Volunteer Computing: A Model of the Factors Determining Contribution to Community-based Scientific Research

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ABSTRACT
Volunteer computing is a powerful way to harness distributed resources to perform large-scale tasks, similarly to other types of community-based initiatives. Volunteer computing is based on two pillars: the first is computational – allocating and managing large computing tasks; the second is participative – making large numbers of individuals volunteer their computer resources to a project. While the computational aspects of volunteer computing received much research attention, the participative aspect remains largely unexplored. In this study we aim to address this gap: by drawing on social psychology and online communities research, we develop and test a three-dimensional model of the factors determining volunteer computing users' contribution. We investigate one of the largest volunteer computing projects – SETI@home - by linking survey data about contributors' motivations to their activity logs. Our findings highlight the differences between volunteer computing and other forms of community-based projects, and reveal the intricate relationship between individual motivations, social affiliation, tenure in the project, and resource contribution. Implications for research and practice are discussed.

Categories and Subject Descriptors
H.5.3 [Information Interfaces and Presentation]: Group and Organization Interfaces — Collaborative computing; J.4 [Computer Applications]: Social and Behavioral Sciences.

General Terms
Management, Human Factors.

Keywords
Volunteer computing, online communities, citizen science, BOINC, SETI@home, crowdsourcing, motivations.

1. INTRODUCTION
Volunteer computing is based on the use of computers volunteered by the general public to carry out distributed scientific computing [2, 4]. It is a powerful way to harness distributed resources to perform large-scale tasks, similarly to other types of community-based initiatives, such as Wikipedia, Delicious, Slashdot or open source software development projects. Volunteer computing is based on two pillars. The first is computational: managing large computing tasks by breaking them down to many small tasks, which are then allocated to a large number of individuals who volunteer their personal computers to the initiative. The second pillar is participative: recruiting and retaining a large number of individuals to volunteer their computer resources to the project, and facilitating their continuous contribution.

A decade since the launch of SETI@home, a flagship volunteer computing project, we are witnessing a substantial increase in the number and scope of volunteer computing projects [e.g. 3]. This rise represents a growing recognition in the potential of volunteer computing as a cost-effective approach for managing computationally-intensive tasks. However, while the computational aspect of volunteer computing received much research attention [e.g. 2, 3, 4, 19, 30, 46], the participative aspect remains largely unexplored. What do we know about the factors driving participation in volunteer computing projects? How can a large scale scientific project provide an environment that would encourage resource contribution from many volunteers? In the present study we address these questions and investigate the factors that determine the contribution of resources to volunteer computing projects. We draw on prior research in the area of online communities and explore the similarities and differences between volunteer computing and other forms of community-based projects.

In recent years the internet and the web have emerged as powerful platforms for harnessing resources contributed by large numbers of geographically distributed individuals. Examples include Wikipedia – a user-created encyclopedia, open source software, and other community based initiatives [1, 7, 10, 27, 37, 51, 55, 60]. Underpinning the sustainability of such initiatives is the willingness of people to contribute resources - knowledge, time and skills – voluntarily [11, 13, 29]. In a recent *Scientific American* article, Shadbolt and Berners-Lee [48] discuss advances in the study of the World Wide Web. They argue that "*we need to know why people who contribute content link it to other material. Social drivers--goals, desires, interests and attitudes--are fundamental aspects of how links are made. Understanding the Web requires insights from sociology and psychology every bit as much as from mathematics and computer science.*" Indeed, studies of motivations have been helpful in explaining participation in various forms of community based projects, such as Wikipedia [37, 47] or open source software projects, [32, 45, 51]. By drawing on prior research on online communities, we investigate the factors that determine the level of resource contribution in volunteer computing projects. In particular, we focus on the following questions: (1) what motivates participants to volunteer their computer resources? (2) what is the role of non-motivational factors, such as social affiliation and tenure in the project? and (3) how do these various factors interact to impact participants' contribution level?

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This paper contributes to the research and practice of volunteer computing in two ways: First, we use theories of motivation and social participation to develop a novel framework of the factors determining volunteered computing (personal motivations, team affiliation, tenure). Second, we test our model and expose the relations between these factors and actual contribution levels.

The setting for our empirical study is SETI@home[1] (*Search for Extra-Terrestrial Intelligence*), one of the best known volunteer computing projects, which is hosted at U.C. Berkeley. Established in 1999, SETI@home harnesses the computing resources of over 500,000 computers worldwide to collaboratively analyze radio telescope data [7, 14], with the aim of detecting intelligent life outside Earth.

