Transferability of Self-Healing Principles to the Recovery of Supply Network Disruptions – The Case of Renesas Electronics

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Abstract

The topic of supply network disruption recovery has started to receive great attention within the academic as well as the business world. This is due to increasingly complex supply networks and the rise of natural and man-made disasters in quantity and severity. In this paper, the topic is approached in an interdisciplinary bio-inspired way. The transferability of biological self-healing principles to the recovery of supply network disruptions is analysed and first propositions are derived. A single case study of the Japanese microcontroller company Renesas Electronics is analysed with regard to the developed propositions. A strategically important plant of Renesas was severely damaged by the triple disaster in Japan in 2011 which led to a disruption of the company’s supply network. Five out of six propositions regarding the transferability of biological self-healing are, at least partly, proven. Furthermore, the importance of close collaboration within a network of suppliers, customers and competitors is emphasized. The results make further research in this academically still underdeveloped field promising, especially with regard to implications and strategies for supply chain risk managers.

1. Introduction

Currently there are two parallel developments in the field of supply network disruptions, which start to receive great attention in the international business world and in academia. Supply network disruptions are defined as “unplanned and unanticipated events that disrupt the normal flow of goods and materials within a supply chain” [1].

The first development refers to current business trends in the area of supply chain management that increase the vulnerability of supply networks [2]. Prominent examples are increases in product variety, lean management, contract manufacturing, reduction of supplier base, global sourcing and just-in-time deliveries [2,3,4]. These cause highly globalized and complex supply networks which, in turn, lead to a high number of risk exposure points, decreased flexibility, and reduced time and material buffers [3].

The second development is related to the rise in quantity and severity of natural as well as man-made disasters, which is indicated by a number of independent studies [4]. Supply network disruptions and their ensuing operational and financial risks are considered to be the single most pressing concern for top executives. This was revealed by a survey of the 1,000 largest European and North American companies in terms of market value [5].

There are numerous possible causes of supply network disruptions, such as socio-political factors, natural catastrophes or terrorism. However, recent academic literature points out that, regardless of the cause of disruption, the immediate and long-term financial consequences for an individual company are severe [3,6]. Immediate consequences include increases in cost and decreases in profitability and net sales [3] whereas long-term consequences refer to negative stock market reactions, decreases in customer service level, or a damaged brand image [1,3,4,7].
There are several parallels between the biological self-healing of human skin wounds and the supply network’s recovery of disruptions. For instance, one might draw a link between the structure of supply networks and cell networks, i.e. the skin. The parallels lead to the assumption that learning from nature (i.e. from biological self-healing) can be helpful in improving the recovery of supply network disruptions, both in terms of time-to-recovery and costs. As a prerequisite, it is necessary to prove if the concept of biological self-healing can actually be transferred to the recovery of supply network disruptions. The objective is to make statements about this transferability in order to assess if further research in this field is sensible. The analysis of this transferability, with principles derived from biological self-healing as basis of analysis, is therefore the key contribution of this paper to the research field of self-healing supply networks.

The next section describes the theoretical background, followed by the methodology section. Parallels between the biological self-healing and the recovery of supply network disruptions are described and characteristics of self-healing networks are presented (section four). In section five, several underlying principles of biological self-healing are identified. These form the basis for the development of five propositions. The case of Renesas Electronics Corporation (“Renesas”) is described, analysed and evaluated in section six according to the developed propositions. Section seven contains a conclusion, limitations of the research as well as suggestions for further research.

2. Theoretical Background

The topic supply network disruption is mainly affiliated to supply chain risk management and supply chain resilience literature. Within this academic literature, there is a differentiation between preventive and reactive strategies when dealing with disruptions [7]. Preventive strategies have the goal to protect companies and supply networks from disruptions by taking advance actions to minimize the occurrence of disruptions. For instance, Kleindorfer and Saad [8] provide a conceptual framework including risk assessment and risk mitigation activities. Knemeyer et al. [9] deal with proactive planning for catastrophic events and Norrman and Jansson [2] analyse the proactive supply chain risk management of the company Ericsson. Reactive strategies, on the other hand, deal with actions after a disruption occurred, thus during the recovery. The focus is to limit the severity of disruptions regarding time-to-recovery and required costs [6]. Bello and Bocell [3], for instance, highlight socio factors of supply partners that are relevant to jointly recover from disruptions. Reactive strategies are closely related to the concept of resilience which generally refers to “the capability and ability of an element to return to a stable state after a disruption” [10]. As supply networks become increasingly complex and risky, companies are less likely to completely eliminate disruptions from occurring [1]. Although reactive strategies are therefore crucial, they receive less attention in literature compared to preventive strategies [11].

