

Communication Complexities: A Software Construction Perspective

LIPENG YONG

Department of Internet Engineering and Computer Science
Universiti Tunku Abdul Rahman
Jalan Genting Kelang, 53300 Kuala Lumpur
MALAYSIA
yongle@utar.edu.my

Abstract: - Half of a century has gone by yet software crisis endure. Many have thought that its Achilles heel is in the ways of constructing software or in the ways of managing the software construction or both thus they attack it vigorously without reserve like Hercules whacking off the Hydra's heads. This paper instead casted an eye on the communication among the software construction team members by first dissecting it into six levels of complexity from individual to Internet communication. Secondly communication was tackled mathematically and the formulas have been further simplified to some rules of thumb.

Key-Words: - Software Crisis, Software Engineering, Communication Complexity, Reflectivity, Responsivity, Standish Report.

1 Introduction

Software construction in the older days, technical personnel were the kings since most of the decision making regarding to the construction of software, such as what to construct, when to deliver, how to do it and etc decided solely by them. When the demand of software product getting more sophisticated and complex, the administrative people wedged in to take off some parts of the decision making; as the demand of software product functionalities still climbing up other stakeholders wanted a say in the decision making. Software construction is best understood from an integrated view of these three stances, for example LipEng and SiewFan [1] has a theory on it with a practical example.

The inference to the demand for increasing software product functionalities are due vastly to the computer power getting faster and faster, the linkage of computer with other technologies expanding wider and wider, the knowledge of using computer digging deeper and deeper per subject area, and the need of integration with other technologies, particular communications are ever expanding in width and in depth and in speed. The first one could be predicted by Moore [2] law: "*Integrated Circuit performance double every eighteen months*", whereas the last three create Humphrey [3], as I would call, law: "*software content increase by about ten times every five years*". Note: ten times every five years is not equivalent to two times every year. The essence of Software crisis is the high impedance of these two contrasting Laws: the pulls

of the Humphrey Law in the demand side of the market and the pushes of the Moore Law in the supply side of the market.

The Achilles heel of software crisis, despite the numerous models, theories and best practices created in the past decades for software construction since the Nato's International Software Engineering Conference in 1968 [1], and 1969 [5], is still at large. The various, diverse, extensive researches and studies on why software project fails starting from a small set of handful possible causes as time pass by to a set of all-imaginable and uncontrollable grow of myriad grounds to be further populated freely. Software crisis is indeed much like the Lerna Hydra's heads described by Bailey [6] in one of the Hercules' tasks

"He stepped aside and dealt it such a crushing blow that one of its heads was immediately dissevered. No sooner had this horrid head fallen into the bog than two grew in its place. Again and again Hercules attacked the raging monster, but it grew stronger, not weaker, with each assault."

Hercules in the fight with Hydra would not have succeeded without Iolaus collaboration. Any task that involved with two or more people effective communication and hence collaboration is a prime factor for success. Successful Collaboration implies effective communication among the parties otherwise it would be as Brooks [7] described "*Schedule disaster, functional misfits, and system bugs all arise because the left hand does not know what the right hand is doing*".

There are many surveys, researches and studies on the success and failure of software project; however they are mostly pointing in the interpersonal communication direction as the crux of the software project's success or failure, for examples The Office of Government Commerce (OGC) and the National Audit Office (NAO) of UK [8], have identified a set of common causes of project failure, in there it had more than fifty percent of the causes pointing to interpersonal communication. Software failure according to Standish Chaos Report [10] the cusp of its top ten success factors is interpersonal communication. The Agile Manifesto [12] has no less than three quarters of their values based on interpersonal communication and were endorsed by seventeen world renowned software construction gurus in the first meeting in 2001 for the launch of Agile Software Development Movement. The name-list of endorsement is ever increasing and can be viewed in [13]. A new movement of Software construction came in the last quarter of 2009 that called itself as SEMAT, Software Engineering Method and Theory, which was initiated by two papers [14] and [15], and its vision [16] include resolving interpersonal communication issues emphatically. Note: the names list of endorsement for both Agile and Semat movements are multi-pages.

Computer supported cooperative work (CSCW) can be traced back in the 1960s when Engelbart D. (1964-1975) embarked in the NLS/Augment system project [17] where NLS stands for oN-Line System. CSCW after eclipsed for a decade was revived by Irene Greif and Paul M. Cashman [18] in 1984. Many people at one time equated CSCW with Groupware, which had appeared few years earlier, but it is more than Groupware. There are two variances, one is represented mainly by the U.S. camp as CSCW which mostly focuses on practical issues; the other camp is represented by the Europe Continent, U.K. included, called European Computer Support Collaboration Work (eCSCW), which is more philosophical and theoretical oriented.

Basing the above knowledge therefore it is imperative to closely analyse the root of interpersonal communication or communication for short. Communication was defined in this paper as Chi-yue Chiu, Robert M. Krauss, Ivy Y-M. Lau [19] did

“Research on communication traditionally has focused on how the listener is affected by the communicator's message. Such an approach conceptualizes communication as a process in which information is transferred

from speakers to listeners through the medium of messages. Since the flow of information is unidirectional, so are its consequences.”

The definition is apt to be applied to software construction. The unidirectional nature of communication can be felt through for example in the requirement elicitation with such incidences as “That was not what we want!”, “Like these! That what I have meant”, “...it is NOT what we have expected!” and etc.

Melvin Conway was probably the first who alluded to the study of communication in which greatly affected the product of the software construction. His seminal paper [20] was rejected by one of the top, by today standard, publishing company, and was accepted subsequently by Datamation but then it was taken few years to be appreciated by F. Brooks and who subsequently named it as Conway law. Conway's law stated that

Any organization that designs a system (defined broadly) will produce a design whose structure is a copy of the organization's communication structure.

“In writing a compiler with three different teams”, he said, “it would result a three-pass compiler.” He explicitly meant that the functionality of each of the three passes is inherited with its team's way of communication among the members. Conway law in general emphasize the importance of social aspect of collaboration, and in particular the interpersonal communication in software construction,

In his exposition of “The Mythical Man-Month” F. Brooks with his vast amount of studies and practical observation in software construction transpired what is now known as Brooks [7] law--- *Adding manpower to a late software project makes it later---* which clearly proclaims the aggravating factor to the software project is the excess times needed for the interpersonal communication. Heeding with William Thomson Kelvin advices that

“When you can measure what you are speaking about, and express it in numbers, you know something about it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely, in your thoughts advanced to the stage of science.”

