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Towards a common framework for knowledge production and diffusion

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Abstract

A broad variety of concepts for scientific and technological knowledge, its production and governance is available in the literature of economics, philosophy of science, systems theory, and sociology. However, there is no generally accepted definition and formalisation of the relevant concepts. To guide the modelling work in NEMO, we therefore agreed on common – or at least, interoperable – conceptualisations of knowledge, starting from the observation that its production and diffusion is a localised, collective and complex activity. Hereby, from an epistemological point of view, we adopted a moderately constructivist approach by assuming that an observer produces a 'construction of an object from reality' which can be handed over from the sender to the recipient in such a way that the receiver can 'recognise the features of the object'.

Thus, although there may be no full compliance with some notions like 'organisational knowledge', we pursue a pragmatic approach to the conceptualisation of knowledge and its sharing in networks: Agents are forming network links either to acquire or to create knowledge. One of the main attributes of an agent – and one of the key features for partner choice – is the knowledge endowment of the prospective partner. Thus we essentially have a situation in which agents' properties and the network of agents' connections itself co-evolve. The representation of the agents' knowledge endowment is an element of some multidimensional space, so that the most important features of knowledge generation/diffusion, as well as network dynamcis, can be covered in the different modelling approaches in a 'sufficient' way.

Inhalt

1 Introduction

There is no generally accepted definition and formalisation of knowledge in the different scientific approaches that are involved in the interdisciplinary project NEMO. In order to provide rough guidelines for the modelling work, we therefore agreed on common – or at least, interoperable – conceptualisations of knowledge. We start from the observation that its production and diffusion is a localised, collective and complex activity. A broad variety of concepts for scientific and technological knowledge, its production and governance is available in the economic and sociological literature on innovation (Antonelli 2005; Foray 2004). However, there is no generally accepted definition and formalisation of the relevant concepts. To guide the modelling work with a conceptual foundation, we therefore agreed on common – or at least, interoperable – conceptualisations of knowledge, starting from the observation that its production and diffusion is a localised, collective and complex activity. This agreement has also a deep effect on the investigations on the desirability of network structures.

Apart from a literature review, taking into account different scientific backgrounds from philosophy of science, systems theory, and the economics of innovation, we focus on the key features of knowledge relevant in the innovation context and feasible representations used so far by the different workgroups. Through an interdisciplinary discussion process during several project meetings, we agreed on a common framework for conceptualisations of knowledge, that is suitable for both generalised random graph models (Barber et al. 2006);, generalised diffusion models (Cowan 2004, Volchenkov and Blanchard 2006) and, last but not least, multi-agent models (Ahrweiler et al. 2004) of knowledge production and diffusion in networks. This joint approach will guide the further development of fully dynamical network models.

2 Knowledge concepts in philosophy of science and systems theory

Before entering the pragmatic level of modelling, we consider it advisable to draw some attention on philosophy of science aspects of knowledge, in order to find the right balance between ‘scientific aspiration’ and ‘pragmatic feasibility’ in the modelling context. In epistemological terms, we find ourselves between two extreme positions: The realist perspective, on the one hand, implies that knowledge is justified true belief. Knowledge can be discovered and accumulated. A ‘belief’ is articulated by a statement which has to fulfil certain truth conditions and has to be justified. The constructivist perspective, on the other hand, takes on the view that knowledge is a context and observer dependent belief. This view starts with the believer, his or her context and object formation. The believer has no exempt perspective but is part of the observed. Statements about beliefs are – if they are shared by many believers – conventions.

2.1 A ‘moderately constructivist’ meta-model of knowledge

Adopting the position of a ‘moderate constructivism’, we assume that an observer creates a ‘construction of an object from reality’. The observer (sender) hands her construction over to a recipient in such a way that the recipient himself is able to recognise the features of the object (Schütte 1999, pp. 225-227). In a radically constructivist approach we would have to deny the possibility of knowledge transfer, since every subject creates his/her own personal view of reality. On the other hand, for the critical realist the meaning (reference) originates in the real object itself and does not require the perception of a subject. Thus, in NEMO, we seek to agree on knowledge concepts that are compatible with this kind of moderate constructivism.

Following Schütte et al. (2003, p. 6), we propose to employ a four-level model of knowledge that is commonly used in the literature (e.g. by Rehhäuser and Krcmar, 1996): The foundations are ‘symbols’, i.e. atoms coming from a symbol pool. Their combination is called ‘data’. Data is supposed to be processed without considering any application context. In contrast, ‘information’ means contextual embeddedness in a framework of practice. ‘Knowledge’, finally, is the subjectively meaningful network of information(s). Its usefulness for the knowledge owner is derived from insights about the relations between the information(s). Summarising the definition, ‘knowledge’ is a meaningfully organised set of information(s).

