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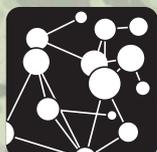
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Collaborative Mapping of London Using Google Maps: The LondonProfiler

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Collaborative Mapping of London Using Google Maps: The LondonProfiler

Maurizio Gibin, Alex Singleton, Richard Milton, Pablo Mateos, Paul Longley[†]

Abstract

This paper begins by reviewing the ways in which the innovation of Google Maps has transformed our ability to reference and view geographically referenced data. We describe the ways in which the GMap Creator tool developed under the ESRC National Centre for E Social Science programme enables users to 'mashup' thematic choropleth maps using the Google API. We illustrate the application of GMap Creator using the example of www.londonprofiler.org, which makes it possible to view a range of health, education and other socioeconomic datasets against a backcloth of Google Maps data. Our conclusions address the ways in which Google Map mashups developed using GMap Creator facilitate online exploratory cartographic visualisation in a range of areas of policy concern.

Keywords: GIS, Google Maps, Visualisation, Cartography, Mashup, Web 2.0

1. An evolving visual representation of spatial data

Cartography is defined as the art and science of making maps that historically have been used to simplify and represent real world features (Monmonnier, 1996). With the advent of Geographic Information Systems and Science (see Longley *et al*, 2005), cartographers have acquired new tools and methods capable of enhancing static maps and introducing multiple layering, interactivity and multimedia (Dransch, 2000). The advent of computer-based visualisation of geospatial data has stretched traditional cartographic domains of visual thinking and visual communication (DiBiase, 1990) to drive the development of a new discipline that embeds these technologically driven tools into a new but wider research agenda. This is the domain of geographic visualisation or "Geovisualisation" (GVis) that *"can be applied to all the stages of problem-solving in geographical analysis, from development of initial hypotheses, through knowledge discovery, analysis, presentation and evaluation"* (Buckley et al., 2000). GV is also embodies the visual elements of exploratory spatial data analysis (ESDA) tools. Thus, for example, through *brushing* ESDA makes it possible dynamically to link graphs, charts, tables and maps with a view to detecting patterns

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in data, formulating initial hypotheses and investigating aspects of model assessment such as goodness-of -fit (Haining and Wise, 1997)

The innovation and astonishingly rapid diffusion of Google Maps and Google Earth has fuelled new ways of deploying GI across computer platforms through a standard, easy to navigate graphic user interface. Google Maps provides a geographically enabled *Web 2.0* service. Web 2.0 is a phrase coined by O'Reilly Media in 2004 to summarise the rise of a series of web communities based on technologies of social networking, social bookmarking, blogging, Wikis and much other open content using RSS/XML feeds (Graham, 2007). The use and reintegration of these technologies through open standards is the core organising framework of Web 2.0. In June 2005 Google officially released their Google Maps Application Programming Interface (API), which enables users to mix Google streamed base data with other spatially referenced material. These data can then be served as bespoke applications through the Google map interface. A number of different terms have been used to describe these applications, including "map mashups" (Purvis *et al.,* 2006) and "map hacks" (Erle *et al,* 2005). The mixing of various data sources through common and open standards is central to Google Maps' position within the concept of Web 2.0.

When using the Google Maps API, programmers can access different pre-built functionalities or *classes*, and create their own applications by using classes to perform operations using their external data. The Google Maps API is essentially a collection of JavaScript classes that can be called from a web page in order to build various elements of an interactive map. Other, more automated, ways exist for users to create and share maps, such as Google My Maps, but the creation of mashups require users to posses some knowledge of JavaScript, XML (Extensible Markup Language), Ajax (Asynchronous JavaScript and XML), XHTML, CSS and VML. The lattermost two of these create the web page layout for the map mashup application.

The Google Maps API should not be thought of as a complete ESDA tool because it lacks the functionality of brushing, yet its wide and free availability has encouraged a very considerable number of users with intermediate and advanced programming knowledge to build their own applications, using Google Maps data as a visualisation interface. There are numerous examples of Google Map mashups online, some of which are detailed in Table 1.