The question now is how much complex the communication would be in adding an extra manpower into the team? Measure conventionally has broadly grouped into two categories---qualitative and quantitative. Qualitative measure of communication was analyzed in session two with

two perspectives: the wider perspective contained the triads--- Internet, intranet, and extranet, and the narrower perspective contained the Watts Humphrey's triads---CMMI, Capability Maturity Model Integration, formally CMM, TSP, Team Software Process, and PSP, Personal Software Process. These communication complexities after the analysis were classified by lumping up the cross boundaries of the two triads into five levels. These five levels could then be Likertized in the scale of one's preference for easier to refer to when in actual use. Session three dealt with quantitative measure, in which three new concepts related to logic were discussed and defined--- reflectivity, responsivity and extensibility. From the finding of the complexity of the upper bounds for these three concepts, mathematical formulas have been derived for each of them. The mathematical formulas were then simplified as some rules of thumb so that they could be applied directly whenever communication complexity is concerned.

2. Qualitative Measure of Communication Complexity

Internet, sometime just Net is a short hand for Internetwork, was coined by Cerf and Kahn [21] a communication and collaboration platform for everyone to anyone and for anyone to everyone, better yet as Weinberger and Doc Searls [8] postulated three virtues of the Internet:

1. Nobody owns it.
2. Everybody can use it.
3. Anybody can improve it.

Internet communication complexity is as large as its size and engaged not only interpersonal communication but most often intercultural communication would be the norm. There are many once familiar terms in the past were no longer applicable in Networked economics, for example the words communication and collaboration would be undermined should one interpret them in the pre-Networked economics context, as Tapscott and Williams [23] have redefined them:

“Google CEO Eric Schmidt says: “When you say collaboration, the average forty-five-year-old thinks they know what you're talking about – teams sitting down, having a nice conversation with nice objectives and a nice attitude. That's what collaboration means to most people.”

The new promise of collaboration is that with peer production we will harness human skill, ingenuity, and intelligence more

efficiently and effectively than anything we have witnessed previously.”

These ideas have been further discussed and expanded in their Macrowikinomics [24] book. In the software construction world The LAMP or GLAMP stack is the exemplary model. The four principles of Wikinomics: Peering, Open, Sharing, and Acting Globally are all based on the effectiveness of collaboration and communication, though the last one intercultural communication standout. Further insight can be seen through Eric Raymond [25] dubbed Linus law in 1999: “Giving enough eyeballs all bugs are shallow”. Note: there is yet another version of Linus law that was self made by Linus Benedict Torvalds himself in Pekka Himanen et. al. [26].

The value and power of conversation and hence communication can be perceived through the message of Jeff Howe concerning the takeover of YouTube by Google [27]:

“Google didn't pay for the expertise housed within that San Bruno office. It paid for the millions of users who create and submit videos to YouTube, and for the traffic they drive to the site. It paid, in short, for the community--- the people who use it to engage in a conversation in a language of moving images.”

There are a number of others similar cases mentioned in Howe's Crowdsourcing book and many other cases in the history, one particular interesting saga was Microhoo [28], in which Microsoft attempted to acquire Yahoo in 2008 and it lasted in months of stressed negotiations with the offered price \$33 a share but rejected, which in the end led to the downfall of Jerry Yang the Yahoo's CEO cum co-founder. The aftermath share price of Yahoo was \$10.63. This crowdsourcing, coined by Jeff Howe himself, and its ten rules were the quintessence of Internet communication.

Next is Intranet which was coined in the 1995 by Telleen [29] of Amdahl Corporation in one of his paper “IntraNet Methodology” and IntraNet (note the spelling) was one of its trademark too. In an interview in 1998, Telleen [30] said

“When I coined the term "IntraNet" at Amdahl Corp. in the summer of 1994, it did have the connotation of an internal Web rather than just an internal Internet. In fact, the term we used internally before this was the too-cumbersome "Enterprise-Wide Web.”

Intranet is used within an organization therefore the size of people involved is limited and the communication complexity is greatly reduced to a fraction to those of the Internet's. Anyone could

have apart for those large corporate known everyone. The exemplar model is ERP, short for Enterprise Resource Planning, system which primary aims are to unifying all databases and integrating relevant processes in an organization. The emergence of ERP systems in the 1990s was owing to the inherently inefficient and ineffective of the functional organization structure commonly referred to the undesirable silo effects. ERP system main creed then is to break down all these possible walls among the functional departments within an organization such that everyone and anyone could communicate and collaborate with every other freely. In this sense then ERP system is a misnomer and should be ascribed to its predecessors' names starting from 1960s, in which was due to the historical reasons of maintaining their compatible allusion.

Extranet was coined by Bob Metcalfe [31, 32] as he claimed it. Extranet is used for the purposes of inputting information from the various business partners from suppliers to stakeholders to customers into business for processing, and its communication complexity is in between of the Internet and intranet. The exemplar model is b-web, business web. B-web, Tapscott and Williams [23] said, are clusters of businesses that come together over the Internet. While each company retains its identity, the companies function together, creating more wealth than they could ever hope to create individually. This dynamic web as they described:

“The bottom line is this: The immutable, standalone Web site is dead. ...In fact, 2006 was the year when the programmable Web eclipsed the static Web every time: flickr beat webshots; Wikipedia beat Britannica; Blogger beat CNN; Epinions beat Consumer Reports; Upcoming beat evite; Google Maps beat MapQuest; MySpace beat friendster; and craigslist beat Monster.

What was the difference? The losers launched Web sites. The winners launched vibrant communities. The losers built walled gardens. The winners built public squares. The losers innovated internally. The winners innovated with their users. The losers jealously guarded their data and software interfaces. The winners shared them with everyone.”

They have proposed seven models which particular suit as they claimed it in the twenty first century for this second triad--- Extranet. Intranet can be viewed as an inward looking platform to internally navigate the organization, while extranet as an outward searching platform for opportunities. Basing on ERP

as the core, its fringes have been greatly expanded to include dynamic functionalities for communication and collaboration, and to avoid misnomer once again a new appropriate name is needed. Enterprise systems in this global economics would be the better words as Magal and Word [33] have put it:

“Because the steps in business processes are performed in locations that are geographically dispersed, it is impossible to manage such processes effectively without the use of modern information systems. Systems that support end-to-end processes are called enterprise systems.”

Communication in a narrower perspective, starting from an organization, communication and collaboration can be further drilled down by the model such as Watts Humphrey's triads--- CMMI short for Capability Maturity Model Integration, TSP short for Team Software Process, and PSP short for Personal Software Process--- which success depends immensely on the effectiveness and efficiency of communication within and without an organization. CMMI was developed to resolve the deficiencies of CMM [34] and the last alphabet I, for integration, indicates those silos effects of organization were resolved. CMMI involves with the whole organization and therefore its communication complexity is the most complex among the triad. Apart from the five maturity levels and six capability levels need a lot of communication and collaboration for preparation within the organization the ARC, Appraisal Requirements for CMMI, and SCAMPI, Standard CMMI Appraisal Method for Process Improvement, too needs no less. There is a set of KPAs, Key Process Areas, over the levels to be appraised in the organization. The five levels of CMMI has actually been extended down with another four levels and these four levels were lump up to be named as CIMM [35], Capability Immaturity Model, by Tom Schorsch.