This construction of knowledge suggests a high degree of formalisation. Therefore, a distinction of knowledge into ‘explicit’ and ‘tacit’ following Polanyi (1966) is a useful amendment. For Niklas Luhmann, ‘communication’ is a threefold selection process where data processing and information sending, following the terminology above, is complemented by understanding where a receiver successfully connects meaning to the transmitted. Communication in this view is ‘sharing knowledge’.

2.2 Organisational knowledge

In the last decades, the debate between realist and constructivist interpretations of knowledge became especially manifest in different approaches to co-ordinate knowledge processes in organisations. A first type of knowledge management activities focuses on knowledge sharing and proceeds from the assumption that valuable knowledge already exists. Its major task – mostly supported or actually driven by information technology – is to enhance the supply of existing knowledge to individuals in an enterprise by capturing, codifying and sharing valuable knowledge. In the context of this approach, knowledge is a representation of a world independent of the observer. Knowledge is seen as a kind of package: true, objective, isolatable, transferable and storable in documents (Krogh and Roos 1999; Probst, Raub and Romhardt 1999).

In contrast, the second type focuses on knowledge producing and assumes that relevant knowledge does not already exist, but is something that is continuously produced and revised in a social process. It compiles methods to enhance the capacity of an organisation to produce knowledge and satisfy its demand for new knowledge. Within this approach, knowledge is defined as a dynamic social construction of reality dependent upon the specific experiences made by an individual. The main task of knowledge management from an epistemological point of view is to pay attention to existing collective and divergent constructions of reality in an organisation and to define a framework to support the interactive process of knowledge production (Güldenberg 2001; Sammer 2000; Willke 1998).

Within this approach enterprises representing autonomous, self-organizing systems are characterised by their autopoietic organisation. Open to matter and energy they are at the same time operationally closed, which means closed to information, instruction, and control. Autopoietic systems adopt no information from the environment and deliver none to the environment, but produce images and conceptions of the reality according to their specific structure (Maturana and Varela 1992; Fischer 1991). As Heinz von Foerster (1993) points out, it is the listener and not the speaker who determines the meaning. One cannot inform a system, it informs only itself: it encounters incoming stimuli from its surroundings and shapes its response by invoking appropriate knowledge contained in its structure or rule sets. Actions produce effects within the system internally or externally, the results of which are fed back into the system for immediate and future reference. Information cannot be transferred between systems, therefore information does not 'instruct' a system, but only 'initiates' internal changes. With Bateson (1988), information can be defined as a difference which makes a difference – in this sense information is to be read as the process of formatting and shaping the system.

Like information, knowledge cannot be seen as an autonomous product that can be used or transferred arbitrarily. Knowledge enables problem-solving actions and is based on the capacity for retrospection, on the discovery of regularities as well as on the embedding in patterns of experience. Heinz von Foerster has demonstrated with his 'Principle of undifferentiated encoding' that perception is the computation of descriptions of the world and that knowledge results from recursive loops of computation of computations, constructed by each person on the basis of his or her own experiences in interaction with others. To mention Heinz von Foerster again, 'you have to act in order to see if your ideas are viable.' Correspondingly, Ernst von Glasersfeld points out that what we make of experience constitutes the only world we consciously live in. Consequently knowledge can be examined only for its viability for someone in a concrete situation, but not for its universal and objective 'truth' or 'validity' in a rigorous scientific sense.

In the context of managing knowledge in enterprises, it is important to state that not just individuals hold knowledge but the organisation itself constructs and stores knowledge. 'Knowledge evolves in the minds of individual learners who sometimes go on to attract one another on the basis of their shared interests. Communities of interest then may be formed, through which groups of many individuals collaborate in the production of new knowledge of a collectively accepted kind. Some of this knowledge may later escalate into adoption by an entire organisation, after which an episode of organisational learning can be said to have occurred' (McElroy 2003, 94). Anchored organisational knowledge relies on the personal knowledge of their members, but it exists independently of the persons. Like individual knowledge, organisational knowledge is based on recursive computations of the knowledge of the individuals, resulting in the formation of 'eigenvalues' of the organisation: common practices, structures, processes, rules and patterns of behaviour. Organisational knowledge as well does not exist objectively and independently of the construction of reality by the organisation. It is based on the resulting differences when internal and external events, situations, objects and processes are continuously observed by the organisation (Krogh and Roos 1999; Walger and Schenking 2001).

