Modeling Lifelong Learning Networks

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Abstract

The provision of lifelong learning facilities is considered to be a major new direction for higher and distance teaching educational institutes catering for the demands of industry and society. ICT networks will in future support seamless, ubiquitous access to lifelong learning facilities at home, at work, in schools and universities. This implies the development of new ways of organizing learning delivery that that goes beyond course and programme-centric models. It envisions a learner-centred, learner-controlled model of distributed lifelong learning. This paper presents a conceptual model for the support of lifelong learning which is based on notions from self-organization theory, learning communities, agent technologies and learning technology specifications such as IMS Learning Design. Some exploratory implementation has been developed and used in practice.

Introduction

The need for better provision for lifelong learning in society is broadly recognised and is expressed in national and international policy documents. For example, the Commission of the European Communities (2000) states in its memorandum on Lifelong Learning: "Lifelong Learning is no longer just one aspect of education and training; it must become the guiding principle for provision and participation across the full continuum of learning contexts". Lifelong learning will ultimately provide a major service catering for the needs and demands of industry and society as a whole (Tuijnman, 1992; Ragget, 1996; Schuetze, 2000). The concept of lifelong learning refers to the activities people perform throughout their life to improve their knowledge, skills and competence in a particular field, given some personal, societal or employment related motives (Aspin and Chapman, 2000; Field, 2001; Griffin, 1999).

To achieve these aims of lifelong learning, educational institutions and other organisations must offer facilities that meet the needs of learners at various levels of competence throughout their lives. People must be able to use lifelong learning facilities to upgrade their knowledge, skills and competence in a discipline as required. They can also contribute to the facilities by sharing knowledge and supporting other learners. Lifelong learners are not merely the consumers of learning content, but can also be produce learning content that is of use for other learners (Fischer & Ostwald, 2002).

The use of ICT networks is crucial for the realization of the lifelong learning agenda, especially the establishment of so-called Learning Networks for lifelong learning (Koper & Sloep, 2003). A Learning Network for Lifelong Learning (LN) is a network of distributed persons and organisations who create, share, support and study learning resources ('units of learning') in a specific knowledge domain. These networks support the seamless, ubiquitous access to learning facilities at work, at home and in schools and universities.

The requirements placed on learning technologies to support lifelong learning differ considerably from those placed on technologies to support particular fragments of a learning lifetime. The time scales involved in lifelong learning, together with its multi-institutional and episodic nature are not reflected in today's mainstream learning technologies and their associated architectures.

In this paper we explore the requirements for LN's and we present the model we developed for the representation and organization of lifelong learning in ICT networks. The model is theory-based, and uses technologies such as software agents and open learning technology standards to establish an interoperable network of collaborating parties. First, we analyse the pedagogical, organizational and technical aspects of LNs. We then present an initial model for LNs that specifies the analysis in terms of requirements and formalizes the representation of an LN. Finally, we present our first attempt at implementing this model in a peer-to-peer network and discuss our findings as to whether the implementation fulfils the stipulated requirements.

Analysis

We will present LNs from three perspectives pedagogical, organizational and technical (Koper, 2004).

Pedagogical Aspects

An LN is a distributed set of people who interact to create and share units of learning in developing their competence in a particular discipline. It is a ‘two-mode network’ with two types of nodes: the members of the LN and the units of learning in the LN (Wasserman & Faust, 1994; Degenne & Forsé, 1999). The members define the learning community (LC) within the LN. The units of learning (UOLs) define the set of learning activities offered in the LN, for example courses, assessments, workshops or seminars. The core questions in this section are: How can effective LCs be developed? And how can effective UOLs be developed and used in LNs?

Learning Communities

Shaffer and Anundsen (1993) define ‘community’ as a dynamic whole that emerges when a group of people share common practice; are interdependent; make decisions jointly; identify with something larger than the sum of their individual relationships; and make long-term commitments to well-being (their own, one another’s and the group’s). Communities tend to be self-governed, self-organized and decentralized. Common goals and values and communal relationships are important moderators in forming communities. Communities have their own identity, which can change and evolve.

Wilson and Ryder (1998) characterize ‘learning communities’ (LCs) as follows: they have distributed control; there is commitment to the generation and sharing of new knowledge; learning activities are flexible and negotiated; community members are autonomous; there is a high level of dialogue, interaction and collaboration; and there is a shared goal, problem or project creating a common focus and incentives to work together.

Within the context of lifelong learning it is necessary to have an enduring membership of the community. Competence in a field evolves over a lifetime. An important requirement for lifelong learning is that the learning results are stored in a portable, standard way, for example in a portfolio. These learning results can be used to identify the LNs; position the person in the network; and provide a classification of the expertise of the person in the field. As seen from a lifelong learning perspective, a teacher is not a separate entity, but is a role that any lifelong learner can take, depending on their expertise, and relative to the expertise of whoever requires support. Anyone can start in a community as a novice and evolve into an expert. During his/her lifetime the person stays a member and is responsible for sharing knowledge and experience as required. The knowledge and support services in the community and the members' knowledge also evolve. In a permanent community, the community itself gets a structure and culture independent of the participants. We adopted this idea of lasting, evolving learning communities as a key principle for the design of LNs.

Lifelong learners must have easy, ubiquitous access to an LN, which should not be location or technology dependent. It should be accessible from anywhere by standard means of communication. In order to sustain it, it must support, among other things, interoperability standards that have been adopted, defined and agreed upon within the community.

Units of Learning

UOLs are developed and used in LNs and can serve various functions in them depending on the design, for example the introduction to a knowledge domain; acquisition of a skill; or assessment of acquired knowledge.

