Historical Gazetteer System Integration: CHGIS, Regnum Francorum, and GeoNames

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24 Jul 2014 [draft chapter for submission to publisher]

Abstract: Integrating digital gazetteers involves the matching of place name records, disambiguation of unique places and conflation of duplicates or variant place names. The challenge of mapping between historical instances of place names is also an ongoing concern for several important projects dealing with ancient place names. Here the matching of historical place names from two unrelated datasets (for China and France) to gazetteer web services is undertaken using a basic *geospatial* and *geonomial* algorithm. The quantitative results of the matching trials are considered, problems in dealing with vernacular scripts considered, and practical implications for integrating historical gazetteers discussed.

1. Gazetteer Web Services and Digital Historical Gazetteers

Online gazetteers provide essential services. They serve as authority records for geocoding place names and for retrieval of place names associated with real world coordinates (reverse geocoding). For example, the expanding interconnections of LinkedOpenData [LOD] [1] on the semantic web have consistently placed GeoNames [2] at or near the center of the semantic web's social graph. The centrality of GeoNames is largely due to three factors: first, it is a free and open Application Programming Interface [API]; second, the API is simple and easy-to-use; and third, it is currently the only global geographic resource with stable URIs. Traffic for the GeoNames web service topped twenty million requests per day (in 2012); and since half of these requests are from smart phones, [3] it is clear that geographic information retrieval [GIR] is being built into many new location-based applications for mobile devices.

Another major GIR web service is provided through the GoogleMaps Geocoding API,[4] which provides free *geocoding* and *reverse geocoding* web services. But the GoogleMaps web service, unlike GeoNames, provides no standard URI or unique identifier for objects returned in their query results, which explains why there is no GoogleMaps presence on the LOD cloud. Even so, the general explosion of webmaps and geocoding applications based on the GoogleMaps is clear to be seen. In 2010, Google declared that more than 350,000 websites were using the service, and that:

> "Google Maps API has established itself as the most popular Google API and the most deployed service-based API on the web." [5]

Clearly, the demand for accurate, automated GIR has become an essential part of the Internet experience for a rapidly growing audience.

The emergence of these robust gazetteer web services -- GeoNames, GoogleMaps Geocoding API, Yahoo Placemaker [6] -- provides an interesting testbed for GIR research. They have clearly outstripped their predecessor, the Alexandria Digital Library [ADL] gazetteer content standard and protocol, in terms of performance.[7] And while ADL established the basic principles of digital gazetteers, [8] the new breed of gazetteer web services simply appear as operational APIs, with technical documentation on query and response parameters but no theoretical underpinnings at all. Therefore it is quite interesting to see the ways in which GIR research is taking advantage of these gazetteer web services, by trying out new methodologies for integrating digital gazetteers, as well as exploring new theoretical aspects of GIR on the semantic web. [9]

One prospect for integration of digital gazetteers, is to augment the existing gazetteers with temporal attributes, turning them into spatio-temporal gazetteers, and enabling Geo-Temporal Information Retrieval [GTIR]. An obvious place to begin with this task, would be to establish links from the dated place name attestations in existing historical gazetteers to the undated place names found in the authoritative gazetteer web services mentioned above. Examples of such a linking process have already been developed for the purpose of parsing place names within historical texts, such as the pioneering Perseus Project,[10] and more recently the Google Ancient Places [GAP] project.[11] In both these cases, natural language parsing of place names, tokenized within digital texts, is combined with geocoding the ancient place names. For this purpose, Google Ancient Places can leverage place names recorded by the Pleiades Project, which provides a consistent means of accessing attestations about specific historical places in the ancient Euro-Mediterranean world. [12]

Despite these interesting achievements, there has yet to emerge a standard way to create linkages between historical instances of place names and the current gazetteer authorities such as GeoNames. One way to approach this will be to "time-enable" existing gazetteer services by establishing explicit links from current place names to the names identified in the major digital historical gazetteers such as: the Great Britain Historical GIS and its Administrative Unit Ontology,[13] the China Historical GIS gazetteer [CHGIS],[14] or the Regnum Francorum Online [RFO][15] collection of resources on the Merovingian and Carolingian Frankish kingdom.

The Regnum Francorum project, for example, has already implemented a number of cross-linked resources involving historical gazetteers. These include GeoNames, Wikipedia, the Princeton Encyclopedia of classical sites,[16] topographical dictionaries,[17] and links to numerous archaeological sites found in GoogleEarth and OpenStreetMap.[18] In this way, Regnum

Francorum Online [RFO] provides a unique point of integration for disparate types of information, such as passages from historical texts, images of artifacts, important historical events, and a variety of spatial correlates, such as vector objects (points, lines and polygons) or high-resolution satellite views. The key point of association is the historical place name, therefore the connections that RFO has established between these resources is both an exemplar and practical demonstration of how the semantic web can be utilized for the compilation of historical gazetteers on a regional scale.

