A Trust Metric for Online Virtual Teams and Work Groups

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Abstract. Online virtual teams publish their particulars on the Internet for collaborators and other stakeholders to make use of their services. It's usual that the stakeholders need to judge the level of trust they can put on a service provider before signing up an association. The process of building a dependent association with an Internet community suffers from usual drawbacks such as lack of proximity, anonymity, misrepresentation, proxy/masquerading, etc. Research of online cyber community and social networking, addresses some of these problems. These teams might be required to register with government agencies to add trust about their existence and functioning but stakeholders are usually in search of methods to verify trust on their own before availing services. This chapter introduces the concept of trust of online virtual teams and quantifies it. The subsequent sections define trust and identify its attributes and properties. They provide methods to quantify each attribute and finally, propose a metric for trust.

Keywords: online virtual teams, workgroups, trust, trust metric.

1 Introduction

Every business depends heavily on trust. Trust serves as a mechanism to reduce collaboration complexity [1]. Trust allows agents to resolve some of the uncertainty in their interactions, and form expectations about the behaviors of others. Good interactions between agents builds trust, which in turn allows future interactions to proceed as if certain unknown (or unknowable) quantities were known. While a great number of definitions of trust have been proposed in various disciplines, the present study defines trust intuitively as the belief that others will not harm or betray, that they will behave as expected, and that they will consider others' interests as if they were their own, when relied on them for some issue. Because of the facilitating role trust plays in multi-agent systems, much has been written on the subject in recent years. Many general-purpose trust models exist, and it is not the intention of the present work to replicate this body of existing work. Rather, the study focuses on dependability by making trust as a component of dependability. In this work, trust is between pairs of agents engaging in collaboration relationships, where tasks are transferred from one agent (the trustor) to another (the trustee) depending on the level of trust between them.

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There are various trust models applied for solving different issues in literature. Some trust models are based on sound theories, e.g. PKI [2], some on reputations and recommendations [3] [4], and some on Probability or Bayesian network [5] [6]. Many trust models have been constructed for special computing environment such as ad hoc networks, peer-to-peer systems, and E-commerce [3] [4] [5] [6] [7] [8] [9] [10]. One of the most widely used definitions of trust in both human-organizational and multi-agent systems domains is given by Gambetta as, "Trust (or, symmetrically, distrust) is a particular level of the subjective probability with which an agent assesses that another agent or group of agents will perform a particular action, both before he can monitor such action (or independently of his capacity ever to be able to monitor it) and in a context in which it affects his own action " [11]. It is useful to mention this definition here, as it is generally well accepted in both human and multi-agent systems, and allows us to avoid negotiating the ongoing sociological debate on the precise meaning of trust.

Online virtual teams publish their particulars on the Internet for collaborators and other stakeholders to make use of their services. It's usual that the stakeholders need to judge the level of trust they can put on a service provider before signing up an association. The process of building a dependent association with an Internet community suffers from usual drawbacks such as lack of proximity, anonymity, misrepresentation, proxy/masquerading, etc. Research of online cyber community and social networking, addresses some of these problems. These teams might be required to register with government agencies to add trust about their existence and functioning but stakeholders are usually in search of methods to verify trust on their own before availing services. This chapter introduces the concept of trust of online virtual teams and quantifies it. The subsequent sections define trust and identify its attributes and properties. They provide methods to quantify each attribute and finally, propose a metric for trust.

1.1 Trust

Trust is primarily a cognitive issue and is perceived to vary from person to person and context. Research on trust has become necessary for activities on the Internet. In particular, the topic has become interesting for study because the trustee and trusted are not aware of each other and sometimes are located far apart. In such environments, computing trust has become a challenging problem. Considering these different problems, there have been several trust computing models. Before proposing a suitable trust model, let us touch upon the features that bear weight when making a model for computing the trust between teams.

Trust, being essentially a matter of cognition and abstraction, still having practical uses that need to be made tangible. The need is more in Internet based associations where there is an inherent difficulty among users because of anonymity and in-between remoteness. To be specific to the problem in hand, the proposed model for computing the trust of a team is based on three aspects — direct, indirect and recommender trusts.

