SKETCHOGRAPHY - AUTOMATIC GRADING OF MAP SKETCHES FOR GEOGRAPHY EDUCATION

A Thesis

by

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ABSTRACT

Geography is a vital classroom subject that teaches students about the physical features of the planet we live on. Despite the importance of geographic knowledge, almost 75% of 8th graders scored below proficient in geography on the 2014 National Assessment of Educational Progress. Sketchography is a pen-based intelligent tutoring system that provides real-time feedback to students learning the locations, directions, and topography of rivers around the world. Sketchography uses sketch recognition and artificial intelligence to understand the user's sketched intentions. As sketches are inherently messy, and even the most expert geographer will draw only a close approximation of the river's flow, data has been gathered from both novice and expert sketchers. This data, in combination with professors' grading rubrics and statistically driving AI-algorithms, provide real-time automatic grading that is similar to a human grader's score. Results show the system to be 94.64% accurate compared to human grading.

DEDICATION

To my parents and grandparents for making me understand the importance and value of education, and to my friends who stood by me through thick and thin.

ACKNOWLEDGMENTS

I would like to sincerely express my gratitude to all the people who helped me in the process of completing this thesis. I am especially thankful my advisor, Dr. Tracy Hammond for her constant support and guidance, and inspiring me with her passion for research and excellence. I would also like to thank Dr. Daniel Goldberg and Dr. Erik Prout, whose expertise gave direction to my efforts, particularly in conceptualizing the pedagogical ideas that got implemented in Sketchography.

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All other work conducted for the thesis was completed by the student independently.

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1. INTRODUCTION

Geography is an essential part of modern education and cartography is a cornerstone of geography. The importance of geography education and the need for research and innovation in the same highlighted to the federal and state governments in the United States. The Geography Education Research report which was part of the efforts led to the national geography organizations such as the National Geographic Society and the National Council for Geographic Education coming together to create the *Road Map for 21st Century Geography Education Project* which provided recommendations for geography pedagogy [2].

1.1 Benefits of sketching for geography education

Maps are the visual encoding of the information we gather about the earth. Besides questions requiring descriptive answers for explaining various atmospheric and earth's physical phenomena, labeling of geographical features already drawn on maps is another common way the knowledge of geography is tested. Learning with maps involves building spatial thinking and cognition. Instructors convey important concepts and features of various entities through different maps while the students also develop reasoning skills comprehending the same [3, 4, 5]. Unlike biology, the case for sketching by students for geography education has not yet been made. While sketching is commonly used in problem-solving and creative processes for illustrating ideas [6], it also aids in developing problem-solving [7] and analytical skills [8]. A good grasp of geography demands three-dimensional spatial recognition ability which can be improved with sketching [9].

1.2 The need for a new interface and technology for education

Digital media and devices are ubiquitous in today's world and children exposed to the same from an early age which has lead to great possibilities with their reach and ease of use. However, the in-place on-line tutoring videos and multiple choice question answering do not cover the entire spectrum of what students need to be involved in so as to be trained in various disciplines. An interactive application would help students learn many things on their own e.g. learning to draw the Rio Grande river on a map with political boundaries, students would realize that it lies along the US-Mexico border and the experience of drawing the same imbibes the knowledge in a more intimate way than just visual memory. Also, as class size increases, students are deprived of one-on-one time with instructors and consequently receive less feedback which is essential for improvement. The instructors also get less time for preparing for classes and other activities such as grading, answering questions become prolonged. This state of affairs provided us with a clear motivation to build Sketchography, an intelligent sketching based tutoring system for geography, with a web interface which allows students to sketch geographical features on maps and obtain on-demand feedback and assessment.

1.3 Benefits of feedback

Feedback is crucial to gauge the progress while learning something. Confirmation of the right steps reinforces the concepts well understood and knowing the missteps also points a learner in the right direction. Immediate feedback was identified as being imperative to an ideal experience while engaging in web-based activities by Chen et al. [10]. Feedback without a wait time can keep a user motivated and hence, gain knowledge and develop skills at a faster pace than when the learning process halts for lack of an instructor being immediately available. Artificial intelligence algorithms can fill in the shoes of instructors by providing immediate feedback when students practice to test their comprehension of the subject material.

1.4 AI, machine learning for improved grading

Machine Learning algorithms are now widely deployed and powering commonly used applications such as recommendation systems on shopping websites to speech recognition in voice-controlled assistants such as Apple's Siri [11] and Amazon's Alexa. Artificial Intelligence techniques can learn as well as discover new features of systems from adequate datasets [12]. For this thesis research work, we planned to utilize artificial intelligence to realize automatic grading of sketches in Sketchography which would involve discovering and validating features which essentially distinguish sketches of geographical entities which instructors would deem to be correct. Aligning the results with the input of the experts, this would also involve finding the relative importance of each feature in determining the correctness of a sketch.

2. RELATED WORK

2.1 Sketch recognition

Sketch recognition can be broadly summarized under three classes, namely Gesture-based, Geometry-based, and Vision-based. Gesture-based algorithms [13, 14, 15] such as the $ family algorithms are powerful discriminators for gestures independent of affine transformations. However, one can perform the same gesture on a map in multiple strokes, directions, sizes and locations, thus making it impossible to model geographical features as gestures. Geometry-based algorithms [16] such as PaleoSketch [17, 18, 19], Tahuti [20], and Ladder [21, 22, 23, 24, 25, 26, 27, 28, 29, 30] are used as low-level recognizers to detect primitive shapes in strokes. Alvarado and Davis, in their paper SketchRead [31], describe a domain independent recognition engine that uses dynamic Bayesian nets to interpret strokes based on a set of defined patterns and constraints. However, this approach requires a user to define a high level language to describe the symbols in the domain. This method is helpful for domains such as circuit diagrams where a set of standard shapes can be defined based on relationships between strokes. While these are powerful for regular shapes, our domain has little scope for regularity. Curvature graphs [32, 33] and corner finding algorithms [34, 35, 36, 37] provide an interesting way of analysing the k-largest curvature changes in a template against those in the sketch. However, the need to merge multiple strokes and explicitly define stroke segments makes this approach too complex for our context since the sketch has to be represented as a point cloud rather than as temporally ordered strokes. Vision-based algorithms [38, 39, 40, 41] focus on the visual appearance of the image rather than its geometric features. These were found to be useful in our context.

2.2 Sketching in education

The use of touch interfaces in education has also been vastly studied to develop Sketch-based Intelligent Tutoring systems (ITS). Mechanix [42, 43, 42, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57] is an automated system which has been adopted by physics teachers for setting interactive assignments in solid dynamics and mechanics. Mathpad [58] is useful for recognizing mathematical equations, which is helpful since sketching is pervasive in mathematics [59]. Feng *et al.* [60] have built a system that can recognize electrical circuit symbols. Several systems have provided sketched-based input to enhance foreign language learning [61, 62, 63, 64, 65, 66, 67, 68], drawing skills [69, 70, 71, 72, 73, 74], biology [75], music [76, 77], and even children development [78, 79, 80, 81, 82, 83].

CogSketch [84] with its Sketch Worksheets [85] model allows teachers to create domain specific worksheets for students to complete, and analyses the assignments using spatial sparsity, and does not automatically evaluate the solutions. The design of CogSketch is generalizable but equally hinders the use of available datasets because they have to be recoded as per CogSketch's encoding strategy. We have focused on geography education and not aimed at evaluating the cognition using parameters such as pauses, etc. CogSketch revolves around the understanding spatial phenomena but in case of maps, other aspects such as direction, shape, etc. can also be critical. We have to take inspiration from CogSketch on how students could demonstrate their understanding of causal and relationship information. The application of sketch recognition algorithms to the geography domain however, is novel and has not been attempted before. While many GIS applications as well as third party tools provide a rich drawing toolkit to doodle on maps, none of them have a recognition engine that can understand a user's gestures on a map beyond the conventional ones for zooming and panning. Additional systems have been created for children to help them learn state geography [86].

2.3 Sketching in GIS

Godwin et al. [87] describes a visualization tool used by the Atlanta police department for making queries by drawing paths and boxes on a map, which does not use any recognition component beyond superimposing pre-defined data points against a drawn path. Drawing on paper maps has also been studied [88] , where a digital pen is used to get coordinates of symbols drawn on a map and then transmit them to a database. Geographical mining [89] has also been subject to a huge body of work, which is a possible extension of our approach. Substantial progress in this direction has also been made by Hammond et al.[90, 91] in their work for recognizing free hand course of action diagrams. They make use of a primitive shape recognizer [17] combined with a high level heuristic and statistical-based recognizer [92] to return the top interpretations of symbols and characters drawn on a map. However, this approach operates on a canvas over a regular map, and does not explore the possibility of integrating the symbol information with GIS data.

3. RIVER SKETCHING

3.1 Traditional pedagogy

For education systems across the world, a major challenge is to improve the geographic knowledge of students. In most schools, students are evaluated based on multiple choice questions on a labelled map (Figure 3.1) which tends to drastically confine the conceptual understanding to a mere mental image of the features.

3.2 Why river sketching makes sense

On the other hand, freehand sketching encourages learners to apply their knowledge and intuition by dynamically constructing visual perspective of the geographic features, resulting in a highly involved process of *learning by doing*. More importantly, the interactive process helps students to appreciate subtle and peripheral aspects of a feature, such as the countries that have common borders or the drainage patterns of certain rivers (eg. the Euphrates river flows from the Syrian border right thorough Iraq). The responsibility of the our system is to recognize the user's intent by extracting a set of shape descriptors from the user's sketch, and validate it against some pre-defined knowledge about the geographical feature using a reasonable notion of 'correctness', along with providing interactive feedback.

3.3 Google Maps JavaScript API

Google Maps has a rich JavaScript API which provides drawing tools as well as utility methods for various functions such as knowing if a points lies within an area defined with latitude and longitude coordinates. Google Maps has also become ubiquitous and hence, provided a great option to develop Sketchography as most users would be familiar with its look and feel, as well as its usage.

Figure 3.1: The conventional method of teaching maps, where students are asked to label already drawn features. [1]

4. SKETCHOGRAPHY

"Sketchography", an intelligent tutoring system for geography with automatic grading capability, was conceptualized by Dr. Tracy Hammond. Dr. Hammond, had worked on similar systems for areas such as mechanics and course-of-action diagrams. I, along with two other students developed the initial prototype as a web application. The prototype provided the users a choice of seven rivers to draw on to a Google Map. The users can draw a river and check their accuracy on the submission while also having the option of seeing the solution i.e. the exact sketch of the chosen river. The accuracy was determined by an empirically derived formula which assigns different weights to the scores calculated by various sketch recognition algorithms. This thesis aimed to develop a more accurate and robust means of assessment driven by a sketch grading algorithm which incorporates the general and unique features of rivers that illustrate the knowledge and understanding of various geographical concepts.

The current implementation of our system focuses on rivers, helping students learn to identify and draw them based on visual appearance. The following two factors define the visual appearance of a river:

1. **Shape**: This primarily refers to the visual appearance of the feature. More specifically, it refers to the relative position of each point to every other point in an image. Such shape descriptors can be used to gauge the visual similarity between two objects.

2. **Location**: The location information is available through the latitude-longitude information of a sketch and can directly be compared.

We employ a recognition method that exploits these two distinctive features, by combining two techniques, namely shape context [41, 93] and Hausdorff distance [38, 39]. Prior to this, we examine the option of flagging incorrect sketches early, by preprocessing the candidate sketch using metrics including bounding box, and path length.