Table 1: Some Example Google Map Mashups (source: adapted from googlemapsmania.blogspot.com)

Name	Data	URL
Chicago Crime – *Community Information*	Crime Incidents in Chicago.	http://www.chicagocrime.org/map
Housing Maps – *Property Search*	Craigslist Housing Data – For Sale & Rentals.	http://www.housingmaps.com/
Wikimapia – User descriptions of places	User generated semantic content about places.	http://www.wikimapia.org/

A commonality between these mashups is that they display spatial point data. However, it is often the case that point objects are misleadingly used to summarise an areal distribution, and as such is an instance of what Martin (2001) describes as instances of spatial object transformations. Viewed from this perspective, the production of many choropleth maps also entails spatial object transformations, since spatially referenced data are aggregated into artificially bounded areas, such as Census Output Areas, or administrative units created to protect data on individuals from disclosure. The low prevalence of choropleth map mashups most likely arises because the Google Maps API neither supplies nor supports tools to incorporate areally aggregated data into Google map interface. In this context, we present here a tool created by the UCL Centre for Advanced Spatial Analysis to enable the creation of choropleth thematic layers which may be integrated into the Google Maps API. Using areal coverages created using this tool, it is possible to build feature-rich cartographic websites that may be readily used and interpreted by individuals who have hitherto had only limited experience of spatial data handling. This paper illustrates these ideas by presenting such an application for London (http://www.londonprofiler.org).

2. Building thematic data layers in Google Maps

External data displayed by Google Maps may originate from a variety of sources and formats. Typically, these data refer to classic GIS data objects such as points, polylines, polygon vectors and rasters. However, GIS files common across desktop GIS software, such as ESRI (Redlands, CA) Shapefiles, may not directly be imported into a Google Map mashup, and therefore require a degree of manipulation before they can be displayed. Vector data can be drawn on top of a Google Map using the Google Map API through conversion of points using the Google class GPoint; polylines can be drawn using GPolyline; and polygons may be drawn using

GPolygon. Each of these three classes needs arguments (points or arrays of points) in order to visualise geographic features. In practice, as suggested above, most mashup applications use point data alone because building complex polylines and polygons requires specification of data arrays pertaining to vertices and coordinates in order to facilitate display: this adds to the download size and slows down the application. For this reason, Google Maps mashups showing polygon data thematised by a particular attribute are uncommon.

In order to ameliorate this situation, and as part of an ESRC National Centre for E Social Science initiative, we have developed a freeware application to simplify thematic mapping in Google Maps. GMap Creator[1] can read and then project shapefiles onto a thematic map layer based on a field attribute from a table. Unlike the standard API method of displaying points, lines and polygons, which requires arrays of vertices and coordinates to be specified in the HTML, GMap Creator renders this information as a series of raster image tiles (256x256 pixels) whose frequency depend on the zoom level selected. The higher the zoom level, the greater the frequency of tiles required to cover any given geographic area. These are represented using a quadtree data structure wherein each region is sub divided into four quadrats that each facilitate an increase in zoom level (see Figure 1).
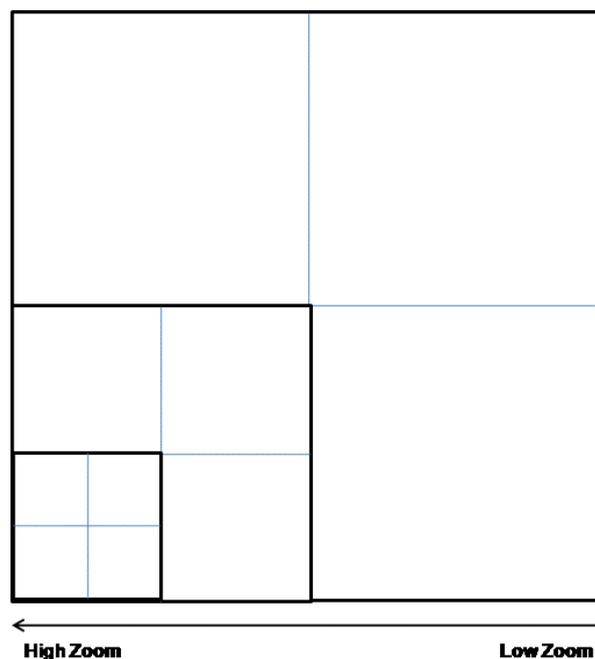

Figure 1: The frequency of thematic tiles created increases with each increased level of zoom.

Using GMap Creator, it is possible to overlay pre-rendered thematic tiles on top of the street and satellite views of Google Maps. This makes it possible to show complex areal coverages, as the client's browser has only to download and display the pre-

rendered tiles, rather than complex vector data consisting of multiple points, lines or polygons. Use of this type of architecture has the added benefit of avoiding infringement of many intellectual property rights, since it is not possible to recover the original vector data from the image tiles. Indeed, even if an image processing algorithm were used to extract the data from the images, the recovered data will only be a scaled approximation of the original.

