Graphic Tools for Knowledge Representation and Informal Problem-Based Learning in Professional Online Communities

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ABSTRACT: The use of graphical representations is very common in information technology and engineering. Although these same tools could be applied effectively in other areas, they are not used because they are hardly known or are completely unheard of. This article aims to discuss the results of the experimentation carried out on graphical approaches to knowledge representation during research, analysis and problem-solving in the health care sector. The experimentation was carried out on conceptual mapping and Petri Nets, developed collaboratively online with the aid of the CMapTool and WoPeD graphic applications. Two distinct professional communities have been involved in the research, both pertaining to the Local Health Units in Tuscany. One community is made up of head physicians and health care managers whilst the other is formed by technical staff from the Department of Nutrition and Food Hygiene. It emerged from the experimentation that concept maps are considered more effective in analyzing knowledge domain related to the problem to be faced (description of what it is). On the other hand, Petri Nets are more effective in studying and formalizing its possible solutions (description of what to do to). For the same reason, those involved in the experimentation have proposed the complementary rather than alternative use of the two knowledge representation methods as a support for professional problem-solving.

1. Introduction

In the discussion group, when trying to best explain one's viewpoint, oral communication is often accompanied by simple diagrams drawn on the spot either on paper or on a board. One therefore gives a sort of conceptual image (van Lambalgen and Hamm 2001; Stokhof 2002; Wheeler 2006) of the portion of knowledge to be discussed. This in turn triggers a process involving explicit, implicit and tacit knowledge (Polanyi 1975; Nonaka and Takeuchi 1995). The same thing often occurs also during interaction among members of an online professional community. In this case though, instead of paper or boards, *ad hoc* graphic editors are used which allow the online circulation of graphical representations as a support for collaborative interaction. This article, in particular, will refer to two specific methods for the graphical representation of knowledge (Concept Maps and Petri Nets) and related software applications.

2. Graphical Representations

Graphical representations are de facto a language of communication and, like any language, syntactic rules are needed for it to act as a medium in communication between two or more individuals (Donald 1987). Hence, specific graphic languages have been defined and formalized that are geared towards knowledge representation (hierarchical representations, semantic networks, concept maps, approaches to the representation of procedural knowledge, etc.). Their development has been given considerable impetus from the field of artificial intelligence and, more in general, from all those areas which have attempted "to capture in digital" knowledge domains. They are formally represented so that they can be used by specific software engines: see for example, intelligent systems, decision support systems, semantic webs (Bosch 2006) and simulation systems.

Thanks to their simplicity and effectiveness, some of these graphic languages later spread beyond the specific area from which they originated where their use was often more simplified and less rigorous (Trentin 1991), so that even non-specialists could capitalize on the basic concepts. The question is: when are these graphical representations useful for the professional communities? A first consideration regards their effectiveness in facilitating the multi-perspective study of a given knowledge domain and/or area of exploration: a new knowledge, the solution to a problem, the functionalities of a complex system. The representation of concepts through graphics amplifies, in the eyes of the interlocutors, the existence of multiple interpretations of one subject of study or debate (Cunningham 1991). A second consideration concerns the community's need for technological aids to improve the flow and organization of community knowledge (Shipman 1993; Prusak 1994; Haldin-Herrgard 2000).

We are aware the knowledge sharing processes (theoretical and procedural) are favored by two types of technological support: one for interpersonal communication and the other for the collection and management of information and knowledge (Auger et al. 2001). Both cases need to give a conceptual schematic representation of the knowledge domain of reference (or portions of it) for a given community. Graphical representations can give an inside view of the conceptual interconnections between elements making up the knowledge that is being discussed and shared. It is therefore an effective way to facilitate the communication of conceptual images as well as the semantic organization of informative, documentary and factual material contained in the community memory (Lave and Wenger 1991). This last aspect is particularly interesting as many research engines now use conceptual representations of the knowledge domain in which they work for the selective recovery of information (for example http://www.webbrain.com).

Before dealing with the experimentation which is the subject of this article, details of the two underlying representation tools of knowledge are summarized here below.

3. Concept Maps

A concept map is a coherent visual logical representation of knowledge on a specific topic which encourages individuals to direct, analyse and expand their analytical skills (Novak and Wandersee 1991; Halimi 2006). The approach was developed by J.D. Novak (1991) based on Ausubel's theories (1963; 1968) and Quillam's studies on semantic networks (1968). Concept maps use diagram representations which highlight meaningful relationships between concepts in the form of *propositions,* also called *semantic units,* or *units of meaning*. A proposition is the statement represented by a relationship connecting two concepts. Therefore, there are two basic features used to construct concept maps: *concepts* and their *relationships* (Figure 1).