When building a sketch recognition system in this domain, it is also important to consider some of the common constraints, especially in regard to accommodating the trade-off between user's drawing freedom and ease of recognition. This system, in particular, requires that the students get complete freedom to reproduce the mental map in mind. The challenges in building such a robust recognizer are therefore manifold.

- Unlike regular sketches which are drawn in an iterative improvement manner [18], we don't expect rivers to be drawn using touch-up strokes. However, there would be continuation strokes as river can be long and have converging or diverging branches. The recognition therefore has to be stroke-independent.

- The system needs to be receptive even towards poor and messy sketches, as long as the essential aspects of a feature are sufficiently captured.

- The sampling rate is heavily dependant on the input device used, and is influenced by the zoom level of the map while sketching.

- Sketches need to be stored as strokes in the geographic coordinate system. However, we do not need to use geodesic distance as we consider 2D maps.

- Geographical features are extremely irregular , and the resulting sketches will vary greatly with drawing style. In fact, there is little uniformity even within the same class of physical features.

The remainder of this section details the three main stages of our system and its algorithms, as shaped according to our goals and recognized constraints.

4.1 User interaction

The system consists of a UI which allows the user to select a river, draw the river, and get the similarity between the actual river information (shape, size, and location) and the drawn river. Comparison with the original river is made possible with a data set of rivers. The details of the UI and data set are provided in the following sections.

4.1.1 Data set

Natural Earth [94] is an open source community funded by some of the leading cartographical research institutions, and hosts a vast pool of map data that is free to use.[1] For this application, we use the `Lake Centerlines and Rivers` data set that contains the information for over a 1000 rivers worldwide. This data is generally in shapefile format which is directly usable on the Google Maps professional version but not the free one. It is, therefore, first converted using Quantum GIS to an array of strokes, where each stroke is represented by an array of points. A lot of the data is also hosted on Google Fusion Tables [95], which is used for gathering, visualizing and sharing data. This data is in SVG(Scalable Vector Graphics) and KML format, thus making conversion easier. We converted the final strokes for all the rivers to an internal representation of strokes.

4.1.2 UI design

The user interface is built using AJAX, PHP, jQuery [96], and the Google Maps API [97], with styling controls to define map appearance, behavior, and its event model. First, the user has to select a geographical feature from the list of known features, following which the template for the choice made gets loaded from the database. Once the user starts sketching, stroke points start getting generated as the pen is moved, depending on the sampling rate of the device. If the user lifts the pen, a new stroke is recorded and appended

[1] The complete data set of all physical features including reefs, coasts, geographic lines and glaciers can be obtained at http://www.naturalearthdata.com/downloads/10m-physical-vectors/

to the list of strokes for the session. The user also has an option to clear the sketch and restart his drawing. For practicing by tracing, an option called "Show Solution" is also provided in the "Learn" mode of the system, to serve as a memory aid for the user before he or she attempts to sketch in the "Test" mode. Finally, on submitting of an attempt by a user for evaluation, their sketch is compared with the template, and the automatic grading results presented on overlay screen.

4.2 Preprocessing

Preprocessing can help reduce the computation to a large extent by identifying grossly incorrect attempts as early as possible. Although currently, our system does not require high computation power, preprocessing would certainly be beneficial as our system evolves to incorporate more sophisticated calculations to improve accuracy. However, we would also explore in future, broader studies whether students would still prefer to see their breakdown of the scores in such cases. The following cases can arise when the student draws a river. Figure 4.5 shows a few examples of these cases.

- The total stroke length of the candidate stroke varies drastically from that of the template stroke
- The candidate is drawn nowhere close to the template, *i.e* there is a little or no overlap between their bounding boxes.

In the first case, the candidate gets removed from consideration based on the difference in stroke length. The system computes the total stroke length or path length by summing the Euclidean distances between every pair of consecutive stroke points.

$$d = \|TotalStrokeLength_{candidate} - TotalStrokeLength_{template}\|$$

The sketch will be flagged as being incorrect if $d \leq 0.5 \times TotalStrokeLength_{template}$.

