The Connection, Communication, Consolidation, Collaboration Interoperability Framework (C^{4}IF) For Information Systems Interoperability

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Abstract: In this paper, we review the growing literature of interoperability typologies for information systems and propose an interoperability typology framework to provide a synthesis. For this we employ a metaphor from linguistics. That is, we perceive the interaction amongst information systems as a discourse and use concepts from linguistics to outline different types of information systems interoperability. The derived framework has been named Connection, Communication, Consolidation and Collaboration Interoperability Framework (C4IF).

INTRODUCTION

The term "interoperability" has been heavily used - and sometimes misused – in the information systems literature. In this paper, we elaborate on the definition, the scope, the use and the types of interoperability. First, we present a set of definitions as given by established actors and give an overview of several interoperability typologies as introduced by various researchers in the field. We then propose our own classification framework of all interoperability types, which we call *C^4 Interoperability Framework (C^{4}IF)* from the initials of the words Connection, Communication, Consolidation, and Collaboration that constitute the core concepts of our framework. Last, we place the existing typologies vis-à-vis the C^{4}IF framework and present its advantages when compared with the other approaches.

Defining interoperability

There are numerous definitions for interoperability in the literature. Instead of trying to add one more, we quote some of them:

- IEEE defines it as the ability of two or more systems or components to exchange information and to use the information that has been exchanged[1].
- Quoting from the IDABC, European Interoperability Framework, interoperability means the ability of information and communication technology (ICT) systems and of the business processes they support to exchange data and to enable sharing of information and knowledge[2].
- DARPA defines interoperability as (a) the ability of systems, units, or forces to provide services to and accept services from other systems, units or forces and

[1] IEEE (1990), IEEE (Institute of Electrical and Electronics Engineers): Standard Computer Dictionary- A Compilation of IEEE Standard Computer Glossaries
[2] IDABC (2004), European Interoperability Framework

to use the services so exchanged to enable them to operate effectively together, (b) the condition achieved among communications-electronics systems or items of communications electronics equipment when information or services can be exchanged directly and satisfactorily between them and/or their users[3].
- TOGAF (The Open Group Architecture Framework) defined interoperability as: '(1) the ability of two or more systems or components to exchange and use shared information, and (2) the ability of systems to provide and receive services from other systems and to use the services so interchanged to enable them to operate effectively together'[4].
- Vernadat defines interoperability as the ability to communicate with peer systems and to access their functionality[5].

Interoperability typologies

In this part, we present several classification frameworks that have been proposed to group together different types and aspects of interoperability. These typologies better clarify the term.
A common feature identified in all typologies is an explicit or implicit evolutionary perspective. This means that there is an assumption that the various interoperability types follow a scale of advancement: the higher a type is placed in the scale, the more advanced the achieved interoperability is considered. For this reason, the interoperability types are sometimes called "levels".
As a result of the above observation, in the majority of these typologies there is a strict linearity. To reach an upper level of interoperability advancement, all the previous levels have to be successfully addressed. There are cases though, where the linearity is looser. This means that certain features of an upper interoperability type may become available without fully addressing all the lower interoperability levels. For example, the organizational interoperability layer as introduced by the European Interoperability Framework exhibits a loose linearity with regards to the proposed lower semantic and technology interoperability layers.

A short presentation of twelve interoperability typologies follows.

1) DARPA presented the Levels of Information System Interoperability (LISI) capabilities model [1] where a matrix structure was introduced with five interoperability maturity levels affecting four interoperability attributes. The levels introduced by LISI are the following:
- Isolated Systems: No physical connection exists (manual).
- Connected Systems: Electronically connected; separate data applications; homogeneous data exchange is possible (peer-to-peer).
- Distributed Systems: Minimal common functions; separate data & application; heterogeneous data exchange is possible (functional).

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3 Federal Standard 1037C, Department of Defense Dictionary of Military and Associated Terms in support of MIL-STD-188.

4 Open Group (2000), TOGAF: The Open Group Architecture Framework, Document No. 1910, Version 6.

5 Vernadat, F.B. (1996) Enterprise Modelling and Integration: principles and applications; Chapman & Hall, ISBN 0 412 60550 3

- Domain Systems: Shared data but separate applications; sophisticated collaboration (integrated)
- Enterprise Systems: Enterprise wide shared systems; advanced collaboration; interactive manipulation of shared data & applications (universal).

