A·L·I·C·E
Adaptive Learning via Intuitive/Interactive Collaborative and Emotional systems

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SEVENTH FRAMEWORK PROGRAMME

Version History			
Version	**Date**	**Changes**	**Contributors**
0.1	30/11/2010	The deliverable structure has been completed, the introduction and the background chapters have been written. Sections 1 and 2 have been completed.	CRMPA
0.2	31/12/2010	A study about intuitive guided learning has been performed. Section 3.1 has been completed. Sections 3.2 and 3.3 are under development.	CRMPA
0.3	31/01/2011	The Semantic Connections Model and the Semantic Connections Customisation algorithm have been defined. A section 3.4 about future work has been added.	CRMPA
1.0	28/02/2011	Relevant literature about typed links has been surveyed and reported in Section 5. Section 3 has been improved and consolidated. A technological view has been provided as section 4.	CRMPA
1.1	31/12/2011	Related work improved with a comparison with similar systems (section 5.3). Improved the definition of the semantic connection model (section 3.2).	CRMPA
1.2	31/01/2012	Compound learning resource authoring system totally redesigned and extended with a graphic editor. A semantic connection editor was added too (section 4).	CRMPA
2.0	28/02/2012	Some improvements to the semantic connections customisation algorithm were made. Added sections 3.3.3 and 3.3.4. Conclusions and future work improved and moved from 3.4 to 6.	CRMPA

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1 Introduction

Semantic Connections are typed links between learning resources purposed to aggregate them in compound structures to be played by learners. They allow connectivity between deepening resources and a core resource via several link types. Basing on these types, semantic connections can be shown and hidden according to teaching and learning preferences as well as to information about contexts.

The purpose of this document is to provide the theoretical foundation for the management of Semantic Connections in the ALICE learning system with respect to requirements described in [1] (section 5.3). This will allow for improvement and extension of existing models, methodologies and components of the ALICE reference platform, IWT, and prepare it for a smooth integration of methodological and technological components coming from other ALICE research lines.

This document is structured in the following sections.

- **Section 2** provides an introduction about how semantic connections are currently implemented in IWT. In particular the structure of a compound learning resource is presented as well as main functions connected to its navigation by the learners. This is a necessary background to understand algorithms defined in section 3.
- **Section 3** defines improvements and extensions needed to IWT, from a theoretical perspective, to support new features based on Semantic Connections. In particular, principles of intuitive guided learning are presented as the paradigm inspiring the introduction of this kind of learning resources. Then proposed semantic connections model is presented as well as semantic connection customisation algorithms. Within this latter point, extensions to preferences and context profiles are described, as well as needed improvements to the learning presentation generation process and a methodology, based on recommender systems, for initializing preferred connections with significant values.
- **Section 4** shows the proposed improvements from a technological perspective by defining new software components to be developed and providing a model for their integration into the existing IWT architecture including components for the visual authoring (based on graph manipulation), the delivery and the persistence of compound learning resources.
- **Section 5** contextualizes the research undertaken with respect to the relevant literature about typed links and their applications in technology enhanced learning. A comparison of our approach with similar systems is also presented.
- **Section 6** concludes the report and introduces next steps.

The document updates and extends [49] in this way: the semantic connections customisation algorithm has been improved giving teachers the possibility to connect preferences about connections to be used by compound learning resources directly on units of learning rather than only on concepts and contexts. The semantic connection model was improved with a better separation among connection types, resource pages and semantic connections themselves. Moreover we introduced a recommender system approach to initialise preferred connections on the basis of connections preferred by similar learners (i.e. learners with similar learning models).

The technological perspective has been improved and extended with a totally new compound learning resource authoring system based on graph manipulation. A new component purposed to the centralized editing of semantic connections has been also defined. The document also extends the related work section with a comparison of our approach with similar systems.

2 Background

The ALICE reference platform IWT includes a kind of learning resource defined as a *compound learning resource* that is structured as hypertext. Within this hypertext, content is organized in multiple files and the navigation among these files is user-driven. The learner can access additional content connected to the resource by clicking on links embedded in the resource text. Links are typed i.e. a semantic meaning is assigned to each one of them.

These links lead to the display of additional content related to the topic covered by the resource. The additional content may be considered as integral part of the resource itself and therefore part of the concepts to which it relates. Five types of links are currently supported (see 2.1). For each type, a specific colour and a tooltip text can be associated with the link by the teacher. In this way the learner can easily recognize the type of link and the tooltip can provide a brief description of the connected content.

Links of a specific type can be hidden or shown by the learner acting on a customisation menu. Links can be clicked and connected content is shown to the learner. Moreover, a learner can visualize graphically the map of connected content and directly select the one he is interested in. The learner can also consult his navigation history within the resource. The following sections provide more details about the structure of the compound learning resource and on connected navigation functions.

2.1 Compound Learning Resource Structure

Compound learning resources can be created by using a specific hypertext editor built into IWT, or by uploading an already existing hypertext. In the first case links can be directly created using the editor. In the latter case, the teacher has to:

- upload an HTML file together with connected content;
- select the main file of the learning resource;
- use the hypertext editor to associate semantic information to each existing link.

A semantic link included in a compound learning resource embeds the following information.

- **Type**: specifies the nature of the link. Currently five types are supported: theoretical deepening, bibliographic deepening, historical deepening, technical deepening and regulatory deepening.
- **Colour**: is purposed to easily identify the type of link and can be chosen within a list of predefined colours. A colour can be associated to a type so links of the same type have the same colour.
- **Tooltip**: is a text purposed to provide a brief description of the connected content and is shown to the learner when he places the cursor over the link.

- **Text**: is the part of resource text on which the link is applied.
- **Target**: is the target content to be shown when the link is clicked by the learner. The target content can be internal (i.e. a file uploaded by the teacher on the IWT server) or external (i.e. a Web resource reachable through an URL).

The resultant resource has a star-like structure: with a resource kernel at the centre, deepening satellite content can be connected with different types of link. Figure 1 shows the current structure of a compound learning resource.

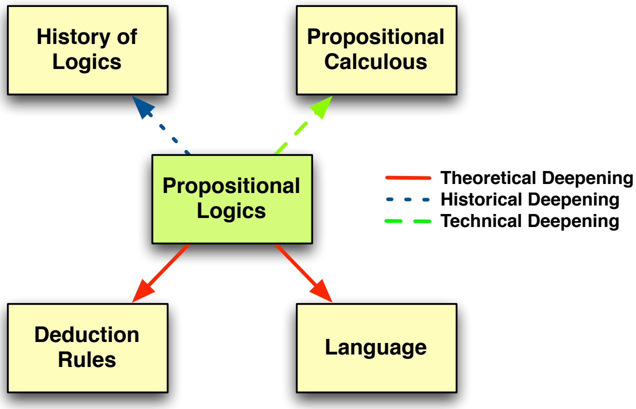

Figure 1. Structure of a compound learning resource.

2.2 Compound Learning Resource Navigation

Within a compound learning resource, starting from the resource kernel, a learner may follow a personalized path according to his interests and learning needs. During the navigation he can access a set of additional features as described below.

- **History**: displays the log of the learner navigation through the content of the resource following available links.
- **Links management**: makes possible the selection of types of links to display within the learning resource. The links that are present but not activated by the selection will be removed in the resource text.
- **Graph**: shows the graphical map of the learning resource including the kernel and all satellite content. Each node of the graph is the target of a link (internal or external content). Clicking on the node it is displayed directly.

Figure 2 shows an example of compound learning resource wherein the red link is a theoretical deepening, and points to a PDF document, whilst the brown link is a historical deepening and points to an external URL.

