

Integrated Treatment of Territorial Statistical Data using a Spatio-Temporal Approach

*Trattamento Integrato dei Dati Statistici a Base Territoriale secondo un
Approccio Spazio-Temporale*

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Riassunto: Nel lavoro proposto viene trattato il tema dell'integrazione di sistemi informativi in ambito statistico-territoriale secondo un approccio basato sulla gestione spazio-temporale dei dati. Partendo dall'assunto che solo in una visione unitaria, che tenga conto della complessa interazione tra contesti, dati ed ambienti applicativi eterogenei, è possibile pervenire ad una integrazione completa, vengono individuati nella *cooperazione applicativa* e nelle *infrastrutture di dati comuni* i principi guida di tale processo, ne vengono illustrate le principali esperienze condotte in ISTAT ed i conseguenti effetti sulle indagini statistiche.

Keywords: Integration, Cooperative application, Spatiotemporal database, Data infrastructures

1. Introduction

While facing the problem of integration in the field of *statistical information systems* we often run the risk of focusing our attention either on the statistic aspects or on the technological ones. Furthermore, if also territorial data are a matter for integration, a subsequent risk rises, due to the peculiar nature of geographical information systems, which need a highly specialistic processing for the spatial data, nearly always hidden to the users and very difficult to be integrated with any other different data.

Giving an exhaustive overview of theories, approaches and solutions for integration is beyond the purpose of this paper, but it is useful to point out that in some cases the methodological aspects are mainly highlighted, in others the technical-operating ones are underlined, in some others- and perhaps they are the majority - the focus is on data repositories. These partial ways of facing the problem are actually forced because on one hand the border among these components is rather fuzzy, especially when the core of integration is the concept of *information* itself and, on the other hand, because technology and methodology don't exclude each other but interact (Wegman, 1998). Referring to the most recent contributions, which are connected to new technologies – not by chance – we can focus our attention on the advent of the Internet above all, the ultimate success of Data Warehouse solutions and the integration between these new opportunities, by means of Web Warehousing solutions. For example, in the field of GIS, new concepts of *Spatial Data Infrastructure* and *Geospatial Data Clearinghouse* (Executive Order 12906, 1994), (Vico, 2000) have been introduced; in statistics we can quote *Corporate Data Warehouse* (United Nations, 1999) or the "*System of systems*" approach (Malmborg and Sundgren, 1995), but it is in the field of information systems that we find the most important innovations: *Distributed Object Computing* (Melis, 1998), *Data Cube* (Gray *et al.*, 1996), *Spatio-Temporal Databases* (Worboys, 1994), (Tryfona and Hadzilacos, 1997), the architectures for *Multi-data Sources* and *Data Fusion* (Lenz, 1998), and so on. Anyway, if the approach to integration is only sectorial we run the risk that one point of view

(either statistical, territorial or technological) prevails over the others. Only handling the complexity of integration by a combined approach is it possible to overcome such a disadvantage. Just to define and carry out an approach to integration which might take that in consideration, some experiences have been performed in ISTAT. These experiences have led to the development of some information systems that are fully integrated with reference to the spatio-temporal components of statistical data.

In order to describe the approach followed in our experience in ISTAT, we will refer to a general principle, knowledge fragmentation and reannexation (Lanzavecchia, 1991), and, quoting theories that lie outside the context of information technology or statistics, as the *holystic* paradigm. On the basis of such a theory it is essential, while studying a complex system, to consider a lot of functional interactions among the several components, so that the whole system has to be considered more than the sum of its single components. According to this point of view, our approach sees the integration problem as a combination of topics concerning territorial, statistical and information systems. So, *common infrastructures* of microdata, metadata and macrodata (statistical field), *spatio-temporal entities management* (territorial and geographical I.S.), *confederation* or *controlled replication of data* (information technology) have to be considered as specific contributions of a single progressive path towards a full-integrated I.S. Following this path to integration we need to pay a great attention to *common and inter-systems properties*, that allow to transform the component systems into a complex, interacting system.

