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Semantics Matters: Cognitively Plausible Delineation of City Centres from Point of Interest Data

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Abstract: We sketch a workflow for cognitively plausible recognition of vague geographical concepts, such as a city centre. Our approach imitates a pedestrian strolling through the streets, and comparing his/her internal cognitive model of a city centre with the stimulus from the external world to decide whether he/she is in the city centre or outside. The cognitive model of a British city centre is elicited through an online questionnaire survey and used to delineate referents of city centre from point of interest data. We first compute a measure of 'city centre-ness' at each location within a city, and then merge the area of high city centre-ness to a contiguous region. The process is illustrated on the example of the City of Bristol, and the computed city centre area for Bristol is evaluated by comparison to reference areas derived from alternative sources. The evaluation suggests that our approach performs well and produces a representation of a city centre that is near to people's conceptualisation. The benefits of our work are better (and user-driven) descriptions of complex geographical concepts. We see such models as a prerequisite for generalisation over large changes in detail, and for very specific purposes.

Keywords: Generalisation, spatial data enrichment, cognitive model, urban structure, city centre

1. Introduction

« I don't believe in maps because it never looks like it says on the maps when you get there. »
Advertisement issued by the Brewers' Society, cited in Board (1967, p. 671)

Generalisation of spatial information can be understood as the adaptation of spatial information to specific applications or user needs. It imitates a human conceptual abstraction process that creates different patterns at various levels of detail. In our research, we take a knowledge modelling perspective at understanding how complex higher-level concepts can be derived out of simpler ones.

Many geographical concepts are vague in the sense that there is no single universally accepted definition of the concept itself, or of the extent of its referents. Nevertheless they are used every day and so there must be a certain consensus of their meaning. To study this meaning and make machines reproduce it has many applications in the domain of geographic information systems (Kuhn, Raubal, & Gärdenfors, 2007). The ability that humans use to process exterior information and previous knowledge to reason about the world is termed cognition (Tusnovics, 2007). In our work, we use this principle to model city centres similar to human conceptualisation. Our model imitates a pedestrian strolling through the streets, and comparing his/her internal *cognitive model* of a city centre with the stimulus from the external world to decide whether he/she is in the city centre or outside (Figure 1).

The term *city* in Britain legally refers to a town that has received the city title by the Crown, but colloquially also large or important towns are sometimes called city. A *city centre* can be outlined as the area of a city where many social and economic functions concentrate and is thus related to the term *central business district* (CBD). A more detailed definition of city centre is given in section 2.

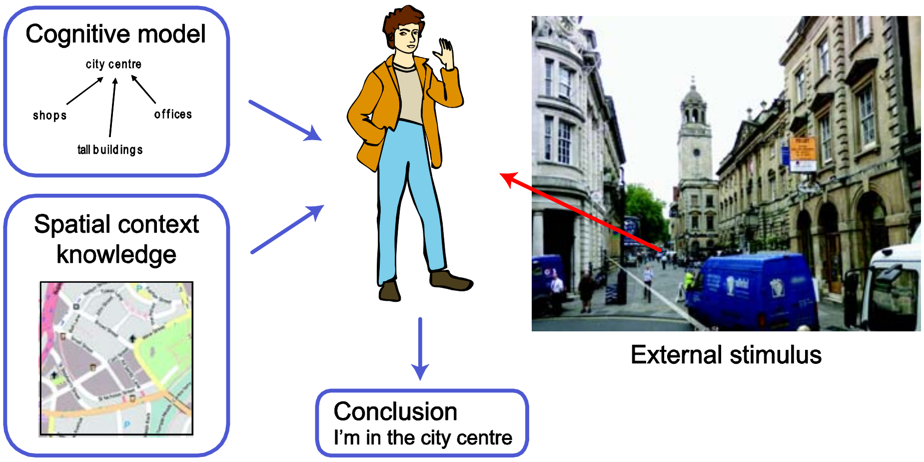


Fig. 1. Cognitive approach for delineating a city centre.