More recently, this volunteer computing initiative was extended through the creation of BOINC (Berkeley Open Infrastructure for Network Computing) [2], an open-source platform dedicated to running volunteer computing projects. Currently, the BOINC platform, of which SETI@home is now part, serves over thirty projects in various scientific fields, including astronomy (e.g. Einstein@home), climate modeling (e.g. climateprediction.net), mathematics (e.g. PrimeGrid), biology and medicine (e.g. Rosetta@home), and others. To contribute, a participant needs to download a client application which is then used for managing the volunteered computer's allocated tasks. After the initial download and installation, contribution is done without any human intervention, and without a need for the contributor to interact with the system. A participant's contribution level is determined by the setting of her profile. The participant can set (and later change) her level of contribution in a number of ways, for example, by determining the amount of disc space, memory and CPU time to be used by the project, by contributing constantly or only when the computer is idle, or determining whether or to contribute when the computer operates on batteries. A participant may also choose to contribute using one or more computers. The BOINC system grants computation credit denominated in "Cobblestones" to participating computers – a measure of how much work the contributing computer did. Cobblestone credit is calculated as the CPU time contributed multiplied by the CPU benchmarks as measured by the BOINC software. Contributors may affiliate themselves with a team – a group of contributors who often share a common institutional or social affiliation, and want to pool their resources to compete against other teams. On the BOINC and the SETI@home websites, message boards serve as a venue for discussions, and the ranking of contributors and teams, based on their accumulated credit, is published.

2. RELATED WORK

There has been only little research on the participative aspect of volunteer computing. A short and descriptive survey of SETI@home participants outlines the motivations for contributing computer resources, including the desire to help scientific research, competition, and gaining technical knowledge [22]. This study also highlights the importance contributors attribute to being part of team and having social ties with other contributors. Results from an internal survey of contribution motivations at BOINC [8] suggests that the motivational factors at various stages in participants' involvement differ, thus in order to maximize contribution, contributors in the various stages should be motivated differently. Both these studies, however, did not link motivations and actual user contribution to explain the factors determining contribution levels.

Given the little work done on motivations in the context of volunteer computing, we extend our review to neighboring areas. An area of research that is highly useful for understanding volunteer computing contribution, is that of social media contributors' motivations. Mass collaboration of large numbers of individuals distributed across time and space represents a new and productive trend in the creation and dissemination of information [7, 60]. This phenomenon is characterized by distributed groups of volunteers, who split up work into modular tasks [35], and are supported by systems that facilitate collective action and social interaction online [59]. Sustained contribution by individual volunteers is critical for the viability of such communities [11, 13, 29]. Reflecting this, understanding the motivations of contributors has been viewed as critical for successfully managing and sustaining web-based community-based projects [6, 12, 36, 47], and extensive research focused on contribution to a wide range of online communities [13, 24, 36, 42], and in particular, communities where contribution is made by volunteering amateurs such as Delicious [33], Flickr [38], Twitter [58], YouTube [23] and Wikipedia [10, 37]. Extrinsic motivations for contribution in such communities - motivations that are instrumental and represent cases where an activity is carried out in order to achieve a separable outcome [44] - include improvement of skills [39] as well as recognition and enhancement of status [32, 45]. Intrinsic motivations on the other hand – which emphasize inherent satisfaction from an activity rather than its consequences [44] - include altruism [58], fun [53], reciprocity [56], intellectual stimulation, and a sense of obligation to contribute [10]. In addition, researchers have examined other factors associated with participation in information sharing communities, at the individual or group level, including social network properties [20, 56], group membership size [11], ideology [51], feedback [23] and others.

Overall, prior research provides useful background, but no conclusive answers to the questions this study aims to address, since there are important differences between contributors' motivations participation in volunteer computing and participation in other types of community-based projects. First, the nature of contribution in volunteer computing is very different from contribution in other community-based projects, such as Wikipedia in that it is largely passive and requires only the harnessing of computing resources. In contrast, in other community-based projects participants actively contribute their skills, knowledge, and time. In other words, the contribution act in volunteer computing is done in the background, whereas in other types of community-based projects it is done in the foreground, requiring more interaction with other contributors and with the project's system. Second, in volunteer computing there is a clear distinction between those using the contribution and benefiting from it (i.e. the scientists who run the project) and the contributors who cannot use the resources contributed. In contrast, in other community-based projects this distinction is blurred, such that contributors are often users (i.e. viewers or readers) of others' contribution. Third, while contribution in other community-based projects can be evaluated and appreciated by others for its quality, the contribution deliverable in the case of volunteer computing is a "commodity" – an indistinguishable unit of CPU time. Fourth, volunteer computing deliverables are an unidentifiable part of a larger and longer process of scientific research – in contrast to

[1] setiathome.berkeley.edu
[2] boinc.berkeley.edu

social media systems where the deliverables (e.g. text, code, photos) are attributable to a specific contributor and are immediately viewable.

These differences between volunteer computing and other forms of community-based projects, as well as the scarcity of research on the factors determining participation in volunteer computing projects, highlight the need to develop a theoretical understanding of the factors driving contribution to volunteer computing initiatives. In the following section we develop a framework which aims to address this gap.

3. RESEARCH MODEL

Building on prior research in the areas of social psychology and community-based projects, we present an integrated individual-social-temporal framework for volunteer computing contribution factors.

