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A REVERSIBLE WEB ARCHITECTURE FOR THE MANAGEMENT OF GEOGRAPHIC INFORMATION

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1. INTRODUCTION

In the last years, the use of the Web for the visualisation and diffusion of geographic data is focusing the attention of developers and users: the idea to reach a wide arena of users in a friendly and simple fashion is really attractive. At a deeper analysis, however, one must admit that the user interaction and the available tools in the traditional applications for geographic data (such as image processing systems and GIS – Geographic Information Systems –) are different from those offered by traditional Web sites. The former systems are richer in terms of elaboration tools and centred on the unavoidable creative activity and experience of the end user; in the latter systems the end users play a passive role (documents are selected and prepared by the site authors), interaction tools are usually limited to access and navigation, but the interaction habits are easier, and results are available without any concern about formats, active/visible layers, etc. The result of this gap is the abundance of applications which are called WebGIS or GIS online, being nevertheless systems for the delivery on the Web of images with geographic reference.

In this paper we propose a Web architecture which is able to present to the users richer environments in terms of both computation facilities and interaction tools. The proposal is based on the use of open technologies for the description and display of geographic information on the Web, i.e. GML (Geographic Markup Language) and SVG (Scalable Vector Graphics). The architecture is reversible, i.e. not only information but also their elaboration/manipulation tools can be suitably exchanged/transformed through the components of the Internet, whereas in the traditional Web architecture information are distributed from the server(s) to the browser(s) in a one-way fashion. The idea is illustrated here in a case study represented by a CBIR (Content-Based Information Retrieval) system of remote sensing images. This system, called SIRS (Signature Information Retrieval System) [1, 2] is based on a model allowing to index and retrieve images by means of their spectral properties.

2. GEOGRAPHIC DATA MANAGEMENT ON THE WEB

The traditional architecture of the Web is based on two dialoguing units:

- a data delivery unit (hardware + software) which collects, gets ready, manages, serves information (the so called published documents), and is usually in charge of the necessary computing activities
- a data display unit (hardware + software) which request, receive and browse the information.

Java™ has allowed to transfer binary modules to the data display unit which becomes therefore also a data computing unit: in fact, in this way some interaction/computation sequences may by performed locally, without bandwidth and server resource overloading and increasing the user-machine interaction speed. Though Java™ opened the way to a new Web concept, allowing to share/distribute computations on both sides of the Web architecture on the basis of design constraints and opportunities, it delivers binary code which is not extensible and can be only executed.

The exchange of open and textual information becomes then the key factor to realise true reversible Web architectures, able not only to deliver passive computation, but also to let the browser read, interpret, modify and exchange the delivered files. XML (eXtended Markup Language) copes with this need by allowing to define fragments of information as texts files which can be matched by programming languages acting at any component of the Internet architecture. XML specification is open and fully documented [3]; it consists of a suite of recommendations, some of which devoted to particular fields of application, such as musical or mathematical documents definition and delivery. But XML tags can be freely defined to reflect the semantics of any application universe and the structure of the documents to be dealt with.

The GIS community is forced to take initiatives and adopt standards for delivering information over the Internet, in order to overcome hurdles in the diffusion and effective exploitation of territorial information [4]. This process is being driven by the heavy investment from academic and industry coalitions into open standard methodologies for information creation and delivery. GML in particular has been defined by the OpenGIS Consortium as the ML for the representation of data in the geographic world [5]. In the XML suite there are also languages for the definition of 2D vector graphics which are particularly promising for the graphic rendering of geographic data. GML provides a common model and common format for the description and expression of geographic entities. SVG (Scalable Vector Graphics), the W3C recommendation for vector graphics [6], represents one of the clever ways to display geo-spatial information by standard Web browsers. Currently, SVG is supported by means of free downloadable players or plug-ins, such as that from Adobe Corporation [7], which assure that SVG capabilities can be exploited by a standard browser without the need of any other special software to view the delivered files. Some interesting works in the recent literature address the relationship of GML (which is considered a semantically-rich content for spatial information description) and SVG (a presentation-rich tool) [8, 9].