In this paper, we sketch a workflow for cognitively plausible recognition of geographical concepts: We elicit the cognitive model of a city centre through an online survey. We use the cognitive model to derive referents of city centre from spatial data. We illustrate the process on the example of the City of Bristol and show methods for evaluation of the generated city centre.

The benefits of our work are better (and user-driven) descriptions of complex higher-level concepts. We see such models as a prerequisite for generalisation over large changes in detail (Mackaness, 2006), and for very specific purposes: we might for example present a different answer to the question 'shopping opportunities in the city centre?' to elderly people than to young people (the former avoiding the night club district because they might perceive it unsafe). Conceptual generalisation carried out in this way could also be important for informing geographic search engines (Purves et al., 2007), for generating better route descriptions (Tomko & Winter, 2009), and for flexible exchange of geographical information in a semantic web environment (Klien, 2007).

Our work adds to previous approaches to derive vernacular representations of urban regions. Montello, Goodchild, Gottsegen, and Fohl (2003) conducted experiments on delineating *downtown* by asking people in the street to draw the outline on a paper map. More recently, georeferenced web content was investigated to delineate vernacular regions. Jones, Purves, Clough, and Joho (2008) presented a method based on georeferenced web pages for deriving large-scale regions. Hollenstein (2009) used georeferenced images from flickr.com to investigate the vernacular use of city core terms. These methods require that there is a sufficient amount of data describing the region. Moreover, since there is no explicit model of the concept behind the computations, it is not possible to adapt the concept to different user requirements. A model-driven approach for creating an index of town-centric activity was presented by the Office of the Deputy Prime Minister (2004), aiming at monitoring of urban economic activities. We use a model-driven approach as well, but our emphasis is on cognitive plausibility, user adaptation, and aiming at semantic improvement of existing cartographic data.

2. Online survey on city centres

The internal cognitive model of a city centre was elicited by means of an online survey that encompassed several experiments to discover which elements make an urban neighborhood a city centre neighborhood. The link was sent to several British academics to distribute among their peers and students. Additionally, the link was published on two websites that focus on urban planning and geography (www.skyscrapercity.com and www.geograph.org.uk). This resulted in 101 completed and valid questionnaires.

The questionnaire was divided into three parts[1]. In the first part, participants had to describe frequent activities, important facilities and physical appearance of a city centre as free text. This was meant to capture an uninfluenced image of a city centre. In the second part, the participants were presented lists of urban features and had to decide whether the features were typical of a city centre. Finally, they were presented a series of 360° panoramas showing urban scenes and they had to decide on the degree to which the scene conformed to a city centre and reason about the clues they used. This was intended to see whether people could recognise a city centre visually and use the same clues for identification as in the previous parts of the questionnaire. The analysis of the results is not yet fully completed, but we would like to present some key findings of the first two parts and show how these can be used to build a preliminary cognitive model of a city centre.

The answers to *common activities* were very consistent. Altogether, there were 41 different activities named by the participants, but only 12 of the 41 activities were named by more than 10 % of the participants. Table 1 shows the 12 frequently named activities.

Activity	**No. of mentions in % of respondents**
Shopping	94.1
Eating out	44.6
Night-time amusement	32.7
Working and doing business	31.7
Going to theatre and shows	31.7
Going to cinema	21.8
Socialising in general	20.8
Using transportation	19.8
Sight-seeing and tourism	19.8
Visiting museums	18.8
Visiting art galleries and exhibitions	14.9
Going to concerts	13.9

Table 1. Types of activities that were mentioned by respondents as being commonly performed in city centres.

The second part of the questionnaire consisted of lists of concepts where the participants had to decide whether they were *rather typical or rather atypical* of a city centre. Answers were possible in a range between -2 (very atypical) and +2 (very typical), where 0 denoted 'can be both outside and inside of the city centre'. Table 2 shows the results of this part. The concepts in the survey were organised into groups as indicated in the table. Shopping facilities can assume various spatial arrangements with different characteristics. Thus it was asked which of the types of shopping (and not shopping in general) were typical or atypical of a city centre. The grouping further differentiates objects that occur only once (or few times) in a city, but are important landmarks that help structuring the urban landscape. Urban regions finally are concepts that have an own internal structure.