When working with printed resources such as the *Barrington Atlas of the Greek and Roman World*,[19] it is readily apparent that the features being depicted at a regional scale are not going to align perfectly with actual locations on the ground. Moreover, the digitization process of the Barrington Atlas sheets [DARMC][20] required the help of several dozen graduate students over the course of more than two years to georeference scanned maps and to align vectorized map features with their positions on the contemporary GoogleEarth basemap. Nor can these GIS features be considered the last word on the subject, because new evidence or new interpretations about historical sites will inevitably follow.

The Pleiades Project, which can be seen as a "next generation" gazetteer, addresses this problem by incorporating multiple attestations about historical places. These attestations may be on a case-by-case basis, or may be the result of a batch integration, as was done with nearly 20,000 place name records derived from the DARMC project. However, neither DARMC nor Pleiades place names contain references to the historical or present administrative hierarchy for their locations, a key factor in disambiguation of historical place names. For integration of historical gazetteers to succeed, we must first augment them with meaningful attributes, such as relationship of named places to the administrative system, (both current and ancient,) and to provide attestations about their known dates of existence.

The major issues related to development of historical gazetteers were discussed during three days of meetings held at the American Association of Geographers [AAG] Annual Meeting in Seattle (2011),[21] out of which a proposal for a global historical gazetteer testbed emerged. In this paper, we will explore the prospects of historical gazetteer integration by running place name matching algorithms between historical source gazetteers and the online gazetteer web service provided by Geonames. We will attempt to match records from CHGIS and RFO with GeoNames, and at the same time augment the records with results from the Google Maps API reverse geocoder, and then compare the results.

It is also worth mentioning that Geonames has quietly enabled the entry of "historical" place names within its editing infrastructure, and between the time of first implementation in 2013 and today, more than 35,000 historical place names are now in the Geonames database. [FIG ONE]

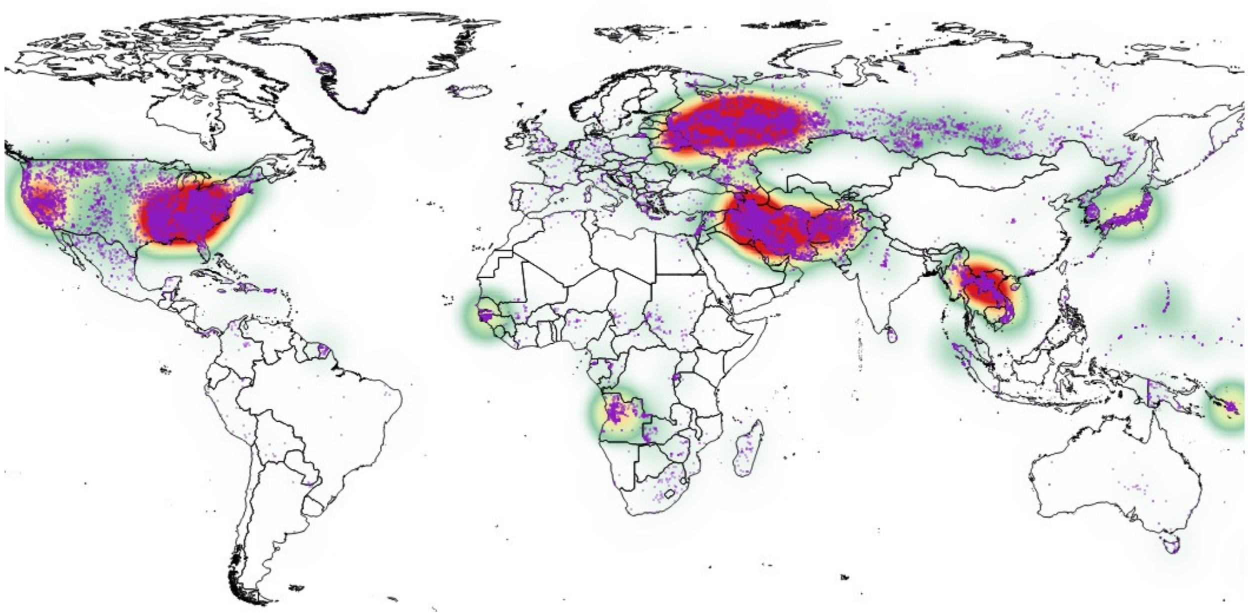


Figure 1: Historical place name features in Geonames (circa July 2014). ***Data Source:*** **Marc Wick.**

2. <u>String Matching Methods</u>

Before starting on the place name matching algorithm, we evaluated current research that makes use of web services (such as Yahoo, Google, and GeoNames) for place name integration.

