March 15, 2017

Race Maps

Developing geovisualization techniques for improving trail running

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GEOG 455W Theoretical and Applied GIS

Table of Contents

Abstract

The popularity of ultramarathon trail running has been continually increasing throughout North America. The increase of trail running athletes is in part due to the ease of access into volunteer geographic information (VGI) through sports applications such as Strava. The purpose of this paper is to identify the geovisualization techniques that would improve navigation of trail runners. The project uses current literature, GPS data, and consultation to assess the possible ways to visualize trail races. Analysis produced quality animations of flyovers, an improvement in 2D maps, and increased social interaction between trail runners. The improvements recommended are access to higher quality satellite imagery, ground truthing GPS data, and testing the visualizations in a real world setting.

Introduction

Due to its mountainous location, the Pacific Northwest is home to a variety of outdoor activities, such as hiking, skiing, and even trail running. With a wide elevation and terrain range, the mountains of the Pacific Northwest can test people to their physical limits. Orienteering through these mountain ranges is both physically and mentally challenging (Qing, 2013). In particular, trail running and trail races is a sport that is growing momentum throughout this area. In 2014, the Coast Mountain Trail Series was started in hopes of creating incredibly challenging, scenic and proffessional run events throughout the coast mountains of British Columbia. This trail running series consists of six races, ranging throughout the coastal mountain (Coast Mountain Trail Series, n.d.). These ultra marathon type races challenges you to your limits. Located along portions of the Western States Trail, these ultra marathons range from 10 km to 100 km races (The Canyon Endurance Runs, n.d.). In order to train for these strenuous races, athletes rely on experience and observation to improve. A way for athletes to do this is by the use of technology, such as GPS trackers and video, to evaluate their progress and improve their training (Qing, 2013).

Our project is to use the wide range of GIS technology to develop new ways of showcasing the Coast Mountain Trail Series. Using GPS data gathered from Strava and given route data, we will be producing interactive, dynamic and easy to use maps and geovisualization products. We will be using 3D technology, game engines, fly over techniques, and 2D maps to showcase each race route. We will be creating an online platform to share these maps with other trail racing enthusiasts. Our goal is to be able to produce meaningful and valuable geovisualization techniques that are beneficial to the athletes running in the Coast Mountain Trail Series.

Literature Review

Ultramarathons and trail running have in recent years grown exponentially as a sport for runners seeking an endurance adventure. The definition of an ultramarathon is “any foot race over 50 or more miles” according to Dictionary.com. According to the International Trail Running Association, trail running occurs on various natural terrain while minimizing the usage of paved or asphalt surfaces. Although there is growing interest in competition of this sport, Hoffman (2009) expresses there is little published on the demographics of ultra runners and the trends associated with participating in the sport. On the other hand, there are a lot of current literature focused on the health and statistics of ultramarathon runners and their kinesthetics. Additionally, the more popular version of competitive running, the marathon, is heavily discussed in several books and scientific papers.

Volunteer geographic information (VGI) and GPS tracking via smart watches or smart phones is becoming an increasingly popular tool to track trail routes, run times, and even one's heart rate (Elwood et al, 2012). VGI has become increasingly popular with natural resource applications, especially with the planning of recreational trails (Korpilo et al, 2017). VGI provides an inexpensive way to gather accurate and detailed spatial information and GPS coordinates (Korpilo et al,2017). Not only is VGI an inexpensive way of gathering information, but by gathering information via a smartphone is user friendly, and it is highly accessible to anyone (Korpilo et al, 2017). Once gathered, this spatial data can be posted onto online sharing platforms, such as Strava, in order to share up to date routes (Korpilo et al, 2017).

In recent years, 3D modelling especially in the gaming industry made significant advancements. At the same time, modelling of geological processes (geomodelling) for business applications, for example managing natural resources (Mallawaarachchi et al., 1995), as well as scientific purposes (e.g. topological analysis) became increasingly important. In order to satisfy this demand, extensive geographic information systems (GIS) were developed (e.g. ArcGIS, TerrSet, QGIS). Although, GIS software enables advanced spatial analysis, they are mostly limited to 2D or 2.5D static maps. A simulation component in these systems is missing which leaves dynamic processes (e.g. earthquake, tsunami, or trail map simulations) disadvantaged, since they can only be represented as static maps.