3.1 Individual motivations

The motivational factors we consider include both intrinsic and extrinsic motivations, a distinction made by scholars of motivations and self determination theory [16], and later applied by researchers of participation in online communities and open source software projects [e.g. 31, 45]. Intrinsic motivations emphasize inherent satisfaction from an activity rather than its consequences [44]. They include motivations such as enjoyment [37, 53], reciprocity [56], and a sense of obligation to contribute [10; 31]. Extrinsic motivations, on the other hand, are related to activities that are carried out in order to achieve a separable outcome [44]. In the context of contribution to online communities, extrinsic motivations represent cases where the expected benefits of contributing are perceived to exceed the contribution's costs [34]. Some of the extrinsic motivations that have been studied are improvement of personal skills [32], gaining reputation [31, 56] and personal enhancement (37).

Furthermore, social psychology research on the motivations for volunteering proposes that, in general, people have two distinct fundamental orientations: self-orientation and other-orientation [e.g. 26, 50]. This approach was later applied in the study of online contribution, where self orientation motivations included utilitarian motives and enjoyment, while other-oriented motivations included social affiliation and reciprocity [42]. Following this distinction between self and other orientation, we classified the motivations for volunteer computing contribution as oriented at the contributor (self-orientation) or at the project (others-orientation). The motivational component of our proposed framework integrates these two perspectives, and can be represented by a two by two motivational matrix: on one axis are intrinsic/extrinsic motivations and the second axis are self/project-orientation. The framework described in Table 1 presents four primary motivations: enjoyment of interacting with others, valuing the project's objectives, gaining reputation among others in the project, and enhancement associated with seeing the project's results get published in scientific journals.

Table 1. Motivational framework

	Self oriented	*Project oriented*
Intrinsic	Enjoyment	Values
Extrinsic	Reputation	Enhancement

We expect that these four motivational states would be related to participants' contribution level, as outlined below.

Enjoyment: Enjoyment has been established as one of the prominent factors explaining volunteering activities [15]. In the context of online communities, enjoying the act of sharing has been shown to be a prominent reason for contributing to open source software projects [e.g. 21, 31, 45] and Wikipedia (e.g. 37,47). Since contribution in distributed computing is largely passive and the work is done by the contributor's computer, we expect that in the volunteer computing context, enjoyment will stem from the social interactions related with being a contributor, for example, being in touch with other contributors. Therefore, we expect that:

Hypothesis 1: Higher level of enjoyment is associated with increased contribution to the project.

Reputation: An extrinsic motivation for community information sharing is the enhancement of status in the community [31, 45]. Gaining reputation among like-minded people has been shown to motivate sharing in online communities and open source software projects [40], and lead to increased contribution [e.g. 31]. At SETI@home, the primary way to enhance one's reputation as a contributor is to be ranked relatively high in the credit tables provided on the project web site. We expect that:

Hypothesis 2: Higher levels of the reputation motivation is associated with increased contribution to the project.

Values: In previous studies of motivations for contribution in community-based projects, the personal values associated with the project were used to explain contribution [e.g. 21]. For example, in open source software contributors [e.g. 51], values associated with the project, such as sharing information and helping others, were found to be related to trust and quality of communication among contributors, which in turn are related to both input and output measures of project activity and success (such as team effort and task completion). Thus, we expect:

Hypothesis 3: Higher level of personal values placed on the project's objectives is associated with increased contribution to the project.

Enhancement: Studies of volunteering (e.g. [15) identified enhancement, defined as positive striving of the ego related to volunteering, to be an important motivating factor. This factor was also found to be correlated with contribution levels among contributors to Wikipedia [37]. Since contribution to volunteer computing projects is largely passive and is carried out by the contributor's computer, in this context we expect that the positive feelings of ego striving would stem from the publication of the project's results in scientific journals. Therefore,

Hypothesis 4: Higher levels of the enhancement motivation is associated with increased contribution to the project.

3.2 Social and temporal factors

Our research model includes, in addition to the four motivational factors described above, two additional factors that we expect would impact participation: team affiliation and tenure.

Team affiliation: volunteer computing projects often allow participants to affiliate themselves with a team. Social psychology research, in general, and studies on volunteers in particular, recognize the importance of identification with a group and the role it plays in enhancing contribution [e.g. 21, 47, 49]. In volunteer computing projects, teams represent a way to attract people with a common institutional or social affiliation. Teams provide contributors a mean of communication on topics often not directly related to the project and team cohesion is frequently enhanced by promoting competition with other teams. For example, in SETI@home, teams represent affiliation to the same university (e.g. *Penn State*), place of work (e.g. *Intel*), national or regional bond (e.g. *SETI.Germany, SETI Alaska*) or alternatively, shared interests (e.g. *The Knights Who Say Ni!* formed by Monty Python fans) [7; 22]. Empirical studies of team activity in online communities found a relationship between team membership and contribution levels. For example, it was shown that goal setting at the group level is related to increased movie rating contribution [6], responses to others' postings increased members' likelihood of contribution [25], and group affiliation was shown to be associated with increased photo tagging [e.g. 38]. Therefore, we expect that:

Hypothesis 5: Affiliation with a team of contributors is associated with increased contribution to the project.