A variety of approaches were found, including the use of Soundex scores,[22] Levenshtein distance,[23] and administrative hierarchy checks.

In the case of Soundex, both source and target phonemes are given pronunciation codes, which can assist to find matches of similar spellings where an identical spelling match would otherwise fail. Unfortunately, there is currently no Soundex equivalent for working with Chinese characters, and for place names based on spellings of romanized strings, the Soundex score cannot be reliably calculated, because Chinese words have both very high degree of ambiguity in phonemes per written character, as well as a variety of possible romanized spellings.

For example, Kuangtung (Soundex value = K52352) and Kwangtung (K52352), (respectively the Wade-Giles and a common variant) would match, and their Soundex scores are quite close to Guangdong (G52352), which is the official Pinyin romanization. However, the same does not hold true for the Pinyin spelling: Tianjin (T525), and it's Wade-Giles form: Tientsin (T5325), where the "*j*" and "*ts*" introduce a difference that is not based on the actual pronunciation of the Chinese word, but only on the spelling variations used by the two romanization systems. Of course, Soundex can only help with identicial or phonologically similar place names, but never for alternate place names, such as Canton (C535) or Cantão (C530). Based on these considerations, we have not implemented Soundex scores in our testbed matching algorithm.

The principle of Levenshtein distance, which calculates the minimum number of deletions or changes in a target string that would result in an exact match to a source string, is useful in theory for matching Pinyin spellings of Chinese words, though the Levenshtein distance is thrown off by the actual instances of Chinese place names contained in our samples. For example, place names in Chinese are generally considered to have two components: a *toponym* [zhuan ming], and a *classifier* [tong ming]. For example, Tengchong Xian [Tengchong

County], is composed of the *toponym* = "Tengchong," and the *classifier* = "Xian."

One problem with using Levenshtein distance method is that the authority gazetteers (including GeoNames), may contain a place name "Tengchong" that lacks the *classifier* "Xian". Therefore, if we were to compare the two strings "Tengchong" and "Tengchong Xian" the Levenshtein distance will include the steps of deleting the blank space and the *classifier* "Xian," and **increase** the distance value; when, in fact, it is precisely the meaning of the classifier, "Xian," which might have semantically disambiguated that match from other candidates.

A recent study (by Gang Cheng, *et al*) specifically applying Levenshtein distance to Chinese place names, takes this aspect into consideration, and claims to improve the completeness and accuracy of the place name matching algorithm, when compared to string match only.[24] Though we are intrigued by the methodology, their results were unconvincing. For example, the authors provide a table of similarity scores based on Levenshtein distance comparing "Puyang City" to "Puyang Country" (*sic*), in which:

"special name" (*toponym*) similarity = 1

"generic term" (*classifier*) similarity is 0.6561

comprehensive similarity = 0.8968

string match similarity = 0.6667 (ie, Levenshtein distance).

The overall conclusion being that a similarity of 0.8968 is much better than 0.6667.

However, if we were to simply match the first five letters of the two strings ("Puyan" = "Puyan"), the Levenshtein Distance would be a perfect 1. Also, as described below, it is possible to avoid complications of *toponym* and *classifier* bound forms in Chinese by limiting the string match to the minimum number of letters possible for two Chinese syllables. This also has the counter-intuitive advantage of finding more, rather than fewer, matches within longer address strings. To illustrate this concept, consider an attempt to match the strings

"Henansheng Puyang Shi Puyang Xian Qinghetou Xiang" and "Puyang" using the method described by Gang Cheng, et al. Note that in the first string, there are four *classifiers*, some of them separated from their related toponyms with a blank space. The parsing method to determine toponym from classifier used by Gang *et al* would fail in the first string, since their inputs require a single *toponym* and *classifier* pair. On the other hand, if we simply stripped out all blank spaces, and matched the first five letters from each resulting place name string to the other, ***in both directions***, we would get a 0 match in one direction and a 1 match in the other:

HenanshengPuyangShiPuyangXianQinghetouXiang compared to *Puyang*

Henan != Puyang [0]

Puyan = Henansheng***Puyan***gShiPuyangXianQinghetouXiang [1]

The advantage of this method is that within any heterogenous list of place names, regardless of completeness or incompleteness of *toponym* & *classifier*, and regardless of completeness in the hierarchical address, we are able to find positive matches. Of course, it's true that the match occurred at a higher level of aggregation in the specific string being searched *against,* and did not match exactly equivalent place names. If this geonomial method is used by itself, all of the locations with "Puyang Shi" in their address would be found, most of which are mis-matches. Ideally, we could use administrative jurisdiction information to complete the match, but this information is lacking in the first string, "Puyang," therefore we have no complete "address" to compare. However, if we add a geospatial buffer process, selecting for only those matches that occur within a certain threshold distance, then matching relevance increases.

