Expert Systems with Applications 39 (2012) 12310–12318

Contents lists available at SciVerse ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

Computing with competencies: Modelling organizational capacities

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ARTICLE INFO

Keywords:
Competencies
Skills
Competency gap analysis
Learning technology
Ontologies

ABSTRACT

The notion of competency provides an observable account of concrete human capacities under specific work conditions. The fact that competencies are subject to concrete kinds of measurement entails that they are subject to some extent to comparison and even in some sense, calculus. Then, competency models and databases can be used to compute competency gaps, to aggregate competencies of individuals as part of groups, and to compare capacities. However, as of today there is not a commonly agreed model or ontology for competencies, and scattered reports use different models for computing with competencies. This paper addresses how computing with competencies can be approached from a general perspective, using a flexible and extensible ontological model that can be adapted to the particularities of concrete organizations. Then, the consideration of competencies as an organizational asset is approached from the perspective of particular issues as competency gap analysis, the definition of job positions and how learning technology can be linked with competency models. The framework presented provides a technology-based baseline for organizations dealing with competency models, enabling the management of the knowledge acquisition dynamics of employees as driven by concrete and measurable accounts of organizational needs.

1. Introduction

Intellectual capital (IC), understood as a collection of intangible firm resources, has been considered to have the potential to be transformed into competitive advantage (Drucker, 1999). Some studies support to some extent such connection, e.g. (Camuffo & Comacchio, 2005; McLennan, 2000). Also, the resource-based view (RBV) of the firm (Barney, Wright, & Ketchen, 2001) can be used as a theoretical framework for supporting the relationship between competitive advantage and IC. In consequence, the management of IC assets can be considered an important aspect of strategy in organizations. If we assume that IC assets are important for organizations, the creation of models, tools and techniques for measuring, tracking and managing those assets becomes an important area of inquiry. Information technology can be used to support the accountancy, reporting and decision making processes associated to IC assets. However, what should be accounted for as an IC asset is subject to different interpretations, including elements as diverse as branding, patents, know-how, culture and corporate memory databases. Here we focus on a concrete component of IC, namely, the competencies (a clarification of the term as well as of other related ones such as "competence" is provided later in this paper) possessed by individuals or teams, which enable them to carry out valuable tasks in everyday work situations (Shippmann et al., 2000). Ramezan (2011) described knowledge as the basis of IC, and characterized organizational capabilities as based on knowledge. Thus, knowledge is a resource that forms the foundation of the company's capabilities, i.e. capabilities that combine to become competencies. These competencies are mainstream categorized as "work related knowledge", as in Campbell, Ridhuan, and Rahman (2010).

As already discussed, competencies are considered one of the key variables determining the intellectual capital of organizations, and there have been several attempts to formally represent them. Ulrich (1998) proposed a formula considering human capital aspects: $intellectual\ capital = competence \times commitment$. Despite the controversies on the validity of such model (Burr, 2002), the accountancy and measurement of competencies can be considered a necessary component for the assessment of IC, and it becomes also a valuable management tool in tasks as selecting project teams or delivering targeted learning activities (Monceaux et al., 2007).

Competencies can be defined as measurable capabilities required in performing tasks in the context of some concrete work situations (Dzinkowski, 2000) or as one of its interpretations (Hoffmann, 1999). If we approach the competencies of workers, then they can be assessed in a behaviourist style as the performance exhibited by an individual to carry out a particular work situation. Individual competencies in turn have been defined in terms of knowledge, skills and attitudes (Rothwell & Kazanas, 1992). Then, the competencies of units or entire organizations can be considered

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http://dx.doi.org/10.1016/j.eswa.2012.02.194

to entail additional elements as standards and values, explicit know-how and technology, management processes and assets, and endowments such as image, relationships, and networks.

The management of competencies supported by computer tools requires models that are able to represent competencies and their components flexibly. An important characteristic of those models is that they should enable different modes of computation. Here, the phrase "computing with competencies" must be understood as enabling the use of competency databases for inference and combination of competencies for different functions and processes, not as a reductionist account of competencies to numeric models. A departure assumption is that we lack a single theory on how competencies and their components can be processed and combined, and even the measurement of competencies can be subject to different scales or assessment paradigms. Examples of measuring techniques range from the general-purpose *Behaviorally Anchored Rating Scales* (*BARS*) (Rarick & Baxter, 1986), to techniques as specific as those reported for measuring diagnostic competency by Hasegawa, Ogasawara, and Katz (2007) or those implemented in the National Competency Standards for Registered Nurses (Cowin et al., 2008). Then, providing common schemes for dealing with competency models entails finding the common semantics and factoring those semantics out as a common model. In any case, competency models should be generic enough to account for different views on competencies and different assessment frameworks, being able to accommodate new theories and frameworks whenever available.

This paper reports on the structure of a *generic competency schema* (GCS) that aims at covering that need for such a common model. It builds on previous work (Monceaux et al., 2007; Sicilia, 2005) and extends it to a more flexible configuration. The computer language used for expressing GCS is the ontology language OWL (Patel-Schneider, Hayes, & Horrocks, 2004).