Use of pre-rendered data stored as images makes it possible to publish geographically extensive data on the Web. However, the tile based architecture described above is more suited to browsing, rather than interrogating, data. Unlike other Web based GIS packages, enabling simple ESDA functions such as brushing a thematic region to discover other associated data is problematic, if not impossible to implement. Similarly, standard spatial analysis functions based on correlations and comparison between different fields of data are not possible without access to the original data stored on the server. However, there is potential for implementing sophisticated GIS functions, in which the server storing the thematic tiles might be used dynamically to create tiles based on user-specified criteria. However, these processes require CPU time on the server, and this limits the number of requests that may be handled at any single point in time. The objective of the GMap Creator software is to reduce the thematic map layer to a set of files that may be stored on a web server, thus making it possible for them to be served using simple file transfers. This is the simplest possible solution and offers users who do not have access to a programmable server the facility to display thematic maps; and this solution can also scale to handle very large numbers of hits.

In addition to the creation of image tiles, the software also renders a basic webpage that contains the Google mapping interface in a standard format and layout. The examples presented in this paper were built using GMap Creator as the main engine to create the tiles, although the style and design of the web pages was manipulated in order to offer additional cartographic features such as the ordering of layers and the ability to select different data.

3. Profiling of London

The purpose of the Londonprofiler website (www.londonprofiler.org) is to create a resource on which multiple spatial data from a variety of public domain or public sector sources may be displayed. The common interface is designed to allow different stakeholders to make improved decisions using spatial and thematic search criteria. The Londonprofiler application interface is designed to be as intuitive as possible. The features of the interface are outlined in Figure 2.
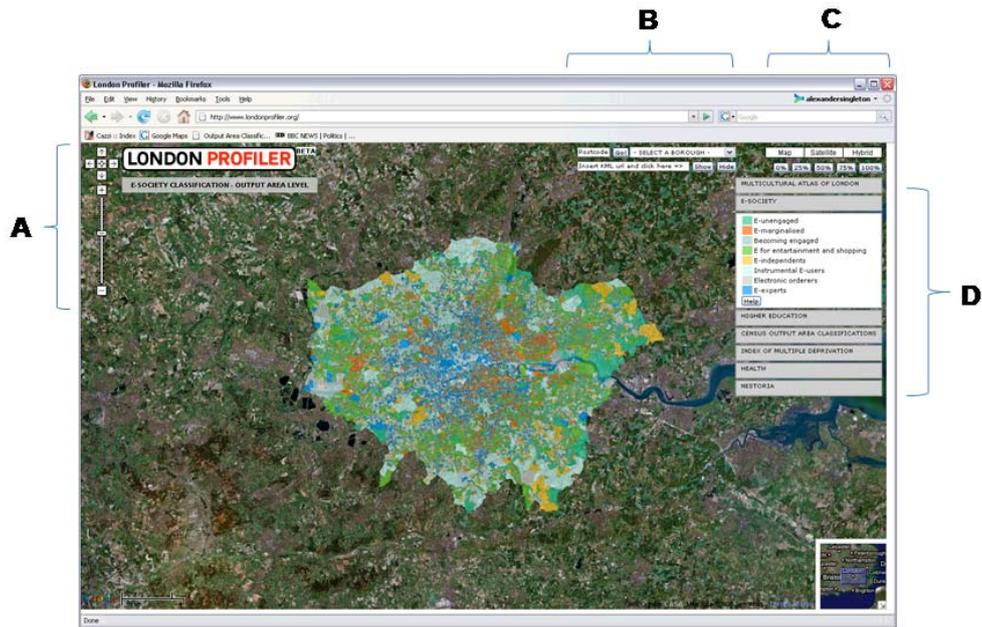
Key: A – The standard Google pan and zoom controls. B – Select a London Borough, or search by unit postcode: each enables external KML files to be loaded on top of the map. C – Standard "Map", "Satellite" and "Hybrid" map buttons and additional map transparency controls to allow fading of thematic layer (0%, 25%, 50%, 75, 100%) over base map. D – Map attribute selection pallet.

Figure 2: The LondonProfiler Interface.

Figure 2 illustrates the similarity between the main map interface and the standard Google Map website. Additional items have been added to this interface in order to refine search capability (e.g. to select by borough or unit postcode) or add interactivity. The function of the standard "hybrid" map button (Figure 2 – C) has been altered to enable overlay of the road network data on both the thematic and satellite data.
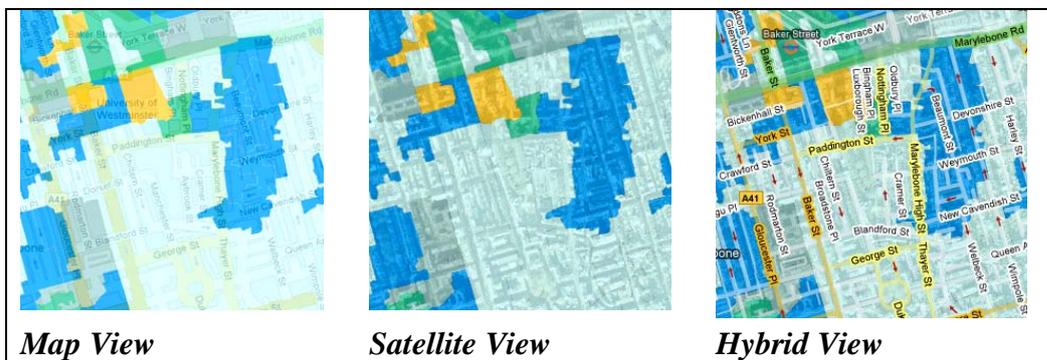