SIT-In (*Integrated Territorial Information Systems* of ISTAT), **DaWinci** (Web-warehouse of Census data), **S.I.H.** (Web-Warehouse of data on handicaps), **Metasds** (integrated metadata database to support social surveys), **AGI** (*Interactive Generalized Applications*), **SIMIS** (*MetaInformation Systems of Social Surveys*) are - each one in its own specific application field - the first ISTAT experiences towards a full integration of social surveys. In particular, SIT-In (De Francisci, 2000) has represented the starting point of the integration process; it was realized to integrate several legacy territorial information systems and we will describe it in section 2. Once realized, this integrated territorial information system has become one of the components - called "*instrumental system*" (Malmborg and Sundgren, 1995) – co-operating inside a broader Statistical Information System, together with other components: data capturing, production, metadata and dissemination systems, Data-warehouse and DataMart, and so on. We will deal with this topic in section 3. To complete the integration path, we need to make the system directly interact with the real statistical process, here considered as a sequence of phases, such as data collection and capturing, check and validation, processing and analysis, aggregation and dissemination. Such an integration is not completed yet, being necessary, first of all, to build up a *surveys support information system* (as the system drawn for multipurpose social surveys, S.INTE.S.I. (Camporese *at al.*, 1998)); through such a system it will be possible to trigger a step-by-step integration of survey phases, using *generalized applications* and *common data infrastructures*; in section 4 we will describe these experiences, collateral to SIT-In, converging towards the development of a confederated system, integrated on the metadata component and more directly linked with statistical problems. Finally, in section 5, we will remark the risks and the main *benefits* already achieved or expected that the choice of an integration approach on a federated and infrastructural basis produces on statistic surveys.

2. Integration of territorial information systems

The systems chosen in ISTAT for the initial integration in SIT-In included SISTAT, the territorial history database system, providing information about the

evolution in time of territorial administrative entities; CENSUS, the ISTAT GIS, providing the cartography of the Italian territory, down to the Census tract level and SISTER, an address normalizing-geomatching system. The first step of the process of integration in SIT-In was represented by a distinction among the several integration planes, depending on their abstraction level: conceptual, application, technological level.

Conceptual integration represents the highest level of abstraction, developing on the plane of concepts, relationships among concepts and constraints; for such a level, a methodology has been set (Ambrosetti *et al.*, 1999). This methodology is based on "integration primitives" that allowed both to detail integration within systems and within levels (*refinement* primitive), and to harmonize similar but heterogeneous concepts among systems (*integration* primitive) or among levels (*derivation* primitive). At the end of the conceptual integration, we obtained a complete design of the system, based on legacy data partitioning, metadata and thesauri confederation and a component-based approach for technological level.

Application integration moves along the functional level of the system; in SIT-in we worked mainly on the principle of cooperation between data and processes: *federated databases*, *DW/Data Mart* and *metainformation infrastructures* when dealing with data components and *component-based computing* as regards processes. The choices to implement systems application integration are based on the introduction of a strict relationship between system components. Each component has to share *and/or* modify the same data, without conditioning the "autonomy" of legacy systems. The relationship among systems is possible through the brokering of application procedures and middleware services, which assimilate heterogeneity and grant data consistence.

In SIT-In, data integration has been achieved on the basis of two distinct kinds of cooperation: *Loosely coupled federation of databases* (collection of databases in which all the components appear on the outside as a single database); *Collection of replicated data system* (also called Data Warehouse), obtained extracting information from single databases and replicating them, i.e. creating a local integrated copy of data of interest.