The attributes defined in LISI and affected by the above-presented maturity level are:

- Procedures
- Applications
- Infrastructure
- Data

2) Within the context of the NATO C3 Technical Architecture (NC3TA) [2], the NC3TA Reference Model for Interoperability (NMI) is used. NMI uses the following categories:

- No Data Exchange: No physical connection exists
- Unstructured Data Exchange: Exchange of human-interpretable, unstructured data (free text)
- Structured Data Exchange: Exchange of human-interpretable structured data intended for manual and/or automated handling, but requiring manual compilation, receipt and/or message dispatch
- Seamless Sharing of Data: Automated data sharing within systems based on a common exchange model
- Seamless Sharing of Information: Universal interpretation of information through cooperative data processing

3) The Levels of Conceptual Interoperability Framework (LCIF) [3] defines five levels focusing on the data to be interchanged and the interface documentation, which is available:

- 0-System Specific Data: No interoperability between two systems. Data are seen as a resource of the system, not meant to be shared with other systems.
- 1-Documented Data: Data is documented using a common protocol,
- 2-Aligned Static Data through metadata management: Data is documented using a common reference model based on a common ontology, common or shared reference models, and standardized data elements. However, the same object model can be used slightly or completely differently by different systems.
- 3-Aligned Dynamic Data: The use of the data within the federate/ component is well defined using standard software engineering methods such as UML.
- 4-Harmonized Data and Processes: Semantic connections between data that are not related concerning the execution code is made obvious by documenting the conceptual model underlying the component. The systems model the same part of the real world and the same relationships.

4) J. Park and S. Ram [4] identified conflicts at
(a) the *data-level* caused by multiple representations and interpretations of similar data (e.g. data-value, data representation, data precision and object versus attribute conflicts) and
(b) the *schema-level* characterized by differences in logical structures and/or inconsistencies in metadata (i.e., schemas) of the same application domain (e.g. conflicts in naming, entity-identifiers, schema isomorphism, generalization, aggregation, schematic discrepancies).

5) Brutzman and Tolk [5] presented five levels of system interoperability:

- technically connected (technical level);
- use the same protocols to exchange data (syntactical level);
- know the context of the data in the form of unambiguous definitions of the entities, attributes and relations (semantic level);
- know how the information will be used when being transferred to a component (pragmatic level) and;
- know the functionality of the component within the common conceptual view of the world to ensure that assumptions and constraints are taken into account respectively (conceptual level).

6) MITRE [6], [7] has presented a matrix structure in order to document all types of interoperability mismatches. In one dimension six levels of interoperability are presented:

- Data
- Object
- Application
- System
- Enterprise
- Community

These levels are then positively correlated to three kinds of Integration:

- Syntactic
- Structural
- Semantic

Taxonomies are provided as examples of syntactic integration, database schemas of structural integration and theory of logic for semantic interoperability. Interestingly, semantic explicitness is positively linked to looseness of coupling. Thus, historically we move from tightly coupled to loosely coupled systems.

7) MITRE again presented [8] another framework for information interoperability, which defines four “problems levels”:

- Level 1: Overcome geographic distribution (infrastructure heterogeneity).
- Level 2: Match semantically compatible attributes. Some independently developed information systems use the same terms for the same concepts, but many don’t.
- Level 3: Mediate between diverse representations. Integrators must often reconcile different representations of the same concept.
- Level 4: Merge instances from multiple sources, through data correlation and data-value reconciliation (sometimes called fusion).

Two main types of information interoperability have been introduced:

- Exchange, in which a producer provides information to a consumer and the information is transformed to suit the consumer’s needs (levels 1-3).
- Integration, in which in addition to being transformed, information from multiple sources is also correlated and fused. In general, the consumer sees a single, coherent view rather than all the different systems’ views (level 4).

8) Clark and Jones in [9] proposed an Organisational Interoperability Maturity Model. The model defines the levels of organisational maturity that describe the

ability of organisations to interoperate. Five levels were identified, closely aligned with the descriptions of the LISI model.

- Unified: a unified organisation is one in which the organisational goals, value systems, command structure/style and knowledge bases are shared across the system.
- Integrated: The integrated level of organisational interoperability is one where there are shared value systems and shared goals, a common understanding and a preparedness to interoperate. For example, detailed doctrine is in place and there is significant experience in using it.
- Collaborative: The collaborative organisational interoperability level is where recognised frameworks are in place to support interoperability. Shared goals are recognised and, roles and responsibilities are allocated as part of on-going responsibilities, however the organisations are still distinct.
- Ad hoc: At this level of interoperability only very limited organisational frameworks are in place, which could support ad hoc arrangements.
- Independent: This level describes the interaction between independent organisations.