Tenure: Prior research suggests conflicting evidence regarding the effects of tenure on contribution: on the one hand, evidence from small-scale qualitative research shows that over time, after the fading of initial excitement, community members often become bored, disappointed, or otherwise less enthusiastic, and as a result decrease their level of community participation [9]. On the other hand, one might expect that as users get used to the contribution system, get noticed by others, receive feedback on their contribution and create relationships with others, they will increase their participation. Some evidence for such a pattern was provided by [23], who showed that viewing by others actually leads to an increase of video sharing on YouTube. A comparative study of different forms of participation in Flickr [40] demonstrated that the relationship between contribution and membership tenure changes with the contribution type: contribution of information artifacts (a first-order contribution) was negatively related to tenure, while contribution of meta-information (a second-order contribution, where a member adds a description to a first-order contribution) was positively related to tenure. Volunteer computing contribution represents a first-order contribution, and we expect that enthusiasm - and with it contribution levels - will decrease over time. Therefore,

Hypothesis 6: The tenure of membership in the distributed computing project is associated with decreased level of contribution to the project.

Team affiliation and tenure interaction: finally, while we expect tenure to be negatively related to contribution, tenure is not expected to affect contribution in the same way for all contributors. The opposing roles tenure and team affiliation are believed to play in determining contribution are expected to lead to an interaction effect, where team affiliation will compensate, at least to some extent, for the negative tenure effect. In other words, we expect that team- affiliated contributors will not be susceptible to the negative effects attributed to increased tenure, and therefore propose:

Hypothesis 7: Team affiliation moderates the effect of tenure on contribution such that the relationship is stronger for contributors who are affiliated with a team and weaker for those not affiliated to a team.

To summarize, our research model attempts to explain contribution using three primary elements: individual (motivations), social (team affiliation) and temporal (tenure in the project). The model is illustrated in Figure 1.

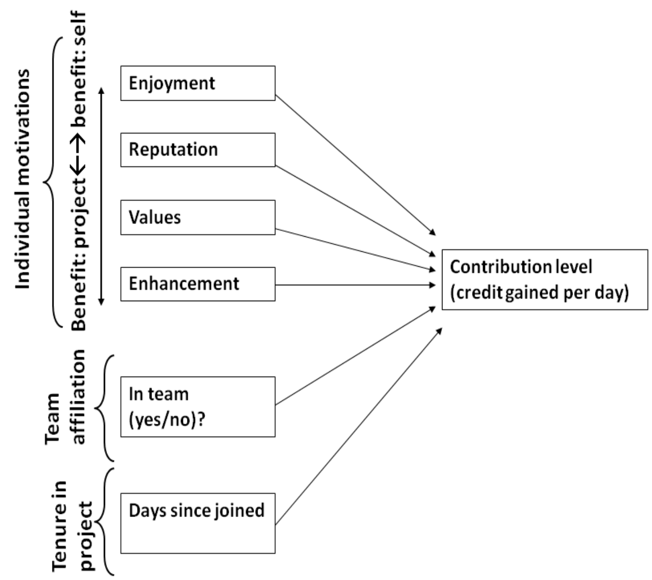

Figure 1. Summary of the research model

4. RESEARCH METHOD

In order to study contribution determinants and contribution activities, we collected data using a combination of survey responses and independent system data about SETI@home contributors.

Among the independent variables, the four motivation factors were measured using responses to a web-based survey. The items for measuring each factor were based on existing validated scales which were adapted to the volunteer computing context – a common practice in social psychology research. Reputation was measured by a scale used by [56] in their study of motivations for contributors to electronic networks of practice, and adapted to the SETI@home context. For example, the item "I participate in the Message Boards to improve my reputation in the profession", was changed to "I contribute computer resources to SETI@home to improve my reputation among others at SETI@home". The scale for measuring enjoyment motivation was adapted from [54] who studied the motivations of software users, and from [38] who applied this concept in the context of Flickr tag contribution. The values motivation scale was adapted from [51], who studied the role of ideology in explaining contribution to open source software projects. Finally, Enhancement was adapted from [15] who studied motivation for volunteering, and from [42] who applied the volunteering framework in the context of contribution to public document repositories. All the scales were validated again in the present study.

The additional independent variables – team affiliation and tenure – were extracted independently from the SETI@home system and recorded anonymously together with the contributors' responses to the questionnaires.

The model's dependent variable – average contribution - was calculated as the amount of contribution credit accumulated by each contributor divided by the number of days since the contributor joined the project, and was extracted from system logs.