Members of an LN should be able to select the UOLs they need in order to attain certain expertise or competencies, given their pre-knowledge. When a UOL is selected, the person must be able to study it and provide feedback about it. When the UOL is used in practice, additional run time data can be added to the design, for example user and usage information, mail messages and forum contributions.

A UOL typically contains a learning design and learning resources. The learning design specifies the workflow in the teaching-learning process (Koper, 2001; Koper & Manderveld, 2004; Koper & Van Es, 2004). At the abstract level, the learning design describes the following process: A person gets a role (e.g. lifelong learner) in a learning context. This role entails a set of learning activities for attaining some specified learning objectives. A learning design method, based on a pedagogical approach, determines which roles get which type of activity at a given time. The learning activities are performed in a learning environment provided with resources and communication facilities. The outcomes of the learning activities are also resources that are added to this environment. Properties are defined to keep track of learners' progress. In addition to learning activities, a person can also get a role to perform support activities to help others learn. This abstract learning design model is implemented in the IMS Learning Design specification (LD, 2003) to create interoperable learning designs.

The same learning design can be used with different resources and vice versa. The process of building UOLs from learning designs and resources is called 'aggregation'. Conversely, the process of breaking down the structure of a UOL into learning design and resources is called 'disaggregation'.

These processes support the reuse of learning designs and underlying learning resources.

In order to develop effective UOLs, the learning design of the UOL should be based on an appropriate ‘pedagogical model’. A pedagogical model prescribes an effective teaching-learning process for a class of learners to achieve a class of learning objectives in a class of situations. A learning design is an instance of a pedagogical model. It is a concrete application of a pedagogical model for a specific learning objective, a target group and a specific situation. Examples of pedagogical models are mastery learning, problem-based learning, active learning, or any teacher’s notion about good teaching and learning practice. There is a wide range of pedagogical models. Some are better suited to specific disciplines, target groups, settings or learning objectives. However, there are no fixed rules for deciding which model is best in which situation (Reigeluth, 1999). At a high level of analysis, Merrill (2003) summarizes current pedagogical models as follows: ‘… the most effective learning products or environments are those that are problem-centred and involve the student in four distinct phases of learning: (1) activation of prior experience, (2) demonstration of skill, (3) application of skill and (4) integration of these skills into real-world activities’. He further summarizes the underlying ‘first principles of instruction’ by stating that learning is promoted when: learners are engaged in solving real world problems; existing knowledge is activated as the foundation for new knowledge; new knowledge is demonstrated to the learner; new knowledge is applied by the learner; and new knowledge is integrated into the learner’s world.

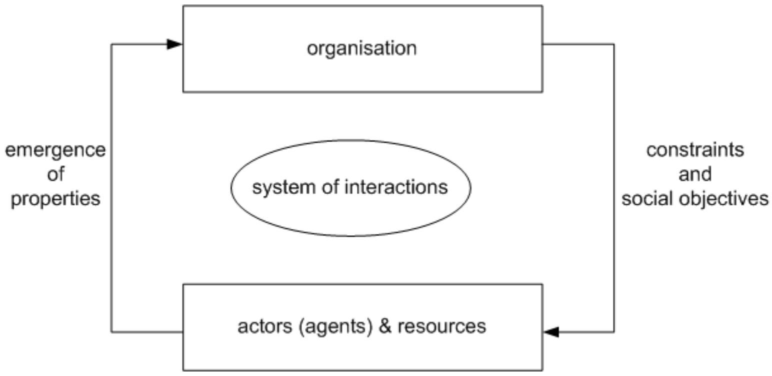
Merrill’s analysis and the instructional design approaches he studied focus on a single learner in a problem situation. In LNs this has to be extended using the notions of learning communities, or more general, social-constructivist notions (Duffy & Cunningham, 1996; Retallick, Cocklin & Coombe, 1999; Hooff, Elving, Meeuwsen & Dumoulin, 2003). One of the notions in social-constructivism is that knowledge is not absolute, but is relative to the interpretation and beliefs within communities of practice. This social notion of knowledge implies that facts, events, data and information can only be interpreted and acted upon when the social context is represented in the learning situation (Lave & Wenger, 1991).

Bransford, Brown and Cocking (2000) summarize this broader perspective on teaching and learning, stating that effective education should be: learner-centred, taking the preconceptions of learners into account; knowledge-centred, paying attention to the subject matter and what competence or mastery appear to be; (formative) assessment-centred, providing feedback; and community-centred, taking care of the application context in the real world, sharing knowledge and developing values.

Organizational Aspects

The core question to be answered in this section is which principles we should apply in organizing an LN. As we have said, LCs tend to be self-organized. One reason is that the management of a large distributed network can be very complex. Different perspectives and powers have to be balanced carefully. A decentralized management approach such as self-organization is desirable. Another reason for introducing self-organization in LNs is to increase the efficiency of the learning support structure in LNs. Active learners in an LN produce work such as written contributions to discussions and research reports. These have to be read, reacted to or reviewed. In a traditional setting, there is a danger that these tasks will be assigned solely to the teacher, whose workload will then increase considerably. Our assumption is that the application of self-organization theory can be a foundation for the establishment of efficient systems with a minimum of planning and control, while maintaining maximum flexibility to adapt to learners' needs. This will reduce overhead costs for maintenance, planning, control and quality. This assumption is based on research into self-organization theory (Varela, Thompson & Rosch, 1991; Maturana & Varela, 1992), which is grounded in complexity theory (Waldrop, 1992; Kauffman, 1995) and studies the characteristics of the social organization of communities that 'emerge' from the interactions of lower level actors. It deals with the way macro-phenomena occur as emergent behaviours from the activities of the subsystems at the micro-level (Prietula, Carley, & Gasser, 1998, p.14). The social organization that emerges (e.g. trust, grouping, role specialization, action coordination, distribution of tasks and resources, conflict resolution, quality norms and interaction standards) in its turn imposes behavioural constraints on the actors and provides for social objectives (Ferber, 1999; see Figure 1).