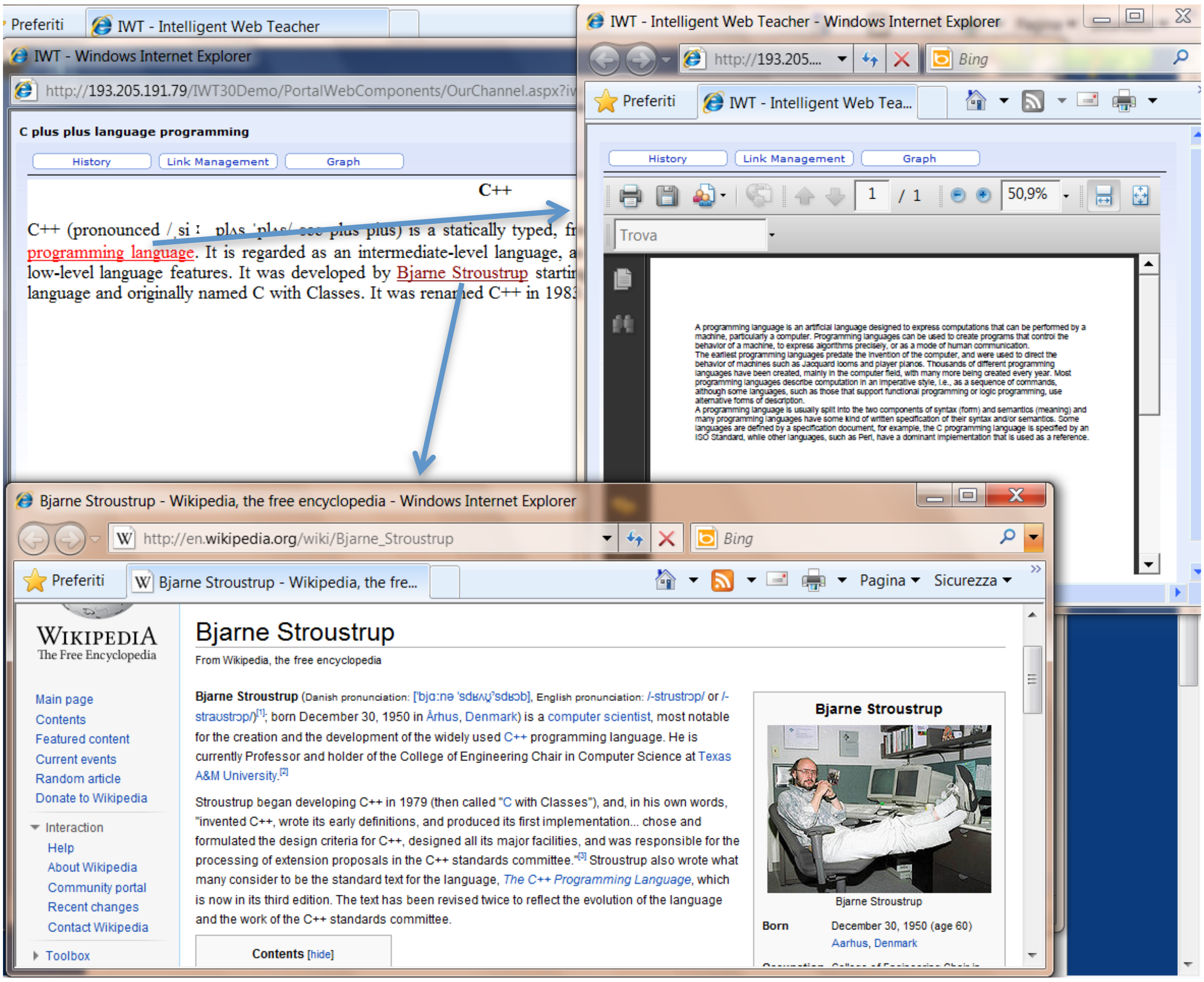

Figure 2. Example of a compound learning resource.

Figure 3 shows instead the *links management* menu allowing the user to show and hide the type of links inside the learning resource. Finally, Figure 4 shows the graphical map of the compound learning resource that can be obtained by pressing the *graph* button.

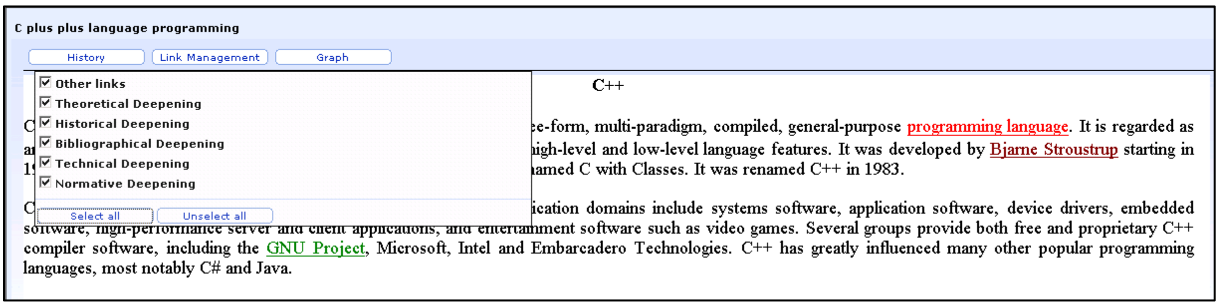

Figure 3. Links Management menu.

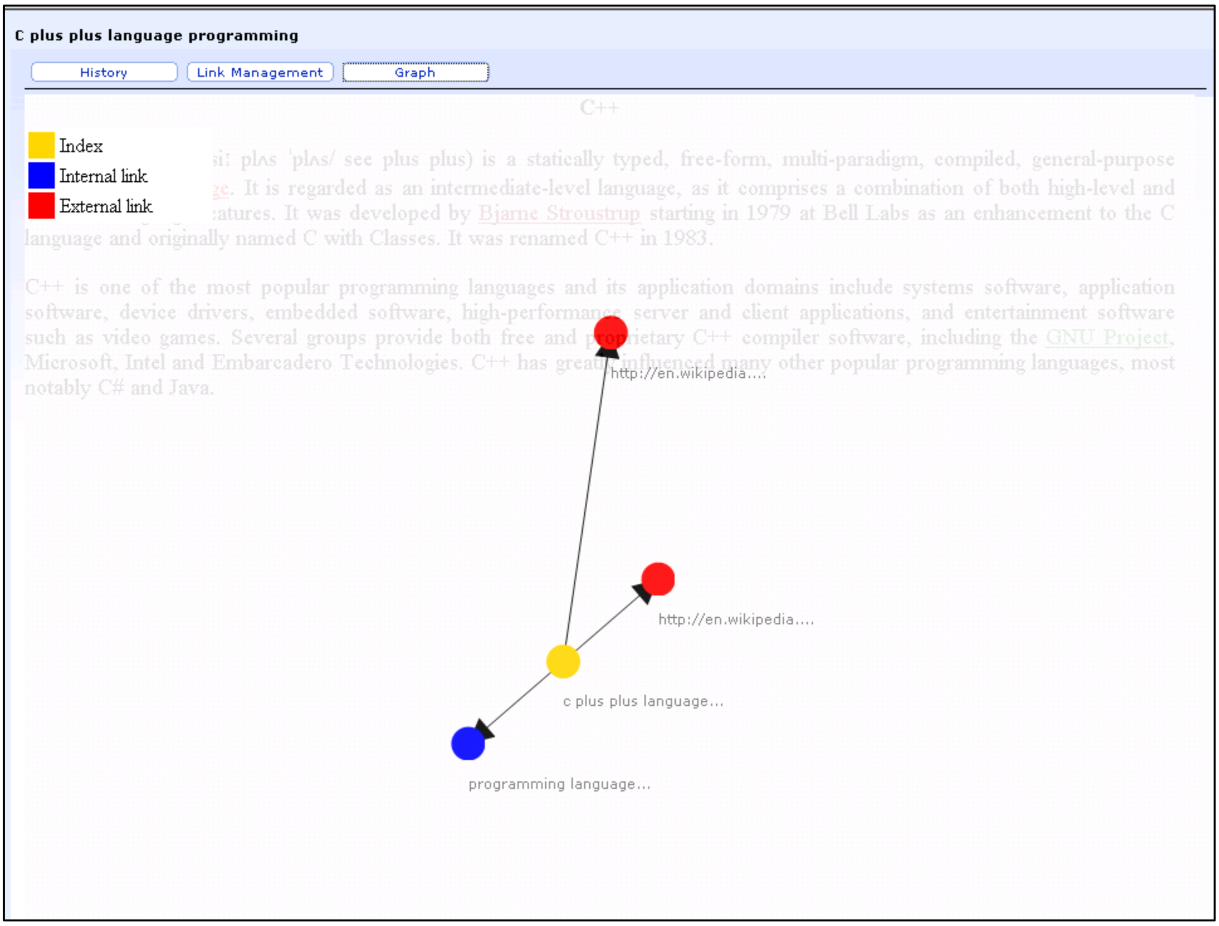

Figure 4. Graphical map of the compound learning resource.

3 Methodological View

In order to improve the effectiveness of the *compound learning resource* (as described in section 2) and provide a sound pedagogical grounding, ALICE proposes, according to the principles of the *intuitive guided learning*, a completely new set of semantic connections divided in two groups. Connections of the first group are purposed to link satellite resources to a resource kernel while connections belonging to the second group are purposed to link learning resources together.

This will facilitate obtaining graph-like rather than only star-like structures, so offering a greater degree of navigability as well as improved customisation capabilities. Moreover, according to [1] (section 5.3), connections within and between resources can be activated and deactivated automatically basing on teaching and learning preferences as well as on context information (defined in [2]).

This section is purposed to describe the theoretical components needed to implement this vision while the next one deals with technological ones. In particular what is needed can be summarized as follows:

- a *semantic connection model* able to define the kind and the meaning of connections within and between learning resources;
- a *resource adaptation methodology* able to modify a compound learning resource with respect to teaching and learning preferences;
- an updated version of the *learning presentation generation algorithm* (see [2], section 2.2.3) able to run the resource altering methodology to obtain the right resource version when needed.

The following subsection introduces the principles of the intuitive guided learning that inspire this learning resource while the subsequent subsection focuses on theoretical improvements needed.