With the aid of all such open and standard specifications, also on the Internet we can conceive application environments able to manage, manipulate and even exchange geographic/spatial information in a reversible way, acting at one of the two logical units of the network or in a mixed fashion [10, 11]. In fact, by exploiting the above technologies, it is possible to design complex systems on the Internet so that only activities strictly related to the management of a data repository and to the direct user/system interaction are in charge of data server(s) and browser(s) respectively; all other activities can be assigned to both logical units on the basis of criteria such as performance, data dimensions, available hardware platforms, etc. The underlying idea is to evolve the concept of electronic document as an information aggregation collecting both pieces of data and their description and manipulation tools [12]. Original data fragments can be stored on different repositories, and follow various data model, formats, languages, etc. Their aggregation, the electronic document, can be exchanged among the different Internet components, transformed and manipulated at each network node and suitably rendered by any Internet data displayer such as a Web browser, a mobile or a sound/voice rendering device.

To test these ideas, in this paper we consider as case study the image retrieval system described in the next section. The proposal uses standard browsers and does not appeal to proprietary software; therefore it is strictly related to the exchange of GML-described information and on the ability of SVG to display vectors and manage graphic user interfaces on the Web.

3. THE SIGNATURE INFORMATION RETRIEVAL SYSTEM

SIRS is a CBIR system under development at the Italian CNR (National Research Council) able to index and retrieve multi-spectral remote sensing images on the basis of a domain specific feature, i.e. their spectral properties (for a discussion on CBIR based on general features, such as colour, shape, or texture, see [13]). There are other examples of approaches and systems to retrieve remote sensing images by spectral features [14, 15, 16], but this is novel with respect to both the representation of information items and the matching approach, which models the uncertainty implicit in the association of a spectral region with a ground cover class. The model assumes that each pixel of a source image belongs to a spectral region, which groups a set of 'homogeneous' pixels and is identified by a representative spectral signature. In fact, each surface type, such as water, bare soil, vegetation, etc. reflects radiation differently in different spectral bands (i.e. different wavelengths). Therefore, the vector of values corresponding to the radiance reflected from a homogeneous cover class in the different bands is characteristic of that class and allows to relate a portion of an observed ground surface to the cover classes of that area. In fig. 1 the spectral signatures of three ground cover classes are represented: the graph shows the spectral response (in digital numbers, DN, in the range [0..255]) as a function of six spectral bands of the TM sensor of a Landsat satellite.

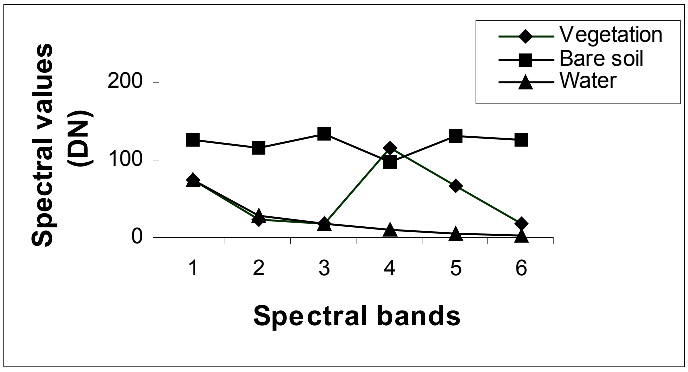

Fig. 1 The spectral signatures of Vegetation, Bare soil and Water

In the SIRS model, the source images are indexed by a classification process, which assigns each pixel to a ground cover class. A multi-spectral unsupervised classification is applied to this purpose [16]: it is based on a first cluster step to group pixels in homogeneous regions, and then on a matching step which exploits the knowledge of a set of reference spectral signatures to label the obtained clusters. The accuracy of the association of clusters with the reference classes depends both on the choice of a meaningful collection of known spectral signatures, and on the definition of suitable distance measures between the signatures.