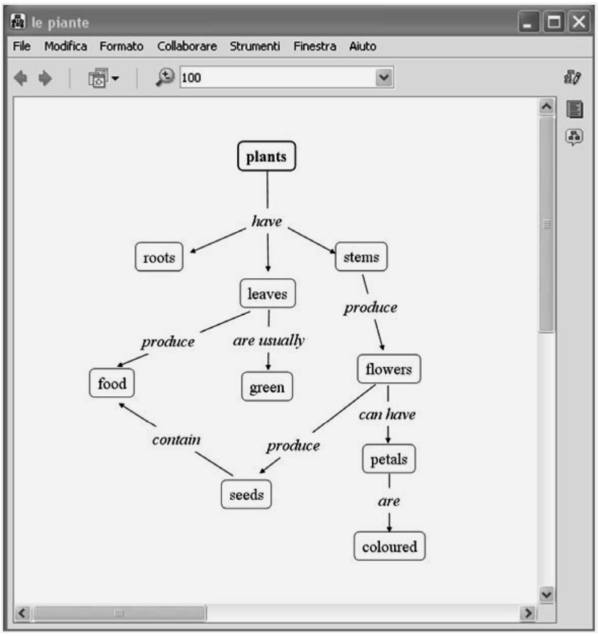

Figure 1. Example of a concept map drawn with CMapTool

Besides the two basic features, a concept map is then characterized by hierarchical relationships between concepts and by cross-links between concepts belonging to different domains of the same map.

Various graphic tools for editing concept maps have been developed and the dialogue window in Figure 1 shows of one of the best-known: CMap-Tool (http://cmap.ihmc.us/). Many of these environments are able to link the different concepts to a variety of items (documents, images, films, URLs, other concept maps) with the possibility then of converting them into HTML format, thereby creating structured repositories that can be accessed online. This, for example, is one of the possible ways to organize an online community's shared memory.

Designing concept maps with these software applications is very simple and here, for example, is how one can work with CmapTool:

- after opening a new map and double clicking on the white area, the starting concept may be defined (Figure 2a);
- by clicking and dragging the arrow one can create a link between a new concept and the starting concept (Figure 2b);
- then the two concepts and the relation type linking them have to be described (Figure 2c).

Figure 2a. The starting concept

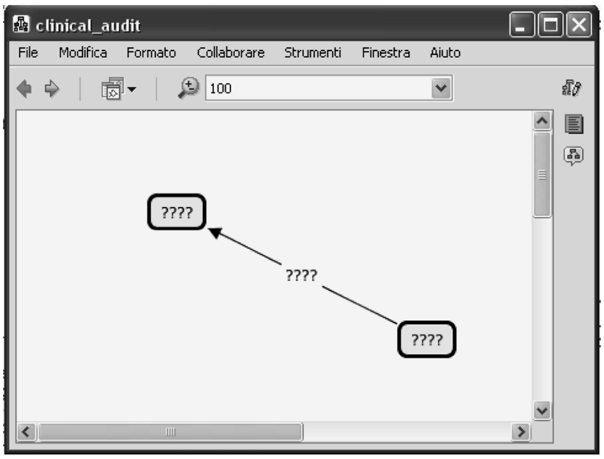

Figure 2b. The link between two concepts

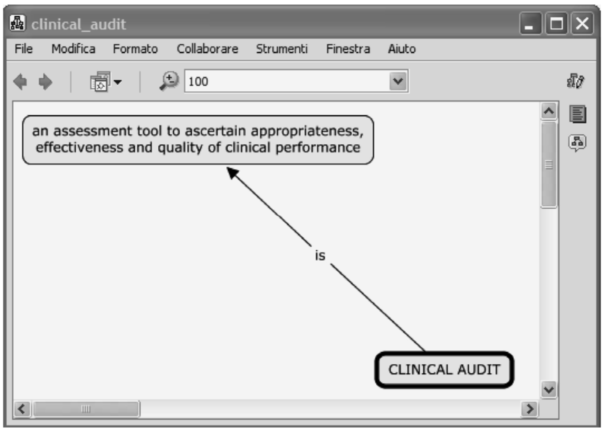

Figure 2c. Description of concepts and relation type

By proceeding in such a way, it is possible to obtain graphical representations like the one reported in Figure 3 showing a maps produced during the experimentation described here.

When very complex knowledge domains have to be described, such as the Clinical Audit in Figure 3, the corresponding concept maps tend to become much larger and difficult to manage. For this reason, CMapTools provide a function to compress/explode sections of the map being drawn. For example, by clicking on the symbol ">>" that appears to the right of "evidence-based practice", the map linked to that concept expands (see Figure 4). Then clicking on the symbol "<<" will take you back to Figure 3.

4. Petri Nets and Procedural Knowledge Representation

Petri Nets provide an effective way to describe and analyze models, whether complex systems, processes, knowledge domains, etc. (Peterson 1981). On account of this characteristic, they are often used in the graphical representation of procedural knowledge.

4.1. Resources and activities

A Petri Net is an oriented graphic in which two node types are represented: *resources* (indicated with circles in Figure 5) and *activities* (indicated with segments)—in literature on Petri Nets these nodes are respectively called *places* and *transitions* (Peterson 1981).

A graphic arc that is directed from a resource to an activity indicates that the resource is necessary to carry out that activity. Similarly an arc that is directed from an activity to a resource indicates that the resource is the product of the same activity.