Map View   *Satellite View*   *Hybrid View*

Figure 3: The three different Google view options, using 50% opacity

A further feature added to the interface (Figure 2 – C) is the ability to change the visibility of the thematic data from 0% (no background data visible) to 100%

(background data only visible, as illustrated in Figure 4). The colour of the thematic layer alters slightly as the transparency changes. Therefore, in order to aid visual interpretation of the data by users, the map key (Figure 2 – D) changes the colours of the labels to compensate for each change in transparency. The thematic layer can be changed by clicking on the relevant tab (Figure 2 – D, here selecting a geodemographic classification of use of information and communications technologies).
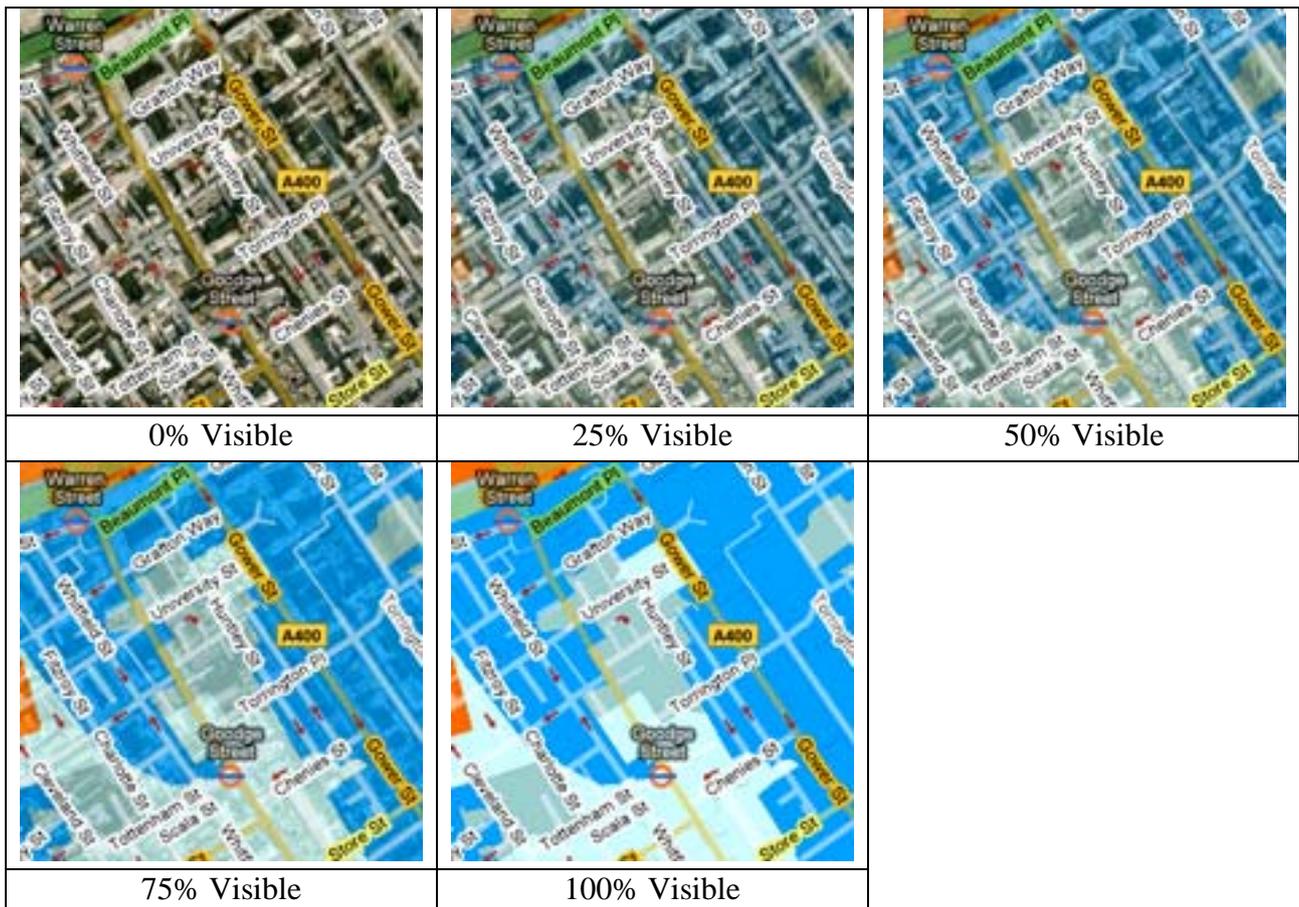
0% Visible	25% Visible	50% Visible
75% Visible	100% Visible	

