An Holistic Approach to Diagnostic and Therapeutic Care Pathways Management

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Abstract: The European Commission EU4Health program (2021-2027) is launched after the severe health crisis caused by COVID-19 to support member states in long-term health challenges to build more resilient health systems aimed at reducing inequalities in access to healthcare. In Italy, the PNRR program has among its goals the enhancement of the Diagnostic Therapeutic Care Pathways, particularly their complete informatisation to reduce the gap currently present at the regional and, in some cases, at the hospital level. This paper describes a possible AI framework as a starting point for a potential solution to this goal. The proposed solution involves the use of GraphDB for information persistence and evolved process management methods for the implementation of Care Pathways.

1 INTRODUCTION

At the European level, there are many community programs activated to tackle chronic diseases and future scenarios of possible non-sustainability of the system in ensuring adequate levels of care. After the severe health crisis from COVID-19, the European Commission launched the EU4Health program (2021-2027) (European Union, 2021) to support member states in long-term health challenges to build more resilient health systems aimed at reducing inequalities in access to healthcare. The programme addresses the following four general objectives:

- Improve and foster health,
- Protect people,
- Access to medicinal products, medical devices and crisis-relevant products,
- Strengthen health systems.

The last objective, most relevant to our area of competence, contains these specific objectives:

- Reinforcing health data, digital tools and services, digital transformation of healthcare,
- Enhancing access to healthcare,
- Developing and implementing EU health legislation and evidence-based decision-making,
- Integrated work among national health systems.

In Italy, the National Plan for Chronic Care (PNC) (Italian Ministry of Health, 2016), issued in 2016 and being updated in 2024 (Italian Ministry of Health, 2024), stems from the need to harmonise activities in this field at the national level, proposing a document, shared with the Regions, which, consistent with the availability of economic, human and structural resources, identifies a common strategic design aimed at promoting interventions based on a unified approach, centered on the person and oriented on a better organisation of services and the full empowerment of all care actors. The aim is to contribute to the improvement of protection for people with chronic diseases, reducing the burden on the individual, his or her family and social context, improving quality of life, making health services more effective and efficient in terms of prevention and care, and ensuring greater uniformity and equity of access to citizens. Specifically, the PNC outlines the overall strategy and objectives of the Plan, proposes some lines of action and highlights the expected results, through which to improve the management of chronicity under scientific evidence, the appropriateness of services and the sharing of Diagnostic Therapeutic Care Pathways (Translated from Italian Percorsi Diagnos-

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tici Terapeutici Assistenziali (PDTA)). PDTAs, also known as critical pathways, care pathways, integrated care pathways, case management plans, clinical pathways or care maps, are used to plan and follow a patient-centered care program systematically. In this paper, we propose a possible IT framework capable of handling all aspects of advanced management via AI of PDTAs.

2 BACKGROUND

In this section, we report the related work and some specific prototypes implementation that could be used to implement the proposed framework.

2.1 Related Works

The importance of clinical pathways has been highlighted through the various surveys published in recent years (Du et al., 2020; Emma Aspland and Harper, 2021), as well as the verification methods adopted from the EU member state (like in (Italian Ministry of Health, 2023)), but for our purposes we are interested in approaches involving the use of ontologies and their representation (Dissanayake et al., 2019). In (Bediang et al., 2021) is proposed an ontology called Shareable and Reusable Clinical Pathway Ontology (ShaRE-CP) which integrates four knowledge domains (CP, guidelines, health resources and context) to make esplicit existing semantic links between them. It is developed using Semantic Web languages, in particular OWL2 (W3C OWL Working Group, 2012), and some specific ontologies like OWL-S (W3C OWL Working Group, 2004), to describe concepts related to process, and Time-OWL (W3C OWL Working Group, 2022) for manage activities related to time in which they are executed. In (Alahmar et al., 2020), instead, an ontology-based framework designed to solve the main challenges related to standardisation, digitisation, and inclusion of CPs in modern computerised hospitals is described. The framework is based on an OWL ontology plus SWRL rules that uses SNOMED CT (Truran et al., 2010) terminology and includes a coding system that is specific to CPs and their artefacts. Much work has also been done concerning the use of GraphDB applied to healtcare (Abu-Salih et al., 2023). Specifically for Health Critical Pathways, ((Naeimaei Aali et al., 2022) explores the potential of analysing complex clinical pathways using an event log representation reflecting the independent clinical processes. The event graph, whose creation is realised using Python and the Neo4J library, is visualised with Graphviz. This event graph representation allows the user' analysis of the relationship between activities of different clinical processes, which was not recognisable in classical process model representation. A work closer to our proposal is described in (Aldughayfiq et al., 2023) where Semantic Web technologies and GraphDB are combined to implement a knowledge graph that can be queried with SPARQL to capture and visualise complex interactions.

