

AN AUTOMATED INTERNET GEOINFORMATION SERVICE FOR INTEGRATING ONLINE GEOINFORMATION SERVICES AND GENERATING QUASI-REALISTIC SPATIAL POPULATION GIS MAPS

S. Shi and N. Walford

Centre for Earth and Environmental Sciences Research, School of Geography, Geology and the Environment, Kingston University London, Penrhyn Road, Kingston upon Thames KT1 2EE, UK – (s.shi, nwalford)@kingston.ac.uk

KEY WORDS: Automatic spatial data handling, internet-based Geoinformation Service, quasi-realistic GIS models, census, spatial population distribution, dasymetric maps, OGC, geoprocessing

ABSTRACT:

This paper presents the design and realisation of a low-cost automated internet geoinformation service, named Kingston Automated Geoinformation Service (KAGIS), that provides the United Kingdom's academic community with fully processed quasi-realistic GIS maps of spatial population distribution, known as dasymetric maps. The key innovative aspect of the service is that it undertakes spatio-temporal interpolation for census area statistics and enable users to overcome the difficulties associated with inconsistent boundaries used by different census events. It is designed and programmed to carry out live, on-demand online integration of Edinburgh University's geospatial data service (EDINA) and Manchester University's census data service (MIMAS), to automatically geoprocess and deliver digital dasymetric maps for any of 2001, 1991 and 1981 census years and any area of interest at all census area levels in the United Kingdom as per user's request. The system is capable of automatically handling large GIS datasets in accordance with users issuing requests. The system unleashes a large amount of geospatial and census data held in these formerly isolated digital repositories and carries out all necessary data processing to generate the requested spatial information products in a novel workflow. The online data transmission, retrieval, integration, processing and generation of quasi-realistic spatial population (dasymetric) GIS maps at the English county level typically take 2 minutes.

KAGIS enables census data special interest group in the UK's academic community to access and utilise this newly available geoprocessing service for a wide range of applications, such as analysing population changes over the time and undertaking fine resolution detailed spatial population estimation for planning at various scales and areas of interest. Online interactive selection of datasets and the entire procedure of online heterogeneous data integration, areal interpolation and data processing for dasymetric maps with ancillary landuse maps derived from remotely sensed imagery are automated to offer end users opportunities to simply follow a few instructive checkbox and button-clicking steps to obtain resultant digital dasymetric maps.

The design of KAGIS adopts the service oriented design architecture to couple the latest web portal technology and ArcGIS Server technology to realise the new secure internet geoinformation service with a set of specially designed and coded geoprocessing programs performing coherent chained actions in a novel workflow and it is programmed as a novel stateful application to be able to provide the runtime online data integration, processing and resultant GIS map delivering service to concurrent internet users.

Novel aspects of KAGIS include its operation as a new fully integrated service system that acts as an automated online integrator, data processor, e-content generator and secure service deliverer. The system innovatively carries out live, flawless, on-demand combination of formerly isolated geospatial and census data-only repositories and services according to user requests. The novel design of coherently chained modules and workflow enables fully automated processes for real-time digital data acquisition, real-time data processing for on-demand GIS model generation and service delivery.

The whole and parts of the secure online service technology of KAGIS are generic and universally applicable in any countries in the world. With the process of globalisation and development, all countries have been and are undergoing significant development and change. The technology and know-how experience of KAGIS can assist any country in the world to develop its secure internet GIS services, integrating geographical information for specific decision making systems as well as providing low-cost and efficient ways to process and utilise existing geographical data for a multitude of purposes such as development planning.

1. INTRODUCTION

Edina is an internet service provider of digitised British census boundary datasets and Mimas is an online service provider of population statistics datasets of the United Kingdom (Figure 1).

To analyse change is one of the most important functions of a census (Rees, 1998) and another aspect of important use of census is to focus on the up-to-date information as representing the contemporary demographic and socio-economic condition of the population.