Owing to the special case of romanized Chinese, we stipulate that Levenshtein distance calculation is not appropriate for string matching process. Similarly, as our previous example demonstrates, the presence or lack of administrative hierarchy information, in the form of a complete "address" spelling, is not consistent enough in the samples for consistent parent / hierarchical matching. Therefore, our first objective is to develop a place name matching process to establish preliminary matches that will allow us to enhance the sample records by leveraging information from one gazetteer to another. Ultimately, the goal is to set up semi-automated processes, enabling temporal and ontological information to be cross-harvested between digital gazetteer sources.[25]

3. Strategy for Gazetteer Integration

Gazetteer **augmentation**, is in our view, by far the most practical approach to pursue for digital gazetteer integration. That is to say, an accumulation of information about particular historical places can be built up by harvesting factual elements from one or more gazetteer sources and then storing those elements, *or links to them*, in a target place name record. In this way, facts can be leveraged and cross-checked between gazetteer authorities.

This approach is very well formalized by Smart *et al*,[26] who have devised a Toponym Ontology as both a means of cross-checking and integrating place names and related information about places from multiple sources. The toponym ontology relies on the use of a GeoFeature Augmenter, which enhances records from the original sources with related attributes from target gazetteers. For example, a place name record in one source, which has only a location and toponym, may query a second gazetteer to discover and store the current administrative district of that location. Or the query may consult another gazetteer to discover and store a feature classification.

Place name being queried: Tengchong Xian

Query target gazetteer one: retrieves parent jurisdiction = Baoshan District, Yunnan Province

Query target gazetteer two: retrieves feature classifications = County, Administrative Unit

In Smart, *et al*, the cumulative results comprise a Geofeature Set, which serves as a container object to bind the elements from different sources together. In this way, the GeoFeature Set can be considered as a means to define a "place" based on queries about toponyms or locations.

GeoFeature Set:

<name>Tengchong Xian</name>

<class src=gaz2>County</class>

<class src=gaz2>Adminstrative Unit</class>

<parent src=gaz1>Baoshan District, Yunnan Province</parent>

Another advantage of the GeoFeature Augmenter concept, is that each gazetteer can be categorized for type of information that it is able to provide. In this way, incoming queries to the proposed system can be vetted with a Resource Selection Policy, and sent to the optimal source, depending on the type of related information being requested.

A concrete example of an augmented gazetteer is shown in Regnum Francorum Online [RFO] place name records, each of which contains official place names, alternate place names, administatrive districts (both historical and contemporary), as well as external identifiers for linking out to other web resources (GeoNames, Pleiades, GoogleMaps, OSM, Wikipedia, etc). An important finding of the partly automated augmentation process in RFO was that proximity filters (such as bounding boxes) when querying the Google Geocoding API for place names resulted in quite ambiguous results, but when providing complete administrative information (ie. a complete "address" such as *Holzhausen, Niedersachsen, Germany* vs. *Holzhausen, Oetwil am See, Switzerland*), the system almost always produces an exact match. Therefore, from the outset we should attempt to leverage existing historical administrative jurisdiction information for inclusion in the basic augmentation process.