[1] The questionnaire can be browsed at the following URI: http://www.geo.uzh.ch/~luescher/citycentresurvey

Table 2 also indicates a measure of consensus *Cns* (Tastle & Wierman, 2007), which is a measure for quantifying the agreement between participants for ordinal scaled variables. $0 \leq Cns \leq 1$, where a value of 0 denotes 'strong disagreement' and a value of 1 denotes 'strong agreement'.

	„Don't know"	**Mean**	**Concensus**
Shopping facilities			
Department Store	0	1.61	0.75
Shopping Centre	0	0.97	0.62
Retail Park	0	-1.35	0.63
Common urban facilities and services			
Theatre	1	1.60	0.77
Night club	0	1.48	0.74
Office	0	1.21	0.69
Restaurant and Pub	0	1.03	0.66
Cinema	1	0.96	0.65
Hotel or Guest House	0	0.87	0.64
Brewery	3	-0.80	0.65
Leisure Centre	1	-0.59	0.61
Factory	0	-1.44	0.72
Public functions			
Museum	0	1.50	0.75
Law Court	3	1.47	0.73
Library	0	1.10	0.66
Place of Higher Education	0	0.54	0.64
Hospital	0	-0.03	0.63
Landmark concepts			
Town Hall	0	1.50	0.72
Main Railway Station	0	1.45	0.76
Cathedral	0	1.42	0.71
Place of Worship	0	0.48	0.67
Castle	0	0.31	0.73
Stadium	0	-0.77	0.67
Urban regions			
High Street	1	1.43	0.71
Old Town	0	1.04	0.73
Public Park	0	0.27	0.67
Business Park	0	-1.31	0.72

Table 2. Typical (+) and atypical (-) concepts for city centres that resulted from the questionnaire.

Information from the survey was then used to create a cognitive model of a British city centre. Our preliminary model is based on frequency of activities and importance of categories of individual establishments only. For example, shopping for special non-daily goods is clearly the most important activity in city centres. Cultural establishments such as theatres and museums are less frequently visited, but thought to be very characteristic for a city centre. Thus, they create a sphere of high city centre-ness feeling. A factory on the other hand has a strong negative impact on city centre-ness. Analysis of the free text part of the questionnaire also revealed that the city's central library, which is not in the list above, is another relevant landmark concept for a city centre. To delineate a city centre, we first compute a measure of 'city centre-ness' at each location within a city, and then merge the area of high city centre-ness to a contiguous region.

3. Delineation of the city centre of Bristol

This section shows on the example of Bristol how a city centre may be computationally delineated. The same experiments were carried out for the following 10 British cities: Birmingham, Bristol, Cardiff, Leeds, Liverpool, Glasgow, Manchester, Nottingham, Sheffield, and York. The selected cities range in number of inhabitants from 198'800 (York) to 1'028'700 (Birmingham) (Office for National Statistics, 2010), and provide a variety of different topographical settings and urban history. Similar results were obtained for all cities, but for lack of space, we present only the example of Bristol.

3.1 Computation of city centre-ness surface

Two Point of Interest (POI) databases were obtained from the Ordnance Survey of Great Britain: MasterMap® Address Layer 2 and PointX, which were integrated into a fusioned dataset for quality improvement. The fusioned dataset covered commercial addresses classified into a detailed hierarchy. Based on the results of the survey, a list of more general functional classes was developed. The commercial addresses were mapped to these classes for calculating city centre-ness. Table 3 shows the functional classes and provides illustrating examples.