Figure 4: The visual impact of the transparency filter

The Google Maps API 2 released in 2006 enabled KML files to be rendered on top of the Google Maps background data. Thus, on the Londonprofiler site a publically available third party URL can be entered into the display box (see Figure 2 – B) and the third party KML file will be displayed on top of the thematic layer. KML data are a type of XML which encapsulate a spatial location and a series of metadata. This creates a range of possibilities for user interaction, such as displaying third party boundaries and point data, or the integration of disparate data feeds. In order to illustrate this functionality, one such link has been formalised as a tab (see Figure 2 – D) to link the Nestoria website (http://www.nestoria.co.uk/), which is a UK property aggregator. Nestoria allows a range of search criteria to be specified and returns a list

of properties for sale within a selected search area. In addition to displaying these properties as a list on a basic webpage, the site also returns a series of data formats including RSS and KML. By copying the URL to the KML data stream from the Nestoria site into the KML display box on Londonprofiler, houses for sale can be displayed on top of the thematic data (see Figure 5).
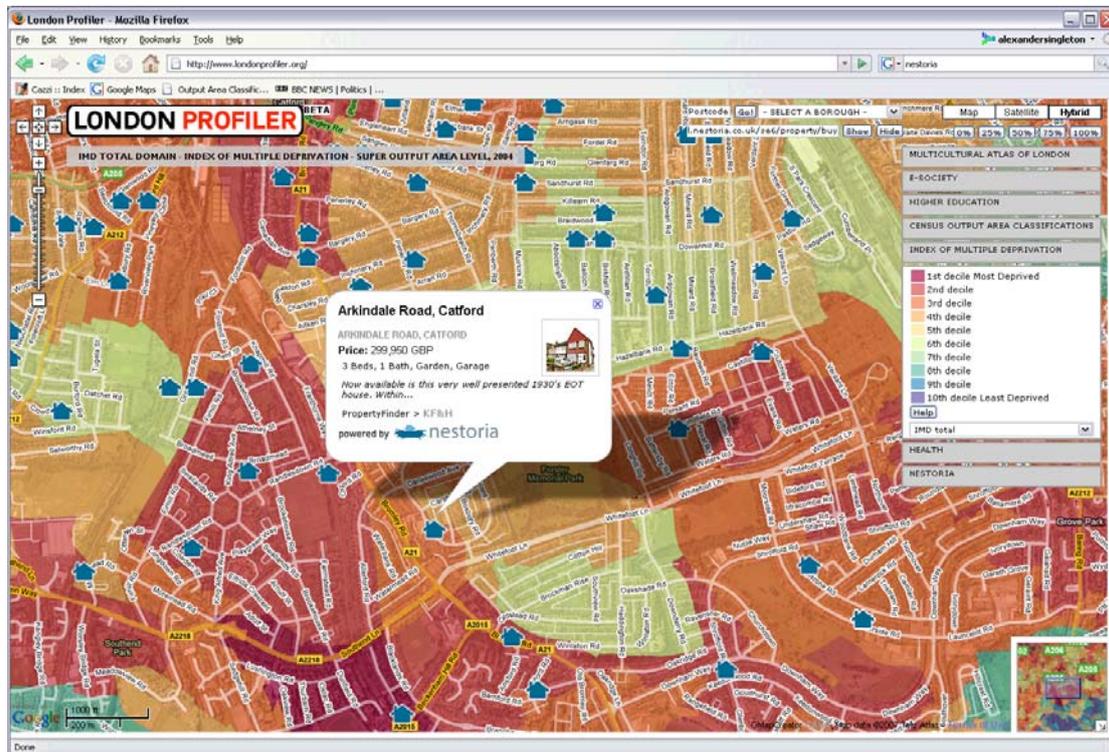

Figure 5: Nestoria generated KML for "SE6" in London displayed over the Summary 2004 Index of Multiple Deprivation Hybrid Map with 75% visibility.