However, existing dataset services and datasets themselves do not offer users any easy and friendly ways to process datasets to summarise and compare geographical and demographic change. Datasets are disparate, census boundaries between separate census years changed and there is also inconsistency in the aggregate statistical counts produced (Martin, 1998a&b; OFFICE FOR NATIONAL STATISTICS, 2001; Mackaness and Towers, 2002; Rees and Martin, 2002; Martin, 2003; Norman, Rees and Boyle, 2003; Walford and Shi, 2009).

This presents a fundamental problem and challenge when analysis of socio-economic change is to be undertaken due to incomparability of the datasets.

Furthermore, aggregate statistics are summarised for each census areas. Landuse information is not taken into account and population is assumed to be evenly distributed throughout the areas. Historically, ward is the smallest spatial resolution area for census data. Thus, conventional GIS map depiction of spatial population distribution is far from the reality.

To produce GIS datasets in order to compare for analysing change over time, GIS datasets need to be processed to conform to the same set of census boundaries. To achieve the result of more realistic spatial population distribution, ancillary landuse information needs to be taken into account. Necessary data processing consists of areal interpolation and dasymetric mapping interpolation (Eicher and Bewer, 2001). Figure 2 synoptically illustrates the effect of areal interpolation and dasymetric mapping techniques by using simplified hypothetical zones of separate census years, as described in Walford and SHI (2009).

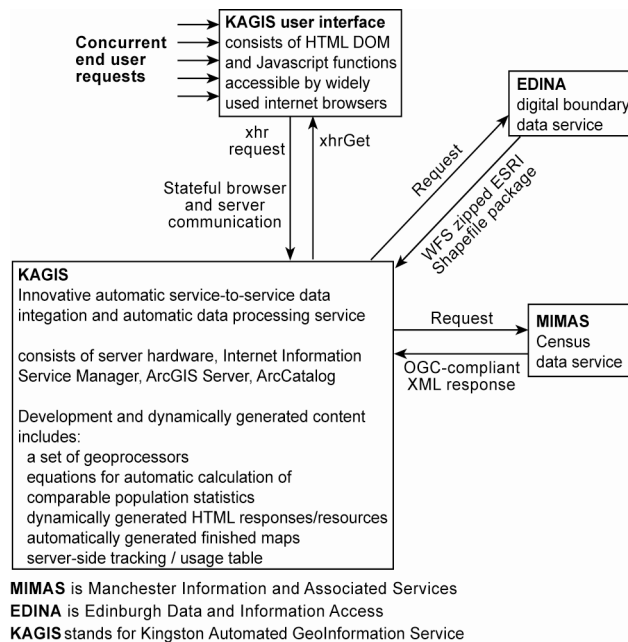


Figure 1: Collaborative relationship of internet services and data flow chart for creating the automatic geoprocessing service

Areal interpolation and dasymetric mapping techniques have been well researched in previous studies and there is a growing interest in achieving comparability over space and time and applying these methods (Flowerdew and Green, 1992 and 1994; Goodchild, Anselin and Deichmann, 1993; Wilson and Rees, 1998; Eicher and Bewer, 2001; Dorling, Martin and Mitchell, 2003; Dorling and Rees, 2003; Geddes, Gimona and Elston, 2003; Norman, Rees and Boyle, 2003; Reibel and Bufalino, 2005; Gregory and Ell, 2006; Hess, 2007; Longford, 2006 and 2007; Shroeder, 2007; Wilson and Rees, 1998).

This paper presents an innovative automated internet service solution to make available comparable quasi-realistic spatial population distribution GIS datasets of any area of interest based on the census boundaries of any of 2001, 1991 and 1981 census years in the United Kingdom to advance analysis of demographic and socio-economic change over time.