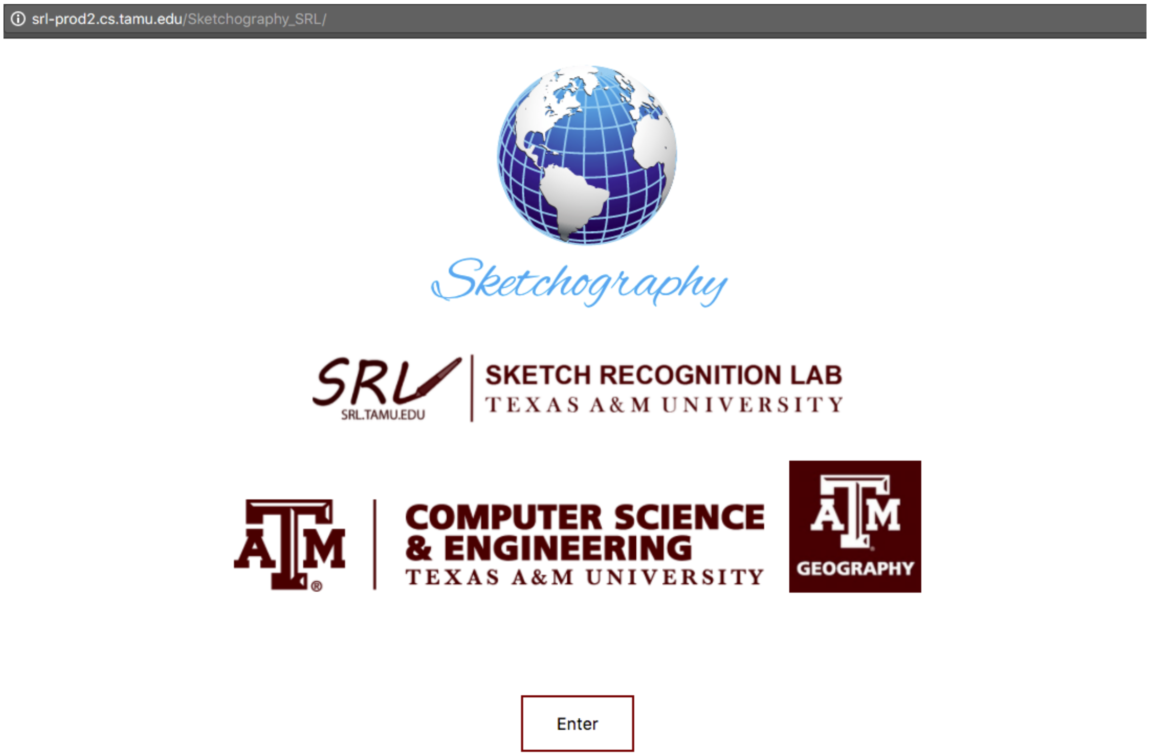

Figure 4.1: Sketchography home screen

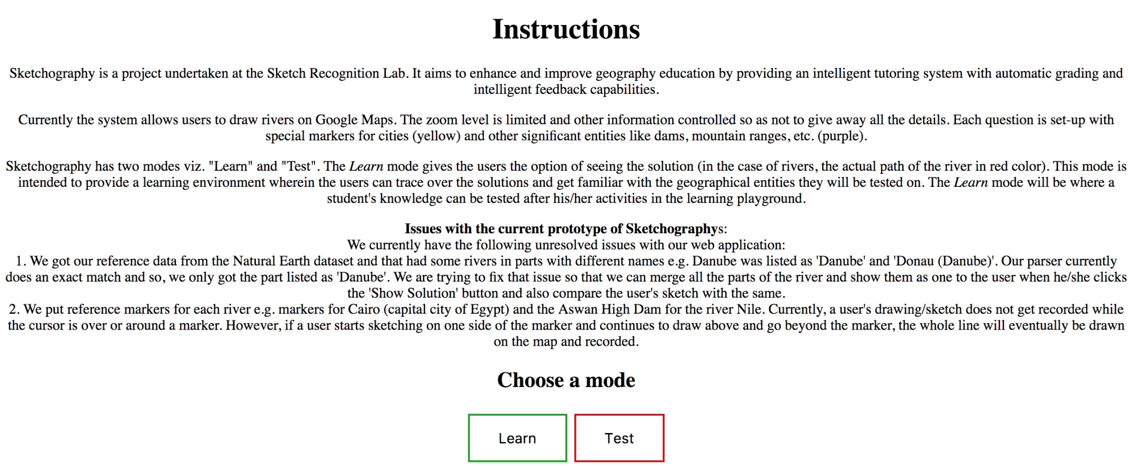

Figure 4.2: Sketchography instructions

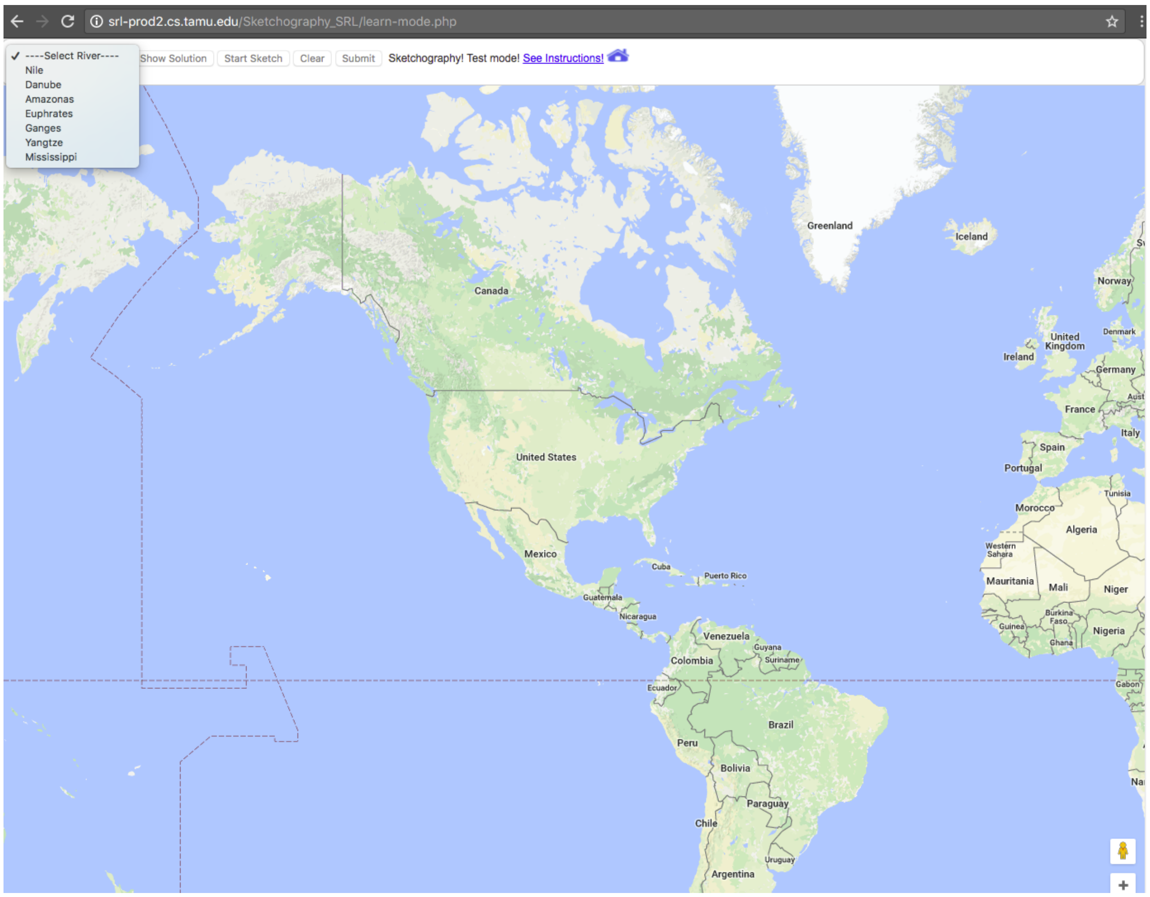

Figure 4.3: Sketchography - choosing a river in 'Learn' mode

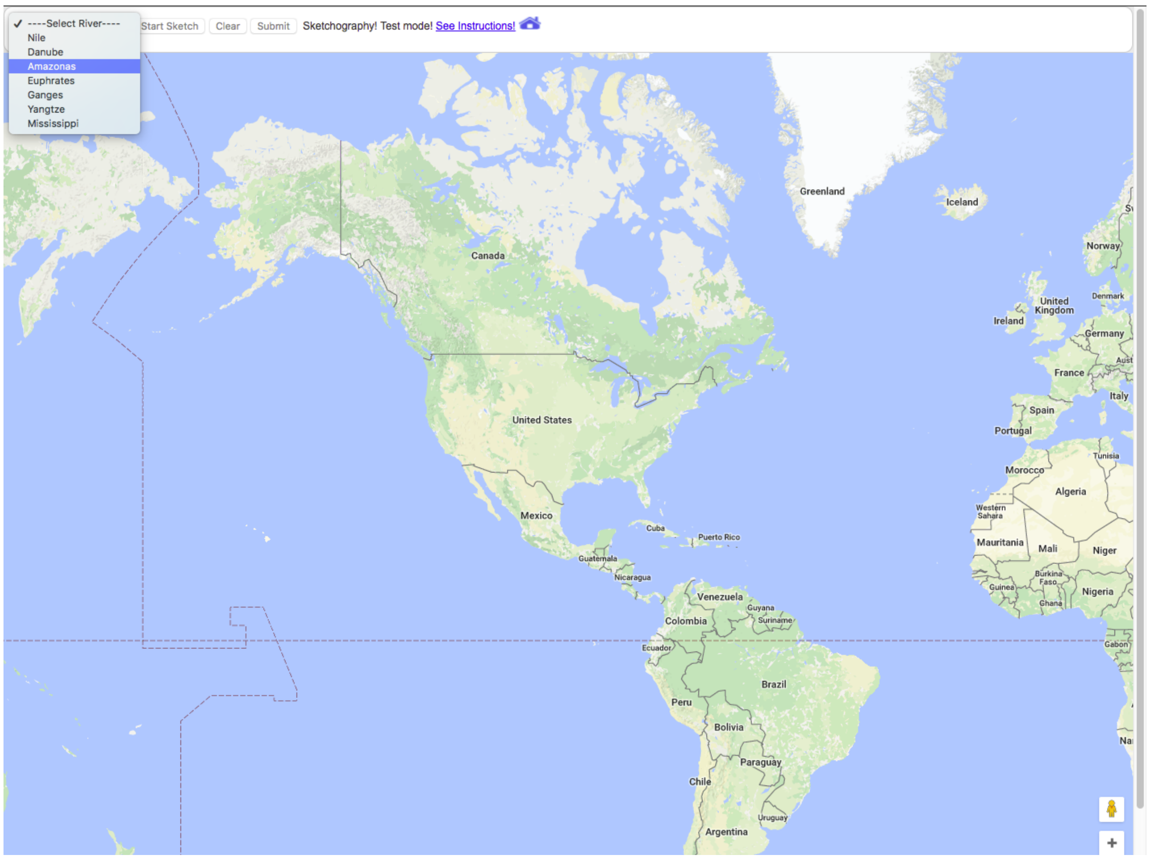

Figure 4.4: Sketchography - choosing a river in 'Test' mode ('Show Solution' option hidden)

Figure 4.5: The figures on the top show possible stroke length errors. Bounding box errors are shown in the two figures on the bottom (the template is shown in red, and the user's drawing in blue)

This ensures that the template stroke is not smaller than half of the stroke length of the template and not larger than 1.5 times of the stroke length of the template.

In the second case, the candidate sketch is marked as being wrong if the percentage of the points of the candidate stroke in the bounding box of the template is less than 10%, *i.e.*, if the sketch is too far from the template.

4.3 Recognition

Vision-based approaches are suitable for recognizing shapes that are irregular, and they primarily try to find the intra-point and inter-point relationships, given two images.

4.3.1 Shape similarity using shape context

The Shape Context algorithm proposed by Belongnie, Malik, and Puzicha [41, 93] gives a measure of similarity between shapes. It tries to find which point in one shape corresponds to which point in another one with the use of a descriptor named 'shape context' which gets calculated for each point. The shape context for a point in a shape gives an indication of how the remaining points in the shape are distributed relative to it. An aligning transform is estimated using the agreement between the shape contexts. The matching errors between the points on the two shapes viz. the template and the attempt of the user are summed and combined with the magnitude of the aligning transform to give the dissimilarity between those two shapes.

For each point on the shape, a coarse histogram of the relative coordinates of the remaining points is computed by taking the vector distance of the point with respect to all other points. The histogram is defined to be the shape context of p(i). Bins that are uniform in log-polar space are used (similar to the Bullseye features diagram), resulting in shape context being affected by the positions of nearby sample points rather than away ones. Chi-square test statistic is used to get a measure of the cost of matching two points. After getting the set of costs between all pairs of points on the two shapes, bipartite graph match-

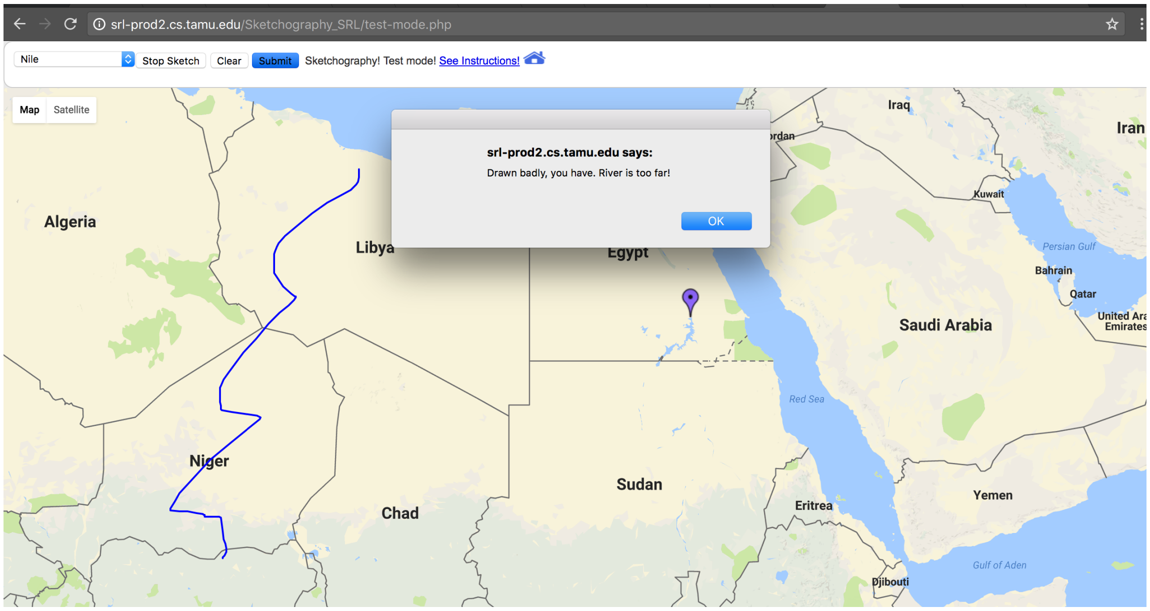

Figure 4.6: Sketchography - river drawn too far

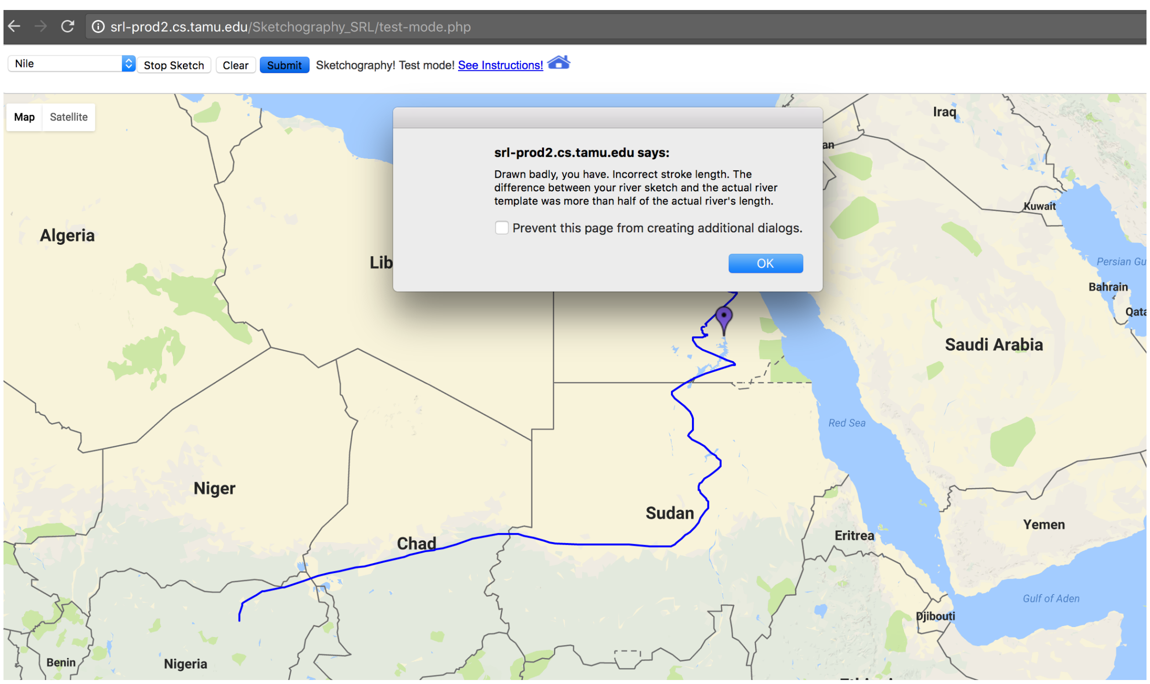

Figure 4.7: Sketchography - river drawn too long

Figure 4.8: Case 1 - the wrong shape in the wrong place

Figure 4.9: Case 2 - the wrong shape in the right place

Figure 4.10: Case 3 - the right shape in the wrong place

Figure 4.11: Case 4 - the right shape in the right place

ing is done to minimize the total cost of matching, *i.e.* we need to find the permutation of the points of the second shape such that the matching has minimum cost.

The sketched input is in the form of an array of points with stroke identifiers. The Shape Context method is used for object recognition, and hence stroke information is not needed. We use a helper method to convert our input data into the SVG format to pass onto the method which gives a similarity measure based on the Shape Context method.