Figure 1 System of Self-Organization (Ferber, 1999)



Using this perspective, the organization of lifelong learning can be realized by installing technical facilities that enable distributed interactions among participants directed at a common purpose (e.g. competence development in a disciplinary field), governed by policies that stimulate participants to learn, share knowledge and support each other.

The management and application of policies in an LN is termed 'sociability' (Preece 2000, p. 26-17). Sociability governs social interaction in a community. It cannot be controlled directly, but can be supported by carefully communicating the purpose and policies of the community. Preece (p. 95-96) identifies several policies in a community: joining or leaving requirements; by-laws; codes of practice for communication; rules for moderation; issues of privacy and trust; practices for distinguishing professionally contributed information; rules for copyright; and democracy and free speech in the community. We identify the policies in LN in terms of: objectives and values; terms of use; membership/role policies; standards and quality policies; and reward policies.

An important factor in establishing self-organization is the creation of first-order and second-order feedback mechanisms. First-order means that people in the community know what their counterparts are doing or have done regarding the UOLs in the network. This provides information for navigation and behavioural models within the community. Second-order refers to feedback about the emergent properties in the system: what is the performance of the community and how is it organized (Gilbert, 1995)? For instance, there is no centralized quality control in the LN. It is expected that the network will uphold a range of quality levels, but that the feedback mechanisms (e.g. reviews and ratings) will ensure that on average satisfactory quality is maintained. Thus, factors such as development costs, frequency of use, incentives, price and satisfaction may be dynamically balanced.

Most effective self-organization systems in nature (e.g. ant colonies) depend on some specialization of roles that perform tasks simultaneously. However, this role-specialization is functional. Individuals can change roles when the demand for a certain activity increases (Bonabeau, Dorigo & Theraulaz, 1999).

The activities of persons in an LN are influenced by the reward system established in it (e.g.

personal need, reputation, money). A theory about reward is elaborated in social exchange theory (Thibaut & Kelly, 1959; Constant et al., 1994). The reward system is typically implemented in the policies of an LN.

We want to stress that self-organization implies *organization*. It is not a synonym for chaos, anarchy or disorganization. The structures that result from self-organization can, in principle, be the same as those proposed by central agencies, except that democratic principles determine the hierarchy and organization.

Technical Aspects

The core questions to be answered in this section are: How can we establish an interoperable network with distributed lifelong learners, distributed support organizations and a variety of different units of learning? And how can we support the actors in the network to perform their tasks as efficiently as possible? The first is related to interoperability specifications and standards; the second to usability and software agents.

Interoperability specifications

In order to establish a network of interacting entities in a technical sense, it is necessary for the entities to use the same underlying standards to support connectivity and exchange. For example, Internet protocols enable the connectivity of millions of computers around the world to establish a network. The entities in an LN also need to be standardized, at least within the community, if they are to connect. A learning resource created in location Y, using infrastructure X, should be usable in location Z, using infrastructure W. Standards can be defined solely within a community or LN. However, it is good practice to use existing open standards and specifications wherever possible. Several open interoperability specifications have been developed, most of them by IMS (imsglobal.org), IEEE (ltsc.ieee.org) and AICC (aicc.org).

Various standards have to be set to establish LNs. The portable coding of the learning resources or knowledge must be specified (e.g. XHTML for non-binary resources). Metadata standards such as LOM (2003), Dublin Core (2003) or RDF (2003) can be used to describe the learning resources. The IMS Question and Test Interoperability Specification (QTI, 2003) can be used for testing. However, after agreement on the set of general standards available for an LN has been reached, discussions have to continue about the customization of standards and the development of additional specifications.

A critical specification for LNs is IMS Learning Design (LD, 2003). LD implements the abstract learning design model discussed above. It enables the representation of the learning and teaching processes in a UOL to be interoperable and machine interpretable. It provides a framework for including learning activities, support activities, assessment and learning or knowledge resources. LD can express the pedagogical approach taken in the UOL, and supports personalization of learning routes and reusability (Koper & Van Es, 2004).

Usability and Software Agents

An LN's usage may be hindered if it is too complex, is unpredictable or contains errors. These factors are addressed in 'usability'. An LN is usable when it supports rapid learning, high skill retention, low error rates and high productivity. It is consistent, controllable and predictable, making it pleasant and effective to use (Preece 2000, p. 26-27). The problem with usability is that it competes with the flexibility and complexity of a system. More flexible systems have more options that tend to overload the cognitive system when not properly designed (Paas & Firrsova, 2004). Measures such as adaptable interfaces, help systems and training facilities can be used to increase the usability of the LN, but so can software agents help users perform their tasks more easily and efficiently. Software agents can be used to automate tasks normally performed by people, or support people in doing certain tasks more effectively or efficiently. Software agents are computational systems that inhabit a complex, dynamic environment, can sense and act autonomously in this environment, and in doing so achieve a set of goals or tasks they are designed for (Jennings, 1998). There are two approaches to implementing software agents: the single (complex, intelligent) approach; and the multi-agent approach (multiple agents, low intelligence, simple). These can be considered as two different paradigms. Multi-agent systems are loosely coupled networks of entities that have the following characteristics: each agent has incomplete capabilities to solve a problem alone; there is no global system control; data is decentralized; and computation is asynchronous. According to Ferber (1999), these systems have skills in social organization, cooperation, coordination, negotiation and communication. The principles of self-organization are applied in software in these multi-agent systems.