In the adopted model, two different distance measures are chosen, which take into account two complementary aspects of vector similarity: the first is the Simple Matching Coefficient (SMC), quantifying the similarity of value vectors, the second is the Correlation Coefficient (CC), evaluating the similarity of vector trends. The values SMCs and CCs obtained by comparing the signature of a homogeneous region with the reference signatures are then aggregated by soft rules, modelling the uncertainty intrinsic in the reference class identification process (for details of the method, see [1], and the overall similarity degree is interpreted as the possibility degree that the considered region in the image corresponds to a reference class [18, 19]. Each region has therefore associated a possibility distribution over the considered reference classes [20].

The indexing phase, which has been briefly described above, generates for each image to be archived in SIRS its formal representation, which is stored in the SIRS data structure. This is constituted by two main components. The first is the dictionary of the spectral signatures of the reference classes: each element of this dictionary represents a reference class and points to the list of all the archived images containing that class at some degree of possibility. The collection of such lists is the second component of the data structure, i.e. the so called inverted file [21]. Each of the images in the lists, which has been submitted to multi-spectral unsupervised classification for the indexing purposes, is archived with its associated ground cover classification (a thematic map).

The SIRS query evaluation mechanism exploits information stored in the data structure. The SIRS query language allows to express constraints on the information elements of the data structure, i.e. on the reference classes and their spectral signatures. Three main types of queries are by now considered in the system:

1. Query by class label: this kind of query is formulated by means of one or more identifiers of the predefined reference classes. When the user specifies for example the identifier «water», he/she is looking for images containing one or more regions possibly classified as water. The class identifiers can be combined (as usual in Information Retrieval) by the Boolean aggregation operators AND and OR. When connecting the class identifiers by the AND aggregation operator the user is requiring the images that contain all the specified classes (intersection of results). When connecting the class identifiers by the OR aggregation operator the user is requiring the images that contain at least one of the specified classes (union of results).
2. Query by a vector of spectral values: this kind of query consists in the specification of a vector of spectral values. The vector is associated with one or more reference classes on the basis of the following procedure. First the possibility degrees of the input vector with respect to the reference classes are computed. Second, just the classes for which these possibility degrees are greater than a given threshold are considered for retrieval. By this kind of query, the user is looking for images that possibly contain the classes with spectral values 'close' to those of the specified vector.
3. Query by a homogeneous sub-region of an unknown image (query by example): in this case the user presents an image to the system, and within this image he/she selects a sub-region which is as far as possible homogeneous. The statistical parameters mean and standard deviation are computed on all the pixel values of the sub-region to check its homogeneity. If the pixels in the sub-region are not homogeneous, the user must select a new sub-region. Then, the spectral signature of the sub-region is computed and used as in the query of type 2.

While the generation of a SIRS archive (corresponding to the indexing phase of the source remote sensing images, the creation of the data structure, and of the pointers to the stored maps) is an once-only activity which is in charge of a back-end unit, the activities involved in the expression/evaluation of queries and in the result examination are going to be implemented on the Web. To follow the reversibility hypothesis described in the previous section, the design of these activities requires an analysis of the involved computation or data transformation steps in order to mandatory assign them to one of the two logical units of the Web architecture or let them be performed indifferently on the basis of pre-identified criteria or performance chances. The following section is devoted to briefly describe this analysis and sketch the resulting architecture.

4. THE ARCHITECTURE OF SIRS ON THE WEB

The activities of SIRS have to be implemented on the Web in order to be managed online by users interacting with their standard browsers. They are described and underlined in table 1 with reference to three activity groups corresponding to the query expression, the query evaluation and the result presentation and analysis.