4.3.2 Location similarity using Hausdorff distance

The location similarity is an important aspect for sketches drawn on maps. If the shapes are similar, but the location is incorrect, it will result in a low similarity ratio. The Hausdorff distance measure is used to find the similarity with respect to distance. In this paper, we have used a modified version of Hausdorff distance. For calculating the Hausdorff distance, we calculate two distance vectors D_A and D_B such that

$$D_A = \min_{b \in P_B} |a - b|, a \in P_A$$

where P_A is a vector of the points in A and P_B is a vector of points in B. Similar to D_A, D_B is calculated. The Hausdorff distance is the maximum value from the average of D_A and D_B. The modification of the original Hausdorff method is that it uses the average of the minimum values to find h(A,B), rather than taking the maximum. The reason to use the modified version of Hausdorff is to avoid large h(A,B) or h(B,A) value caused due to a small number of outliers. By taking average we make sure that the distance from all the points, *i.e.* all the values in D_A and D_B are contributing to h(A,B) and h(B,A) respectively.

$$h(A, B) = \frac{\sum(D_A)}{N_A}$$

where N_A is the number of points in A, defines the distance h(A,B). We calculate h(B,A) similarly using D_B. The Hausdorff distance H(A,B) is the maximum value from h(A,B) and h(B,A). The maximum is taken so as to take into consideration the difference in stroke length of the candidate and the template.

We restricted the Hausdorff distance to a high of 10 while finding the similarity. If the Hausdorff distance value is more than 10, we consider it to have zero similarity with respect to location. This similarity is measured as:

$$similarity_{Hausdorff} = 1 - H(A,B)/10$$

4.3.3 Stroke length ratio

The stroke length also is an important feature while we consider similarity between two sketches. To take this into consideration, we take into account the ratio of the difference in stroke lengths to the total stroke length of the template. The following gives the similarity measure based on stroke length:

$$similarity_{strokeLength} = 1 - \frac{d}{TotalStrokeLength_{template}}$$

4.3.4 Bounding polygon

Based on the graded (labelled) river sketches, we can estimate a polygon shape which bounds the sketches which were graded as being correct. There would be other factors which the instructors would look for, but this bounding area should be a strong indicator of the correctness of a sketch if the majority of the points lie within it.

4.3.5 Unique features

The instructors teaching geography teach important features unique for rivers such as the countries a river is located in, the direction of the flow, distribution at important deltas, etc. A river drawn into a country where the actual river doesn't flow would lead to the sketch being graded as incorrect even though other features would give it a high score (e.g., the Mississippi river flows entirely in the United States).

5. GRADING RUBRIC

To simulate the grading process, we consulted Dr. Erik Prout, who teaches the Introductory Geography course at Texas A&M University, to gather a grading rubric as well as information on any setup that should ought to be done for each river. Dr. Prout envisaged an intelligent tutoring system which would help students to learn about rivers and also serve as an automated evaluation system to test the knowledge and comprehension of the students. Dr. Prout's feedback resulted in the formulation of the following criteria for Sketchography.

5.1 Question set-up and grading rubric for grading the sketches of the 7 rivers in Sketchography

5.1.1 Weight or importance for each feature

Table 5.1 contains the information regarding the weight assigned by Dr. Prout for the main aspects of a river.

Feature	**Percentage**
Origin point/area	25%
Course (shape)	25%
End point	50%

Table 5.1: Weight or importance for each feature

5.1.2 General criteria such as deviation allowed or approximate origin location

Table 5.2 contains the information regarding the general criteria that Dr. Prout thought should dictate the grading of a river sketch.

Feature	Criteria
Origin	general area (mountain range and/or country if different from course/end)
Course/shape	must follow terrain/contour when its visual on map; very close to places along
End point	specific point at Ocean or (arc of) delta; must be in correct country

Table 5.2: General criteria such as deviation allowed or approximate origin location

5.1.3 Set-up (things to be shown such as state borders, terrain, etc. and custom lines, labels, etc.) and unique features for each river (countries through which the river passes, direction of flow, etc.)

Table 5.3 contains the information explaining what references should be available to a students in order to remember the location of a river.

River	Setup
All	terrain layer should be on; students can switch between satellite image and reference map
Nile	Political borders, Cairo, Mediterranean Sea, Aswan High Dam
Danube	Political borders, capital cities along river (Vienna, Budapest, Belgrade, etc.), Black Sea
Amazonas	Political borders (Brazil/Peru), Andes, cities (Iquitos, Manaus)
Euphrates	Political borders (Iraq, Syria, Turkey), Persian Gulf
Ganges	Political borders (India, Bangladesh), regional Indian borders, Bay of Bengal
Yangtze	Regional Chinese borders, cities (Shanghai, etc.), Sichuan basin, Plateau of Tibet, Three Gorges dam
Mississippi	US regional borders (states), cities (along the river: Minneapolis, St. Louis, Memphis, New Orleans), Gulf of Mexico

Table 5.3: Setup instructions

5.2 Data collection

To train machine learning classifiers, we had to prepare a dataset with good as well as bad sketches. To ensure the same, we asked study participants to draw a river thrice in the following sequence i.e. Test, Learn, and Test. The first sketch for each river in the Test mode made without looking at the solution template was meant to produce the most examples of bad sketches. On the other hand, the second one in the Learn mode with option of seeing the actual river sketch and tracing over the same available to the user was expected to yield the most number of good examples.

The exceedingly poor sketches got eliminated by preprocessing, and we noted the scores for each feature for the remaining sketches while also grading the same using Dr. Prout's rubric. Dr. Prout verified the grading of the river sketches. This process resulted in a labeled dataset.

5.3 Classification

Weka [98, 99, 100], an open-source machine learning tool, was used to perform the following:

1. To test if the features can distinguish between correctly and badly drawn rivers: Table 5.4 shows the results of Random Forest classification [101] (10-fold cross-validation [102, 103]) on the labeled dataset.

Accuracy	Precision	Recall	F-measure
94.64%	0.947	0.946	0.946

Table 5.4: Results of random forest classification

2. To obtain a final score for the course of the river, the feature weights were determined using gain ratio analysis. Gain Ratio is calculated using multi-fold (k=10) cross-

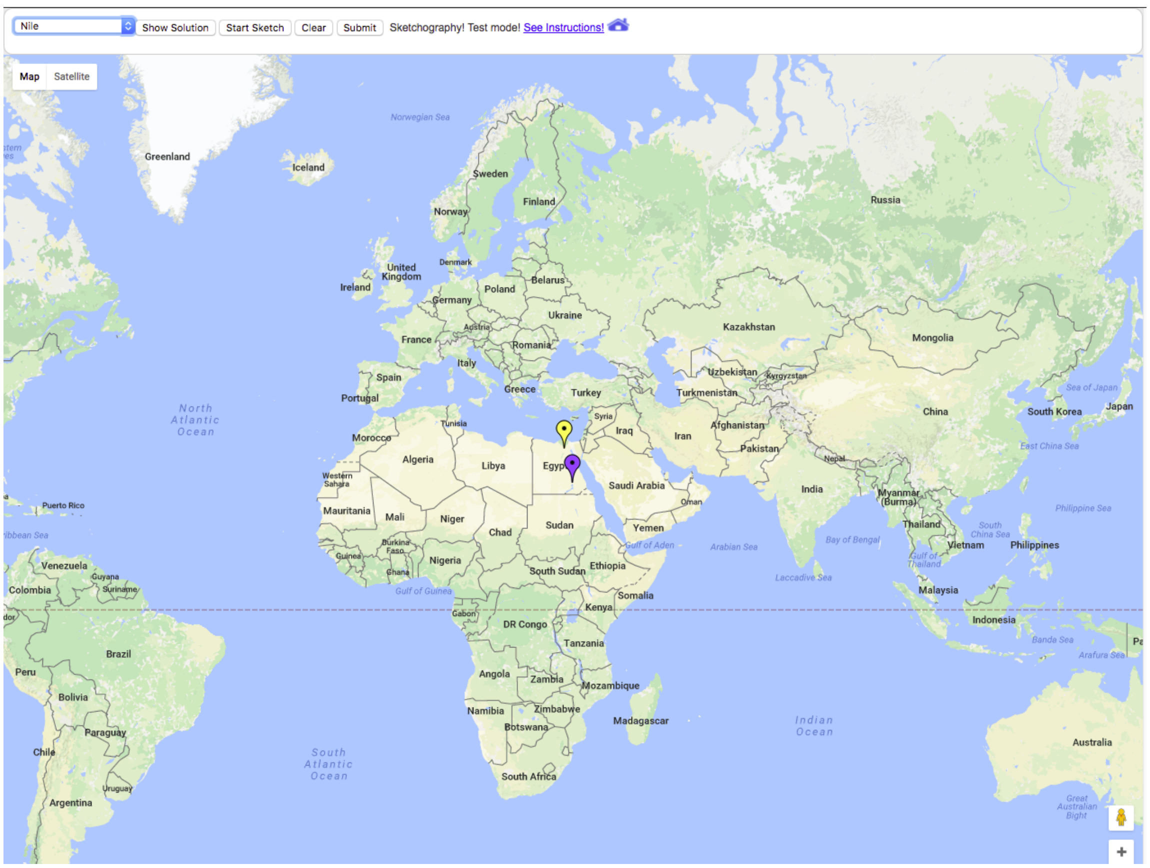

Figure 5.1: Sketchography - after choosing Nile

validation where the set is divided into k sets randomly, and one set is used for testing every time. The process is repeated k times.

Feature	**Weight**
Modified Hausdorff's Distance	4/14
Ratio of points inside the bounding polygon	4/14
Stroke Length Offset	3/14
Shape Context Score	3/14

Table 5.5: Feature weights for grading

5.4 Automatic grading

Based on the feature weights, the total score for the course of the river is calculated according to the following formula (See also Table 5.5.):

Total score for the course of a river sketch = (Modified Hausdorff's Distance score * 4/14 + Ratio of points inside the bounding polygon * 4/14 + Stroke Length Offset * 3/14 + Shape Context Score * 3/14) * 100.