Functional class	**Examples**
Shopping (non food and special goods)	Book shops, department stores, clothing
Food and drink consumption	Restaurants, take aways, cafés
Consumer services	Hairdressers, travel agencies, employment agencies
Law courts	Law courts
Business services	Marketing services, architects, insurers
Museums and art galleries	Museums, art galleries
Theatres and concert halls	Theatres, concert halls
Evening and nighttime leisure	Discos, night clubs, amusement arcades, casinos
Industry and extensive business	Manufacturing, farming, engineering
Shopping – food & convenience (not used for calculation of city centre-ness measure)	Bakeries, groceries, convenience stores, markets
Other (not used)	Infrastructure features, sports facilities

Table 3. Functional classes used for the calculations and examples for each class.

As previously mentioned, in the preliminary model urban areas such as the business district, retail parks, or purely residential areas such as terraced house settlements were not yet included and this investigation is restricted to the influence of functional criteria. Individual similarity surfaces for functional criteria were computed as follows:

- For each of the relevant landmark concepts (town hall, cathedral, main railway station, central library), a surface of Euclidean distance to the feature was calculated.
- For each functional class as listed in Table 3, a kernel density surface was computed.

Kernel Density Estimation (KDE) is frequently employed to estimate spatial footprints from point densities in ecology and geography (Seaman & Powell, 1996; Jones et al., 2008). Two parameters need to be chosen: The window width (also called bandwidth h, or smoothing parameter) and the kernel function, which determines the weighting of the points. Commonly, a normal distribution or quadratic function serves as kernel function. In our case, we used a quadratic function. While it is reported that the choice of the kernel function has little influence on the results (Lloyd, 2007, p. 184), the selection of window width is more important. Small values exaggerate local minima and maxima, while large values smooth away local variations. In our experiments, we set the window width to 350 m by considering the size of the spatial context influencing a person's cognition of an urban environment. Validation of the window width within reasonable limits ($200\ m \leq h \leq 500\ m$) resulted generally in small changes of the city centre, i.e. the core area and global form remained the same.

Each surface was subsequently normalised to similarity surfaces, such that 0 = minimum similarity within the investigation area, and 1 = maximum similarity. For landmark concepts, it was assumed that they influence a neighbourhood of 3 *km*, so that all points further away received a similarity of 0, and points with distance between 0 *km* and 3 *km* were linearly scaled to values between 0 and 1. Since all landmark features received a similar importance in the questionnaire, the surfaces for landmark concepts were averaged to one similarity surface. Figures 2a–c show the surfaces for shopping, evening and nighttime leisure, and the distance surface, respectively.

The final city centre-ness value at each location was calculated by weighted summation. The weights were set according to the intensity of activities and the typicality of concepts obtained from the survey. Figure 2d shows the computed city centre-ness surface.

3.2 Boundary formation

In the next step, crisp boundaries for a city centre had to be created from the similarity surface. Previous approaches manually selected a threshold that produced visually a matching result (Office of the Deputy Prime Minister, 2004), or set the threshold such that e.g. 90% of the volume falls within the boundary (Hollenstein, 2009). While the first approach is not automatable (the threshold is individual for each city) and somewhat subjective, the second approach is only suitable for unimodal distributions.

Our approach determines in a first step the area of the city centre, and then iteratively grows the city centre from the point of highest similarity until the area determined in the first step is reached. Analysis of city centres derived from alternative sources (see section 3.3) revealed a correlation between city centre size and population (or, alternatively, size of urban area). A linear regression based on reference city centres for the 10 cities listed above was thus used to estimate city centre areas. For Bristol, this resulted in a city centre area of 2.35 km^2.

The city centre area was subsequently generalised through morphological operations (i.e., shrinking and expanding the polygon) (Millward, 2004). Figure 3 shows the final *cognitive city centre*.

