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Distributed Manufacturing as Co-Evolutionary System

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For Peer Review Only

Distributed Manufacturing as Co-Evolutionary System

ABSTRACT

Research into Distributed Manufacturing – originally focusing on control of autonomous production cells - has embraced over time the challenges of research into industrial networks and more and more identical issues are pursued in both of these fields. Existing strands of research in networks often explore social-dynamic relationships and contractual aspects, thereby ignoring the underlying dynamics based on characteristic issues: collaboration, decentralisation of decision-making and inter-organisational integration. Therefore, theories relating to the loosely connected regime of networks should account for both the instability caused by the autonomous behaviour of agents and the collaboration necessary for sustainability and inter-organisational integration (all pointing to mutual dependencies).

Within evolutionary (biological) models, co-evolution has gained a prominent place in the description of mutual relationships for collaboration. Essential to the modelling of co-evolution is the combined development of agents involved, expressed by the factor for connected traits in the $NK[C]$ model. However, in this model co-evolution happens in semi-static landscapes, which hardly exist in reality. Hence, more advanced game-theoretic applications might serve as a foundation for understanding the development of networks since these describe the interactions between agents. This paper expands on co-evolutionary models and it includes the autonomous development of agents in a network, the connectivity between agents and the dynamic forms of collaboration and communication to advance research in Distributed Manufacturing.

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Keywords: Co-evolution, Collaboration, Evolutionary models, Fitness Landscapes, Game Theories, Industrial Networks.

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Distributed Manufacturing as Co-Evolutionary System

INTRODUCTION

For industrial networks, we may assume that collaboration has become a well-known issue, which has already drawn the attention of academics for some considerable time. Strands of research into industrial networks cover typologies of networks (e.g. New & Mitropoulos, 1995; Robertson & Langlois, 1995), industrial and national settings (e.g. Capello, 1996; Porter, 1990), collaborative networks, supply chain management (e.g. Hwarng, 2005; Wilding, 1998) and the behaviour of agents in networks, to name but a few. But what about Distributed Manufacturing with its strong origins in information technology? Most efforts in Distributed Manufacturing have been directed towards applications of information technology from the mid-1990s onwards, like the design of its architecture (e.g. Maturana & Norrie, 1996; Ryu & Jung, 2003), resource and task allocation (e.g. Maropoulos *et al.*, 2002; Tharumarajah, 2001), and scheduling and control (e.g. Azevedo & Sousa, 2000; Candadai *et al.*, 1996; Duffie & Prabhu, 1996; Fujii *et al.*, 1998; Kingsman, 2000; Maturana & Norrie, 1995; Shen, 2002). All these contributions have in common that they take autonomous agents in a network as starting points (Sousa *et al.*, 1999). This originates in the 1980s when the introduction of Flexible Manufacturing Systems called for a new control paradigm. That meant moving away from the centralised resource allocation embedded in MRP applications towards decentralised decision-making and towards related computer applications to supersede the control of independent units. Consequently, the emphasis has been on manufacturing architecture and control within single plants. Later, the term Distributed Manufacturing came to include the virtual manufacturing of products crossing the borders of a

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2
3 monolithic company (Holonc Manufacturing Systems [Van Brussel *et al.*, 1998, p. 255],
4
5 Bionic Manufacturing Systems, Fractal Factory and Multi-Agent Systems [Leitão & Restivo,
6
7 2000, pp. 2-4]) and started to include the networked organisation. However, the
8
9 consequences of this expansion have been little discussed because of the traditional focus on
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11 information technology.
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15 With its contemporary meaning, the research into Distributed Manufacturing has disconnected
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17 from the traditional drive towards developing simulations and software applications to the
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19 issues that surround industrial networks (Kühnle *et al.*, 2005). As a result, only a few have
20
21 written about collaboration in Distributed Manufacturing (e.g. Fagerström & Jackson, 2002).
22
23 Collaboration is also a hot topic in industrial networks that needs expansion beyond the
24
25 current concepts to arrive at more grounded theory (Bennett & Dekkers, 2005; Dekkers *et al.*,
26
27 2004; Dekkers & van Luttervelt, 2006). This call embraces the remark of Nassimbeni (1998,
28
29 p. 539) that the bulk of available works is devoted to the contractual aspects and the social
30
31 dynamics of inter-organisational relationships in collaboration. That seems hardly surprising.
32
33 The attention to contractual and social aspects might originate in the direct conversion of
34
35 approaches from the hierarchical firm to networks. Hierarchical firms, sometimes called
36
37 Strategic Networks (e.g. Jarillo, 1988), with the direct control of resources and the related
38
39 strategy towards suppliers, differ from networks, which have more loosely connected entities;
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41 Camarinha-Matos & Afsarmaneshi (2005, p. 443) provide a similar argument. So far, the
42
43 research into industrial networks has mostly neglected the dynamic forms of communication
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45 and coordination, although networks do not present a new phenomenon and have different
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47 characteristics. For this reason, this paper deliberates on collaboration in Distributed
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3 Manufacturing and connects this theme to co-evolutionary models to address dynamic forms
4 of communication and coordination in networks.
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7 8 9 ***Emergence of Industrial Networks***

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11 Academic attention paid to particular characteristics of networked organisations has not
12 appeared overnight (Wiendahl & Lutz, 2002, p. 1). In particular, academic interest has risen
13 during two periods (Bennett & Dekkers, 2005). The first of these was during the 1970s and
14 1980s when attention was focused on Japanese manufacturing concepts and techniques,
15 including Just-In-Time, co-makership and keiretsu networks. The second period started
16 during the 1990s because of the drive for even lower cost, greater efficiency and
17 responsiveness to customer demands. This resulted in the networked organisation following
18 the paradigm of core competencies (Prahalad & Hamel, 1990). This paradigm has its origin
19 in the same theories as the Resource-Based View (Hemphill & Vonortas, 2003, p. 261).
20 Consequently, both streams of thought preceded the move towards outsourcing and the
21 emphasis on supply chain, value chains and collaborative networks. The overview by Miles
22 & Snow (1984, p. 19) illustrates the move from the simpler paradigms for the monolithic firm
23 to the more complicated forms of network-based organisations that we have witnessed during
24 the recent decades (see Table 1).
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48 In this respect, the shift from make-or-buy to co-makership and alliances, the search for
49 flexibility in manufacturing, the implementation of Computer Integrated Manufacturing, the
50 design of production cells, all demonstrate a continuous move to more loosely connected
51 industrial entities. The associated flexibility has allowed an increasing degree of
52 customisation and the production of goods on demand (Lee & Lau, 1999, p. 83).
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3 Contemporary changes point to a further repositioning along the dimension of loosely
4 connected entities (Larsson, 1993, p. 52) with increasing pressure to respond to market
5 opportunities and to create flexibility (Wüthrich & Philipp, 1998). Hence, networks can be
6 perceived as potential solutions to the increasing demands on performance, especially those of
7 flexibility and customisation (Dekkers & van Luttervelt, 2006).
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15 16 ***Scope of Paper***