Although several approaches in the field of reactive strategies exist, collaborative efforts of involved actors are not emphasized enough. Most academic literature focuses on effort and capabilities of individual companies. Collaboration is also required for successful and efficient healing of skin wounds [12]. Organisms are able to heal wounds not because of the robustness of individual cells. It is because of the interactions between large numbers of cells [13]. Therefore, it is sensible to take an interdisciplinary approach to compare biological self-healing with the recovery of supply network disruptions, an approach which does not yet exist.

Currently, interdisciplinary bio-inspired approaches are promising especially in the field of technical and engineering solutions. Generally, there is the expectation that transferring concepts from nature to areas such as engineering or business can have advantages. This is because natural concepts are challenged within their environments and, in this way, being constantly optimized for their respective setting [14]. Thus, they are validated trough evolution [13]. In the field of logistics and supply chain management, only few bio-inspired approaches exist. Gleich et al. [15] state that one would have expected more effort in this direction, especially with regard to the increasing complexity in this topic.

The concept of biological self-healing can be found in bio-inspired literature mainly with regard to technological topics, e.g. self-healing materials [16]. However, it has not been addressed much in supply chain management literature. Cordes and Hülsmann do not elaborate on the biological process, but they refer to self-healing of supply networks as ‘the process of autonomous recovery after the supply network faces a targeted attack or random damage’ [17].

In the field of computer science, the concept of self-healing is transferred to software-based systems [13,18,19]. The motivation to apply principles of living systems to computer science is the fact that biological systems exhibit remarkable adaptation and robustness when confronted with widely changing environments. In addition, Ghosh et al. [18] stress that the self-healing procedure of bringing back a system to normalcy will decrease maintenance time of software-based systems and thus saving money. George et al. [13] emphasize that the capacity of organisms to adapt to changing environments and to heal organs is due to the interaction between cells. Transferring this capacity to software may lead to systems that operate adequately even in the face of disruptions, i.e. catastrophic failures and large scale software attacks [13].

3. Methodology

As described above, there is only little academic literature about the collaborative efforts during the recovery of a supply network disruption. Especially, an interdisciplinary approach of combining biological self-healing with the recovery of supply network disruptions does not yet exist. In this respect, case study research is especially appropriate for underdeveloped topics and in the early stages of research on a topic [20]. Consequently, this qualitative exploratory research approach was chosen to generate further insights in this topic.

As such, this empirical inquiry of a case study ‘investigates a contemporary phenomenon in depth and within its real-world-context’ [21]. Yin [22] illustrates that in order to verify
a case’s fit into the theoretical research topic, the case subject has to meet a number of selection criteria. In this research, the criteria include that the case subject has been affected by a disruption, the existence of a supply network and a successful recovery. With regard to the design of the case study, a holistic single-case design with a single-unit of analysis is chosen for a more detailed analysis. The use of single case studies is sometimes criticized for having little or no generalizability. It should be noted that with single case studies analytical, not statistical, generalizations can be achieved when the proposed claim is represented soundly and can resist logical challenge [22]. An advantage of single case study research is the likelihood of generating novel theory when dealing with relatively underdeveloped topics [20].

Regarding the data collection, different kinds of sources have been consulted, analysed and triangulated to achieve a high consistency of findings. The sources included scientific journal papers as well as documents such as newspaper and magazine articles, mostly in Japanese to accommodate the setting of the case study.

With respect to characteristics and the process of biological self-healing, five underlying principles are derived from existing scientific research. Based on these, theoretical propositions are formulated. These are subsequently compared to the settings of the case subject and its network. Starting with theoretical propositions implies the drawback of limiting the ability to make discoveries apart from the propositions [22]. However, advantages of using a structured approach prevail. In order to conduct the data collection as well as the data analysis in a systematic manner, a case study protocol is derived from the developed propositions. This procedure increases the reliability of the research [21].