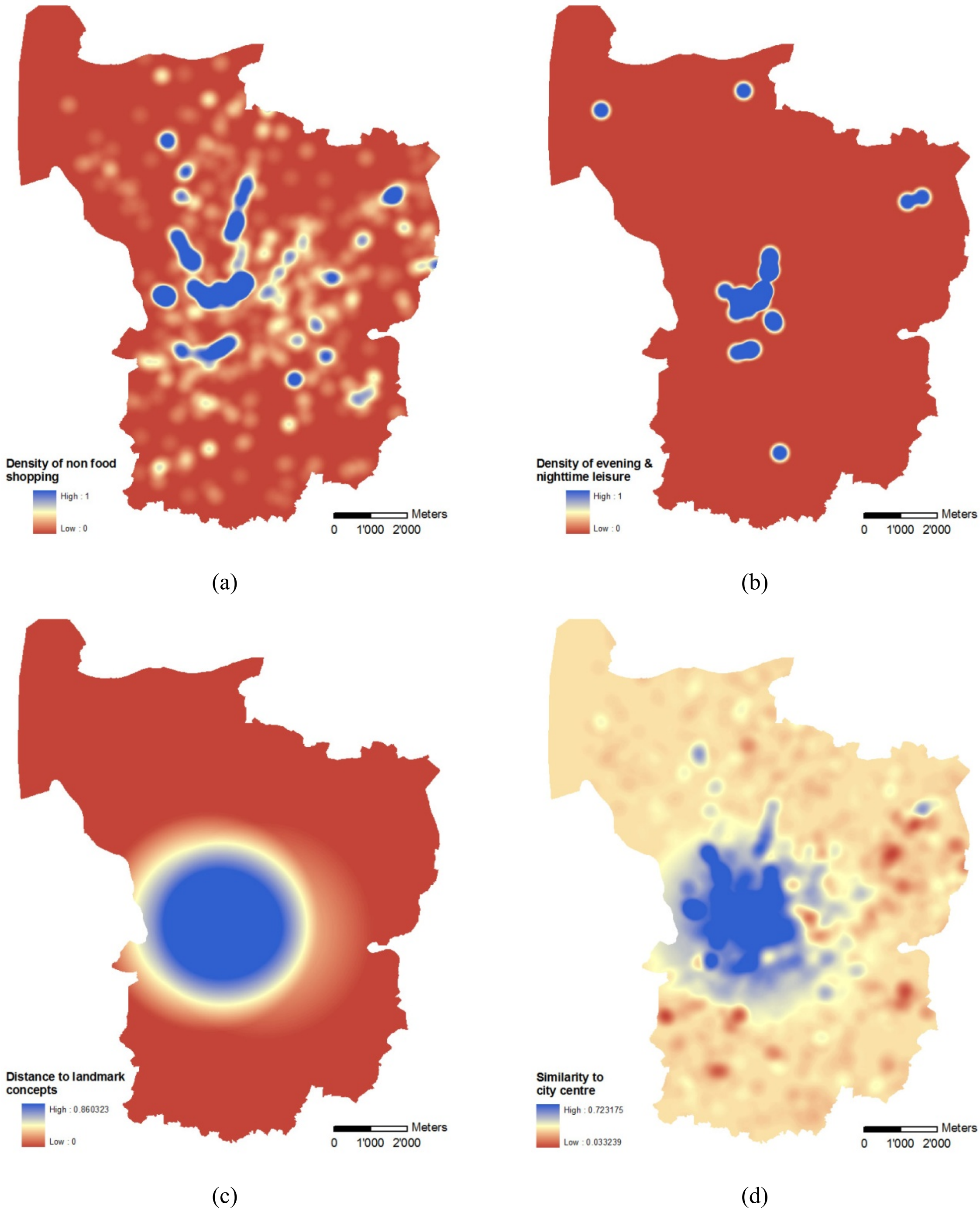


Fig. 2. Computed similarity surfaces. (a) Non food shopping. (b) Nighttime leisure establishments. (c) Distance to landmark concepts. (d) Similarity to city centre as calculated by weighted summation.