9) Klischewski in [10] identifies and discusses two types of integration:

- information integration aims at facilitating information flow, i.e. providing access to structured informational resources across technical and organisational borders in order to enable new services based on a virtually shared information environment.
- process integration pertains to interrelating steps and stages of process performance across technical and organisational borders in order to enable new services based on an overarching monitoring and control of process flow.

10) The European Interoperability Framework (*ref EIF*) published by IDABC recognizes three interoperability levels:

- Technical, linking computer systems and services.
- Semantic, ensuring that the precise meaning of exchanged information is understandable by any other application that was not initially developed for this purpose.
- Organizational, defining business goals, modeling business processes and bringing about the collaboration of administrations [11].

11) Medjahed [12] adopts a similar to the previous interaction model, which consists of three layers:

- Communication: Protocols for exchanging messages among remotely located partners.
- Content: Languages and models to describe and organize information in such a way that it can be understood and used.
- Business Process: Enable autonomous and heterogeneous partners to engage in peer-to-peer interactions with each other.

An additional set of parameters defines how applications interact on the Web. This set is applicable to enabling technologies and prototypes, and consists of the following parameters: coupling, autonomy, heterogeneity, external manageability, adaptability, security and scalability.

12) Mylopoulos and Papazoglou [13] in their seminal work introducing the notion of Cooperative Information Systems identified among others, two broad categories of challenges to IS design and development:

- Interoperation. This category covers topics such as generic, open architectures, distributed object management, network-centric computing, compartmentalized applications, factoring out global control from individual components, integration of user and subsystem communication, communication protocols, translation mechanisms, data-integration mechanisms, semantic metadata repositories, knowledge sharing and blackboard architectures.
- Coordination. The topics in this category include computer-supported collaborative work, synchronous and asynchronous sharing, virtual workspaces, performers and customers, concurrency control, transaction management, mediation architectures, workflow systems, AI planning, multiagent technologies, intelligent scheduling, self-describing systems and reflective architectures.

The C^4 Interoperability Framework (C^4IF)

In this part, we propose our own typology for information systems interoperability. We have called it the Connection, Communication, Consolidation, Collaboration Interoperability Framework (C^4IF).

The C^4IF has been developed using some well-defined concepts from linguistics. Following a language/action perspective (e.g. [14]), we focus on the ways information systems communicate, modeling this communication as a discourse. To better understand, analyze and study this, we employ from language theories well-elaborated concepts such as the language form, syntax, meaning and use of symbols and interpretations. Interestingly, these issues are considered common to all kind of communications. The specific type of communication that interests us here is that amongst Information Systems. Thus, we transfer basic linguistics concepts to the domain of IS communication.

Linguistics is the study of language and this latter covers a wide range of phenomena: sounds (phonetics and phonology), word formation and word endings (morphology), word combinations (syntax), meaning (semantics) and language use (pragmatics).

- Phonetics is the study of the different sounds that are employed across all human languages.
- Phonology is the study of patterns of a language's basic sounds.
- Morphology is the study of the internal structure of words.
- Syntax is the study of how words combine to form grammatical sentences.
- Semantics is the study of the meaning of words (lexical semantics), and how these combine to form the meanings of sentences.
- Pragmatics is the study of how utterances are used (literally, figuratively, or otherwise) in communicative acts.

We transfer the above concepts to Information Systems communication and use these broad categories to build our interoperability typology, namely the C^4IF.

The framework defines four interoperability types. These are the followings:

- Connection
- Communication
- Consolidation
- Collaboration

A short description of these types follows:

Connection refers to the ability of information systems to exchange signals. To succeed in this, a physical contact/connection should be established between two (or more) systems. In a linguistic analogy, this level guarantees that phonemes can be uttered and received by the two interlocutors.

Communication refers to the ability of information systems to exchange data. To succeed in this, a predefined data format and/or schema need to be accepted by the interlocutors. The focus of this type is on the data content. At least two levels of communication can be considered:

- At the first level, the exchange is based on a commonly accepted data format. Agreement on the data format is needed between the interlocutors. The focus is on each separate data string (e.g. date=dd/mm/yyyy). We call this type of interoperability *Morphological/Structural Communication*.
- At the second level and more advanced level, the exchange includes data, which is placed in commonly accepted and agreed data syntax/schemas (e.g. Entity-Relationship diagram, XML Schemas). Agreement on the data syntax/schema is needed between the interlocutors. The focus is extended from the separate data string to the data syntax/schema. We call this type of interoperability *Syntactic Communication*.