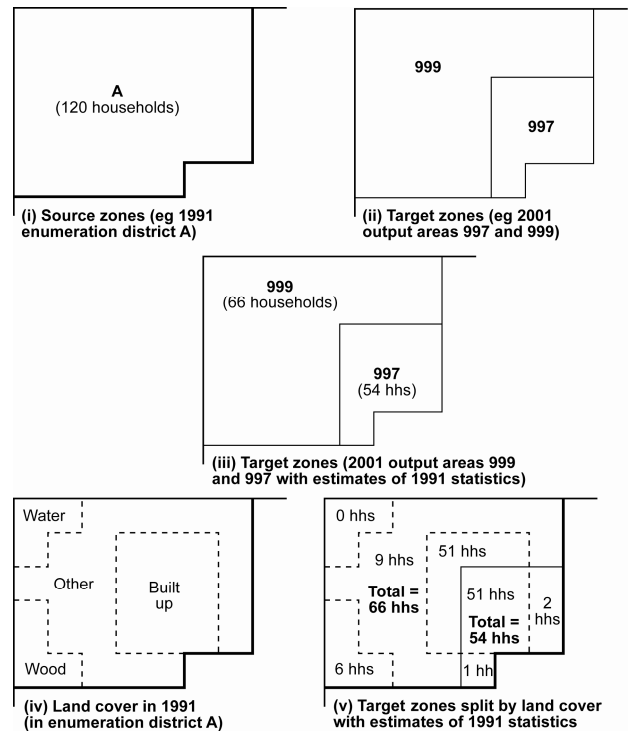


Figure 2: Synoptic illustration of the effect of areal interpolation and dasymetric mapping techniques by using simplified hypothetical zones of separate census years (hhs denotes households). Scenario: source year = 1991 & target year = 2001 effect of areal interpolation (iii) is the result of transferring population statistical data in (i) into 2001 census boundaries (ii); effect of dasymetric mapping (v) is the result of reallocating population statistics in (iii) by incorporating landuse information in (iv)

2. AIM

The aim of the Kingston Auto Geoinformation Service (KAGIS) project was set to develop an innovative automated internet-based geoinformation service to implement automatic spatial data handling mechanism, procedures and modular programs to integrate heterogeneous datasets, automate necessary data processing to allow end users to simply follow a few instructive checkbox and button-clicking steps to obtain digital quasi-realistic GIS models of spatial population distribution of any area of interest based on a set of zone boundaries of a selected census year in the United Kingdom.

In order to compare GIS maps of spatial population distribution across time, these GIS maps need to be produced by using the same set of geographical boundaries. To satisfy a diverse range of users, the service system needs to be designed to allow users to choose any of existing census boundaries. Automatic spatio-temporal interpolation with areal interpolation needs to be carried out based on user's decision on the selection of a specific boundary dataset pertaining to a particular census year as target year's geographical boundaries. Any of other year's census data can be set as source year's population statistical data. The spatio-temporal interpolation (areal interpolation) processes the data and allocates population statistical data into the target year's geographical boundaries.

By utilising landuse GIS map derived from remotely sensed imagery, dasymetric mapping interpolation processes the resultant target GIS map to result in quasi-realistic spatial population GIS dataset.

3. SYSTEM ARCHITECTURE, DESIGN AND OPERATION

In the KAGIS project, the system design adopts service oriented architecture and couples the latest web portal technology and ArcGIS Server technology. ArcGIS Server and ArcCatalog are installed on an internet server which runs Windows Server Operating System with Internet Information Services Manager (IIS) (ArcGIS Resource Centre).

On the server, a set of specially designed and coded geoprocessing modules written in Python scripting language are published by ArcCatalog, managed by ArcGIS Server Manager and made available as Representational State Transfer services (REST services) by ArcGIS Server. Python geoprocessing tools/scripts are designed and programmed for integrating web services and ESRI tools at the back-end of KAGIS. Server-to-server communication and data exchange are achieved through services' compliance with OGC standards (Gardels, 1997; Doyle and Reed, 2001; OGC, 2004).

3.1 Applying unified ontological coding approach for both spatial and statistical datasets

Central to the successful design, development and implementation of automatic spatial data handling mechanism, procedures and modular programs employed in the KAGIS system is a unified ontological coding system for spatial and statistical datasets. The standardised codes are used in the design and implementation of both front-end user interface and server-side lookup tables. The logical design of the coding system and the logical design of scripts of KAGIS allowed full automation. In addition, a linking table between legacy population statistical variables and new comparable statistical variables have been developed and used as a code look up table for practical solution of correct data extraction.