Thus, organisational knowledge does not consist of discrete knowledge objects, which are explicitly documented or present in the heads of single employees. In contrast, cross-linking of heterogeneous elements of knowledge, the intelligent shaping of linkage patterns as well as the attention for the necessity of circularity determine the special meaning of organisational knowledge for the enterprise (Willke 1996).

3 Knowledge and its sharing in innovation networks

In the neoclassical school of economics, information and knowledge are already present, as elements of the endogenous growth models (e.g. Romer 1990), though they are treated as synonyms and considered as a public good, i.e. a stock, highly indivisible, inappropriable and non-excludable, so that, once produced, it can be transferred at no cost. However, the public good nature of knowledge has been increasingly questioned, since – in the view of evolutionary theory – the dynamics of economic development rests on the heterogeneity of actors, on novelty and selection. Evolutionary economists support the notion that knowledge is to a large extent embodied in minds, tacit, complex, and as such hard to acquire i.e. to be learnt. Thus, knowledge is widely recognised as the most fundamental resource in modern economies and, accordingly, knowledge creation and learning have become the most important economic processes, in order to overcome the hampering aspects of tacitness and low absorptive capacity. The increasing complexity of technology, the accelerating pace of the creation of knowledge and the shortening of industry life cycles are considered to be responsible for the rising importance of innovation networks because no single actor can keep pace with the overall knowledge creation.

The '[p]roduction and transfer of scientific knowledge within these networks usually emerges as a result of an interactive and collective process within a web of personal and institutional linkages that evolve over time.'(Tijssen et al., 2004, pp.7-8). Tijssen also gives an account of factors that favour the engagement of actors in R&D collaboration networks; and in fact, many of them are directly related to knowledge processes: Capturing knowledge of suppliers and users; a learning vehicle to access, accumulate and deploy new knowledge, capabilities, techniques and skills; the increase of efficiency and synergy through networking; and to minimise transaction costs associated with tacit knowledge and intangible assets.

In the evolutionary literature, several features of knowledge and how it is generated and transferred have been named; they are all closely related to the context of R&D collaboration networks:

- **Knowledge exchange in cases where it is not a public good:** Agents are engaged in collaborative innovation processes because of severe restrictions in their individual knowledge bases. They need to get access to external knowledge sources, and innovation networks are a prominent organisational device for this in cases of high appropriability of knowledge. With missing public good features of knowledge an automatic knowledge transfer via technological spillover effects is only rarely possible.
- **Exchange and creation of knowledge in networks:** In innovation networks actors mutually exchange knowledge which allows for both (i) extending the individual

knowledge bases of actors involved in the networks and (ii) creating new knowledge by so-called synergies or cross-fertilisation effects (so-called collective learning processes).

- **Trust:** An easy access to external knowledge sources is not possible because of the reciprocal character of knowledge exchange in networks (i.e. trust is required for knowledge exchange) and also because of several features characterizing new knowledge which do not allow for an instantaneous and efficient diffusion. In this perspective, knowledge loses its public good nature and its diffusion requires specific prerequisites on the side of the sender as well as the receiver of the knowledge.
- **Sending new knowledge:** The sender has to be able to articulate the knowledge (i.e. the knowledge needs to be codified). In cases of high degrees of tacitness of the respective knowledge severe difficulties will hinder an efficient diffusion. Besides these actor-specific obstacles in the diffusion of knowledge, also technology-specific reasons may restrict the diffusion of the respective knowledge. Technological knowledge only rarely is global applicable. Due to its local character only a small subset of technologies may allow an immediate usage of the new knowledge.
- **Receiving new knowledge:** On the receiver´s side missing absorptive capacities might prevent the smooth diffusion of new knowledge from one actor to another. Without the necessary competencies actors might not be able to apply new external knowledge, even if it made freely accessible to them.
- **Knowledge transfer requires time:** All these bottlenecks in knowledge diffusion are potentially dissolved in collaborative innovation networks. These collaborations are created for longer time spans and allow for the necessary redundancy in the communication and learning processes. Participating in innovation networks offers the possibility to interrogate (so-called evolutionary articulation).
- **Dynamic positive feedbacks:** The potential benefits of a network organisation of innovation processes are aggravated by the dynamic features of learning and knowledge accumulation. The combination of specific individual knowledge in innovation networks generates an increasing variety of knowledge in time via cross-fertilisation. Learning and knowledge accumulation are processes driven by and causing positive feedback effects.