3.1 Intuitive Guided Learning

It frequently happens that the complex nature of a course prevents teachers to easily find a correct, fluid and comprehensive sequence of learning resources able to fit any learners' need. This can be due to a lack in learner mental structures (arising from a lack of knowledge about concepts that are object of teaching or about their prerequisites) or because of their own learning (for example [3] shows the learning style for "approximation" later in the case of learners who are so-called Digital Natives). The result is an inefficient learning experience allowing few crossing possibilities in contrast with the educational principles of the *criss-cross landscape* [4].

According to the *individualized teaching approach* [5] [6], learning is a "journey" that is different for each learner in order to support individual and group goals. Personalization is the plot that the learner builds on the theme to be analysed. In order to maximize the navigational control and avoid the user noticing the steps between or within learning resources as too sharp (probably due to a learning design made through the assembly of different parts), teachers should take advantage of educational artefacts that propose a conscious "zapping" among different sources according to the *intuitive guided learning approach* [7] [8].

The *intuitive guided learning* is the teaching approach to which we turn our attention in order to enable the learner to not be "forced" in a certain sequence of activities. In this approach *learners are not forced down a particular course of action, but the surrounding pedagogic design guides them towards learning objectives in an unobtrusive fashion.* One of the most important characteristics of such pedagogy is that *the experience is non-linear: 'guided' (as an antonym of 'forced') implies that the learner can deviate from the intended path through the learning experience* [9] [10].

The *intuitive guided learning* is strongly linked to the notion of *scaffolding* [7] [9] [10]. In fact, studies confirm that the key point is knowing how to assess the autonomy of students and to find the right balance by adopting an approach based on *scaffolding* and *fading* methods [11] [12]: the *scaffolding* motivates the adoption of specific "structures" in the form of links or "interpretation keys" to follow while the *fading* consists in decreasing the scaffolding when the learner shows a greater autonomy with respect to the course objective.

The level of scaffolding to be adopted also depends on the learning style of the target user. Experiments made on navigation styles on teaching material by the learner, demonstrated the existence of three specific navigational tendencies [13] described below.

- **Searcher/Reader Learner**. This type of learner focuses on the objective and does not distract from the large amount of information (*intentional learning*). He learns by deepening clearly delineated knowledge. He behaves as someone who goes to the library for a precise reason with a certain amount of information and some familiarity with the content. The behaviour of the searcher is essentially deliberated and ordered. He tends to apply, to his navigation, strategies for the selection of the most important things looking insights, focusing on a specific objective and applying a form of relative isolation against the multiplicity of stimuli that the environment might suggest. It applies a deductive approach that proceeds from general to specific in a sequential manner.
- **Browser/Streaker Learner**. This type of learner explores in general, and has no interests well delimited (*incidental learning*). He learns more from accidental paths based on slightly structured resources and relying mainly on the on going construction of knowledge obtained focusing on relatively general information. He behaves very similar to the reader of a newspaper which turns the pages but reads only some articles or some sidebars and, from these, he sometimes learns something but, what he learns, is not necessarily placed within an overall scheme of knowledge or interests.

- **Serendip/Stroller Learner**. This type of learner explores the full potential, does not use resources more fragmented. He is curious and browses aimlessly (*incidental learning*). He learns in a totally incidental manner, because he wants to "discover" something through direct test. He has pleasure from the discovery of something new. His behaviour is the most interesting: unlike searchers he doesn't make a partial and finalized use of learning resources but he explores all their openings and potential. He learns by sharpening his skills, by exploring the resources and by finding a personal key to understanding them.

Main skills that are used during the resource navigation are: *skimming* (to capture the overall sense of the screen), *scanning* (to grasp quickly the elements of particular significance) and *anticipation* (to imagine the result of a link.

While digital immigrants typically behave as searcher/reader learners, digital natives mainly adhere to the stereotype of serendip/stroller learners. Digital natives in fact tend to favour an intuitive mode of knowledge acquisition and of interaction with learning resources. They consider this modality as more natural and stimulating than the sequential reading. These learners use a logic that is more close to the *abductive* one than to the *inductive* or *deductive* and prefer to proceed with a multi-perspective discovery of educational resources rather than to study them in a sequential or systematic order.

The *exploration space control* research field [14] emphasizes the importance of navigational aspect of the learning material. According to its principles, it is appropriate to introduce some parameters related to navigational paths among learning resources and the way they should be seen in order to create different views of the same resources to suit different needs [15]. Among these parameters, semantic connections inside and between learning resources are recognized as fundamental in order to adhere to the navigational style the learner.

For these reasons ALICE introduces the concept of *compound learning resource*: a complex didactic artefact that brings together multiple connected objects that may be browsed in different ways [16] according to learner preferences and teacher-set rules. This will overcome the definition of a learning object seen as monolithic entity that can be "strong" or "weak" but cannot be decomposed [17]. In particular, connections may be placed inside a learning resource itself or between learning resources as detailed in the next paragraphs.

3.2 The Semantic Connections Model

Connections between learning objects find their motivation in the theory of Ausubel [18] and on the distinction he proposes between *learning by rote* and *learning meaningfully*. When we learn by rote, we relate new ideas in cognitive structures with existing ones without effort. In contrast, when we learn meaningfully, we have to integrate new concepts in specific ways with ideas and propositions already existing in our cognitive structures [19].

In the latter case, semantic connections between learning resources are able to drive and support learning. These connections can be *advance organizers* as defined by Ausbel in [20] [21]. They in fact facilitate the integration of new concepts and ideas with the relevant existing knowledge. In this way it is possible to obtain from the learner a correct "learning behaviour" that put him in a position to achieve the learning goals in a controlled and directed way.

To comply with this vision we can define a **semantic connection type** as a list of four parameters. The meaning of such parameters is described below.

- **Name**: it specifies an unique meaningful name for the connection type.
- **Group**: it specifies the group the connection type belongs to. Two groups are defined: connections between and within learning resources. The meaning of these two groups is later defined.
- **Colour**: it is the colour associated with connection and it (differently to the previous version described in section 2) remains the same for all existing compound learning resources to avoid confusion in the learner.
- **Description**: it is a textual description of the semantic connection explaining its meaning both to teachers that want to use it in compound learning resources and to students that can find it inside a compound learning resource and want to decide if follow it or not.

Starting from the semantic connection type defined in this way, we can define a **compound learning resource** *CLR* as a set of resource pages *Rp* and a set of semantic connections *Sc* between pages. A **resource page** belonging to *Rp* can be one of the following objects:

- a *hypertext* created or uploaded by the teacher;
- any kind of *file* (e.g. an image, a video clip, a PDF file, etc.) that can be rendered in a Web browser;
- a *URL* pointing to an external Web page;
- a *IWT resource* belonging to the IWT repository.

A **semantic connection** included in *Sc*, between two resource pages included in *Rp*, can be represented as a list of six parameters whose meaning is described below.

- **Type**: specifies the nature of the connection among pages, it refers to a semantic connection type described above.
- **Source**: specifies the resource page in *Rp* from which a connection starts.
- **Scope**: specifies the part of resource text on which the connection is applied (for text connections). If blank it applies to the whole resource (i.e. it is a page connection).
- **Target**: is the resource page to be shown when the connection is clicked by the learner among those included in *Rp*.
- **Optionality**: specifies if a connection is optional or mandatory. Optional connections can be removed by the connections customisation algorithm while mandatory ones can't be removed (but only re-ordered if they refer to the whole page).

- **Tooltip**: is a text purposed to provide a brief description of the connected page and is shown to the learner when he places the cursor over the connection activator (i.e. the piece of text where the connection applies or on the connection icon if the connection refers to the whole page).

As described by the *scope* parameter, differently from the previous version, connections can be applied to the whole resource (page connections) or to pieces of it (text connections):

- *page connections* refer to the whole page of the resource and are shown as coloured boxes (or icons) on the right side of the page (see figure 9);
- *text connections* refer to parts of the document and are represented by highlighting the text where the connection applies (see figure 9).

Concerning the *semantic connection type*, it is important to note that in literature several studies exist about connections between digital resources in general as well as between learning resources. A complete survey about that is proposed in section 5. Starting from this survey, we selected meaningful connections and included them in two *groups*:

- *connections between learning resources* are purposed to link any kind of resource page with an external learning resource;
- *connections within a learning resource* are purposed to link together any kind of resource pages apart an external learning resource.

In particular, by exploiting results coming from the *rhetorical structure theory* [22] that have been used also to describe *learning objects networks* [23] [24], we propose the list of connection *types* reported in table 1 to be included in the first group (connections between learning resources).

Connections within a learning resource are generally purposed to enhance the educational intentions underlying the architecture of a learning resource [25]. Moreover such kinds of connections also favour for the student a proper *learning behaviour* that put him in a position to achieve the goals of learning in a controlled and directed way.

Several studies [26] can guide to the identification of the feasible typologies for this type of connections. In particular, the *theory of conditions of learning* [27] [28] argues that, in order to promote the establishment of new skills, a learner has to follow a learning process involving a sequence of instructional events.

Starting from these events and mixing tags coming from the *educational rationale metadata* initiative [29] it is possible to define some hypothesis of connections within a learning resource as summarized in table 2.