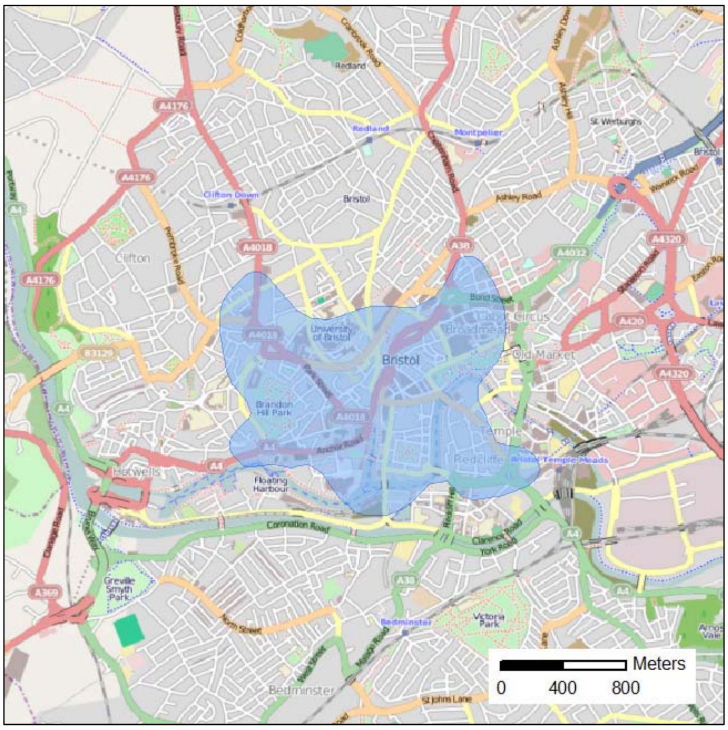


Fig. 3. City centre delineated by our algorithm. Background mapping openstreetmap.org licensed under a Creative Commons Attribution-Share Alike License.

3.3 Comparative evaluation

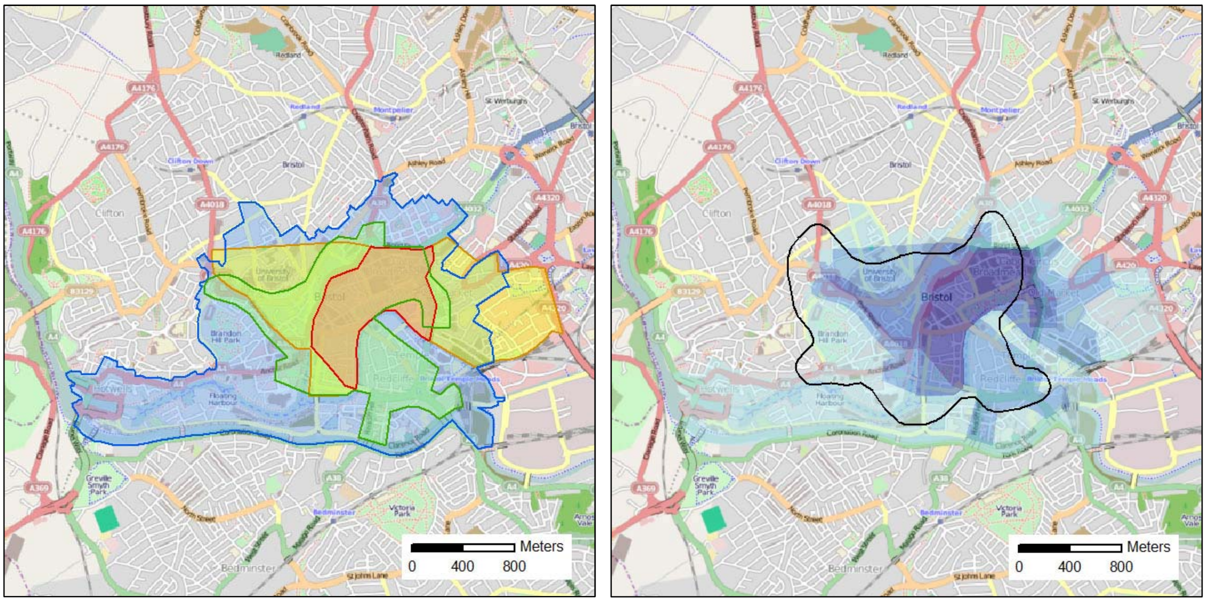
The city centre area obtained above was evaluated by comparing it to city centres from alternative sources. Several websites provide descriptions or maps of Bristol city centre as shown in Figure 4a. Wikipedia's article on Bristol city centre contains a narrative description of its extent, which was interpreted and mapped: "*The central area of the city of Bristol, England, is the area south of the central ring road and north of the Floating Harbour, bounded north by St Pauls and Easton, east by Temple Meads and Redcliffe, and west by Clifton and Canon's Marsh. It is contained entirely within the Council ward of Cabot.*" [2]. This short description contains contradictory statements that lead to two possible city centre areas: The area between the central ring road and the Floating Harbour is marked red in Figure 4a. The second part of the description refers to district names and Bristol's main railway station (Temple Meads). It was mapped by outlining the named districts and drawing the city centre boundary along these outlines (yellow in Figure 4a). A third possible city centre area was obtained by manually drawing a tightly fitting hull around 'city centre bus stops' from a bus map of Bristol city centre[3] (green in Figure 4a). The 'Bristol City Centre Strategy and Area Action Plan 2005–2010'[4] provides an 'official' outline of the city centre (blue in Figure 4a).