The issue is to characterise knowledge in a way that permits it to be incorporated into models of network formation. More specifically, if network structures are being used to model knowledge creation and diffusion, how can we effectively model something as inchoate as knowledge itself.

4 The modelling context and feasible representations of knowledge

Facing the numerous approaches to representing knowledge in theory and modelling – even within the project consortium – we are led to pursue a pragmatic approach with respect to the representation of knowledge. At the most general level, agents are forming links either to acquire or to create knowledge. One of the main attributes of an agent, and one of the key features in deciding whether that agent might be a good partner, is his knowledge endowment. Thus we essentially have a situation in which agents' properties and the network of agents' connections itself co-evolve.

4.1 Knowledge as a single type

The simplest characterisation of knowledge is as a scalar. An attractive partner is one who has a lot of knowledge, suggesting he is efficient at performing a given task. The objective behind the decision of forming a link is twofold: agents care for agents who a) have a lot of knowledge themselves, and b) are well-connected to others who have a lot of knowledge. The importance of first versus second degree neighbours depends on how knowledge degrades with transmission from one agent to another. This can be cast as an issue of absorptive capacity.

With a single type of knowledge, transmission cannot be modelled as trade. Implicitly there is the 'set-superset' assumption that if my knowledge level is x and yours is y, and if $x>y$, I know everything you know plus some extra things. Otherwise knowledge could not be measured simply as a scalar. (There is perhaps a way to finesse this, which is discussed below.) Hence, diffusion is a form of spillover (an epidemic of knowledge spreading via network contacts)—when we interact, one agent's knowledge simply increases (that of the less knowledgeable) while the other's stays constant. Knowledge creation or innovation is similarly simple. It can only be an increase in knowledge levels. It is possible to make this increase dependent on stimulus from outside. For example, in Cowan, Jonard, Ozman (2004) agents broadcast their new knowledge to their neighbours. This invokes learning or imitation (mediated through absorptive capacity) but might also induce independent knowledge creation. Even so, it is not possible to get further inside the knowledge creation process, other than to say that the amount of knowledge created depends 'somehow' on the amount of new knowledge received from this broadcast or gift. It is possible to use this simple structure to get at changes in industry life cycle, for example using the idea that technological opportunities decline as an industry ages, making leap- frogging more difficult. As a model of innovation however, it remains thin.

4.2 Knowledge of several types

To get richer diffusion or innovation models it is necessary that knowledge be of higher dimension. In essence, an agent's knowledge stock can be characterised by level and type, capturing expertise levels in various categories of human capital. One appealing way to do this is to represent it in polar co-ordinates, restricting to one quadrant. An agent thus has a level of expertise, and a type of expertise belonging to a continuum of possible values. The polar representation is compact, but immediately creates what economists feel to be ad hoc assumptions regarding joint innovation. That is, if two agents agree to innovate jointly, their knowledge must somehow be combined. If knowledge is represented as a length and a type for each partner, how are these four ingredients combined? They certainly represent very different things, rendering a convincing representation of the innovation process difficult to obtain. (See Cowan, Jonard, Zimmermann 2004, for one attempt.)

A representation that somewhat obviates this objection is simply to use a vector to describe knowledge. Less compact perhaps than the polar representation, but containing as much information, in a form more naturally embedded in an economic production process. What we are aiming at here is the idea that innovation is largely the recombination of existing knowledge. Thus the knowledge production function will use existing knowledge stocks as inputs, to make new knowledge as an output. Here, elements of the partners' knowledge vectors are natural inputs to a standard production function (CES, Cobb-Douglas, or fixed coefficients (Leontieff), for example).

The other advantage of a vector representation is that it permits a richer model of diffusion. Only with several different types of knowledge is trade or barter possible, and this is a type of transaction that is commonly observed empirically.

4.3 Knowledge as collection of ideas

The universe of knowledge can be represented as a set of facts. The set can of course grow over time, but at any moment it is finite, and any agent can know or possess only a finite (not proper) subset of it. Thus a binary string represents an agent's knowledge stock. Here transmission can take place through barter or gift, but imperfect absorptive capacity makes little sense here. This is a departure from reality that makes this representation useful in some instances but not in others.

One way to introduce imperfect absorptive capacity would be to assume that it takes $n>1$ attempts to transmit a piece of knowledge from one agent to another. In each attempt the agent gains a clearer understanding of the piece of knowledge, and after n attempts understands it well enough to be thought to know it. One obvious objection is, 'What does he know when he has made between 1 and n-1 attempts?

This model lends itself naturally to diffusion (as opposed to innovation) and transactions involving gift or barter. Innovation could be introduced in two ways.