The Londonprofiler website is currently available as a beta test site, and it is expected that many more datasets will be added in the future. The datasets that are currently live include:

- Multicultural Atlas of London (Mateos *et al*, 2007)
- E-Society Classification (Longley *et al,* 2006)
- HEFCE POLAR Classification and Associated HE data (Corver, 2005)
- Hospital Episode Statistics (www.hesonline.nhs.uk)
- Index Multiple Deprivation (DCLG, 2004)
- National Statistics Output Area Classification (Vickers and Rees, 2007)

A help section is provided for each dataset which provides details of how the source data were created with links to www.spatialanalysisonline.com, an independent source of geospatial reference material (also available as de Smith et al 2008).

The remaining part of this paper considers three applications in health, higher education and ethnicity. For each domain, the data currently present on the site are outlined and comment made on how these data could be used in problem solving relevant to current public policy.

3.1 Profiling of London: Higher Education

A range of UK sources of Higher Education (HE) data are publicly available, including those sourced from the Higher Education Statistics Agency (HESA) or the Universities and Colleges Admissions Service (UCAS). The HE data currently displayed in Londonprofiler are derived from data supplied by the Higher Education Funding Council for England (HEFCE). HEFCE developed a classification of Participation of Local Areas (POLAR: Corver, 2005) which divides wards into five quintiles based on their 'young' (18-19 year old) participation rate. In June 2007 HEFCE supplemented these data by conducting a pilot exercise to assess the value to its stakeholder groups of other local area statistics related to young participation rates. Both the POLAR classification and these additional data were provided as Excel files, detailing a range of variables for 1991 Wards.

These data provide a wealth of useful information for institutions and their provision should be applauded. However, the value of this information is heavily circumscribed by their interpretability. Cartographic representation of these data potentially offers a much improved method for end users to visualise and interpret any inherent spatial patterns. In a traditional GIS environment, each institution would have to: input the POLAR data into a specialist software package such as ESRI's ArcGIS; obtain boundary data; join the files; and finally create an appropriate visualisation and colour palette. Together with the GMap Creator, the Londonprofiler website allows anyone creating data on HE an opportunity to centralise findings through a common visual interface. The potential savings for such a centralised facility should not be underestimated, not least because few institutions have in-house GIS trained analysts. If every HE institution in the UK (of which there were 327 in 2006) desired to create a set of maps for their local areas using the standard procedure of employing a GIS consultant (typically two days labour @ £400/day) the cost to the HE sector as a whole would be approximately £261,600. This very large amount of money could easily be saved through the use of centralised mapping such as Londonprofiler.

The ward level HEFCE generated data included in the Higher Education tab are:

- The POLAR Classification (% of 18-19 year old age cohort that participate in HE)

- The percentage of participants whose parents come from NS-SEC socioeconomic classes IIIM, IV and V
- The percentage of entrants who attended independent school
- The percentage of entrants that had deferred application from a previous year
- The percentage of entrants whose successful applications were made through the UCAS clearing system
- The percentage of participants whose highest entry qualification was not at A-level
- The percentage of entrants ordinarily resident with their parents

The spatial organisation of participation in HE is an important growth area of public policy research, of acute concern because of the political imperatives of extending participation to underrepresented groups in an era of increasing fees and increasing socio-economic differentiation in prior attainment. In addition to these policy concerns, institutions operate within an increasingly competitive environment, wherein identification of the areas supplying the most suitable students could assist both in leveraging market advantage and increasing the efficiency of the sector as a whole. The HE data presented in the Londonprofiler application could easily be used to explore the spatial arrangement of data relevant to these policy issues. An admissions officer at a university in London, for example, might enter local applicant postcodes into the postcode search facility in order to assess the level of deprivation with the ward in which a series of applicants are domiciled. A further application might entail widening participation officers using a supplementary KML file of secondary schools to identify schools in wards of high recruitment priority, perhaps defined by the lowest participation quintile in the POLAR classification.

3.2 Profiling of London: Health

The health tab of Londonprofiler accesses data from the Hospital Admissions for Long-Term diseases (HALT) dataset at Lower Layer Super Output Area (LLSOA) level. These data are derived from four years of individual level admissions to all hospitals of London. For a selected number of conditions, hospital admission ratios have been calculated as the observed number of admissions for an area divided by the expected number that would prevail assuming that the age- and sex-specific rates were the same as for the whole of London. An admission ratio of 100 is the London average; 50 is half and 200 the double.