Due to these limitations, experiments with game engines were conducted since the 1980s, mainly by the military to develop flight simulators with realistic maps (Ahlqvist, 2011). Prof. Nick Hedley (Hedley et al., 2014) and other researchers (Mat et al., 2014; Corbett & Wade, 2013) further explored the possibilities of game engines.

Additionally, GIS technology is highly in demand in the information era. In the recent decades, it has dramatically developed and facing a new evaluation. For example, GIS has integrated with Internet application and uses web platforms, which is also called Web GIS(Fu, 2010). Currently, most of the GIS outputs no longer just present as 2D maps, but with more powerful capacity. We can make our outputs as mobile apps, online maps, 3D models and so on. The change of GIS technology is also the change of maps. Many cartographers believe that the role of map is a medium of communication; it supports “visual thinking and decision making” (Andrienko & Andrienko, 1999). However, interaction and dynamics are the two key additions to make the role of map more effectively (Andrienko & Andrienko, 1999). Interactive map and Web GIS have become popular trends. For instance, many cities in Canada has launched web-based mapping application; it does not only provide an efficient platform for municipalities to manage their data asset, it also allows public to access some mapping services and data inquiry services (Gasparini, 2001). Users do not need to be GIS specialists, they can interact with the apps or maps by just clicking or moving their mouse (Fu, 2010). The GIS web app’s function can be in vary, people can configure the apps based on their needs. There are various types of GIS-based apps, such as story maps, reporter app, survey app and so on (ESRI, n.d.).

Data

The study gathered data from primary and secondary sources to ensure data was as current and accurate as can be. It is because the application of geovisualization techniques on trail mapping is a fairly new subject, therefore there was limited literature supporting our methods and results. Previous research in geovisualization techniques, volunteer geographic information (VGI), and usage of game engines in cartography provided a broader scope of the issue at hand. Our research was then applied to observations of current geovisualization techniques and maps, therefore inspiring us on how to create value added geovisualization products of trail maps.

a. Our Global Positioning Satellite (GPS) data for the individual trails were provided by Ryan Robertson, part of the Coast Mountain Trail Series organizing team, and from Strava. Data received from Robertson and Strava were in GPX files, which required the data to be converted in ArcMap to produce vector files.
b. Geogratis online portal where anyone can acquire free topographic information which is provided by Natural Resources Canada
c. The flyover method is achieved by our data projected onto a global Cube projection in ArcGlobe 10.3. ArcGlobe is part of the ArcGIS 3D Analyst Extension and is designed to view a large dataset of raster and feature data (ArcGis, n.d.). ArcGlobe has the ability to render a representation the surface of the earth more accurately and realistically than other projections. Vector features in ArcGlobe are generally rasterized, which assists in very fast navigation and display.
d. Terrain Resource Information Management (TRIM) terrain data from GeoBC which was provided by librarian Julie Jones at Simon Fraser University
e. Video footage was provided by Alvin Wai, using a Gopro Hero 2 and GoPro Studios for editing. The videos are sped up two times in editing through Wondershare Filmora. Photos are retrieved from the *Coast Mountain Series* website.

Methodology

Flyover Technique

The use of geovisualization techniques to assist in navigation of a physical activity, especially in trail running, is currently in short supply for athletes and recreational enthusiasts. The need for geovisualization technology to be implemented in trail maps originates in finding an improvement for orienteering purposes. Orienteering can take part before the activity, by practicing and visualizing the trail, and during the activity, which incorporates both a mental and physical aspect to trail running. Focusing on the aspect of before a trail run or race, athletes may find themselves training by observing video data or trail data conditions, in order to prepare for the inevitable (Qing, 2013). Visual data comprised of photos or videos are considerably good resources for visualizing the trail route. Additionally, GPS data has been proven to be an useful tool for recording trail data because many trail runners will have access to a GPS-enabled mobile phone or device that will collect route data easily (Korpilo, Virtanen, Lehvavirta, 2017). Meijles, de Bakker, Groote, and Barkse (2014) explains that GPS devices have significantly decreased in cost in recent years, and high resolution data can be obtained with little effort from the user. The time it takes to record a set of coordinates, follow a route, or record a route has lessen because of the improvement in GPS technology. This is vital as both GPS usage and visualization are increasingly popular amongst athletes.