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18 Especially, since network organisations differ from monolithic companies in the absence of a
19 central decision-making unit, in the lack of a consistent strategy across all the different agents
20 and in the capability for reconfiguration (for example, the elimination of existing agents and
21 the inclusion of new agents). This makes it difficult to deploy the concepts of the monolithic
22 company to the domain of industrial networks (e.g. Dyer & Singh, 1998, p. 661, 675; Möller
23 & Halinen, 1999, p. 416). Additionally, direct transferences of these approaches to networked
24 enterprises regularly fail as they lack problem-oriented interdisciplinary inferences (which
25 should rely on consilience [Wilson, 1998, p. 8, 68]); this is congruent with the remark of
26 Camarinha-Matos & Afsarmanesh (2005, pp. 443-444) that research into Collaborative
27 Networks constitutes a new interdisciplinary domain. Since Distributed Manufacturing
28 employs concepts from manufacturing control in monolithic companies, the paper will refer to
29 the difference between this strand of research and the research into industrial networks,
30 although this is not the main theme of the present paper.
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50 The core of this paper will outline issues for collaboration by looking at evolutionary models;
51 additionally, it will offer a synthesis of several studies that contribute to understanding co-
52 evolution in this respect. It represents an extension of the evolutionary concepts as introduced
53 in Dekkers *et al.* (2004, pp. 70-71). It aligns with the call for theoretical foundations by
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3 Camarinha-Matos & Afsarmanesh (2005, p. 444, 449), especially network analysis and game
4 theory. Most of all, game theories have been identified by many others (e.g. Larsson *et al.*,
5 1998) to tackle issues of collaboration; similarly to the domain of evolutionary biology, where
6 these theories have gained a prominent position for co-evolution. This paper must be viewed
7 as a contribution to the discussion about foundations for a theory on networked organisations
8 by converting models from the domain of natural sciences, with an emphasis on evolutionary
9 biology (particularly co-evolution), to the domain of management science (the application to
10 collaborative networks).

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23 The paper will start by exploring three main strands of research associated with the networked
24 organisations; it will not examine literature about industrial districts, a common related
25 research theme in economics (see Harris & Pritchard, 2004; Robertson & Langlois, 1995),
26 especially the so-called *Third Italy* (e.g. Biggerio, 1999). While the strands constitute only
27 part of the literature on (industrial) networks, it appears that the broad variety of works
28 insufficiently address collaboration as a *modus operandi*. Thereafter, the paper examines co-
29 evolutionary models to describe collaboration. The next section deals with the link between
30 co-evolution and collaboration in networks. Particularly, it researches the *NK[C]* model,
31 already identified as being of paramount importance to understanding organisational
32 development (see McKelvey [1999]). This paper extends that model to collaboration and co-
33 evolutionary approaches by linking it to game-theoretical approaches. A final section
34 concludes by discussing the findings of this paper and further avenues for research.

51 52 **EXISTING STRANDS OF RESEARCH**

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55 Within the domain of industrial networks, many studies have preceded this one in outlining
56 prospects for research (e.g. Camarinha-Matos & Afsarmanesh, 2005; Gulati *et al.*, 2000;
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3 Karlsson, 2003). In the view of Camarinha-Matos & Afsarmanesh a discipline of
4 Collaborative Networks should focus on the structure, behaviour and evolving dynamics of
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6 Collaborative Networks should focus on the structure, behaviour and evolving dynamics of
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8 autonomous entities that collaborate to better achieve common or compatible goals. There are
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10 many perspectives from which to look at the structure and dynamics of collaborations, like
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12 technology transfer and valorisation, knowledge management, contractual relationships. This
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14 paper presents three of these perspectives: the Strategic Network Model – as representative of
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16 approaches residing in the monolithic firm - , the Resource-Based View – as a popular
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18 foundation for explaining inter-firm relationships - and the social dynamics of inter-
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20 organisational relationships – as an extensively researched issue -, before elaborating on the
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22 complexity perspective for collaboration as co-evolution.
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28 ***Strategic Network Model***

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30 The first perspective defines Strategic Networks as long-term, purposeful arrangements
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32 among distinct, but related, for-profit organisations that allow members to gain or sustain
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34 competitive advantage over their competitors outside the arrangement (Jarillo, 1988, p. 32).
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36 Kogut (2000) describes this type of network for the Toyota Production System. In this view,
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38 Strategic Networks are merely a superior method of managing the process necessary for the
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40 production and sale of a chosen set of products (like in Freiling [1998]). It should be noted
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42 that some associate the term Strategic Networks with the concept of networked organisations
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44 in general (e.g. Gulati *et al.*, 2000) and some with supply chains (e.g. New & Mitropoulos,
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46 1995). Levin (1998) discusses the advantages of networks for small businesses. Most of all,
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48 (Strategic) alliances, joint-ventures typically exemplify these Strategic Networks. Studies
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50 focused on (a) the inclination of firms to enter alliances and the formal contracts, (b) the
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52 formation and performance of alliances and (c) the firm- and industry-level factors that impel
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3 organisations to enter alliances (Gulati, 1998, pp. 294-295). Still less attention has been paid
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5 to the management of these arrangements. However, it appears that the factors power and
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7 trust dominate these types of network relationships (Das & Teng, 2001; Huemer, 2004;
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9 Thorelli, 1986, p. 38). Hence, these Strategic Networks come into existence through strategic
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11 objectives of one or more of the partners, which make it necessary to collaborate and which
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13 create tensions in inter-organisational relationships.
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18 Such Strategic Networks, as purposeful arrangements (e.g. Gulati *et al.*, 2005), hardly address
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20 the issues of autonomous agents. Even alliances, which everybody perceives as more stable
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22 relationships between firms, dissolve over time or end up in mergers, according to a study into
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24 92 alliances by Kogut (1989). Consequently, if the balance shifts to independence of agents,
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26 depending on the uniqueness of their resources, the network will perform local optimisation
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28 and will create power shifts (Medcof, 2001). The need for more loosely connected agents and
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30 the flexibility to capture market opportunities undermines the arrangements of Strategic
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32 Networks, resulting in issues of power and trust in the relationships (Vangen & Huxham,
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34 2000). That way, instability seems to dominate the continuity and constituency of industrial
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36 networks, depending on the uniqueness of their resources.
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42 ***Resource-Based View***

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45 The Resource-Based View quickly followed the concept of Strategic Networks in the 1980s;
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47 although this view can be traced back to the 1960s and 1970s when organisational theorists
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49 combined research on inter-organisational relations and the political economy of
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51 organisations (Hemphill & Vonortas, 2003, p. 261). Later, resources were defined as tangible
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53 and intangible assets that are tied semi-permanently to a firm (Wernerfelt, 1984, p. 172).
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55 Others, especially Barney (1991), have articulated this view by shifting the emphasis of
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3 organisational theory to the organisation's goal of reducing the uncertainty and the
4 dependency on other organisations for its survival. To confer competitive advantage,
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6 resources must not be possessed by all competing firms, they must be difficult to imitate or
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8 duplicate through other means (Barney *et al.*, 2001, p. 625) and contribute positively to
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10 performance; Hamel & Prahalad (1994) follow similar reasoning for the concept of core
11
12 competencies. Contrarily, the resource dependencies among organisations constrain their
13
14 behaviours and ultimately translate into power differentials that must be effectively
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16 controlled. Hoopes *et al.* (2003, p. 897) remark that the Resource-Based View arrives from
17
18 simple applications of micro-economics, industrial organisation, organisational theory and
19
20 traditional business policy and that it would be better treated in the context of competitive
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22 heterogeneity (a view shared by Dyer & Singh [1998]). By using this perspective, a network
23
24 can develop and exploit a set of resources, such as knowledge, technology and organisation
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26 skills, for specific products (Grant, 1996, pp. 119-120) and market positioning to capture
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28 market opportunities (Chakravarty, 2001). The network strategy must not only focus on the
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30 exploitation of the competitive advantage but also on the utilisation plus acquisition of
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32 resources to create that advantage.
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42 ***Social Dynamics of Inter-Organisational Relationships***

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44 But that raises questions to examine the third perspective about industrial networks: the social
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46 dynamics of relationships. Within the mindset of this interpretation, Uzzi (1997, pp. 36-37)
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48 refers to other research that has shown that network relationships in the Japanese automotive
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50 industry (e.g. Toyota [Dyer & Nobeoka, 2000]) and the Italian knitwear industries are
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52 characterised by trust and personal ties, rather than by explicit contracts. Additionally, he
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54 points to investigations that reveal that embedded actors in regional production networks
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satisfice rather than maximise on price; they shift their focus from the narrow economic goal of winning gain and exploiting dependence to cultivating long-term, cooperative ties (similar findings appear in Hardy *et al.* [2003] who investigated a Palestinian non-governmental organisation). Kaufman *et al.* (2000, p. 660) arrive at a similar conclusion: collaborative relationships pay off for the supplier. Their findings suggest that suppliers should focus either on low-cost strategy or on a collaborative partnership to yield most profits. Uzzi (1997, p. 54, 61) found that embeddedness assists adaptation because actors can better identify and execute coordinated solutions to organisational problems. In networks of close ties motivation is neither purely selfish nor cooperative (in contrast to arm-length's relations) but an emergent property of the social structure within which actors are embedded.