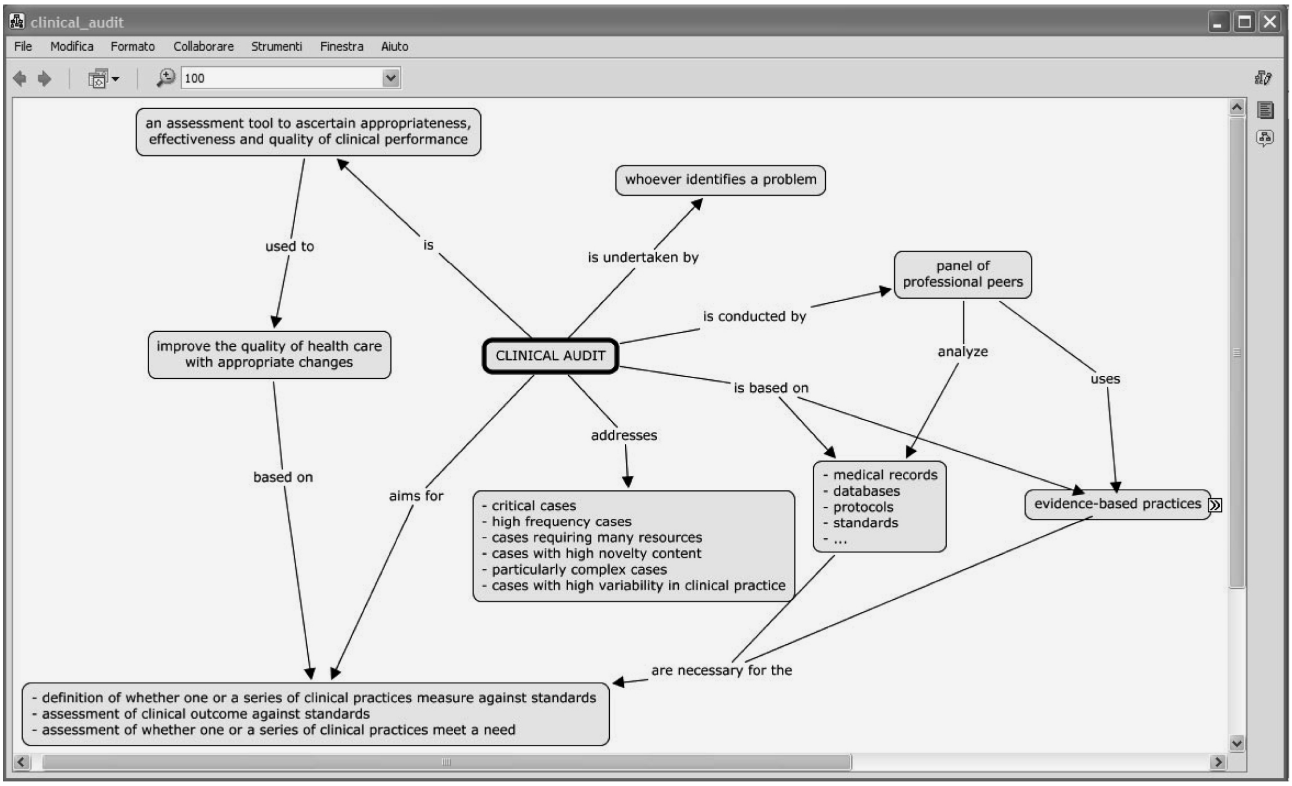

Figure 3. A concept map on the Clinical Audit developed with CMapTool

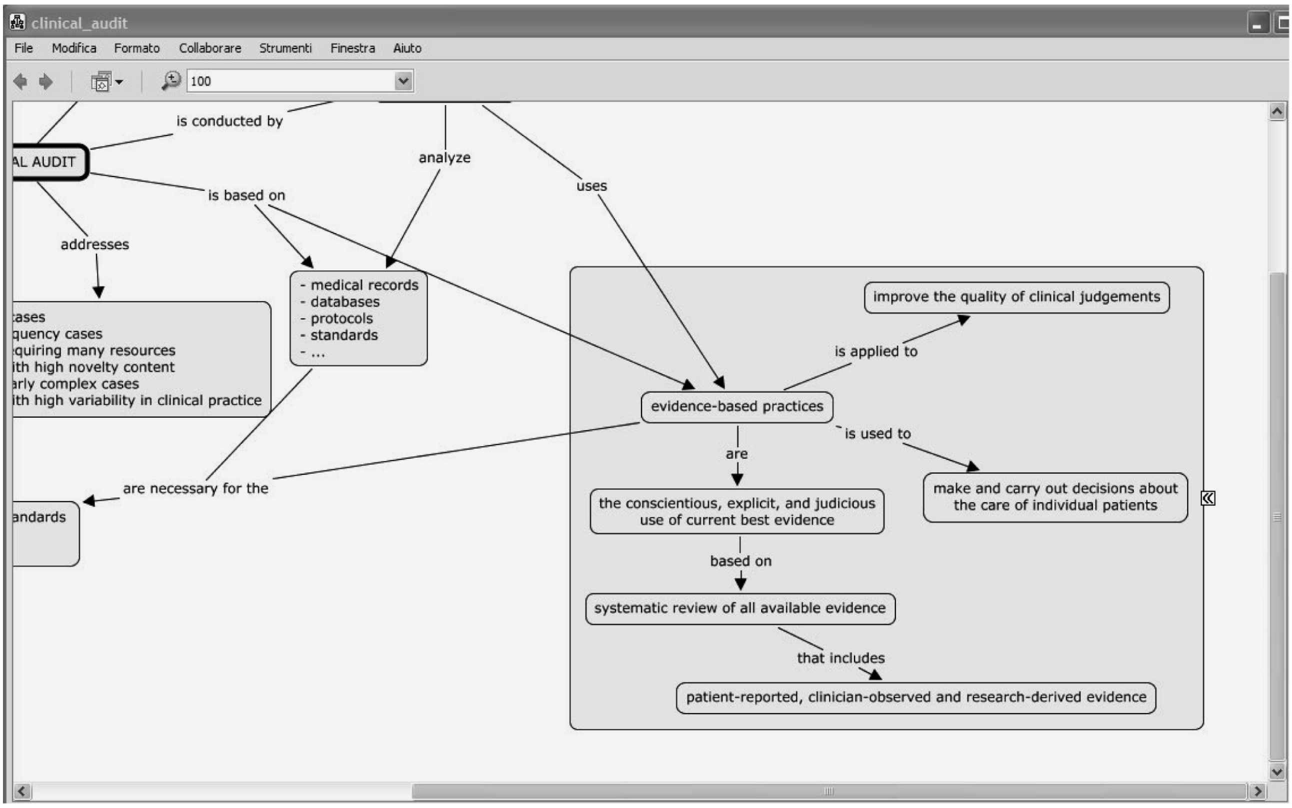

Figure 4. Example of a complex concept expansion

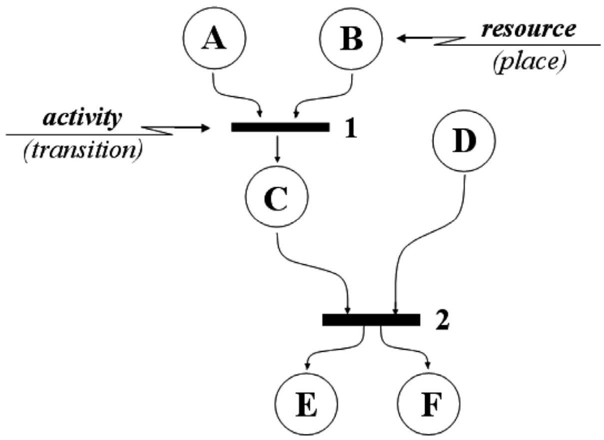

Figure 5. An example of Petri Net

What has just been listed are, so to speak, the basic "ingredients" to give shape to Petri Nets according to the use suggested within the experimentation referred to here. In actual fact, the theory presupposed by the Petri Nets is much more articulated and rigorous (Peterson 1981). In our case only the key concepts have been used to enable the two communities involved to assess the general philosophy governing the specific approach.

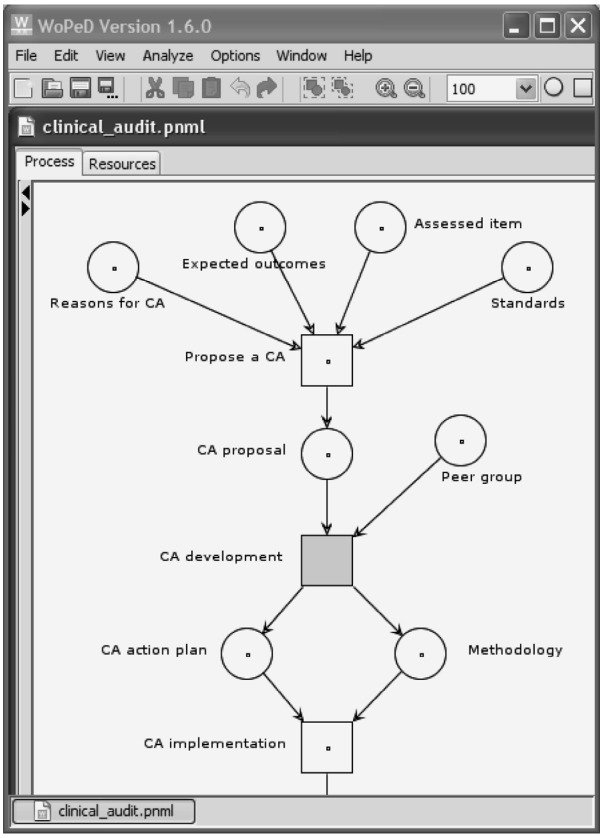

Figure 6. Example of environment to edit and implement Petri Nets

Just as for concept maps, ad hoc software environments have been developed also in the case of the Petri Nets. By way of example, Figure 6 shows the dialogue screen of one of these environments, specifically that of WoPeD (Workflow Petri Net Designer— http://www.woped.org/).

The features of such applications not only provide an editing environment of Petri Nets, but also check syntax functions and simulation of procedures/systems that they describe.

4.2. Successive refinements (top-down expansion)

Starting from an initial Petri Net - in attempting to describe the process/procedure or knowledge domain with even greater precision - activities, resources and links are often increasingly added. This therefore produces very complex graphs that are hard to process and read. A good method to overcome this drawback is to describe the network through successive refinements (or stages), expanding it using a top-down approach (Trentin 1991). In the first stage an overall (undetailed) representation is given of what one wants to describe. The resources and main activities are reported together with their respective interconnections. In the same network the complex activities are then highlighted that will be described in more refined detail in a specific subnetwork. See, in Figure 6, activity "AC development" represented with a grey square.

The following stage involves developing the refinement sub-networks giving a detailed description of the more complex activities. For example, Figure 7 reports the refinement of activity "AC development" shown in the Petri Net of Figure 6.