TSP deals mainly for the team members' communication hence the number of people there would be relatively small and its communication complexity is lesser than that of the CMMI. Motivation and leadership are prime concerns in team, but then to motivate and to lead would not go far without considerable communication. Humphrey [36] has, based on Maslow Hierarchy of Needs, proposed four requirements--- all are but boiled down to talking and documenting what have been discussed, i.e. communication--- to be applied in motivating the team members. For the leadership let's hear one of the software construction guru Humphrey [36] a few words: “In the fifty-plus years since I started doing development work, I have

worked on, led, managed, directed, assessed, or coached literally hundreds of creative development teams. While I have drawn many lessons and guidelines from this experience, the one clearest message is that leadership makes the greatest difference." Leadership makes the greatest difference" is certainly easily said than done. How hard and tough would be more appreciated by the leaders themselves especially when numerous obstacles exist. Team leader not only needs to communicate with his team member but he too needs to communicate with his superiors and management, which might have some very different ideas from what have been found within the team.

The following was one of the Humphrey's [36] experience concerned with the largest computer system procurement IBM had ever received from the FAA's Request for Proposal. Humphrey at that time was an unspoken project team leader in the marketing division worked under George Kennard the development division president. Kennard, Frank Carey the marketing division president, and Vin Learson the IBM Senior Vice President for Marketing and Product Development, were in the meeting in deciding who among the many IBM project team leaders would be most suitable to be the team leader, after many intrigue twists and turns of opinions these three key directors, finally through the rationale of Learson, Humphrey was chosen as the project leader as Humphrey was a project team leader in the Marketing division but worked in the Production Division--- a cross functional project team leader:

"I held resolution sessions and invited everybody who wanted to contribute..."

In my first status meeting with Learson, Carey, and Kennard, Learson didn't agree with our design strategy and started to tell me how to change it. I stopped him right then. "Look." I said, "If you want to design this system you can but you will have to run the proposal too. If I am to do the job, I'd be glad to listen to your ideas but it's too late to change the design." Learson backed off and I finished the status review.

...I learned the answer from the TSP. The design strategy we had adopted for the FAA proposal was not my design--- it was the team's. I could not image going back to the team and telling them that Learson and I had decided to change it. You will also find that when you involve the team in key decision, you will not only have better decisions, but you will also have the evidence and conviction to defend them."

PSP focuses individual disciplines and its success though is controllable by oneself in the respect of, among other factors, alertness of responsibility and constructive determination, even then one should heed Humphrey's [37] following advice:

The PSP is a self-improvement process. ...But the PSP is not for everyone. ...The PSP is for people who strive for personal achievement and relish meeting a demanding challenge.

Even highly motivated people might properly question whether they should pursue the PSP. If you feel this way, you should review it and decide for yourself. Personal improvement involves many hours of effort and many years of gradual improvement. The PSP can be highly rewarding; at times it also can be frustrating.

The PSP has four very similar levels and the set of KPAs like those of the CMMI's to be appraised though this time is all depend on individual's command.

The six levels of communications--- from Internet to individual--- the terms in the wider perspective are well established and accepted therefore reinventing the wheel is futile; the terms in the narrower perspective are yet to be named, thus the following terms after searching through the Internet were purposed with caution of conflicting the existing ones as infracommunication, or infracomm for individual communication for communication below oneself; circacommunication or circacomm for team communication around team's members; and intracommunication or intracomm for organizational wide communication. These levels were shown in Fig. 1: Levels of communication complexity.

All the level-boxes in Fig. 1 should be interpreted to represent one or more boxes i.e. duplicating itself within Figure 1 except the outermost Internet box which is exactly one, for examples the Extranet box is supposed to be more than one in the sense of a business entity normally operates its business with one or more business partners; and for infracomm, there should be at least two individuals to be considered as a team. The size of the overlapping area between Extranet and Intranet are determined by the degree of the business parties' collaboration, and there are situations that some circacomm boxes too would intersect with that of the Extranet; for example, teams collaboration on certain project. The complexity of the intranet and intracomm is same therefore they are to be treated as one with two different names. The usage of the different names should be depending on the discourse content:

intranet is used for business concerns as it is always been used, while intracomm should be used to the general discourse of communication. Communication complexity in this way would result in five levels and to aid memorizing them it would be better to re-label them in term of Likert scale of one's choice such as from one to five.

3 Quantitative Measure of Communication Complexity

Information theory was come much earlier than Information system actually though the latter has taken over in breadth and depth in research and application. Information theory was originated in Bell Labs and was populated by Claude E. Shannon through his 1948 seminal paper [38] A Mathematical Theory of Communication. Due to its wide-span significance into many fields and its last part of the title "Theory of Communication" that it was inappropriately used, referred and quoted in many of the studies of communication as Robert T. Craig [39] once said:

"Perhaps the most egregious case involved Shannon's mathematical *theory of information* (Shannon & Weaver, 1948) [40], which communication scholars touted as evidence of their field's potential scientific status even though they had nothing whatever to do with creating it, often poorly understood it, and seldom found any real use for it in their research."

Note that "theory of information" was Craig's original words, it was italicized for emphasis. And that the Shannon & Weaver's book title is actually "The Mathematical Theory of Communication". In a communication that involves two or more parties, there are fifteen possibilities to a receiver in terms of acceptability and responsiveness. There are five dimensions for acceptability: 1. acceptable, 2. acceptable but the receiver acted he is not, 3. indifference, 4. not-acceptable, and 5. not-acceptable but the receiver acted as he is. There are three dimensions for responsiveness: 1. respond directly to the sender of the message, 2. respond indirectly to the sender of the message, and 3. no-respond. These fifteen possibilities have been tabulated into a five by three matrix as shown in Table 1: Responsiveness vs Acceptability. The cells in the matrix represent the choice or choices that the receiver will take as his decision toward a message. An individual could have chosen more than one choice. For example, while a person inwardly could have decided to accept the message but then he

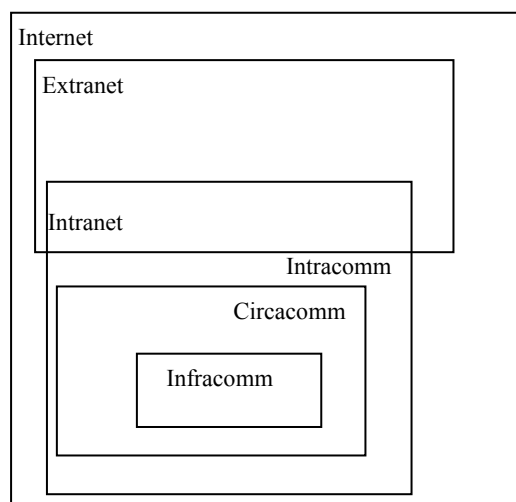


Fig. 1: Levels of Communication Complexity

could also on one hand discuss with those who near to him pretending he is not accepting the message, on the other hand he could perform the other way round, or just keep everything to himself.