A specific area in the social dynamics of relationships between entities in a network that has received much attention constitutes interorganisational learning. Through “learning alliances” firms can accelerate capability development and minimise their exposure to technological uncertainties by acquiring and exploiting knowledge developed by others. These studies focus on “student-teacher” relationships (Lane & Lubatkin, 1998), initial conditions (Doz, 1996), conflict management (Sonnek & Stüllenberg, 2000), proprietary assets (Kale *et al.*, 2000) and organisational characteristics (Lane & Lubatkin, 1998). However, learning introduces self-organisation, which makes the interactions difficult to guide (Moldaschl, 1998, p. 22).

EVOLUTIONARY PERSPECTIVES

These existing strands of research into interactions are rooted in empirical studies, taken as theories drawn from observations; but they hardly touch on the exchange of information – the realm of Distributed Manufacturing – and collaborative issues other than at a more or less

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2
3 strategic level. One other route is the formation of tentative theories, alike the logic of
4
5 induction (Popper, 1999, p. 14). One origin of tentative theories is the natural sciences. The
6
7 possible yield of perspectives of natural sciences for the domain of social sciences, which
8
9 includes management science, has been elaborated by Wilson (1998, pp. 125-163). Such a
10
11 quest for consilience requires the evaluation of different perspectives. However, within the
12
13 context of the paper, the issue of collaboration has been narrowed down to the formation of
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15 tentative theories that are mainly based on co-evolution.
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20 In that perspective, the development of organisations, and therewith networks, might follow
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22 universal laws that arrive from the conversion of models from evolutionary biology. Hence,
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24 in work preceding this paper, a reference model was developed to describe the interaction
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26 between organisation and environment (see Figure 1). It consists of two intertwined cycles:
27
28 the generation of variation and the selection by the environment (Dekkers, 2005, pp. 150-
29
30 155). Now, one might argue that organisations are not comparable with biological entities. In
31
32 any case, sufficient similarities exist to allow drawing an analogy (e.g. McCarthy, 2005). In
33
34 this sense, collaboration should be seen as a strategy for the phenotype, which is expressed in
35
36 the fitness of an entity for selection. Kauffman (1993) describes these fitness landscapes as
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38 mathematical models. A more powerful description is found in the emerging theory of
39
40 Adaptive Dynamics (Geritz *et al.*, 1997; Meszéna *et al.*, 2001), which is based on game
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42 theory, but has not been linked yet to co-evolution. The metaphor of co-evolution, the mutual
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44 dependence on each other, explains collaboration, the working together with one or more
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46 others; although organisms and organisations are not exactly identical, it provides an
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48 opportunity to explore collaboration with models from evolutionary biology.
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Co-evolution and Industrial Networks

Even within the domain of biological (evolutionary) models, a large number of theories exist that might describe adequately the existence of industrial networks and collaboration. In biology, co-evolution, as an adequate description for collaboration, is the mutual evolutionary influence between two species that become dependent on each other. This concept from evolutionary biology covers a wide range of interaction between agents, for example reciprocal altruism (Trivers, 1971). Within the domain of industrial networks, the mutual dependence has been recognised as a potential direction for research into collaboration (Levine & Kurzban, 2006). If this is true, how might collaboration evolve?

[Insert Figure 1 about here]

Other management scientists have also discovered that this co-evolutionary perspective might have value for advancing insight in the development of organisations, like Lewin & Volberda (1999). They focus on the emergence of new organisational forms (Lewin *et al.*, 1999), without clearly defining the “organisational form” (McKendrick & Carroll, 2001, p. 662). Co-evolution has appeared in writings that build on the work of Nelson & Winter (1982). For the purpose of this paper, it suffices to remark that these models do not address the intertwined cycles of the reference model in Figure 1. Especially, the concept of fitness landscapes lacks in these type of writings, which limits the validity of the outcomes. Co-evolution, when used in its sense of the mutual development of organisms, benefits for selectional forces (i.e. survival on the long-run). Thus describing co-evolution starts with fitness landscapes as an expression of the fitness of the belonging genotypes.

Fitness Landscapes

Fitness resembles height, a measure for expressing the fitness of a genotype, equal to thoughts of Wright's adaptive landscape (Wright, 1982). Fitter genotypes move at greater heights than less fit genotypes. Consider a genotype with only four genes, each having two alleles: I and O (i.e. a Boolean representation of the state of each gene), resulting in 16 possible genotypes, each an unique combination of the different states of the four genes (see Figure 2). Each vertex differs only by one mutation from the neighbouring ones, representing the step of a single mutation, thereby stating that each mutation as such is independent from the state of the other genes. An adaptive walk begins at any vertex, moves to vertices that have higher fitness values and ends at a local optimum, not necessarily the highest optimum, a vertex that has a higher fitness value than all its one-mutant neighbours. The figure shows that three local optima exist where adaptive walks may end. On random landscapes, finding the global peak by searching uphill is useless; it equals searching the entire space of possibilities (Kauffman, 1995, pp. 166-167). This simplified N model treats the traits as being entirely independent from each other.

[Insert Figure 2 about here]

However, in reality, the fitness landscapes that underlie the mutation steps of gradualism are correlated and local peaks do often have similar heights. Through the existence of particular evolutionary phenomena (developmental pathways, regulatory genes and epigenetics), each gene does not exist on its own, it correlates to other genes; this is often referred to as epistatic coupling or epistatic interactions. Rugged landscapes are those landscapes in which the fitness of one gene depends on that part and upon K other parts among the N present in the landscape. The NK model offers further insight in the mechanisms of evolution and selection