Within the Edina's dataset, each census zone is coded with a unique identifier. This identifier possesses a regular pattern and presents an ontological hierarchical relationship among census zones enabling service-to-service data retrieving specific to demand. Mimas uses this coding system together with a standardised population statistical variable coding system newly developed at Kingston for service call to search and produce responses of OGC-compliant XML data streams (OGC, 2004). Automatic service calls are made by dynamically composing service request strings with variable values utilising these coding systems.

3.2 Automatic session and information management for stateful personalised service

The application is designed to offer a personalised service in order to meet envisaged concurrent individual demand which varies from session to session and enables session and state of use tracking. The approach of creating and using a session identifier and implementing session management plays an important role in realising the concurrent personalised service of the application. A session identifier is used to create a temporary folder on the server specific to each use session, which stores HTML DOM objects and intermediary and final products of map data files, automatically generated at various stages of that particular session. Each use session consists of a number of stages/steps with a user making choices and selections to query into the databases, and commanding geoprocessors to perform (Figure 3).

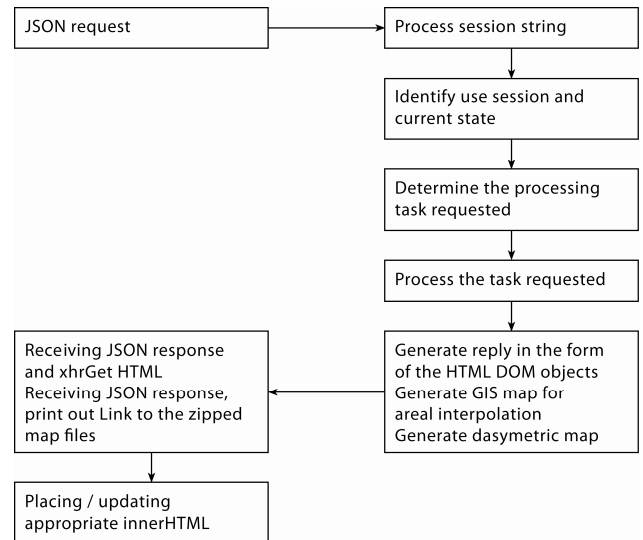


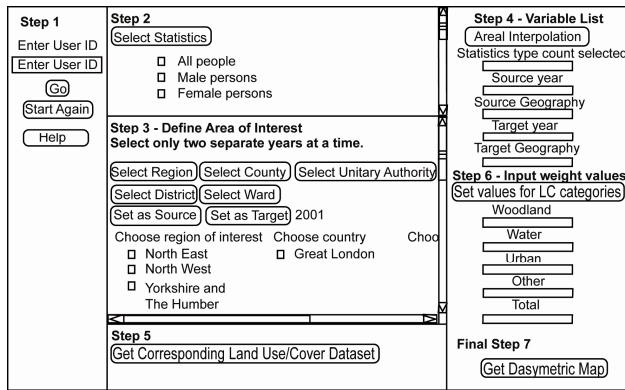
Figure 3: Application flow chart for stateful automatic generation of responses in the form of HTML DOM objects

The system is a secure service system, prior approval is required and approved registered user will be given a user identifier. Only with issued user identifier, user can trigger off a service-side geoprocessor to create a personalised session folder to store all dynamically generated intermediary files and geoprocessed results.

