QUANTIFICATION OF SELF-ORGANISED SYSTEM AT REAL TIME

*A Method based on the observation of attributes and divergence

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***Abstract*—A distributed system with a large number of autonomous agents exchanges their local information. As an outcome, they establish a pattern and maintain self-organized system this is known as self-organisation. This paper is discussing the principle and attributes of self-organisation that helps to measure the self-organized system i.e. emergence and complexity. Some pre-requisite is found in a set of multiple homogeneous individuals with decentralized authority that control the overall processes and facilitate individual interaction with each other. Individuals are self-motivated and self-organized. Literature explained some indifferent approaches that help to measure runtime processes of a system and considers agents as black boxes. To aid this understanding, technical system is a concept that is used on the base of the matrix that can observe the behavior of system externally with some defined limitations and benefits.**

***Index Terms*—Self-organisation, measuring, quantification, organic computing**

I. Motivation

In 1991 Mac Weiser has given the concept of "ubiquitous computing". According to him a device with a built-in microprocessor and controller functionally communicates with other entities i.e. refrigerator, washing machine via a protocol or medium will work intelligently to help humans. These systems are self-organized and perform tasks independently.

These concepts have the ability to work independently to self-organize. A centralized system depends on decision which can be taken by humans which increase the complexity of the system. Different researchers have worked on different terms including Proactive (Tennenhouse,2000), Autonomic (Kephart and Chess, 2003), Organic Computing (Tomforde et al., 2011) and Complex Adaptive Systems (Kernbach et al., 2011) in their time. [1]–[4], [11]

The idea is to observe the nature that how it works i.e. flocking birds, school of fish. How they organized with different structures? What are the parameters they use to organized the structure? This system will remain decentralized and achieve goals like higher robustness, higher efficiency etc. Self-organized systems benefit humans such as task has been divided by multiple individuals, each system has the ability to take decisions, each autonomous agent has strong command on its attributes.

II. Prerequisite

The basic idea of self-organisation is to arrange structure at runtime where agents communicate with each other and take distributive decision to rearrange themselves via exchanging information of attributes.

III. Problem statement

If the system is fully self-organized, it becomes prone to errors because the systems should be stochastic that has some random probability distribution or patterns that can be analyzed statistically but not be predicted precisely. In this context, non- linearity should be reduced to get predictable results. Also, there is an example of urban road traffic control system (tomforde et al., 2010) where agents are interacting with each other to make the flow better. To explain briefly, emergence is the phenomena that can occur by resulting behaviors of subsystems. Emergence can be positive or negative. It can either harm the system or get benefit from the systems by its property The agents get the response through communication and build the structure. The system has the certain degree of self-organisation. [5]

IV. Related Work

The approach of self-organisation can be found in nature, technical and non-technical which can be observed such as, ant colonies in 2010(Dorigo and birattri). In 2013 (Polani) and 2001 (Shalizi), a scientist also gave the definition of self-organisation but that was almost mixture with emergence. Another, attempt can be found in OC by Muehl et. Al. in 2007 which describe the self-organisation in technical system. It describes self-managing, structure adaptive and decentralized control. The self-managing system is organized by itself without any external control. Insisting on a complete absence of external control is not desirable since user influence is part of the overall concept, see e.g. (Tomforde et al., 2011). [7]–[11]

Literature gives abundant approaches to make the assessment for self-organisation. Initially, Shalizi (2003 to 2004) was a pioneer to introduce a mathematical model to rate the information and define the process of self-organized system by forecasting the information. The system's internal complexity is directly proportional to self-organiation. Every system has different attributes, for instance, location and sensor. [12]

On the basis of statistical entropy the degree of self-organisation introduce by Heylighen . (Heylighen, 1999; Heylighen and Joslyn, 2001). Furthermore, the term controlled self-organisation introduced by Schmecket al., 2010). It defines the maximum limits with no external influence and internal system. The internal system consists of control mechanism (CM) and elements (M). All these concepts facilitate to compute the self-organisation in the technical system. [13]–[15]

V. Main Approach

The self- organized system consists of a large number of autonomous agents $a_i \in$ A. Every agent a_i has the control mechanism that takes information by sensors and performs the action through the actuator. Control mechanism has goals to make the system productive. Figure 1 explains there are two parts of autonomous agent Control mechanism and productive system. The productive system is influenced by the internal control mechanism. A user provides a goal that defines good and bad behavior. Although, CM sends the command instruction, the system has been designed by its own requirement. All agents work independently and regulated by different users and attributes. They have a different design and random abstract. It makes it more complex to decide what strategy and tactics to follow the control mechanism. That is the reason for the complexity to find how and what strategy is followed by the control mechanism. We can observe the behavior and communication in between sender and receiver.