| | | Responsiveness | | |
|---------------|-------------|----------------|--------------|--------------|
| | | Direct | No respond | Indirect |
| Acceptability | Acceptable | Acceptable | Acceptable | Acceptable |
| | Pseudo | Pseudo | Pseudo | Pseudo |
| | Acceptable | Acceptable | Acceptable | Acceptable |
| | Indifferent | Indifferent | Indifferent | Indifferent |
| | Pseudo | Pseudo | Pseudo | Pseudo |
| | | Unacceptable | Unacceptable | Unacceptable |
| | | Unacceptable | Unacceptable | Unacceptable |

Table 1: Responsiveness vs Acceptability

To measure the effectiveness of communication, three of the communication properties are of great value--- reflectivity, responsivity and extensibility. Reflectivity concerns with the receiver of a message in a communication that he analyzes the message only inwardly in his mind and reflect it out indirectly while in the communication. Characteristics: The receiver never voices out his opinion, due to this or that reason, directly to be heard by the sender of the message. Communication complexity: It grows in the power of two as the number of people increase to be classified in reflectivity. In other words, n^2 , where n is the number of people in the set reflectivity. Responsivity concerns with the receiver of the message in a communication that how he reacts directly to the sender of the message. Characteristics: It is at least involves with two persons, one is the sender of the message, and the other the receiver. It could be a wild forest fire started with a tiny spark. Communication

complexity: It grows exponentially as the number of people involved. Extensibility concerns with the receiver of the message in a communication the way he relates the message to a third party via a second party, and that third party related what he has understood the messages (the original message from the sender plus the message from the receiver) to a fourth party, and so on and on. Characteristics: It involves with at least three persons in the communication. It pregnant with cyclical chain effect by reflectivity and responsivity and could easily go out of control and making the communication crumpled. Communication complexity: It grows factorially, that is a number post-fixed with exclamation mark, !.

3.1 Reflectivity

When one talks about communication normally the discourse would be expected to involve with at least two persons and therefore often ignoring the case of communication with oneself---the dialogue within oneself reflected from the message received from outside--- sometimes a soliloquy but could be heard only by those who closely nearby the soliloquist. Reflectivity comes with three varieties. A receiver in type one reflectivity would reflect his thinking to another person or persons within the communication other than to the sender of the message--- a tale-teller. It has the characteristics of undertone and normally through whispering to those who are nearby. Type two of reflectivity is an open soliloquy solely aims for those who nearby and sometimes accompanies with some gestures and body movements just in case others would not able to heed. It is a kind of murmuring with an intention to be heard and made used of. Type three reflectivity, though it would be more appropriate to classify it as irreflectivity, the reflection to a message is kept in the receiver's mind and would not be known by the people while in the communication, but most often than not expressed out emotionally and vehemently after the communication by the receiver himself among his close associates. The effect of it must not be underestimated though most would think there would be little or no influence to the outcome of the decision made in the meeting as the meeting was over. Yes, it would not in any way affect the made decision, but it is not so simplicity as a decision made is but the first step moved along a long journey toward the decision to be implemented successfully. Anything could happen, in between would happen---Murphy Law: "Anything that can go wrong will go wrong". The crux is the talks among close associates after the meeting could be

multiplied fast like communicable disease after flooding via each and every associate's associates and therefore could jeopardise and increase the risk to the implementation of the decision so made.

All three types of reflectivity could lead to profound consequence if one would not be careful enough especially the communication is a critical kind of meeting to simply invoke the rule of by default--- silence means agreeing. No. Silence does not necessary mean agreeing or disagreeing, the virus could have spread through other carriers. Reflectivity is a set consists of those people, the receivers of a message, in a communication descriptively defined to be

A receiver of a message must, be it acceptable, not acceptable or indifference, indirectly voice out his thought genuine or disguised in the communication.

That is a participant, Mr. A, is considered to be in the set of reflectivity, if he voices out in the communication but not directly to the speaker of the message, otherwise he is considered to be in the set of irreflectivity. Noted that reflectivity from above discussion is defined to at most two levels. Level one concerns only the receiver himself, level two includes to those who heard from the receiver directly, and it must not be extended to any other participants in the communication. The reason to restrict up to two levels in that way is the assumption that at a higher level, any level above two, the original ideas of A would be significantly diluted or lost completely by those in between levels' ideas and hence A should not be considered to have contributed anything at all and should not be in reflectivity.

The value of reflectivity is crucial in determining the success of the communication. The larger the value of reflectivity the better the communication, on the other hand the complexity would grow at the same time as the value grows to the point of chaos and the communication could collapse. Reflectivity has minimal value of one obviously as it could not be negative, and that the value zero would mean no participant ever voice out in the whole duration of the communication and hence would be assigned to irreflectivity. The value of reflectivity depends on the number of participants less one, the one who brought out the message, in the communication and can be determined mathematically. To avoid repeating what would have been done, the following mathematical method will be used throughout for the finding of the upper bound of reflectivity, responsivity and extensibility with minor notation changes. Instead of finding any particular reflectivity value, its upper bound will be

established first and then if necessary each individual value could be calculated.

Mathematically, Let A be the set of n, n>2, people in the communication. Define a reflectivity relationship between two persons, say a_j and a_k and write (a_j, a_k) to mean a_j talks to a_k. Depending on circumstance that a_j might be the same person as a_k, in this case it would be written as (a_j, a_j). Let @ be the set of all sets that have the property of being reflectivity, and write a_j@a_k to mean a_j and a_k are in @ otherwise it is irreflectivity. Note that the set @ assuming initially is empty, which is the normal assumption of a set, i.e. the empty element { } is in @, then when the notation a_j@a_k is valid it would imply @ now contains four sets, together with the empty set, as its elements that is a set of {a_j}, a set of {a_k}, a set of {a_j,b_k} and a set of { } i.e. @ = { { }, {a_j}, {a_k}, {a_j,b_k} }. In this way the complexity of reflectivity could be checked by simply counting the number of elements in @. Note: “simply counting” is valid is due to these two set properties: one of the set properties is duplicated element is not allow and another is the order of the element appearance is immaterial, and because of them too to reconstruct after it was formed the reflectivity relationship among the elements in @ would need considerable efforts. Another way to tell the complexity of reflectivity is to assign a value initially equal zero to a counter in @, then whenever a reflectivity has shown up in a communication the counter is increased recursively by one after checking for duplication of entry into @, and at the end of the communication the value of the counter can be directly read out as its complexity.