The trustworthiness of a team is usually sensed from its activities and performance. A team that has been consistently working with perfection as per

the specification is usually deemed the most trustworthy. Of course, another source for trust information about a team could be other users who had availed some service(s) earlier and also have something to say about the service providing team. And the third means to gather trust information on a team is from recommendations. A recommender could be thought of as an agency or expert committee that monitors team performance. They judge a team by observing its skills, professionalism, or scrutiny by visit. Before computing trust, let us study some of the properties of trust with respect to teams.

Properties of Trust. Some important properties of trust that are to be true in case of online teams [12] [13].

- Context dependence: A trust relation concerns a precise action or a particular entity and cannot be generalized to other actions or entities. In other words, trust is specific to a service being provided by a trustee. For example, team A may trust team B on a service such as *'providing raw material'*, but not on *'processing it'*. Thus, trust is specific to services that team offer in the context of a particular business.
- Measurability: Trust is also a measurable dimension of one's behavior. There can be several degrees of trust. For example, A may trust B more than C for a specific service. This property emphasizes the need for a suitable metric to represent trust. The measurement can be quantitative (e.g., a probability assignment) or relative (e.g., by means of a partial order).
- Dynamic: Trust is dynamic since it may evolve over a period of time. The fact that A trusted B in the past does not guarantee that A will continue to trust B in the future. B's behavior, performance and other relevant information may lead A to re-evaluate the trust on B from time to time. During a collaboration, the more A is satisfied with B's performance for service X, the more A trusts B. On the other hand, A's trust in B may decrease if B proves to be less trustworthy than anticipated by A.
- Sensitivity: Trust is very sensitive to malicious behavior. Trust declines very quickly with the detection of malicious behavior in a team. Once lost, a team needs many good interactions to regain a good level of trust.
- Asymmetry: A trust relation is asymmetric. That is, if A trusts B, it does not imply that B also trusts A equally. A may have high trust for B, but B may have much less trust or even distrust for A.
- Transitivity: Though controversial, in online teams, trust relation can be transitive. That is — if A trusts B, and B trusts C, then A can also trust C — to a certain level. But this is subject to constraints, and this property can hold true to a larger extent in teams. This property is essential for computation of indirect trust.

Context dependence property is satisfied by calculating trust with respect to a service. Measurability property is satisfied by attributing a quantitative value to the trust. Dynamic property is satisfied by calculating trust at random intervals. Sensitivity property is satisfied by defining penalties for malicious behaviors.

Asymmetry property is satisfied by computing trust with respect to each team. Transitivity property is satisfied by using recommendations from other teams and third parties.

Trust is to be calculated in three parts to satisfy all the above properties. That is, when team B calculates trust of team A, the first part is computed using the direct experiences with team A, the second part is obtained from associated teams which had direct experiences with team A, the third part is from the recommenders (expert committee). So, in essence, trust is of three forms — direct trust, indirect trust, and recommender trust.

Direct Trust Direct trust is based on self experiences and interactions with a target team. It is computed for behavioral features such as quality, speed of completion, cost effectiveness, and durability. Let us suppose that $team_i$ computes the direct trust value of $team_j$. If $team_j$ has interacted with $team_i$ before, then $team_i$ will have an opinion about the behavior of $team_j$. So, quantifying these behavioral features will help $team_i$ compute the direct trust of $team_j$. Let us represent direct trust value of $team_i$ on $team_j$ as $DT_{ij}^{a}(t)$, where 'a' represents the service and t represents the time at which trust is being calculated, since trust is time dependent and dynamic (a property of trust). As trust is also context dependent, trust is calculated for each service of $team_j$.

Trust is dynamic and therefore the trust value is to be updated each time a team encounters a situation that affects the trust value. When $team_j$ interacts with $team_i$ at time t, then $team_i$ updates its trust value for $team_j$ as follows:

$$DT_{ij}^{a}(t) = \begin{cases} DT_{ij}^{a}(t' + \delta t) + \Delta_{DT}(t) & \text{if } team_j \text{ is not new } team_i \text{ and } t' < t, \\ \Delta_{DT}(t) & \text{if } j \text{ is new to } i \end{cases}$$

Here, 't' represents time, and $t = t' + \delta t$. Here, δt represents the '*time elapsed*' since last update of trust value, and t' represents the time of last update. $\Delta_{DT}(t)$ represents the direct trust value that resulted due to direct experiences with $team_j$ at time t. On occasion, $\Delta_{DT}(t)$ could also be negative. Thus the trust measurement preserves the property of dynamic nature of trust [14].