4. From Biological Self-Healing to Supply Network Healing

Self-healing, in its biological sense, is used in medical literature in reference to ‘self-repair’, ‘wound repair’ or ‘wound healing’. The human skin wound healing is referred to as self-healing because it is a process with no external help used or required, i.e. medical treatment [23]. This concept of wounds repairing themselves can be found in literature on computer science as well. Ghosh et al. [18] describe self-healing systems as being able to work without human intervention and to make adjustments to restore themselves to normalcy. Thus, all resources and capabilities needed to successfully heal are readily available within the network.

The biological self-healing discussed in this paper is limited to the wound healing of human skin for two reasons. Firstly, because this kind of wound healing is covered well in literature. Secondly, there are several parallels between wound healing and the recovery of supply network disruptions.

4.1. Parallels between Biological Self-Healing and Recovery of Supply Network Disruptions

First, one parallel refers to the actors (i.e. entities) of these two concepts. The entities involved in wound healing are cells that form the tissue. Similarly, a supply network consists of different connected entities [1]. These entities are comprised of resources belonging to individual companies that are available within a supply network. These can be different kinds of resources, such as physical, financial, human resources or knowledge.

Second, an injury of the human skin and an event that disrupts a supply network share the characteristic of being unpredictable [1].

Third, a skin wound is similar to an externally or internally disrupted part of a supply network. A wound is the result of an injury and is defined as ‘a disruption of normal anatomical structure and function’ [23]. Similar to disrupted parts of supply networks, skin wounds may originate from external or internal forces [23]. In case of supply networks, internal refers to all resources within the network.

Fourth, healing is described as a complex and dynamic process that results in a return to normal anatomic structure, function, and appearance [23]. The recovery of supply networks refers to the process of restoration to full functionality after a disruption [6]. Thus both have the goal of a complete restoration to original conditions. This goal is also stressed by the literature of self-healing software systems with a more general description: A self-healing system should recover from an unhealthy state and return to the healthy state, and function as it was prior to a disruption [18]. These parallels lead to the expectation that it can be fruitful to look closer at the process of biological self-healing in order to be able to analyse the transferability to the recovery of supply networks.

4.2. The Process of Biological Self-Healing

Wounds normally proceed through an orderly and timely reparative process. Orderliness refers to a predefined sequence of events. Timeliness is relative as it is determined by different factors, namely by the nature and the degree of the healing process, the status of the host, and the environment [23]. According to the classification described by Diegelmann and Evans [24], biological self-healing consists of four distinct, but overlapping phases, called hemostasis, inflammation, proliferation and remodeling. The phases can be divided into two categories, referred to as short-term action and long-term repair.

The short-term action, consisting of the hemostasis phase, describes a temporary mending which occurs immediately after an injury of the human skin occurred [24]. Within this phase, a clot plugs the wound [12]. The cells involved in the hemostasis send chemical signals which initiate the next phases [24].

The long-term repair includes the inflammation, proliferation and remodeling. The wound is cleaned out, a new collagen matrix is deposited and becomes cross-linked and organized [24]. Important within these phases is the cell migration and the cell division. A specialized cell has the ability to move into the wound [24] and the ability to divide itself into two separate cells [13]. Therefore, cells have the properties of localization, adaptation, adequate redundancy, and awareness towards the environment [13]. The complete restoration defines the end of the long-term repair.
What becomes evident is that the successful and efficient healing of a skin wound requires collaborative efforts of many actors involved [12]. George et al. [13] emphasize the importance of the interaction within the whole network of cells during the healing process. In the discourse of self-healing software systems, the related aspect of the maintenance of systems health is addressed [18]. In case of supply network disruptions, it is crucial that other parts of the network continue working. This further reinforces the importance of focusing not only on individual entities, but on the perspective of the whole network.

In order to limit the scope of the analysis, not all similarities between the concept of biological self-healing of skin wounds and recovery of supply network disruptions are taken into account. This research is focused on the resemblance of the surrounding conditions and prerequisites of the involved processes to initiate an analysis of transferability. The self-healing process is based on several principles which, in turn, lead to theoretical propositions.

5. Developing Propositions

To analyse the transferability of biological self-healing to supply network disruptions, five propositions are developed. The propositions and the underlying principles, derived from the concept of biological self-healing, are shown in Table 1.