One potential methodological issue in interpreting survey results is common method bias [52] whereby all variables are measured using a single data source. In our study, the motivations were measured using survey responses, while other variables, including the dependent variable, were retrieved directly through the SETI@home system, therefore mitigating the risk of common method bias.

4.1 Data Collection

A randomly chosen sample of 1500 SETI@home contributors were emailed an invitation to participate in our web-based survey. A total of 274 usable responses were received. This represents a 18.3% response rate, which is typical studies in similar contexts [e.g. 18, 57]. For each respondent, SETI@home system usage data was collected and recoded together with the survey responses. The data included the amount of credit gained, tenure in the project, and team affiliation.

An analysis of the data reveals a diverse set of contributors. The amount of average credit gained by the contributors (calculated as the total credit gained divided by the number of tenure days) varied greatly across contributors, and, as is the case in many community-based initiatives was characterized by a power law distribution (see Figure 2 for a distribution of the average credit gained; the Y axis represents the number of contributors). On average, the contributors in the sample gained 286,829 Cobblestones of credit (median = 37,859; SD = 11792272) and their average tenure on SETI@home was 1983.7 days (median = 2,092.3; SD = 1,345.6).

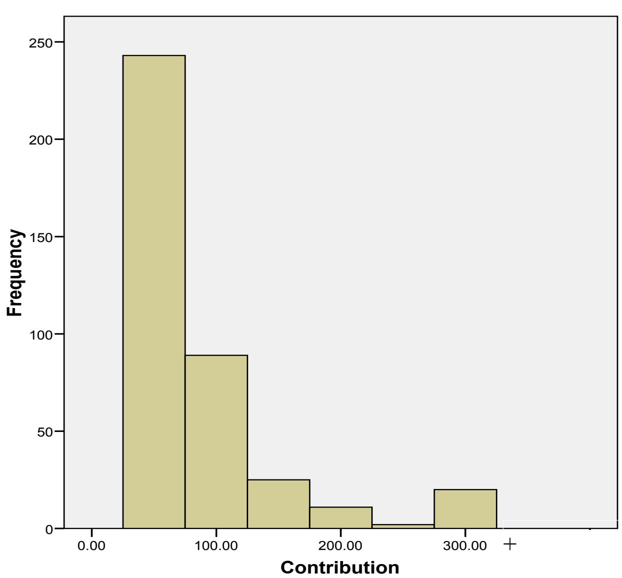

Figure 2. Histogram of average contribution (credits per tenure day).

4.2 Instrument validation

Prior to testing the hypotheses, we validated the survey instrument that was used. To confirm the reliability of motivations survey items, we conducted a principle component analysis (PCA) with varimax rotation using SPSS. Four factors emerged in the PCA, corresponding directly to our framework of four motivation factors, with 75.6% total variance explained. Each item had factor loading higher than 0.6 on the intended construct, and each item had stronger loadings on intended variables than cross-loadings, confirming measurement validity [52]. Further, to confirm convergent and discriminant validity, we calculated the average variance extracted (AVE) for each construct [17] For each construct, AVE exceeded 0.5, thus demonstrating good convergent validity. The square root of AVE (RAVE) exceeded the correlation with other constructs, thus displaying high discriminant validity [17]. In addition, before proceeding with the statistical analysis tenure and its impact on contribution levels, we verified that other factors which are associated with tenure (i.e. being early adopters, motivations) are not responsible for the differences in contribution. To do that, we compared the populations of early and late community members using t-test: we divided the sample of users to a sub-sample of users whose tenure in the community is below the median tenure, and a sub-sample of users whose tenure in the community is above the median. We compared these two sub-samples on a number of variables, such as self-rated computer expertise and the four motivations examined. No significant differences were found between the two sub-samples on any of the factors compared, thus lending support to our assumption that the differences in contribution can be attributed to the effect of tenure in the project, rather than to any other differences between these populations.

5. RESULTS

Descriptive statistics of survey responses regarding contributors' motivations is presented in Table 2. Self-oriented motivations (reputation, enjoyment) were found to receive higher scores, while project-oriented motivations (enhancement, values) received lower scores.

Table 2. Descriptive statistics

Variable	Mean	Std. Dev.
Enjoyment	4.5	1.21
Reputation	6.4	0.73
Values	4.4	1.48
Enhancement	2.8	1.29
Team Affiliation (1 = Yes; 0 = No)	0.4	0.49
Tenure (in days)	1983.7	1345.6

In order to test our proposed hypotheses, we performed a regression analysis using the mean score of the constructs (as extracted from the survey's responses to the questionnaire items) and the system-derived variables (team affiliation, tenure, and average credit). Since a participant's contribution level could be influenced by his available computational resources, we added to the regression the number of computers used by contributors as a control variable. We log-transformed tenure, average contribution, and the control variable, since – similarity to what has been reported in studies of community-based projects [6,28] – these variables exhibit power law distribution.