The refinement process is iterated until the desired level of detail given to the representation is attained.

The refinement activity is a consequence of the need to foster the so-called "functional abstraction" (Stein 2002), the process through which the attention of the individual or whole group/community focuses on one aspect of what is being described at a time.

This is a process developed stepwise. It begins with an overview of the subject matter, such as a professional issue, where the key elements characterizing it are identified (macro-representation of the domain). In the following steps, each key element is isolated and described in more detail by breaking it down into less complex sub-elements (for example, a complex activity is broken down into sub-activities). This is

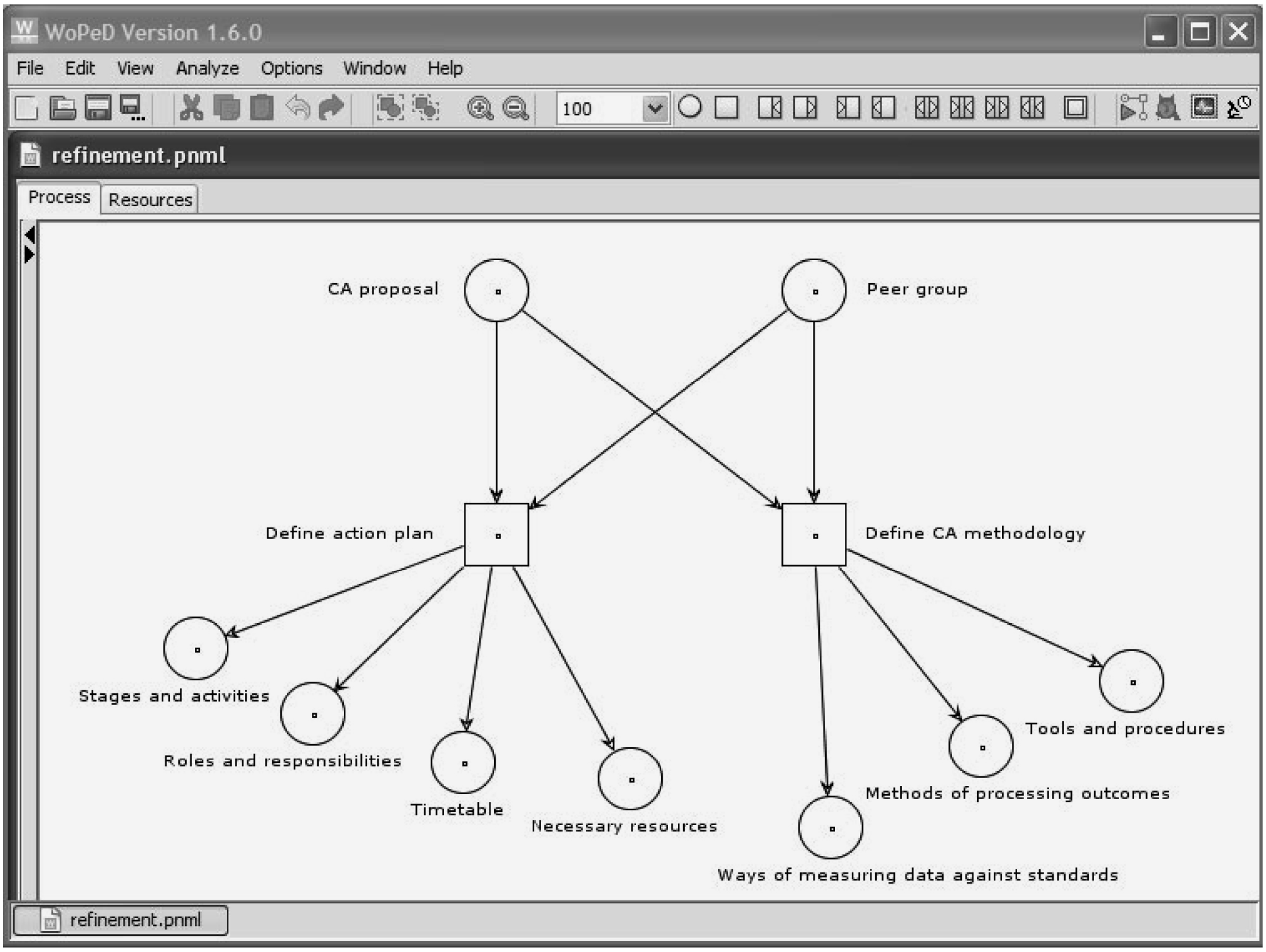

Figure 7. Example of refinement derived from Figure 6

done by trying to abstract as much as possible from what is within the confines of the element that is considered one by one (the other elements), to guarantee maximum success of its specific analysis.

Should this refinement step be inadequate for a deep analysis of the element being dealt with, the refinement process is iterated until the level of detail is considered the most functional to reach the final objective (analyzing a situation, solving a problem, describing a complex system).

5. Research Issue

The use of graphical representations is very popular in information technology and engineering. Although the same tools could be applied effectively in other areas, they are not though since they are not well known or are completely unheard of. This is due to study curricula and/or training courses where there is no occasion to learn these techniques and technologies since they are not considered important for a given disciplinary/professional area.

This is the reason why - within the two specific projects aimed at fostering the launch and development of professional communities in the health care sector - research was carried out on the use of graphical approaches to professional knowledge representation. The aim was to analyze and discuss their actual usability and effectiveness in fostering collaborative interaction, debate and reciprocal clarification during a process geared towards examining a specific professional theme/issue.