All these representations must be interpreted with care, as they are themselves vague interpretations (as in the Wikipedia example), represent an individual opinion, or are the result of a political compromise and are therefore different from people's conceptualisation of a city centre. Including the stretch along the river in the south-western part into the Bristol City Centre Area Action Plan is explained by the derelict industrial areas along the river which were designated for intensified

[2] http://en.wikipedia.org/wiki/Bristol_city_centre. Accessed 14 April 2010.
[3] http://www.bristol.gov.uk/ccm/cms-service/stream/asset/?asset_id=33482055. Accessed 14 April 2010.
[4] http://www.bristol.gov.uk/ccm/cms-service/stream/asset/?asset_id=5361002. Accessed 14 April 2010.

regeneration and conservation of heritage sites. However, collectively, these descriptions give us hints about the 'true' extent of the city centre as a reference.

The overlay of these alternative representations with the derived city centre in Figure 4b shows that the core areas agree, but the derived city centre seems to omit the eastern part. This is due to the many industrial features in these areas.



(a) (b)

Fig. 4. (a) City centre areas derived from alternative sources. Red: Wikipedia #1. Yellow: Wikipedia #2. Green: Hull around 'city centre bus stops' from the bus map of Bristol City Centre. Blue: Bristol City Centre Action Plan. (b) Overlay of city centre derived by algorithm (black line) and derived from alternative sources. Background mapping openstreetmap.org licensed under a Creative Commons Attribution-Share Alike License.

We also compared the derived city centre to georeferenced photographs tagged with 'city centre' from flickr.com. Flickr is a website where people can upload photographs. It is also possible to attribute the photographs with a geographical location and to describe their content through free text tags.

Flickr provides a public API for accessing flickr content[5]. The API includes search operations that use metadata associated with images, such as the tags, upload timestamp, or user name. A Java application was written that globally retrieved all flickr image objects that were publicly accessible, had a geographical location, and were tagged with 'citycentre'. To obtain a set of georeferenced images for each of the cities, the global dataset was intersected with a bounding box for each city.

As of 29 March 2009, there were 135 distinct locations uploaded by 29 different users in Bristol. The locations are shown in Figure 5. Although the photographs are somewhat concentrated along a central square called 'The City', it can be seen that they are relatively well distributed within the *cognitive city centre* and few points lie outside – this suggests that our representation is nearer to people's conceptualisation of Bristol's city centre than the representations shown in Figure 4a.

[5] http://www.flickr.com/services/api/. Accessed 19.07.2010.

