portability metric;
- $C_{integration}$ – the costs supported for the porting process;
- $C_{develope}$ – the costs supported for the developing process of a collaborative system;

The domain for this metric is defined by the following values:

$PM \in [-\infty;1]$

In the best case scenario, if a collaborative system must be moved in other working environments without extra costs then PM = 1, otherwise the metric will behave as follows:

$$PM = \begin{cases} 1, C_{integration} = 0; \\ (0;1), C_{integration} \in (0; C_{develope}) \\ (-\infty;0], C_{integration} \geq C_{develope} \end{cases},$$

The scenario in which $PM \leq 0$ is the one in which the costs for changing the environment are greater than the design costs and it represents an unpractical solution, in this case, a new system should be developed.

Functionality is defined as the ability of a collaborative system to interact properly among its own components and the external ones. Functionality can be calculated for collaborative systems that already have passed the implementation phase, using the following formula:

$$FM = 1 - \frac{\sum_{k=1}^{n} BN_k}{\sum_{i=1}^{m}\sum_{j=1}^{m}(C_i \cap C_j)}, with\ j \geq i,$$

where:

- FM – functionality metric;
- BN_k – number of bytes affected by error *k*;
- n – total number of errors;
- $C_i \cap C_j$ – number of bytes transferred between *i* and *j* components;
- m – total number of components.

The domain for the functionality metric is:

$FM = [0;1]$

When no errors are detected functionality metric equals 1, otherwise, if errors occur in the transfer between the internal or external components affecting all information processed, FM=0, because each error is counted for every transfer failed.

Maintainability is the characteristic which give users, if present, easiness in correcting bugs, meet new requirements or improve future maintenance. Metrics have been developed for measuring the maintenance index like:

- lines of code measures;
- McCabe measures – cyclomatic complexity;
- Halstead complexity.

Maintainability characteristic is defined by several system properties and for each one, metrics could be built:

- changeability;
- testability;
- analyzability.

The following metric aims to reveal the maintainability power of a collaborative system from the perspective of adding new features, changing existing ones to comply with the new requirements or even eliminating some, aggregated also with the level of complexity defined by the graph associated with the collaborative system. Changeability metric is defined below:

$$(1) CM = \llbracket (SL \rrbracket_0 - SL_R + SL_A) / (SL_0 + SL_R + SL_A + SL_M),$$

where:

- SL_0 – initial number of source line;
- SL_R – number of lines removed from the system;
- SL_A – number of lines added to the system;
- SL_M – number of lines modified from the system.

Another metric used for the maintainability index is the one which describes the number of paths from the initial point of the collaborative system's oriented graph to every functionality described as a node. The collaborative system's graph is represented by its adjacency matrix AM defined below:

$$am_{ij} = \begin{cases} 1, \exists\ edge\ from\ vertex\ i\ to\ j \\ 0, \nexists\ edge\ between\ i\ and\ j \end{cases}$$

Based on this matrix GCM, the graph complexity metric is defined as:

$$(2) GCM = \sum_{i,j}^{n} am_{ij},$$

The maintainability index will be computed by (1) and (2) as follows:

$$MM = \frac{1}{GCM} * CM$$

The two components found in the MM index influence in the following way:

- CM – if no changes are made in the system at the maintenance stage then CM=1, otherwise CM will decrease to zero accordingly with the degree of changes made; $CM \in [0,1];$
- GCM – the minimum value of the GCM is 1, representing just a single functionality, otherwise if increase the number of functionalities and the connections between them, the complexity will increase unrestrictive; $GCM \in [1; +\infty);$
- $1/GCM \in (0,1]$ representing the weight of the changeability metric resulting in $MM \in (0;1] \times [0;1] = [0;1].$

Other factors could also influence maintainability but the power of code changeability and system complexity level are ones of great importance for a collaborative system.

Reliability refers to the capacity of collaborative systems to perform tasks given a certain stressful setting without any unpredictable stops.

The metric referring reliability is described below:

$$RM = \frac{\sum_{i=1}^{m} \frac{DS_{0i} - DS_{1i}}{T_i * \overline{DS}_i}}{m}$$

where:

- RM – reliability metric;
- DS_{0i} – data segment before unpredicted errors occur (bytes) in functionality *i*;
- DS_{1i} – data segment after re-entering in normal functionality (bytes) in functionality *i*;
- T_i – time needed for recovery in functionality *i*;
- $\overline{DS}_i$ – data segment average calculated for the *i* functionality of the system;
- m – total number of functionalities for the collaborative system.