The way to analyze the path and direction is to create a flyby by path (flyover) in ArcGlobe 10.3. The GPS data points are converted into a polyline. A polyline is required so that the animation will have a path to follow, in the case of our project, the polyline becomes the trail route that runners will reference to. Utilizing the function “Create a flyby by path”, an animation of following the polyline is achieved and exported to become a video file. At this stage, the video file can be uploaded and distributed accordingly. The exporting of the animation for the trail race route required more attention to the frame rate and keyframe selection in order to produce a smoother and better quality video. Selecting two keyframes per clip allowed for easier transition between frames and to avoid frame repetition. Before exporting, the flyover recording in either ArcGlobe or ArcScene needed to be filmed four times slower so that, when the video is edited in Wondershare Filmora, a video editing software, it is sped up to produce a smoother video.

Post-editing of the flyover video in a video editing software will enhance the video output for uploading onto a web service.

Geovisualization with Unity

For this project, a geovisualization of trail maps for the Coast Mountain Trail Series is planned. The geovisualization is created with the popular game engine Unity3D in its current version 5.5. Unity3D allows the developer to create scenes in which a digital elevation model (DEM) can be imported. The process of adding DEM's to the scene differs greatly compared to regular GIS (e.g. ArcMap) where a DEM can be imported as a georeferenced GeoTIFF or shapefile. Unity on the other hand, does not use a coordinate system to project a terrain instead shapefiles or GeoTIFF DEM's will be imported into Adobe Photoshop, cropped to the desired extent, saved as a RAW file (Photoshop specific format to store images), and finally imported into Unity3D [Figure 1]. Even though Unity itself does not use coordinate systems or projections, the DEM still retains its spatial "correctness" from the software it was created in (e.g. ArcMap), since the image is not altered after the export from a GIS.

After this important initial step to create a real-world reference, other steps for replicating (e.g. trail, aid and water station visualizations) and improving trail maps can be taken by creating objects and scripts (written in the programming language C# or JavaScript). Scripts are a series of commands which can be considered as behavior components for objects in the Unity scene.

By utilizing scripts and objects, following improvements to original trail maps can be anticipated:

- Animated elevation profile, which shows the exact elevation change at a user-defined location instead of static profile where the user must guess the location on the map
- Integrated pictures and videos showing specific location on the map to improve what a user/race participant can expect of the race
- Animated “runner” avatar which runs the race in order to visualize the race
- Virtual Reality support for immersive user experience

2D Static Map

For our project, 2D static maps were created for each race within the Coast Mountain Trail Series. With the use of spatial datasets, i.e DEMs or TRIM, high resolution satellite images, and with the use of the new VGI method, 2D maps has the ability to convey visually appealing, cartographically accurate and useful maps (Korpilo et al, 2017). Therefore, GIS provides a structured means to display complex data elements with multiple data layers (Snyder et al, 2008). 2D maps has the opportunity to provide users with a simple, straightforward design, and with value added analysis to showcase the needed information.

The 2D maps were created within Esri’s Arcmap. High resolution DEMs were incorporated within each map in order to obtain the elevation for each trail. By showing the elevation and slope, the users and runners of the trail races can pinpoint the locations where the trail becomes steep. Users can also pinpoint the elevation gain of locations.

GPS coordinates were transformed into a polyline, which was then overlaid with a 5m DEM to derive the slope of the trail. Since the use of DEM’s is a more raster based technique, rather than the vector technique that is being used, each trail had to be transformed into a smaller cell size in order to minimize the look of pixels.

Interactive Web App

Currently, the Web App technology is very popular in GIS industry due to its rich interactive function and powerful user experience. For example, *Vancouver Trails* has applied the concepts of Web-GIS and interactive map to their trail maps. When users click on the point features, pop-up windows will show up and detailed information will be listed there (Vancouver Trails, n.d.). For example, clicking the point on the top-right corner, the message of “the third peak of the chief” will show in the pop-up window. But the multimedia content and site information are not displayed in the map window, they are under different sections on the website, users need to scroll down and go through the entire webpage if they want to get more information.

Based on the limitation of the existing race map outputs we mentioned above, we decide to build web app for our project to make our final output more powerful. Multimedia content can be shown in this app. Also, users can interactive with the map by clicking the feature points. Here is the procedure and methodology to configure our app:

1. **Software preparation and set up**: create an Arc GIS online account and download a story map series app template from Arc GIS Online;

2. **Map data collection and processing:** obtain all the trail shapefiles, process them in Arc GIS Desktop by using the tool of “points to polylines” and modify the attribute table as well; since the map data is ready, we need to upload them to the ArcGIS online and create web maps for each trail.