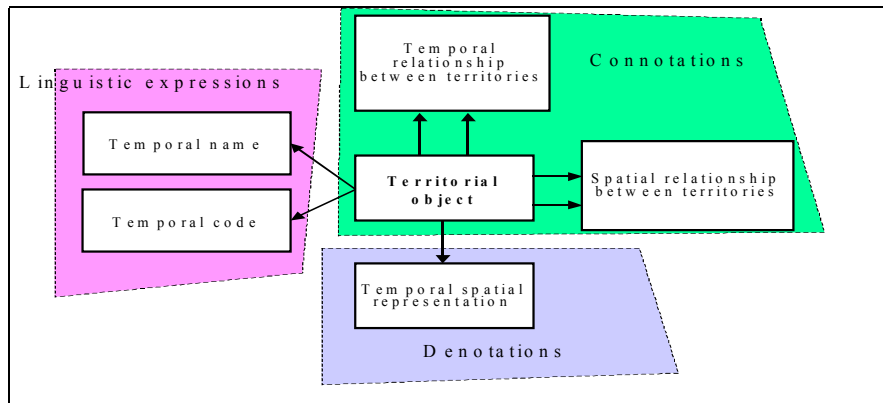
As regards metadata, generally called *Reference data*, in SIT-In they have been integrated on three levels: lexicon, syntax, semantics.

The lexical level (*Thesauri*) is formed by the consolidated repository of information managed by the system: nomenclatures, definitions, standard classifications, and so on. In other words, they represent the controlled vocabulary of concepts and terms, generally little changeable, used in all the components of the integrated system. On the syntactic level, *Integration metadata* allow to harmonize concepts belonging to thesauri and the definition of syntactic rules to surf and query on statistical data. Finally, on the semantic level, *Production metadata*, belonging to several component systems, allow to give the correct and direct meaning of the managed data and to describe the data structure, both on a conceptual (objects, properties, relationships) and physical level (type, range, soundness, etc.).

Maybe, the most significant feature of conceptual design of SIT-In data is the construction of a semiotic-based model of territorial objects; by this modelling all the quality topics of spatio-temporal database (coherence, consistence, completeness, semantic conflict solving (homonymies and synonymies), interschema enrichment) are achieved. In such a model, besides the concept of *object identification*, the *object identity* is also represented. In the model, each territorial object O_i is defined by a complex triplete $\{O_i=(E_i, S_i, R_i)\}$, composed of a set of semantic marks $S_i=(Id_O_i, R_i^{t_{ij}}, R_i^{s_{ij}})$, expression $E_i=(D_i^{t_j}, C_i^{t_j})$ and spatial references $R_i=(P_i^{t_j})$, in which:

Id_{O_i} : object O_i identification; Dt_i : O_i denomination at time t
 Rt_{ij} : relationship between O_i e O_j at time t ; Ct_i : O_i code at time t
 Rs_{ij} : relationship between O_i e O_j in space s Pt_i : O_i spatial representation at time t

Figure 1 - *Semiotic approach to spatio-temporal data modeling*



As regards cooperative application on processes side, SIT-In prototype realizes a process-centred application infrastructure, focused at the moment on the principle of functionalities wrapping and triggering. They are referred to interconnection of software distinct layers, as *visualisation*, *querying*, *spatial selection*, *relational selection*, *data coupling*. The several software layers are referred to manifold application and deployment architectures: users visualisations have been developed by means of WEB-languages tools, queries take place through relational languages, spatial queries via GIS engines, data coupling is possible through both parameters exchange and execution of highly-parametric queries, while Java language operates overall as an interface connective layer.

From the technological point of view, the integration process is characterized by a three layer/multi tiers architecture, in which data, application and interface layers are modelled and distributed on three or more physical tiers: databases and spatial databases (*tier 1*); brokering and confederation middleware engines (*tier 2*); browsers for users on thin clients (*tier 3*) (Paolucci *et al.*, 2000). Although this point seems to be of little interest in the field of statistics integration, a correct approach to build up data, application and user interface levels allows to obtain a great benefit in the treatment of data for several reasons - especially when there is a strong heterogeneity among components - as we will show later. The data level is composed of a few RDB instances, the application layer consists of various application servers (Java server, Internet Map Server, report server), while the system-user interaction is enabled to dynamic generation of HTML pages.