The first and the last groups present activities that call for direct and active participation of the users (they are marked in italics in the table). The query evaluation group does not include any activity of this kind and therefore can be performed everywhere except for activities requiring data access which are in charge of the data delivery unit which hosts data repositories and server(s). On the other hand, the activities in italics challenge, in most cases, the features of a plain display unit (such as a standard Web viewer): they must be endowed with abilities to interpret and transform information delivered by the other architecture components (see by example *change visualization modes*, *merge by different criteria*, *edit*) and to run the interaction tools (see by example *zoom*, *pan*, *localise*).

Activity group	Activities and their explanation
Query expression	For the queries of type 1 and 2, the users interact with some forms to *select the query items* (class labels or vector values) and, for type 1, to *select the aggregation operators*. For usability purposes, it is useful to show the available reference classes with their signatures. The expression of a query of type 3 is much more complicated, as it requires the visualization of the unknown image at a suitable scale (*zooming*, *panning*, exact geographic *localization* are then required), and aided by overlaying topography; the *selection of a region* that should be spectrally homogeneous by a graphic tool (as a consequence this fires a control on the size of the region and on its 'homogeneity'); the extraction of the spectral signature of the region to be used to evaluate the query.
Query evaluation	The evaluation is performed by a matching process between the expressed query and the data structure components; in the case of a query of type 1, the query is decomposed in its atomic elements to be processed independently; an atomic query term is searched in the dictionary and, if found, the pointed list of images is retrieved; the operators are applied to the lists retrieved by atomic terms evaluation to make their union or intersection. In the case of a query of type 2 or 3, the matching process computes the possibility degree of the query vector with respect to all the reference classes; a threshold is then applied to the possibility degrees to select only the classes associated with the higher degrees; at last, the pointed image list is retrieved for each selected class.
Result presentation and analysis	The overall purpose of this group is to let the user examine the results of the evaluation phase in a fashion and with tools that should be as far as possible tailored with her/his habits, skills and objectives; the obtained results of the query evaluation are one or more lists of remote sensing images and their classifications; they must be merged and ordered in decreasing order of their relevance with respect to the query; have to be arranged so that they can be displayed in different fashions (taking into account also the properties of the display device in the mobile perspective); they should be *manipulated to change visualization modes*, *merged by different criteria*, or *priorities*, *edited* to extract significant sections or to enhance worth-noticing aspects (by example, *bookmarking* the most significant images or *annotating* meaningful regions), and partially or fully *saved* for further sessions; some interesting results could be reused to *submit new queries*.

Table 1 Activity groups of SIRS

In mono-directional solutions (such as those suggested in [22, 10, 23], documents are created at the data delivery side with a content-based markup language (such as GML in the case of geographic information) and are then transformed to obtain a plain display document (in HTML or SVG, by example) for browsing. From an architectural point of view, these solutions are poor, as they do not keep the semantics and relations of the original documents. As a consequence, there is an asymmetry between information distributed from the data delivery unit to the browser and vice versa: the user interacts with display-only documents which cannot be re-interpreted and exchanged to the other architecture components. In some cases the loss of semantics, relations and constraints avoids the user manipulation itself as interaction events act on plain graphic signs on which it is difficult to fire controls. To enrich the computation and data manipulation abilities of the users we need a more complete architecture assuring the reversibility of the information exchanged through the logic units even if submitted to transformations (of meaning, structure and style).

Therefore, if a user interacts with a region, by example modifying its SVG shape, this action must be brought back to the GML document - and therefore to the geographic meaning of the shape - before its delivering to the other components. It’s worth noticing, however, that a user interaction affecting only the display properties of information (by example, if the user requires an alternative representation of a spectral signature, changing it from a table of values to a Cartesian graph) should not affect the GML document which does not matter of visualisation issues.