In order to find the upper bound of reflectivity three steps are required. First step is to find the upper bound of soliloquy reflectivity. Second step is to find the upper bound tale-telling reflectivity. The third step is to add up the result of both, soliloquy and tale-telling, together and that sum would be required upper bound of reflectivity. In the soliloquy case with n, n>2, people in a communication it would be for all i, j such that a_i@a_k = 1 otherwise a_i@a_k = 0. And that the one who brought up the issue is ignored because he is not supposed to know or hear of the soliloquy, therefore there would be actually have n-1 people need to be considered. Each of these n-1 people would likely to be a soliloquist, so there would be (n-1) pair of (n-2) cases for up to two levels deep in the chain. Summing all of them up it would be (n-1)(n-2), that is

$$\sum_i^{n-1} \sum_j^{n-1} a_i @ a_j = (n-1)(n-2) \tag{1}$$

For the tale-telling case, it would expect the same way of analyzing as in soliloquy except with minor different in reasoning, In soliloquy, the soliloquist would not and must not interfere his listeners if they pay any attention to his words, while in tale-telling, the tale-teller is actually interacting with his listener and therefore will have greater effect to his listener. This does not mean a participant say A, can only talk to one other participant in the communication. A can talk or broadcast his ideas to many other participants, e.g. B, C, D etc. as he thinks necessary. From another angle to reason it, it could be thought of having n-1 people, excluded the speaker of the issue, in an assembly and in order to find all its possible permutations for any two persons at a time, this would give

$$P_2^{n-1} = \frac{(n-1)!}{[(n-1)-2]!} \tag{2}$$

The last step in finding the upper bound of reflectivity is to add up both, soliloquy and tale-telling, results, and doing it then the total would be twice (n-1)(n-2)=2n²-6n+4. The upper bound value therefore, using the big oh notation, is O(n²).

3.2 Responsivity

In a communication with two or more people, say n people where n∈N and n>2, when an issue was raised, followed by one or more responses and then there shall be at least one further response, be it agree, indifferent or disagree then the communication is responsivity, otherwise anti-responsivity. Note: Someone disagrees an issue while in a communication does not necessarily mean he opposes to the issue put forth as he may be just to elicit more information for further consideration. The final judgment is at the end of the communication. According to the above description then responsivity of communication is defined to be

A receiver of a message in a communication must, be it acceptable, not acceptable or indifference, directly voice out his thought genuinely or disguised to be heard, and there will be at least one further response from the crowd other than the receiver and originator of the message in the communication.

Note: The last part of the definition “...at least one further response...” is needed for the definition of responsivity because without it, it would be having two different issues one followed the other. And that the third person’s response could be against or for the second person’s idea, and could be against or for

the first person's idea as well as having his own idea independent to the other two persons. Similarly that applies to the second person to the first person.

A communication with a handful of people the complexity could be handled easily without many problems as one knows every others such as by their names or by their wearing. Communication complexity increase as the number of people involved increase and soon would be very difficult if not impossible to tell each and every one that is for and against an issue except those of a few famous guys there.

To establish the mathematical lower and upper bounds of the complexity of responsivity, first noted that given a communication consists of $n > 2$ people the number of cases needed to be analyzed is $n+1$. That is starting from case 1 with no response; case 2 with only one response; and all the ways up to the last, $n+1$, case with everyone in the communication is involved. The first two cases are according to definition belong to anti-responsivity. Next case is obviously the lower bound of responsivity, and the rest of the other cases would be used to establish the upper bound. This upper bound could be systematically derived by consideration of only two among the n people are involved; only three among the n people are involved; only four among the n people are involved, and so on and on up to everyone are involved. There are in total $n-1$ cases.

Let A be the set consists of n people with $n > 2$. Let $@$ be the set of all complexity of responsivity communication. The notation (a, b) denote a relation in a communication between two different persons, say a and b where $a < b$. such that a bring up an issue and b responds to a at least one time. Similarly when $n=3$ then the notation (a, b, c) would mean a communication of relation between three different persons such that a brings up an issue and b responds to it followed by c responds to b or a or both.

According to the above description and notation then for the first case, it needs to check for all a and b such that if $(a, b) \in @$ and $(b, a) \in @$ then write it $a@b$ as a kind of shorthand for responsivity otherwise anti-responsivity. The maximal complexity of responsivity thus is the sum of them, and mathematically

$$\forall i, j \text{ and } i \neq j \sum_j^n \sum_i^n a_i @ a_j = \binom{n}{2} = \sum_{i=1}^{n-1} i \quad (3)$$

Where $\binom{n}{2}$ is the combinatorial notation, in this case which means among the n people in the communication only two of them are actively involved.

This particular series $\sum_{i=1}^{n-1} i$ has some nice interesting

stories [41, 42, 43 and 44], which should be called the Dog Eared number because it is much like a page of a book with a corner dog eared. The term n^2 can be treated as a coin with two sides, and this

series $\sum_{i=1}^{n-1} i$ which sum to $n(n-1)/2$ was actually one

side of the coin of n^2 and it is less referred compare to its counter-part. What is often referred is the other side of the coin of n^2 normally called the triangle

number that is $\sum_{i=1}^n i$ and it is sometimes referred as

“The sum of the first n natural number”. The dog eared number plus the triangle number is equal to n^2 .

$$\text{i.e. } \sum_{i=1}^n i + \sum_{i=1}^{n-1} i = n^2$$

The second case to be analyzed is the responsivity of three persons in $@$: $a @ b @ c$ (read the colon as such that). For the case of only three persons are involved with a communication of n people, the required condition as mentioned earlier would be

if $(a, b, c) \in @$ then $(a, c, b) \in @$, $(b, a, c) \in @$, $(b, c, a) \in @$, $(c, a, b) \in @$, and $(c, b, a) \in @$. otherwise anti-responsivity.

Note: the outside comma that goes in between two terms “ $(b, c, a) \in @$, $(c, a, b) \in @$ ” represents an ‘or’ rather than ‘and’ function.

The maximal complexity of responsivity thus is the sum of them, and mathematically

$$\forall i, j, k \text{ and } i \neq j \neq k \sum_k^n \sum_j^n \sum_i^n a_i @ a_j @ a_k = \binom{n}{3} \quad (4)$$

Where $\binom{n}{3}$ is the combinatorial notation, in this case which means among the n people in the communication only three of them are actively involved.

Extending above methods likewise for the rest of other cases, and then summing them all up the total will be the upper bound of Responsivity. In doing so the result is equal to $2^n - (n+1)$. It would a bit hard to memorize it for long and that for large n the $(n+1)$ term is insignificant. For example, when n is 20 then the accuracy difference would be only 0.00002 percent. As in section 3.1, the computational complexity notation would be normally used instead of the original formula and this is written as $O(2^n)$ and be read as on the order of two to the power of n .

