PROPOSITION DE SUJET DE THESE

Doctoral School : INFORMATIQUE - AUTOMATIQUE - ELECTRONIQUE - ELECTROTECHNIQUE - MATHEMATIQUES (ED n°77, IAEM Lorraine)

Host laboratory :
- **Centre de Recherche en Automatique de Nancy, CRAN UMR 7039, Université de Lorraine, CNRS**
Département : Ingénierie des Systèmes Eco-Techniques (ISET)

Location : Faculté des Sciences et Technologies, Vandoeuvre-les-Nancy, France

PhD directors :

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PhD Subject title : The future of digital twins towards the acquisition of cognitive skills through Polyadic Concept Analysis.

Project description :
The term Digital Twin (DT) was first used by John Vickers of the National Aeronautics and Space Administration (NASA) in 2002. It also gave the first formal definition of the digital twin in 2010 as "an integrated multi-physics, multi-scale, probabilistic simulation of an as-built system that uses the best available physical models, sensor updates, etc., to mirror the life of its corresponding twin" [1]. The use cases of DT span the entire life cycle of a product.
Let us refer to the concept of Cognition. Neisser's classic definition of cognition [2] includes "...all the processes by which the sensory input is transformed, reduced, elaborated, stored, recovered and used...". Fundamental aspects of cognition include attention (selective focus), perception (forming useful precepts from raw sensory data), memory (encoding and retrieval of knowledge), reasoning (drawing inferences from observations, beliefs, and models), learning (from experiences, observations, and teachers), problem-solving (achieving goals), knowledge representation, etc.
The standard DT is the one which has a digital part, a corresponding physical part, and a connection between them. **This version of the DT has the ability to learn and to store automatically the knowledge in formal structure like ontologies and knowledge graphs.** One of the characteristics of the DT is the fact that its activities are related to a massive amount of data to recover, to link and to treat. Those data come from heterogeneous sources.
The DT with cognition abilities in addition to having the ability to learn, is endowed with the other elements of cognition such as perception, attention, memory, reasoning, problem-solving, etc.

Multi-relational Data Mining (MRDM) [3] is the process of discovering knowledge or patterns from massive amounts of data (data mining), when the data comes from heterogeneous linked sources (multi-relational). Additionally, unsupervised learning is the name given to the process of extracting patterns from unlabeled data. Several mathematical frameworks have been proposed to deal with this task having their strengths and weaknesses each, between them Formal Concept Analysis.
Formal Concept Analysis (FCA [4]) is a formalism that establishes a connection between classical binary data (crosstables) and the structure of concepts and rules that can be found in said data. It is very powerful as it offers well-studied mathematical structures to be exploited by algorithms.
As crosstables are a rather limiting way of representing data, various extensions of the formalism have been proposed to deal with more complex data, such as Pattern Structures [5], Relational Concept Analysis [6], fuzzy FCA [7] or graph FCA [8]. Just like FCA, they are based on lattice theory [9].

Triadic Concept Analysis [10] and Polyadic Concept Analysis (PCA) [11] aim to extend FCA to data in the form of n-ary relations (i.e. multidimensional cross tables) and have the peculiarity of involving n-lattices instead of lattices. Such structures are considerably less known and studied, and results that would be considered basic in lattice theory are missing. The opportunities are however numerous as multidimensional data is now ubiquitous: RDF datasets, DT data sources, folksonomies knowledge are all inherently at least triadic and transforming them to fit dyadic cross tables only results in lost information. Some work has already been done in this direction in the field of multidimensional association rule mining [12,13].

The scientific challenge is to investigate the best way for DTs to acquire cognitive skills such as reasoning. The methodological tools that will be analyzed in order to achieve this goal are the extensions of FCA with a particular interest in PCA and its ability to study n-air relations.
The ultimate goal is to be able to structure the knowledge contained in the various DTs as multidimensional association rules.

This thesis topic, involving both theoretical and applied research, is complementary to the research themes of the S&O-2I project team (next COPIL) of the ISET department (next MPS2I) of CRAN. At the international level, this subject is partially covered by the community of researchers from IFAC TC 5.3 "Enterprise Integration and Networking", which is also interested in this problem of formalising semantics and models for the interoperability of systems.

Conditions
The duration is three years: September 2023 to September 2026.
The place of work will be the University of Lorraine, CRAN laboratory in the ISET department in Vandoeuvres les Nancy.
The remuneration is linked to the doctoral contract related to the French government scholarship.
We expect a student with strong competences in mathematics, computer science and who knows the industrial world.
During this thesis it will be necessary to acquire knowledge of lattice theory, in particular lattice concepts, in order to master the
concepts, in order to master the analysis of formal concepts. This knowledge is a prerequisite for the development of a
This knowledge is a prerequisite for the development of a method that allows the evaluation of interoperability processes of enterprise management systems (ERP,
MES, SCM, CRM, ..).

Références :

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