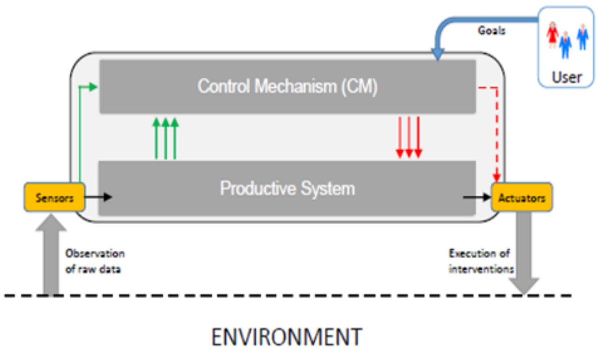

Fig. 1.

For example, there are three agents A1, A2, and A3. A1 and A2 make a connection and share their information according to their attributes then A2 wants to exchange their information with A3. Then A2 request to A3 for connection then exchange their information by sending and receiving. These connections are dynamic. This example can relate to Internet Protocol(IP) communication model. Initially, it generates source message and then it is received by its destination but with the assumption that no attacker will change the data and system shouldnt be open.

VI. Self-organisation

Self-organisation takes place to change the structure of system because of an internal control mechanism. This is a multi-element system which consists of m element (m > 1) with an internal control mechanism (CM). The control mechanism(CM) of a self-organized system has some degree of distribution over m elements. There are three types of control mechanism centralized, distributed over m element and distributed over a hierarchy. The self-organisation can be quantified with a static and dynamic degree.

Let S be an adaptive system consisting of m element $m \geq 1$ with a large degree of autonomy and distributed control mechanism CM $k \geq 1$ to determine the degree of self-organisation. The system can be strongly self-organized if K=m and the degree of self-organisation is (m:m) if $k > 1$ and it has a medium degree of self-organisation (k:m). The system S is called weakly self-organized, if k=1 and this is a centralized control mechanism with the degree (1:m). There are three types of graph G1, G2, and G3. G1 have all communication path with all reachable vertices. G2 contains observable communication between all the nodes and G3 represent mutually stable relationships between agents. [11]

$$(G_R, G_Y) := \frac{|e_{i,j} : e_{i,j} \in E_1 \oplus e_{i,j} \in E_2|}{0.5 * (|V_1| + |V_2|)} \qquad (1)$$

Gy could be G2 or G3. E1 shows the edges from G1 and E2 represent the edges from Gy. Furthermore, V1 and V2 are the vertices of the graph. The concept was implemented (Rudolph et al., 2016) by using the smart cameras. The organisation can be observed by developing the matrix. Also, to measure the graph we need to relate with each graph state. [16] . There are three states namely "Initial", "during the disturbance" and recovery. But it has some limitations there is no full knowledge in the communication model i.e. observer dont know the message sent by the agent will cause to rearrangement or not. Also, the agent will not send same information every time. The model shares minimum information. Suppose distributed agents have the stable relationship through the system than it builds a graph and then system define observed communication. To elaborate in technically, let us think outside the black box the required knowledge and semantic is not available. Every distributed agent broadcast its information. Lastly, communication should be continuing. these are the drawback which could affect the system.