In contrast to these approaches, our goal is to build a system that manages to exploit GraphDB as a repository of data and relationships between data whose meaning is specified through OWL ontologies.

2.2 GraphBRAIN

GraphBRAIN (Ferilli and Redavid, 2020) is a general-purpose tool that allows designing and collaboratively populate knowledge graphs, and provides advanced solutions for their fruition, consultation and analysis. The GraphBRAIN functionalities are achieved by combining different tasks, techniques and approaches of artificial intelligence able to improve knowledge management and (customised) user experience, including database technology, ontologies, data mining, machine learning, automated reasoning, natural language processing, personalisation and recommendation, collaborative and social interaction tools, and social network analysis. While most of these items are investigated and exploited separately in the state-of-the-art, the relevance of the GraphBRAIN methodology is in their being really integrated, and not simply juxtaposed, so that each of them takes direct or indirectly advantage from all the others. This allows GraphBRAIN to find relevant, personalised, and non-trivial information, e.g., a social approach is used to build and integrate ontologies; user models are used to guide data mining; ontologies are used to guide database interaction and interface generation; data mining is used to filter a manageable and relevant portion of a huge graph on which carrying out automated reasoning, etc. GraphBRAIN's functions can be used online, interactively by end users or delivered as Web services to other applications for obtaining selective and personalised access to the stored knowledge. For the formal representation of CPs, a simple taxonomic representation model is not sufficient, but more expressive models are needed. For this reason, GraphBRAIN was chosen as it supports multiple knowledge representation formal languages ranging from OWL (so it is possible to reuse existing ontologies) to FOL (more flexible for the variable knowledge structures representation such as context- and situation-dependent ones).

2.3 WoMan

WoMan (Workflow Manager) (Ferilli, 2014) is a framework for workflow learning and management, based on First-Order Logic representations. Its process mining engine, applicable to activity logs coming from actual process executions, can learn models involving concurrent, repeated, optional and duplicate tasks in any combination, also with weighted elements. Its full incrementality (Ferilli et al., 2013) avoids the need for having all the examples available from the beginning, still allowing the learning to start from scratch. Correct models can be learned using very few examples (in principle, any set of examples including at least one representative of each allowed process). It can also handle noise in a very straightforward, intuitive way. Finally, the representation language allows the description of not just the flow of events, but also the context in which the activities take place, and hence the learning of complex (and human-readable) pre- and post-conditions for the workflow elements. A relevant issue in Process Management in general, and in Process Mining in particular, is to assess how well a model can provide hints about what is going on during the process execution, and what will happen next. Indeed, given an intermediate status of a process execution, knowing how the execution will proceed might allow the (human or automatic) supervisor to take suitable actions that facilitate the next activities. The task of activity prediction may be stated as follows: given a process model and the current (partial) status of a new process execution, guess which will be the next activity that will take place in the execution (Ferilli et al., 2017a). WoMan models can be used for the monitoring and supervision of processes and, when applicable, can be translated into standard representations (like BPMN or Petri nets). Both controlled and real-world experiments show that WoMan outperforms existing process mining systems in accuracy, effectiveness and efficiency. It ensures quick, correct convergence towards the correct model, using much less training examples than would be required by statistical techniques, even in the presence of noise. WoMan is currently being wrapped in a Web service that can be exploited by external applications for workflows learning, simulation and checking.