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3 (Kaufmann, 1993, pp. 40-54). Again, consider an organism with N gene loci, each with two
4 alleles, 1 and 0 . Let K stand for the average number of other loci, which epistatically affect
5 the fitness contribution of each locus. The fitness contribution of the allele at the i^{th} locus
6 depends on itself (whether it is 1 or 0) and on the other alleles, 1 or 0 , at K other loci, hence
7 upon $K+1$ alleles. The number of combinations of these alleles is just 2^{K+1} . Kauffman selects
8 at random to each of the 2^{K+1} combinations a different fitness contribution from a uniform
9 distribution between 0.0 and 1.0 (see Figure 3). The fitness of one entire genotype can be
10 calculated as the average of all of the loci. Generally, the epistatic interactions create a more
11 deformed landscape.
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25 *[Insert Figure 3 about here]*
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28 Despite the importance of fitness landscapes for evolutionary processes, Kauffman (1995, p.
29 161) states that biologists hardly know what such fitness landscapes look like or how
30 successful a search process is as a function of landscape structure. The landscapes may vary
31 from smooth, single-peaked to rugged, multi-peaked landscapes. During evolution, species
32 search these landscapes using mutation, recombination and selection, a process for which the
33 NK model provides insight into particular phenomena accompanying the adaptive walk.
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42 These fitness landscapes already have been used in the context of manufacturing and
43 networks. McCarthy (2004, p. 129) explains that fitness can be understood as the “capability
44 to survive by demonstrating adaptability and durability to the changing environment”. That
45 implies that fitness for manufacturing and firms covers dimensions of perceived
46 competitiveness and environmental expectations placed on the firm, e.g. cost, quality and
47 product range. For applications in business and management, fitness might cover many
48 dimensions, whereas the modelling of fitness has not yet exceeded one dimension. Wilkinson
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3 *et al.* (2000) apply the concept of fitness landscapes to the case of interdependence between
4 automotive distributors and dealers. They conclude that interrelated firms operate as a
5 complex adaptive system in which control is distributed throughout the system; in fact, the
6 realm of Distributed Manufacturing. Worth mentioning is the work of Kaufman *et al.* (2000),
7 who show that searches are most likely more effective for combining technologies rather than
8 searching for new technologies; this finding indicates the firms collaborating by combining
9 technologies might have more success than those search solely for new technologies.
10 Nevertheless, the *NK* model needs supplementation because it describes the fitness of one
11 species, i.e. one type of companies, and not of more species dependent on each other, the
12 domain of co-evolution.
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28 ***Co-Evolution and NK model***

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30 Kauffman (1993, pp. 243-245) extends the *NK* model to co-evolution by adding the constraint
31 that each trait in species *I* depends epistatically on *K* traits internally and on *C* traits in species
32 2, the so-called *NK[C]* model. More generally, in an ecosystem with *S* species, each trait in a
33 species will depend on *K* traits internally and on *C* traits in each of the *S_i* among the *S* species
34 with which it interacts. Therefore, if one species adapts, it both changes the fitness of other
35 species and deforms their landscapes in the *NK[C]* model.
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45 The coupling of the fitness landscapes will affect the search for increased fitness (Kauffman,
46 1993, pp. 252-253). When a new link is introduced (i.e. increasing *C*), the genetic locus
47 spreads throughout a population in three ways: (a) the new epistatic link, when it forms,
48 causes the genotype to be fitter, (b) the new epistatic link is near neutral and spreads through
49 the population by random drift and (c) the new link not only has a direct effect on the fitness
50 of the current genotype but also increases the inclusive fitness of the individual and its genetic
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descendants. It suggests that optimisation in co-evolutionary dynamics becomes possible by optimisation mechanisms that search for optimal traits in relation to the coupled traits (we could view the development of the Pearl River Delta in that respect [Noori & Lee, 2002, 2006; The Economist, 2002]). The second option for a network consists of increasing its reach, which compares to increasing the number of species. When that happens the waiting time to encounter a new equilibrium increases, the mean fitness of the co-evolving partners decreases (McKelvey, 1999, p. 312) and the fluctuations in fitness of the co-evolving partners increase dramatically. The increase of agents might lead to a new optimisation in traits and coupled traits but only after going through a period of instability.

Percolation in Networks

These instabilities might come along with phase changes, or percolation, in the Boolean networks captured in the NK model (Kauffman, 1995, pp. 80-92). Four particular states arise when the NK model is analysed for the principles of self-organisation. Firstly, at $K=1$, the orderly regime appears, in which independent subsystems function as largely isolated islands with minimal interaction. At $K=2$, the network is at the edge of chaos, the ordered regime rules at maximum capacity but chaos is around the corner. At values ranging from $K=2$ to $K=5$ the transition to chaos appears although indications are that this transition happens already before $K=3$. From $K>5$, the network displays chaotic behaviour. All these four possibilities of K indicate that the behaviour of networks strongly varies according to the interrelation between traits; this will be the case for combination of K and C (for the connectivity between entities), too. Henceforth, dynamics and percolation in networks are driven by the interrelationship between traits and by connectivity between entities.

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3 In addition, human-influenced complex networks, e.g. World-Wide Web, human
4 acquaintance networks, have common properties for connectivity, which are hardly
5 compatible with existing cybernetic approaches (as mostly present in software applications).
6
7 The so-called *small-world property*, the best known of these specific properties, states that the
8 average path length in the network is small relative to the system size (Milgram, 1967). This
9 phenomenon has already been scientifically studied more than three decades ago, long before
10 becoming notorious. In fact, the phrase *six degrees of separation* (Guare, 1990), another
11 popular slogan depicting the small-world phenomenon, is due to Milgram's 1967 experiment.
12
13 Another property of complex networks is clustering, i.e. the increased probability that pairs of
14 nodes with a common neighbour are also connected. Since then, increased efforts have been
15 dedicated to identify other measures of complex (enterprise) networks (Fricker, 1996).
16
17 Perhaps, the most important is the *distribution of degrees*, i.e. the distribution of the number
18 of links the nodes have. It has been shown that several real world networks have scale-free
19 distributions, often in the form of a power law. In these networks, a huge number of nodes
20 have only one or two neighbours, while a couple of them are massively connected
21 (comparable with order and chaos in the *NK* model). These three specific properties of
22 human-influenced networks strongly influence the behaviour of the constituent agents and the
23 development of these networks.
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46 The properties have been translated into mathematical models and applications focusing on
47 large networks and connectivity (e.g. Klemm *et al.*, 2003; Krapivsky & Redner, 2001;
48 Newman, 2003; Watts & Strogatz, 1998); most of these applications show that these
49 properties make networks behave more dynamically. Industrial networks consist of a limited
50 number of agents – think about the industry sector for flow-wrapping packaging equipment
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3 that consists only of 300-350 companies worldwide - and therefore, might display other
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5 behaviour than large networks. The expansion to industrial networks should include the
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7 behaviour of agents (not just agents as nodes) and the development of traits for selection for
8
9 smaller networks.
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11 12 13 *Symbiosis*

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15 The concept of symbiosis deserves some more attention as a form of co-evolution in
16
17 networks. Symbiosis is an interaction between two organisms living together in more or less
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19 intimate association or even the merging of two dissimilar organisms. The various forms of
20
21 symbiosis include:
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25 • parasitism, in which the association is disadvantageous or destructive to one of the
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27 organisms and beneficial to the other;
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29 • mutualism, in which the association is advantageous to both;
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31 • commensalism, in which one member of the association benefits while the other is not
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33 affected;
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35 • amensalism, in which the association is disadvantageous to one member while the other is
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37 not affected.
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41 In some cases, the term symbiosis is used only if the association is obligatory and benefits
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43 both organisms. Sometimes, altruistic behaviour benefits another organism, not necessarily
44
45 closely related, while being apparently detrimental to the organism performing the behaviour
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47 (Trivers, 1971, p. 35). Aldrich (1999, p. 301) differentiates between commensalism referring
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49 to competition and cooperation between units and symbiosis taken as mutual interdependence
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51 between dissimilar units. Symbiosis as defined in this paper does not restrict the term to only
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3 the mutually beneficial interactions. It has strong similarities to the coupling of the traits in
4 the *NK* model to describe co-evolution; these traits might lead to cooperative species as Potter
5 & de Jong (2000, p. 26) demonstrate, albeit based on generic algorithm that will hardly
6 account for the dynamics of the organisations' environment. It indicates that the mutual
7 relationships have at least two dimensions: the fitness of each of the two agents involved.
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11 Similar to the mutual relationships of symbiosis, Khanna *et al.* (1998) have used the terms
12 private and common benefits. They state that in a partnership, each enterprise has cooperative
13 as well as competitive motives. The cooperative aspect arises from the fact that firms can
14 collectively use their knowledge to produce something that is beneficial to them all (common
15 benefits). The competitive aspect is a consequence of each firm's attempt to use the
16 knowledge of its partners for private gains, the motive for setting up Strategic Networks
17 (Hemphill & Vonortas, 2003, pp. 260-261). For a sustainable partnership, a combination of
18 private and common benefits is needed, its ratio described by the relative scope (Khanna *et*
19 *al.*, 1998, p. 195). When private benefits are the only motive of a company, racing behaviour
20 will arise and the alliance will be cancelled after a while. Kale *et al.* (2000) demonstrate the
21 same based on a contingency model for inter-organisational learning and opportunistic
22 behaviour. Henceforth, the perception of agents in networks about the relative scope will
23 drive their behaviour and ultimately the development of the network.
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47 ***Autopoiesis***