Let us compute values for the components that comprise the direct trust.

$DT_{ij}^{a.quality}$: This is the rating of team i to team j about the quality of service provided by j for the service/product/task a. Team i estimates $DT_{ij}^{a.quality}$ by verifying/observing/experiencing the quality provided by j at time t. Usually teams i and j make an agreement regarding the standard of quality that is to be maintained by team j. The range of values for quality component is {0,1}. If team j maintains quality standards and provides the service/product at an agreed quality, then $DT_{ij}^{a.quality} = 1$. Otherwise, if there was a compromise in the quality, then $DT_{ij}^{a.quality}$ value lies between 0 and 1. If the supplied quality is too inferior to the agreed quality, then $DT_{ij}^{a.quality} = 0$.

$DT_{ij}^{a.complSpeed}$: This is the value given by team i to team j about the speed of task execution by team j. This value is based on i's direct observation of j's performance. Usually teams i and j have an agreement regarding

the speed of completion and deadlines to be followed. The range of values for complSpeed component is { 0,1 }. If team j adheres to the deadlines perfectly, then $DT_{ij}^{a.complSpeed} = 1$, otherwise, if the speed of completion is very slow, then $DT_{ij}^{a.complSpeed} = 0$. In other cases, it will be any intermediary value between 0 and 1.

$DT_{ij}^{a.costEffect}$: This is the value given by team i to team j about cost effectiveness of j with respect to service/task a at time t. This value is based on i's research on cost of 'a' quoted by j compared to other providers/executors. The range of values for costEffect component is { 0,1 }. If j has quoted less than the others, then the cost effectiveness of j is good, which is represented as $DT_{ij}^{a.costEffect} = 1$. If team j is found to be not cost effective, then $DT_{ij}^{a.costEffect} = 0$.

$DT_{ij}^{a.durability}$: This is the value given by team i to team j about durability of service/ product 'a' of j. This value is based on i's direct observation of j's product/service. Durability is the measure of life of a service/product. Durability does not always depend on quality. Sometimes one may use high quality components in making an item, but the durability of such an item may be much less. Mechanical systems characteristically fail from wear out mechanisms, while electronic systems more closely exhibit a constant failure rate over their useful life. Durability testing is the duration of time a product, part, material, or system can meet its performance requirements e.g. lifetime span. Depending on the type of material or product, team i simulates environmental factors or conditions to determine the operating limits or life span of the products, parts, and materials. Besides others, some of the tests are aging, operational limits, component degradation, failure points, material testing, tensile testing, burst testing, environmental testing, load testing, etc. The range of values for durability component is { 0,1 }. If the durability of an item a is high, then $DT_{ij}^{a.durability} = 1$, else, $DT_{ij}^{a.durability} = 0$.

Now that the values of all the attributes were quantified, $team_i$ can now compute direct trust value for $team_j$. Since the range of values for each attribute is {0, 1}, the range of values for direct trust will be {0, 4}.

$$DT_{ij}^{a}(t) = DT_{ij}^{a.quality}(t) + DT_{ij}^{a.complSpeed}(t) + DT_{ij}^{a.costEffect}(t) + DT_{ij}^{a.durability}(t)$$

Indirect Trust. The second part of trust is indirect trust. This value is computed by an team for a target team with the help of the peers. A team can ask the peers to offer an indirect trust value for the target team. It is good if the peers are common friends to both the evaluating team and the target team. If such common peers are not available, then any teams that have direct experience(s) with the target team may be considered. Indirect trust value can be computed using feedback, associations, or social intimacy degree. Let us detail the strategies to calculate indirect trust from the behavioral features of teams.