3 AN APPLICATION CASE

3.1 Updated PNC

One of the strengths of the updated Italian National Plan for Chronic Care (PNC) 2024 (Italian Ministry of Health, 2024) is the definition of population stratification tools to be used in health planning. This provides a specific framework of chronic disease types and quantities sorted by geographic areas. Based on this stratification, it is then possible to act in a targeted manner with digital health techniques that can take advantage of telemedicine more effectively in accordance with best practices and scientific evidence respecting the reference legislation (i.e., EU, National and regional). Particularly for Italy, where health management information systems are regionally established and therefore vary, there is a need for an integrated platform containing information on the characteristics of the assisted population. This is especially necessary to manage a stratification model that enables the holistic estimation of the different dimensions of care needs with a patient-centred analytical approach. A strong impulse was given by the technological evolution and the experience gained during the pandemic emergency by COVID-19, which stimulated the development of telemedicine and digital health by strengthening especially the tools useful to improve the quality, effectiveness and efficiency of the services provided to people with chronic diseases. Based on these factors, the following lines of action have been identified:

- Improving the quality, equity, efficiency and appropriateness of care through the activation of care models that combine telemedicine services with in-person healthcare delivery methods, starting from the health needs of the persons assisted.
- Strengthen health of initiative and promote multidisciplinary of interventions through the implementation of new organisational models and best practices, also through the development of Artificial Intelligence tools.
- Strengthening and adapting telemedicine pathways to facilitate the taking charge and continuity of care of people with chronic conditions in the territory, favouring de-hospitalisation and improving the quality of care also through the activation of innovative organisational models and the development of digital health.
- Promoting and enhancing the interoperability of systems, even through corporate interconnection.
- Enhancing training and continuing education courses in digital health for health professionals.

The expected results concern the implementation of:

- Care models that, in accordance with the indications of Ministerial Decree 77/2022 (Vinceti, 2023), combine telemedicine services with the development of regional projects and good telemedicine practices as a tool to support patient management.

- New organisational models envisaged by Ministerial Decree 77/2022, also through the development of digital healthcare, including corporate interconnection and telemedicine.

Through the implementation, treatment with telemedicine tools of the chronically ill population is expected to increase.

3.2 PDTA

PDTA stands for Diagnostic Therapeutic Care Pathway. Pathway means both the patient's iter, from his or her first contact with the Health System to the therapeutic treatment after diagnosis, and the organisational iter, i.e. the phases and procedures for taking charge of the patient carried out by the Health Authority. Diagnostic, therapeutic and care means the total taking charge of the patient, together with all those multi-professional and multidisciplinary interventions that follow. Thus, PDTAs represent specific models for a given territory (Corporate for the population treated by that specific regional hospital organisation) that contextualise the Scientific Guidelines concerning the organisation of the Health Authority and the Region, taking into account in the analysis the available resources and guaranteeing the Essential Levels of Care (LEA). PDTAs are complex interventions based on the best scientific evidence and characterised by the organisation of the care process for specific groups of patients, through the coordination and implementation of standardised consequential activities by a multidisciplinary team. For several years, PDTAs have been used to improve the quality and efficiency of care, reduce variability in care and ensure appropriate care for the greatest number of patients. These pathways enable practitioners to act on the appropriateness of therapeutic and care interventions, reorganising and standardising care processes and monitoring their impact not only clinically but also organisationally and economically. PDTAs, also known as critical care pathways, integrated care pathways, case management plans, clinical pathways or care maps, are used to systematically plan and follow a patient-centred care programme. As reported in (Mincarone et al., 2018), the languages used to model CP processes are Unified Modeling Language (UML)[1] and Business Process Model & Notation (BPMN)[2]. These languages are suitable for the modelling phase but are not optimal for the execution phase: UML does not provide for execution engines, whereas BPMN although it has various implementations, are based on XML-based representations not designed for the representation of process semantics. To manage CPs during both phases, a more powerful representation language is required; to this end, we propose WoMan as a tool for their management.