The quality of the tasks performed by software agents is dependent on the technical advancement of these agents and the state-of-the-art in the field. Some possibilities are: agents help users search for information using semantic web principles (Berners-Lee, Hendler, & Lassila, 2001); agents help answer e-mails with certain common characteristics; or agents help organize and plan the activities in an LN.

Design of a Learning Network

Based on the principles of units of learning, learning communities, self-organization, interoperability specifications and software agents, we developed a design framework for LNs. We will present this design by summarizing the requirements model and outlining a formal representation of an LN. First, we need to introduce the concept of an ‘Activity Node’ to formalize the design. Like any network, an LN can be represented as a graph with nodes. However, an LN is a two-mode network, with the nodes being LN members and UOLs. In the following sections we will aggregate the two modes into a single node, called an Activity Node (AN). An AN contains all the runs of all the versions of a UOL, including information about the members who are (or have been) active in it and the information the members have produced about it (e.g. feedback, completion data). Moreover, it contains a set of rules that govern its lifetime, specifically its ‘fading out’ and ‘staying alive’ behaviour. There are subtle differences between a UOL, a UOL run, and an AN. A UOL is the learning facility that is abstractly defined for any set of learners at any time. A UOL run is its instantiation for a specific set of learners in a certain time frame (e.g. a class, the actual run of a workshop). An AN is the set of all possible runs for different versions of the UOL.

Requirements

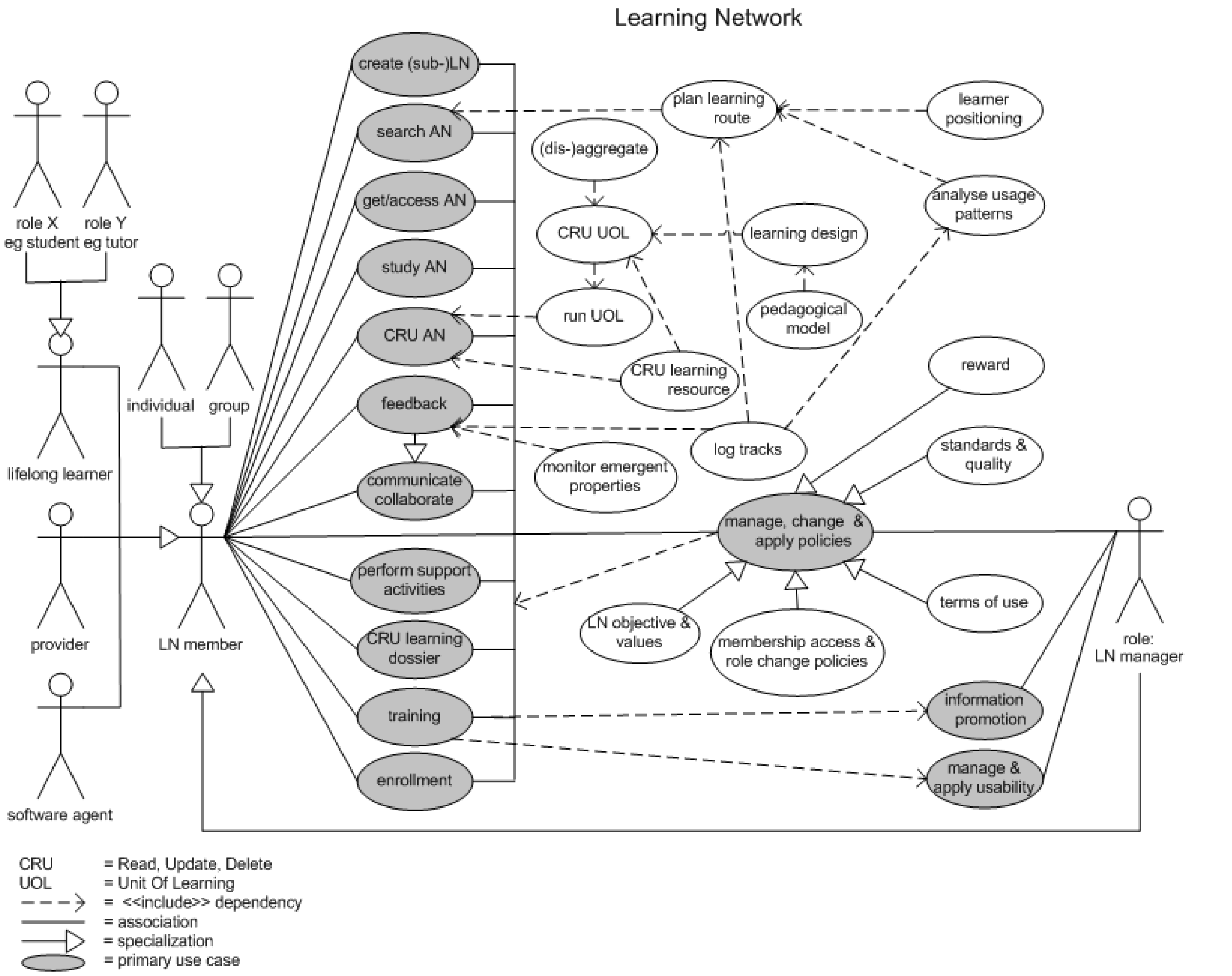
In the analysis section, several statements about LNs were formulated that can be translated into general requirements for LNs (see Table 1).