Feedback. This is one of the methods for obtaining the indirect trust value of a target team. The peers of a target will be asked to give feedback for the target team. Indirect trust obtained from feedback can be represented as $IT_{ij}^{a.Feedback}(t)$ where IT represents Indirect Trust, 'a' represents the service/product for which Indirect Trust is being calculated, Feedback is the method employed, ij indicates that team i is computing Indirect Trust for team j. Feedback is usually taken for the following five aspects — cost, quality, transparency, timeliness and response time. As per [15], feedback for a team can be calculated as follows. Each aspect is measured on a 3-point scale calibrated as high, average, and low, and numerically each aspect may assume a value from set (1,2,3). For example, when cost is low, this aspect scores a value of 3; but for quality, low indicates a value of 1.

Let the components of feedback i.e. cost, quality, transparency, timeliness and response time, be represented by x_i. Then, feedback on team j to be obtained by team i for the service a can be computed from $\sum_{i=1}^{n} a.Feedback.x_i$. It is the sum of the scores of the components provided by the peers about the target team. Let us say that there are n components and let S_{mx} represent the 'maximum value of the scale' used to calibrate each satisfaction level. Currently, we considered only five aspects, each calibrated by a scale with S_{mx} value 3. Now we can compute the indirect trust value resulting from feedback using the below equation.

$$IT_{ij}^{a.Feedback} = \sum_{i=1}^{n} \frac{a.Feedback.x_i}{n * S_{mx}}$$

Associations. Feedback is not an *'always preferred'* approach. In society, trust on a person can be ascertained to a certain degree by judging the quality of his/her associations. Usually, a person is trusted if his/her associations are trusted [15]. Similarly, a team can infer an indirect trust value for a target team by looking at its associations for service/resource. So, it is possible for a team to choose alternate approaches to feedback due to circumstances, such as, peers not responding with feedback, the team does not have time to wait for the peers to respond, the team could not rely on the peers' responses, etc. One advantage of associations over feedback is the aspect of time. Inferring from associations has less delay compared to feedback. To compute feedback, a team needs to wait until the peers reply. But in the case of associations, there is no waiting time; a team itself can infer an indirect trust value by checking how good the associates of the target team are.

Let n be the number of associated teams, and CR_r^a represent the CollabRating value of a team r associated with team j for a service 'a'. Then, the association value that can be obtained by team i for team j can be represented as:

$$IT_{ij}^{a.Assocn} = \frac{\sum_{r=1}^{n}(CR_r^a)}{n}$$

1.2 Recommender Trust

The third part required for computing the total trust value for a team is *Recommender Trust*. In practice, recommendation has been a successful approach in building trust [15]. The team coordinator has a set of expert recommenders for each type of service in the online team system. These recommenders are experts in specific service/product domains they represent. When a team seeks recommendation regarding a target team, the recommenders check their data or use their custom methods to return a recommendation value for a target team. If $RT_{ij}^{a}(t) \in [0,1]$ indicates the recommender trust assigned to team j and revealed to team i for the service/product a, then $RT_{ij}^{a}(t) = 1$ implies that the recommenders fully recommend team j to team i regarding service a, and $RT_{ij}^{a}(t) = 0$ implies that the recommenders do not recommend team j to team i regarding service a. And, intermediate values show the degree of recommendation.

Trust Scale. On detailing the methods to compute the said three forms of trust, we can compute a trust value (T_{ij}^{a}) for a team as follows:

$$T_{ij}^{a} = DT_{ij}^{a} + IT_{ij}^{a} + RT_{ij}^{a}$$

Using the above computation, it is possible to arrive at a final trust value for a team with respect to a particular service/product a. The range of values for trust scale is {0,6}. This is because, the maximum value for IT_{ij}^{a} and RT_{ij}^{a} is 1, and for DT_{ij}^{a} is 4, and the minimum value for all three is 0. Now, $T_{ij}^{a} = 0$ implies that team j cannot be trusted for the service a, and $T_{ij}^{a} = 6$ means that the team j can be fully trusted for the service a. If it is any intermediate value, then level of trust for the specified service/product can be assumed accordingly.

1.3 Direct Trust Computation

To calculate direct trust for a service/product of a target team, we first need to compute values for quality, work speed, cost effectiveness, and durability.