Ontologies (Gruber, 1993) are shared conceptualizations of specific domains, based on logic languages like description logics (Nardi & Brachman, 2002). The use of an ontology language facilitates the expression of formal computational semantics and the use of inference mechanisms. Sharing ontologies, as envisioned by Semantic Web researchers (Berners-Lee, Hendler, & Lassila, 2001) allows for the immediate availability of models on the Web, in a format that is ready to be used by Semantic Web technology, and it also enables a higher degree of semantics in sharing information available openly on the Web (Morsey, Lehmann, Auer, Stadler, & Hellmann, 2012). Ontologies have been used for a number of significant problems and purposes to date in the domain of organisational learning (Valaski, Malucelli, & Reinehr, 2012) and Knowledge Management Systems (Hee Han & Woo Park, 2009). Further, ontologies are prepared to be extended and reused for particular purposes, which is a critical feature in representing the heterogeneous definitions and models of competencies available.

The rest of this paper is structured as follows. Section 2 reports related work on schemas and ontologies used in modelling competencies. Then, Section 3 is devoted to define discuss the main elements of the GCS schema for competencies. Section 4 then discusses how different computing schemas can be built on top of GCS. Section 5 sketches how the competency models presented can be linked to learning processes, considering instruction and learning as a catalyser for the creation of new competencies inside the organization. Section 6 provides conclusions and future research directions.

2. Related work

In Sicilia (2006) a comprehensive reference on current topics that deal with Information Technology as applied to competency management can be found. Formal ontologies (Gruber, 1993) have been proposed elsewhere (Sicilia, Lytras, Rodríguez, & García, 2006; Sure, Maedche, & Staab, 2000; Vasconcelos, Kimble, & Rocha, 2003) in works dated previous to that review as an adequate supporting framework for competency management. In other direction, Ley et al. (2008) described a conceptual model for competencies with the distinguishing characteristic of explicitly linking competencies to work tasks and the context in which they are carried out, similar in objectives to the KM model described by Sicilia et al. (2006), but introducing the notion of "knowledge space" to capture contextual issues.

Regarding normalization and standardization, there are several specifications related to the interchange of competency data as IMS RCDEO or HrXML (HR-XML 3.1 Standard, 2010). The competency format specified by the HrXML consortium is of a special relevance for practical purposes, since it is the result of an industrial effort in the direction of interchanging data about competencies in a common format. The Reusable Definition of Competency or Educational Objective (RDCEO) specification provides a means to create common understandings of competencies that appear as part of learning activities, as learning pre-requisites, or as learning outcomes. It has been applied to model competency cards (Sampson, Karampiperis, & Fytros, 2007), however it is not intended to provide a semantically defined schema but as a flexible and interoperable data interchange mechanism. These specifications in general focus on data interchange between systems, but the provision of formal semantics that enable computation are currently out of their scope. Dodero-Beardo, Sánchez-Alonso and Frosch-Wilke (2007) and Naeve, Sicilia, and Lytras (2008) have discussed the need for richer models in terms of computational semantics. To the best of our knowledge, there are no other publicly reported competency models than the GCS that explicitly target reusability and extensibility.

In the field of applications, ontologies of competencies have been used for gap analysis (Sure et al., 2000; Vasconcelos et al., 2003) and for managing competences based on multi-agent systems (Cicortas & Iordan, 2006) among other applications as those described by Krause, Hacker, Debitz, Kind, and Strebel (2006). De Leenheer, Christiaens, and Meersman (2010) described a vocational competency ontology wanted to provide a candidate best practice for engineering a community-shared and reusable semantic pattern base covering competencies, skills and functions. A generic architecture and methodological issues for competency acquisition, assessment and representation was proposed by Berio and Harzallah (2007) as a synthesis of previous works. The role of competency models has also been discussed by Sgouropoulou and Grant (2010) focusing on learner mobility across borders. Recent applications of competency models also include resume annotation (Abdessalem Karaa & Mhimdi, 2011), expert modelling (Janev & Vraneš, 2011) and assessment of competencies (Biletska, Biletskiy, Li, & Vovk, 2010).

The explicit relationship between competence models and learning activities has been presented by Naeve et al. (2008). These authors extend previous work (Sicilia et al., 2006) dealing with the connection of models of Knowledge Management to learning activities. They provide a process-oriented view on learning in organizations, and link this model with IMS Learning Design (LD), a language for the description of pedagogical arrangement of multi-role activities (IMS Global Consortium, 2003). The approach is based on a modelling approach based on describing processes in terms of goals, obstacles, actions, and prerequisites (GOAP). As the IMS LD specification states that competency models as IMS RCDEO can be used to specify learning objectives, goals connect with the objectives of the learning designs, and prerequisites and outcomes can also be expressed using the same kind of formalisms. However, the authors state that schemas as the RCDEO lack the computational semantics required for the automation of competency gap assessment. Paquette (2007) described the ontology-based tool TELOS which provides a graphical language for modelling learning activities similar in purpose to IMS LD, providing mappings to learning objectives and properties for annotating resources with competency definitions.