Consolidation refers to the ability of information systems to understand data. To succeed in this, a commonly accepted meaning for the data needs to be established between the interlocutors (e.g. a reference ontology). The focus here is on the data meaning, interpretation and semantics.

Collaboration refers to the ability of systems to act together. Action results in changes in the real world. To succeed in this, a commonly accepted understanding for performing functions/services/processes/actions needs to be established between the interlocutors or information systems in our case (e.g. agreed distributed workflow patterns). The focus is on the process, the behaviour and the use of data. Paraphrasing Austin's seminal work in Speech Act Theory, "*How to do things with Words*" [15], we may say that this layer in information systems interoperability refers to "*How to do things with Information*".

These four interoperability types are organized in three demarcated areas based on the characteristic object of the achieved interaction. The first and last types constitute separate areas alone, while the second and third types together form the third area. The objects of integration, which formulate each area are:

- Channel: this refers to the connection layer and the ability of information systems to exchange signals.
- Information: this refers to the communication and the consolidation layers, and the ability of information systems to exchange data and information. Actually a continuum is defined with regard to this item: we may have morphological/structural (data format), syntactic (data schema) and/or semantic (data meaning) interoperability. The

"continuum" character implies that these three types constitute analytical abstractions. In between these types several intermediate states can be identified. The first two types clearly refer to the communication layer, while the third to the consolidation layer.

- Process: this refers to the collaboration layer and the ability of information systems to act together.

The relationship amongst these three areas within the C4IF interoperability types is depicted in Fig. 1. These three areas are considered disjoint to a great extent. This means that the C4IF allows for example advanced level of communication/consolidation with low IS interoperability available at the connection level, and/or advanced level of collaboration with low interoperability at all other levels, and the reverse. In other words, although advancements in one area usually provide the enabling infrastructure for advancements in another area, each area can be considered autonomous and may evolve separately.
As an example, passing from a situation where data is exchanged manually between two IS (e.g. using disks) to an advanced mode of exchanging data via a wireless broadband network is clearly a substantial advancement occurring in the channel area and at the connection level of IS interoperability. However, this advancement alone does not guarantee any interoperability advancement in the other areas/levels (e.g. data/communication, process/collaboration). Similarly, agreeing on a common terminology to be used for describing the various entities modeled in the information systems of a group of organizations constitutes a remarkable advancement in the information exchange area (consolidation interoperability level). But this does not automatically lead to advancements in the process area (collaboration interoperability between these organizations).

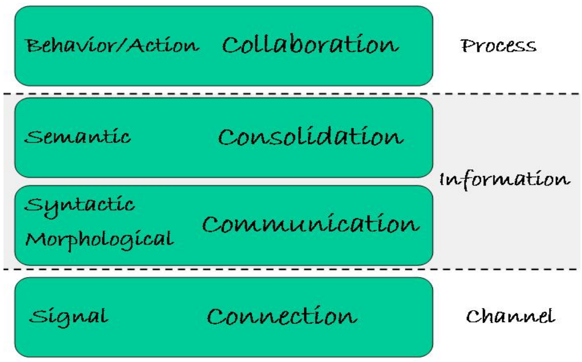

Fig. 1: The C4IF

The analogy to the above-presented linguistic concepts is presented in Table 1.

Language	***Information Systems Communication***	***Substance***	***Focus***
Phonetics	Connection	Channel	Communication channel
Phonology			
Morphology	Communication	Information	Data Format
Syntax			Data Schema
Semantics	Consolidation		Meaning
Pragmatics	Collaboration	Process	Action/Behaviour

Table 1: The C4IF and its mapping to linguistics

An important aspect of the proposed framework should be mentioned. C^4IF is clearly focused on information systems interoperability but at the same time avoids a mere technology-based approach with respect to organizational integration. This means that it clearly separates and does not mix the advancement in information systems interoperability with the advancement in organizational integration. Although technology-based integration (interoperability) is perceived as a catalyst to achieving advanced levels of organizational integration, organizations exhibiting low information systems interoperability, e.g. due to a general low technology level, may however develop advanced integration. For example, organizations supported by weak technology (e.g. no computerized information system support) may exchange semantically rich information (e.g. using cryptographic code over telegraph) and participate in advanced collaboration patterns (e.g. complex and conditional pre-defined workflow patterns based on the messages received). In this case, we may have an advanced level of organizational integration between the interacting organizations. Conversely, although information systems interoperability is considered a powerful instrument and means for integration, it does not always guarantee the achievement of a high degree of organizational integration as other important "soft" aspects (e.g. culture) may affect the final organizational integration level achieved.
Each of the C^4IF interoperability levels corresponds to and may be realized through a set of enabling technologies. We present examples of such technologies in the table that follows. The list of technologies presented is indicative.