Table 1 (General Requirements for LNs)

No.	General Requirement
R1	The objective of any LN is to offer long lasting, evolving facilities for the members to improve and share their expertise and build the competencies needed in a disciplinary field.
R2	The LN should offer facilities for members to create, search, get/access and study LNs, ANs, UOLs and learning resources as a means of building expertise and competence.
R3	The LN should be governed by community policies that reflect the common goals and values of the membership. Instruments must be available to manage, change and apply the different policies (LN objectives and values, terms of use, standards and quality, reward system, membership policies).
R4	The LN should have facilities to assign its members to specialized roles according to certain role policies. Roles are not fixed. Role change policies must be available.
R5	The LN should offer facilities to search for ANs and UOLs that match the members needs and LNs, and should support flexible learning routes (positioning, logging of tracks of others and usage patterns).
R6	The LN should contain ANs and UOLs for different levels of expertise to serve a heterogeneous membership.
R7	The LN should offer ANs and UOLs in which learning designs are based on pedagogical models that are selected as suitable for the discipline, the membership and the learning objectives (e.g. problem-based and learner-centred, formative assessment, knowledge and community-centred).
R8	The LN should facilitate a high level of dialogue, interaction and collaboration within the LN and within ANs.
R9	The LN should support guidance/scaffolding, or more generally: support activities.
R10	The LN should support distributed control. The LN managers are LN members with specific assigned management tasks (according to the change policies).
R11	The LN shoud provide first order and second order feedback to all members to support the optimization of organization and quality according to self-organization principles.
R12	An explicit exchange reward system which is consistent with self-organization principles should be available in the LN.
R13	The LN should have distributed, ubiquitous access.
R14	The LN should have facilities to provide automated support (software agents) for some members' tasks to make performance more efficient.
R15	The LN should use community standards for interoperability (e.g. units of learning, learner dossiers, learning/knowledge services and resources) and provides facilities to discuss and change these.
R16	The LN should find the right balance between usability for the participants and flexibility/complexity (information/training facilities, adaptable user-interfaces, error free technology).

These requirements can be elaborated in a 'use case model'. Use cases are abstractions of scenarios in which the concrete behaviour of persons within a system, or using a system, is described (Fowler, 2000; Cockburn, 2001). A use case model contains, among other things, use cases, actors and relationships (Armour & Miller, 2001) . 'Use cases' (the ellipses in the diagrams in Figure 2) are sequences of actions required of the LN to function properly. The 'actors' (the stick figures) are the persons or software agents that initiate the use cases, perform them or benefit from them. 'Relationships' (the lines in the diagrams) link two elements to show the interaction. The diagram in Figure 2 is drawn according to the UML specifications (OMG; Booch, Jacobson & Rumbaugh, 1999).

Figure 2 Use Case Model for Learning Networks



There is only one actor in an LN, the LN member. There are three types of LN members: lifelong learners (primary actors), providers and software agents, each of which can play roles in the management of the LN. Members can act individually or in groups. Groups can be formal (e.g. company employees) or informal. Software agents can, in principle, perform the same use cases as any of the human actors, but in most situations they will support a human member in performing a specific use case. Lifelong learners have specific expertise and competence in the discipline and these must be registered and updated in a learning dossier. The competence and expertise levels stored in the dossier must be standardized to be able to position a learner in an LN. A key notion in LNs is that lifelong learners can perform all the use cases, including those that are traditionally the responsibility of teachers. Control is expected to be distributed democratically using a set of agreed policies. Providers can be educational institutions, companies and libraries that provide lifelong learners (e.g. employees), the learning services (e.g. tutoring services) or the learning resources (e.g. books, CDs).

LN members can perform a variety of primary use cases, for example search an AN to plan a suitable learning route; get or access an AN; study an AN; or provide feedback about an AN. Figure 2 shows the primary use cases as grey ellipses. The other use cases are specializations of a primary use case or are included in them.

Formal Representation of a Learning Network

Using the AN concept, we can represent the formal structure of an LN (figure 3) as a graph in disciplinary domain *D*, with ANs as its nodes $\{a1,\ldots,ai\}$. The nodes of the graph represent the available learning events, called Activity Nodes (ANs). An AN can be anything that is available to support learning, such as a course, a workshop, a conference, a lesson, an internet learning resource, etc. Providers and learners can create new ANs, can adapt existing ANs or can delete ANs. In a Learning Network, ANs are described with their metadata (title, objective, etc.) together with a link or reference to the actual AN.

An LN typically represents a large and ever-changing set of ANs that provide learning opportunities for lifelong learners (“actors”) from different providers, at different levels of expertise within the specific disciplinary domain.