6. Experimental Setting

Two distinct professional communities have been involved in the research. The first (Audit community) was made up 31 head physicians and health care managers pertaining to Local Health Unit 11 of Livorno (Tuscany Region) who had the task of dealing with the theme of Clinical Audit, the key elements characterizing it and the working methods to carry it out. The second (Alert community) formed by 18 technical staff from the Department of Nutrition and Food Hygiene coming from all the health care units in Tuscany. In their case, the task was to define the organization of a Regional Working Group on the problem of managing food alerts.

In both cases, as already mentioned, concept maps and Petri Nets have been proposed as methods for graphical representations of knowledge. The development of each graphical representation has been divided into three stages:

- a face-to-face meeting for the first familiarization with the graphic approach and the related editing software;
- two weeks of online collaborative activities in sub-groups;
- a closing meeting to evaluate and compare the graphical representations produced, and to discuss the online collaborative process implemented to produce them.

The participants were divided into sub-groups of 5-6 units and were asked to structure their work into two one-week periods:

- individual drawing up of one's draft of the graphical representation;
- sharing of graphical representation and convergence towards one single sub-group version of it.

To co-construct the two representations the following applications have been used:

- CMapTool (http://cmap.ihmc.us/) and WoPeD (Workflow Petri Net Designer) (http://www.woped.org/) respectively for the development of concept maps and Petri Nets;
- Moodle (http://moodle.org/) as environment to run interpersonal group communication.

7. Methodology

At the end of the collaborative activity, the participants were given a questionnaire divided into 4 sections:

A. *Learnability,* intended to pinpoint the times and possible learning difficulties of the approaches to the formal representation of knowledge used in the experimentation.
B. *Study and/or problem-solving*, intended to research the perception of the general usefulness of the tools proposed for the study activities, analysis and search for solutions.
C. *Usefulness on an individual level in one's own professional practice*, intended to research the perceived usefulness of tools proposed in relation to an individual use in one's own professional practice.
D. *Usefulness in facilitating collaborative group work,* intended to discover the perceived usefulness of tools proposed in fostering or not fostering group work when dealing with aspects related to their own professional practice.

In the questionnaire, two questions are associated with each survey indicator: one with a closed-ended answer based on attributing a score (on the Likert 1-5 scale); the other with an open-ended answer asking to explain the attribution of the above-mentioned score or to give further information about the same indicator. 25 participants belonging to the Audit community and 16 to the Alert community answered the questionnaire anonymously.

8. Results

The survey data revealed positive evaluations regarding the professional use of proposed graphic formalization methods. However, there were various and sometime considerable differences between what was expressed by the two communities. This likely to be related to the different roles covered by the respective individuals: on the one hand, positive but lower scores were given by the Audit community made up mainly of people with a managerial role; on the other hand, higher scores were assigned by the Alert community made up of staff with a more technical role. A more analytical examination of the participants' answers is provided in the next section.

8.1. Learnability

As shown by Table 1, both groups stated that they found it more difficult to enter the logic of the Petri Nets than the concept maps.

Learnability	*Audit*	*Alert*
How easy has it been for you to master the logic and syntax of the concept maps?	3,1	3,7
How easy has it been for you to master the logic and syntax of the Petri Nets?	2,6	2,8

Table 1. Average data relating to answers on learnability

It is a fairly common reaction, met in other similar experimentations (Trentin 1991; Stein 2002), and should be related to the greater effort of abstraction (and of dissection) that the top-down development of a Petri Net requires. The free answers given by the participants show how the use of concept maps seems to best mirror their way of coping with professional problems i.e. considering the elements characterizing them all together and simultaneously. The use of the Petri Nets, with a top-down approach, generally baffles the professional not used to functional abstraction mechanisms which are more familiar in information technology and engineering.

This was confirmed by directly observing the participants' first approach towards elaborating a Petri Net where individuals tended to draw a very detailed, and therefore complex graph already at the overview stage of the knowledge domain. Some open answers given by participants pointed out, among the probable causes of difficulties, how they are used to a sequential approach to analyzing problems which is closer to the logic of flow-charts (used occasionally by some of them) than to the logic of top-down.

8.2. *General usefulness for study activities, analysis and problem-solving*

To best understand the convergences and divergences expressed by the participants on this point, we will firstly make a quantitative comparison of the average scores assigned by the two communities and then summaries the usefulness of the two approaches in relation to every single activity indicated in the questionnaire.