Connection Name	Definition
Elaboration	The referenced resource elaborates the content of the described resource or of a part of it.
Evidence	The referenced resource provides information to increase the belief in the claim mentioned in the described resource or in a part of it.
Interpretation	The referenced resource interprets or explains the described resource or a part of it.
Justification	The referenced resource justifies the described resource or a part of it.
Summary	The referenced resource summarises the described resource or a part of it.
Contrast/Opposite	The content of the described resource (or a part of it) and of the referenced resource are opposites.
Condition/Restriction	The referenced resource limits the content of the described resource or of a part of it.
Restatement/Alternative	The referenced resource provides an alternative of presenting the described resource or a part of it.
Sequence	The referenced resource is the sequence or chronology of the described resource

Table 1. Connections between learning resources.

Connection Name	Definition
Motivation	The referenced content is an activator i.e. it strongly motivates and justifies the importance of the topic explained in the described resource or in a part of it.
Critique	The referenced content presents a critical review of the issues included in the described resource or in a part of it.
Collaboration	The referenced content includes spaces for discussion or cooperation about the topic described within the described resource or a part of it.
Engaging	The referenced content leads students to discover the validity of what they are studying by displaying bad behaviours held by those who do not know the topic explained within a resource or a part of it.
Integration	The referenced content is purposed to deepen (from several viewpoints) the theme explained in the described resource or in a part of it.
Anchor	The referenced content is purposed to anchor the knowledge explained in the described resource (or in a part of it) within an authentic context.
Perspective	The referenced content explains the knowledge provided by the described resource (or by a part of it) from a different perspective.

Table 2. Connections within a learning resource.

The compound learning resource obtained through the application of the defined semantic connections model has a graph-like structure rather than a star-like one. In fact to each page of a compound resources, other pages or external resources can be connected recursively. The figure 5 shows the new structure of a compound learning resource.

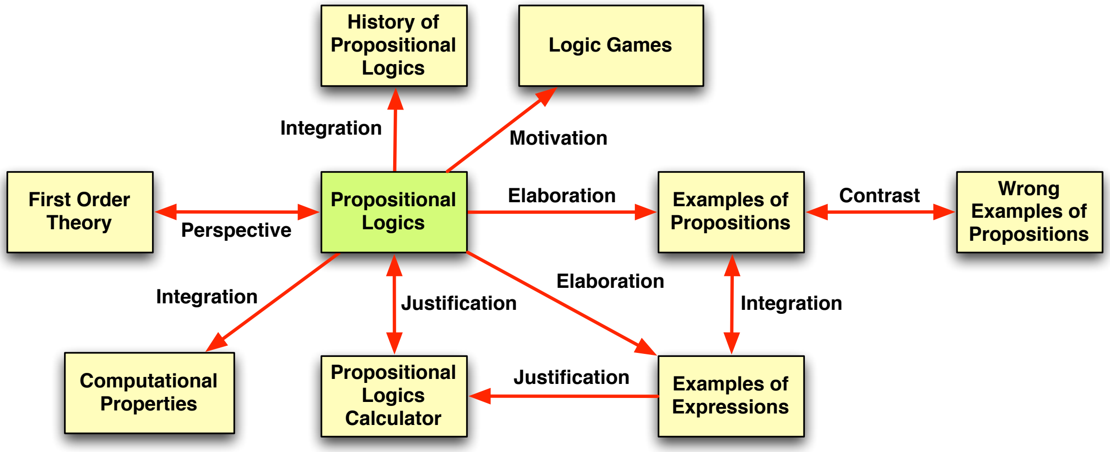

Figure 5. The new structure of a compound learning resource.

3.3 Semantic Connections Customisation

Semantic connections included in compound learning resources can be automatically hidden with respect to teaching preferences, context profiles and learning preferences. While the behaviour to apply by the compound learning resource with respect to teaching preferences and context profiles will be defined by the teacher and included in the domain model, learning preferences about compound learning resources are inferred by the system and included in learner model. These behaviours will be described in section 3.3.1.

Modifications needed to the learning presentation generation algorithm in order to apply the resource adaptation methodology and to obtain the right resource version when needed are described in section 3.3.2 while sections 3.3.3 and 3.3.4 present additional improvements to the adaptation methodology.

3.3.1 Extensions to Preferences and Context Profiles

As described in [2] (section 2.1.1) **teaching preferences** are linked to the domain model in order to define feasible teaching strategies that may be applied for each available concept *C*. Such preferences are represented as an application $TP\ (C \times Props \times PropVals) \rightarrow [0, 10]$ where *Props* is the set of didactical properties and *PropVals* is the set of feasible values for such properties. In order to support compound learning resource alteration a new kind of property is added named “allowed connections” whose feasible values are those reported in tables 1 and 2. Allowed connections for a given concept are specified by teachers during the definition of the domain model.

As described in [2] (section 3.1) a **context profile** is linked to a context in order to define feasible teaching strategies that may be applied to teach domain concepts in such context. It can be defined as an application *CXP* (*CX* x *Props* × *PropVals*) → [0, 10] where *CX* is a set of available contexts, *Props* is the set of didactical properties and *PropVals* is the set of feasible values for such properties. In order to support compound learning resource alteration a new kind of property is added named “allowed connections” whose feasible values are those reported in tables 1 and 2. Allowed connections for a given concept are specified by teachers during the definition of the domain model.

As described in [2] (section 2.1.2) **learning preferences** are linked to the learner model in order to provide an evaluation of learning strategies that may be adopted for a given learner. They are represented as an application *LP* (*Props* × *PropVals*) → [0, 10] where *Props* is the set of didactical properties and *PropVals* is the set of feasible values for such properties. In order to support compound learning resource alteration a new kind of property is added named “preferred connections” whose admitted values are those reported in tables 1 and 2. Preferred connections for a given learner will be inferred by the system through an algorithm that analyses his behaviour during the compound learning resource navigation.

First of all, when a new learner model is created, *LP* (“preferred connections”, *c-type*) is initialized to 5 for each type of connection *c-type* (i.e. for each value reported in tables 1 and 2). This means that, initially, all connections types are equally preferred. Then, each time a learner finishes a compound learning resource (i.e. when he moves to another resource) a modifier $mod_{c\text{-}type}$ is calculated for each *c-type* for which at least a connection in the resource exists, in this way:

$$mod_{c-type} = \frac{\sum_{c \in conn-type} toggle_c}{|conn - type| \cdot counter} \qquad (1)$$

where *conn-type* is the set of resource connection whose type is *c-type*, $toggle_c$ = 1 if the connection *c* has been followed by the learner and -1 otherwise, while *counter* is the number of times the user accessed this learning resource till now.

This means that each time a learner follows a connection, the preference for the related type is increased while each time an existing connection is skipped, preferences for the related type is decreased. The level of increase/decrease depends on the number of connections of that type available in the resource as well as on the number of time the learner accesses a learning resource (i.e. connections accessed or skipped the first time produce greater modifications with respect to the following accesses to the same resource).

Once the modifier is calculated for all connection types after a compound learning resource fruition, the new value for *LP* (“preferred connections”, *c-type*) is then calculated in this way:

$$\max\{\min\{LP(\text{“preferred connections”}, c\text{-}type) + mod_{c\text{-}type}, 10\}, 0\} \qquad (2)$$

so adding the modifiers to the learning preferences of the learner model but limiting the resulting value between 0 and 10.

3.3.2 Learning Presentation Generation Improvement

As specified in [2] (section 2.2.3), the presentation generation algorithm is purposed to build a fragment of presentation (i.e. a part of an unit of learning) suitable for a specific learner basing on a learning path (a sequence of domain concepts to be covered), a set of teaching preferences *TP* and a set of learning preferences *LP*. The algorithm is made of three steps, the first is purposed to select a subset of the learning path to cover, the second is purposed to select the best sequence of learning resources covering the defined subset according to *TP* and *LP*, the third purposed to add testing activities.

In order to support semantic connection customisation, it is necessary to include a *fourth step* whose purpose is to apply the following algorithm to every compound learning resource (if any) of the generated fragment of presentation:

1. to remove from the resource (covering the concept *c*) optional semantic connections whose type is *c-type*, if *TP* (*c*, "allowed connections", *c-type*) < θ_1;
2. to remove from the resource optional semantic connections (basing on the optionality parameter) whose type is *c-type*, if *LP* ("preferred connections", *c-type*) < θ_2;
3. to reorder page connections suggested to the learner for the current page following the decreasing order of *LP* ("preferred connections", *c-type*);

where constants θ_1 and θ_2 range from 0 to 10 and will be determined experimentally.

Context profiles also participate in the customisation of semantic connections but indirectly. As specified in [2] (section 3.2.2), in fact, a contextualisation algorithm is applied in order to transform context profiles in teaching preferences before the application of the learning presentation algorithm. Starting from obtained teaching preferences the preceding algorithm can be so applied as is.