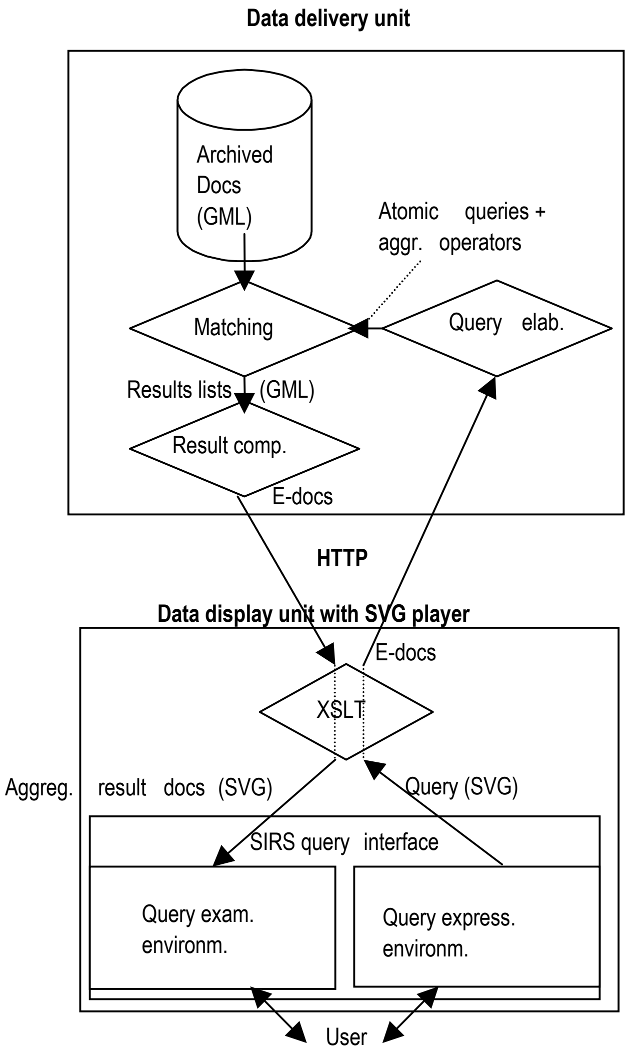

Fig. 2 A sketch of the proposed architecture

In this architecture a GML document coming from a data server is included in a complex structure, that we call electronic document, with descriptions of the delivered information, code for its manipulation, interpretation and display. Before arriving to the browser, it is converted to a set of drawing objects, i.e. transformed into SVG, to draw the graphic elements (as maps, images, texts, etc.), and also to realise and run the interaction tools which require vector graphics/events management and programmability.

Under the above requirements, the architecture of the matching and retrieval modules of SIRS on the Web can be sketched as in Figure 2. It includes also environments to perform the computations and language transformations required by the SIRS. Some of them, such as the query elaboration, the matching between queries and stored documents (which are both described by GML at this step), and the first aggregation of result list(s) are delegated to the data delivery unit. In fact, they do not require direct user manipulation (as discussed in Table 1). The data display and interaction (mainly query formulation and results examination) activities are included in the display unit and performed directly on the transformed SVG version of the documents. The e-documents delivered between the units by a plain HTTP protocol are not limited to the GML data description but contains also code to guide presentation, interaction and computation.

5. CONCLUSIONS

SIRS is a content-based information retrieval system to store and query remote sensing images by their spectral properties. We are going to design it so that the users can interact online by expressing queries on the image content and examining the obtained results. The online system architecture we propose is a reversible one: it is not only aimed at enriching the users interaction and computation tools at the browser side, but also at giving him/her an active role in creating new information. The users' actions are not simple display adaptations but he/she can operate also on the content/structure of the information, whose semantic richness is maintained through the various information delivery and transformation steps. The users' actions themselves can be saved and directly delivered to the other Internet components (such as other user browsers) without going back to the original server(s).

In the architecture we propose a subdivision of computation/transformation actions which are no more in charge of the data delivery unit only but can be performed everywhere on the basis of needs and suitability. The architecture will be tested soon to verify its real reversibility and other possibility activity subdivisions.

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