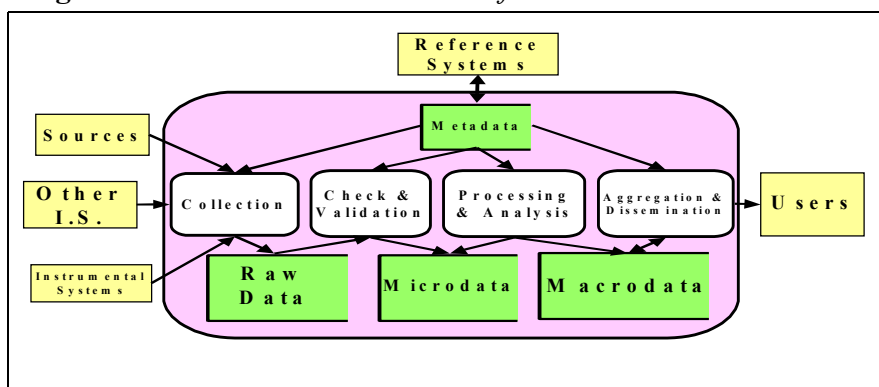
3. Context of statistical integration through SIT-In

SIT-In, which was born as a project to integrate territorial data only and developed in a prototypal release, has furtherly evolved as a broader statistical integrated system, through the connection of statistical aggregated data and metadata.

As a brief explanation about the process of SIT-In integration with statistical data context, we will describe the method followed to integrate Territorial Data Bank System (BDT) - originally not included in the project - that allowed to exploit both thematic cartographies and temporal exchanges among territories, already included in SIT-In system.

First of all, we will show the context diagram of a generic Statistical I.S. according to a classical model describing I.S. processes. In figure 2 you can recognize: *External Agents*, i.e., typically, sources and users, but also other I.S., as reference data systems, instrumental systems, other surveys support systems; *Processes* (in statistic context): data gathering or capturing, check & validation, analysis & processing, aggregation & dissemination; *Internal Data Repositories*: raw data, microdata, macrodata; inter-changing *Information Flows* between processes and repositories.

Figure 2 – *Functional architecture of Statistical I.S.*



According to such a scheme, integration of Territorial Data Bank, at the beginning considered as an external system, in SIT-In, has been developed by a reverse engineering step of legacy conceptual scheme of BDT into the new model of SIT-In. In particular, the spatio-temporal dimension has been extracted from each thematic variable, so that it was possible to make use of spatiotemporal metadata infrastructure already existing in SIT-In. Once the other BDT metadata and aggregated data have been re-engineered in RDBMS, a unique selection criteria for end-users was developed: through a transfer of spatio-temporal parameters from SIT-In to BDT, queries on statistical data are executed aligning territorial structure and relating statistical data automatically. When, in the year span between a survey and a new one, we face an updating of the territory, the system allows to highlight the discontinuities, "warning" the users about the occurred changes. After all, SIT-In allows to select space and time of interest by a single starting operation. All the components co-operating in the system assume the space-time parameters previously chosen and provide the access to statistical and geographical data really allowed by current selection. Furthermore, temporal updating of territory are reflected on all the querying operations parametrically (Sindoni *et al.*, 2001a).

Figure 3 - Management of *Spatio-temporal* evolution in SIT-In

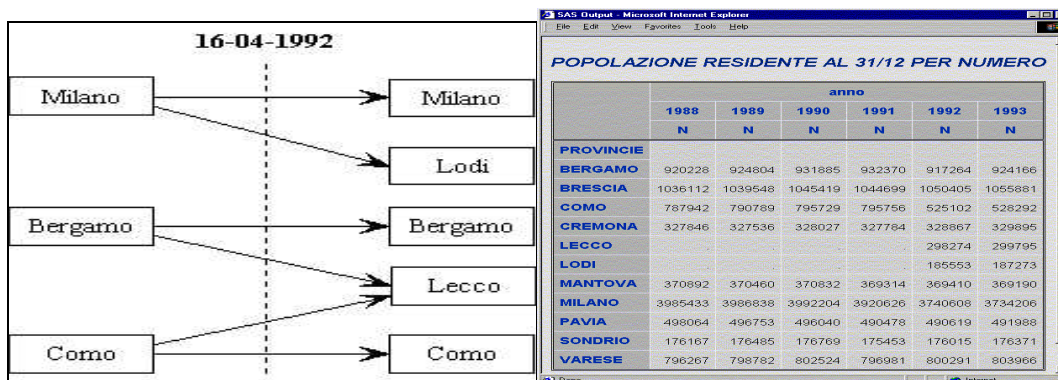


Figure 3 explains the result of such operation by showing territorial updating occurred in some Provinces of Lombardia in 1992 (graph on the left of figure) and how, consequently, in SIT-In statistical time series of resident population inherit territorial updating automatically (table on the right of figure).