3.3 Extensibility

Extensibility has a chain like structure which concerns with the receivers of the message in a communication. Interpersonal communication begin with a speaker, the chain like structure of extensibility is activated when a receiver of the message (spoke out by the speaker) relates that message to a second person in the communication, and that second person relates what he (second person) has understood the messages (the original message from the speaker plus his ideas mixed with the message from the first receiver) to a third person in the communication, and that third person to a fourth person in the communication and so on and on with each stage has been adulterated with some subjective opinions. Note that, when a person relates what he has gathered from the message to another person, that another person must be one of the participants within and during the communication otherwise it would be counted as anti-extensibility. Also, the path of extensibility is unidirectional and acyclic for the first three persons, e.g. x to y to z where x, y and z are three different persons. In other words, extensibility involves at least three different persons in a communication. After that the path could be multidirectional as well as cyclic, see Fig. 2: The First Three Levels of Extensibility.

Extensibility is with the above description in mind defined to be

A receiver of a message in a communication must, be it acceptable, not acceptable or indifference, express his thought, genuine or disguised, directly to a second person in the communication and that second person relates it to a third person. At this point, when the third person acknowledges the first and the second persons' thought then extensibility is said to having value one. When the chain move on from the third person to a fourth person, extensibility is increased by one to two, and the fourth to a fifth, extensibility will be three and so on and on with each extra person added to the chain the value one will be added to extensibility.

Let A be the set of people in a communication with $|A| > 3$. Let @ be the set of all sets that people talk to each other,. Note that for all a, b and c in A, the case that when $(a, b) \in @$ and $(b, c) \in @$ then $(a, c) \in @$ but would be considered to be different case with $(a, b, c) \in @$ as the former concerns only with a pair of people and the subjective ideas were passed through

indirectly from a to b and then from b to c, in other words, c gets the second-hand ideas. Whereas in the latter case the subjective ideas were directly channeled among the three parties, in other words all three parties get the first-hand ideas, and would be written as $a@b@c$.

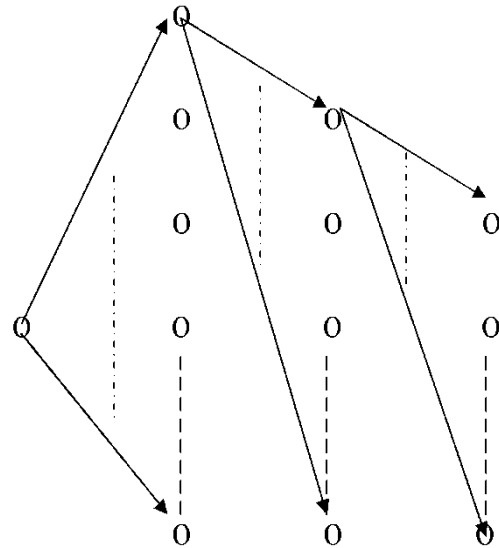


Fig. 2: First Three Levels of Extensibility

The extensibility value of a communication that involves with three persons, a, b and c is mathematically defined as

$$\text{for all } i \neq j \neq k \ a_i@_j \text{ and } a_j@_k \rightarrow a_i@_k=1$$

$$\text{otherwise } =0$$

Above is but a snapshot of extensibility's value, what is needed is to find out the actual extensibility's value for a whole communication---the theoretical upper bound. This upper bound could then be used as a yardstick to measure any other communication to tell its complexity. To do this one can systematically reason the steps to produce this yardstick of extensibility as follow, first find the extensibility value of three persons actively involved in a communication of n-people, next then basing on this procedure just done extend it slightly by adding one more participant, after the second step then for the third step add again with one more participant, and so on and on until everyone in the communication has been added. The value after summing up these two parts would then be the required theoretical upper bound. The first part of the above description can be translated into following six steps.

- 1) Fix the first person among the n people, say this first person is a_i with $i=1$.
- 2) Fix the second person among the n-1 people, say this second person is a_j with $j=2$

- 3) Run through the third person among the rest of the n-2 people, say this third person is a_k with starting k=3, one by one, to k=n-2. Each run will contribute the value one to the extensibility. In other words, after step 3 the value of extensibility is equal to n-2.
- 4) Repeat step 2, 3 and 4 with each cycle the value of j increases by one till j = n until k = n inclusively, after that goes to step 5. The total number of cycles in this step is n-1.
- 5) Repeat step 1, 2, 3, and 4 with each cycle the value of i increases by one until i = n. The total number of cycles in this step is n.
- 6) Summing up all the values in the first five steps then that value will be the value of the extensibility for three persons involved actively in a n-people communication.

Mathematically the value of extensibility for three persons involved actively in a n-people communication can therefore be expressed as

$$\text{Extensibility} = \sum_i^n \sum_j^n \sum_k^n a_i @ a_j @ a_k$$

The partial workout for it, from step 1 to step 6, was shown in Fig. 3: Size of Extensibility for Three Persons. Extensibility is indeed a chain-like structure that starting with three people, it could be extended to four, five, six and to all the participants in the communication. In doing so, we would get the upper bound of extensibility. Before doing it, first noted that one of the powerful and time saving techniques use in science and in software testing too is induction, in that one needs only consider the boundary conditions and then randomly looks into some in between cases and that would suffice to conclude all have been done. This procedure will be applied to the second part of calculating the theoretical upper bound for extensibility, as well as in extending the logic for the case of three persons just done too.

Let A be a set of n-people in a communication, |A|= n >3, and for all i=1, 2...n a_i ∈ A.

@ is extensibility:

for all i j...l...n a_i @ a_j ... @ a_l @ ... @ a_n
 such that i≠j≠...≠l≠...≠n then

$$a_j @ a_k = a_j @ a_1 = \dots = a_j @ a_{n-1} = a_i @ a_n = 1$$

otherwise = 0.

Note: the ellipse i.e. ... in the last line immediately above includes all the in between cases for the group of three persons, the group of four persons, and so on to the last group of n persons.