A. Analysis of self-organisation

We need to overcome the previous limitations. The communication helps us to get better results by updating and establishing. Simply, measuring self-organisation from technical systems S, we should observe the communication behavior of autonomous agents ai. Every agent performs normal communication behavior. For instance, by using same communication context. The same pattern will follow in all cases. we represent each subsystem ai as a process that generates observable samples (i.e. messages). When measuring self-organisation (e.g. by means of sensors monitoring the communication channels), we have to use communication-specific pre-processing techniques to extract the values of attributes (features) from those samples (observations). Each agent ai is a subsystem that originates the sample (message). By measuring the self-organisation, the sensor that monitors the communication channel use specific attributes values that use by samples. These attributes are the features which can get by observation. These attributes define the recent state of the observed system. To send the message through communication channel we need four basic information that can be add in the header of the message. Its starting point where the message originates, a destination where the message would be delivered, size of packet and time stamp of that packet. Also, we can model the attribute space(z) that is one dimensional with the categorical and continuous attribute. Ever message is observed in a time period of our model. All the observation should be real time that is the requirement and the systems should be self-organized. If the system is not self-organized either no need to measure the communication. All the agents start communicating with other agents. The first agent stops their communication with a current agent then start it with another agent. Some other messages have been passing to the agents but do not cause to change the structure. Disturbance(message) can change the internal or external structure. Self-organisation can be observed by samples but it is unexpected change (behavior). Furthermore, a divergence can quantify by comparing two density functions. Let p(x) and q(x) are two density function p(x) is previous point in time and q(x) is a current observation cycle. A divergence measure by Kullback-Leibler (KL) divergence KL(p ∥ q), see (Bishop, 2011). It defines continuous variable. [17]

$$KL(p||q) = -\int p(x) ln \frac{q(x)}{p(x)} dx \qquad (2)$$

KL is representing as relative entropy but also there is a discrete version that is done by (Shannon,2001) [18]. Also KL has not been applicable in symmetric. By measuring symmetric we can use.

$$KL_2(p,q) = \frac{1}{2}(KL(p||q) + KL(q||p)) \qquad (3)$$

KL has limitation such as if both the densities are equal to each other (p (x)= q(x)) then KL(p ∥ q) is zero. While kL greater than and equal to zero. To get the desired results we need to change the equation 2. KL divergence is not a true metric since it is not symmetric.

$$KL(p||q) = -\int p(x) lnq(x) dx + -\int p(x) lnp(x) dx \qquad (4)$$

Equation 4 represents the desired amount of information that has both the new distribution and reference distribution of sample set. Although, there is a symmetric concept merge equation 3 we get equation 4 is:

$$KL_2(p,q) = \frac{1}{2}(-\int p(x) lnp(x) dx - \int p(x) lnq(x) dx + \int q(x) lnq(x) dx - \int q(x) lnp(x) dx) \qquad (5)$$

Equation 5 represents the measuring of self-organisation processes which uses basic idea to compare the distribution. It's also known relative entropy. Suppose we have self-organize system with autonomous agents. Each agent input to rearrange the pattern. The greater the divergence from previous distribution the more the system is self-organize. The hierarchical element in the self-organized system will decrease the degree of self-organisation. If the system has centralized structure, there would be no self-organisation take place.

The most important advantages of this approach are as follows: 1) Compared to, e.g., (Schmeck et al.,2010) it does not require internal information (such as the number of CM). 2) As an alternative to, e.g., (Muehl et al., 2007) it is continuously quantifiable. 3) In comparison to, e.g., (Gershenson and Fernandez,2012) it is independent of emergence and what is understood to be emergent behaviour. 4) In contrast to, e.g., (Kantert et al., 2015) it is applied continuously and not just for disturbed periods. 5) In contrast to most of the concepts, a general model of how the system works is not necessaryit is applicable with low effort. 6) In contrast to, e.g., (Shalizi et al., 2004) it takes only attributes that are relevant for the structure of technical systems into account. Finally, it can easily incorporate system boundaries by specifying communication addresses. [10], [19], [20], [20]–[22] [23]

The process has two probabilities a current distribution and a referential distribution. Assume there are number of processes generated samples occur probability distribution. We need to define sample time period which is equal. Time period assigns to current observation as for a reference period. The sliding window approach used for this process. To observe the sample, t is the fixed time period for current process between t0 and t1. The equal time duration used for reference observation.