Afterwards, inspiring principles of BDT integration also allowed us to develop the navigational system of Census 2001 temporary data (DaWinci) and Handicap Information System (that are about to be available on the Internet), that show more flexible and integrated querying criteria.

4. Integration in statistical surveys production process

As regards the final step of integration process, it is heading towards a gradual integration in SIT-In of the *surveys support information systems*, just taking advantage of the intrinsic capacity of the approach based on metadata infrastructures and cooperation among applications. In such a context, several applications and data infrastructures have been developed and are being used at present in ISTAT, especially in the multipurpose system of social surveys. In this section we will draw an essential map of these experiences and how we will conjecture their integration in SIT-In, which will lose its former and unique connotation as territorial information system, assuming the role of the main engine of social statistic integrated information systems.

The path drawn to integrate the surveys production life-cycle according to the principles of cooperation based on metadata infrastructures is manifold. On the whole it will be managed through an *Integrated Surveys Support System* (S.INTE.S.I.) (Camporese *et al.*, 1998), already designed and partially prototyped. It is assimilable to a bunch structure of which it represents interconnection layer, linking two classes of elements: procedures called AGI (*Generalized Interactive Applications*) and METASDS (*Metadata Database*) (Camporese *et al.*, 2001).

METASDS Metadata can be considered as an "instrument" directly linked to statistical process both in the check and validation phase and in the pre-validation analysis one. Furthermore, the use of database during production process gives the opportunity of getting feedback on survey re-engineering and questionnaire re-drafting phase in case of new editions of surveys. This is possible because a trace of the responses on variables reliability and answers coherence, for example, is kept.

AGI procedures have been built on the basis of disassembling of production process in "bricks" (phases, sub-phases, steps), connected to the statistical process independently one from the other. They derive from legacy procedures, re-engineered into three modules: Input, Processing, Output. Such a modularisation have allowed to separate Input and Output modules - more easily replaceable by generalized procedures on common data infrastructures, integrated through Metasds metadata - from processing module, which has been left unchanged in order to not weigh on current surveys. At the moment, the operating generalized integrated procedures are: Check and correction of Sex and Age Variables, Household Procedure, Family Procedure, Bleaching Filtered Sections and a procedure (SAX) to control and correct full sections of a questionnaire.

Therefore, the integration process has been implemented, on one hand, wrapping in application infrastructures the generalized procedures to check and correct data; on the other hand, the metadata component of METASDS has been exploited to share common data among the set of surveys on social structure and dynamic; finally, we foresee the development of *historical repository*, which will take into account both the various releases of data files and check operations on data. This will happen as to documentation (through metadata) and processing (through file access pointers).

Furthermore, a component to create, analyse and manage surveys quality indicators has been provided in the repository. The main feature of this component is that indicators could be built as a work in progress rather than as a final statement of the survey. Even in that case, it is a generalized application, in which users choose what indicators to build (e.g.: a missing answers indicator combined with a supplied answers indicator provides the *missing answer tax*, stratified by territory, interviewer, time, or any other available variable).

5. Benefits expected from the integration through spatio-temporal systems

In this paper we have shown how ISTAT is moving along two distinct integration paths in the field of Social Statistics information systems. Through these paths we are implementing a progressive integration of current statistical i.s. according to a unitary design, avoiding to interfere on the current surveys (especially production and dissemination phases). As to spatio-temporal i.s. and DW, SIT-In experience has generated two sub-systems (DaWinci and S.I.H.), which are more limited as thematic fields and have richer navigational and querying tools compare to SIT-in itself. They adopt SIT-In baseline (spatio-temporal approach for statistical data) and, together with it, they will represent the basis of follow-up integration phases. As to statistical surveys, we have already created a common data infrastructure and a *corpus* of generalized applications and we are implementing *survey support information systems* - by means of S.INTE.S.I. approach - in order to manage the production process. At last, these two lines can be flow together in a single confederated i.s. of social surveys systems, also by inter-changing further specific functions with other metainformation (SIMIS and SDOSIS), documentation (SIDI) and cataloguing (ARMIDA) systems, which are in progress in ISTAT at present.