Connection (out of content)	**Communication (out of context)**	**Consolidation (out of usage)**	**Collaboration**
• Cable • Infrared • Bluetooth	• Data Formats • Data Dictionary • SQL • E-R Schemas	• Thesaurus • Taxonomies • Common Vocabularies • RDF Schemas • Ontologies • Semantic Web technologies	• Workflow Languages • Distributed Workflows • BPML • Service Ontologies • SOAs • Web Services • BPL4WS • Semantic Web Service technologies

Table 2: Technologies used in the C4IF layers

Two technologies presented in the table deserve special attention:

- Semantic Web technologies combine state-of-the-art Connection (e.g. TCP/IP, http), and Consolidation technologies (e.g. RDF Schemas, Ontologies).
- Semantic Web Service technologies combine the Semantic Web family of technologies with advanced collaboration technologies (e.g. service ontologies, distributed workflows). They are actually a combination of advanced technologies from all the other layers.

Lastly, we provide a mapping between all the above presented interoperability typologies and the interoperability levels they propose vis-à-vis the C^4IF layers. The correspondence can be seen in the two figures that follow.

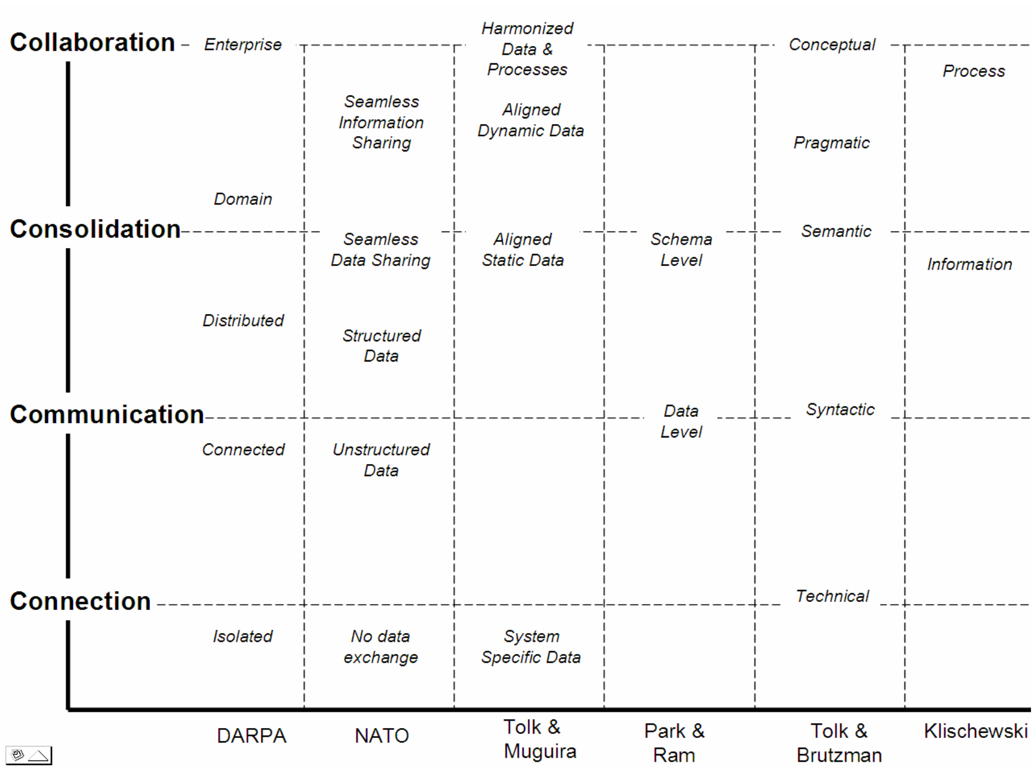

Figure 2.a: Mapping the interoperability typologies to C4IF layers

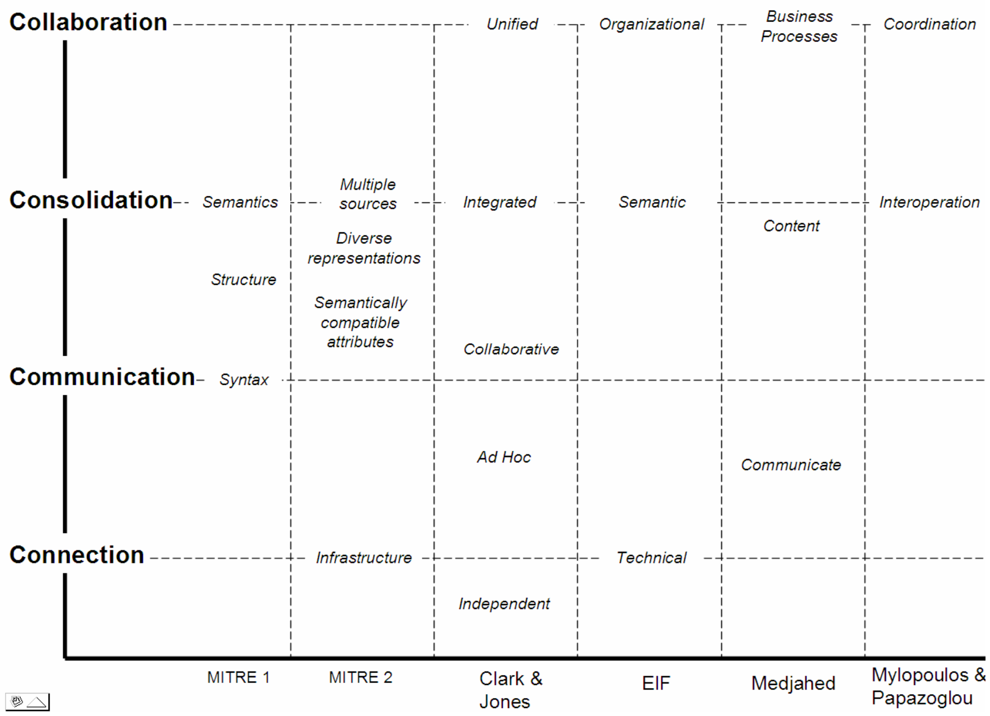

Figure 2.b: Mapping the interoperability typologies to C4IF layers

Concluding the presentation of C^{4}IF, we identify the following advantages of the framework when compared to the other interoperability typologies.

- **Sound theoretical foundation**. The C^{4}IF interoperability types are derived from a well-elaborated theory of language and thus have a sound theoretical foundation that cannot be found in any other of the proposed typologies.

- **Introduction of an innovative perspective to the "interoperability" discussion.** The linguistic metaphor that we employ provides a new approach to this demanding and active field. This perspective is based on a simple yet powerful metaphor, analyzing information systems communication (interoperation) as a discourse.