8.2.1. *Quantitative comparison of the scores assigned by the two communities*

As can be observed in Figure 8, the trends of average scores attributed by the two communities are fairly similar even though they are quantitatively different. The only divergence that is rather noticeable corresponds to the use of concept maps for study activities. In this regard, 8 members of the Audit community justified the low score claiming that drawing up a concept map on a given topic can be done only if one already has sufficient knowledge about it. They

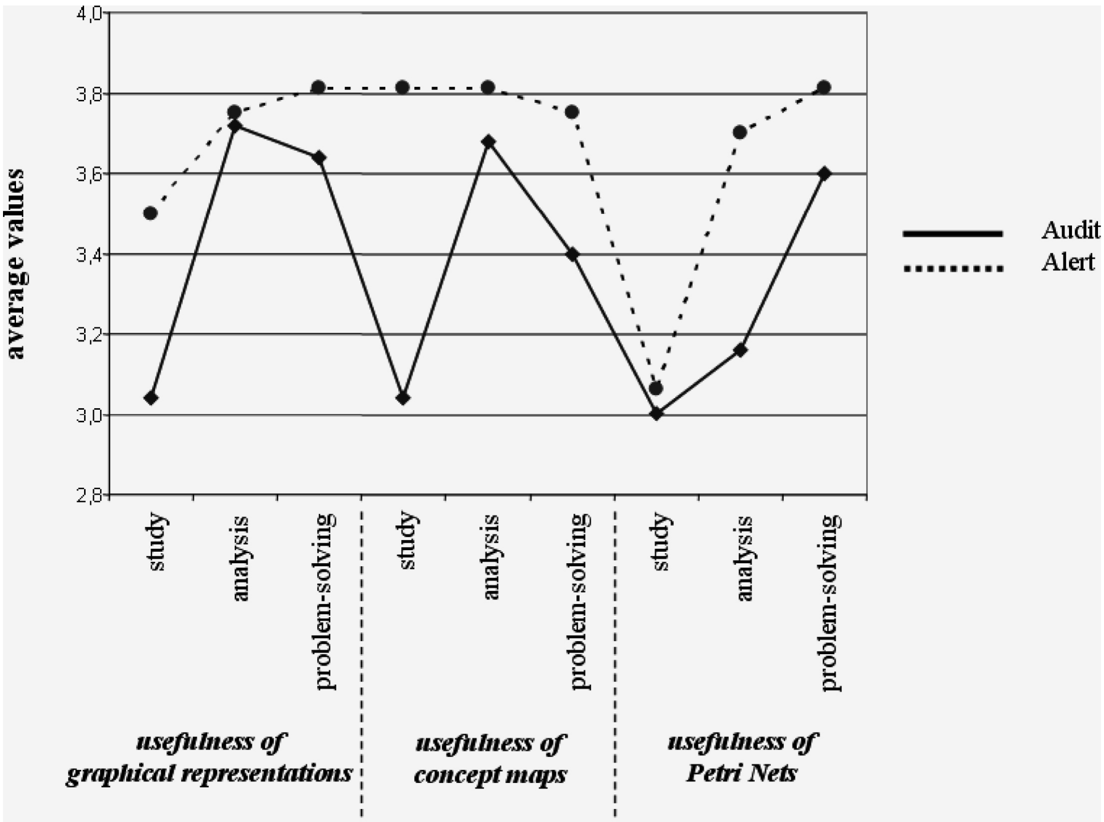

Figure 8. Quantitative comparison between the average scores assigned by the two communities in relation to the usefulness of graphical representations in their profession

therefore think that the use of the concept maps can be more useful as a self-check tool of one's learning than as an aid to studying (at least the basics). On the other hand, the rather high score attributed by the Alert community should be related to their idea of using the concept maps as a tool to support the collaborative study processes.

8.2.2. Summary on the different usefulness of the two approaches

Apart from the deviation between the quantitative evaluations formulated by the two groups and the above-described divergence, from the graph in Figure 8 it can be deduced that:

- the graphical representations are considered useful particularly for analysis and problem-solving activities and less useful for study activities. The evaluation of the Alert Community is an exception to this in correspondence with the use of concept maps;
- both communities showed concordance (despite attributing rather different average scores) in evaluating that the use of the concept maps are more recommended in analysis activities whilst that of the Petri Nets in problem-solving activities.

To sum up, the participants indicate that the concept maps are more useful in describing "what it is" whilst the Petri Nets in describing "what to do to."

8.3. Usefulness of graphical representations on a personal and group level

After the general considerations, described in the previous sections, participants were asked to evaluate the perceived usefulness of the two graphic methodologies as a tool for both personal and group use in their professional practice. Here are their evaluations:

Personal usefulness of graphical representations	*Audit*	*Alert*
How much do you think Concept Maps can/could be useful in your professional practice?	3,3	3,8
How much do you think Petri Nets can/could be useful in your professional practice, for the representation of procedural knowledge?	3,3	3,3
How much do you think Petri Nets can/could be useful in your professional practice, to describe complex situations/systems?	3,2	3,6

Table 2. Average data relating to the personal usefulness of graphical representations

As can be seen, both communities gave between average and high average scores regarding the personal usefulness of graphical representations.

The attitude changes when instead the same tools are considered for collaborative group activities.

Usefulness of graphical representations in group work	*Audit*	*Alert*
How much do you think Concept Maps can/could be useful in group work?	3,7	4,1
How much do you think Petri Nets can/could be useful in group work, for the representation of procedural knowledge?	3,8	3,8
How much do you think Petri Nets can/could be useful in group work, to describe complex situations/systems?	3,7	3,9

Table 3. Average data relating to the usefulness of graphical representations in group work

A comparison between Table 2 and Table 3 shows how the participants underline how graphical representations are more useful in group work than in individual work. Here, both communities have shown a certain convergence of opinion, although there are the usual deviations in average values.