In the case of considering learning resources as content units instead of learning activity designs, similar approaches to use competencies as objectives have been described elsewhere. Concretely, the IEEE LOM standard can be translated to ontology description languages by mapping or repurposing elements. Annotating with ontology elements is done basically by establishing profile usages of the `Classification` element in IEEE LOM. Using that element in combination with ontologies requires some idioms that have been addressed elsewhere, e.g. (Ng & Hatala, 2007).

In spite of the significant amount of previous work using competency ontologies of a diverse kind, the separation of concerns in the use of competency description – identified as shortcomings a by Berio and Harzallah (2007) – has still not been explicitly addressed, e.g. differentiating measures and levels. Competency ontologies and models available either lack computational semantics or are narrow in their possibilities to be used for these different concerns, hampering their reusability. The ontology presented in what follows is an attempt to consolidate previous work and to provide a broader and more flexible model while preserving strict computational semantics.

3. A general competency schema

Before starting the discussion on the conceptual schema, terminological clarification is needed regarding the two terms "competency" and "competence". These terms are often used interchangeably, in fact, the Merriam Webster's online dictionary (http://www.merriam-webster.com/) lists competency as synonym of competence.

There are several arguments to differentiate competency from competence, including the following:

(a) Performance versus description. According to some definitions as the Glossary of New Zealand Customs (http://www.customs.govt.nz/), competency refers to "the description of the knowledge, skills, experience and attributes necessary to carry out a defined function effectively" and competence is measured through observance of the behaviours exhibited by the person required to have the particular competency being measured. According to this definition, we are primarily interested in descriptions and not recording actual behaviour.

(b) Capacity versus activity. According to others, competences are broad capacities. In contrast competencies are used for a narrower concept used to label particular abilities or episodes. In the case of the former we might talk of a competent educator; in the latter a competent piece of driving. In this way the first, capacity, sense of the term refers to the evaluation of persons; whereas the second sense refers to activities.

We are interested here in this latter narrower sense using the differentiation in (b), as what can be observed and measured is actual behaviour, i.e. performance in activities. The notion of competency used here is linked to the concept of human performance, which according to the model of Rummel (Rothwell & Kazanas, 1992) encompasses several elements: (1) the work situation is the origin of the requirement for action that puts the competency into play, (2) the individual's required attributes (knowledge, skills, attitudes and other elements) in order to be able to act in the work situation, (3) the response which is the action itself, and (4) the consequences or outcomes, which are the results of the action, and which determine if the standard performance has been met. In consequence, models of competencies serve as a catalogue for the concrete capabilities of employees, and many organizations maintain competency databases as a record of the capacities of their human resources. Nonetheless, building universal catalogues of competencies is a difficult task because of the volume and complexity of competency definitions, and it is controversial that such kind of general-purpose "competency description database" could be pragmatically attainable, since competencies in many cases are specific to the requirements of particular organizations (Becker, 1980), and a single, generic database would end up with lack of flexibility for some applications. This is why the approach to build the GCS was that of providing a basic core that could be extended or used in diverse ways to fill diverging competency models or organizational needs.

In this section, the main elements of the general competency model in the GCS are described. The aim of the model is that of being flexible enough to adapt to different accounts of competencies, while preserving some minimal computational semantics that allow some forms of inference and computation.

3.1. Ontology structure

The GCS can be considered an "upper ontology for competencies", since it only provides definitions at a high level of abstraction, and is intended to be extended for particular purposes. Fig. 1 depicts the typical arrangement of GCS with other components. This structure follows some principles that are derived from the nature of the kind of things that should be modelled in a competency database. A first principle for the creation of ontologies representing competency models is that there will be a ***plurality of models***, and some of them will eventually be incompatible, e.g. they can differ in the components required for an individual to exhibit a concrete competency, or they can use different calculus schemes to aggregate competencies for concrete tasks as team building. Then, the GCS model in itself is minimal in the sense that it attempts to capture features that can be considered as essential to any competency account and to provide the necessary hooks for extensions that accommodates additional elements. For example, the model of Nordhaug (1993) distinguishing between competencies that are specific to firms, tasks and economic sectors, and this difference can be reflected in three extended models from the GCS. In another direction, many definitions of competency focus on behaviour at the workplace. However, the GCS may also be used to represent standards as those oriented to K-12 education that are useful for course sequencing, see for example (Aldridge & Strassenburg, 1995).