[1]UML - https://www.omg.org/UML/

[2]BPMN - https://www.omg.org/bpmn/

3.3 Health Record

In Italy, the Electronic Health Record (Fascicolo Sanitario Elettronico - FSE) was established in 2012 and is defined as the set of health and social-health data and digital documents generated by clinical events, concerning the patient, referring to services provided by the National Health Service and also by private health facilities. With the National Recovery and Resilience Plan (PNRR), an implementation of the NextGenerationEU program, measures for its enhancement have been released. The PNRR investment includes:

- The full integration of all health documents and data types. This will be achieved through the creation and implementation of a central repository, interoperability and service platform, the design of a standardised user interface and the definition of the services to be provided by the FSE.
- The integration of documents by regions within the FSE. This will also be achieved through financial support to healthcare providers to upgrade their technology infrastructure and data compatibility, and to regions adopting the FSE platform through human capital and skills support to implement the changes necessary for its adoption.

Therefore, the objective of the intervention is to foster the development of a homogeneous FSE through a technological transformation of information systems at the national and regional levels to:

- Guarantee a single access point to health services for citizens and patients.
- Guarantee a single source of information for health professionals detailing the patient's medical history.
- Ensure that Health Authorities, Regions, and the Ministry of Health have at their disposal tools to perform data analysis to improve care and prevention.

Concerning the Apulia Region, the health record has the following fields: Vaccination certificate, Medication supply, Discharge letter, Hospitalisation prescription, Pharmaceutical prescription, Specialist prescription, Specialist services, Outpatient specialist and Vaccination card. As can easily be deduced, the type of information is very varied, including structured and unstructured text, image text and images of reports (X-rays, CT scans, etc.), all data that are well suited to the application of Artificial Intelligence techniques ranging from NLP to Image Processing. Persistence through tools such as Neo4J would therefore be optimal for this purpose, as it can contain all types of data and represent the relationships between them with a powerful query engine.

3.4 Issues to Be Tackled

To achieve the objectives set at the ministerial level, it is necessary to establish at the technical level what characteristics the representation languages and techniques to be applied must fulfil.

1. Combine existing ontologies to represent CP. There is no accepted standard terminology for CP, which makes it difficult to represent all aspects of CP uniformly.
2. Customise a generic CP with a specific disease. This will require the use of a hospital CP in use, the collaboration of experts in the field, and the definition of specific modelling steps.
3. Make explicit not formalised medical data and activities. CP is often not followed precisely, but it is important to be able to capture differences that could lead to the specification of valid variants for a certain territory or the reporting of incorrect practices.
4. Provide the CP in a format that is understandable by medical professionals. Providing a simple, user-friendly, and logical interface for medical professionals could be complicated.

Semantic Interoperability can be achieved through the use of Semantic Web ontologies that enable implicit information through automatic reasoning. However, to achieve the expected results, a holistic approach is required, which is often not achievable by using these technologies alone. Moreover, the semantics of the CP must be represented uniformly to that of the data. In this way, it is possible to carp the possible influences on the CP as the data changes.

4 PROPOSED APPROACH

In this section, we report how the proposed framework works identifying how prototype implementation will be used. The approach involves the use of GraphBRAIN, for the persistence of data and semantics related to both data and CPs, and WoMan, as the CP management system. In detail, the following phases can be identified:

- Import existing ontologies or create new ones. In this phase, the system administration uploads the existent upper ontologies describing Health Record and CP. The imported ontologies must be harmonised so a semi-automatic alignment or merge operation involving domain experts will be required. This operation will allow both the representation of semantics in GraphBRAIN's internal format, in particular, complex relationships will be expressed in FOL, and their parts remaining in the decidable fragment in OWL (see Fig. 1).