Quality
Quality is assessed by a team for a target team's service/product. Quality evaluation can be made using a quality table. The attributes in the quality table are — Service/Product, team_id, Material Quality [MQ], Design Correctness [DC], Timeliness [TB], and Compliance to Standards [CoS]. Upon observation of the previously availed services from the target team, the evaluating team assigns values to each of these attributes of a service. Each attribute is given a 1 or 0 or any intermediate value between 0 and 1 such that 1 implies good/true and 0 for bad/false. The final value for quality is obtained by dividing the sum total of all the attribute values by 4.

$$\therefore \textit{Final quality value} = \frac{MQ+DC+TB+CoS}{4}$$

Table 1. Quality assessment for Direct Trust

Service / Product (a)	Material quality [MQ]	Design correctness [DC]	Timeliness [T]	Compliance to standards [CoS]	Quality assessed
a	1	1	1	1	1
b	0	0	0	0	0

If a supplied service/product has good material quality, design correctness, timeliness, and compliance to standards, then MQ=1, DC =1, T=1 and CoS =1, and the quality value for that service/product is 1. But if a supplied service/product is poor in material quality, design correctness, timeliness, and compliance to standards, then MQ=0, DC =0, T=0 and CoS =0, making the quality value for that service/product to be 0. For intermediate values of these attributes, quality will also get an intermediate value between 0 and 1.

Work Speed

Based on the previous experiences, it is possible to compute work speed of a target team for a task using the following attributes — No. of days allotted for task completion, No. of days actually taken for completion, ratio of difference in days (±), Speed of Completion.

Table 2. Speed of Completion of Task

No. of days allotted for task completion (N)	No. of days actually taken for completion (M)	(±) Delay ratio $\frac{(N-M)}{N}$	Speed of Completion
10	8	0.2	1
10	12	- 0.2	0.8
10	10	0	1

If $\frac{(N-M)}{N} = 0$, it means that the team has completed the task in perfect time and speed of completion = 1. If $\frac{(N-M)}{N}$ ¿ 0, it means that the team has completed the task ahead of time and speed of completion = $1 + \frac{(N-M)}{N}$. But this is rounded to 1 as the maximum value for speed of completion is 1. If $\frac{(N-M)}{N}$ ¡ 0, it means that the team has delayed the task execution and speed of completion = 1 - $\frac{(N-M)}{N}$. The minimum value it can have is 0, since the minimum value of speed of completion is 0. For intermediate values of these attributes, work speed will also get an intermediate value between 0 and 1.

Cost Effectiveness

A team measures the cost effectiveness of a target team by comparing the cost claimed/levied by target team against the cost quotations of others. The attributes required for checking cost effectiveness are: Lowest cost quoted by other teams, cost quoted by target team, cost effectiveness, etc.

For a service, if the costs levied by the target team are more than what is quoted by the others, then the target team is not cost effective. Hence cost effectiveness in such a case is 0. However, if the target team quotes less than

Table 3. Cost effectiveness of service/product

Service/ Product	Lowest cost quoted by other teams (N)	Target team	Cost levied by target team (M)	Difference ratio $\frac{(N-M)}{N}$	Cost effectiveness
a	100	team j	80	0.2	1
b	100	team j	120	- 0.2	0
c	100	team j	100	0	0

the cost compared to other teams for the same service, then the target team is cost effective and the value of cost effectiveness is 1. For intermediate values of these attributes, cost effectiveness will also get some intermediate value between 0 and 1.

Durability
A team computes the durability of a target team's service/product by testing/observing the supplied service/product. To compute durability it uses a table with the following attributes — Service/Product, Type of Durability Test, Result, and Durability. Each service/product is tested with the relevant procedures.

Table 4. Durability of a product

Service/ Product	Durability Tests	Result	Durability
a	Pressure Testing, Thermal Testing, Load Testing	success	1
b	Aging, Burst Testing, Operational Limits	failure	0

Having computed values for Quality, Work Speed, Cost Effectiveness, and Durability of a service/product, Direct Trust for that service/product of the target team is computed by summation of all the four attributes.

1.4 Indirect Trust Computation

Indirect trust is computed with the help of the peers of the target team.