3.3.3 Connecting Teaching Preferences to Units of Learning

As described in 3.3.1, teaching preferences can be currently connected to both domain concepts and context profiles. Such preferences are explicitly and implicitly taken into account in the semantic connection customization algorithm described in 3.3.2. Nevertheless, in some cases, it can result too difficult for a teacher to foresee, during the creation of a domain model, how compound learning resources will be designed for this domain. So it can be difficult for him to provide feasible values for the *TP* function related to the "allowed connections" property.

To overcome this difficulty we introduce an additional *TP* function connected to the Unit of Learning rather than to domain concepts and contexts. Given the units of learning space *UL*, such function is an application *TP* (*UL* × *Props* × *PropVals*) → [0, 10] where *Props* is the set of didactical properties and *PropVals* is the set of feasible values for such properties. Such properties can override teaching properties provided at domain model level if the "override domain model preferences" checkbox is selected at course design time.

In order to support compound learning resource alteration, a new kind of property is added with respect to those listed in [2] (section 2.1.1) named “allowed connections” whose feasible values are those reported in tables 1 and 2. Allowed connections for a given unit of learning, if settled, override all teaching preferences connected with concept and contexts connected with the learning path composing the unit of learning.

In order to support semantic connection customisation when teaching preferences are defined at unit of learning level, it is necessary to modify the first step of the algorithm described in 3.3.2 in this way:

1. if teaching preferences *TP* (*ul*, “allowed connections”, *c-type*) are defined for the current unit of learning *ul*
   - then, if *TP* (*ul*, “allowed connections”, *c-type*) < θ_1, remove from all compound learning resources in *ul* optional semantic connections whose type is *c-type*;
   - else, if *TP* (*c*, “allowed connections”, *c-type*) < θ_1, remove from any compound learning resource in *ul*, covering the concept *c*, optional semantic connections whose type is *c-type*.

The meaning of the parameter θ_1 is the same defined in section 3.3.3. Moreover, with $ul \in$ UL we indicate an automatically generated unit of learning.

3.3.4 Introducing a Recommender to Initialise Preferred Connections

As stated in 3.2.1, learning preferences, for a new student, are initialised by settling the function *LP* (“preferred connections”, *c-type*) = 5 for each type of connection *c-type* (i.e. for each value reported in tables 1 and 2). This means that, initially, all connections types are equally preferred by any student. In order to improve this generalization we propose in this section an algorithm, based on the principles of recommender systems, to initialise these values taking into account preferences of similar users.

An extensive state of the art about recommender systems has been provided in [48]. In this case we combine a cognitive and a collaborative approaches: as in collaborative ones, we approximate unknown values of an utility function (in our case the preference of a learner for a given connection type) from those made available by people considered similar to it. According to cognitive approaches, similarities are considered starting from knowledge about learners maintained in learner profiles.

By indicating with *u*(*l*, *c-type*) the preference of the learner *l* for the connection *c-type*, i.e. by settling *u*(*l*, *c-type*) = *LP* (“preferred connections”, *c-type*), we can determine unknown values for *u*(*l*, *c-type*) for a learner *l* by aggregating the utilities expressed for *c-type* by users similar to *l* with the following equation:

$$u(l, c\text{-}type) = \frac{\sum_{l' \in L'} u(l', c\text{-}type) \cdot sim(l, l')}{\sum_{l' \in L'} |sim(l, l')|} \quad (3)$$

where *L'* is the set of *n* learners considered most similar to *l* (with *n* chosen between 1 and the total number of system learners) and *sim*(*l*, *l'*) is the similarity between learners *l* and *l'*.

The similarity between two learners can be calculated using similarity measures such as the cosine similarity or the Pearson's correlation coefficient [48]. These measures are applied to the vectors $l = (w_{1,1}, \ldots, w_{1,n}, \ldots\ w_{m,1}, \ldots, w_{m,n})$ that characterize learners, where each vector component $w_{i,j} = LP\ (Prop_i,\ PropValue_j)$ i.e. the preference value connected to the *i*-th property and the *j*-th property value with respect to tables included in [2] (section 2.1.2), so excluding the new introduced property "preferred connections".

To apply this recommendation component, preferred connections are not initialized and they remain undefined until a compound learning resource is encountered by the student. Before entering in the first compound learning resource, only preferences related to connections used by the resource are initialized by applying equation 3. Once initialized, connection preferences are further modified according to learner behaviour by applying the algorithm defined in section 3.3.1.

4 Technological View

Chapter 4 of [2] already presents the IWT logical architecture divided in the following layers:

- *Framework* used by developers to design and implement core services, application services and learning applications;
- *Core Services* providing basic features like resources management, ontology storing, user authentication, content storing, metadata, role and membership management, learning customisation, logging, profiling etc.
- *Application Services* used as building blocks to compose e-learning applications for specific domains including document management, conferencing, authoring, learning management, learning content management, ontology management, communication and collaboration, process management and information search services.
- *Learning Applications* covering specific learning scenarios obtained as integration of application services.

The subsequent sections focus on the extensions needed to this architecture in order to obtain compound learning resources management and customisation functions.

4.1 Extensions Needed to IWT

From the technological point of view, the integration in the reference platform IWT of compound learning resources management and customisation functions, as specified in [1] (section 5.3), requires a set of additional/improved components as depicted in figure 6 (where additional components are in grey while improved ones are in black). The figure also contextualizes such components with respect to the IWT architecture.

In the following we briefly describe needed components and their impact on the architecture.

- **Models Data Storing and Retrieving Service**. We foresee the extension of data structures maintaining the compound learning resource to implement the semantic connection model defined in 3.2. Moreover data structures for learning preferences, teaching preferences and context profiles will be extended too in order to support what defined in 3.3.1. Related storing and retrieval services will be modified accordingly.
- **Semantic Connection Editor**. The editor will allow knowledge managers to create and modify the list of available connection types managed by the system. Connection types can be added, modified and removed from the list as well as related parameters described in 3.2: *name*, *group*, *colour* and *description*. Only unambiguous connection names are provided through this editor while each teacher can associate available connections in different ways throughout compound learning resources.

- **Compound Learning Resource Manager**. It is a component dealing with the design and the execution of compound learning resources. It includes two sub-components:
  - the *Compound Learning Resource Designer* allows teachers to author compound learning resources according to the model defined in 3.2;
  - *the Compound Learning Resource Player* allows learners to execute a compound learning resource according to the behaviour defined in 3.2 and implements the algorithm of learning preferences updating as well as the 4th step of the learning presentation generation algorithm defined in 3.3.2.

  It uses the models data storing and retrieving service for persistency.

The next subsection provides further details about compound learning resources authoring and delivery functions.

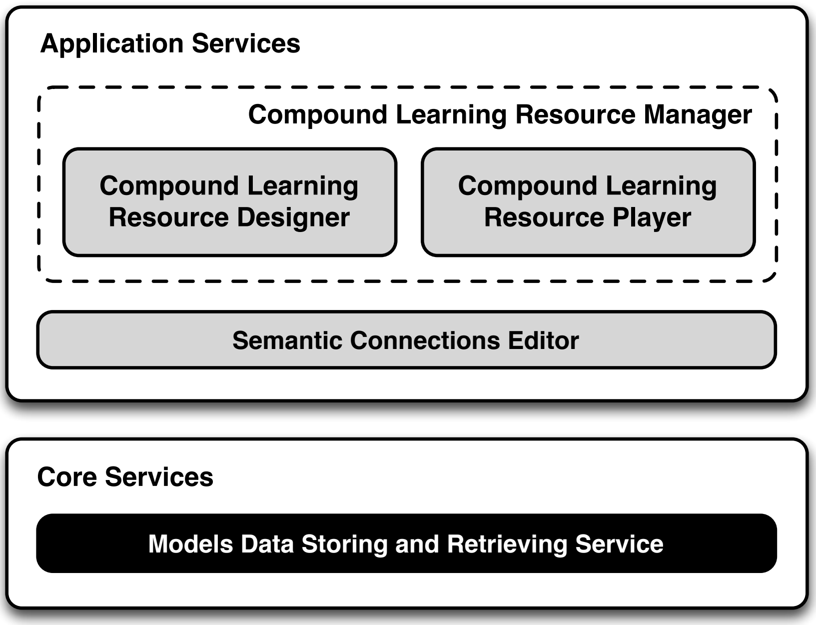

Figure 6. Additional IWT components foreseen.

4.2 Compound Learning Resource Designer

The figure 7 shows a mock-up of the compound learning resource designer. On the left side there is the list of available resource pages (initially empty). To insert a new page the “new page” button must be pressed. Once pressed this button, a dialog box appear in the right section of the page (named *Workspace*) asking to enter the details of the new page. The first information to enter is the page name and the page typology. This latter can be chosen between “Hypertext”, “File”, “URL” and “Resource”. Basing on the typology, additional info is required as reported below.

- For a new **Hypertext** the teacher can chose to upload an HTML file (including related resources) from his desktop or to create a blank hypertext (to be modified later). In the first case the new page is initialized with the uploaded resource, in the second case the new page is initialized with a blank hypertext. In both cases the WYSIWYG editor described below is opened soon after in order to allow to edit the hypertext.
- For a new **File** the teacher must upload any kind of Web deliverable resource (e.g. images, video clips, PDF files, etc.) from his desktop.
- For a new **URL** the teacher must insert a link to an external Web page.
- For a new **Resource** the teacher must select a resource from his own IWT resources repository.