3. **Web Map configuration:** modify and configure each Web Map for each trail. For example, edit the pop-up window content; change the color and symbol for trails etc.

4. Multimedia content collection: go site visit each trail and use Go Pro Camera to record videos and GPS locations for certain sections; review previous event pictures on the *Coast Mountain Train Series* website.

5. Multimedia content processing: upload all the videos to YouTube/ upload all the related pictures to Arc GIS online; create a csv file to store the video/photo links, GPS locations, and some other key features as well (all the information will link to the point feature on the map); In terms of the Go Pro video, we need to upload the CSV file to the app template, and make each feature point relates to a video link on the map (the location we take videos will be pined as point on the map);

7. Configure the web app template: integrate all the trail web map into the app; use the tab function to separate each trail map; change the layout design and make the map series consistent; configure the user interface in the template as well; A lot of scripts and API need to be changed here;

8. Make the share button available and publish the app on Arc GIS online;

9. Test the app on different devices;

10. Download the app and embed the app to our website.

Results

Flyover Technique

The flyovers are displayed onto our project website for viewing. It is important to note that each trail race contained its own elevation profile requiring each flyover to contain different settings to produce a viable product for use. The settings involved in creating a flyover are azimuth, inclination, vertical offset, and path destination. Azimuth refers to the angular distance between the direction of a fixed point and the direction of the object. Inclination is the angle made by the horizontal and vertical plane to allow the camera to face upward or downward onto the trail. The vertical offset sets the camera's elevation in accordance to the trail's elevation. And the path destination in this case, for all the trail races were set to move both observer and target along pre-determined path. In the Bucking Hell trail race, the flyover created produced white square patches that momentarily appeared and disappeared in the animation. This is due to the long length of the race requiring a better video codec to process the length of the trail route in a flyover animation.

It is because the flyover feature is an animation feature in ArcGlobe, the advantage to GIS users is the simplicity in creating a flyover for trail map visualization. Unlike Unity, a flyover can be created with basic GIS knowledge and allow trail racers to analyze trail races from an elevated position. The use of ArcGlobe is also an advantage as ArcGlobe provides a basic projection of the Earth's surface using satellite imagery, and does not require the creator to find more detailed satellite imagery. The flyover animation offers a simplistic way for trail runners to study the direction and heading of the trail race without manually navigating map viewers like Google Earth. Moreover, while a flyover may not accurately navigate a trail runner through the forest, it can offer those who are unfamiliar with the road intersections that the trail races occur on to predict a oncoming course change. As a result, we see the most value in flyovers that incorporate a gravel or paved roadway where the resolution of the imagery from ArcGlobe is most improved.

Geovisualization with Unity

Since geovisualization with game engines is a relatively new way of GIS, the process of map creation is an exploration of available tools as well as the need for creating new tools and scripts to realize the proposed features. Unity is designed mainly for video games which gives the geovisualization a “game-like” character instead of an pure research-based identity. Due to the fact that race maps are designed for and used by trail runners in order to prepare for their race, this “game-like” character actually supports the purpose of race maps.

The creation of a Unity race map had to be limited to one race (“Run Ridge Run”) due to the amount of programming and setup of the project. Especially, the path-finding implementation required extensive amount of work, since a total of over 230 marker had to manually placed on the map to allow a runner to follow the trail. The original plan of using the wayfinding AI (artificial intelligence), which is integrated into Unity, failed due to the fact that character was not able to climb mountains as well as follow the trail accurately. Therefore, the 3rd party libraries iTween Editor and iTween Multi Paths, which were downloaded from Unity asset store, were used to create a path consisting of over 230 manually placed points that is followed by an object. By the use of these 3rd party libraries, it was possible to realize the animation of a runner showcasing the race. Furthermore, video footage from actual race locations (e.g. Sasamat Lake) has been included in the simulation which can be watched by clicking on the video in the map.