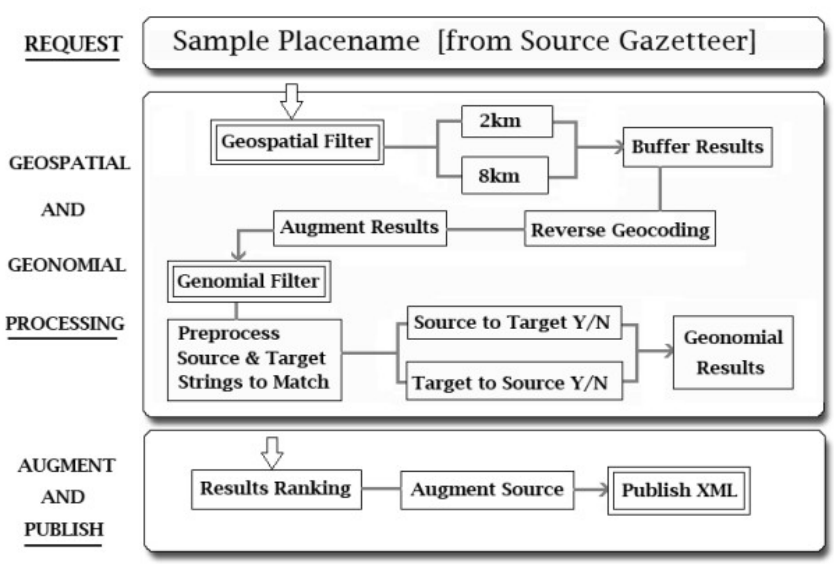
The augmented gazetteer idea was also central to Connecting Historical Authorities with Linked data, Contexts and Entities [the Chalice Project].[27] Chalice set out to use the Unlock Places API [28] to geocode gazetteers published by the English Place Names Society as well as other historical texts. Following Chalice, a new project, called Digital Exposure of England's place names [DEEP] [29] was launched in 2012 with plans to complete the development of the historical place name gazetteer begun by Chalice.[30]

Even more promising is the international project, Pelagios 3, which has created the first practical infrastructure for integrating historical gazetteers and references to digital objects. Although the main objective of Pelagios 3 is to annotate, link and index place references in digitized Early Geospatial Documents, one of the by-products is the development of an interchange format in RDF, which is already being actively developed and deployed by the project's research partners.[31]

3. Gazetteer Integration Testbed

Our testbed aims to integrate place names in an existing digital historical gazetteer with the unique IDs used by GeoNames. In this way, we can take advantage of the centrality of GeoNames in the LinkedOpenData web, and conduct future experiments to harvest linked data on the semantic web that is related to particular historical place names *via* the common GeoNames ID. The overview of the testbed system is shown in Figure 2. [FIG TWO]

Figure 2: Overview of the gazetteer integration testbed system architecture



As a starting point, we developed an algorithm to iterate through a subset of China Historical GIS [CHGIS] place names, (the historical county seats of Yunnan Province), and to augment them with GeoNames IDs by conducting geonomial and geospatial matching tests on each. To speed up the process, the matching tests were not processed via the GeoNames API, but were run using SQL queries upon a downloaded subset of the GeoNames dataset for China and stored locally in a MySQL database.

As a point of comparison, an identical test was be run using historical place names of France found in Regnum Francorum Online [RFO] database. The RFO place name records already contain GeoNames identifiers, hand-coded by the editor, and cross-checked with Google Geocoding API. Therefore, the matching of RFO names to GeoNames results will provide an interesting control dataset, to show similarities or differences in the hand-coded vs. auto-generated matches.

It is tempting to rely completely on GIS spatial analysis for the integration of digital historical gazetteers, especially when both source and target datasets contain mappable x, y coordinates. For example, it is trivial to produce areal buffers around the CHGIS historical county seats of Yunnan and then overlay the GeoNames points to see which GeoNames locations fall within those buffers. In this way, a number of buffer distances can be quickly tested to find the preferred radii to use for our basic distance filtering process. [See Figure 3]

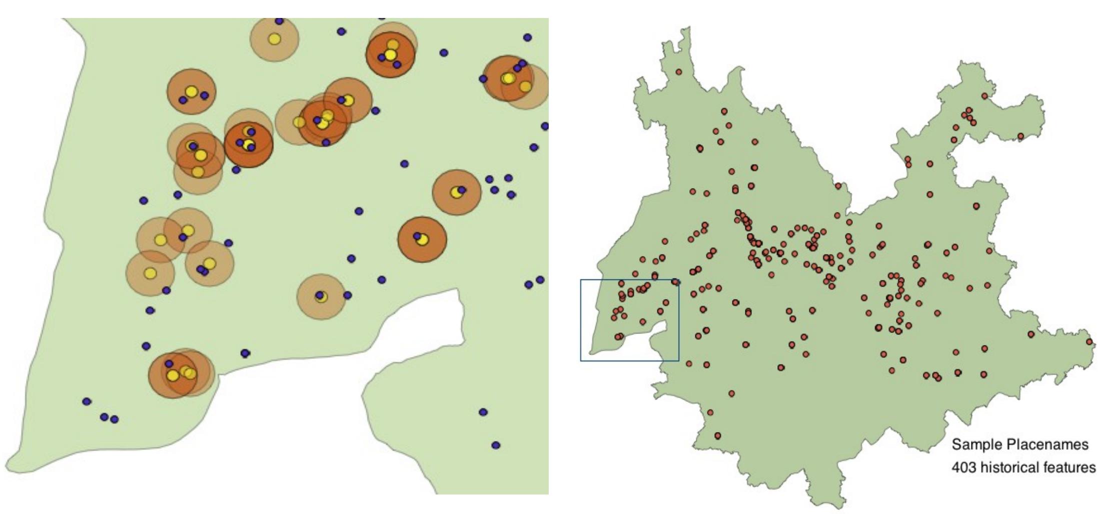
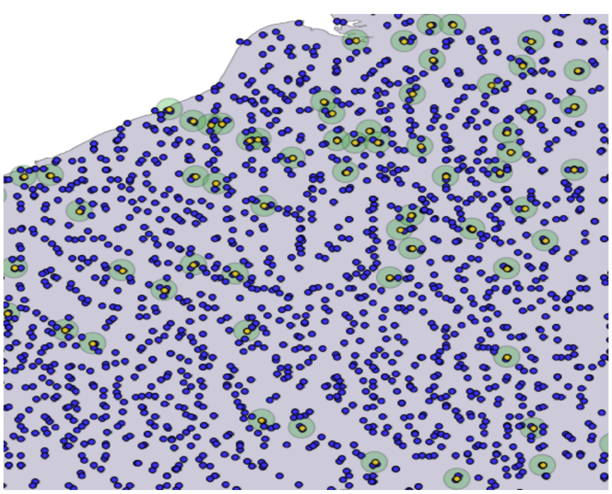