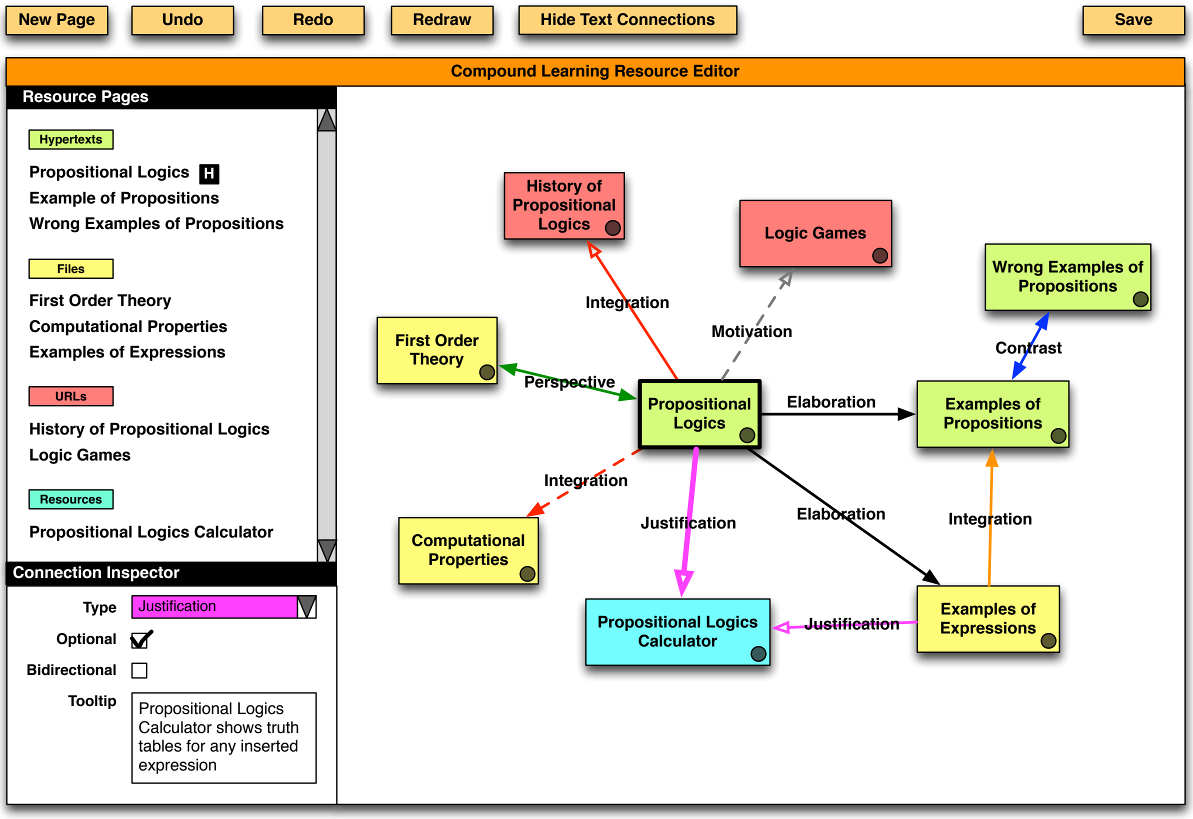

Figure 7. Mock-up of the Compound Learning Resource Designer.

After having inserted information related to the resource typology, the teacher can optionally select a "Set as home" checkbox (the checkbox is selected by default for the first created page) and then can save it. Once a new page is created, its name is listed in the *Resource Pages* section under the label corresponding to its typology (see figure 7).

The home page in this list has a black "H" on the right of the name. Only one page can be the home, so if a new page is select to be home, the previous selection is cancelled. By right clicking on the page name in the *Resource Pages* section, an item from the following list can be selected by the teacher.

- **Preview Page**: to preview the page in a new window (also accessible by double clicking the page name).
- **Modify Page**: the teacher can modify the page name or the connected hypertext, file, URL or resource through the same dialog box used during the creation phase. In the same dialog he can also specify that a given page should become the home page.
- **Edit Content** (only for hypertexts), a WYSIWYG editor is opened in the Workspace to modify the page content (see figure 8). The features of such editor are defined below.
- **Remove from Workspace**: to remove the page and all the related connections from the Workspace. The page remains in the *Resource Pages* section and can be re-inserted in the Workspace. The option is only visible when the page is shown in the workspace.
- **Delete Page**: to delete the page and all connected files.

Items from the *Resource Pages* section can be dragged and dropped in the *Workspace* on the right. Once dropped they become rectangles of the same colour of the resource typology. The home page is represented by a rectangle with a ticker border. The name of the page is displayed inside the rectangle. Rectangles can be freely moved in the workspace in order to place them where the teacher wants.

A new connection between pages ("page connection" according to the definition provided in section 3.2) can be drawn by clicking on the circle in the lower-right corner of a rectangle representing a page, dragging there and dropping in the rectangle representing the destination page on the *Workspace*. The new connection is initially un-typed and appears in black with a tick line. Connection properties can be settled in the *Connections Inspector* panel in the lower-left corner of the screen.

- **Type**: it is the connection type selected from those defined in section 3.2. Available types are selectable from a drop down list. Each type have a connected background colour that correspond to the connection colour.
- **Optional**: it is a checkbox specifying if a connection is mandatory or not. Optional connections are represented with continuous lines with an empty arrowhead while mandatory connections are represented with continuous lines with a filled arrowhead.
- **Bidirectional**: it is a checkbox specifying if a connection is bidirectional or not. If it is selected then an additional arrow is placed on the connection. If it is removed, the original direction is restored. Bidirectional connections are represented in the semantic connection model with two opposite connections.
- **Tooltip**: it is a textbox where the teacher can insert the tooltip that should be shown to the learner when he places the mouse cursor over the connection activator.

A drawn connection can be selected by clicking on it. In that case the line becomes ticker and the *Connection Inspector* shows its properties that can be freely modified. When no connections are selected, the *Connection Inspector* is deactivated. Between two pages just one connection can exist. If a teacher draws a connection between two pages already connected then the existing connection is selected. If the drawing direction is opposite with respect to the existing connection then the connection is selected and the bidirectional checkbox is automatically checked.

Undo button cancels the last operation done while the *Redo* one restores a cancelled operation. The *Redraw* button redraws the graph by applying standard graph drawing algorithms. As already described before, when a teacher selects the *Edit Page* option after having right clicked on a hypertext page name then a WYSIWYG editor is opened in the *Workspace* in order to edit such page. Figure 8 shows such editor.

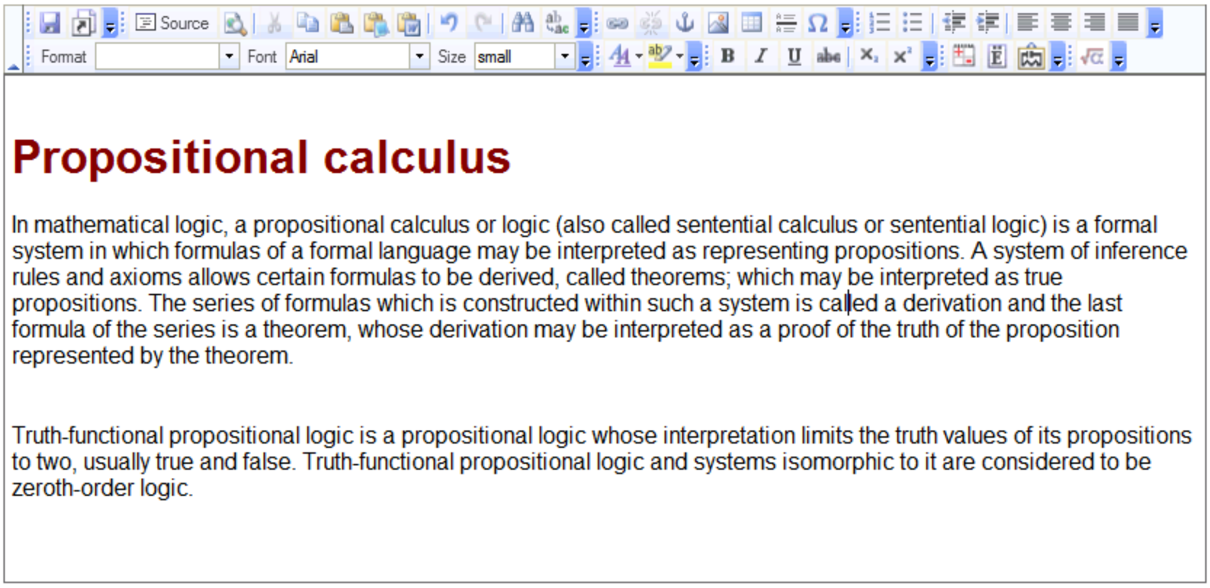

Figure 8. The WYSIWYG hypertext editor.