The same duration is used for a reference observation (i.e. the time period directly before the current observations are done: between t1 and t2). Alternatively, the reference window might be fixed (i.e. static), e.g. at the begin of the observation (here, slow changes can be detected easier, but oscillating behavior may be harder to detect). Figure 2 illustrates both approaches. However, it may be beneficial to use a hybrid approach that combines both concepts: estimating the change compared to the previous period and against a static distribution to be able to cover all aspects. [23]

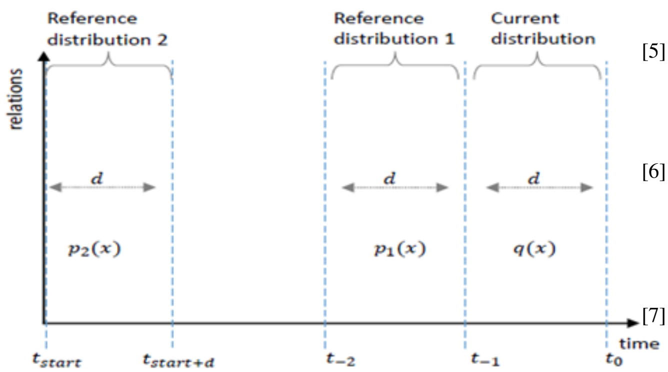

Fig. 2.

Figure 2: There are two approaches, sliding window and static window.

These approaches are depending on the underlying application, for instance, the size of the window should be greater to calculate probability distribution and might be small to observe in time variant. While there is not a proper solution that how we can configure the window size.

VII. Conclusion

We introduced the concept of self-organisation which is inspired by the nature. The system has many prerequisites to quantify the self-organisation i.e. decentralization, homogeneous individuals etc. To measure self-organisation, the paper describes many problems and solutions provided by different researchers respectively. In technical systems, we observe the system externally and try to find out how the information is shared among the different individual agents of the system by comparing the information from previous activities. The information(messages) is shared by autonomous agents using some sort of communication model. The messages are sent within a fixed time by using probabilistic models. These distributions help to identify the degree of self-organisation. The higher the probability distribution the higher the self-organisation. We believe that Kullback-Leibler(KL) divergence calculates dissimilar probability distribution. There are different divergence measures in the paper and we need to identify which performs best among all. The idea is based on observation of communication. If there is an external interruption and systems is influenced by it, the possibility of system being self-organised is less.

References

[1] Tennenhouse, D. (2000). Proactive Computing. Communications of the ACM, 43(5):4350.

[2] Kephart, J. and Chess, D. (2003). The Vision of Autonomic Computing. IEEE Computer, 36(1):4150.

[3] Prothmann, H., Tomforde, S., Branke, J., Hahner, J., Muller-Schloer, C., and Schmeck, H. (2011). Organic Traffic Control. In Organic Computing A Paradigm Shift for Complex Systems, Autonomic Systems, pages 431 446. Birkhauser Verlag, Basel, CH.

[4] Kernbach, S., Schmickl, T., and Timmis, J. (2011). Collective adaptive systems: Challenges beyond evolvability. ACM Computing Research Repository (CoRR). last access: 07/14/2014.

[5] Tomforde, S., Prothmann, H., Branke, J., Hahner, J., Muller-Schloer, C., and Schmeck, H. (2010). Possibilities and Limitations of Decentralised Traffic Control Systems. In 2010 IEEE World Congress on Computational Intelligence (IEEE WCCI 2010), held 18 Jul - 23 Jul 2010 in Narcelona, Spain, pages 32983306. IEEE.

[6] Tomforde, S., Prothmann, H., Rochner, F., Branke, J., Hahner, J., Muller-Schloer, C., and Schmeck, H. (2008). Decentralised Progressive Signal Systems for Organic Traffic Control. In Brueckner, S., Robertson, P., and Bellur, U., editors, Proceedings of the 2nd IEEE International Conference on Self-Adaption and Self-Organization (SASO08), held in Venice, Italy (October 20 - 24, 2008), pages 413422. IEEE.

[7] Dorigo, M. and Birattari, M. (2010). Ant Colony Optimization. In Sammut, C. andWebb, G., editors, Encyclopedia of Machine Learning, pages 3639. Springer US.

[8] Polani, D. (2013). Foundations and Formalisations of Self- Organisation. In Prokopenko, M., editor, Advances in Applied Self-Organizing Systems, chapter 2, pages 23 43. Springer Verlag.