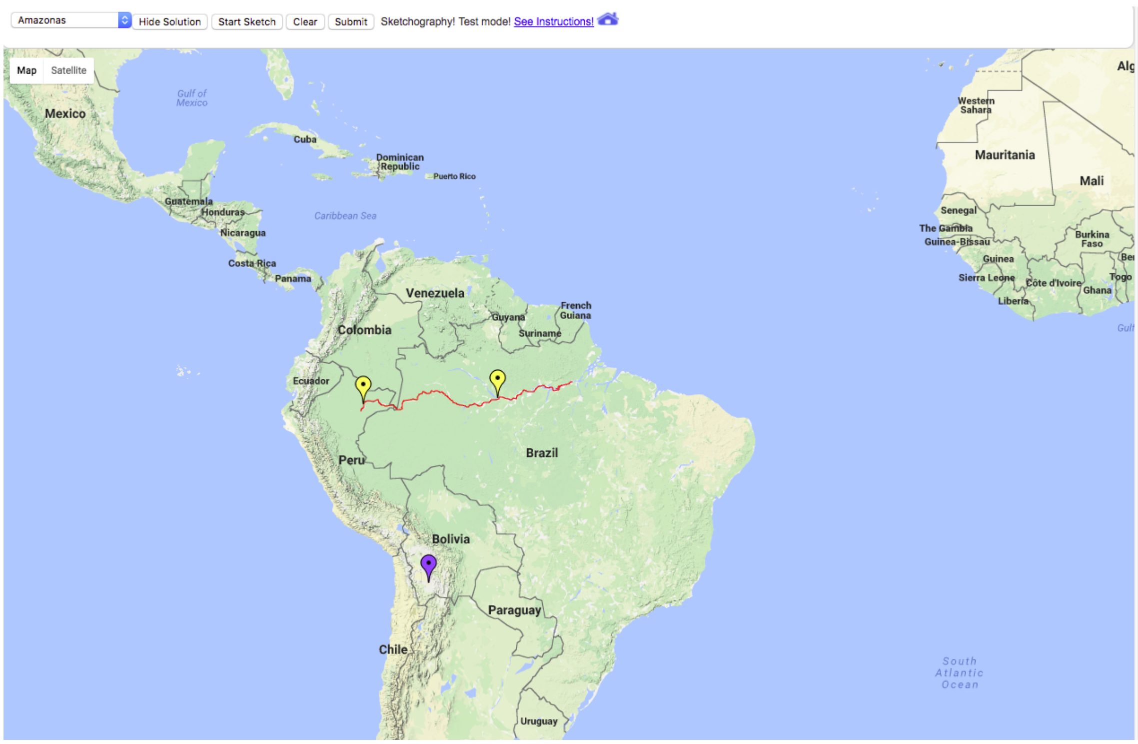

Figure 5.2: Sketchography - solution shown for Amazonas

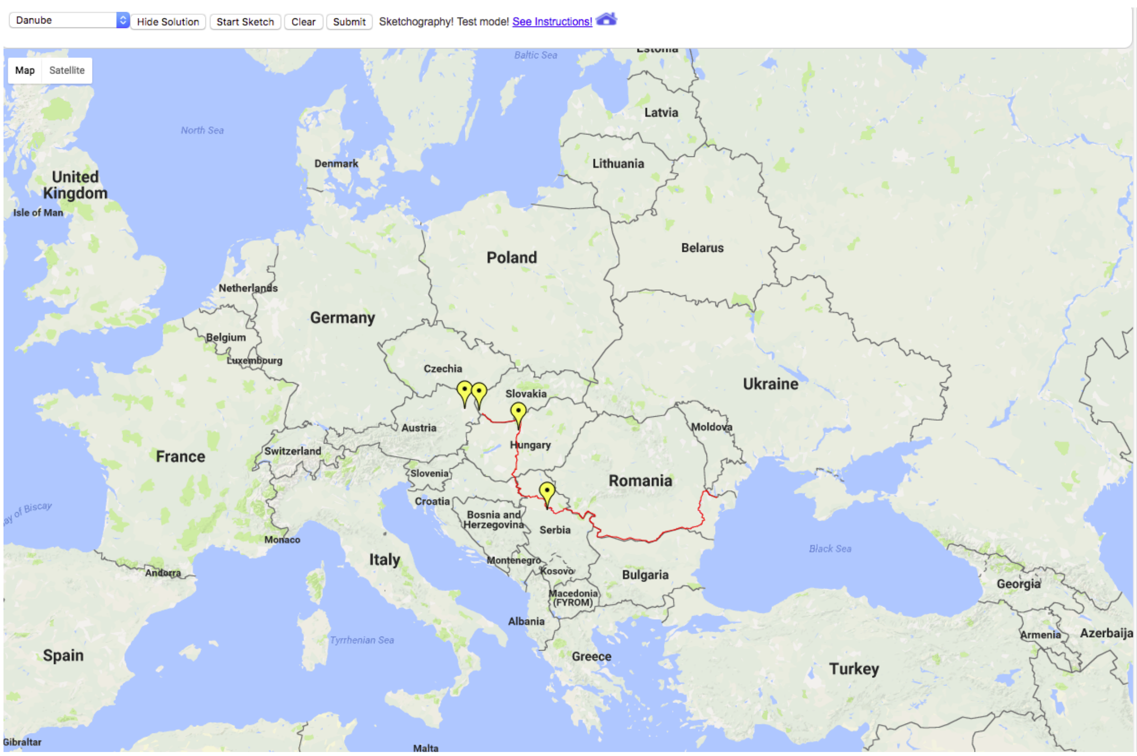

Figure 5.3: Sketchography - solution shown for Danube

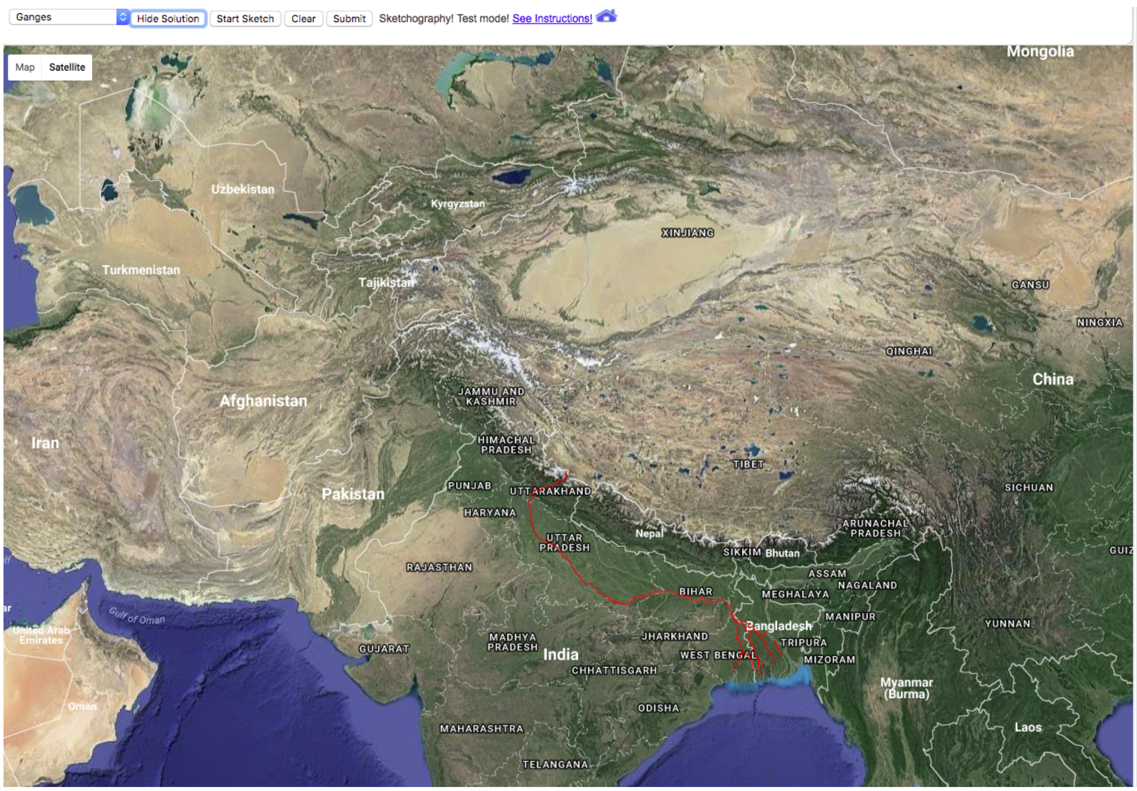

Figure 5.4: Sketchography - solution shown for Ganges in satellite mode of Google Maps