In Fig. 1, the GCS is represented as the base ontological schema, with the main definitions of terms, and some common inference mechanisms (examples are provided below). The combination of the Semantic Web Rule Language (SWRL) (Horrocks et al., 2004) with OWL enables the expression of inference rules in an open, shared format. Then, other ontologies can import and reference GCS concepts to adapt them or define their own ones. This can be done by modelling reference databases as the O∗Net, or as the effort of a single organization as part of its plan for building its own competency database. The Occupational Information Network (O∗NET) is being developed under the sponsorship of the US Department of Labor/Employment and Training Administration (USDOL/ETA), information can be found here: http://www.onetcenter.org/. Computing mechanisms for such specific databases can be expressed in SWRL or in other form (Tejo-Alonso, Berrueta, Polo, & Fernández, 2012) that is outside the capabilities of the logics-based semantics of OWL+SWRL. An example of a complex

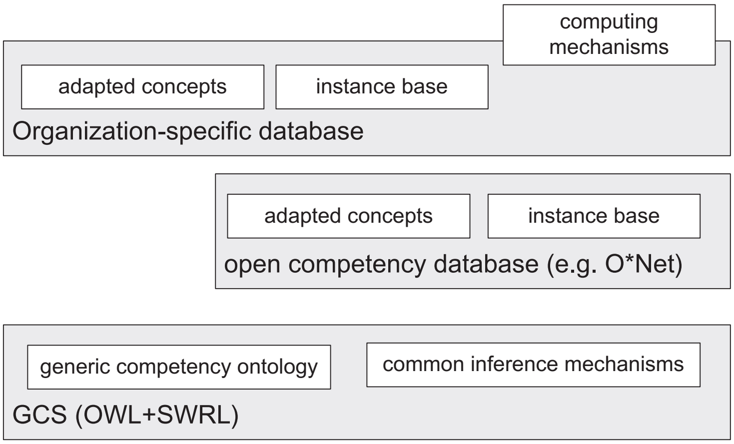

Fig. 1. General structure of the GCS ontology and how more specific schemas can use it.

computing schema can be found in (Sicilia, García, & Alcalde, 2005).

A second principle is that of ***independence of domain models***. This entails that the definition of competencies need not necessarily be tied to some particular domain ontology. Let's consider the example of a competency ontology for the domain of Software Engineering as `onto-swebok` (Abran et al., 2006; Sicilia, García-Barriocanal, Sánchez-Alonso, & Rodríguez, 2009). If the competencies required in the context of software development organizations are linked to that particular ontology by using some kind of predicates, then the competency ontology becomes dependant on it, and this prevents the use of other ontologies. There are several techniques to avoid these dependencies, from using mappings external to the ontology language to splitting the predicates that link competency elements separately to each domain ontology in different namespaces that can be reused separately. The GCS allows for these two concrete techniques.

3.2. Competency definitions

When talking about competencies, in many cases we are referring to competency descriptions, i.e. stereotyped definitions of competencies that are present to some extent in many individuals. This concept is in contrast with the actual competencies exhibited by an individual at a given date. This leads to the concept of `CompetencyDefinition` as a specification of the general characteristics of competencies that are exhibited by individuals to some extent. These specifications can be expressed in terms of components of competencies (but the model does not require that all the requirements and relationships be stated, as will be explained later). For example, some concrete piece of knowledge could be considered as a required component of a competency, or a given attitude can be considered as a requisite for an individual to successfully carry out some group activity. All these components are modelled as `CompetencyElementDefinition`s.

Competencies can also be described at different levels of detail. Fig. 2 depicts the basic elements of the competency definition schema in GCS. The notation used in this diagram is the UML class diagram, http://www.uml.org/. OWL and UML are mapped in a common metamodel called ODM http://www.omg.org/ontology/. Three kinds of elements are defined: chunks of declarative knowledge (`KnowledgeElementDefinition`), tasks considered as procedural knowledge (`SkillDefinition`), and attitudes. These are not the only kinds of categories of knowledge possible, but they account for the difference between declarative and procedural knowledge (Gagné, Briggs, & Wager, 1988). Other categories complementing these can be included in extensions of GCS following the structure depicted in Fig. 1. The definition of skills is usually dependant on some particular previous knowledge pieces, e.g. a typical K-12 competency definition as "Connects via modem to other computer users via the Internet, an on-line service, or bulletin board system", obviously requires some previous knowledge on modems, on-line systems and possibly some specific software.

The difference between a competency and a competency element is controversial, since it is related to notions of *value*, which are not domain-independent (for example, a given piece of knowledge is not equally valuable in all jobs). Since value can be understood differently in different work contexts, providing a definitional rule that differentiate competencies and their elements remains a challenge. This is why in GCS the terms are not defined concepts in the logics sense, that is, there is no logical rule that enables their automatic classification. In any case, as a general rule, a competency should have a clear manifestation in external, observable behaviour that is meaningful as a task that produces