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49 That imperative of perception (about the relative scope) is also found in the final concept of
50 evolutionary biology: autopoiesis. This theory offered by Maturana & Varela (1980) explains
51 some principles of evolutionary processes: the ability to self-create or self-renew through a
52 closed system of relations. In this view, living systems engage in circular patterns of
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3 interaction whereby change in one element of the system is coupled with changes elsewhere,
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5 setting up continuous patterns of interaction that are always self-referential. A system enters
6
7 only interactions that are specified by its organisation. Therefore, a system's interaction with
8
9 its environment is ultimately a reflection and part of its own organisation. An autopoietic
10
11 system interacts with its environment in a way that facilitates its own self-creation. The
12
13 structural coupling governs by which interactions a component of living system is influenced.
14
15 When interactions initiate changes in the structure and composition, the structure is called
16
17 plastic. Through repeated interaction and initiations, the selection of subsequent structures is
18
19 affected by the environment. Hence, the selection is driven by the environment and by the
20
21 plasticity of the structure by its own components and internal relationships (Danilovic &
22
23 Winroth [2006] performed an exploratory case study into networks using these concepts).
24
25 The environment does not determine the internal adaptations! Therefore, autopoietic systems
26
27 are interactively open and structurally closed (van der Vaart, 2002, p. 11).
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35 One of the foremost reasons for the research into autopoiesis stems from the quest for the
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37 nature of perception and cognition (e.g. Hernes & Bakken [2003] on Luhmann's
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39 interpretation for social systems, which is not settled yet). Perception and cognition derive
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41 from the nerve system realised by the autopoiesis of the organism. To exist, continuously
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43 interactions should be repeated since the structural coupling exists; in this sense cognition
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45 represents gathering knowledge about all effective interaction for sustainability (see Maula
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47 [2000, p. 161] for its application to the case of Arthur D. Little). Learning as a process of
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49 cognition originates in the properties of self-reference of the system (coined in the 1980s by
50
51 de Geus [1999, p. 111], which inspired the movement of the Learning Organisation by Senge
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53 [1992]). When learning exceeds the level of direct interaction and moves towards orientation
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3 in the common domain of two autopoietic systems, communication is established. When
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5 descriptions of communication and interaction lead to becoming an observer of own
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7 behaviour by an entity, self-consciousness arises. The composition of a system related to an
8
9 external point of reference defines the identity of an autopoietic system (van der Vaart, 2002,
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11 pp. 7, 24-25). The identity is strongly related to the composition of the entity, changes in the
12
13 composition lead to a changed identity; through self-reference autopoietic systems seek to
14
15 maintain their identity unless perturbations provoke adaptations. These notions lead Mingers
16
17 (1995) to connect the theory of autopoiesis to the systems hierarchy of Boulding (1956). But
18
19 it also leads to models for interaction between agents, where perception of the interaction
20
21 drives the (mutual) behaviour of agents; a comparative case study by Mota & de Castro
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23 (2004) confirms this position.
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30 **DISTRIBUTED MANUFACTURING AND CO-EVOLUTION**

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32 Taking Distributed Manufacturing as a concept for autonomous agents that are somehow
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34 mutually dependent on each other, equivalent to complex adaptive systems, what does the
35
36 perspective of co-evolution hold? This question exceeds issues like network architecture,
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38 resource allocation and scheduling, the traditional domain of the software applications.
39
40 Rather it focuses on the specific characteristics of (international) networks of companies:
41
42 collaboration to deliver products and services, decentralisation of decision-making and inter-
43
44 organisational integration to meet imposed performance requirements in competitive markets
45
46 (adapted from: O'Neill & Sackett, 1994, p. 42). The traditional themes of Distributed
47
48 Manufacturing are much directed towards the decentralisation of decision-making and the
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50 inter-organisational integration; the methods for optimisation models often take a singular
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52 perspective as if the network constitutes one entity and behaves accordingly. The move
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3 toward industrial networks implies that collaboration should be covered, too, and the
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5 behaviour of individual agents should be included.
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8 9 *New Rationales for Distributed Manufacturing*

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11 This calls for new rationales for the contemporary meaning of Distributed Manufacturing,
12
13 which view the networks as a co-evolutionary system, i.e. agents dependent on each other.
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15 The similarity in the new and the old approach, the autonomous agents, serve as a base for
16
17 looking for models and tools that adequately address the challenges of networks. The move
18
19 towards more loosely connected entities calls for models of collaboration that stretch beyond
20
21 the emphasis on contractual and social dynamics of inter-organisational relationships, which
22
23 represents the main stream of research into networks. In that respect tools, like matchmaking
24
25 and brokerage through webservices (Field & Hoffner [2003], Molina *et al.* [2003]), and
26
27 electronic contracts (Angelov & Grefen [2003], Barata & Camarinha-Matos [2003]) will
28
29 insufficiently counter the challenges of industrial networks. Concepts like Factory-on-
30
31 Demand (Lee & Lau, 1999) and the research into industrial districts (e.g. Biggiero, 1999)
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33 align more with the principles of complex adaptive systems as systems of human interaction,
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35 driven by the search for governing laws of collaboration. Hence, the research into Distributed
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37 Manufacturing should include concepts of agents dependent on each other to account for the
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39 human factor.
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48 Even though some of the concepts for Distributed Manufacturing account for the human
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50 factor, like the concept of Holonic Systems, or take the biological perspective, like the
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52 concept of Bionic Systems (Leitão & Restivo, 2000, p. 3), they do so by looking at the
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54 collaboration from an information technology perspective. The conversion of truly biological
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56 concepts to the domain of networked organisations will yield additional insight, especially on
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3 the interaction between human (actors) as agents. The mutual relationships point to
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5 connectivity and coupling where traits become interrelated, companies engage in new
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7 relationships and industrial networks evolve. The dynamics of these networks represent the
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9 search for increased fitness by the constituent agents; henceforth, research into Distributed
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11 Manufacturing should embrace connectivity and coupling of traits to describe the mutual
12
13 relationships of agents.
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16 17 18 ***Models for Co-evolution in Collaborative Networks*** 19