The regression analysis (see Table 3) demonstrates that the two self-oriented motivations – enjoyment and reputation - were not related to actual contribution (i.e. the coefficients were 0.09 and 0.03 respectively and were not statistically significant). Of the two project-oriented motivations, only enhancement was found to be positively related to contribution in a statically significant way (the coefficient was 0.18). It is interesting to note that the enhancement motivation received the lowest average score of the four motivational factors. The intrinsic project-oriented motive, values, did not exhibit a statistically-significant positive effect on the outcome variable (in fact, its coefficient was negative). Affiliation to a team was found to be significantly related to the contribution level (the coefficient was 0.16), while tenure exhibited a statistically significant negative relation (the coefficient was -0.27). Finally, as expected, the number of computers allocated to the project was significantly related to the contribution level. Together, these variables explained 21.6% of the variance in the outcome variable (average contribution).

Table 3. Regression results

Variable	Standardized Coefficients	t	Sig.
(Constant)		48.524	.000
Enjoyment	0.092	1.394	.165
Reputation	0.030	0.534	.594
Values	-0.144	-2.218	.027
Enhancement	0.182	2.779	.006
Team Affiliation	0.160	2.892	.004
Tenure	-0.291	-5.299	.000
Team Affiliation x Tenure	0.113	2.058	.041
Control (no. of computers)	0.272	4.961	.000

An analysis of the interaction between tenure and team affiliation is illustrated in Figure 3. Affiliation with a team moderates the relationship between tenure and contribution, such that while for team-affiliated contributors increased tenure is associated with only a minor decline in contribution, this decline in contribution is much steeper for contributors who are not affiliated with a team.

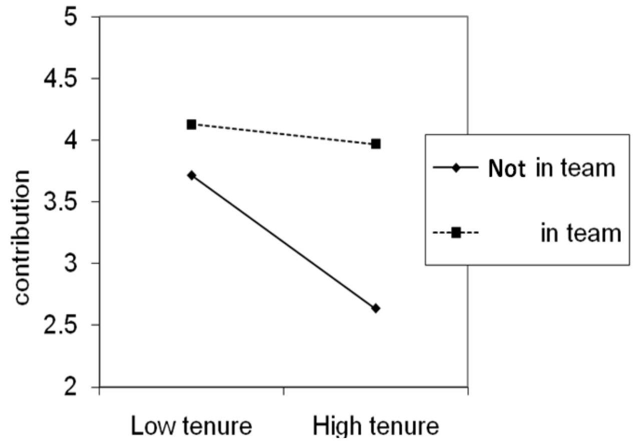

Figure 3. Interaction effect: tenure moderates the relationship between team affiliation and contribution.

The analysis we presented above was based on the sample of users who have completed the survey. However, some of the relationships in our model could be estimated directly from the SETI@home system data. To analyze these relationships on a larger scale, we extracted activity logs for 8,257 contributors. When studying the relationship between tenure and average contribution (see Figure 3), we found that for relatively new contributors (log tenure < 3) contribution levels are relatively high. Then, for increased tenure levels, contirbution decreases, and then picks up again (when log tenure is approx. 7), forming sinus-shaped contribution pattern, as illustrated in Figure 4.

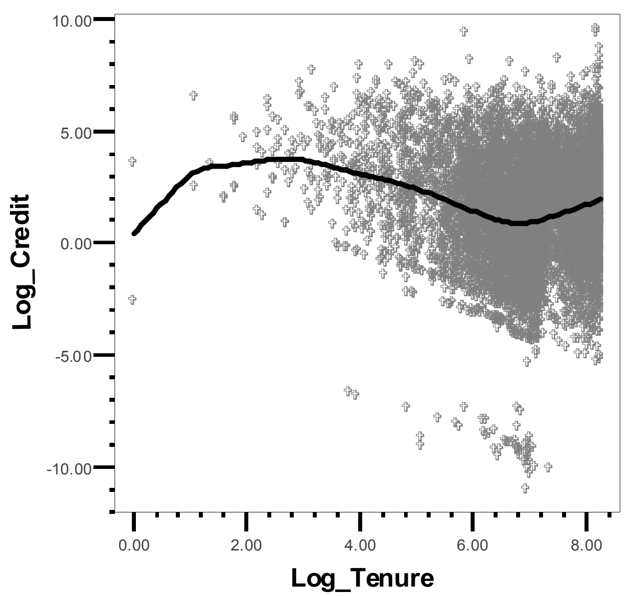

Figure 4 (log) contribution as a function of (log) tenure for a sample of 8,257 users

6. DISCUSSION

Volunteer computing is emerging as a powerful way to conduct computation-intensive scienctific research by harnessing computing resources from large numbers of geographically distributed individuals. Volunteer computing is founded on two pillars. The first pillar is computational: allocating and managing large computational tasks, and the second is "participative": making a large number of individuals to volunteer their computer resources to the project. While the computational aspects of volunteer computing have been investigated extensively in recent years, the participative aspects remain largely unexplored. Research in the related areas of social media and community-based projects shed some light on the factors motivating people to contribute content online. However, there are some fundamental differences between volunteer computing and these neighbouring areas, suggesting that the factors driving participation may not be same.