Several kinds of cells move during the process of wound healing [24]. This implies the existence of a surplus of cells. There are enough cells available for the healing process of an unpredictable injury [13]. When transferring this to the recovery of supply networks, the proposition states that in a supply network, a surplus of resources exists.

P1: In a supply network, a surplus of resources exists.

The second principle relates to the actual movement of cells. The specific (surplus) cells are able to move to the areas in need [24]. Transferred to supply networks, the proposition is that resources have the ability to move within a supply network, for example between different companies.

P2: Within a supply network, resources have the ability to move.

The principle of adaptation refers to the capability of cells to perform different functions depending on changes in the environment [13]. This leads to the proposition that resources within a supply network can adapt in case of disruption and are able to take over tasks in disrupted parts of the supply network. For instance, employees are able to perform new tasks in order to temporarily substitute the actual workforce of a damaged plant.

P3: Within a supply network, resources can adapt (i.e. take over tasks of disrupted parts).

The next principle emphasizes the maintenance of the network’s health. While one specific area is recovering from an injury, it is important that other body functions continue working as usual [18]. Thus, the proposition states that if a part of a supply network is recovering from a disruption, other parts of the network, i.e. suppliers, customers, competitors and their respective resources, are left unaltered.

P4: If a part of a supply network is recovering from a disruption, other parts of the network are left unaltered.

Another crucial principle concerns the chronology of the self-healing process. There is the differentiation between the short-term action and the long-term repair. Therefore, it is proposed that during supply network recovery this distinction does exist as well.

P5: During a supply network recovery, there is a distinction between short-term action and long-term repair.

The case of Renesas is analyzed in the following section according to these five developed propositions.

6. The Renesas Case

The situation of the Japanese company Renesas was chosen as a case study as it strongly aligns with the selection criteria stipulated in the methodology chapter. First, Renesas’ supply network was directly affected by the March 11 triple disaster in Japan in 2011 when eight of its production plants in Northeast Japan were severely damaged. Second, as a worldwide leading supplier of semiconductor products to a number of industries [25], Renesas is closely linked to its customers, of which the top ten accounted for approximately 50 percent of the consolidated net sales [26]. Third, after the triple disaster Renesas was capable of completely recovering its operations and continue business until today. Despite the severe damages to its main plant, Renesas was able to recover its supply network and start test running its operations only one month after the disaster. This presents an unusually short time-to-recovery that warrants further investigation.

Renesas is a Japanese manufacturer of semiconductor products. The Tokyo headquartered company employs roughly 34,000 people worldwide with revenue of approximately 785 bn Japanese Yen in 2012 [26]. Among its main products are microcomputers, memories, large-scale integrated circuits and logic integrated circuits that are used in a number of industries. Renesas supplies between 20 to 40 percent of automotive microcontrollers worldwide [27,28,29,30,31]. These microcontrollers are a critical part of engine-control units, transmission controls, safety devices, navigation and communications within a car and are highly customized [27,32]. Both, the criticality of products as well as their dominant market share [25], make Renesas a key supplier for global automotive manufacturers [33]. The company has nine production sites in Japan and seven others throughout Asia. The distribution of its products is conducted through its more than 18 subsidiaries in 16 countries and four continents worldwide. This extensive geographic coverage was aided by the fact that Renesas originated out of a merger between NEC Electronics and Renesas Technology in 2010 [34] and also incorporates former operations of Mitsubishi and Hitachi [30].

Renesas rose to popularity when the March 11 earthquake, ensuing tsunami and nuclear meltdown wreaked havoc in Northeast Japan in 2011 [30]. Renesas major chip factory in Hitachinaka was directly affected and heavily damaged by the earthquake [35], resulting in production shortages to major automotive customers and inadvertently causing global supply disruptions [27,30]. Seven of the company’s other plants in the region were not as badly affected but still ran at diminished capacity due to fragile or broken supply networks.
Resource requirements in terms of electricity also turned out to be a critical element, whereas a supply of clean water and gas could quickly be re-established. In an effort to recover their supply network as soon as possible, Renesas aimed to use their fab network as a short-term action [30] to manufacture products at other plants or through outsourced manufacturing. Renesas’ other Japanese plants also suffered from energy shortages and were not able to cover missing production volumes. Moreover, only very few of Renesas’ products manufactured in Hitachinaka were standardized to a degree which would allow production to take place in other, internal or external, facilities [36,37]. This was further complicated by the fact that severely damaged infrastructure in and around the production vicinities would not allow for immediate substitute machinery to be delivered. As a consequence, even figuring in substitute products from their fab network, Renesas only reached pre-disaster production volumes in September 2011, six months after their main production site was damaged [36].