The theoretical upper bound value of extensibility is obtained by summing up all the ones (and zeros). In other words $\forall i, \dots, n$ and $i \neq j \dots \neq n$, Extensibility Upper Bound (EUB) is

$$\sum_i^n \dots \sum_j^n a_i @ a_j \dots @ a_n = \sum_{i=0}^{n-3} \frac{n!}{i!} \tag{5}$$

To see how the left hand side equal to the right

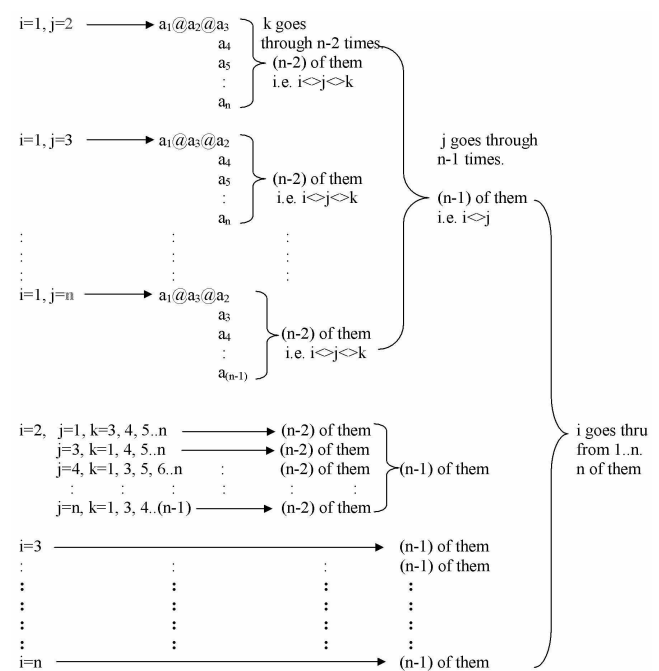


Fig. 3: Size of Extensibility For Three Persons

hand side of (2) inductive reasoning was applied and based on the previous derivational logic of (1) for involving three persons case therefore

for 4 persons is n(n-1)(n-2)(n-3) = n! / (n-4)!

for 5 persons is n(n-1)(n-2)(n-3)(n-4) = n! / (n-5)!

for (n-2) persons n(n-1)... [n-(n-4)][n-(n-3)] = n!/2!

for (n-1) persons n(n-1)... [n-(n-3)][n-(n-2)] = n!/1!

and for n persons n(n-1)... [n-(n-2)][n-(n-1)] = n!/0!

Adding up all the above included for the case of three persons gave the right hand side of (2).

Extensibility example, the right hand side of (2) is a nice number indeed and for sufficiently large value of n, that is large number of people involved in a communication then the theoretical upper bound of extensibility can be approximated by eⁿ!. Where e is the natural logarithm symbol and the exclamation mark still represents the factorial symbol not as an exclamation. Note: the summation series starts at zero. The first few values for EUB are, for n=3 EUB=6, n=4 EUB=48, and n=5 EUB=300. (All calculations were done by direct substitution). It is evidence that the series grows exponentially, for example when n=6 EUB=1920 (four digits, by direct substitution), and when n=9 EUB ~ 1million (seven digits by approximation). In other words, adding three persons in a

communication, the complexity was magnified in three orders of magnitude! Note: this last exclamation mark is an actual exclamation not factorial.

The beauty of this approximation i.e. $n!$ is that it can be used as a rule of thumb to decide if an extra person should be added or not into a meeting. It can be seen (using spread sheet to tabulate a series of value on $n!$ or $n!$) that the theoretical complexity of adding one extra person into a meeting or communication of four people will increase the complexity of roughly ten times, and adding three would be a thousand times more complex.

4 Conclusion

In the last five decades of solving software crisis new theory, best practice and methodology crops up one after another; look as if they are to be added to the derisive database for other engineering fields. The unweaving of software crisis disparages software professionals indeed like the boulder debases Sisyphus. Ariadne's thread---communication--- as this paper suggested could lead to the way out of software crisis. Communication has been long investigated by the social scientists and philosophers though it was noted in software construction some fifty years back such as Conway and Brooks law have clearly elicited the overload of communication and hence pointing to the direction needed to be addressed but since then little has been done quantitatively to investigate its nature and complexity instead its peripherals are aplenty.

The definition of communication in the past needs adjustment to suit the Net generation [45] (Tapscott 09 Grown up Digital: 1997) as well as to software construction teams otherwise *knowledge* as well as generation gaps appear. Communication complexity has been first examined qualitatively, in which the dissected levels of complexity was sketched in fig. 1. Levels of Communication Complexity. The levels and dissecting do not end there as shown, for example more detail analyse could be done in another paper with at least one level, say supranet, on top of Internet and one level at the bottom, say contracomm, underneath of infracomm. The quantitative nature of the communication was derived mathematically by creating three new concepts: reflectivity, responsivity, and extensibility. Theirs complexity can be treated hierarchically in that reflectivity is the simplest of the three with complexity of $O(n^2)$, responsivity is next on the hierarchy with complexity of $O(2^n)$, and extensibility is the most

complex type of communication with complexity of $O(n!)$.

One caveat needs to be emphasized and it is from George Santayana: "*Those who cannot remember the past are condemned to repeat it*", although one might laugh at its simplicity at first sight, in reality it occurring quite often as Cliff Mitchell's [8] of Manchester Business School, UK investigation said it:

Just recently (March 2009) the NAO published a report into a failed project: The National Offender Management Information System (C-NOMIS). The project (C-NOMIS) was massively over budget and schedule and, when analyzed by the NAO, they found that "...C-NOMIS suffered from four of the eight common causes of project failure in full and three in part."

Now, we can debate the list of eight common causes of project failure but that's not the point – the point is that this is a perfect example of a project failing for reasons that were well know, understood, and indeed were checked with the project team at the start of the project: "In May 2005, as part of the project approval process, the Home Office's Programme and Project Management Support Unit certified C-NOMIS as not suffering from the common causes of failure."

So why did the project still make seven out of eight of the same, documented mistakes?

In a word: communication.

And finally, in Weinberg [46] parlance:

This *work* has only one major purpose—to trigger the beginning of a new field of study: *software construction* as a human activity, or, in short, *communication in software construction*. All other goals are subservient to that one.

...At the moment, *software*—sophisticated as it may be from an engineering or mathematical point of view—is so crude *in communication* that even the tiniest insights should help immeasurably.

References:

- [1] LipEng Yong, SiewFan Wong. Software Project: A Three-Legged Race. *Symposium on Progress in Information and Communication Technology. SPICT09*, Royal Bintang Hotel, Kuala Lumpur, Malaysia. Pp102-104. 2009.