Figure 3: Yunnan place names [left - showing zoom area and overlay of blue GeoNames points]

As a case in point, when testing the Yunnan study sample, we discovered that place name matches occur most frequently at break points within 2km and 8km, (a rather large planimetric error to account for). Another interesting consequence of creating buffers from instances of historical place names, is that, when symbolizing the buffers as semi-transparent, the darker hues indicate the points where more historical instances are recorded, an indicator of greater number of changes over time.

Since the source of many Chinese GeoNames records is the USGS GNS China files, their locational accuracy should be attributed to legacy errors inherited from original source data, and not to subsequent processing by GeoNames. Also, when considering the planimetic accuracy of points in GeoNames, it is important to know that regional variations are dramatically different. Point buffers for CHGIS points in Yunnan typically needed 2km to 8km buffers to find reasonable matches in Geonames; while matches between the RFO points in France with their GeoNames counterparts never exceeded the 2km buffer, and often were found with Haversine calculated distance of less than 250 meters. [Figure 4]



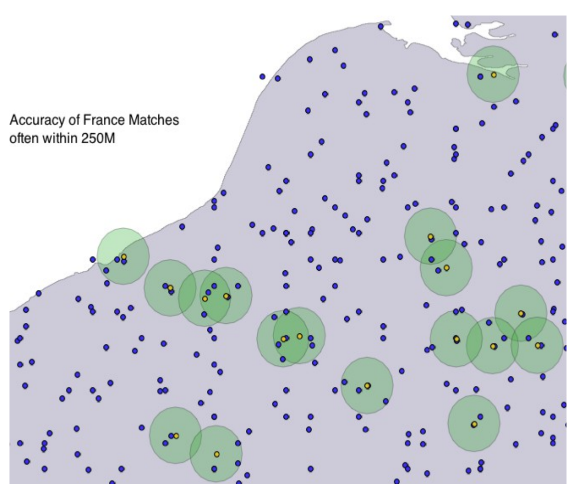


Figure 4: France place names [right - showing overlay of blue GeoNames points within 2km zones]

4. <u>Geospatial Matching</u>

Although geonomial (string matching) of place names was the primary task for our algorithm, it is much more efficient to filter by Haversine distance before conducting the geonomial function. Working from the findings of the preliminary GIS buffering, radii of 2km and 8km were calculated for the Yunnan sample, and 2km radii for the France sample. Note that Smart, *et al,* worked with a 500m radius, which would have been slightly too constraining to match all of the France data. In the following chart, the total number of source names is shown, and the total number of matches made purely on calculated Haversine distance from source point to any possible GeoNames point, within 2km or 8km buffer zones. The Average distance within the zones is also shown, along with the total average distance of all points found. [Figure 5]

Sample	Total Names	2km Hits	Avg < 2km	8km Hits	Avg <8km	Avg All
Yunnan	403	297	1.15 km	1994	4.67 km	6.07 km
France	4164	17705	0.84 km	n.a.	n. a.	1.02 km

Figure 5: Number of matches found within 2km and 8km buffer zones, with average distances

For CHGIS Yunnan points, the 2km radius was clearly not enough to capture the majority of matches, while the density of GeoNames hits with 2km of RFO data was sufficiently large to capture all the candidates.