[9] Shalizi, C. R. (2001). Causal Architecture, Complexity and Self-organization in Time Series and Cellular Automata. PhD thesis, The University of Wisconsin - Madison.

[10] Muehl, G., Werner, M., Jaeger, M., Herrmann, K., and Parzyjegla, H. (2007). On the Definitions of Self- Managing and Self-Organizing Systems. In Communication in Distributed Systems (KiVS), 2007 ITG-GI Conference, Kommunikation in Verteilten Systemen, 26. Februar - 2. Marz 2007 in Bern, Schweiz, pages 111.

[11] Tomforde, S., Prothmann, H., Branke, J., Hahner, J., Mnif, M., Muller-Schloer, C., Richter, U., and Schmeck, H. (2011). Observation and Control of Organic Systems. In Muller-Schloer, C., Schmeck, H., and Ungerer, T., editors, Organic Computing - A Paradigm Shift for Complex Systems, Autonomic Systems, pages 325 338. Birkhauser Verlag.

[12] Shalizi, C. R. and Shalizi, K. L. (2003). Quantifying Self-Organization in Cyclic Cellular Automata. In Schimansky-Geier, L., Abbott, D., Neiman, A., and den Broeck, C. V., editors, Noise in Complex Systems and Stochastic Dynamics, Proceedings of SPIE, volume 5114, pages 108 117. Bellingham,Washington.

[13] Heylighen, F. (1999). The Science Of Self-Organization And Adaptivity. In Knowledge Management, Organizational Intelligence and Learning, and Complexity, in: The Encyclopedia of Life Support Systems, EOLSS, pages 253280. Publishers Co. Ltd.

[14] Schmeck, H., Muller-Schloer, C., C akar, E., Mnif, M., and Richter, U. (2010). Adaptivity and Self-organisation in Organic Computing Systems. ACM Transactions on Autonomous and Adaptive Systems (TAAS), 5(3):132.

[15] Heylighen, F. and Joslyn, C. (2001). Cybernetics and Second-Order Cybernetics. In Meyers, R. A., editor, Encyclopedia of Physical Science and Technology. Acadmeic Press, New York, US, 3rd edition.

[16] Rudolph, S., Kantert, J., Janen, U., Tomforde, S., Hahner, J., and Muller-Schloer, C. (2016). Measuring Self- Organisation Processes in Smart Camera Networks. In Varbanescu, A. L., editor, Proceedings of the 29th International Conference on Architecture of Computing Systems (ARCS 2016), chapter 14, pages 16. VDE Verlag GmbH, Berlin, Offenbach, DE, Nuremberg, Germany.

[17] Bishop, C. M. (2011). Pattern Recognition and Machine Learning. Information Science and Statistics. Springer, 2nd edition. ISBN 978-0387310732.

[18] Shannon, C. E. (2001). A Mathematical Theory of Communication. ACM SIGMOBILE Mobile Computing and Communications Review, 5(1):355.

[19] Schmeck, H., Muller-Schloer, C., C akar, E., Mnif, M., and Richter, U. (2010). Adaptivity and Self-organisation in Organic Computing Systems. ACM Transactions on Autonomous and Adaptive Systems (TAAS), 5(3):132.

[20] Gershenson, C. and Fernandez, N. (2012). Complexity and Information: Measuring Emergence, Selforganization, and Homeostasis at Multiple Scales. Complexity, 18(2):2944.

[21] Kantert, J., Tomforde, S., and Muller-Schloer, C. (2015). Measuring Self-Organisation in Distributed Systems by External Observation. In

Proceedings of the 28th GI/ITG International Conference on Architecture of Computing Systems ARCS Workshops, pages 1 8. VDE. ISBN 978-3-8007-3657-7.

[22] Shalizi, C., Shalizi, K., and Haslinger, R. (2004). Quantifying Self-Organization with Optimal Predictors. Phys. Rev. Lett., 93:118701.

[23] Measuring Self-organisation at Runtime A Quantification Method based on Divergence Measures Sven Tomforde1, Jan Kantert2 and Bernhard Sick1 DBLP:journals/corr/abs-1205-2026