From the diagram in Figure 9 it is interesting to observe how there is an appreciable divergence between the two communities regarding the usefulness of the Petri Nets. The Audit community believe they are more effective for representation activities of procedural knowledge. On the other hand the Alert community consider them more useful for those activities connected to the description/analysis of complex systems. This is for both individual and group activities. Again, the divergence of opinion is likely to be related to the members' role within the two different communities in the respective local health units.

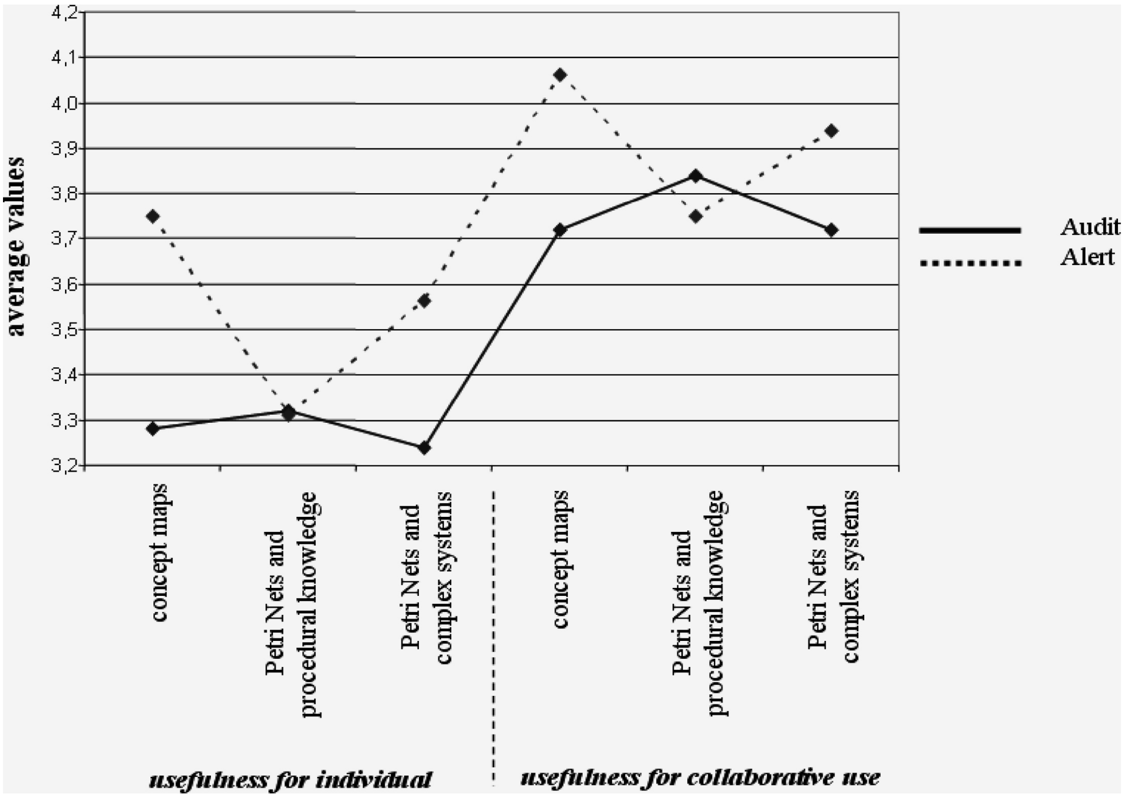

Figure 9. Comparison between the average scores assigned by the two groups regarding the usefulness of graphical representations respectively for individual and collaborative use

9. Conclusions

Perhaps the most interesting result emerging from the research is the idea of combining the use of the two graphic tools for professional problem-solving activities. In particular, as the participants indicate explicitly in some answers, the concept maps are believed to be more effective in analyzing the knowledge domain related to the problem to be faced. On the other hand, the Petri Nets are thought to be more effective in studying and describing the procedures to solve the very problem.

Indeed this is confirmed by the typical stages characterizing problem-solving strategies (Heller and Reif 1984; Gick 1986):

1. analysis of reference scenario related to the problem;
2. description of what is already known regarding the specific problem;
3. formalization of the problem and of its possible breakdown into sub-problems;
4. identification of actions to undertake to provide a solution to the problem and/or individual sub-problems where it can be broken down;
5. identification of necessary resources to carry out actions determined in the previous point

As can be observed, in the high stages (see points 1-2), where the question is to define the problem in terms of "what is it", the concept map would in fact appear to be the most suitable tool. In the successive stages (3-4-5), the Petri Nets would instead have the advantage of favoring the procedural description of "what to do to", at a macro level (solution overview) as well as micro level (solution details to sub-problems comprising the general problem).

With regard to the procedural representation of knowledge, it is worth pointing out how some participants found Petri Nets more effective than flow-charts in describing processes/solutions. This is due to at least two reasons:

– because besides indicating the link between activities characterizing a process, Petri Nets require the necessary resources for their development to be defined (flow-charts focus only on the statements);
– the top-down refinement helps focus step by step on the specific parts of the process and therefore

avoids managing the complexity of what is being studied/analysed with just one graphical representation.

These are a fairly interesting conclusions that could lead to new developments in researching technological solutions to support the integration of the two methods of formal knowledge representation discussed here. The solutions need to be able to offer, through the same software environment, support functions to the conceptualization and to the proceduralization in problem-solving activities.

These activities, as is known, provide the ideal opportunity to trigger informal peer-to-peer learning processes which are typical in online professional communities.

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