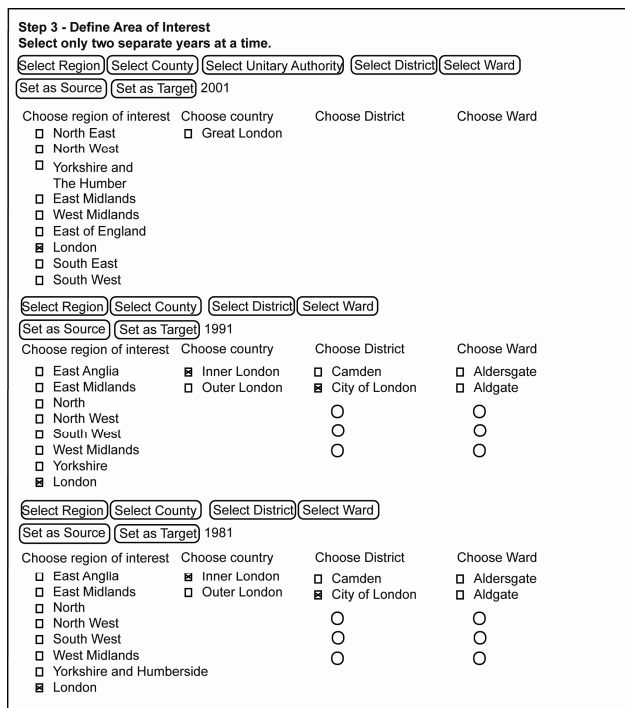
3.3 Design of front-end user interface, accessing and consuming geoprocessing services

The front-end user interface is designed in the form of HTML webpage allowing user access with commonly available internet browsers over the internet. HTML Document Object Model (HTML DOM) and Javascript scripting was made to produce user interface and interactive feedback messaging. Javascript functions contained in the user interface HTML document creates instances of geoprocessors and consumes REST services and monitor the progress and status of REST services through ESRI's Javascript API. Ajax data exchange employs ESRI's Javascript API and dojo toolkit functions in client-side browsers to interact with REST services of ArcGIS Server technology. Dojo functions are embedded in the Javascript to undertake JavaScript Object Notation (JSON) Ajax calls to ArcGIS Server's REST services to invoke geoprocessors and monitor their progress (Figure 3) (ArcGIS Resource Centre; dojotoolkit). The webpage is partitioned into a number of interactive functional sections as HTML divs (Figure 4) and the programming of Javascript functions enables information interchange between sections and validates user interaction and input to ensure the necessary procedure is followed.

The system presents users with historical British census databases (statistical and spatial) reflecting the development of such data resources over recent enumerations. It allows users to make selections of geographical areas of interest at various levels (region, county, unitary authority, district, ward and output areas) and key population statistical accounts dynamically (Figure 4).



(i)



(ii)

Figure 4. Schematic illustration of (i) KAGIS user interface and (ii) sub-window of dynamically generated listings of geographical area names

3.3.1 Dynamic re-presenting historical heritage of census data resources and user monitoring of selection

The service offers automatic listing of geographical names at the different levels in HTML markup language with unique identifier codes to provide users with a means of interactively making choices for querying into and searching geographical databases (Figure 4). These listings for 2001, 1991 and 1981 censuses respectively are presented as a stack in sections as HTML divs to allow interaction with back-end databases for areas associated with 2001, 1991 and 1981 censuses. Users' querying into these databases and selection of census areas are processed in parallel and the service system automatically generates HTML DOM objects and presents these as innerHTML.

Applying the mechanism described above, the content of large databases is unleashed and presented to users for dynamic interrogation into databases. Once users have selected areas of interest at a particular level, the required statistics, the source

and target zones and years are specified as variables to be fed into a server-side geoprocessor. These are dynamically presented in the variable sub-window (Step 4 in Figure 4) for user monitoring of selection of population statistics variable, source geography and target geography, ready to be submitted to server. These variables/parameters are passed onto server-side geoprocessors to search and extract requested data from distant servers, which allows the user requested data to be obtained in preparation for geoprocessing.

3.4 Automatic spatial data extraction and downloading as per dynamic user request

The Edina's geospatial dataset service produces server-to-server responses that are OGC compliant Web Feature Service (WFS) responses. WFS supports either GML or zipped ESRI Shape File package, as returns for service requests. The dataset service used by KAGIS is known as UKBORDERS, sponsored by the Economic and Social Research Council (ESRC) and Joint Information Systems Committee (JISC), U.K..

On demand calling and extracting of necessary map datasets are achieved by means of a specially designed Python module callable and executable by a server-side geoprocessing script. It feeds into the distant server with search patterns of census zone codes obtained from the front-end user selection for fetching source and target GIS datasets.

The geoprocessing script programmatically takes the responses of zipped files, saves these into the folder specific to the session and automatically unzips them by importing and executing a Python unzip module to perform to make available datasets for further processing.