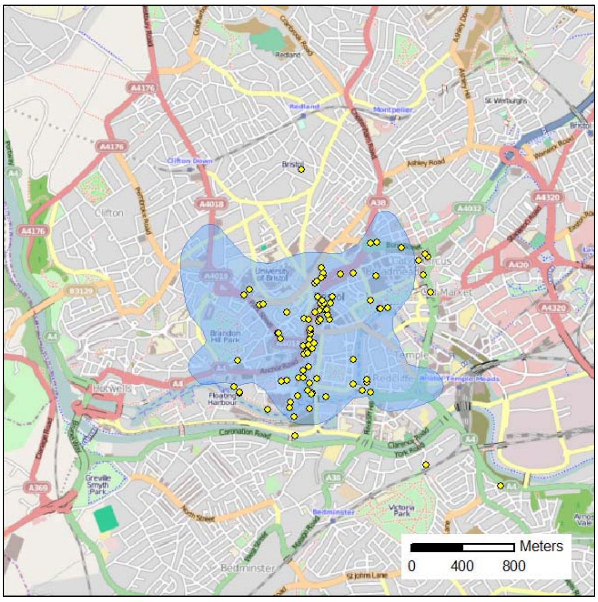


Fig. 5. Overlay of city centre and georeferenced Flickr photograph locations. Background mapping openstreetmap.org licensed under a Creative Commons Attribution-Share Alike License.

4. Discussion and outlook

Representing the world as it is conceptualised by people is of great importance in many situations when interacting with GIS (Montello et al., 2003; Jones et al., 2008; Hollenstein, 2009). We have shown that such a conceptualisation can be obtained through a questionnaire survey. Since the concepts that are thus extracted relate to high-level semantics, they are also immediately useful for driving the generalisation process. The type of data used is widely available and hence the approach is applicable not only in the UK.

In the remainder, we are discussing some conceptual issues concerning the delineation of regions: Vagueness of boundaries and representation. Many geographic regions are ill-bounded in the sense that it is unclear where to draw a line that separates the inside from the outside (Fisher, 2000; Montello, 2003); the boundary is a zone where region membership is contestable. This clearly holds for city centres as well. A number of approaches were proposed for modeling vague regions within GIS, such as fuzzy logic (Fisher, 2000), probabilistic surfaces (Montello et al., 2003), and supervaluation semantics (Kulik, 2001). The former two approaches assume that a value of region membership can be assigned to each location in the boundary zone. It can be argued that vagueness is not a property inherent to the phenomena, but arises from individual interpretations of the world, each interpretation being crisp on its own (Varzi, 2001). Supervaluation semantics follows this view and differentiates between instantiations that are that are *super-true* (true in all possible interpretations), *super-false*, and instantiations where interpretations differ and statements are thus problematic. While it is possible to produce a fuzzy city centre region from the similarity surface, it makes more sense to produce crisp boundaries for many applications (Couclelis, 1996), such as cartographic visualisation, query processing, and urban planning.

While we represented a city centre as a region, it could also be represented as a point, depending on scale (or better: map purpose). This location would be the cognitively most representative point within the city centre (the 'cognitive centre of gravity'). It would be interesting to investigate whether that point would coincide with the location of highest city centre-ness value, the centroid of the region, or the location of a landmark concept such as the town hall.

In our experiments, the weights were determined through analysis of the questionnaire. In our future work, the influence of individual factors and the sensitivity of the result to the choice of weights will be evaluated. Previous research (Bromley, Tallon, & Thomas, 2003; Hubbard, 2002; Tallon & Bromley, 2004) revealed dependencies of individual city centre use and perception from social group and age. It could thus be sensible to calibrate the cognitive model to different user groups in order to better represent their view of a city centre. We also do not claim that the cognitive model as elaborated in our experiments holds universally for all cultures. The same experiments should be carried out for cities in other countries in order to find out whether there are differences in the conceptualisation of city centres between cultures.

The survey revealed that criteria other than functional facilities are also important when perceiving city centre-ness. Clearly, criteria such as presence of pedestrian zones and absence of large green spaces, or absence of large pure residential neighbourhoods are also important. We are currently working on including these in our model as well. Given the large spatial extent of such concepts, they have to be modeled and integrated into the calculations as regions. We also aim at describing the city centre model in a logics-based language. This would allow increased flexibility for adapting the model to different settings and better interoperability (Lüscher et al., 2009).

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