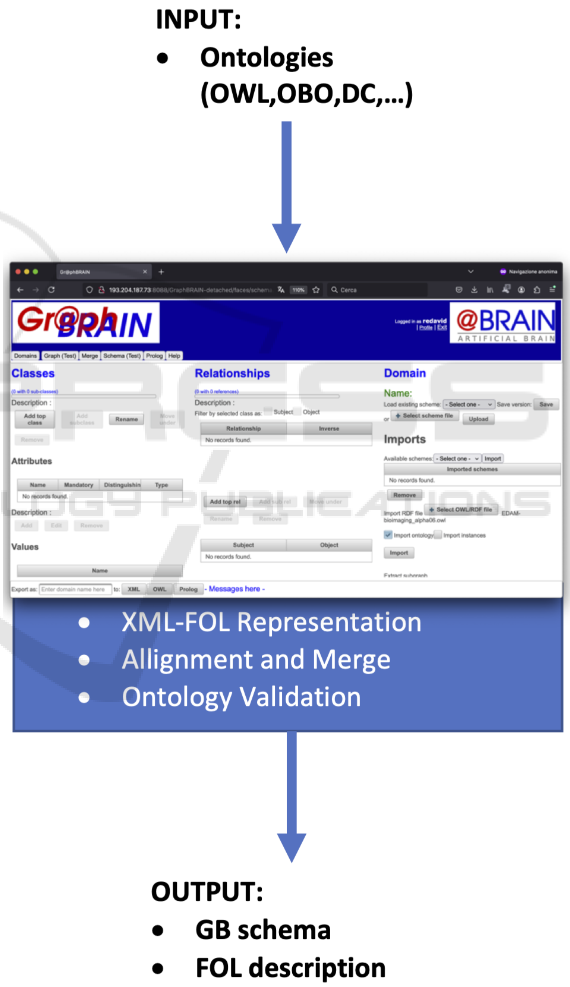

Figure 1: Ontology Concepts and Relations Import.

- Import of existing Health Records and PDTA. The Health Records can be migrated from other sources to the Neo4J GraphDB used by GraphBRAIN. Guidelines for formatting the data in the structure provided by the GraphBRAIN ontology representing the schema of the data in the graph will be released. Once imported, the data can be further validated by domain experts through GraphBRAIN's front-end interface. Furthermore, existing PDTAs will be formalised in the WoMan formalism. The transition from the major languages currently used for CP representation (BPMN and PetriNet) is already available among the import features of WoMan itself, for other representations import is always guaranteed as FOL has sufficient expressive power to include the primitives of any logical representation (see Fig. 2).

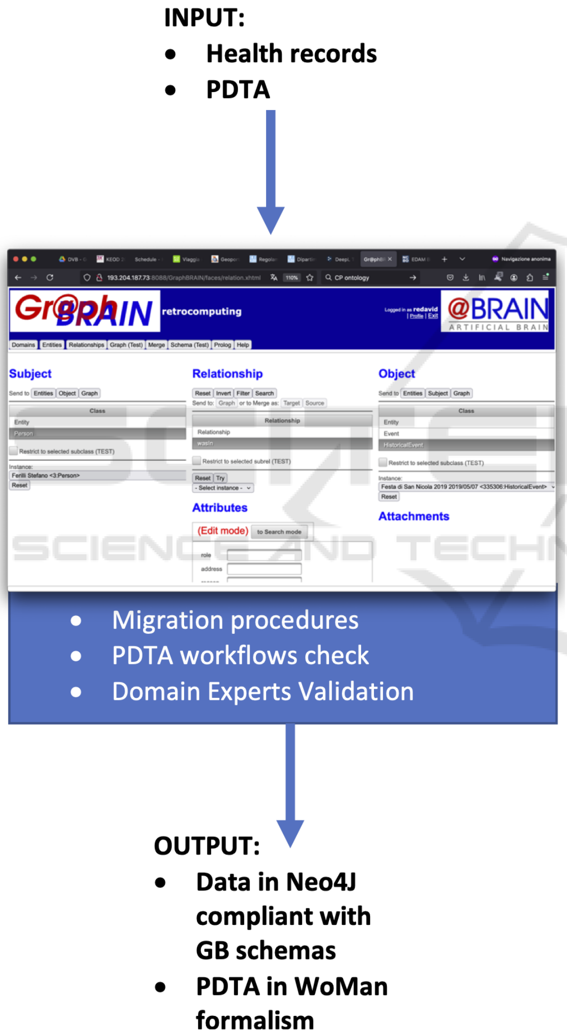

Figure 2: Data and PDTA workflow Import.