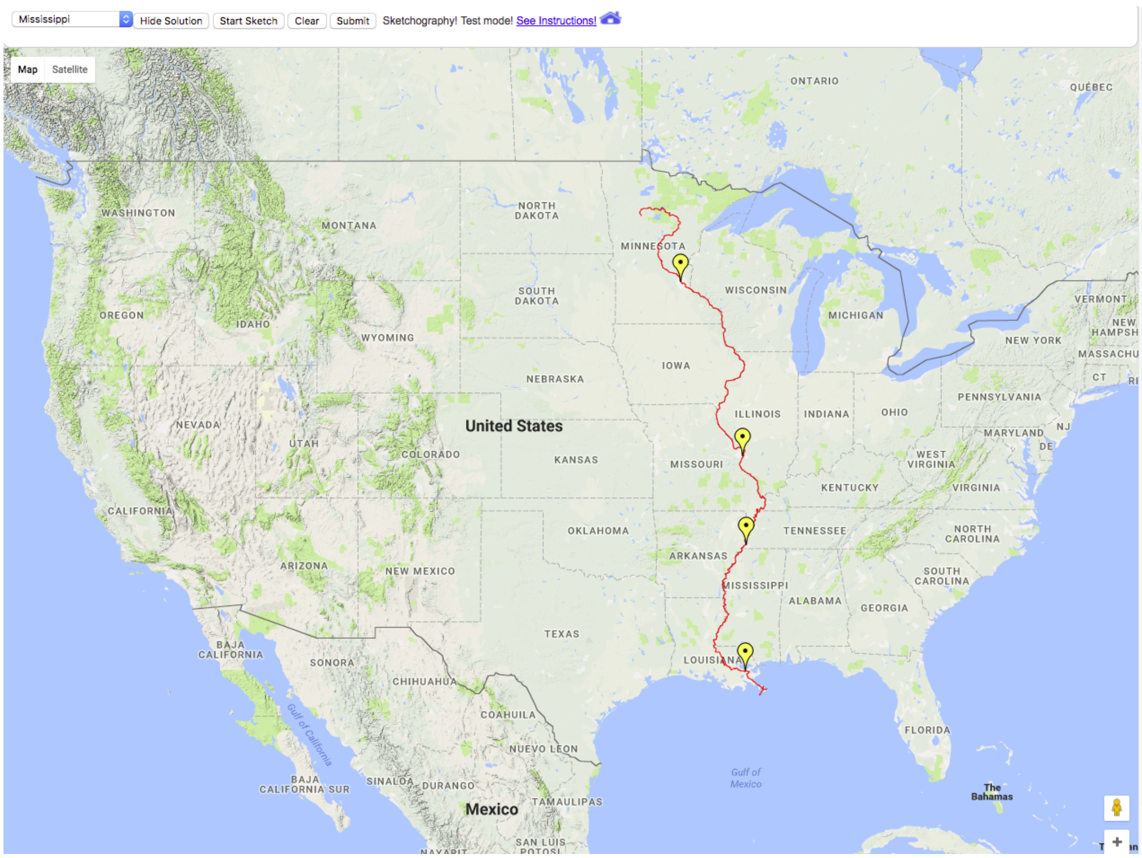

Figure 5.5: Sketchography - solution shown for Mississippi

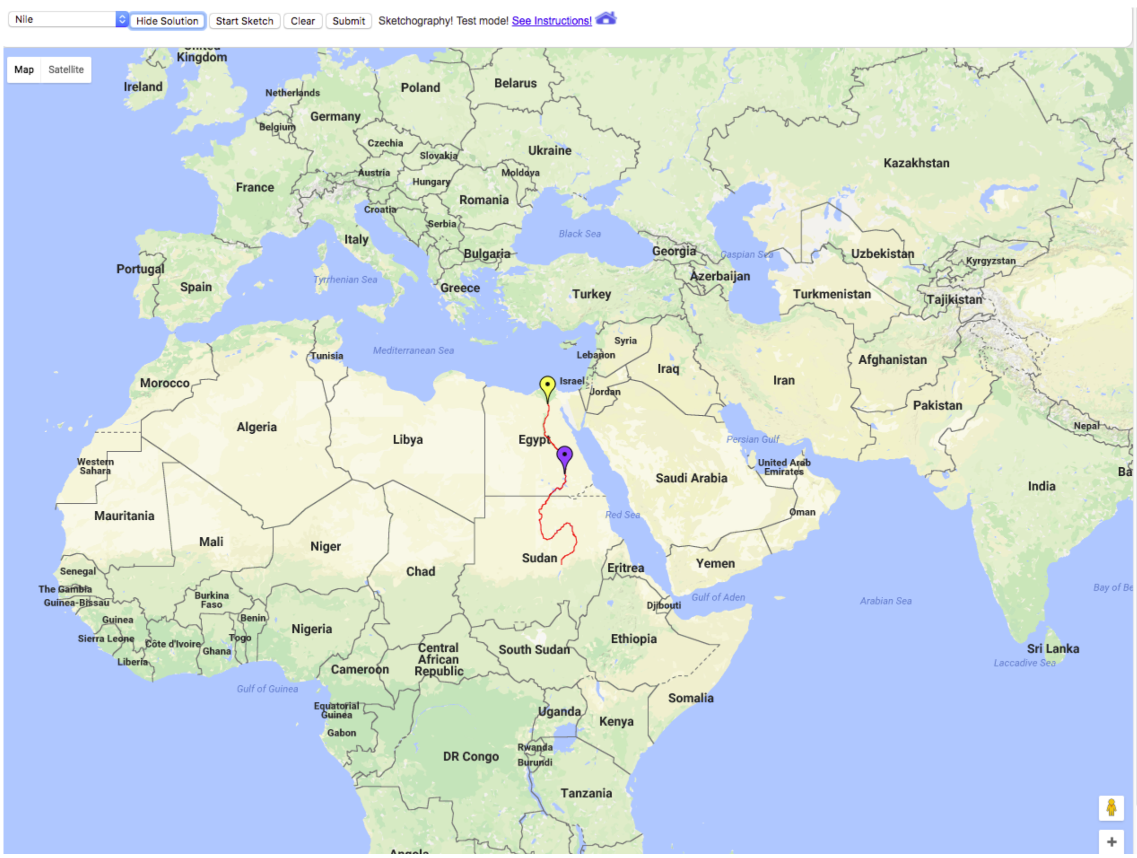

Figure 5.6: Sketchography - solution shown for Nile

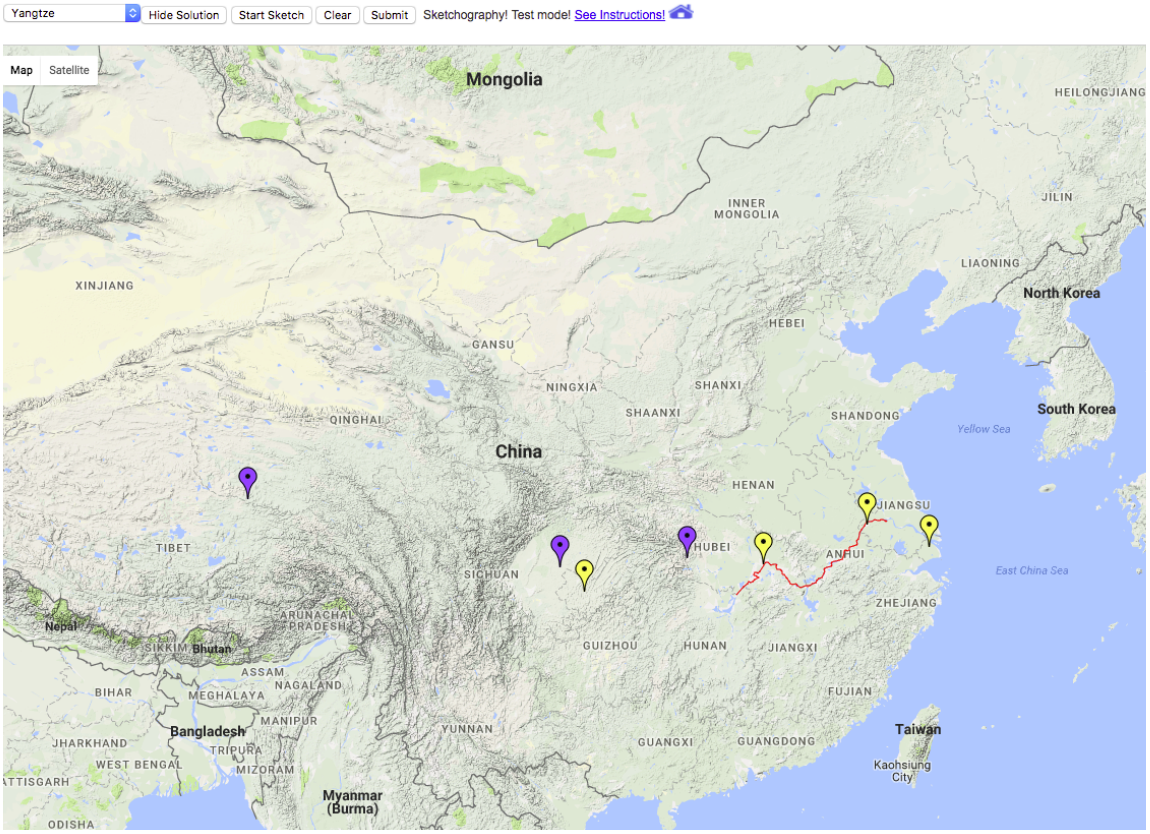

Figure 5.7: Sketchography - solution shown for Yangtze

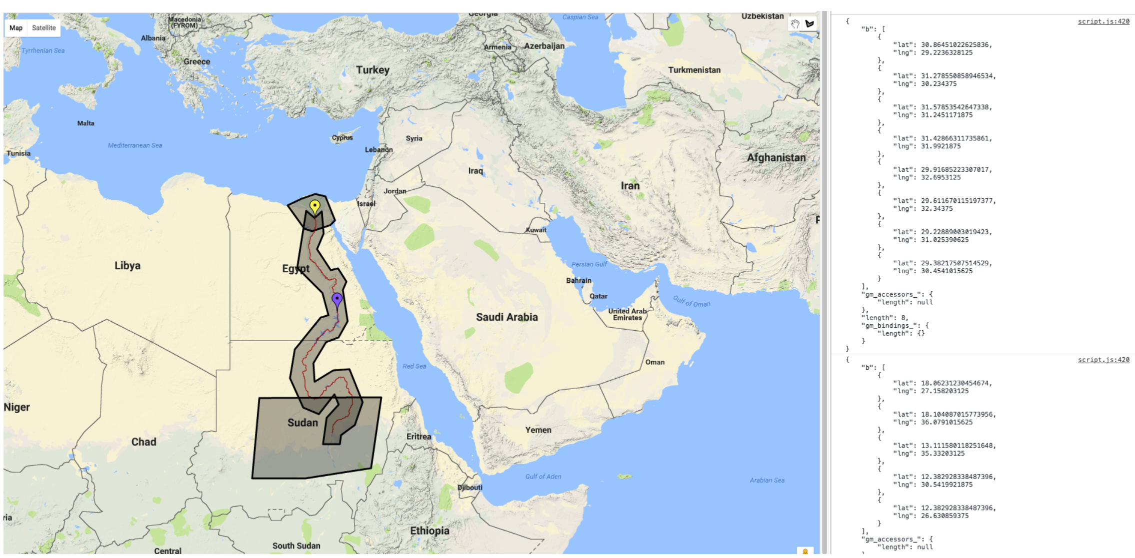

Figure 5.8: Drawing the bounding polygons for a river

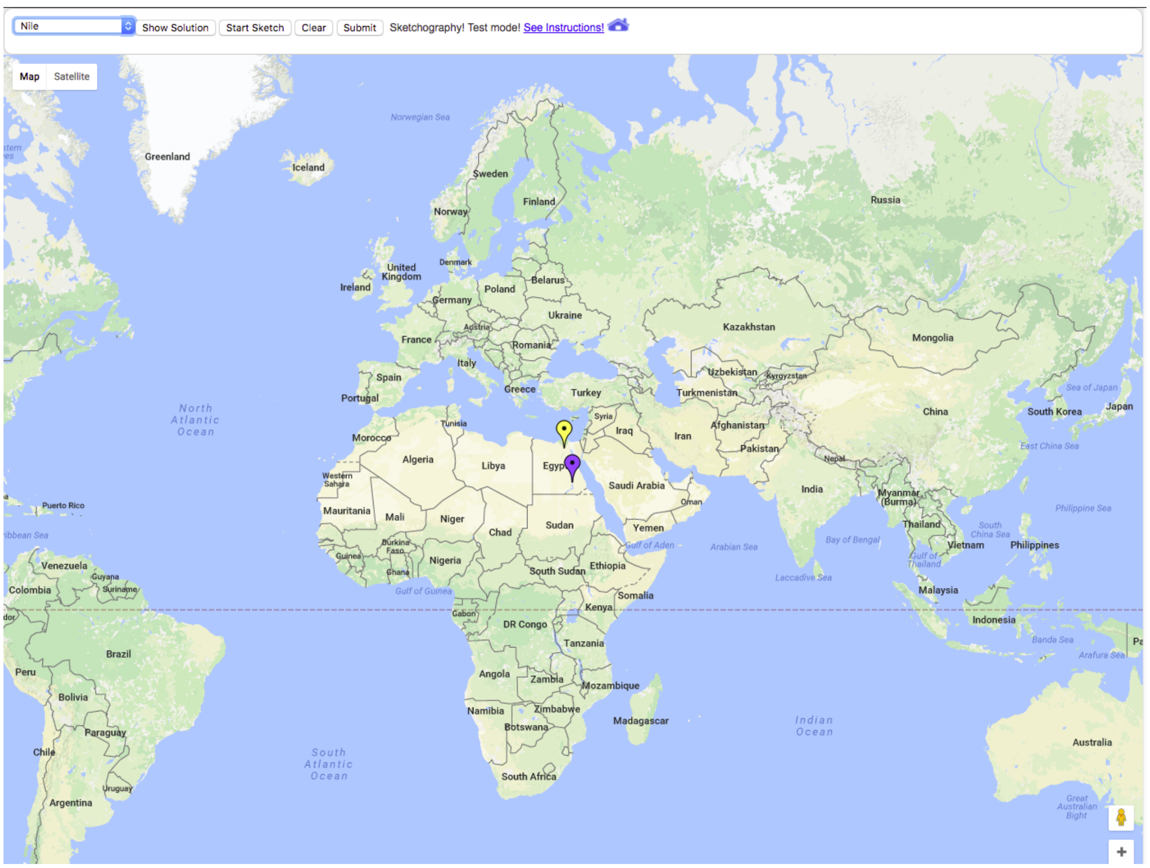

Figure 5.9: Sketchography - after choosing Nile in 'Test' mode

Figure 5.10: Sketchography - tracing the solution for Nile stopped mid-way in 'Learn' mode

Figure 5.11: Sketchography - tracing the solution for Nile and ready to submit in 'Learn' mode