In addition to the London wide health data, additional data have been derived from registered patients within the 48 General Practices located in the Southwark Primary Care Trust area of responsibility. Data at individual level for Southwark have been aggregated into unit postcodes and then imported into a GIS. Using this point dataset, the density of registered patients per square kilometre was calculated using a kernel density estimation algorithm (Silverman, 1986) with a bandwidth of 500m and a cell

size for the output raster of ten metres. The health tab of Londonprofiler can also display the Percent Volume Contours[2] (PVCs) of the densities of registered patients for each general practice in Southwark Primary Care Trust. PVCs represent the boundaries of a certain cumulative percentage in the density function. Thus, for each practice, the PVCs show the areas within which approximately 50%, 75% and 95% of the patients live whom are registered with a corresponding general practice.

A range of applications is possible by using PVCs to infer areas of primary responsibility for each General Practice, and overlaying these on top of the thematic layers of the Londonprofiler. Visualisation enables decision makers to assess different GP practice areas in terms of their aggregate spatial characteristics across a range of domains. For example, if a GP practice has a catchment in an area where there is a high prevalence of hospital admissions related to heart attacks, the GP could supply targeted information about healthy lifestyle choices and their likely effects in reducing the probability of heart disease.

A further application concerns the E-society geodemographic classification (Longley *et al*, 2006), which maps the level of household engagement with information and communications technologies at the unit postcode level of analysis. This information is very important when considering the use of new technologies in health care service provision, such as targeting GP practices where Internet based booking systems for appointments and repeated prescriptions may be successful.

3.4 Profiling of London: Ethnicity

The ethnicity tab of Londonprofiler consolidates the provisional findings of a new methodology of classifying areas into groups based on the common cultural, ethnic and linguistic origin of the resident surnames and forenames. By appending the classification of names developed by Mateos *et al.,* (2007) to the UK Electoral Roll, a range comprising some 18 groups in London have been mapped at output area level, specifically: Bangladeshi, Chinese, English, Greek, Indian, Irish, Italian, Jewish, Nigerian and Ghanaian, Other Muslim, Pakistani, Polish, Portuguese, Russian, Sikh, Sri Lankan, Turkish, and Vietnamese. The advantage of using names to classify ethnicity rather than decennial census returns is that the data have finer granularity both in terms of the groups they represent and the temporal interval for which they may be updated.

The ethnicity data presented on Londonprofiler have a plethora of potential applications that cannot be covered in the space available here. However, one core application concerns the identification of areas where recent migrants to the UK may have clustered, e.g. those related to recent EU expansion. In terms of public sector service delivery, use of a current and disaggregate ethnicity classification provides a

tool that might enable targeting of supplementary information in minority languages spoken by residents of an area, perhaps enabling better uptake or appropriate usage of local facilities and services.

4. Discussion and Conclusions

Google Map mashups in their basic form are straightforward to implement and currently remain a free solution for online exploratory cartographic visualisation. Use of mashups as described in this paper provides a cheap and effective platform for visual communication of health and education data to both internal and external users. The interface is well designed and intuitive, and so needs only limited instruction on usage and navigability, saving time on training in more complex GIS technologies.

The simple cartographic design of the Google Map base layers which are integrated into all of the mashups makes ideal background for thematic overlays. In health, education and public sector applications it is now possible for users to visualise thematic layers made up from boundaries of unfamiliar size and location within the context of local and scalable geographical features such as roads or gazetteer entries.

Visualising essential geographic information of the *"where?"* with the *"what?"* needs careful design (Tufte, 1990). For example, the colour scheme choice for the thematic overlay must avoid tones that can be confounded with the underlying Google Map. A solution deployed in the examples reported here uses a combination of thematic overlay transparency and the Google hybrid map layer. Setting a 100% transparency for the thematic layer and putting the street layer on top allows essential geographic information to be conveyed along with additional attribute data.

Because of the ways in which Internet and web browsers work in general, the Google Maps API makes best use of the available technology for a data publishing solution. The challenge is to leverage this towards solutions that allow publishing of geographically extensive and interactive data. A 'browse-tool' for data is technically possible using the vector data capabilities of the Google Maps API, but these solutions are not scalable for large geographical coverages. Furthermore, this architecture is slower than the pre-rendered approach that the GMap Creator takes. As an example, data for the entire UK at lower output area level exceeds 380MB. With just a handful of users accessing datasets of this size, the server would quickly run out of memory and CPU cycles. Thus, the approach taken by Google Maps is to push all of the computation over onto the browser, in order to produce a scalable solution. Unless there are huge advances in computing, the browser will never be able to handle large datasets through the Google Maps API. At present, it is possible to handle about