Familiarity with the sample data led us to believe that many of the Chinese historical place names would not successfully match geonames place name spellings, so we implemented two other geospatial matching functions in the test algorithm. The first was a reverse geocoding request to the Google Geocoding API, based on the source place name's geographic coordinates.

32 The second was to geocode the locality name returned in the reverse geocoding response.

For example, when reverse geocoding the CHGIS location for Yongping Xian, the top return (ie. the closest location found in Google API) was a "rooftop" located at Number 1 Bonan East Road, Yongping, Dali, 672600. Since this "address" found is not optimal for our place name string matching checks, we parsed the "locality" element from the first response (which, in this case = "Yongping").[33] In this way, regardless of the place names stored in the CHGIS gazetteer, we have established a simple cross-check to find the nearest Google API locality (*ie* "Yongping" rather than "Number 1 Bonan East Road, Yongping, Dali, 672600").

5. Geonomial Matching

The geonomial matching algorithm, which checks for toponym string matches, is designed to take the simplest path to matching Chinese place names, taking into account the obstacles mentioned previously. The CHGIS place names, consist of the historical place names (in UTF8 encoded Chinese characters, and romanized Pinyin names), as well as a Present Location description (in UTF8 encoded Chinese and an auto-generated Pinyin transliterations). By contrast, the GeoNames place names consist of a default toponym, and Alternate Names (consisting of a comma-delimited array of mixed vernacular scripts using UTF8 encoding). The difficulty in matching the CHGIS to GeoNames place names is primarily due to the fact that typically only one segment of the CHGIS Present Location string will match any segment of the GeoNames string.

As an expedient to enable matching in either direction, we used a preprocess to strip all blank spaces from the source place names, and then trim each sample string down to the first five characters. In this way we have a "source" string consisting of only five roman letters that we can check against the complete address string in the target gazetteer.

The reason for limiting the string to only five letters is based on the problem related to bound forms of Chinese place names, mentioned above. The majority of Chinese syllables in romanized spellings rarely contain less than three letters. For example, the Pinyin syllable "Ou" may sometimes be spelled "O" in Wade-Giles, and very rarely are one letter syllables in toponyms possible, such as "E," as in "Emei Shan." In addition, there are no syllables at all containing more than six romanized letters, ie "Zhuang" or "Shuang." The majority of syllables fall into groups spelled with two to four letters, meaning that six letters should be enough to capture the majority of possible Chinese place names that might consist of one *toponym* syllable and one *classifier* syllable.

An example of a two letter *toponym* is: "Ai Xian." There might be cases of a single letter *toponym* and a three letter *classifier*, something like "O Cun," but that would be a rare occurrence indeed.**[34]** It would not be at all uncommon, on the other hand, to encounter romanized *toponym* / *classifier* combinations such as: "Yi cun," "Ao cun," "An Xian," etc. Even more typical for Chinese place names would be a two syllable *toponym* and a one syllable *classifier*, on the order of: "Mengba Xian," "Fujian Sheng," or "Shuangcheng Xian." Based on these possible syllable length combinations, the minimum number of letters for an intellible match was deemed to be five letters. This will be a practical method for handling Chinese place names until a more reliable means of comparing romanized Chinese place names with their vernacular Chinese characters can be developed. **[35]**

Stripping out all blank spaces was necessary because an auto-generated romanization was used for the Present Location address in the CHGIS source data, and those values contained no spaces between syllables. By stripping out all blank spaces in both source and target strings, even the extreme case of short syllable spellings such as "aicun" resulted in postive matches.

Similarly, a long name such as "Shuangbai Xian" stripped to "shuan" resulted in positive matches.

6. Quantitative Study of Matching Historical place names to Contemporary Gazetteers

When combined with initial filtering based on the Haversine distance, the overall successful matching rates for the algorithm can be summarized in the following table. [Figure 6]

Sample	Total Names	One-way match	Two-way match	Source to Target	Target to Source
France	4164	97%	86%	97%	192%
Yunnan	403	74%	18%	27%	87%

Figure 6: Percentage of matches found with algorithm

As we can see from the France source, even though we know in advance that each name has a corresponding GeoNames ID, the actual match between RFO place name spellings and GeoNames spellings in both directions was only 86%. If we check for only one match, in either direction, we find a 97% match rate. Because matching from source to target is one-to-many relationship, the percentage of matches from target back to source can be higher than 100%; for the France data this figure was 192%. The multiple matches from GeoNames back to RFO names is mostly an indication of ambiguity; more than one matching RFO place name string (within 2km) was found in GeoNames, which is not surprising. Although we have not examined the complete set of place names that failed to match, a small sample were retrieved (based on the known GeoNames ID in the RFO gazetteer), which revealed 80% of the inability to correctly match was due to inconsistent character set encodings of accent marks, and another 20% due to actual difference in place names or variant spellings.