- [2] Moore Gordon E. Cramming more components onto integrated circuits. *Electronics*, Volume 38, Number 8, April 19, 1965.
- [3] Watts S. Humphrey. *TSPsm: Coaching Development Teams*. Addison Wesley. 2006.
- [4] Naur P. and B. Randell, (Eds.). *Software Engineering: Report of a conference sponsored by the NATO Science Committee, Garmisch, Germany, 7-11 Oct. 1968*.
- [5] Randell B. and J.N. Buxton, (Eds.). *Software Engineering Techniques: Report of a conference sponsored by the NATO Science Committee, Rome, Italy, 27-31 Oct. 1969*.
- [6] Bailey Alice A. *The Labors of Hercules*. Lucis Publishing Company. 1974.
- [7] Brooks F., P. Jr. *The Mythical Man-Month*. Twentieth Anniversary Edition with Four New Chapters. Addison Wesley. 1995.
- [8] Cliff Mitchell. Why don't we learn from our project failures? *Transforming Management, Manchester Business School*. 16 Aug, 2011. http://tm.mbs.ac.uk/DesktopModules/FlashPublish/ArticleDetail/ArticleDetailPrint.aspx?ArticleID=72&Template=Standard_Print.ascx&siteID=0
- [9] OGC and NAO. Common Causes of Project Failure 2005. *Office of Government Commerce*. 2005. Downloadable from: <http://www.swan.ac.uk/media/cp0015.pdf>
- [10] The Standish Group International Inc. Chaos. Technical report, *The Standish Group International Inc*. 1994.
- [11] France Hayes, Chaos is back, *Computer World*. 08 November 2004. Downloadable from http://www.computerworld.com/s/article/97283/Chaos_Is_Back
- [12] Martin Fowler and Jim Highsmith. The Agile Manifesto. *Software Development Magazine*. 2001.
- [13] Ward Cunningham. Independent Signatories of The Manifesto for Agile Software Development. *Agile Manifesto Organization*. 2006. Downloadable from: <http://agilemanifesto.org/sign/display.cgi?ms=00000061>
- [14] Ivar Jacobson and Bertrand Meyer. Methods Need Theory: Is It Time for Software Development methodology to Undergo a Transformation? *Dr. Dobb's Journal*. August 06, 2009
- [15] Ivar Jacobson and Ian Spence. Why We Need a Theory for Software Engineering: Our Greatest Challenge to Understanding How to Build Great Software. *Dr. Dobb's Journal*. October 02, 2009.
- [16] Ivar Jacobson, Bertrand Meyer, and Richard Soley. *Software Engineering method and Theory – A Vision Statement*. *Semat Organization*. 2010
- [17] Douglas Carl. Engelbart. The NLS/Augment system. *Stanford Research Institute* (1964-1975). Engelbart's series of papers can be downloaded from <http://dougengelbart.org/>
- [18] Greif, Irene. *Computer-Supported Cooperative Work: A Book of Readings*. Morgan Kaufmann, San Mateo, CA, 1988.
- [19] Chi-yue Chiu, Robert M. Krauss, Ivy Y-M. Lau, Some Cognitive Consequences Of Communication. *Social and cognitive approaches to interpersonal communication* (pp. 259-278). Hillsdale, NJ: Erlbaum. 1998.
- [20] Conway, Melvin E. How do Committees Invent? *Datamation* **14** (5): 28-31, 1968.
- [21] Vinton G. Cerf and Robert E. Kahn. A Protocol for Packet Network Intercommunication. *IEEE Transaction on Communications*, Vol. Com-22, No 5 May 1974.
- [22] Weinberger, David, and Doc Searls. What the Internet Is and How to Stop Mistaking It for Something Else. *World of Ends*. 10 Mar. 2003. Downloadable from <http://worldofends.com/> Accessed on 24 Jan. 2012
- [23] Don Tapscott and Antohony D. Williams. *Wikinomics: How Mass Collaboration Changes Everything*. Portfolio. 2006
- [24] Don Tapscott and Antohony D. Williams. *Macrowikinomics: Rebooting Business and the world*. Atlantic Books, London. 2010.
- [25] Raymond, Eric S. *The Cathedral and the Bazaar: Musings on Linux and Open Source by an Accidental Revolutionary*. O'Reilly Media. 1999.
- [26] Pekka Himanen, Manuel Castells, Linus Torvalds. *HACKER. Ethic and the Spirit of the Information Age*. Random House. 2001.
- [27] Jeff Howe. *Crowdsourcing: Why the Power of the Crowd Driving the Future of Business*. Crown Business. 2009.
- [28] Microhoo. Yang to Step Down as Yahoo CEO: Co-Founder's Rebuff of Microsoft Haunted Tenure; Will Stay Until Successor Is Found. *The Wall Street Journal: Technology*. Tuesday, November 18, 2008. Downloadable from <http://online.wsj.com/article/SB122697024336935679.html>
- [29] Steven L. Telleen. IntraNet Methodology. *Internet Planning and Management*. *Adaml Corportion*. 1995. Downloadable from <http://www.iorg.com/papers/amdahl/concepts1.html>. Accessed on 18 Jan 2012.

- [30] Steven L. Telleen. The Difference Between Internet, Intranet, and Extranet. *Intranet World*. Oct, 1998.
- [31] Robert Metcalfe. The Internet After The Fad. In Monticello Memoirs. *The Computerworld Smithsonian Program*. 1997.
- [32] Metcalfe, Bob, "Private Information Highways will Avoid all Congestion on the 'Net,'" *InfoWorld* Vol. 18, October 21, 1996.
- [33] Simha R. Magal and Jeffrey Word. *Integrated Business Processes with ERP Systems: Written With The Support of SAP[®]*. John Wiley International. 2012.
- [34] Watts S. Humphrey. Characterizing the Software Process A Maturity Framework. Technical Report. CMU/SEI-87-TR-11, ESD-TR-87-112. *Software Engineering Institute*. June 1987.
- [35] Tom Schorsch. Capability Im-Maturity Model, *Crosstalk*. 1996.
- [36] Watts S. Humphrey. *TSPSM: Leading a Development Team*. SEI Series in Software Engineering. Addison Wesley. 2006.
- [37] Watts S. Humphrey. *A Discipline For Software Engineering: The Complete PSPSM Book*. SEI Series in Software Engineering. Addison Wesley. 1995.
- [38] Claude E. Shannon. A Mathematical theory of communication. *Bell System Technical Journal*, vol. 27, pp. 379-423, 623-656, July, October, 1948.
- [39] Robert T. Craig. Communication Theory as a Field. *International Communication Association*. 9(2), 119-161. May 1999.
- [40] Shannon C. & Weaver, W. *The Mathematical theory of communication*. Urbana: University of Illinois Press. 1949.
- [41] Lam Lay-Yong. "On the existing fragments of Yang Hui's Hsiang Chieh Suan Fa" *AHES*, Volume 6, Number 1, 82-88, 1969. DOI: 10.1007/BF00327264.
- [42] Jean-Claude Martzloff, J. Gernet, J. Dhombres, S. Wilson *A history of chinese mathematics*. Springer, Berlin, ISBN-13 978-3540547495. 1996.
- [43] Terrel Trotter, Jr. "Some Identities for the Triangular Numbers". *Journal of Recreational Mathematics*. 6(2), Spring, pp. 127-135. 1973.
- [44] Hayes, Brian. Gauss's Day of Reckoning. *American Scientist*. Volume 94. Number 3. pp 200-205. May-June 2006.
- [45] Don Tapscott. *Grown Up Digital: How the Net Generation is Changing Your World*. The McGraw-Hill Companies, Inc. 2009.
- [46] Gerald M. Weinberg. *The Psychology of Computer Programming*. Computer Science Series. Van Nostrand Reinhold Company. 1971.