In the event of user's multiple selections of wards, the geoprocessing script automatically detects the number of datasets to be fetched and the process is iterated until completion. Thereafter, the shape files are merged automatically into unified source and target maps ready for further processing.

3.5 Design for runtime generation of comparable population statistics

Three arrays of newly researched and developed equations for calculating comparable population statistics for 1981, 1991 and 2001 census datasets from data extracted at runtime from Mimas are designed and contained in a Python module to be dynamically called and executed.

3.6 Automatic extracting statistical data and calculating comparable population statistics as per dynamic user request

Mimas broadcasts server-to-server responses by using Geolinked DATA Access Service specification of Open GIS consortium Inc. (2004) and its service responses are in the form of OGC-compliant XML streams. The specific dataset service used is known as Casweb as a census programme sponsored by the Economic and Social Research Council (ESRC) and Joint Information Systems Committee (JISC), U.K.. An *ad hoc* Python module has been developed and implemented in the KAGIS system to make service call to the Mimas service with values of census zone identifiers and population statistical variables requested by user, read into memory the XML stream and is callable and executable in the geoprocessing script. A high performance Python XML parsing module (lxml) is employed and imported to perform extraction of data contained in XML into a Python list and extracted data are automatically inserted into an automatically created column in the database associated with the source ESRI map shape file.

Within the geoprocessing script, automatic decision making is devised and implemented to check against lists of statistical variables which need to be calculated for comparable population statistics. If calculation is required for a specific statistical variable contained in the list, an *ad hoc* calculation function is invoked to call and execute the corresponding equation contained in the arrays of equations to produce values of comparable statistics for the variable prior to automatic creation of the column and automatic insertion of data values.

As a number of statistical variables are involved in calculation, the geoprocessing script is devised to be capable of automatically deciding on the number of iteration of multiple service calls and data extraction to be made and carry out calculation of comparable statistical values.

3.7 Automatic spatio-temporal interpolation with areal interpolation

A specially designed geoprocessing script for areal interpolation transfers population statistical data from the source map to the target map and automatically generates a new resultant map.

Once a user has selected the source zones and required statistics associated with a particular census year and the target zones for a certain year (e.g. total male population, source: in 2001 output areas; and target 1991 enumeration districts), upon clicking on the button (Step 4 in Figure 4), user triggers off server-side geoprocessor to perform tasks described in 3.3, 3.4, 3.5 and 3.6 and the task of areal interpolation.

3.8 Preparing landuse map with the same geographical coverage

Large landuse GIS maps derived from remotely sensed imagery are stored in a dedicated folder of the KAGIS server. Maps are vectorised polygons of land cover categories derived from the Ordnance Survey (OS) Strategi® dataset. A dedicated geoprocessing service is published for consuming in the front-end HTML to be activated by clicking the button (Step 5 in Figure 4). The geoprocessor extracts from large landuse datasets for the UK on KAGIS and produces the landuse map with the coverage of the map created by the above areal interpolation.

3.9 Empowering census analysts with decision making in assigning weights to landuse categories

Users are presented with opportunities to make decision on weights to be used and click a button to confirm (Step 6 in Figure 4). The weights assigned overwrite the default preset values.

3.10 Automatic generation of quasi-realistic spatial population distribution count models (digital dasymetric maps)

Once the areal interpolated map is produced, landuse map with the same geographical coverage is prepared and user's decision on weights is applied on the landuse categories, dasymetric mapping geoprocessing module can be triggered off to perform the task upon user's click on an *ad hoc* button (Step 7 in Figure 4). The Javascript function associated with the button submits the service request and commands the server-side dasymetric mapping geoprocessor to produce quasi-realistic spatial population distribution count model incorporating landuse information.

The algorithm used in the dasymetric mapping geoprocessing script has been described in Mennis and Hultgren (2006) and it

produces dasymetric GIS dataset as actual spatial population distribution count model, by applying the principle illustrated in Figure 2.