The Yunnan matching results tell a somewhat different story. Not only were there only 74%

one-way matches, but the two way match was dramatically lower, at 18%. This indicates that there were **very few** cases in which the *historical* place name spellings in the source gazetteer were direct matches with the target gazetteer place names. In fact, for the Yunnan data, we find that source to target matches were only 27%, meaning the occurrence of historical place names in the GeoNames Alternative place names field were quite low. By contrast, 87% of the one way matches were found when matching GeoNames to the CHGIS Present Location. This indicates that the match was three times **more** likely to occur when checking in the direction of FROM the contemporary gazetteer TO the historical gazetteer record (as long as the historical gazetteer contains an attestation of the present location), vs. checking FROM the historical gazetteer TO the "alternate" names field of the contemporary gazetteer.

7. Augmented Gazetteers: the Convergence of Historical and Modern Gazetteers

Having examined the preliminary matching results, we can now harvest the actual place names into an augmented gazetteer for public consumption. As mentioned above, there has yet to emerge a "standard" metadata schema for exchange of historical place name data. But thanks to the collective efforts of the Pelagios 3 members, we now have a working version of an RDF interchange format that we can use as a *de facto* standard for the time being.

Here is an example of RDF output for the canonical place name record 腾越厅 using our new Temporal Gazetteer Web Service: [36]

http://chgis.hmdc.harvard.edu/placename/rdf/hvd_115868

@prefix dcterms: <http://purl.org/dc/terms/> .
@prefix pelagios: <http://pelagios.github.io/vocab/terms#> .
@prefix pleiades: <http://pleiades.stoa.org/places/vocab#> .
@prefix geo: <http://www.w3.org/2003/01/geo/wgs84_pos#> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .

```
@prefix skos: <http://www.w3.org/2004/02/skos/core#> .
@prefix foaf: <http://xmlns.com/foaf/0.1/> .
@prefix gn: <http://www.geonames.org/ontology#> .
<http://chgis.hmdc.harvard.edu/placename/hvd_115868> a pelagios:PlaceRecord ;
  dcterms:title "Tengyueting" ;
  dcterms:description "sub-prefecture 厅" ;
  dcterms:temporal "start=1819; end=1911" ;
  gn:countryCode "cn" ;
  pleiades:hasName [ rdfs:label "騰越廳" ] ;
  pleiades:hasName [ rdfs:label "腾越厅" ] ;
  pleiades:hasName [ rdfs:label "Tengyueting" ] ;
  pleiades:hasLocation [ geo:lat "25.02435"^^xsd:double ; geo:long "98.49498"^^xsd:double ] ;
```

Notice that the permanent URI to this gazetteer instance is provided, along with terms drawn from other vocabularies, such as Dublin Core [dcterms] and the Geonames ontology [gn]. For our purposes we can simply add an additional vocabulary to this schema for the actual Geonames IDs, such as: *@prefix gnid: <http://www.geonames.org/#>* and then we can provide an explicit reference to our match in Geonames, for example, *gnid: "http://www.geonames.org/1279891" ;* .

Although the RDF interchange format contains only a subset of the full record, we can easily access the complete listing in several formats by changing the URI segment *rdf* to *xml*, *json*, or *html*. and there find the canonical record for each place name and its spellings, including definitions for written language, transcription system, source notes, historical jurisdictions, and so on. See, for example: http://chgis.hmdc.harvard.edu/placename/json/hvd_115868

In the future, we plan to extend the augmentation of gazetteer entries with links to other potentially useful cross-references, such as DBPedia pages, or their Chinese language equivalents such as Baidu pages.[37]

In conclusion, we find that the use of "alternate names" in the current gazetteer authorities are not well suited to matching of historical place names. On the other hand, there is much higher degree of reliability in matching on place names obtained from reverse geocoding, whenever an attestation of "present location" is provided in the historical gazetteer. Based on these findings, our recommendation is augment the historical gazetteers with explicit links to their contemporary locations using permanent identifiers (such as GeoNames IDs), and persistent URIs. In this way, the augmented historical gazetteers functionality is extended to provide programmatic methods for retrieval of both historical and contemporary location-based information. As a means of bootstrapping historical place names into the realm of LinkedOpenData, the potential use cases for historical gazetteer resources will be expanded, and also make it possible for practical tests of the next wave of gazetteer research: Geo-Temporal Information Retrieval.

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