From one point of view, the risks connected to this complex project derive from the basic features of the system itself and are mainly of two kinds. First of all, SIT-In - being a confederated system - inherits good qualities and lacks of the component systems, since data and applications can be managed and updated by owner system exclusively and SIT-In can *only* point out any incoherencies on intermediation. The second risk is connected to proliferation of technological instruments available to manage statistical data, wrapping of more and more numerous heterogeneous systems and consequent increase and redundancy of metadata for brokering. These problems can make difficult to keep under control the integration process, unless we use particular integration protocols and suitable monitoring. In our opinion, this represents the main open problem to face as soon as possible. At last, from the statistical point of view, it is only right to underline that the impact of a system integrated according to SIT-In paradigm on statistic problems, such as quality or errors check, has not been completely solved yet and up to now it has been partially settled. However, some benefits are already clear in the present phase, both upstream and downstream of the statistic process. It is indirect benefits, deriving from the "existence" of the integrated system itself and not quantitatively assessable, but also direct benefits on the survey quality, also measurable by quality indicators, and efficiency in carrying out of the survey. As regards indirect benefits we can remark:

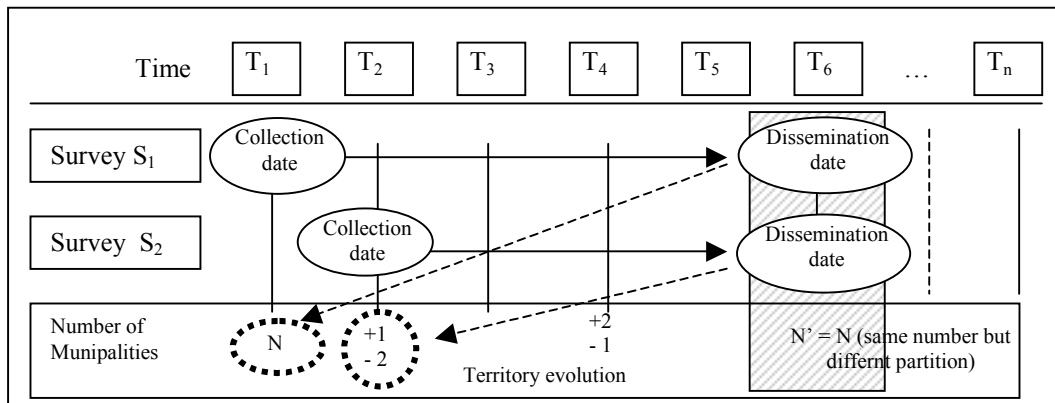
- 1) Benefits inherited in statistics terms from spatio-temporal database features: coherence, integration, solving of conceptual semantic conflict and so on
- 2) Upstream guarantee of the quality of some data, through the direct integration with the legacy system owning data authentication (list of Municipalities at a fixed date

and corresponding evolution, matching a statistic area of a phenomenon surveyed by its exact position on territory, the real set of variables used by surveys);

- 3) The criterion of spatio-temporal data modelling adopted in SIT-In is of great importance. Unlike the principles followed by models usually adopted, in SIT-In the "*existence*" of spatial objects and their relationships is valid apart from "*current identification*" of concepts themselves and of any relating links. Therefore, it is a model based on the existence of spatial objects and not on their mere identification. It means that for those database instances that at a certain point don't match any currently existing objects, the "non-existence" status is not valid whereas the "suspension in time" one is valid. Such a property allows on the one hand to avoid a mismatch between surveys and territorial registers (e.g. lists of *Municipalities per Year*), on the other hand to re-build virtual population or territories. For example, in DaWinci (Italian Census Web-Warehouse) the first operation consisted in a reconstruction of 1991 Census data according to the territorial partition valid in 2001, taking into account temporal evolution occurred in order to permit the comparison between *old* and *new* data, if significant. This allows to discover the anomalies of values during the phase of space-time series construction, the mistakes of re-calculation for aggregation and, in general, to control any anomaly depending on spatio-temporal dynamics.