Nonetheless, the company started their long-term repair efforts only ten days after the triple disaster when it had drawn up and was starting to execute a recovery plan [38]. The plan foresaw to recover operations by repairing the cleanrooms used for production, reinstalling production equipment, and running test operations to ensure sufficient production quality. At first this was estimated to be a lengthy process as only restarting microcontroller plants even under normal circumstances can be a process of up to a week [25,27,39]. The ensuring energy shortages in Japan even further complicated any outlook in this respect [39]. Renesas immediately institutionalized a special task force at their headquarters to monitor the status of individual plants. Delegates from this task force were also dispatched to assist individual plants on-site [28,40]. Even though Renesas’ customers were not completely certain how to assist their supplier in recovery efforts [2,27], the on-site task force was joined by representatives from Renesas’ major automotive customers, members of the Japan Automotive Manufacturers Association as well as individuals from Renesas’ suppliers only days after the disaster [38,41]. Automotive customers clearly expressed their concern for Renesas, putting aside doubts they might look for new suppliers. At this point, employees had already ensured the safety of their families and were also assisting in the recovery efforts, even though they were initially supposed to be put on mandatory leave. As a consequence an average of 2,500 supporters per day [38,30]. In terms of production machinery as a resource within the supply network, there was a clear deficit as numerous machines and other production equipment was destroyed during the disaster. Contrary to this, in biological systems there is always an adequate redundancy available. Self-healing aims at allocating the surplus cells currently most suited to facilitate tasks to reach the status quo. The aforementioned surplus of human resources within the supply network was deliberately moved and redirected by the overall joint steering committee based on prioritized tasks. Once a task was completed they would support other teams, even if they lacked specialized skills, but would then focus on performing generalist tasks. Once an employee’s usually performed tasks had been reinstated, they would resume their original tasks. The ability to move also holds true in case of know-how, which was proactively shared between all involved parties to facilitate the flow of information and ease of understanding complex problems. Visualization and distribution of information was even allowed up to the degree of confidential information to support the goal of recovering operations as soon as possible. In terms of machinery, there was no ability to move as the majority of specialized machines had been destroyed within the disaster. Undestroyed machines within the supply network were not able to produce the customized products. Whereas for biological self-healing, specialized cells have the ability to move and replicate to mend wounds, within supply networks this capability requires standardization in terms of machinery and products (e.g. when outsourcing production) or availability in terms of information (e.g. when substituting tasks).

The allocation of surplus human resources, individual employees could only adapt to perform new tasks as long as they did not require specialist knowledge. Based on the timeliness required in this process lengthy retraining was not sensible. In terms of machinery, the customized products and little experience with outsourced manufacturing prevented an efficient utilization of the fab network. Considering biological self-healing, individual cells have the ability to adapt to new functions. In terms of supply network elements
this might be an aspirational goal in terms of standardization and availability of information as already indicated.

Table 1. Overview of developed principles, propositions and results from the case study.

| Biological principle | Proposition | Transferability | Examples from Renesas case |
|----------------------|-------------|-----------------|-----------------------------|
| Existence of a surplus of cells | In a supply network, a surplus of resources exists | Partially proven | Surplus of human resources due to daily tasks being rendered redundant and redirection of resources. |
| Cells have the ability to move | Within a supply network, resources have the ability to move | Partially proven | Allocation of human resources based on prioritized tasks and utilization for generalist topics. |
| Cells have the capability to adapt | Within a supply network, resources can adapt (i.e. take over tasks of disrupted parts) | Partially proven | Adaption capabilities of human resources limited to generalist topics. |
| Emphasis on the maintenance of the network’s health | If a part of a supply network is recovering from a disruption, other parts of the network are left unaltered | Not proven | No formalized alterations of the supply network are occurring (relationships stay the same). |
| Chronology of healing: Differentiation between short-term action and long-term repair | During a supply network recovery, there is a distinction between short-term actions and long-term repair | Proven | Short-term action includes intended utilization of fab network and externals. |