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21 Several approaches exist in literature to describe the evolution of cooperation and
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23 collaboration as mutual behaviour. Dierkes *et al.* (2001, p. 665) state that the evolution of
24
25 corporation can be seen as the development of a cooperative alliance over time. Doz (1996, p.
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27 55) stresses that the evolution of cooperation might be constrained by the conditions at the
28
29 inception of the alliance and influenced by the collaboration process that takes place
30
31 consequently. Larsson *et al.* (1998, pp. 291-295) propose two different inter-organisational
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33 learning dynamics, by using game theories. Both describe the dynamics of the transparency
34
35 and receptivity as result of (initial) conditions; receptivity closely aligns with the concept of
36
37 structural coupling of autopoiesis. The first kind of inter-organisational learning dynamics
38
39 deals with possible barriers while the second one concentrates on empowerment.
40
41 Understanding the evolution of alliances can provide critical insight into how such ties can be
42
43 managed (Gulati, 1998, pp. 305-306) mutual. This underlines that collaboration in concepts
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45 for Distributed Manufacturing should account for learning behaviour.
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53 *[Insert Figure 4 about here]*
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56 According to Larsson *et al.* (1998, p. 289), inter-organisational learning is a joint venture of
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58 the interacting organisations' choices to be more or less transparent or receptive (note that this
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3 thought resembles principles of autopoiesis). Within this setting, each organisation has five
4 different strategies at its disposal: collaborating, competing, compromising, accommodating
5 and avoiding (see Figure 4). Collaboration represents then the ultimate strategy for both
6 agents to create benefits but because of the high score on transparency might easily lead to
7 exploitation by other firms. The framework is expanded with the initial research of Parkhe
8 (1993) who proposed a game-theoretic view to understand and describe the mixed-motive
9 (cooperative vs. collaborative) nature of interfirm relationships. The resulting dynamic
10 barriers to inter-organisational learning (Larsson *et al.*, 1998, p. 292) are presented in Figure
11 5. Pihkala *et al.* (1999) report a similar finding on a more global level of analysis for SMEs
12 participating in virtual organisations. These inter-organisational learning strategies show
13 different outcomes depending on the initial strategies of each agent in the network. To that
14 purpose, the effect of initial conditions on learning behaviour potentially influences the
15 effectiveness of concepts for Distributed Manufacturing.
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35 *[Insert Figure 5 about here]*
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38 ***Game Theories and Collaborative Networks***

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40 In comparison to the $NK[C]$ model, the development of inter-organisational learning might
41 have a limited number of outcomes. Clearly, in both models the individual organisations
42 undertake adaptive walks to increase fitness and these fitnesses mutually depend on each
43 other. But according, to the NK model, more local optima will exist, which aligns with the
44 more advanced modelling by Adaptive Dynamics; this strand of research has a strength that it
45 recognises different criteria for (in)stability that will affect the evolutionary outcomes.
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47 Others, like (e.g. Pacheco *et al.*, 2006) have also used game-theoretical approaches to link co-
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3 evolution to behaviour. All four streams exploit the game-theoretic applications in different
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5 fashions.
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9 It will be too early to conclude which models or which combinations best explain the phase
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11 transitions in collaborative networks, as in Distributed Manufacturing. This becomes more
12
13 complicated when considering the outcomes of social-economic research into networks.
14
15 Greif (1993) examined the social-economic relationships with respect to the Jewish Maghribi
16
17 traders who operated during the 11th century in the Muslim Mediterranean, by using game-
18
19 theoretic considerations. This investigation reflects a reciprocity based on a social and
20
21 commercial information network with very flexible but not bilateral agency relations (even
22
23 when imposing rules on the distribution of common and private benefits); Uzzi (1997, p. 38)
24
25 points out that these types of regularities fit with the behaviour observed in networks. The
26
27 Maghribis' network expanded from within rather than relying on outsiders. Hence, collective
28
29 punishment prevailed in contrast to the Italian traders who operated (particularly from the 12th
30
31 century on) in the same area as the Maghribis, trading in the same goods and utilising
32
33 comparable naval technology. Among the Italian traders bilateral rather than collective
34
35 punishment existed (Greif, 1994; Uzzi, 1997, p. 38). Within a game-theoretic view, networks
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37 might operate in different mode with quite different rules, guidelines and interactions (Gulati
38
39 *et al.* [2000, pp. 209-210] mention similar findings); and the emphasis should shift from
40
41 managing the network to managing interactions (Batt & Purchase, 2004, p. 171; Ritter *et al.*,
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43 2004, p. 181).
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51 ***Avenues for Research***

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54 If evolutionary models based on game theories address issues of collaboration in industrial
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56 networks, they should incorporate fitness landscapes with at least two dimensions of fitness
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3 (i.e. the fitnesses of mutually dependent agents) to fully account for interactions. The current
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5 model of Larsson *et al.* (1998) and the semi-static *NK* model insufficiently incorporate these
6
7 features but do not address the evolution of the network itself; the *NK[C]* model offers an
8
9 explanation by addressing the coupled landscapes but still offers a semi-static view.
10
11 Therefore, these models might be expanded with the dynamics of the environment captured
12
13 by Adaptive Dynamics. According to Lawless (2002), the more advanced Quantum Game
14
15 Theory also accounts for these dynamics (e.g. Eisert *et al.*, 1999) and avoids the traditional
16
17 pitfall of game theory that it overstates cooperation (e.g. van Enk & Pike, 2002); Colman
18
19 (2003) points to the weakness of the orthodox game theories. Pietarinen (2004, pp. 403-407)
20
21 propagates that game theories adequately connect to multi-agent systems (which closely relate
22
23 to general systems theories) and Li *et al.* (2006) take multi-agent modelling as starting point
24
25 for simulating supply networks. The research as proposed in Dekkers *et al.* (2004) captures
26
27 these findings as starting point for new avenues.
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34 Those directions could be strengthened by research into a few specific areas for collaborative
35
36 networks, like those of Distributed Manufacturing:
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- 38
39 1. the development of models for interaction based on game-theory, particularly Adaptive
40
41 Dynamics, relative scope (private and common benefits) and autopoiesis; preferably,
42
43 embedded in agent-based simulation. Additionally, models for interaction building on the
44
45 *NK[C]* model might help to create insight;
46
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- 49
50 2. the study of continuity of partnerships and relationships in networks, particularly from the
51
52 perspective of social dynamics of relationships, based on principles of autopoiesis and
53
54 human influenced networks and inter-organisational learning. It should be noted that the
55
56 industrial networks like Distributed Manufacturing not only rely on interaction but also on
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interdependence for the delivery of products and services. When developing models both aspects should be included;

3. the impact of different models for private and common benefits on stability of collaborative networks;
4. the impact of viewing collaborative networks as more than networks exchanging data, the traditional realm of Distributed Manufacturing. Principles of interaction between agents and the effect of the interaction on perception and cognition should be studied in networks that share and utilise data for scheduling, planning and resource allocation;
5. the impact of network size on the behaviour of agents constituting the network.

For almost all these prospects no precedent seems to exist in current literature. Further, through consilience by synthesis (Wilson, 1998, p. 68) such research will be able to relate these models and the findings through simulations to the contemporary challenges of industrial networks. The loosely connected entities experience greater instability than the fixed forms of initial networks like alliances and partnerships. Even then, other research has indicated the instability of these arrangements, from a natural perspective of dissolving (Kogut, 1989) or from a power and trust perspective (Gulati *et al.*, 2000, p. 209). This will emphasise the search for chaos and order in the networked regime.