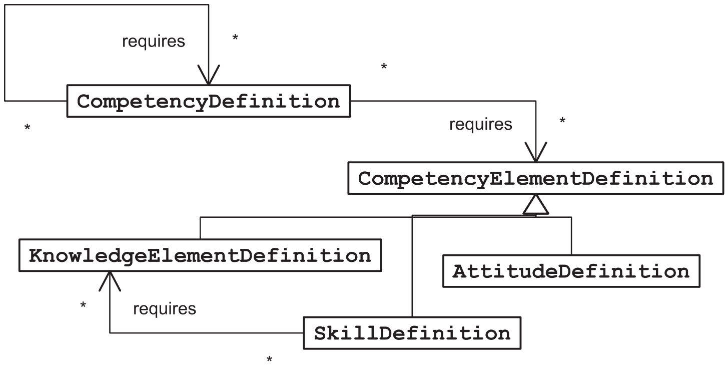

Fig. 2. Basic model of competency and competency element definitions in GCS.

a value in itself. For example, in the O∗Net model version 12, task definitions describe situations that can be considered competencies, as "Confer with clients, engineering personnel, and architects on overall program". In contrast, skills examples in the O∗Net model report include things as "reading comprehension", which can be considered as required for the tasks, but not a work task in itself.

The elements in Fig. 2 can be used as the basis for declaring classifications of competencies. For example, industry specific competency definitions (Nordhaug, 1993) could be defined in a separate ontology using GCS by creating a `IndustrySpecificCompetencyDefinition` concept subclassing `CompetencyDefinition` and adding the following OWL necessary and sufficient restriction:

`specificTo` some (`oc_IndustryType` or `oc_IndustryLocalized`)

The prefix "oc_" denotes that the concept definition is borrowed from the OpenCyc ontology (http://www.opencyc.org/). The `oc_IndustryType` concept models industrial sectors, e.g. the automobile industry and `oc_IndustryLocalized` models geographical subsectors, e.g. the United States automobile industry, which in turn can be defined in terms of a particular group of organizations, as General Motors and the other automobile manufacturers in the US. As a consequence of the definition provided, each time a competency definition is linked to a particular industry or industry type, an automated OWL reasoner would be able to infer that that definition belong to the category of industry specific ones. Further, the predicate `oc_SubIndustryTypes` allows for defining part-of relationships among industry types, which could also be used for determining competencies that belong to aggregate industries from the competencies of their constituent industries. This example illustrates classification in a strict sense. However, sometimes the classifications found in the literature are a matter of degree – e.g. 'low' versus 'high' or 'medium' industry specificity. This calls for computing mechanisms (see the "computing mechanisms box" in Fig. 1) that use the concepts in the ontology but use numeric of fuzzy information instead of purely logical axioms and rules as those that can be expressed with OWL+SWRL.

Some authors consider that skills can be decomposed in other component skills. The GCS currently does not provide support for that decomposition but it can be extended to account for it. In an effort to keep the core model minimal, only a relationship between `SkillDefinitions` and `KnowledgeElementDefinitions` has been included, since every skill requires obviously some previous knowledge.

The acquisition of competency descriptions can be done via pattern identification based on particular job contexts as demonstrated in the work of De Leenheer et al. (2010), and these can be a useful complement to occupational databases as O∗Net that due to its much broad coverage usually do not reach a level of detail as high as those specifically targeted to specific job functions. It should be noted that the GCS allows the definition of competency ontologies at these diverse levels of granularity. In the case of having different ontologies that require reconciling, the `owl:sameAs` predicate that is mainstream use in the linked data Web can be used as a basic mapping mechanism, accounting for some precise semantics that avoid different uses as discussed by Halpin and Hayes (2010).

3.3. The competencies of individuals

So far the discussion has stayed at the level of descriptions of competencies. However, the measurement of competencies in organizations is tied to measuring the competencies of concrete individuals. Concepts that parallel to the descriptions described above are included to represent the competencies, knowledge, skills and attitudes of concrete individuals. The use of two levels – descriptions and actual competencies – clearly differentiates the database of capacities of the employees from their classification. It is at the level of competency *descriptions* that important information on relationships between competencies is located. The link from actual capabilities (competencies or their components) possessed by individuals to definitions is established through a `instanceOf` predicate.

The model of employees and organizational positions has been kept deliberately minimal in the current version of GCS. Thus, GCS includes the term `oc_Person` (and `oc_Processor` as a more generic concept covering the case of non-humans exhibiting competencies in work situations), but no explicit organizational structures (as departments, units or the like) are represented. Such structures could be represented in a supplementary ontology.

The model that links organization to competencies is based on the concept of *job position*. The generic term `JobPositionDefinition` that is useful for describing the competencies required by some particular positions inside the organization. The concrete job positions existing in concrete organizations can be modelled by `oc_JobPosition`. The definition of such concrete positions as "open" or "filled" is the link to applications of recruiting that are based on competency profiles.

The competencies of individuals may also be expressed in terms of qualifications and certifications, such as academic degrees. However, these synthetic expressions of capacities are not in all the cases defined in term of competency models, so that they have been separated from the core GCS ontology. Ongoing work in the normalization of models for the transfer of career data (Brown, Lundqvist, Williams, & Baker, 2007) could be fit with GCS as a upper ontology for competencies to come up with the automated inference of competency data from certifications, qualifications or even normalized descriptions of job positions. There is still a long way to reach that goal of readiness for the human resources sector, but the use and merging of ontologies with a common core model represents a first step towards that direction.