Feedback: Feedback is computed from the feedback values obtained from the peers of the target team. The obtained feedback values are fed into a feedback table. The attributes in the feedback table are — Servicename, teamId, Cost, Quality, Transparency, Timeliness, ResponseTime, Trust, and Timestamp. Each peer of the target team is sent a feedback form in which it has to respond to questions relating to quality, cost effectiveness, transparency, timeliness, and responsiveness of the target team. Each tuple in the feedback table represents the feedback by a team which has some direct trust value to the target team.

Feedback value of a target team can be computed as follows:

$$IT_{ij}^{a.Feedback}(t) = \sum_{i=1}^{n} \frac{a.FB.x_i}{n * S_{mx}}$$

$$= \sum_{i=1}^{n} \frac{a.FB.x_i}{15}$$

$FB.x_i$ indicates the attributes of the feedback table. S_{mx} represents the maximum value of the scale used for measuring each attribute, and n is the number of attributes. Since, $n = 5$ and $S_{mx} = 3$, we have $n * S_{mx} = 15$.

Associations
Computation of an association also needs the peers of the target team. For computation of association, a team uses the association table. The attributes in the table are — Target-team-id, ServiceName, Stakeholder1-CollabRating, Stakeholder2-CollabRating,.., AvgCollabRating. If a is the service, n is number of associated teams, then, association trust value of a target team is given by,

$$IT_{ij}^{a.Assocn}(t) = \frac{\sum_{i=1}^{n} a.CollabRating_i}{n}$$

Computation of trust due to association is not time consuming because it avoids waiting time for receiving feedback from all the peers; it only considers the Collaborativeness ratings of the peers and makes an average of it. Hence it is a time saving process.

1.5 Recommender Trust Computation

To compute recommender trust, a team uses the Recommenders Table which is managed by the coordinator or recommenders. It consists of information regarding all the expert recommenders nominated by the coordinator, and their areas of expertise. The attributes of the recommenders table are Recommenders, Service/Product, RecommendedTeam, RecommendationValue. The Recommendation value is given on the basis of the confidence of the recommenders and their discretion about the service/product of the target team. The highest value

Table 5. Feedback on the product

Service/ Product	Target teamId	Cost	Quality	Transparency	Timeliness	Response Time	Feedback giving team	Time stamp	Feedback Value
a	team098	3	3	3	3	3	team567	12-2-2012:04:50	1
a	team098	0	0	0	0	0	team433	22-2-2012:08:44	0

Table 6. Associations Trust

Service/ product	target teamId	Trusts of stakeholders	AssociatedTrust
a	team007	1,1,1	1
b	team007	0,0,0	0

for recommendation is 1, i.e. $RT_{ij}^{a} = 1$ and the lowest value is $RT_{ij}^{a} = 0$. Intermediate values carry the corresponding level of confidence in recommendation.

Table 7. Recommender Trust

Recommenders List	Service / Product	Recommended team	Location	Recommendation Value
rec_100, rec_34, rec_78	carpentry	team_007	Guntur	1
rec_120, rec_233, rec_484	garments	team_908	Hyderabad	0.5

2 Conclusion

This chapter introduced the concept of trust in teams and discussed its framework in the online team system. It also proposed a strategy for computation of trust of a team. The concept of trust arises when a team wants to collaborate with another team or when the coordinator wants to assign a task to a team. In both cases, verification is done for teams to determine if they are trustable or not. The properties and types of trust are discussed with relevance to teams. Trust, which is of three types — direct trust, indirect trust and recommender trust, is explained with a simple example. Also, the components of each type of trust are explained. Direct trust is computed from attributes such as quality, speed of completion, cost effectiveness and durability. Indirect trust is computed using one of the behavioural attributes such as feedback, associations, or social intimacy degree. Recommender trust is computed using recommendations of an expert committee. Competency and integrity are defined along with the processes of quantifying them have also discussed. The computation details for each of the attributes of direct trust, indirect trust, recommender trust were also given. The trust metric and its implications were also discussed. This chapter considered most of the attributes that have a significant influence on trust. It is possible to find even more attributes, but we feel that it is not required. The present attributes are good enough to determine whether a team is good enough for collaboration or not.

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