Through the editor it is possible to create or modify an hypertext page. Among the other things, new text connections can be added by selecting a piece of text and by pressing the second button on the upper-left corner of the editor. When a new text connection is added, a dialog box appear to collect the connection parameters i.e. *type*, *optional* and *tooltip* with the same meaning with respect to page connections. In addition, also the *target page* should be selected by the teacher among pages that are currently displayed in the Workspace (excluding pages already connected to the current page).

When a new text connection is added, after the closure of the editor, the connection is displayed in the Workspace as a dashed line with empty (for optional connections) or filled (for mandatory connections) arrowheads.

Text connections can't be selected or modified from the graph. To modify them, the page including the connection must be edited and the connection modified from the WYSIWYG editor. Text connections can be removed from the graph by clicking the "Hide Text Connections" button (once hidden, the button modifies in "Show Text Connections").

After having designed it, the obtained compound learning resource can be saved by pressing on the "Save" button.

4.3 Compound Learning Resource Player

Figure 9 shows the mock-up of a compound learning resource. Learners start the navigation from an index page and may follow semantic connections between resource pages. Pieces of text that activate a connection are highlighted with different colours according to the connection type. Connections can also appear on a vertical bar on the right side of the resource as coloured boxes (colour is chosen according to the connection type) and refer to connection linking the whole page rather than a part o it.

When a page differs from the index, a back connection is added to the right side bar in order to navigate the last followed connection backward. The back connection is represented as a filled coloured triangle where the colour is chosen according to the connection type. Once a learner puts the cursor over highlighted text or over a coloured box/triangle, a tooltip appears indicating the type of connection and showing the tooltip text defined by the teacher.

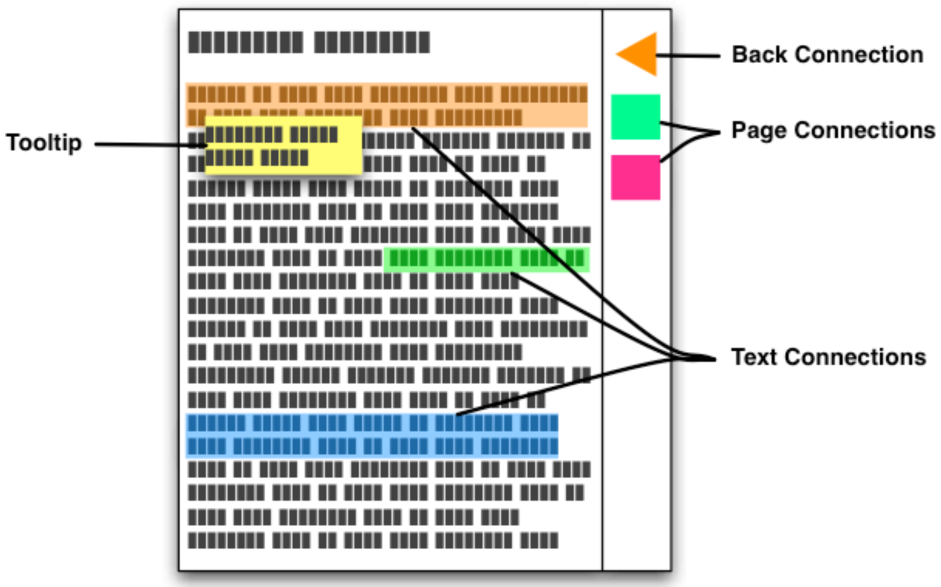

Figure 9. Compound learning resource mock-up.

5 Related Work

This research falls into the fields of Intuitive Guided Learning and Intelligent Tutoring Systems. In particular it describes a new kind of learning resource (compound learning resource) that can be navigated in different ways by different types of learners and, at the same time, can enable personalized and contextualized navigational paths taking into account teaching and learning preferences.

The pedagogical justification for this kind of resource is given in 3.1 where we introduce the principles of intuitive guided learning. In the definition of types of connections between the parts of a compound learning resource we have taken into account the literature about typed links between digital resources and their applications in the domain of e-learning. The next two paragraphs will survey relevant initiatives in both fields.

5.1 Typed Links

A **typed link** [30] in a hypertext system is a link to another document or part of a document that includes information about the character of the link. For example, rather than merely pointing to the existence of a document, a link might also specify that the document supports the conclusion of the article pointing to it, that it contradicts the article pointing to it, that it is an older version of the document, that it serves to define the word next to the link, that it is an index to other documents of the same type, or some other relationship.

This allows a user to take actions such as searching only certain types of links or displaying them differently. It may also allow browsing software to do things like pre-fetching documents it expects the user to browse. Typed links were a common feature in pre-Internet hypertext systems such as Xanadu [31], NoteCards [32] [33], HyperWriter [34], etc. Unfortunately, the lack of a standardized set of link attributes has always hindered the use of typed links beyond prototyping purposes.

Version 4 of the HTML standard defined by the World Wide Web Consortium supports typed links using the *rel* (forward relationship) and *rev* (reverse relationship) attributes [35]. These attributes are applied to either the *<link>* tag (for links between whole documents) or the *<a>* tag (for links from a specific part of a document). For example, the tag:

<link rel="contents" href="top.html">

specifies that the document "top.html" is a table of contents for the work that includes the document you are currently reading, while the tag:

<link rel="next" href="chap3.html">

specifies that "chap3.html" is the next document in logical sequence after the one you are reading. The table 3 lists link types defined in the HTML 4 standard.

Link Type	Definition
Alternate	Designates substitute versions for the document in which the link occurs. When used together with the *lang* attribute, it implies a translated version of the document. When used together with the *media* attribute, it implies a version designed for a different medium (or media).
Stylesheet	Refers to an external style sheet. This is used together with the link type *Alternate* for user-selectable alternate style sheets.
Start	Refers to the first document in a collection of documents. This link type tells search engines which document is considered by the author to be the starting point of the collection.
Next	Refers to the next document in a linear sequence of documents. User agents may choose to preload the next document, to reduce the perceived load time.
Prev	Refers to the previous document in an ordered series of documents. Some user agents also support the synonym *Previous*.
Contents	Refers to a document serving as a table of contents. Some user agents also support the synonym *ToC* (from "Table of Contents").
Index	Refers to a document providing an index for the current document.
Glossary	Refers to a document providing a glossary of terms that pertain to the current document.
Copyright	Refers to a copyright statement for the current document.
Chapter	Refers to a document serving as a chapter in a collection of documents.
Section	Refers to a document serving as a section in a collection of documents.
Subsection	Refers to a document serving as a subsection in a collection of documents.
Appendix	Refers to a document serving as an appendix in a collection of documents.
Help	Refers to a document offering help (more information, links to other sources information, etc.)
Bookmark	Refers to a bookmark. A bookmark is a link to a key entry point within an extended document. The *title* attribute may be used, for example, to label the bookmark. Note that several bookmarks may be defined in each document.

Table 3. Types of links from HTML 4 standard.

In [36] **Semantic Link Network** (SLN) is defined as a directed network consisting of semantic nodes and semantic links. A semantic node can be a concept, an instance of concept, a schema of data set, a URL, any form of resources, or even an SLN. A semantic link reflects a kind of relational knowledge represented as a pointer with a tag describing such semantic relations as *causeEffect*, *implication*, *subtype*, *similar*, *instance*, *sequence*, *reference*, and *equal*.

The semantics of tags are usually common sense and can be regulated by its category, relevant reasoning rules, and use cases. Table 4 lists the semantic link primitives and relationships defined in the SLN.

Link Type	Definition
Cause-effective	Denoted as **d-ce → d'**, where the predecessor is the cause of its successor, and the successor is the effect of its predecessor. The cause-effective link is transitive.
Implication	Denoted as **d-imp → d'** which states that the semantics of the predecessor implies to that of its successor. The implication link is transitive. It can help the reasoning mechanism find semantic implication relationship between documents.
Subtype	Denoted as **d-st → d'** where the successor is a part of its predecessor. The subtype link is also transitive.
Similar-to	Defines that the semantics of the successor are similar to those of the predecessor, denoted as **d-(sim, sd) → d'**, where sd is degree of similarity between d and d'. Similar to the partial–inheritance relationship, the similar-to link is not transitive.
Instance	Denoted as **d-ins → d'** which states that the successor is an instance of the predecessor.
Sequential	Denoted as **d-seq → d'**, which defines that d should be browsed before d', i.e. the content of d' is the successor to the content of d. The sequential link is transitive. The transitive relationship allows the relevant sequential links to be connected to form a sequential chain.
Reference	Denoted as **d-ref → d'** which means that d' is the further explanation of d. The reference link has a transitive characteristic.
Equal-to	Indicates that two resources are identical in semantics. Obviously, a resource is equal to itself. Equality relationship can be regarded as a special case of the similar relationship. So all rules of the similar-to link also holds for the equal-to link by replacing the similar-to link with the equal-to link. The equal-to link is useful in SLN reasoning processes.
Empty	Represents that two resources are absolutely irrelevant in semantics.
Unknown	Indicates that the semantic relationship between two resources is uncertain or unknown. Null relationship means that the semantic relationship between two resources is not known, although there may exist some semantic relationship. Null relationship can be replaced with some other relationship, once it is changed by users or derived by reasoning mechanism.
Non α -relationship for some semantic relationship α	Indicates that there does not exist the α relationship between two resources. Sometimes, it is useful in reasoning process if we know that there is no certain semantic relationship between two resources.
Opposite relationship	States that the successor declares the opposite idea of the predecessor.