It is acknowledged that no single assessment can evaluate all competencies and that assessments can be combined in complementary ways (Leigh et al., 2007).

3.4. Measures and levels

So far we have considered that individuals either possess or not a given competency or competency element. However, competencies are subject to assessment and measurement, and are definitely a matter of degree. Typical approaches to assessing competencies use ordinal scales for measuring levels of competency, but there is not a single commonly accepted measurement scale or instrument. In consequence, GCS provides a flexible mechanism for recording measurements of competencies (or their components). The `MeasurementScale` concept allows the representation of different scales or ways of measuring. `IntegerMeasurementScale` represents the common approach of using a subset of integer numbers including zero for representing the levels. Each scale has a number of levels allowed, e.g. some BAR scales use the levels zero, two, three, four and five.

Relevant types of measurement scales include ordinal and integer. Integer scales consider arithmetic operations on the values valid, while this needs not be true in general for ordinal scales. One important category of measurement scales is that of bipolar ones, represented by the class `BipolarMeasurementScale`. Bipolar scales are characterized by having some levels that are considered negative, that is, the competency is not present or there exist factors in the individual that inhibit the competency. For example, a typical ordinal BAR scale may be expressed with levels "superior", "full performance", "adequate", "ineffective" and “counter-productive”. The last two ones are negative, and this has important consequences for decision-making and computing that are not relevant in unipolar scales. Bipolar scales have a `highestFailLevel` predicate referring to the best of the negative values, “ineffective” in the previous example.

The GCS allows for stating levels of competencies at several points in the model, summarized in Table 1.

Hoffmann (1999) identified three main positions in defining competencies:

1. Observable performance.
2. The standard or quality of the outcome of the person’s performance.
3. The underlying attributes of a person such as knowledge, skills or attitudes, that are required for competent performances.

The three elements are considered in the GCS under different labels. Concretely, (1) is captured as `CompetencyProcessor-MeasuredLevel`, (2) are captured as `Competency-RequiredLevel`, and (3) are defined as instances of `CompetencyElementDefinition`. It is important to highlight the need that these three uses of competency descriptions as modeling as separate concepts. For example, Paquette (2007) is providing specializations for target, actual and prerequisite competencies but without specific semantics as all the attributes are defined at the level of a generic `Competency` concept.

The case of measured levels serves the function of recording competency measures for particular individuals. These include typically a timestamp, since the competencies of individuals vary during their life. Further, it is possible that one individual has more than one measured level at the same time, obtained through different instruments. This allows applications for dealing with measures or indicators that complement each other, e.g. performance metrics combined with peer assessments. The fusion of information coming from different scales is outside the scope of GCS, and it may combine several indicators into a single one, thus becoming the result of the fusion of information a new measurement scale.

Measured levels for processors are also applicable to competency elements, and required levels are also applicable for competencies that are components of other competencies. All the levels have an attribute value that points to the concrete value of the level (usually an integer), and also to the `MeasurementScale` that is used as the reference framework for that level. This allows for defining different scales, check the compatibility of required or measured levels, and eventually map between them. Measurement scales provide also the reference framework for the expression of desired or required competencies.

It should be noted that levels are considered ordinal, so a required level is always considered a minimum requisite. The required levels, if present, provide detailed information that is also present in predicates `requires` as those depicted in Fig. 1. In fact, the `requires` predicate instances can be derived from the levels by simple inference rules as the following:

$$\begin{aligned}&\mathtt{CompetencyElementRequiredLevel}(?\mathtt{cerq})\wedge\\&\mathtt{requiresLevelOf}(?\mathtt{cerq},?\mathtt{ce})\wedge\mathtt{requiredFor}(?\mathtt{cerq},?\mathtt{c})\\&\rightarrow\mathtt{requires}(?\mathtt{c},?\mathtt{ce})\end{aligned}$$

This enables cancelling the levels and dealing only with the more abstract “all or nothing” version for requirements. If bipolar scales are used, the abstract requirement should only be defined on positive values, since requiring inappropriate or ineffective competency is obviously wrong.

4. Introducing computational frameworks

The previous section has introduced the main elements in the GCS model. In this section, different forms of inference and computation that take these elements as the basic operands are discussed. The discussion is aimed at illustrating the different facets of computing with competencies that should be subject to further research.

4.1. Inference and relationships

Competencies and competency definitions can be used for some inference tasks. At the level of competency descriptions, the model includes a boolean predicate `isCompletelyDefined` that applies to `CompetencyDefinitions`. If a competency description is stated to be completely defined (by its components), this enables for a concrete form of inference: an individual possessing some competency elements to some level results in inferring that the individual possesses the completely-defined competency. This can be chained in several steps if some competencies are defined in terms of others. This behaviour is especially useful for bottom-up approaches in acquiring competencies, since partial attainment is accumulated progressively following a pre-specified system of competencies and competency elements. This can be alternatively described as SWRL rules per each completely defined competency, but in the general case, it requires traversing the competency definitions, the concrete competencies of individuals, and then creating new competency instances with the results of the inference. If required levels are specified, then the inference algorithm must match that these minimal levels are covered in the competency profile of the individual.