Besides, it is also possible to distinguish the actual *statistic* dates of a territory from the *administrative* ones, and to refer the data gathered by means of a survey to the territorial partition that was valid at the collection date of that survey and not at the dissemination one, independently from the administrative registration of territorial change. In figure 4 this particular case is shown.

Figure 4 - Territorial evolution management and statistical surveys. An example



In the example, surveys S_1 and S_2 have a different collection date and the same dissemination date. While the two surveys were being carried out, a change of territorial partition occurred: between T_1 and T_2 one municipality rose and two municipalities disappeared, between T_3 and T_4 one municipality disappeared and two rose, that is to say at time T_n the territorial structure has the same number of municipalities but different structure and denominations. SIT-In is able both to align the surveys to their own original territorial structure and to re-build the virtual territorial partition valid at the time of data dissemination, if microdata exist.

- 4) Full use of technological solutions adopted in SIT-In for all the integrated surveys, concerning dynamical navigation in data-warehouse and geographical maps. As regards the cartography, the system exploits an advanced topological model. It consists of a "base level" with both lines and polygons topologies, where each

feature represents atomic geographic information and it is coded by attribute data to derive upper aggregates. That means regions and routes were built aggregating basic features, so that the hierarchical structure shares the geometry, and every time an update is needed only the geometry updating is necessary. Because of this, in order to visualize the territory evolution, the temporal evolution of the area of interest is made dynamically on a set of maps. For each distinct *version* of the territorial partition a different layer is created and the evolution of objects is highlighted by establishing a 1-1 correspondence between objects and colours.

As regards the navigational system for statistical data (e.g. Web Warehouse for Census data) we can point out the following (Sindoni *et al.*, 2001b):

- a) Spatio-temporal evolution: the integrated system enables its users to perform time dependent roll-up and drill-down operations, by automatically selecting the correct time- dependent territorial hierarchies;
 - b) Multidimensional navigation: the spatio-temporal selection is used as an access plane to the navigation through aggregated data. Each dynamic report refers to chosen time stamp and set of territorial entities. Besides dynamic dimensions are effectively managed;
 - c) Time series of aggregated data: a time-slice selection of spatial aggregated data can be "extruded" along the time dimension to produce a time series of spatial data which takes into account the heterogeneity of the space dimension;
 - d) Dynamic integration of users' data: users can dynamically link their own data to the system.
- 5) Solving of data confidential and semantic significance problems as the particular navigation approach plans the access to the existing and disseminable data tables only (thus avoiding useless navigations to cross-tables which present either unreal or non disseminable data).

In addition to these indirect advantages, veritable direct benefits exist, concerning effectiveness - also assessable via quality indicators - and efficiency of management of survey production processes. As main properties we can quote the following (especially referred to SAX application, belonging to the last generation of AGI):

- 1) *Reusability*: the corpus of rules generated by AGI applications can be involved in several phases of a same survey and several datasets for several surveys;
- 2) *Automatic generation of I/O product*: e.g.: generation of validated microdata and metadata shared by different phases, datasets, surveys is enabled;
- 3) *Modularity*: AGI can be easily customized and fitted with reference to the different objectives
- 4) *Interactivity*: all the AGI applications allow to generate the rules of correction separately, the cross-table for checking and analysis;
- 5) *Synchronicity* of correction processing: all the rules defined from time to time are included in a single catalogue, accessible through predefined rules by the coordinator
- 6) *Redundancy reduction and application proliferation*: data-file generated as output by correction rules is unique;
- 7) *Semi-automated documentation*: each survey is able to manage all the information concerning its production process in a semi-automated way;
- 8) *Process information storage*: the process can be documented step-by-step, in this way an a-posteriori documentation (not always easy and reliable) is avoided;
- 9) *Correction process transparency*: a real transparency is nearly always hard to achieve. AGI logic combined with METASDS infrastructure gives an account of each developed step.

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