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# Understanding Petri Nets in Health Sciences Education: The Health Issue Network Perspective

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**Abstract.** Scarce literature exists as to the use of Petri Nets (PN) to model the dynamic evolution of health issues in a deterministic way. Starting from the HIN (Health Issue Network) approach, the paper aims at describing the suitability of PN in supporting the Case–Based Learning method for improving an educational simulation environment in which students can manage realistic clinical data related to the evolution of a patient's health state over time.

**Keywords.** Health Issue Network, Case-Based Learning, Electronic Health Record, Petri Nets, Medical education

## 1. Introduction

The increase of both life expectancy and incidence of chronic diseases and disabilities in western societies that goes under the name of "epidemiological transition" [1] implies that nowadays physicians must provide healthcare activities over time to patients with multiple chronic diseases and, eventually, with an acute concomitant condition. Unfortunately, the concept of time is not present in current models of clinical reasoning [2-4], as they focus on the cognitive process of making a diagnosis and do not address the problem of how medical conditions evolve over time in a patient's clinical history, and/or how each condition interferes with the evolution of the other co-existing conditions. Case–Based Learning (CBL) is one of the most effective methods for teaching/learning clinical reasoning [5]. CBL has been successfully implemented through computer-based simulations [6], but these "virtual patients" are generally acute cases rarely described under the perspective of health evolution over time. Although the clinical question "What is the diagnosis in this patient?" remains pivotal, our aim was to develop the ability to answer to three other important questions, that is: starting from the available information on a patient in his/her present state (i.e.

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given a specific pathophysiology and treatment), (1) how health conditions may evolve in the future given the present patient's health status? (2) which past health conditions have possibly evolved in the present health status? (3) which health conditions have influenced the evolution of other health issues?

The HIN (Health Issue Network) approach was introduced [7] to improve CBL in a simulation environment for medical education. HIN allows: (i) reconstructing the implicit knowledge that lies behind and origins the physician's way of thinking, turning it into an explicit knowledge that makes possible to extract real clinical cases from Electronic Health Records; (ii) formalizing the description of an evolution path of a health issue of a person, through the implementation of the Petri Nets (PN) formalism [8], which is capable of translating HIN's key concepts in a graphical language. In HIN the PN marking represents the health status of a person, which evolves from one issue to another: each place node can only contain one token at a time. The transition from a HI (place node of the PN) occurs via a well-defined evolution (transition node of the PN) – PNs are bipartite graphs. Moreover, HIN model is a P/T safe net [8]. More details on the HIN model can be found in [7].

The present work investigates more in depth how Petri Nets, and therefore the HIN model, are an accurate way to represent the evolution of a patient's health state over time. The article summarizes the main features of the HIN model, discusses why PNs are suitable as a formal model underlying the HIN model and highlights the added value of HIN project.

## 2. Basic concepts of Health Issue Network

The guiding idea of HIN is a network of clinical problems as a basis for modeling a person's medical history. Each episode of care starts with an initial clinical problem (e.g. a symptom) and is described by its evolution together with the healthcare activities that make up the care path implemented to solve the original issue. The HIN model is characterized by two key concepts underlying the evolution of a health state:
(i) *health issue* (HI), that is any problem related to a patient's health (diagnosis, diagnostic hypothesis, symptom, sign, condition or risk factor, iatrogenic problem, general class of problems) [9], and; (ii) *evolution*, that is any change in a HI through which the patient moves from one health state to another. Five fundamental evolutions have been identified: *examining in-depth, worsening, complication, recurrence and improvement*. A HI can evolve for its own dynamics and/or – if more than one HIs occur in the same patient – be influenced by other HIs in its evolution. Both evolutions and influences are intended as probabilistic events, but in the real history of a patient, a HI evolution has occurred or not: alternative paths (evolutions in conflict) do not exist.

## 3. The choice of Petri Nets

In order to represent the evolution path of a person's health state, the choice of the Petri Nets formalism is based on the characteristics of the evolution path, as these well match with the properties of the PNs. Moreover, PNs allow to reduce the complexity of real clinical cases of patients with chronic multimorbidity into a rather simple mathematical model, which allows a representation of cases suitable for an educational environment, in particular: realistic as to its ability to reproduce the concepts of evolution of HIs and influence between HIs; customizable according different learning outcomes. Here following are some of the properties of PN related to their use in a HIN-based simulation environment to represent clinically meaningful situations:

the PN is a *linear system* – the aim of the HIN approach is to extract real cases from medical records and let the students carry out exercises based on real/realistic data. The learning outcome is the ability to identify the HI evolutions that really occurred. A patient's clinical history is the "sum" of the evolutions of each HI and, at any given time, the patient's health state is the "set" of the active HIs. The evolution over time of a patient's health state can then be represented as a linear system composed by a series of defined states. For example: in a patient with chronic pulmonary disease (COPD) and initial prostatic hypertrophy (BPH) these co-existing HIs make up the initial health state and the clinical history is composed by all the evolutions of these HIs. PNs represent a series of transitions in a deterministic manner. Moreover, in PNs the effect of a "sum" of input perturbations is equal to the "sum" of the effects produced by each individual perturbation, with the possibility of breaking up a linear problem;

the PN is a *discrete distributed system* – not all HIs are connected to each other: this implies that the evolution of a patient's health state actually comprises parts (subnets) that can be independent from each other. In the above example, the BPH can worsen and produce the need for surgery without any influence on COPD. A PN – as well as the system of the evolving health states;