The above are not the only possible significant relationship between competencies. Concretely, there is a category of competency relationships that raises naturally as parameterized competencies, in which the competency exercised is similar, but the elements used or some aspect of the context differ. For example, let’s come again to the competency expressed as `c1` = “Connects via modem to other computer users via the internet, an on-line service, or bulletin board system”. Here the basic competency is connecting to an on-line service, but this in practice can be interpreted as being able to connect by using a concrete operating system, as Windows or Linux (let’s call these `c2` and `c3` respectively), and being able to connect to a concrete system, e.g. a portal or a Wiki or so on. Here the

Table 1
Main concepts included in the GCS and examples.

Concept	Purpose	Example
`CompetencyProcessor-MeasuredLevel`	To record the level of competency measured for a given individual (or processor)	“The level of John in competency c1 is five”
`CompetencyElement-RequiredLevel`	To specify the level of a given competency element required for a competency	“A level of four in skill sk1 is required for competency c1”
`Competency-RequiredLevel`	To specify the level required for a job position or a competency	“Individuals that hold the position of Chief Architect are required a level of three for competency c1”
`Competency-TargetLevel (and CompetencyElement-TargetLevel)`	To specify the competency (or competency element) level targeted by a learning activity (e.g. a unit of training)	“Course C provides a level of four in competency c1 when successfully completed”

`requires` semantics that has been explained before is not necessarily appropriate, since a child being able of connecting with Windows might be unable to do the same with Linux. The semantics of this relationship is captured in GCS by the predicate `isConcreteInstanceOf` that connects two competencies or competency elements, in our case, both `c2` and `c3` would be concrete instances of `c1`. The elements that differentiate concrete instances may be really relevant depending on the task, for example, for some highly specialized job functions, the knowledge on a particular software product is critical, and it cannot be substituted by knowledge on a similar product. In other cases, this is not really important, e.g. the capability of SQL querying on the MySQL database system can be perfectly substituted by SQL querying on, let's say, Postgres, in most of the situations. Since these *substitution* inferences are highly relevant on the context, the details on when to use substitution or not are left outside GCS, and should be defined on extensions for particular contexts or domains.

4.2. Competency gap analysis

Competency gap analysis is the process of computing a set of competency (or competency element) amounts that would be required to reach a set of desired concrete levels in a concrete situation. This requires in many cases numerical algorithms that exceed the logics-based language of OWL+SWRL. The output of a competency gap algorithm in GCS is modelled as a set of `CompetencyAmount` instances (or competency elements amounts), expressed according to some `MeasurementScale`. The general signature of a competency gap algorithm for an individual is the following (the notation used for the signatures is close to that of the Java programming language, since the software libraries associated to GCS are developed in that language):

```
computeGap(Person p, Collection
  < Competency − RequiredLevel >)
: Collection < CompetencyAmount >;
```

This kind of competency gap computation is useful for tasks as targeting learning for a given individual, or building career paths. In the first case, a possible application is that of selecting the individuals in the organization that are closer to a particular set of capacities, so that they become priority targets for training to fill the gap. In the second case, the individual might ask for the competency gap for given job position definitions, so that the individual might plan to fill the gap to attempt to rise to another position in the organization. Obviously, the requirements and the competencies of the individual should be expressed in the same (or compatible) measurement scales.

4.3. Aggregated competencies

Aggregating competencies entail combining measurements of individual competencies (or competency elements) to compute an aggregated competency level. A straightforward way of doing this is simply adding the competency levels of the instances of the same competency. However, the interpretation of such aggregated competencies is not well defined, and it should be taken into account carefully. Since competencies are features of individuals, the typical case of aggregating competencies is that of measuring the competency level of a group of people, as a project team, a unit or even an organization. Two kinds of figures should be clearly differentiated here, as summarized in Table 2.

For the first case, it is important to note that the competencies of individuals in general are not *additive* in a sense, i.e. two individuals with level two for `c1` may not perform as one individual with level four. Also, effort and other restrictions enter into play in the capabilities of groups. In the second case, a simple approach is that of averaging the level of the competencies. However, some other approaches could be considered more appropriate for some situations. Flexible aggregation operators are an option to simple averaging, for a general overview of aggregation operators see (Calvo, Kolesarova, Komornikova, & Mesiar, 2002).

The case of computing the gap of a group cannot be resolved with a single, universal algorithm, since there is not a complete understanding on how the competencies in a group interact and compensate. However, a general signature for a gap computation for groups can be the following:

```
computeGap(Collection < Person > team,
          Collection < Competency − RequiredLevel, effort >,
          [othervariables]) : Collection < CompetencyAmount >;
```

In this case, the specification entails amounts of effort required for some given levels of competency. This algorithm is useful in assessing the overall capacity of a team for a given project or task. An alternate formulation is that of team-building algorithms, that select the individuals for the competency requirements of a given project, or at least the team that is closer to matching the needs of the project.