Therefore, the application of the evolutionary models of fitness landscapes and game theories might underpin new and more effective models for comprehending the dynamics of collaborative relationships. In addition, the different modes of these theories, arriving originally from evolutionary biology, call for synthesis to fully understand the interrelationships between agents and their actions. The research domain of Collaborative

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3 Networks will profit from these new, more effective models and in that way will become a
4 true discipline on its own. Even archival research might be used to compare findings related
5 to these more dynamic approaches to enhance our understanding of their development; the
6 literature used in this paper represents only a fraction of the available works on the matter and
7 can only be considered as indicative of the advancements in research into collaborative
8 networks and Distributed Manufacturing. Although others (like Gulati, 1998, pp. 304-306)
9 reached similar conclusions, the underlying theories have not been expanded as in this paper.
10 We have not yet got to the stage that the formation of tentative theories and their evaluation
11 have resulted in grounded theory that underpins the behaviour of autonomous agents in
12 networks and that allows the design of sustainable industrial networks.
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28 **CONCLUSION**

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30 The research into Distributed Manufacturing, characterised by control of autonomous agents,
31 has exceeded the reach of information technology itself, hence it becomes necessary to
32 include collaboration. This inclusion drives the research in the direction of that into industrial
33 networks where collaboration (emerging in different forms) is common ground. Many
34 research efforts into industrial networks focus on the identification of contractual aspects and
35 the social-dynamics of inter-organisational relationships. Often, the investigation of
36 contingencies derived from perspectives on monolithic companies, like the one on Strategic
37 Networks, guides these efforts. They prove insufficient to address the characteristics of
38 networks: collaboration, decentralisation of decision-making and inter-organisational
39 integration, which calls for approaches that are more dynamic. But Distributed
40 Manufacturing has always taken autonomous agents as a starting point for developing
41 software applications for control; the loosely connected entities in contemporary networks
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3 follow their own autonomous strategies and, henceforth, the base of Distributed
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5 Manufacturing might address the issues surrounding the dynamics of networks if it includes
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7 concepts for collaboration.
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11 Models for co-evolution, originating in evolutionary biology and especially those based on
12
13 game theories, might prove fertile ground for developing more adequate collaboration models
14
15 for industrial networks. Part of the literature views co-evolution from the perspective of the
16
17 monolithic company and arrives at inferences that fit circumstances that are more static. The
18
19 decentralisation of decision-making entails that partners in industrial networks behave like
20
21 autonomous agents that mutually interact and requires dynamic descriptions. The interaction
22
23 in networks will benefit from insight in game-theoretic applications to understand the
24
25 underlying patterns, alike the investigations of ancient trading networks. Even that research
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27 shows that industrial networks display dynamic behaviour that evolves over time and that
28
29 bilateral relationships or collective networks shape the interactions.
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35 Game-theoretic models that incorporate private and common benefits and that make it
36
37 possible to analyse the instability of networks should lead to new, grounded theory. Those
38
39 models cover then the internal development of traits by agents, their belonging strategy, the
40
41 connectivity (including the inter-organisational integration) and the dynamics of the
42
43 environment. So far, these models are found in separate strands of research and need to be
44
45 synthesised into new insight that will advance our understanding of how industrial networks
46
47 operate.
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Table 1: Evolution of organisation forms (Miles & Snow, 1984, p. 19). The table indicates the evolution of organisation forms that are both internally and externally consistent. Miles & Snow state in their paper that a minimal fit is necessary for survival, and that tight fit associates with corporate excellence, and early fit provides a competitive advantage. Therefore, dynamic networks (industrial networks) require both internal fits and external fits, giving early adopters a competitive advantage.

Period	Product-market strategy	Organization structure	Inventor or early user	Core activating and control mechanisms
1800 -	Single product or service. Local/regional markets.	Agency	Numerous small owner-managed firms.	Personal direction and control.
1850 -	Limited, standardized product or service line. Regional/national markets.	Functional	Carnegie Steel.	Central plan and budgets.
1900 -	Diversified, changing product or service line. National/international markets.	Divisional	General Motors, Sears, Roebuck, Hewlett-Packard.	Corporate policies and division profit centres.
1950 -	Standard and innovative products or services.	Matrix	Several aerospace and electronic firms.	Temporary teams and lateral resource allocation devices such as internal markets, joint planning systems, etc.
2000 -	Product or service design. Global, changing markets.	Dynamic network	International/construction firms. Global consumer goods companies. Selected electronic and computer firms (e.g. IBM).	Broker-assembled temporary structures with shared information systems as basis for trust and co-ordination.

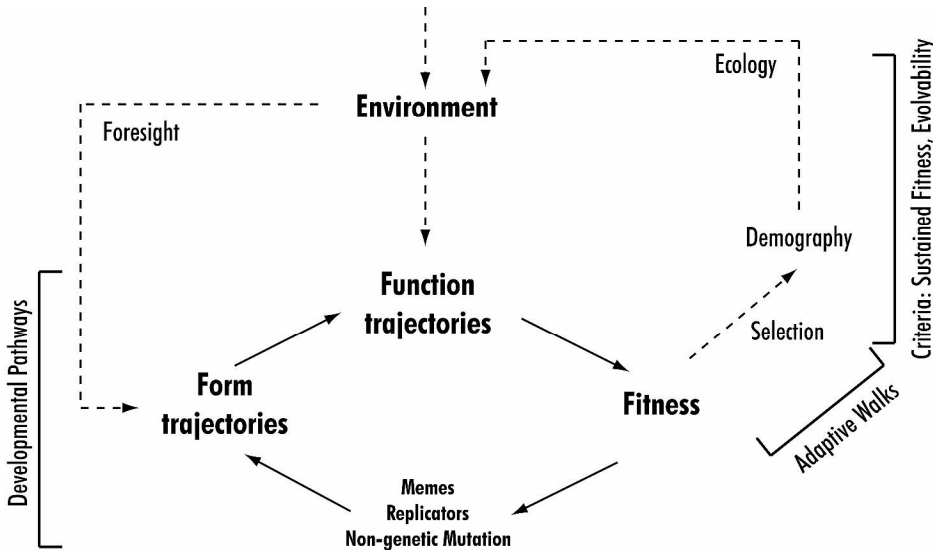


Figure 1: Evolutionary mechanisms for organisations as reference model. Memes and replicators serve as input for genetic formation, which exists besides non-genetic formation. Developmental pathways determine the form and function trajectories. These pathways also relate to organisations being a class of allopoietic systems. The selectional processes select beneficial phenotypes on fitness following adaptive walks. Organisations have the capability of foresight in contrast to organisms.

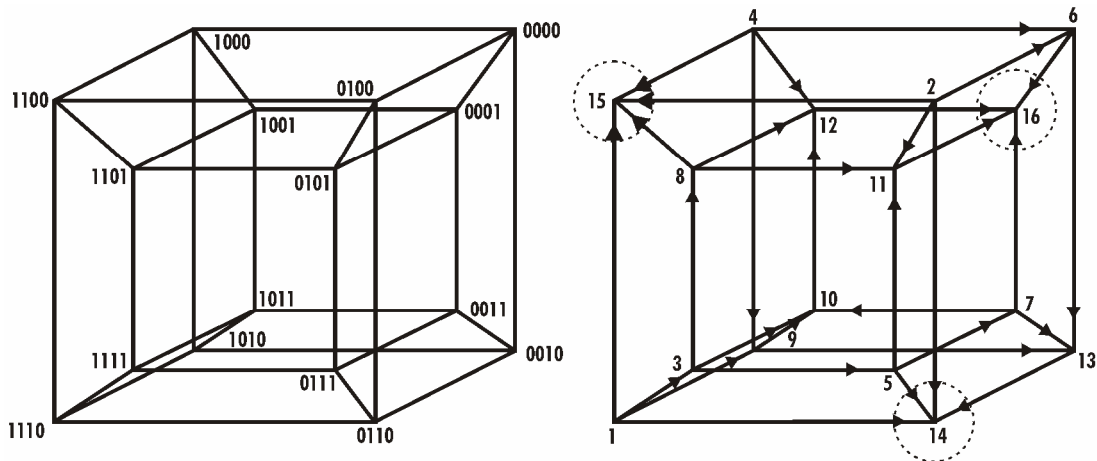


Figure 2: The N -model as proposed by Kauffman (1993, p. 38). 16 possible peptides of length 4 aminos are arranged as vertices on a four-dimensional Boolean hypercube. Each peptide connects to its four one-mutant neighbours, accessible by changing a single amino acid from 1 to 0 or from 0 to 1. The hypercube on the left represents this four-dimensional peptide space. In the hypercube on the right-hand side, each peptide has been assigned, at random, a rank-order fitness, ranging from the worst, 1, to the best, 16. Directions of such moves between adjacent positions are shown by arrows from the less fit to the more fit. Peptides fitter than all one-mutant neighbours are local optima (three in this case).