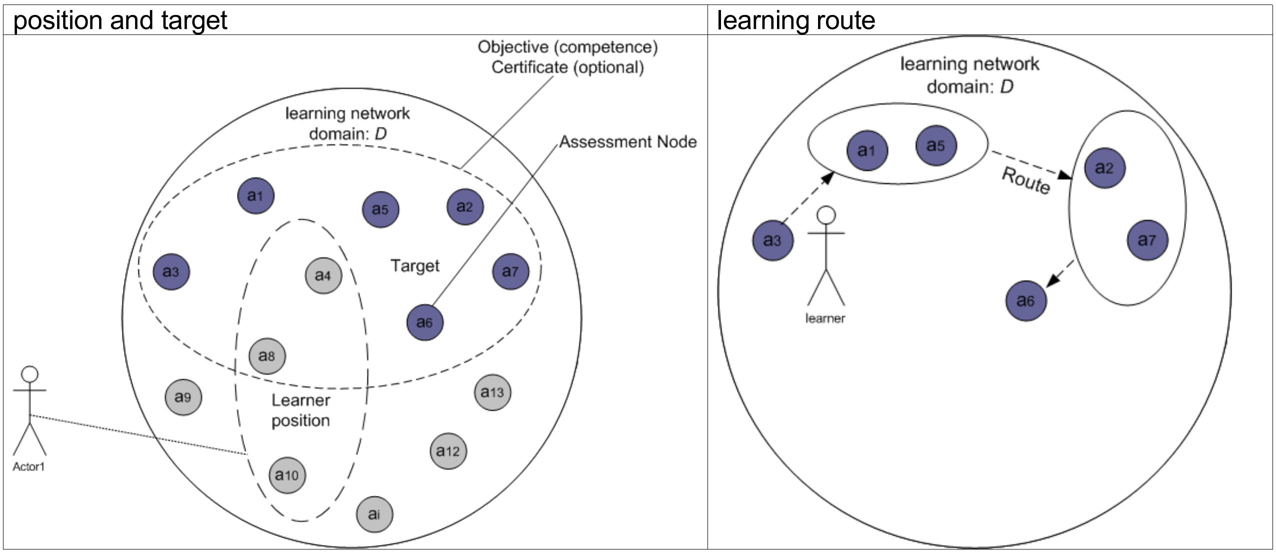


Figure 3: Learning network in domain D with activity nodes {a1,…,a13}

When using the LN, actors travel from AN to AN. The path of ANs completed sequentially over time by an individual actor is called a learning track. A track represents the actual behaviour of actors. Paths through a Learning Network that are planned beforehand are called routes (see Figure 3). In traditional education, teachers or instructional designers are responsible for this route planning (eg, curriculum planning). In lifelong learning, a different approach may be followed. Learning tracks can be shared between the participants in an LN. This can be a single track or an analysis of the aggregated, collective tracks from a set of participants to determine the most successful routes. This data is expected to help actors "navigate" in the LN.

Another concept in an LN is the learner's position in the LN (in Figure 3, the set {a4, a8, a10}). This is defined as the set of ANs marked as completed in the LN, based on the actors portfolio. This does not necessarily mean that the actor completed the concrete ANs, but covers situations in which the objectives associated with the ANs are already met by the actor (eg, as a result of exemptions arising from previous study or work experience).

A target is any set of ANs that is sufficient to reach a particular level of competence or expertise in the domain (in Figure 3 the set {a1, …, a8}). These targets and connected competency levels may be self-defined (eg, step-by-step) or are predefined in the network. When creating an LN conforming to a predefined competency framework (eg, European Language Levels/CEFRL, 2001), it is a requirement that every AN indicates its prerequisites and learning objectives in terms of the framework.

A target can be associated with one or more formal assessments to certify knowledge or a competency. This can either involve an additional, specific kind of AN, or can be integrated into one or more ANs. The difference between the set of target nodes and the set of position nodes defines the set of ANs that a learner has to perform to reach the target. Figure 3 shows this to-do list as the set {a1, a2, a3, a5, a6, a7}. Given this list, a sequence of learning steps can be established, by deciding on the order in which the ANs are taken (eg, first a3, then a1 and a5 simultaneously, then a2 and a7 simultaneously, and finally a6; see Figure 3). This decision can be based on the tracks of other successful and comparable learners in the LN. A learner can also follow a more exploratory route or can change routes on demand. Ultimately this will also create a track that can be shared.

The Architecture of a Learning Network

Using the above model and the pilot we described in Koper et al (2004b) we designed an architectural model for an LN (see Figure 4). This model is specified as a UML class model. It identifies the entities (the named boxes in Figure 4) that are of importance in a learning network and it specifies the relationships between the entities (the lines in Figure 4). The main aspects of this architecture are the following. The available LNs are listed in a web portal where persons can come-in freely for information on the LNs. People can take on different roles in the LN according to certain policies in the community. Members can be learners, tutors, assessors, providers of learning content, etc (see Koper et al, 2004a).

The LNs themselves are not a part of the portal: the portal only describes the LNs and provides links to them. This allows also for the establishment of different portals, with different views on the available learning networks, running at different locations in the world.

Software agents (Jennings, 1998) can be integrated in the architecture to support users, eg, provide recommendations on next ANs to study, to search and filter information and knowledge sources in the network and to help users in performing certain tasks, such as filling in forms or using the system. Jennings and Wooldridge (1996) identified the following four characteristics of software agents:

- they are autonomous, work on their own and have some kind of control over their actions and internal state;
- have a kind of social ability, can interact with other agents (and humans beings) via some kind of agent-communication language;
- are reactive, perceive their environment, (which may be the physical world, a user via a graphical user interface, a collection of other agents, the Internet, or all of these combined), and respond in a timely fashion to changes that occur in it;
- and are pro-active, do not simply act in response to their environment, but are able to exhibit goal-directed behaviour by taking the initiative.

The ANs in an LN are listed according to the learning goals they can be used to attain. The behaviour of learners is logged and feedback and advice can be provided based on analysis of the behaviour of learners. ANs can be rated by learners or other reviewers to indicate their quality. For every person

enrolled in an LN, a dossier, including a portable ePortfolio is kept (together with some local data). The social interaction between the different participants is governed by policies, including terms of use, quality, membership policies, etc (Preece, 2000). We distinguish two aspects in every AN: its design as available in the so-called unit of learning package, and its runtime resources. Every AN is designed to a certain extent. This design plans the activities of the learners (and other roles) and the use of resources (distributed objects and services). The design can be described using the IMS Learning Design specification (IMSLD, 2003; Koper and Olivier, 2004) that represents the complete elaboration of the unit of learning package, including learning design, and resources.
When a unit of learning package actually runs as an AN, additional runtime resources become available. Examples are mail and conference contributions, and also the traces and resources produced during additional and non-described activities.