Table 4. Semantic link network formalism

A set of general semantic relation reasoning rules was suggested in [37]. If a semantic link exists between nodes, a link of reverse relation may exist, e.g., *A-isSouthOf→B* is the reverse link of *B-isNorthOf→A*, where *isSouthOf* and *isNorthOf* are common sense. A relation could have a reverse relation. Relations and their corresponding reverse relations are knowledge for supporting semantic relation reasoning.

Semantic links between resources can be established in two ways: user definition and automatic discovery. User definition relies on a software tool with the interface for specifying semantic nodes and semantic links between two sets of resources or connecting a new resource to an existing resource by semantic link.

The automatic generation of semantic links may be performed several ways[38]: discovering semantic links in a given set of resources by analysing the contents of resources and their metadata and determining their relations according to the semantic links between contents (e.g., similar relation and co-occurrence relation), relations between metadata, and relations between link structures; deriving new semantic links by relational reasoning and analogical reasoning on existing semantic links according to reasoning rules; inferring a semantic link according to the frequency of its appearance in SLNs.

5.2 Typed Links in e-Learning

Compared with the classical Web hyperlink structure, typed (or semantic) links have several advantages in supporting e-learning [39]:

- they support semantics-rich browsing and semantic reasoning at both the instance level and the abstraction level;
- they provide learners with not only the required knowledge but also relevant contents that semantically link to that;
- they foster inductive and analogical reasoning, help to understand new semantic relations and can inspire creative thinking and broaden the knowledge of learners.

A first list of possible types of relations between learning resources is proposed by the *Dublin Core* [40] standard for the annotation of digital resources and is integrated in the *Learning Object Metadata* standard for the annotation of learning objects [41]. The list of link types proposed by these standards is reported in table 5.

Link Type	**Definition**
isVersionOf	The described resource is a version, edition, or adaptation of the referenced resource. Changes in version imply substantive changes in content rather than differences in format.
hasVersion	The described resource has a version, edition, or adaptation, namely, the referenced resource.
isReplacedBy	The described resource is supplanted, displaced, or superseded by the referenced resource.

Link Type	Definition
Replaces	The described resource supplants, displaces, or supersedes the referenced resource.
isRequiredBy	The described resource is required by the referenced resource, either physically or logically.
Requires	The described resource requires the referenced resource to support its function, delivery, or coherence of content.
isPartOf	The described resource is a physical or logical part of the referenced resource.
hasPart	The described resource includes the referenced resource either physically or logically.
isReferencedBy	The described resource is referenced, cited, or otherwise pointed to by the referenced resource.
References	The described resource references, cites, or otherwise points to the referenced resource.
isFormatOf	The described resource is the same intellectual content of the referenced resource, but presented in another format.
hasFormat	The described resource pre-existed the referenced resource, which is essentially the same intellectual content presented in another format.

Table 5. Types of relations between learning resources from the IEEE LOM standard.

Further studies extend these relations from the pedagogical viewpoint. As an example, the *Educational Rationale Metadata* [42] initiative defined some metadata to record process-oriented information about instructional approaches for learning resources, though a set of tags which would allow authors to describe the critical elements in their design intent. Such tags, described in table 6, can be also used to link additional content to the learning resource core.

Link Type	Definition
Anchor	Anchor new knowledge in authentic contexts.
Goals	Set a goal to solve a non-trivial case or problem.
Motivate	Develop motivation to perform tasks and understand knowledge.
Apply	Apply theory in practice.
Styles	Employ multiple styles of learning.
Customize	Customize the learning agenda.
Monitor	Monitor comprehension and adjust learning strategies.
Adapt	Adapt task difficulty to match needs and capabilities.
Teach	Engage in expository or teaching activities.
Discover	Use trial and error to discover something new.

Link Type	Definition
Collaborate	Collaborate to accomplish part of the learning task.
Evaluate	Engage in self-evaluation.
Reflect	Reflect on the learning process.
Misconceptions	Confront and resolve misconceptions.
Extrapolate	Extrapolate beyond the information provided.
Relate	Relate new knowledge to prior knowledge.
Perspectives	Examine new knowledge from different perspectives.
Differentiate	Differentiate knowledge types *e.g., heuristics, context-dependent.*
Integrate	Integrate new knowledge.
Elaborate	Elaborate new knowledge.
Critique	Think critically about new knowledge.

Table 6. Types of tags proposed by the Educational Rationale Metadata Initiative.

5.3 Comparison with Similar Systems

The Compound Learning Resources Manager discussed in this document is able to support adaptation while adopting intuitive guided learning. It is composed of a designer allowing teachers to edit such kind of resources according to a semantic connection model and by a player allowing learners to execute them. The player includes a personalization engine able to adapt semantic connections with respect to the learning context as well as to learning and teaching preferences.

The so obtained system can be compared with adaptive e-learning systems that provide automatic page link annotation. Some of such tools like **AHA!**, **INSPIRE**, **InterBook** and **NetCoach** have been already introduced in [2] (section 5.2). In the following we present a selection of other systems and prototypes in this area trying to determine the distinctive features carried out by our approach.

ALE (Adaptive Learning Environment) [43] is an environment for creating adaptive courses. It tracks students' progress through the course and annotates links using this information. Domain structure is represented using classical concept network. The **Knowledge Sea** [44] system tries to help students with navigation to additional outside content by providing adaptively annotated links based on the topics and recommendations from other students. It integrates adaptivity and social navigation.

MetaLinks [45] is a system for creating web based adaptive electronic text books. The system monitors a student's path through the content and provides adaptive annotation of links telling the student if all prerequisites for given page have been met or not. **NavEx** (Navigation to Examples) [46] is a system designed to provide students with an adaptive annotation of programming examples without the need for manual indexing of examples by teachers. The system monitors student's progress with individual examples and recommends links to examples matching current study goal with all prerequisites met.

QuizGuide [47] helps students to select the most relevant examples by providing adaptive annotation to links to problems. Links are annotated on the basis of known prerequisites using students' knowledge and previous performance and relevance of the topic to current lectures. The table 7 compares the various available systems and prototypes for adaptive e-learning also dealing with link annotation.

System	Status	Semantics on		Link annotation based on		
		Pages	Links	Knowledge	Preferences	Context
AHA!	Full System	Yes		Yes		
INSPIRE	Full System	Yes		Yes	Yes	
InterBook	Full System	Yes		Yes		
NetCoach	Full System	Yes		Yes		
ALE	Prototype	Yes		Yes		
Knowledge Sea	Prototype		Yes		Yes	
MetaLinks	Prototype	Yes	Yes	Yes		
NavEx	Prototype	Yes		Yes		
QuizGuide	Prototype	Yes		Yes		
OUR SYSTEM	**Prototype**	**YES**	**YES**	**YES**	**YES**	**YES**

As it can be seen, the majority of surveyed systems adapts the links basing on learner knowledge i.e. links that are not feasible or relevant for a learner given his current knowledge of domain concepts are removed or identified with specific colors or icons. Only two systems show or remove links also basing on preferences. The solution we propose is the only one that also uses information about the learning context to provide link annotation together with information about learner preferences. Information about previous learner knowledge is also used for course adaptation basing on standard IWT adaptation features.

Link adaptation, in the greatest part of surveyed existing systems, is based on semantic information connected with the pages composing the learning resource or the learning course. One exception is *Knowledge Sea* that, being based on external resources, connects semantics only to links to such resources. Another exception is *MetaLink* that uses typed connections like "related concepts", "historical background", etc. The solution we propose is one of the few connecting semantics both to pages and links and using a comprehensive set of link typologies.

6 Conclusions

We defined in this document the theoretical foundation for the management of Semantic Connections in the ALICE learning system. The document updates and extends [49] and takes into account results of interim experimentation activities. With respect to [49]:

- we improved the semantic connections customisation algorithm giving teachers the possibility to specify preferences about connections directly on units of learning rather than only on domain model concepts and contexts;
- we improved the semantic connection model by introducing a strong separation among connection types and compound learning resources, composed by resource pages and semantic connections;
- we introduced a recommender system approach to initialise preferred connections on the basis of connections preferred by similar learners (learners with similar learning models);
- we improved and extended the compound learning resource authoring system that is now a visual tool based on graph manipulation;
- we introduced a new component purposed to the centralized editing of semantic connections;
- we extended the related work section with a comparison of our approach with similar systems and research prototypes.

After having developed and integrated with other IWT components the defined models and methodologies, a final experimentation phase will follow. Results coming from that can be used for a further step of models and methodologies improvement before industrialization.

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