- **Well-defined layers**. As a result of the two above-mentioned points, the proposed types of interoperability are clearly defined and no ambiguity exists.
- **Loosely related layers**. The three broader model areas demarcated here (channel, data, and process) may evolve separately, influencing but not determining the advancement of the others. This provides the necessary flexibility to surpass crude categorizations imposed by other models that are based on a single categorizations criterion. Moreover, it overcomes the simplistic, single-dimension linearity imposed by almost all other typologies.
- **Clear focus on IS interoperability avoiding technological specificity.** C^4IF clearly distinguishes advancements in information system interoperability from advancements in organizational integration, which is rarely the case in other interoperability typologies.
- **All-inclusive typology**. C^4IF is a framework where all other typologies can find a place.

Conclusions and Future Work

In this paper, we propose a new approach to information systems interoperability. We perceive the interaction amongst information systems as a discourse and thus we transfer some concepts from linguistics to information systems interoperability research.
We plan to further elaborate on the C^4IF and put it into practice. One direction is to identify generic types of interoperability obstacles per category. Towards this direction, concepts from linguistics may again prove valuable. We then plan to propose technological and/or other strategies/solutions as a roadmap to overcome the identified obstacles. Another research direction will involve identifying and studying interoperability problems in real eBusiness/eGovernment environments and attempt to group these problems according to the proposed framework. This exercise could also be employed for validation purposes. Interesting areas for future research could also include the interrelationship that exists amongst the various problems in a specific layer and the impact of possible advancements in one layer to others.
Our aim is to keep C^4IF as domain-independent, transferable and reusable as possible.

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