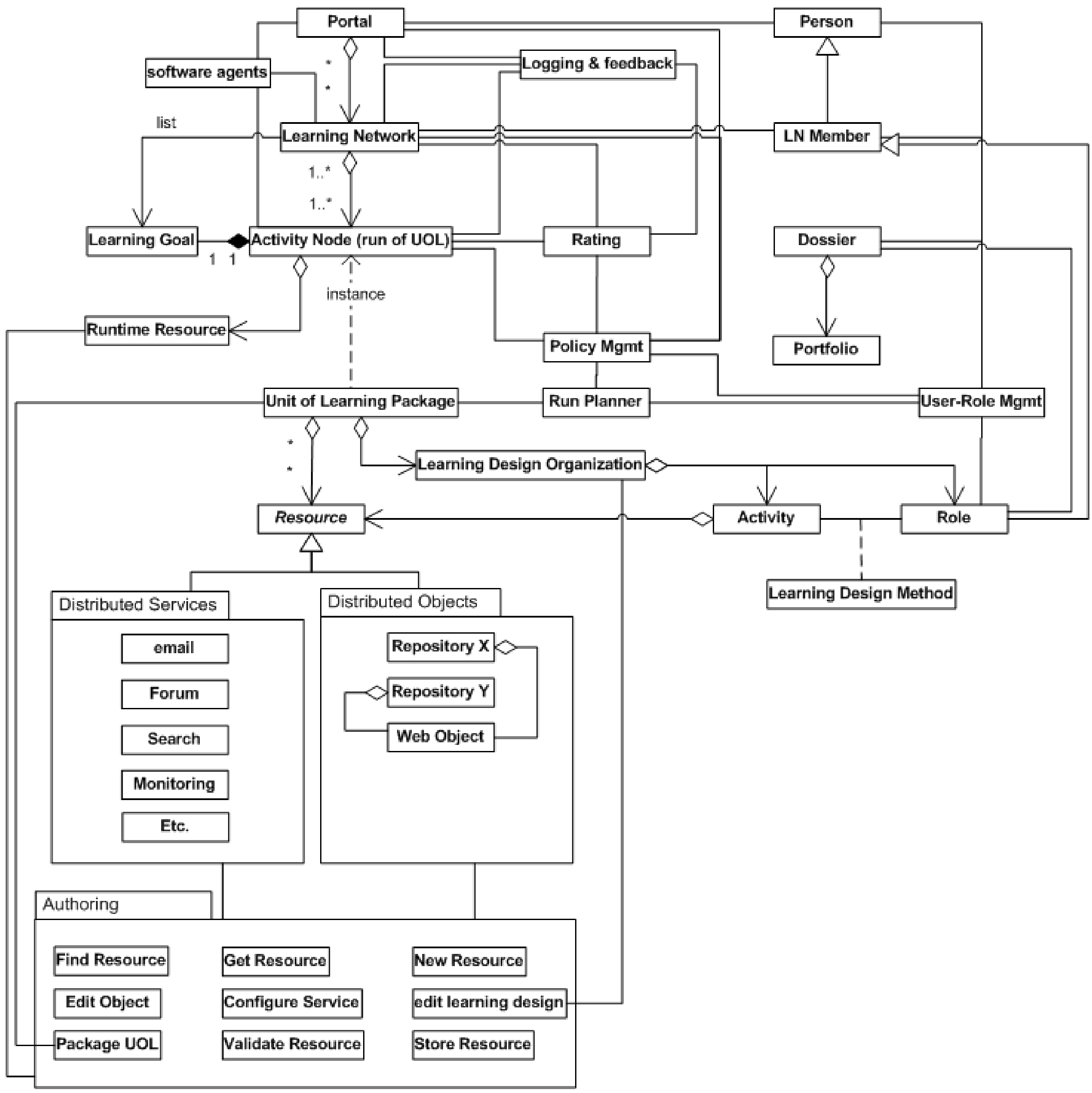


Figure 4. Conceptual model of a learning networks architecture

Simulation of a Learning Network

In order to test some of the assumptions about the dynamics of learning networks, we created a simuation programme of a learning network. The programme and experiment itself is presented in another publication (Koper, 2005). The study is focussed on the selection process of units of learning within a learning network. One of the problems learners face in a learning network is to select the most suitable path through the units of learning in order to build the required competence in an effective and efficient way. The idea is that learners can be supported in selected more adequate UOL's by providing navigational support (through collaborative filtering, also called indirect social interactions). One of the questions learners can have when searching for learning opportunities is: Given my current knowledge and competences, and given my personal characteristics, preferences and circumstances: "When I want to learn more about topic X, or want to build up more competence in domain X, what UOLs can I study best and in what order?"

The hypothesis was that introducing an indirect social interaction mechanism to support the selection of suitable UOLs will increase the proportion of learners who attain their study target in a learning network for lifelong learning.
A learning network has been simulated in which learners search for, enrol in and study units of learning, subject to a variety of constraints: a) variable quality of the different units of learning, b) disturbance, i.e. interference by priorities other than learning and c) matching errors that occur when the entry requirements of the selected unit of learning do not align with the pre-knowledge of the learner. Two conditions are explored in the network: the selection of units of learning with and without indirect social interaction. It was found that indirect social interaction increases the proportion of learners who attain their required competence in the simulated learning network (by around 10% under optimal conditions).