2D Static Map

Multiple simple, aesthetically pleasing, and cartographically accurate maps were created showcasing the routes of each trail race. For each race, one map showing the steepness levels (i.e. easy, moderate, and steep) of the longest distance within each race, and a map showing the elevation throughout the trail for each distance race per race, were created. By creating multiple maps for each race, the user has the ability to gather the needed information easily. The simple and straightforward design provides the user with value added information that is accessible to all and easy to understand. Other than the showing the slope and elevation, each map showcases the start and finish line, and the locations of each aid station, water station, bag drop off areas. Arcmap provides the needed tools for analysis, and allows the map generator to present the data in a way that the user can understand.

Even though 2D maps cannot show 3D aspects, which may make more sense since these races are located on the Coast Mountains, and one cannot pinpoint the exact elevation of a certain location, 2D maps provides users with a quick and easy medium to figure out directions and to plan routes.

Interactive Web App

As a result, an interactive web app for the Coast Mountain Trail series is successfully created and ready to use. People can access this app both from desktop and mobile devices, it is very convenient and user-friendly. Moreover, especially for new runners, they can explore and even get familiar with the trials without being there by just using this app. The Coast Mountain Trail Series have multiple different trail races in Lower Mainland, users can use this app to assist them to find a suitable one for them. If they think this app is useful and interesting, they also can click the share button to share this app with their friends on social media.

This interactive web app is including one overview web map and six individual trail web maps. The overview web map provides general idea to users, such as the location of trails. In terms of the individual one, user can obtain detailed information: they can click on the feature points to watch the Go Pro videos for a specific part of the trails. However, Go Pro videos are not available for all the trails due to the snowy weather condition. So we use flying over videos and related pictures to show the trail condition instead of using Go Pro video only. Therefore, the trail's information is displayed in the format of video, pictures and text.

In general, this app is easy to use and self-directed. Users do not need to be familiar with GIS or cartography, they still can use this app by themselves. They can click on the tab bar in the apps to switch different trails. They can navigate the trail map based on their needs. Also, there is no software requirements to use this app, users just need to have a digital device that is able to connect to internet. It is simple, but useful and powerful.

Discussion and Future Improvements

Flyover Technique

The flyover technique produced varying versions of quality in the visualizations. The quality of the imagery layer in ArcGlobe was hindered by the study area, and by the limitations of ArcGlobe. Firstly, the trails' sites located in ArcGlobe had a low resolution Cubic projection of the earth's surface. For example, the resolution of the study area in Whistler had a very low resolution, thus when the vertical offset is set at a low elevation, the quality of the flyover animation is very low. However, if the vertical offset is set at too high of an elevation, then the level of detail and the goal of a flyover is not achieved. This is because we are using the ArcGlobe interface and feature, whereas, the flyover animation can be completed more successfully potentially through ArcScene. For example, we see this problem in the flyovers created for the Sky Pilot, Survival of the Fittest, and Whistler trail races. ArcScene allows for navigation and interaction with three dimensional (3D) features and raster surfaces (ArcGis, n.d.). Using ArcScene requires a digital elevation model (DEM), a satellite image and the polyline of the trail route. The satellite image and polyline will then have its base heights referenced to the DEM and thus producing a 3D model of the trail route. However, this method was hindered by the availability of satellite imagery. The advantage to better satellite imagery will allow GIS developers to better construct a 3D profile of the study area and more accurately display the gradients and elevation changes of the trail races. We see that to improve on this method in the future, there would need to be more easily accessible satellite imagery or aerial photographs for trail map developers, thus allowing trail race organizations to improve their race support for racers. Additionally, to improve the video quality of the flyovers, a better video codec will produce smoother frames per second for the video.

One challenge that we have encountered in our geovisualization process of trail race routes for trail runners is the GPS data that we have received and collected. The challenge of GPS devices explained by Meijles *et al* (2014) is the limited accuracy of signals in a dense or closed-canopy environment and area, because of the lack of direct line of sight from the satellite to the GPS device. For the creation of a flyover animation, if the GPS device did not accurately record the path, then there would be times where the flyover seems to be off trail. The strength of a GPS device sets the precedent for the accuracy of the trail that the flyover requires and follows in flight. As a result, the GPS data for our project is limited by its accuracy because there is user error and all of our trail routes are located in dense forested areas, therefore the accuracy of the GPS data will need to be considered as a systematic error.