3.11 Instant delivery of spatial statistical models processed with automatic spatial data handling

Immediately upon completion of dasymetric mapping geoprocessing, Python zipping function imported into the geoprocessing script zips the session folder and creates a zipped package file on the server. The front-end Javascript function detects the completion of the server-side geoprocessing task and prints out the internet address link to the automatically generated zip file as innerHTML. All user needs to do is to click on the link, download the zip file and save it locally for examination and analysis.

4 CONCLUSION AND IMPLICATION

KAGIS innovates the ways of digital data requisition, data processing, digital GIS model generation and service delivery as a fully integrated and automatic service and represents a landmark in the development of census-related services to the U.K Higher Education sector.

The newly available KAGIS service will enable inter-censal comparison of spatial population models and analysis of demographic and socio-economic change to be undertaken at any of existing spatial scales and of any area of interest in the United Kingdom. The system allows users to obtain digital quasi-realistic spatial population distribution models at any existing spatial scales and of any area of interest by utilising any of 1981, 1991 and 2001 census boundaries.

The service system is designed to be extensible to offer fully processed digital dasymetric models for the forthcoming 2001 census (Martin, 2000) to offer the most up-to-date digital quasi-realistic spatial population distribution models for a multitude of purposes such as quasi-realistic service and development planning. KAGIS will enable development of advanced research and teaching in a wide range of areas such as quantitative demography and population geography, regional science, spatial economics and quantitative social policy.

With the process of globalisation and development, all countries have been and are undergoing significant development and change. The technology and know-how experience of KAGIS can assist any country in the world to develop its secure internet GIS services, integrating geographical information for specific decision making systems as well as providing low-cost and efficient ways to process and utilise existing geographical data for a multitude of purposes such as development planning.

ACKNOWLEDGEMENTS

The research conducted in this paper forms a project titled *Web-based Spatio-temporal Interpolator for Census Area Statistics* which has received financial support from ESRC (RES-348-25-0012). The work is based on data provided with the support of ESRC and JISC and uses boundary material which is copyright of the Crown and the ED-LINE Consortium. The work is based on 2001 Census Output Area Boundaries, Crown copyright 2003. Crown copyright material is reproduced with the permission of the Controller of HMSO. The work is based on an Ordnance Survey/EDINA supplied service, © Crown Copyright/database right 20(01).