(4) Even though there were no formalized alterations to the supply network during the recovery, individual network elements had to be altered and adjusted to enable maintenance of the overall network. In the case of human resources, these were temporary dispatches from all involved parties. As for machinery, other plants or external contract manufacturers had to take over as much production volumes as possible. Generally, the disruption in one part of the network caused a ripple effect throughout other network elements (e.g. supply shortage for customers or lost sales for suppliers). In terms of biological self-healing, the maintenance of one part of the network does, in most cases, not cause these ripple effects as it is as a rather isolated event. Being able to isolate individual disruptions to limit the effect they have on the overall supply network would indeed be an aspirational feature.

(5) Shifting of production volumes to other plants as well the utilization of contract manufacturers to take over production as much as possible was the immediate short-term action taken by the Renesas management, fully aware that all other measures would take considerably more time. Nonetheless, these other measures were started given the formulation of a recovery plan and institutionalization of the joint steering committee. In essence, Renesas completed steps that would provide a temporary solution to prevent worsening of the situation but also laid the foundation for and completed a long-term recovery process. This is also reflected in the differentiation between short-term action and long-term repair in terms of biological self-healing in a similar fashion.

6.2. Discussion of Results

Summarizing these findings on the basis of the stipulated propositions the following picture emerges. First, the existence of a surplus of resources within a supply network only holds true for human resources, but not for the severely damaged machinery resources and could, therefore, only partly be proven. Second, the ability to move could also only partly be proven as human resources were only utilized within a generalized context without requiring specialized knowledge. The flow of information was merely intended for efficiency improvement purposes within the given circumstances. Third, the adaptability of resources was limited to general tasks for human resources and non-customized products in case of machinery resources and, therefore, only partly holds true. Fourth, the proposition that other parts of a disrupted network are left unaltered could not be proven as ripple effects were clearly causing distress for other involved network parties. Fifth, in terms of chronology of healing the proposition that there is a clear distinction between short-term actions and long-term repair could be proven, as has become evident by the attempted utilization of the fab network as well as Renesas’ recovery plan.

7. Conclusion and Further Research

The analysis of the single case study of Renesas shows that four of the five illustrated principles identified in human skin wound self-healing can, at least partly, be transferred to the recovery of a supply network disruption. Transferability of principles is, however, often dependent on the type of resource (e.g. human resources). Only the principle related to the chronology of healing can be entirely transferred. In contrast to this, the principle concerned with the maintenance of a network’s health cannot be transferred at all in the case of Renesas. The mixed results of this single-case study, nonetheless, warrant further analysis in this research field. Especially with respect to the management of supply network disruptions, decisions taken as well as techniques to improve collaboration (e.g. visualization and sharing of information) many more examples can be drawn from the Renesas case that would exceed the scope of this current paper.

Limitations of the presently discussed contents pertain to a differentiation of whether a cell temporarily or permanently fulfils a certain function and what implications this entails, something that is evident in the Renesas case. In this respect, not much attention was given to what types of cells act at any given time and what characteristics they exhibit. This missing segmentation is in turn causing difficulties in clearly defining the degree of externality of actual supply networks.
The analysis’ results regarding the transferability reveal a potential which makes further research in this field sensible. For instance, looking into the biological processes and principles on a more detailed level to derive even more beneficial insights from biological self-healing could be a next step. As indicated by the results of this case study, a higher level of detail may also be relevant regarding the different types of resources or external network elements and their functions within a supply network. Other potential topics in this research field may be to analyze the way in which cells and resources are communicating, i.e. sending and receiving signals, and analysing how the principles change with respect to the importance of individual network elements in relation to other network elements.

Regarding the research approach, single case study research has several limitations especially with regard to its generalizability. Therefore, further research should analyse a larger quantity of cases, including cross-case studies. Furthermore, additional information sources, for instance derived from interviews, should be consulted. In the long-term, after setting a comprehensive qualitative base, quantitative data analysis to validate results might be sensible. Additionally, a long-term goal would be to operationalize the signals, and analysing how the principles on a more detailed level to derive even more complex systems perspective. In: Essig M, Hülsmann M, Kern E-M, Klein-Schmeink S, editors. Supply chain safety management - security and robustness in logistics. Berlin, Heidelberg: Springer-Verlag; 2013. p. 217-230.

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