The simulation was implemented using the Netlogo (version 2.0.1; 7 May 2004) multi-agent simulation environment developed by Wilensky (1999). The learners are the agents ('turtles') who are moving in an environment that consists of a variety of different ANs ('patches', see figure 5). Several settings can be modified in the interface: the number of ANs (0-180), the number of weeks (0-1040), the simulation runs, the mean number of learners entering the system every week (0-1000), the risk of disturbance (0-100%), the matching error (0-100%), the minimum and maximum quality of a ANs (each 0-100%), the mean weekly study time a learner has available (0- 40 hours), the study load for a AN (0-200 hours) and the proportion of learners that will follow the advice given based on indirect social interaction (pheromone strength, 0-100%). The source of the simulation program can be found at: http://hdl.handle.net/1820/249 . Figure 5 provides a snapshot of the user-interface.

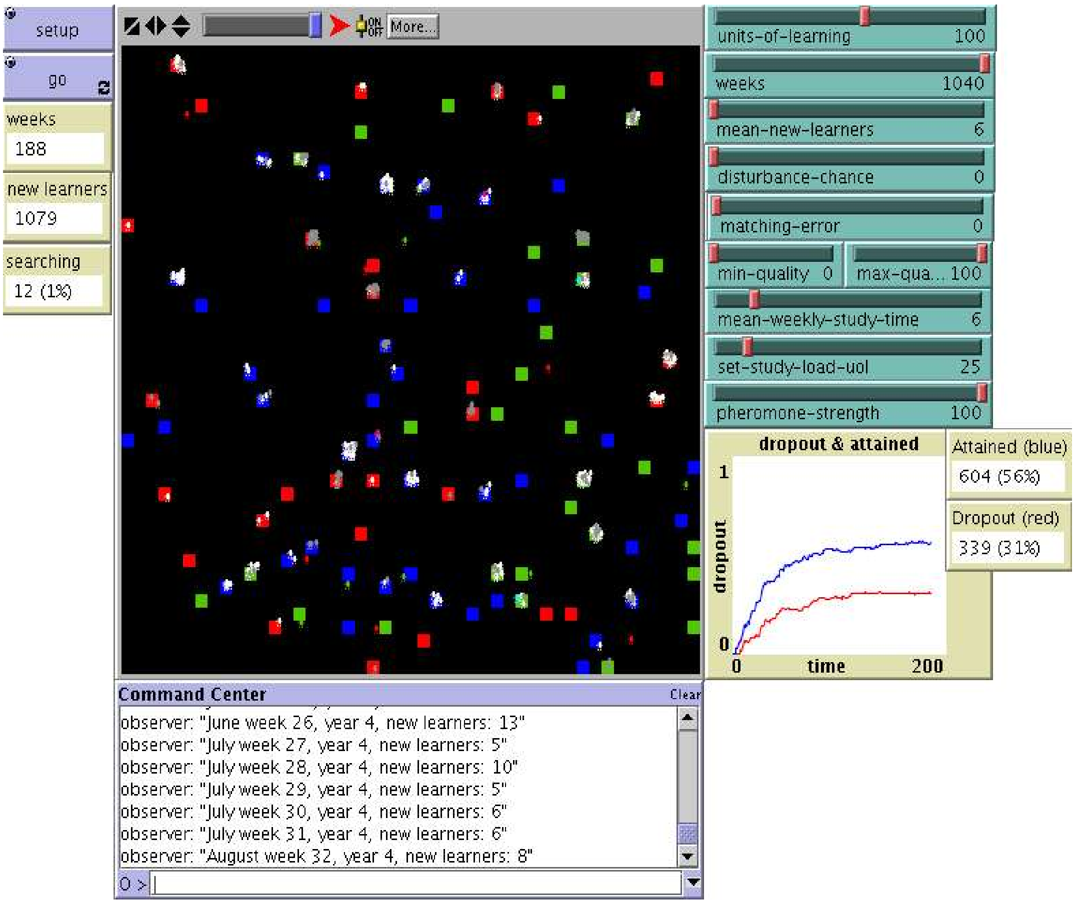


Figure 5. Simulation of a Learning Network

First implementations

Several pilot implementations have been created and experimented with. The results of some are published in journals. The first implementation was an implementation in the peer-to-peer system Groove (http://groove.net). The platform was arranged as a learning network and used for the (experimental) professional training of e-learning experts. The results are reported in Koper (in press). The second implementation has been done for the project LN4LD, that aimed at setting-up a learning network for professionals interested in e-learning standards, more specifically the IMS Learning Design Specification (http://www.imsglobal.org). This implementation has been reported in Koper & Tattersall (2004). At the moment we run a third implementation for the EU UNFOLD project (http://www.unfold-project.net) that is a slightly changed version of the second one (the portal has been replaced by a joint UNFOLD portal).

The central question of all pilot implementations were twofold: First, to ensure that the architecture is implementable and second, to examine whether the resulting LN meets its functional requirements. The first question can be answered positively - we were able to set up an infrastructure (the last ones completely based on Open Source components). It is too early to evaluate the results of the second aim. This will be done in future publications.

Conclusion

We have presented a framework for the design of a distributed network to support future lifelong learning based on self-organization principles and technologies such as LD, agents and ICT networks. In order to explore how to implement the requirements, we created a simulation programme, build pilot implementations and used these in practice. The study of LNs is still in its exploratory phase. A great deal of future research and development work remains to been done to refine the framework, improve the implementation and evaluate the effectiveness and usability of the facilities in practice. We will perform further work in feedback for navigation, learner positioning, calculation of learning routes based on positions and targets, suitable reward systems and the use of software agents.

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