- Imitation, in which the firm spontaneously learns something that some other firm already knows.
- Innovation new to the market, in which a completely new piece of information is discovered, thus increasing the length of the (universal) knowledge vector.

A problem with this representation of innovation is that it cannot capture the path dependence in knowledge creation that we observe. There is no notion of the global knowledge stock following a trajectory through knowledge space here. It is relatively straightforward to introduce this sort of trajectory at the individual level though. One solution to the aggregate level trajectory would be to have a very large vector initially, mostly filled with zeros (unknown facts). If the vector is initially sparse enough a trajectory might be visible in the way it is filled in, as facts are discovered.

4.4 Knowledge as a collection of expertise

A second vector approach is to use a real valued vector of fixed length k. Here each element represents not a fact but a type of knowledge. Again if my knowledge of type a is x, and yours is *y*, then if *x*>*y*, I know everything you know, plus something you don't know. Knowledge here is learned only cumulatively. This seems unnatural until we observe that if there is something non-cumulative, it represents a different type of knowledge. Here diffusion can take place through barter or gift; innovation can take place through a standard production function.

Knowledge combination presents a challenge. When two agents come together, what is their joint knowledge stock? One suggestion here is simply to treat knowledge production has having 2*k* inputs. The problem here is that either there is a decision about which of the partners is the 'first' partner, or each element of my knowledge is treated identically to that element of your knowledge (in which case we have something much like an element- wise mean), or finally there is quite some randomness in knowledge output, due to the lack of determinism regarding whose knowledge vector becomes the first k inputs, and whose vector becomes the second k inputs. It seems simpler and clearer to create a joint stock. Some natural candidates: the element-wise minimum; element-wise maximum; element-wise mean or sum. It seems very likely that which of these is most reasonable will depend very heavily on the nature of the innovation production process. (On this see Cowan, Jonard, Zimmermann, 2006 and 2007).

4.5 Knowledge as action space

Knowledge enables 'action'. Every action has a conceptual level, the action orientation, where we can find our meaningful descriptions about the real world and what can be done. In that, knowledge is a 'resource' for action. Unlike knowledge itself, actions as knowledge manifestations can be observed and evaluated. For a sociologist observability is important. Therefore, you often find the statement: Knowledge is action (or something similar). You can decipher knowledge from actions though everybody is aware that the relation between concepts and actions is difficult and therefore most often black-boxed.

Actors are enabled by their **knowledge domains (capabilities)** to be active in a certain action field where their specialised knowledge about the technical correctness of a certain action – their **abilities** – can be applied building up more and more **expertise**. This framework is an action space, and treated as a 'kene triple' in a modelling approach that is utilised and adapted to our project (Ahrweiler et al. 2004); it is hardly possible to divide knowledge into elements or units otherwise but artificially. However, knowledge can turn into a 'good' when it manifests itself into products and processes – if they are new you call them 'innovations'.

A suitable modelling approach has to capture two different aspects of innovation: **Generating innovation** and **diffusing innovation**. Hereby, the emergence of the new is the most challenging task. The model has to grasp things such as invention, exploration, discovery, and construction defining criteria for novelty and looking for appropriate emerging elements on the micro-level. A little easier to model is the diffusion of innovations. Starting from the perception of a diffusing substance, one can introduce diffusion accelerators (epidemic processes, absorptive capacities, exploitation, spill-overs etc.) and diffusion impediments (Intellectual property rights, reward structures, forgetting, misunderstanding etc.)

Following the question how to distinguish **incremental and radical innovation**, the idea of knowledge landscapes is quite appealing. However, severe problems arise since one has to define distance for that purpose, and this distance is completely dependent on the observer, at least in a radical constructivist perspective. Thus it is by no means clear how to define a metric in a general knowledge space: For example, one cannot know define the distance between the ‘knowledge embodied in a wooden box with holes’ and the ‘knowledge embodied in a robot sowing machine’. In terms of disciplinary location, materials, market sector and knowledge intensity they are far apart, in terms of function and problem solving they are really close (the wooden box was the sowing technology in the middle-ages).

5 Summary and concluding remarks

Summing up, the representations of knowledge discussed for the NEMO project are rooted in some ‘moderate constructivist’ epistemological position, and fit into the context of evolutionary economics. The feasible representations are all some kind of multidimensional space representations of knowledge, so that the required features of knowledge generation and diffusion on networks, as discussed in section 3, can be covered, and were found to be mutually compatible.

These representations can be used in different simulation exercises building on specific network structures provided by the structural models in the modelling Workpackages of NEMO.

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