100 data points or about 1000 points making up polylines or areas. Yet geographic solutions at the scale of a large city involve areal data entailing millions of points that therefore cannot be rendered on the fly. Resolution of this problem is therefore unlikely to be achieved by transferring the original vector data to a client's browser prior to rendering. Furthermore, this also effectively gives the client access to the server's dataset, and this may have implications in terms of intellectual property rights and disclosure control. Therefore, using the Google Maps technology, it is possible to build systems for small numbers of users similar to traditional GIS where data can be manipulated and displayed over the Google Maps street view or satellite images. With an appropriately large server it would potentially be possible to handle any type of geospatial analysis and manipulation that could be handled by a desktop GIS. However the cost of these resources would be great and as such the current solution is only able to support a small number of users at any one time. If the target audience of a Google Maps based application is a large number of users, then pre-rendering of data is the answer, but with its consequential implications for provision of data storage facilities and also lack of manipulation options. We think, however, that there also exists a class of system somewhere between these two. Using pre-rendered tiles, it may be possible to overlay different thematic layers and make comparisons manually based on the values contained within the raster data. Thresholding and Boolean comparison of thematic regions from pre-rendered layers can be done as this can be reduced to a pixel operation between map tiles from different sources on the web server. For example, a system has been tested that renders a demographic classification for areas where house prices are greater than a specified threshold. The inputs to this system are two pre-rendered thematic maps built using the GMap Creator with the output a hybrid overlay. This opens up some interesting possibilities in which people can publish data that may be explored interactively by large numbers of users.

References

Buckley, A.R., Gahegan, M., Clarke, K. (2004). Geographic Visualization. In, R. B. Mcmaster and E. L. Usery. *A Research Agenda For Geographic Information Science*. Boca Raton, Fl: Crc Press.

Corver, M. (2005). Young Participation in Higher Education. HEFCE 2005/03. Bristol: HEFCE.

de Smith, M. J., Goodchild, F. M., Longley, P. A. (2008). *Geospatial Analysis: a Comprehensive Guide to Principles, Techniques and Software Tools (Second Edition)*. Leicester: The Winchelsea Press/Troubador.

DCLG (2004). Index of Multiple Deprivation (online). Available from: http://www.communities.gov.uk/archived/general-content/communities/indicesofdeprivation/216309/.Accessed 18th December 2007. London: Department of Communities and Local Government.

Dibiase, D. (1990). Visualization in the earth sciences. *Bulletin of Earth and Mineral Sciences, Pennsylvania State University* 59(2), 13–18.

Dransch, D. (2000). The Use Of Different Media In Visualizing Spatial Data. *Computer & Geosciences* 26(1), 5-9.

Erle, S., Gibson, R., Walsh, J. (2006). *Mapping Hacks: Tips & Tools for Electronic Cartography*. Sebastopol, CA: O'Reilly Media, Inc.

Graham, P. (2007). *Web 2.0* (Online). Available from: http://www.paulgraham.com/web20.html.Accessed 24th April 2007.

Haining, R. and Wise, S. (1997). Exploratory Spatial Data Analysis, *NCGIA Core Curriculum in GIScience* (online). Available from: http://www.ncgia.ucsb.edu/giscc/units/u128/u128.html. Accessed 18th December 2007.

Longley, P.A., Goodchild M.F., Maguire D.J. and Rhind D.W. (2005). *Geographic Information Systems and Science.* Chichester: John Wiley & Sons.

Longley,P.A., Ashby,D.I., Webber,R., Li,C. (2006). Geodemographic classifications, the digital divide and understanding customer take-up of new technologies. *BT Technology Journal* 24, 67-74.

Martin, D (2001). *Geographic Information Systems: Socioeconomic Applications.* London, Routledge.

Mateos, P., Webber, R., Longley, P.A. (2007). The Cultural, Ethnic and Linguistic Classification of Populations and Neighbourhoods using Personal Names. *CASA Working Paper* 116. Available online from: http://www.casa.ucl.ac.uk/working_papers/paper116.pdf

Monmonier, M. (1996). *How to Lie With Maps.* University of Chicago Press: Chicago.

Purvis M., Sambells J., Turner C. (2006). *Beginning Google Maps Applications with PHP and Ajax.* Berkeley: APress.

Silverman, B.W. (1986). *Density Estimation.* London: Chapman And Hall.

Tufte, E. (1990). *Envisioning Information.* Cheshire, CT: Graphic Press.

Vickers, D., Rees, P. (2007). Creating the National Statistics 2001 Output Area Classification, *Journal of the Royal Statistical Society*, Series A 170(2).

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[1] GMap Creator is part of the GeoVUE Project at CASA, a project sponsored by the ESRC as a node in the National Centre for e-Social Science. GMap Creator is developed at CASA by Richard Milton.
[2] Percent volume contours were calculated with a free ArcGIS extension called *Hawth's Analysis Tools* developed by Hawthorne Beyer and downloadable from the website http://www.spatialecology.com.