- System Execution. The CP management information systems in use provide a web-based front-end interface from where management and control features can be performed. These interfaces may be in an initial phase gradually extended to use GraphBRAIN and WoMan as a back-end.

Later, these interfaces will be modified and extended to provide new functionality. With the power of these tools, it will be possible to respond to the issues shown in Sect. 3.4:

1. Combine existing ontologies to represent CP semantics. GraphBRAIN allows to export of ontology concepts and relations in several formats, such as OWL, SWRL and FOL
2. Customise a generic CP with a specific disease. WoMan allows you to learn new processes from scratch, observe whether a process is executing correctly, or learn deviations during the execution of a process. Therefore, finding possible customisations of existing processes and representing them as variants for a specific territory is possible.
3. Make explicit not formalised medical data and activities. The ability to export portions of knowledge into OWL allows automatic reasoning to be applied to find implicit knowledge. In addition, WoMan's supervision feature allows the system to alert physicians and patients if CP is not being performed correctly.
4. Provide the CP in a format that is understandable by medical professionals. The simplicity of process representation in WoMan allows for the construction of ad-hoc interfaces that also report explanations of why an activity is a consequence of previous ones. This will enable medical professionals to understand the peculiarities of a CP in more detail.

Multistrategy reasoning (Ferilli, 2023) is the key to being able to find appropriate solutions to these problems. Since GraphBRAIN uses a Labelled Property Graph as a persistence medium, the following forms of automatic reasoning can be applied:

- Symbolic/Logic approach: deduction, abduction (also with probabilistic Reasoning support), abstraction, Argumentation for Induction. These approach can be useful to infer new information from data (how a patient should be followed up, what possible CPs are applicable, completeness of information present on the patient, completeness of medical reports, and so on).
- Statistical/Mathematical approach: Subgraph Extraction with the application of Spreading Activation or PageRank algorithm, Centrality with different assessment strategies (i.e., Closeness, Betweenness, Harmonic, Katz and Page Rank), Link Prediction and Clustering. These approaches can be useful for obtaining statistical information on the healthcare state at different levels of granularity.

The ability to interoperate with external sources (particularly GraphBRAIN with OWL ontologies and WoMan with SWRL rules (Redavid and Ferilli, 2023)) simplifies the acquisition of data and information from existing healthcare systems.

Another important issue for telemedicine is the availability of the back-end support described here. By using it, it is also possible to capture information from physician-patient interaction during remote visits, as well as data from computer sensing, which is critical to the goals to be achieved. The same technologies proposed in this paper are also able to address these needs (Redavid et al., 2022). Different is the security aspect where, however, good solutions, especially when we talk about social networks designed for CP consolidation, have been proposed (Pellicani et al., 2023).

5 CONCLUSIONS AND FUTURE WORKS

In this paper, we have outlined a possible framework that can handle existing or learned PDTA formalised in the WoMan formalism. Through GraphBRAIN it will be possible to handle different knowledge representations and apply multi-strategic reasoning to improve CP related to Health Records. Combining these tools we can cover one of the fundamental requirements of National Plan for Chronic Care: an holistic approach to managing the different dimensions of care needs with a patient-centred analytical approach.

In a specific vision, the implementation of NextGenerationEU program can be an opportunity to converge toward a common line of CP management, in a general vision, the idea that in any territory of the European community, it is possible to know the treatment path of a citizen of the community leads to a greater awareness of being part of an evolution represented by the European Community itself. The holistic approach underlying GraphBRAIN (Ferilli et al., 2023) as well as the innovative AI approach to process management (Ferilli et al., 2017b) enables a concrete response to the problem we have been discussing. The PNRR AMICA project is a good test case for implementing the proposed approach. In future work, starting from local solutions it will be possible to generalize them to seek valid solutions at the European level.

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