In this study we proposed a framework of the antecedents of contribution in volunteer computing projects, by building on the body of literature on online volunteer contribution, and adapting it to the unique context of volunteer computing. Using a combination of survey and system data about contributors to SETI@home, a large and highly popular volunteer computing project, we identified the individual, social, and temporal factors that are associated with participants' contribution levels. We tested our proposed framework and performed a regression analysis to examine the impact of these various factors on actual contribution levels. In addition, we performed a larger-scale analysis of activity logs. Our findings reveal the factors that are most important for motivating people to share their computational resources, and highlight the distinctive features of the volunteer computing context. Insights from our study offer practical guidelines for the design and management of volunteer computing projects.

Our analysis of self-oriented motives shows that while users perceive these motives to be important (i.e. the average scores were high: 4.5 and 6.4 out of 7 for enjoyment and reputation respectively), they do not have a statistically-significant impact on contribution levels, thus our hypotheses H1 and H2 were rejected.

Enjoyment: We believe that enjoyment from social interaction did not impact contribution because social interaction in volunteer computing has a different role than social interaction in other types of community-based projects, in that social interaction is not inherent to the act of contribution itself. Computing resources contributed by a participant who does not interact with others are not different in quality from resources contributed by someone who does interact with others. In projects such as Wikipedia or open source software development, by contrast, the role of social interaction is inherent to participation in the project. First, the production process in these projects involves interactions with other participants, through commenting on others' contributions and by modifying and integrating them. Second, in such projects the borders between participation periphery and core are permeable [10], such that peripheral participants (occasional, non-committed contributors who have no project decision making authorities) can progress to the core, and take part in the collaborative management of the project (for example, take part in defining the project's procedures). Volunteer computing is different in that actual act contribution does not require interaction with others, and contributors are not – and cannot become - part of the project management and decision making core.

Reputation, too, was important to participants (it received the highest average score out of the motivational factors), although – inconsistently with studies of social media and community-based projects [45] - it was not linked to contribution. We believe that the explanation to this discrepancy is somewhat similar to that of social enjoyment: due to of the nature of the the contribution act, the daily visibility of the project to the contributor is limited primarily to the project client application and the screen saver associated with it. However, the project's website, which contains rich information - including reputation-related information about credit gained - is not visible to the contributor as part of the day-to-day contribution. In this respect, there is an inherent difference between volunteer computing and other community-based projects: contribution can be done in the background, and does not require interaction with the project system. In other community projects, where contribution requires active use of the system, such as Slashdot.org, a participant's reputation score is foregrounded and each contribution is clearly associated with the contributor and his score. Even in systems where there is no built-in reputation system, such as Wikipedia, participants are often aware of peers and their reputation due to the collaborative production process. We therefore suspect that the fact that SETI@home reputation motivation was not linked to contribution levels stems from the decoupling of the contribution act from human interaction with the project system (this link is automatic in many other types of community based projects), and in particular, the decoupling of contribution from exposure to information such as credit scores and rankings.

A design implication for volunteer computing projects, therefore, is to present contribution levels – both absolute and relative to other contributors, in ways that couple it with the contribution act, maximize exposure, but do not require an additional effort. In other words, we propose to bring to the foreground features that draw on contributors' motivations as a design guiding principle in volunteer computing systems.

Given these differences in the nature of the contribution act, and the relatively narrow channel for human interaction that is required for volunteer computing contribution (client application vs. website; background vs. foreground), the high ranking placed by contributors on reputation, together with the lack of correlation between this factor and contribution levels, suggest that increasing the number and availability of channels for communicating reputation would increase contribution. In other words, it is recommended to bring social interaction and reputation to the foreground.

Values, an intrinsic project-oriented motivation was not linked to increased contribution levels, despite having a relatively high average score (4.4 out of 7). This finding is consistent with previous results from community-based projects such as Wikipedia [47]. This finding suggests that sharing the project's objectives is a characteristic that helps to explain why people *join* the project in the first place, however once active contributors, sharing the project's objectives and values is not linked to contribution levels. An alternative explanation is that contributors who are motivated by sharing the project's values may be contributing - in addition to the project at hand - to other volunteer computing projects, in which case the amount of computing resources allocated to each project will be relatively small.

Enhancement was the only motivational factor to exhibit a statistically significant positive relation with contribution levels. Interestingly, the average enhancements scores were the lowest of the motivational factors (2.8 out of 7). We believe the average low score reflect the fact that volunteer computing participants are often not aware of whether findings from projects they contributed to get published. Nevertheless, the significant link to contribution levels suggests that participants are interested in seeing the outcome of their involvement bear fruit, such that they are more likely to contribute more when they know that their contribution leads to publishable results.