REFERENCES

- ARCGIS RESOURCE CENTERS, JAVASCRIPT APIs. http://resources.esri.com/help/9.3/arcgisserver/apis/javascript/arcgis/help/jshelp_start.htm (accessed 1st August 2008)
- Dojotoolkit. <http://www.dojotoolkit.org/> (accessed 1st August 2008)
- DORLING, D., REES, P., 2003, A nation still dividing: the British Census and social polarisation 1971-2001, *Environment and Planning A*, **35**: 1287-1313.
- DORLING, D., MARTIN, D., MITCHELL, R., 2003, *Linking censuses through time*, project website, <http://census.ac.uk/cdu/software/lct/> (accessed 30 January 2006).
- DOYLE, A. REED, C., (Eds.), 2001, OGC, *Introduction to OGC Web Services, OGC interoperability white paper*. Available online at: www.opengis.org (accessed 26 June 2006).
- EICHER, C.L., BEWER, C. 2001 Dasymeric mapping and areal interpolation: implementation and evaluation, *Cartography and Geographic Information Science*, **28**: 125-138.
- FLOWERDEW, R., GREEN, M., 1992, Developments in areal interpolation methods and GIS, *Annals of Regional Science*, **26**: 67-78.
- FLOWERDEW, R., GREEN, M., 1994, Areal interpolation and types of data. In FOTHERINGHAM, S., ROGERSON, P. (eds.) *Spatial Analysis and GIS*. London: Taylor & Francis, pp. 121-145.
- GARDELS, K., 1997, *The Open GIS Approach to Distributed Geodata and Geoprocessing*, Open Geospatial Consortium. <http://www.opengis.org> (accessed 1st August 2008)
- GEDDES, A., GIMONA, A., ELSTON, D.A., 2003, Estimating local variations in land use statistics, *International Journal of Geographical Information Science*, **17**: 299-319.
- GOODCHILD, M.F., ANSELIN, L., DEICHMANN, U., 1993, A framework for areal interpolation of socioeconomic data, *Environment and Planning A*, **25**: 383-397.
- GREGORY, I.N., ELL, P.S., 2006, Error-sensitive historical GIS: Identifying areal interpolation errors in time-series, *International Journal of Geographical Information Science*, **20**: 135-152.
- HESS, D.B., 2007, Transformation of spatial data to a new zone system: a survey of US metropolitan planning organizations, *Environment and Planning B – Planning and Design*, **34**: 483-500.
- LANGFORD, M., 2006, Obtaining population estimates in non-census reporting zones: An evaluation of the 3-class dasymetric method. *Computers Environment and Urban Systems*, **30**: 161-180.
- LANGFORD, M., 2007, Rapid facilitation of dasymetric-based population interpolation by means of raster pixel maps, *Computers Environment and Urban Systems*, **31**: 19-32.
- LONGLEY, P.A., GOODCHILD, M.F., MAGUIRE, D.J., RHIND, D.W., 2001, *Geographical Information Systems and Science*. (Chichester, UK; Wiley).
- MACKANESS, W., TOWERS, A., 2002, Handling and accessing census boundary data. In REES, P., MARTIN, D., WILLIAMSON, P. (Eds.) *The Census Data System*. (Chichester, UK; Wiley). pp. 85-95.
- MARTIN, D., 1998a, Optimizing census geography: the separation of collection and output geographies. *International Journal of Geographical Information Science*, **12**: pp. 673-685.
- MARTIN, D., 1998b, Census geography 2001: designed by and for GIS? In CARVER, S. J. (Ed.) *Innovations in GIS 5*. (London; Taylor and Francis), pp. 198-209.
- MARTIN, D., 2000, Towards the geographies of the 2001 UK Census of Population, *Transactions of the Institute of British Geographers*, **25**: 321-332.
- MARTIN, D., 2003, Extending the automated zoning procedure to reconcile incompatible zoning systems, *International Journal of Geographical Information Science*, **17**: 181-196.
- MENNIS, J., HULTGREN, T., 2006, Intelligent dasymetric mapping and application to areal interpolation, *Cartography and Geographic Information Science*, **33**: 179-194.
- NORMAN, P., REES, P., BOYLE, P. 2003, Achieving data compatibility over space and time: creating consistent geographical zones, *International Journal of Population Geography*, **9**: 365-386.
- OFFICE FOR NATIONAL STATISTICS, 2001, *Administrative area boundary changes in England and Wales between the 1991 Census and the 2001 Census*. Available online at: http://www.statistics.gov.uk/geography/downloads/ONSG_user_guide_2001.pdf (accessed 25 June 2006).
- OPEN GIS CONSORTIUM INC., 2004. *Geolinked Data Access Service (GDAS)*. Open GIS Discussion Paper.
- REES, P., MARTIN, D. 2002, The debate about census geography. In REES, P., MARTIN, D., WILLIAMSON, P., (Eds.), 2002, *The Census Data System*. (Chichester, UK; Wiley). Pp. 27-36.
- REIBEL, M., BUFALINO, M.E., 2005, Street-weighted interpolation techniques for demographic count estimation in incompatible zone systems, *Environment and Planning A*, **37**: 127-139.
- SHROEDER, J.P., 2007, Target-density weighting interpolation and uncertainty evaluation for temporal analysis of census data, *Geographical Analysis*, **39**: 311-335.
- W3C, 1999. HTML 4.01 Specification. W3C Recommendation. <http://www.w3.org/TR/html401/> (accessed 1st August 2008)
- WALFORD, N., & SHI, S., 2009: Web-based Spatio-temporal Interpolator for Census Area Statistics. 2011 Census research: new data, linkage and outputs. The Royal Statistical Society, London. 13 May 2009.
- WILSON, T., REES, P. 1998. *Lookup tables to link 1991 population statistics to 1998 local government areas*. Working Paper 98/5 School of Geography, University of Leeds, wpaper/wp98-5.pdf.