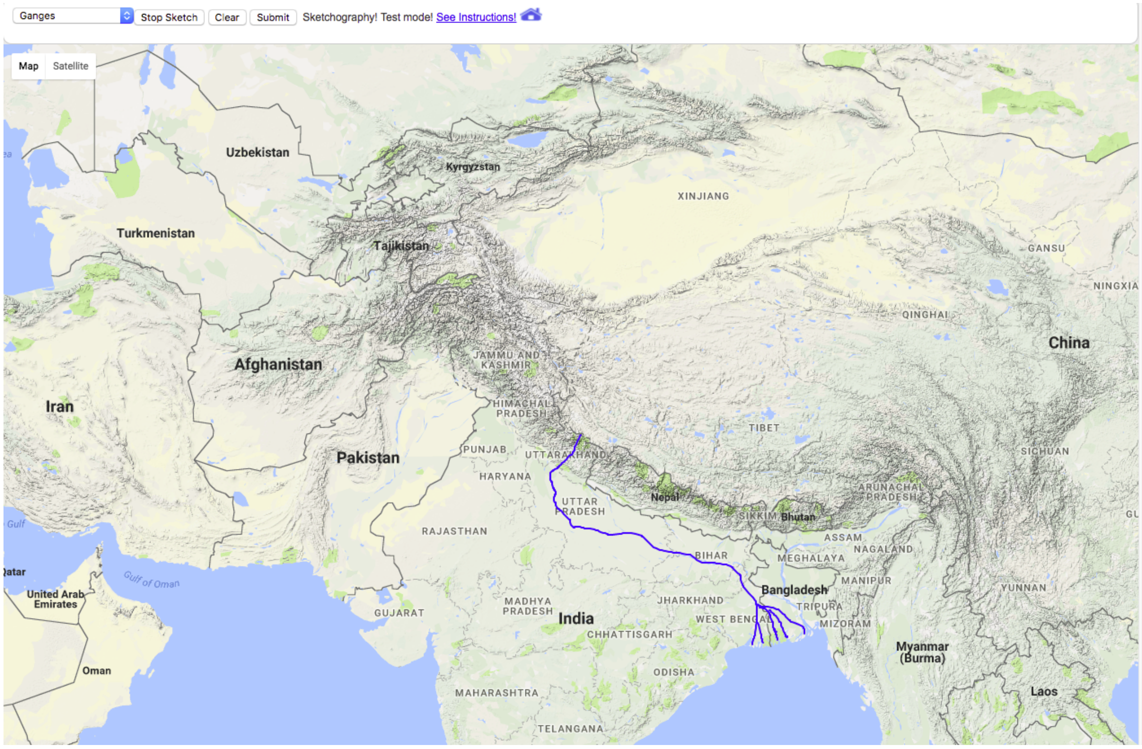

Figure 5.12: Sketchography - Ganges drawn in ’Test’ mode

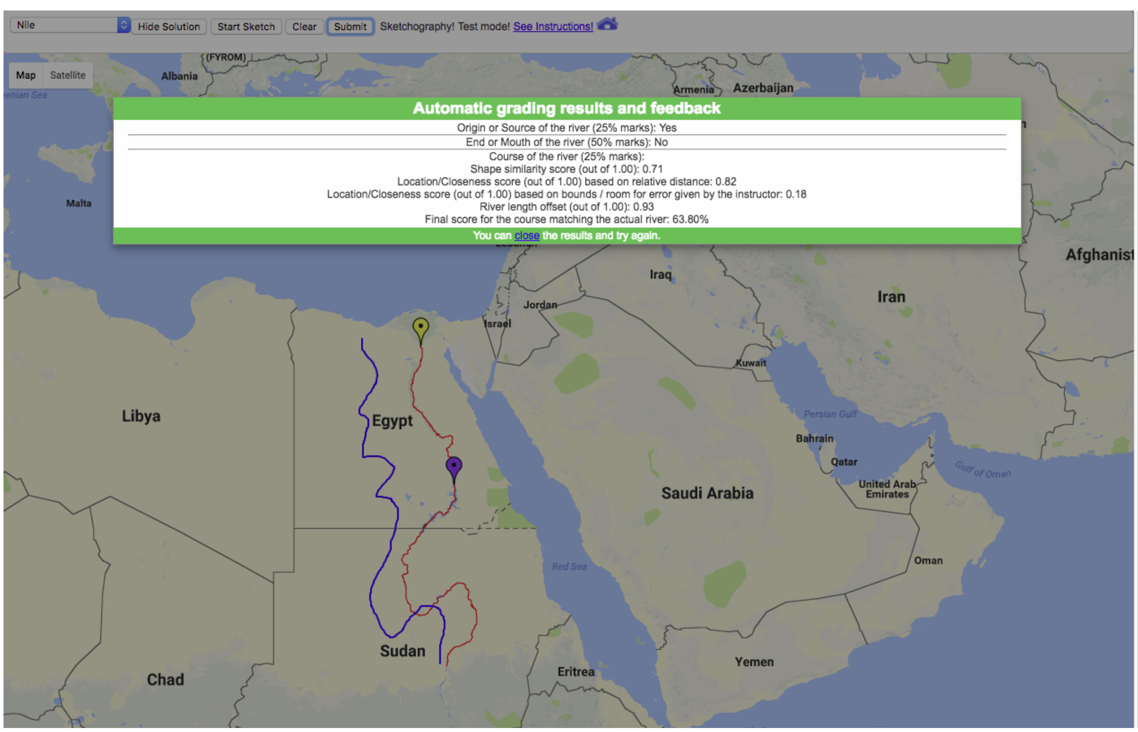

Figure 5.13: Sketchography - automatic grading results for a bad case

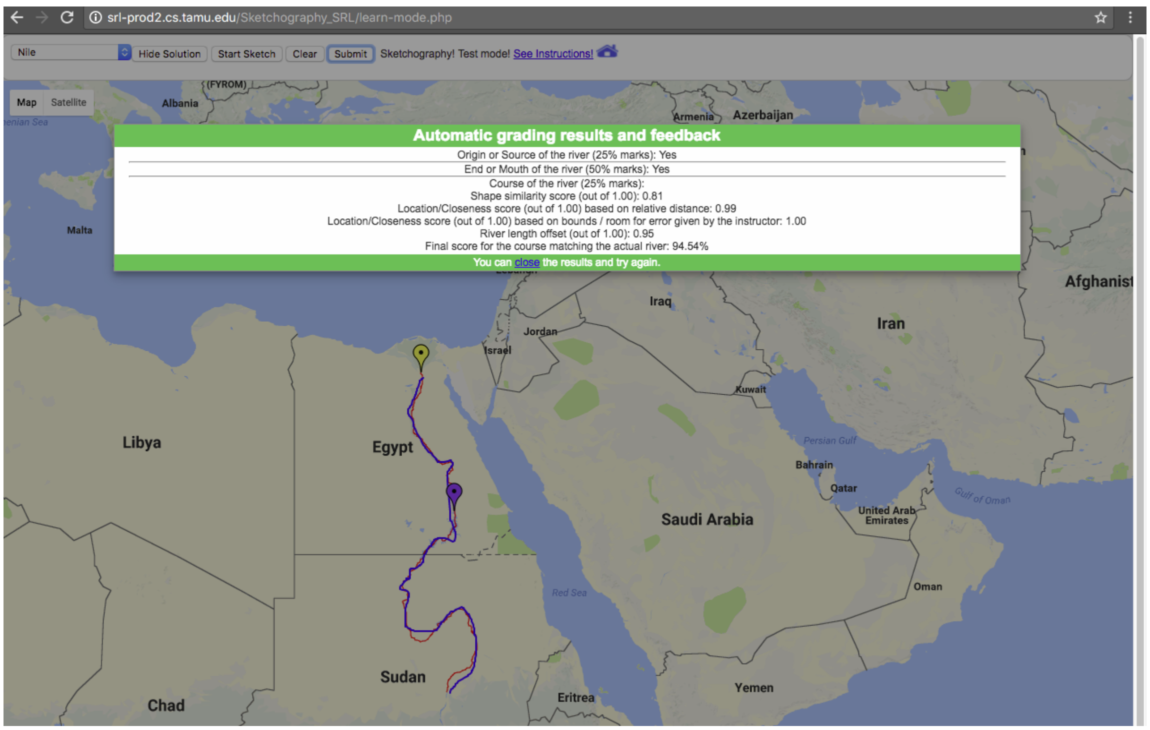

Figure 5.14: Sketchography - automatic grading results for a good case

6. EVALUATION

To validate our assumption that Sketchography has the potential to become a useful way of learning geography in an intimate and interactive way, we performed a user study with students at Texas A&M University.

6.1 Study method

We performed the user study in the following way: First, we explained the purpose and usage of the system to the users. After obtaining consent, the users would draw all the rivers in the system, first in the 'Learn' mode with as many attempts as they liked till they felt confident of going for the 'Test' mode, for which only one attempt was allowed to simulate the feeling of an actual exam. The following details were noted for each attempt:

- The mode (Learn or Test)
- The number of times the user used the 'Clear Sketch' option
- Time taken
- Whether the user got the origin of the river right (Yes or No)
- Whether the user got the end of the river right (Yes or No)
- Shape Context score
- Modified Hausdorff's distance score
- Ratio of points inside the bounding polygon
- River length offset
- Final score calculated for the course of the river calculated by the system

Afterwards, the user study participants were requested to fill in a post-study questionnaire in order to gauge their perception of the usability and effectiveness of the system.

6.2 Study results

6.2.1 Demographics

Tables 6.1, 6.2, 6.3, 6.4, 6.5 show the demographics of the participants.

Major	**Number of participants**
Aerospace Engineering	1
Biochemistry & Genetics	1
Biology	1
Business-Marketing	1
Communication	1
Computer Science	6
Computer Engineering	1
Curriculum and Instruction	1
Electrical Engineering	1
Environmental Geoscience	1
Geology	1
GIS&T	1
Geography	1
Information Systems	1
Urban Planning	1

Table 6.1: Educational background of the study participants - majors

Classification	**Number of participants**
American	8
International	12

Table 6.2: Composition of the study participants

Gender	Number of participants
Male	13
Female	7

Table 6.3: Gender of the study participants

Proficiency	Number of participants
Beginner	13
Intermediate	6
Expert	1

Table 6.4: Proficiency in geography

Introductory geography course	Number of participants
Taken	13
Not taken	7

Table 6.5: Introductory geography course experience

6.2.2 System use

Tables 6.6, 6.7, 6.8, 6.9, 6.10, 6.11, 6.12, 6.13, 6.14, and 6.15 show the results of the students participating in the user study:

Mode	Number of attempts
Total	305
Learn	165
Test	140

Table 6.6: Attempts breakdown

Mode	**Number of times option used**
Total	146
Learn	74
Test	72

Table 6.7: 'Clear Sketch' option usage

Mode	**Average time (in seconds)**
Total	46.62
Learn	50.82
Test	41.66

Table 6.8: Average time taken (in seconds)

Mode	**Yes**	**No**	**No result due to pre-processing**
Total	282	20	3
Learn	151	11	3
Test	131	9	0

Table 6.9: Origin identified correctly

Mode	**Yes**	**No**	**No result due to pre-processing**
Total	251	51	3
Learn	135	27	3
Test	116	24	0

Table 6.10: End identified correctly

Mode	**Average score**
Total	0.77
Learn	0.78
Test	0.75

Table 6.11: Shape context scores

Mode	Average score
Total	0.977
Learn	0.982
Test	0.972

Table 6.12: Modified Hausdorff distance scores

Mode	Average score
Total	0.956
Learn	0.988
Test	0.918

Table 6.13: Ratio of points inside the bounding polygon for the course of a river

Mode	Average score
Total	0.893
Learn	0.904
Test	0.881

Table 6.14: River length offset scores

Mode	Average score (%)
Total	90.67
Learn	92.62
Test	88.40

Table 6.15: Final percentage scores for the river course

6.2.3 Usability

Figures 6.1, 6.2, and 6.3 show the usability feedback from our user studies.

Of the 20 study participants, 10 experienced one or multiple issues while using the Sketchography application. The following issues were highlighted by the users:

- Sometimes the Submit button wouldn't work.