Team affiliation was found to be positively related to contribution level, as we hypothesized. We believe that this finding is of particular importance, since it demonstrates that even in the context of volunteer computing, where the act of contributing does not require any social interaction, being part of a social structure is important. One design feature of SETI that promotes the link between team affiliation and contribution is the ability to see the total credit of each group. This feature encourages competition between groups, and thus may influence participants to increase their contribution. Other potential design features may include an easily viewable display of other team-members who are currently contributing, social networking features, or even offline activities (for team members).

Tenure was negatively related to contribution, as we hypothesized. In line with findings in other online communities [39], it may be the case that as the novelty of project participation wears off, contributors lose interest in the project. In the context of volunteer computing, the decrease in contribution levels may result from different reasons. First, it is possible that a participant gets involved in additional volunteer computing projects (indeed, many SETI@home participants contribute to other projects within the BOINC platform), such that the resources allocated to the original project are reduced. Or, it is possible that some contributors becomes more heavily involved with other tasks, such that their computer is idle (and available for volunteer computing) less time. Alternatively, it is possible that the contributor actively changes her settings to allocate fewer resources to the project.

The interaction between tenure team affiliation was positively and significantly related to contribution levels, such that the decrease in contribution levels associated with tenure (see above) was substantially less severe for participants that were affiliated with teams. This findings, once again, stresses the importance of social interaction in volunteer computing. It demonstrates that if participants are kept engaged - possibly through an artifact that is secondary to the project's core activities such as team affiliation – they will be more likely to be engaged in the primary project activities (i.e. contributing computer resources). We believe that this finding is highly useful from a design and management perspective: since it is difficult to keep participants engaged in the primary activity of resource contribution over long periods, volunteer computing projects could engage participants through secondary activity channels.

7. CONCLUSION

In summary, our study contributes to the research and practice of volunteer computing by enhancing our understanding of the factors determining contribution to volunteer computing projects. In this study we have identified a number of contribution determinants (personal motivations, tenure and team affiliation), and exposed the relations between these factors and actual contribution levels. In addition to understanding the implications of the unique nature of the contribution act in volunteer computing, it is important to highlight the findings that highlight the differences between volunteer computing and other types of community-based projects: (a) self-oriented motivations - enjoyment and reputation - not having a significant impact on contribution, (b) the importance of the project-related enhancement motivational factor, (c) and the moderating effect of team affiliation on the (negative) relationship between tenure and contribution. We were able to overcome the single-source data problem that plagues many motivations studies and link participants' perceptions and attitudes to actual usage data.

In addition to volunteer computing research, our study makes several important contributions for practice. Insights from the study could be employed to guide volunteer computing projects, and we recommend that designers and leaders of such projects focus their recruiting and retention efforts on determining factors that have a positive relation with contribution. We make some more specific recommendations, as follows. First, because of the differences between the act of contribution in volunteer computing and other community-based projects, we suggest that volunteer computing projects provide more channels for social interaction. Participants seem to enjoy socializing in the context of the project, and when they find avenues for interacting with others, for example by affiliating with teams, this affiliation has a substantial positive impact on contribution levels. Second, we encourage designers of volunteer computing interfaces to better communicate to the community the contribution scores of participants in the day-to-day contribution medium. This could be provided through graphic representations on the project-related screen saver, or by creating a dedicated widget. Such steps, we believe, would overcome the fact that contribution does not require human interaction with the project system and its associated reputation information, and it would be helpful in translating the reputation motivation into increased contribution. Finally, we propose that leaders of volunteer computing report to the community of the project accomplishments in as many communication channels as possible. Knowing that their contribution eventually lead to scientific publications is likely to influence participants to contribute more.

In view of the sinus-shaped relationship between tenure and contribution (see Figure 4), designers and leaders of volunteer computing projects should pay special attention to contributors who are at their post-initial period. Retaining efforts should be focused on this phase of the contribution life-cycle, for example through interventions, such as communicating to contributors reminders, social (team-related) information, or project–related news.

In terms of limitations, the study's findings should be taken with caution, as it was conducted on a specific volunteer computing project, SETI@home. Studies of other volunteer computing projects, in different fields or with different goals, could help verify the generalizability of our findings. Also, we applied a cross-sectional research design, which only allows establishing correlations between constructs; all theoretical arguments regarding causal relationships should therefore be taken with caution.

In conclusion, our research model explains contribution using three elements: individual (stated individual motivations), social (team affiliation) and temporal (tenure of contribution to the project), and an empirical testing at SETI@home provides partial support for our hypotheses. Our study advances the understanding of the participatory pillar of volunteer computing. Still, a number of questions remain open and warrant future research. Some of the key future research directions we identify are (a) investigating the mechanisms by which participants increase or decrease their contribution levels (e.g. resources become occupied, (b) studying additional factors that may impact contribution levels, such as personality traits, additional motivations, and additional types of social interaction, and (c) exploring changes in the design of volunteer computing software application that could possibly enhance contribution.

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