The idea of accumulating capacities in relation to human effort raises the significant problem on how competencies and their levels for different individuals can be aggregated, and eventually, how individuals more effective in a given competency may compensate the lack of efficiency of others. It should be noted also here that the performance of a group is not only dependant on the capacities of individuals, but also on the interaction and relationships among team members, among other possible variables including *team competencies* (Margerison, 2001), as opposed to individual ones. Social capital theories that are based on social network structure (Burt, 2000) might become a complement to computing with competencies, since they provide a quantitative approach to social capital, another kind of intangible capital. However, the GCS in its present version is focused on the competencies of individuals, so concepts related to social interaction are left for future work.

4.4. Compensating schemes

Algorithms computing competency gaps for groups eventually consider *compensation*. Compensation entails that lower levels for a given competency can be compensated by excess of another competency, or that gaps of some individuals can be compensated by competencies of a higher level than required from other individuals. This approximation approach to competencies has been used

Table 2
The different purposes of aggregating competency levels and their implications.

Purpose	Interpretation
Computing the gap of a group	In this case, there is a tacit assumption that the group is intended to undertake some given task. Then, the requirements of the competency for the task should include an estimation of the effort required for a given competency level. For example, "four man-months of level four of competency c1 are required for the project"
Assessing the general level of a competency inside a group	In this case, the objective is having an estimate of the level of a given competency in a group. For example, "which is the average level of competency c1 in the finance department?"

for example in *OntoProPer* (Sure et al., 2000). However, in the general case the match is approximate and it may lead to results that miss critical competencies, e.g. there is a need to distinguish mandatory from desirable competencies.

Another situation in which compensation of competencies takes place is where it is acceptable that some competency requirements that are not fulfilled can be compensated by the presence of other competencies. The GCS provides support for that kind of compensation by providing a `similarTo` predicate relating competencies. Information on similarity can be use to guide compensatory computation, so that only a competency similar to the target one can be used for the compensation. If more detailed information on similarity between competencies is available, this can lead to better compensation. For example, similarity measures can be used for that purpose. The `isConcreteInstanceOf` relationship described above can be considered a particular form of similarity.

5. Linking competencies to learning resources

The GCS model and its extensions can be used for several purposes. Among them, targeting instructional or training activities enables the link of competency gap analysis with planned instructional sequences. The details on how competencies can be used to learning activity models was sketched by Naeve and Sicilia (2006).

The main idea behind mapping competencies and learning resources is that `CompetencyDefinition`s and/or `CompetencyElementDefinition`s can be used for describing the outcomes or prerequisites of learning resources. Following the approach to separation of concerns in GCS, this relationship should be split in a separate ontological namespace, guaranteeing that the GCS is independent of this particular use. The concept of ''learning resource'' has evolved in the last year with the maturation of learning technology standards and specifications as IEEE LOM[1] and IMS LD[2]. The former defines a metadata schema for learning objects, while the latter defines a model for learning activities including sequencing, roles and typical services in on-line learning environments (as chats, newsgroups, etc.). Several ontologies of learning resources modelling such standards are available, so that they can be linked to GCS by stating levels of competency, in this case target levels.

6. Conclusions and outlook

The competencies of individuals can be considered one of the elements of intellectual capital that determine the capabilities of an organization. Competencies can be considered as observable behaviour in work situations, and are thus subject to some forms of measurement and accountancy. The management of competencies requires models that allow specific forms of computation, together with a degree of flexibility that accounts for organization-specific elements. This paper has reported the current state of the evolving GCS model, a generic competency model that can be tailored for specific needs and provides common built in computational semantics. The model is not intended to be a definitive artefact, but it provides a point of departure for enhancements and tailoring to specific needs or applications.

The GCS provides a representation for requirement relationships between competencies and their constituents that enable inference of competencies, and features the possibility of using several measurement scales for competencies and for specifying levels of required competencies or competency elements. The GCS is provided in OWL+SWRL form and it is in continuous update and improvement. Java programming libraries are provided as part of the results of project LUISA (http://www.luisa-project.eu/).

Ongoing work includes mapping existing competency and skill databases to the GCS and providing a collection of algorithms for computing competency gaps. Such collection of algorithms aims at serving as a basis for future experimentation on the appropriateness of computational schemas for different practical situations of assessment in practice. In another direction, the flexibility of the GCS will be assessed by modelling concrete competency models on top of it, along with diverse measurement scales and modes of representing employee capabilities. These extensions are aimed at providing an open library of models that can be reused or extended for particular needs.

Acknowledgements

The research leading to these results has been partially supported from the European Union's Competitiveness and Innovation programme (CIP ICT PSP) under grant agreement n° 250525 (project VOA3R).

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[1] http://ltsc.ieee.org/wg12/.

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