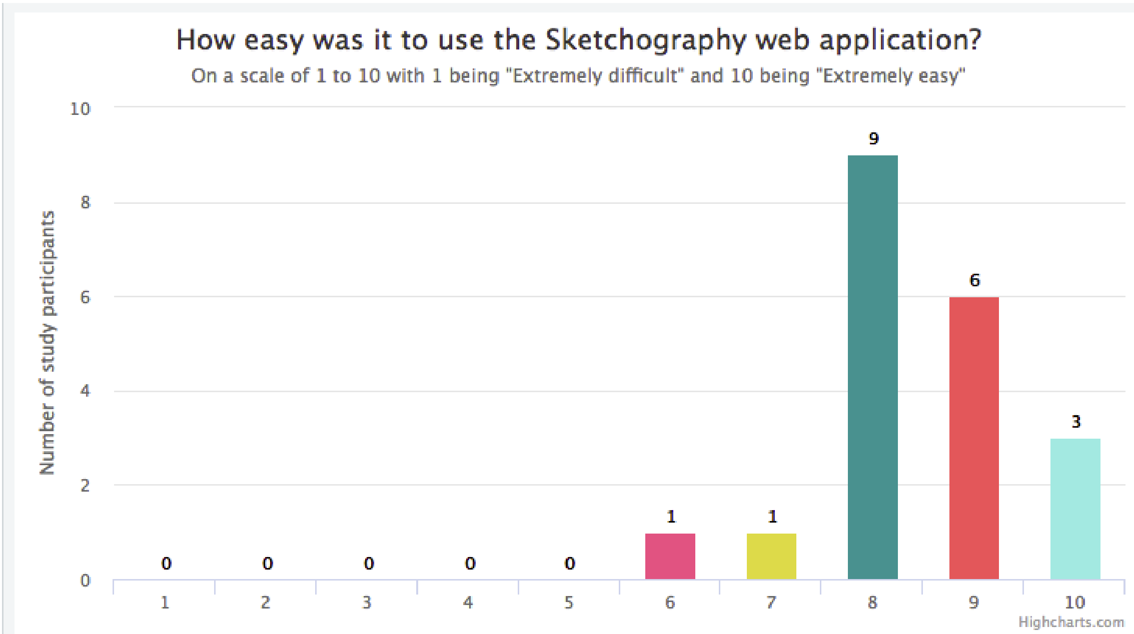

Figure 6.1: Sketchography user study results - ease of use

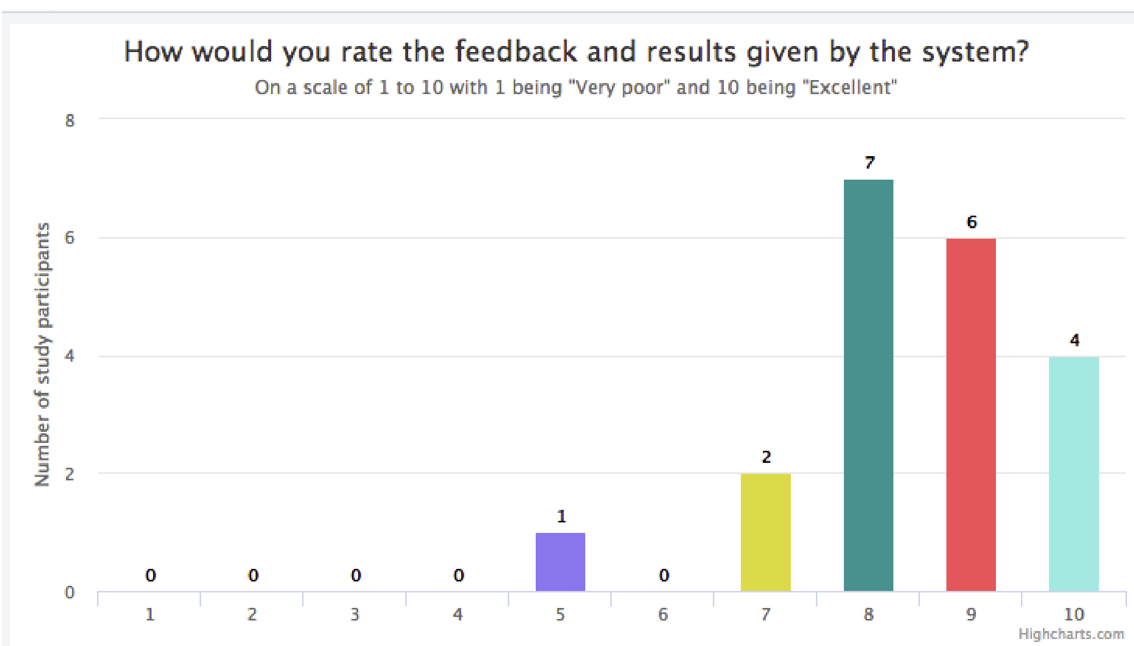

Figure 6.2: Sketchography user study - feedback ratings

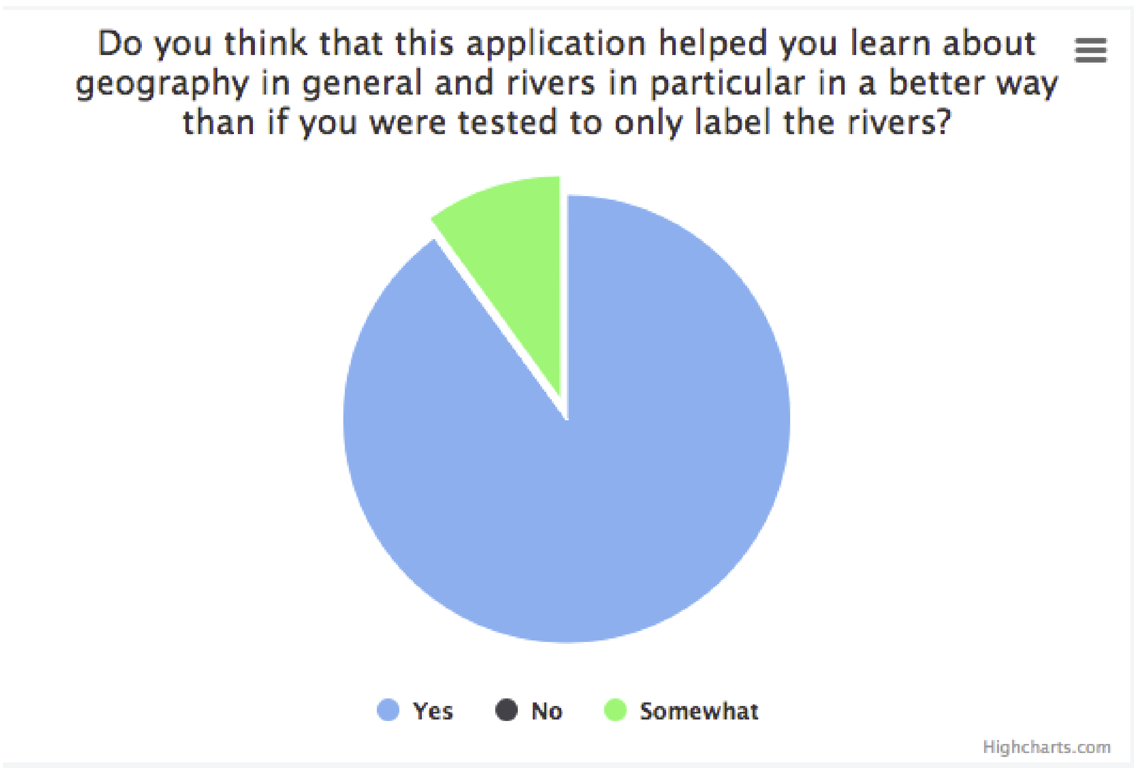

Figure 6.3: Sketchography user study - learning rating

- It was not clear as to how to get back to the tab that lets you choose between "Learn" and "Test".
- Sometimes the system did not work with the full rivers.
- Markers disturb the line sketched.
- Sometimes it took time for the results to be displayed
- Resolution issues occurred when there was confusion if the map or the whole browser was being zoomed.
- Stylus sensitivity and freezing.
- Minor problems when wrongly clicked instead of dragging

6.3 Analysis

The average time taken as well as the mean scores obtained by the users in each mode did not differ significantly. The average duration for attempts in either mode is less than a minute. This is a strong indicator that they were able to learn and retain information about the rivers in an effective way.

The various issues face by the users can be explained as follows:

- Currently the x, y coordinates are not collected accurately if touch input (instead of the stylus) is used during sketching. This cause errors during various calculations which are logged on the JavaScript console but not shown to the users.
- The UI can be improved using principles of human-computer interaction so as to make the application more intuitive and not cause confusion if a user wishes to switch between the modes.

- The markers currently have a higher z-index (elevation) than the surrounding areas. They should be both lowered users should also be allowed to sketch over them.
- An alert should be generated if a user tried to zoom-in or zoom-out while in the sketching mode to prevent causing the browser resolution to change.

7. FUTURE WORK

We plan to enhance and improve Sketchography in multiple ways. The current version of Sketchography is bare-bones with a lot of scope for UI improvements. We intend to use a UI library to standardize the UI elements and ensure that the web application renders well across different browsers. Currently, the level to which a user can zoom on the Google Map in Sketchography is fixed and uniform for all rivers in the system. We observed that for some rivers such as the Nile and Amazonas, a noticeable amount of details were visible while others were far less conspicuous. We plan to investigate this and have a dynamic limit for the zoom level to ensure consistency concerning the degree of detail that is presented to a user. We will prioritize allowing users to easily draw over the reference markers for each river so that their sketching experience is not hindered. We will work to merge the different parts of a river if they are listed under different names in the Natural Earth dataset so that a unified picture is presented to the user and any misunderstanding is avoided. We plan to add hints for remembering the characteristics of a river and info boxes to supplement the knowledge about a river in the learning mode. Besides the general UI improvements, we also plan to introduce visual means of help and instructions through videos, animation, and overlay markers. Also, we plan to improve the feedback by highlighting the differences between an attempted solution and the exact template.

As Sketchography developed, the application codebase kept increasing, and as more researchers join the project, maintainability becomes a concern. Modularity and proper documentation of the code base are some of the ways we can ensure the long-term stability of the project. We plan to introduce session and identity management in the Sketchography web application so that the system is practically deployable in classrooms. That would also necessitate getting the user results stored in a database rather than just display on the user.

We also plan to explore other datasets which would be more comprehensive, especially for rivers, and ensure normalization between the user sketches and the river templates from such databases so as to ensure fair comparisons for a user's sketches.

We plan to introduce an "Instructor" mode which would allow instructors to create new custom problems, define how each problem should be set up such as the level of details shown and any reference markers or labels to added and see the student submissions. Geography involves the study of many other things besides rivers, and we plan to expand to other kinds of geographical features and phenomena such as mountain ranges, contours, and ocean currents, to make Sketchography a more comprehensive tool for geography education and research.

8. CONCLUSION

Knowledge of geography is essential for all students. In this research, we kicked off the development of an intelligent tutoring system to help students learn geography in a novel and interesting way. The grading rubric provided by a geography professor was the basis for the evaluation of user sketches and feedback given to users. The grading rubric required the system to evaluate different aspects of a user's attempt. While the origin and end of the river drawn could be checked conclusively with the Google Maps JavaScript API, assessing the course of a river needed the calculation of various features which could satisfactorily determine the accuracy of an attempt. A combination of four features was used to give a score for the course of a river which aligned closely with the way a human grader would rate the same. The user study reaffirmed our expectations for the system as students from varied backgrounds found our system to be effective in improving their knowledge about some of the major rivers in the world. There is much scope for improvements and enhancements which could make Sketchography a comprehensive tool aiding geography education in varied ways and hopefully, herald a new era of improved geographical awareness among the masses.

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