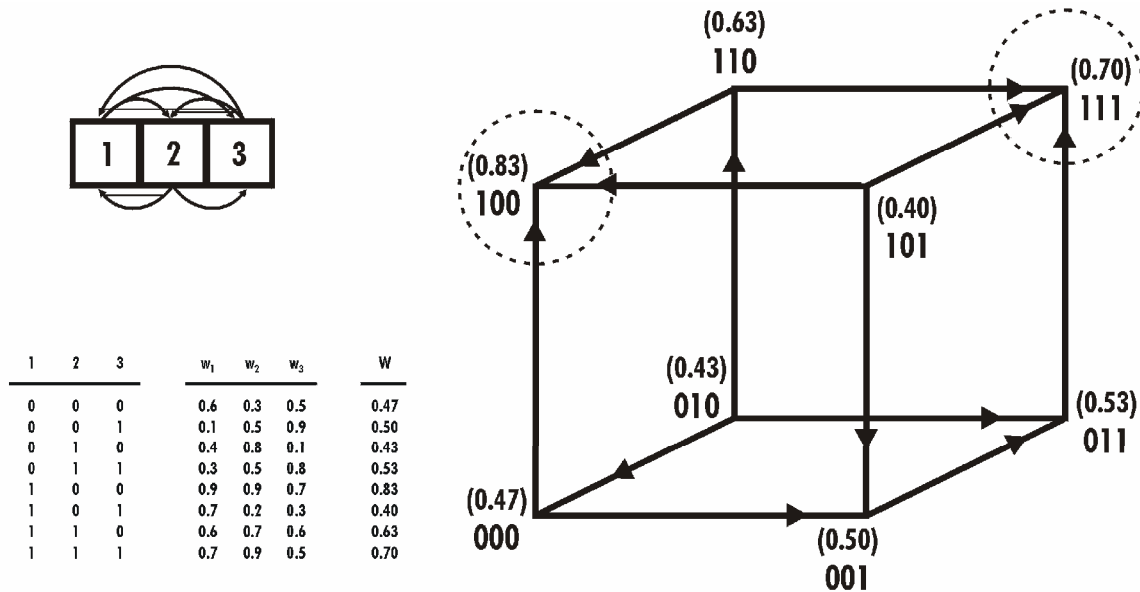


Figure 3: NK-model as developed by Kauffman (1993, p. 42). In the upper left corner it shows the assignment of $K=2$ epistatic inputs to each site. The assignment of the fitness values to each of the three genes 1, 2 and 3. These fitness values then assign fitness to each of the $2^3=8$ possible genotypes as the mean value of the fitness contributions of the three genes. The figure depicts the fitness landscape on the three-dimensional Boolean cube corresponding to the fitness values of the eight genotypes. More than one local optimum exists.

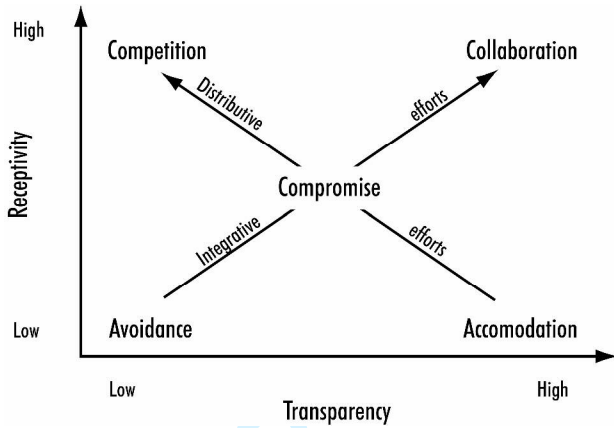


Figure 4: Individual strategies for inter-organisational learning (Larsson et al., 1998, p. 289). The integrative dimension concerns the total joint outcome, from avoidance to collaboration, and the distributive dimension indicates one party's share of the joint outcome, ranging from accommodation to competition.

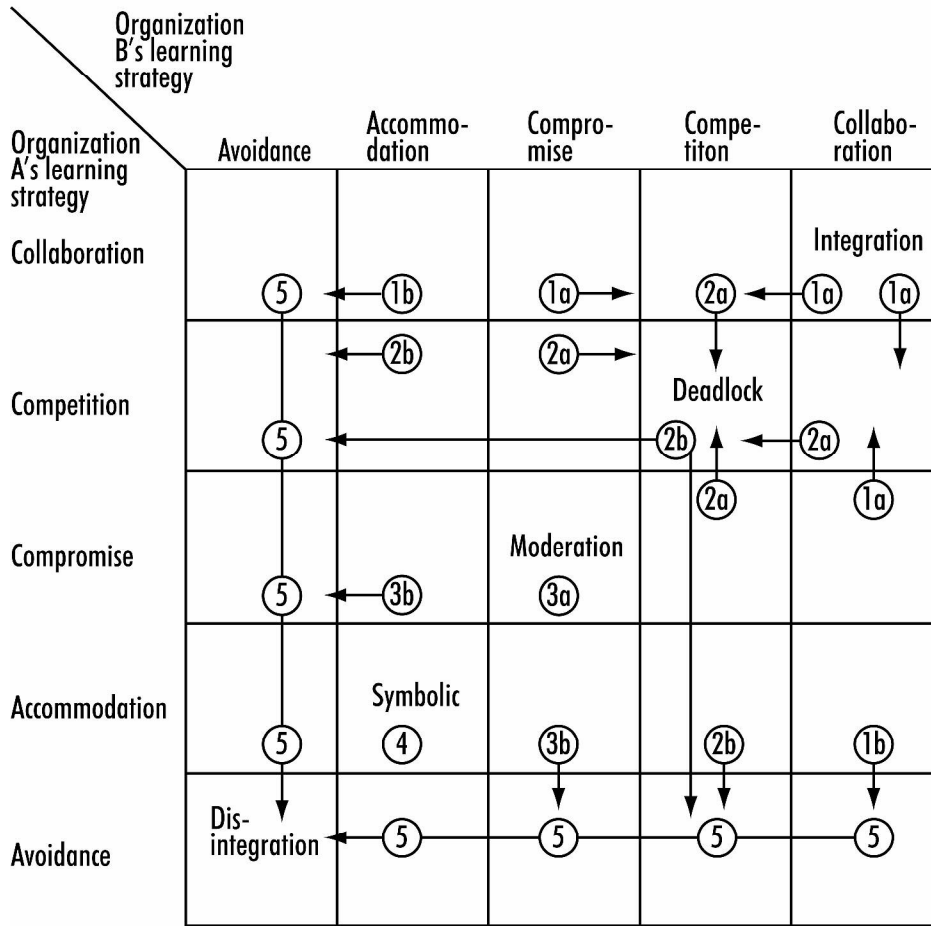


Figure 5: Dynamic Barriers to Organisational Learning (according to Larrison et al., 1998, p. 292).

The figure indicates the pathways of interaction depending on the individual organisation's actions. Arrows show which new combination is likely to develop from original starting positions determined by the actions from Figure 4. Most likely, the dyadic relationships will end in disintegration (resulting in arm-length's contracts) or collaboration.