the PN (as evolution of a patient's health state) is an *asynchronous system* – the evolution concerns one HI at a time and not more HIs together. Since each health state can be interpreted as sum of several partial and independent subnets, an evolution only influences a part of the overall state; the firing of an evolution at a time preserves the locality of evolution of HIN diagram: two unrelated evolutions "never occur at the same time". In the above example, surgery makes the HI BPH evolve into "operated BPH". Because of the process of care (surgery) the HI COPD may evolve in "acute respiratory failure". If the patient has another unrelated HI (for example a symptomatic uncomplicated diverticular disease), this can evolve or not, but in any case, its evolution is recorded in a different time than the other ones;

a PN is a *system without memory* – when an evolution takes place, a new health state must be assessed to envisage potential health evolutions: new possible evolutions may have been enabled and some others disabled; the identification of the new potential evolutions doesn't depend on how the new health state has been reached. Furthermore, for the educational purposes of HIN, the input to every single evolution of an HI is made up of all the HIs that make the firing of that evolution possible. In the above example, in managing the patient with a present state of BPH and COPD, a physician can only envisage through what series of evolutions the patient got to his present state. The set of previous evolutions are summarized in the actual state but cannot be detailed or inferred in any way.

**Table 1.** The correspondence between evolution for a patient's health state and for Petri Nets

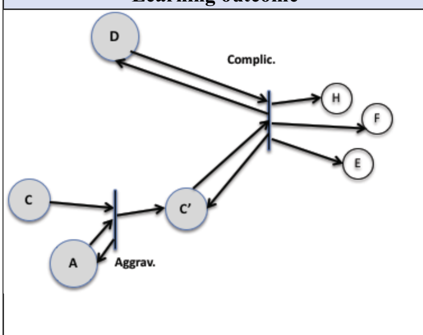
| Evolution of a patient's health state | Petri Net |
|---|---|
| Health Issue | Place |
| Evolution | Transition |
| Evolution path of a Health issue | Firing sequence |
| Health state | Marking |
| Clinical history | Reachability graph |

Tab.1 shows the kernel of the correspondence between the concepts of the evolution for a patient's health state and those for a PN system.

## 4. Results: the use of Petri net in the simulation environment

The HIN method also deploys the computational properties of PNs. The three previously reported clinical questions can be solved in terms of the PN property of reachability [8]. These questions can be expressed as: (i) which HIs are achieved starting from a specific health state? (ii) which HIs are needed to reach a specific HI? (iii) what link exists between two identified HIs? Example: the learning outcome is the management of a patient with chronic co-morbidities (cardiac and renal failure) undergoing abdominal surgery for cancer and developing complications. The left box of fig. 1 shows the PN that represents the prototypical clinical condition, while the right box shows the HIN of a real case, selected from a database of medical record according to the selection criteria derived from the learning outcome. The real case has much more details and possibly slightly different paths of evolution.

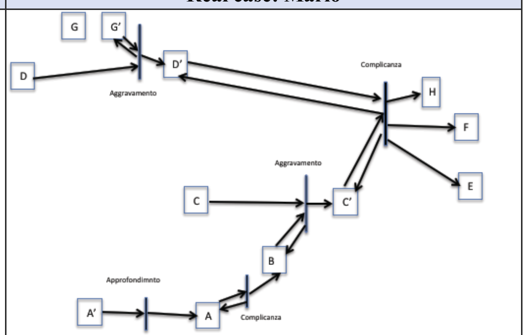
**Learning outcome**




Legend:

A: GIcancer
C: chronic heart failure
C': severe chronic heart failure
D: chronic renal failure
E: pleural effusion
H: diffuse peripheral oedema
F: peritoneal effusion

**Real case: Mario**




Legend:

A': sub-occlusion
B: pulmonary oedema by acute hearth failure
D': severe chronic renal failure
G: urinary tract infection
G': urinary tract infection, second relapse

Complicanza = Complication Aggravamento = Worsening

**Figure 1.** An example of HIN diagrams

Examples of the above questions (right box of fig. 1) are the following: (i) which HIs are achieved starting from the health state {D', C, A}? (ii) which HIs are needed to reach the HI C'? (iii) what link exists between the HIs C' and A'? In modelling a health state as a set of HIs, and therefore as a marking in the HIN model, PNs allow solving these clinical questions by means of the reachability graph and of a firing sequence. Another use of PNs is to measure the "distance[2]" between two HIN diagrams. This problem is solved via a rewriting of a PN (e.g. deleting a place-HI or a transition-

[2] We indicate with the term *distance* the difference in terms of places, transitions and edges, besides the possibility that the two diagrams can become equal after their rewriting.

evolution, or an edge). The analysis of graph distance is useful in the following scenarios:

- Choice of the real case – how far is the HIN diagram of a real case from the HIN diagram of the condition in the learning outcome? In the example of Fig. 1 the "distance" was analyzed between the HIN diagram for a didactic goal, and the HIN diagram of a real case (Mario).
- Given a set of HIs (without the related evolutions) with an indication of the initial and final health states, the learner is asked to envisage the possible evolutions of the health state, i.e. to draw the evolutions and influences and link them to the related HIs: how different will be the resulting HIN diagram drawn by the learner from the HIN diagram drawn by the teacher as correct solution of the exercise?

## 5. Discussion and Conclusions

Scarce literature exists as to the use of modelling tools for representing the evolution of a health issue. A number of papers describe modelling tools for developing workflows [10], protocols [11], or guidelines [12], but in all these cases the focus is on a flow of clinical activities planned and executed so as to accomplish specific tasks, or to work out clinical issues. No mention is made for what concerns the way activities can change the health state, or how this evolves over time. From an educational point of view as well, few works have been produced to develop educational models and tools for the competence of clinical management of chronic and multimorbidity conditions. Basically, the indications are about practical training and the use of virtual cases, which are not based on a sound theoretical model [13]. The HIN project is developing an integrated environment of theoretically based technical solutions to design, implement and assess the simulation of clinical cases of chronic and multimorbidity patients [7].

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