The domain for the reliability metric is:

$$RM \in [0; +\infty)$$

The reliability metric represents an average of every single reliability functionality and the more it gets higher the less effective is the system.

Efficiency is defined as the ability of a collaborative system to achieve its objectives without waste of resources, such as memory, space and processor utilization, network bandwidth, time, etc.

The efficiency is described as an aggregated index of the efficiency of each functionality. Number of operations per time weighted with the complexity of an operation given by the Halstead complexity describes the efficiency for one functionality of a collaborative system.

$$EM = \sum_{j=1}^{m} \frac{nop_j * HC_j}{T_j} \Big/ m$$

where:

- EM – the efficiency metric;
- nop_j – the number of operations done for the *j* functionality;
- HC_j – Halstead complexity for the functionality *j*;
- T_j – necessary time for doing operations nop_j;
- m – number of functionalities.

Having the following we can define the Halstead complexity:

- n_1 – the number of distinct operators;
- n_2 – the number of distinct operands;
- N_1 – the total number of operators;
- N_2 – the total number of operands.

Program length: $N = N_1 + N_2$;

Program vocabulary: $n = n_1 + n_2$;

Volume: $V = N * \log_2 n$

Difficulty: $D = {n_1}/{2} + {N_2}/{n_2}$

Efficiency: HC = D*V.

The efficiency metric, being defined as an average of each functionality efficiency found in $(0; +\infty)$, has also its values in:

$$EM \in (0; +\infty).$$

When the time factor $T \to \infty$ then efficiency is defined as a ct/∞ which $\to 0$, meaning the lowest level of efficiency, otherwise the value of the indicator is improving.

5. Discussions

Building on existing models of general system quality characteristics, this paper provided two important contributions. First, these general quality characteristics were applied to collaborative systems in particular and specific characteristics were distinguished for different criteria, namely target group criteria, technology aspect criteria, social or economic area of activity and the nature of the activity. Second, a set of metrics were developed for assessing the quality characteristics of collaborative systems and supporting the design of such systems These insights are relevant both to those who want to design effective collaborative systems and to those who engage with these systems, both in the realm of social, web-based collaborative tools and in the area of work-related collaboration.

Although the different quality characteristics as identified in existing models have proved useful to develop quality characteristics and quality evaluation metrics for collaborative systems, we have identified three additional features that could be useful for the design and assessment of collaborative systems, hence, should be explored and computed (?) in the future, namely: tailorability, scalability, and engageability. These three quality characteristics are primarily important from the perspective of the user and will be explored as follows.

First, tailorability refers to the capability of the system to be adapted to the specific needs and wishes of the user. In specific, we think that appropriation—that is, how an individual or group adapts a technology to fit their own particular situation—is an important characteristic of collaborative systems from the perspective of the target group. Given that collaborative systems will often be used for purposes that were unforeseen or unintended by the designer, the systems needs to be adaptable to the user-specific situation.

Second, scalability, as aforementioned, refers to the ability of a system to handle growing amounts of data or work and to be readily enlarged. A scalable system can deal with increasing amounts of throughput and users without sacrificing efficiency. In particular in the context of collaborative systems, where the number of users and the number of information that the system needs to carry can grow rapidly and unexpectedly, scalability is a highly desirable quality characteristic that needs further attention.

Third, engageability is a sub-characteristic of usability. Whereas usability refers to the overall ease with which people can employ a collaborative system, engageability refers to the ability of the system to attract and hold the attention of the user. Therefore, engageable collaborative systems promotes the cognitive-affective enjoyment the user experiences when engaging with the system, hence, increases the odds that the user will engage with the system again. Moreover, engageable systems provide the user with a positive cognitive or physical challenge so as to provoke and sustain ongoing engagement with the system.

6. Conclusions

With the rise of the knowledge society and increasing needs for collaboration, both within organizations as in society in general, we witness a growing popularity of collaborative systems. Collaborative systems provide individuals, groups, and organizations with enhanced possibilities to interact, exchange ideas, create jointly, and innovate collaboratively. Building on existing models of general system quality characteristics, we formulated a set of quality characteristics for collaborative systems and defined several metrics for the assessment of such systems. Moreover, we suggested several additional characteristics that could enhance the quality of a system from the perspective of the user, namely tailorability, scalability, and engageability and which should be explored further.

We submit that the quality characteristics and assessment criteria as outlined in this paper can assist systems designers to develop high-quality systems that involve boundary spanning and collaborative work. Moreover, we suggest that a thorough understanding of these collaborative systems and their quality characteristics through future research can help us understand how collaborative systems can enhance organizing and connecting in general as well as the way people work and interact in particular.

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