Geovisualization with Unity

The geovisualization with Unity resulted in a good display of the geovisualization technique using a game engine. Even though the race map project is limited by the DEM resolution of 10 meter, a terrain smoothing function could be applied to the Unity simulation which helped to remove the “block” shape of the original imported terrain. The terrain smoothing interpolates terrain heights based on neighbouring heights and therefore makes the terrain appear smoother and also slightly increasing resolution. A future improvement would be to get high-resolution data with resolutions of less than 3 meter to ensure accurate representation of the terrain and to avoid the use of terrain smoothing. Another factor, which is unique to the Unity simulation is the simulated “runner” running the trail. Originally proposed as human-shape character, the runner had to be replaced with a sphere following the path due to problems with the AI (artificial intelligence). The AI could not climb mountains and would instead slide downhill making it impossible to simulate a runner taking part in the race. Despite this simplification, an accurate representation of the race can be simulated. Also the current race information on the right side of the screen shows the runner real-time statistics (e.g. elevation, remaining distance and distance walked) which is rare to be seen in race maps (usually represented by static elevation maps). Further improvements in this area could be a functioning human-shaped AI which is able to follow the trail accurately.

Including videos in maps is a method which is fairly common, though these videos are usually located on additional webpages or provided as URL’s. In Unity, on the other hand, it is possible to include videos directly into the simulation as shaders which can be projected onto any object in the simulation and therefore creating a unique way of displaying video footage. Increasing the amount of coverage especially difficult parts of the race can be a way to improve the usage of video in the simulation.

Overall, the Unity simulation despite being a relative new way of GIS delivers a complete simulation of a trail race which can be used by race participants to receive an overview of the race and also to prepare themselves for the race.

2D Static Map

The creation of multiple 2D static maps using traditional GIS techniques produced accurate, aesthetically pleasing, and value added maps for each race within the Coast Mountain Trail Series. Since I was only deriving the slope and elevation of the DEM, the 10m resolution did not hinder my result like it would with a 3D model, or with the flyover technique. However, since I was working with raster data, my output trail resulted looking a little “blocky” due to the pixels. I was able to reduce the cell size in most maps, however, this proved challenging when it came to the Cap Crusher race. For most of the maps, I reduced the cell size to either 10 x 10 or 12 x 12. However, for the Cap Crusher race, I reduced the cell size to 4 x 4. If I would to go smaller, I would have lost information, creating holes in the trails. In order to produce aesthetically pleasing, yet cartographically accurate maps, I reduced the cell size to the size right before holes in the data started to appear. An improvement on the cell size issue would be to a higher resolution DEM.

Another value added feature that could be added in the future is slope direction. Due to my limited knowledge on coding and script, I was not able to produce slope direction. However, since this is 2D map, not a 3D, adding slope direction could have the potential of not conveying value added information since the slope already indicates the steepness level.

Overall, the 2D maps produced showcases a simple, yet value added map series that allows the users to easily understand the terrain the each individual race.

Interactive Web App

Even though there are a lot of great features in the web app, some challenges still need to be considered. Time consuming and knowledge gap are the main challenges. For example, the Go Pro video requires us to site visit each trial in person. We cannot explore all of the trails and highlight the interesting points in a short time period. Additionally, we want to add more valuable information into the app, such as the character of the trails, but we are not very familiar with the trails. Our knowledge about the trails are limited.

It would be more meaningful and useful, if we can allow users to share their unique experience in the app, such as real time pictures, comment etc. Ideally, each trail web map should have a section that allows people to engage,which means that users can pin a point on the web map and they can edit on it as well. Each of the comments and pictures that users share on the app can make a contribution. This may be considered as a plan for this project's next phase.

Conclusion

This project served two purposes for improving navigation and knowledge of ultramarathon trail races. First, we see that through the initiative and outcome of this project, the possibility for GIS services to collaborate with trail race organizations would be beneficial to both runners and other sports that involve long distance events. Second, our intentions to fill the gap of academic literature regarding geovisualization for ultramarathon-type events established a need for more research in navigation of trail races from the trail runner's perspective. The overall project can be improved by the availability of satellite imagery or aerial photographs to improve visualization techniques and the overall quality of the animations and videos. It is important to note that although the Unity and Flyover results are similar, the method, data and time required is dependent on the resources of the GIS user and the desired output of their project. For trail runners, having access to multimedia visualization methods, such as our Web App, will have the potential to further increase participation, contribute to the sharing of social media posts, and facilitate friendly competition. The Web App provides an interactive approach for trail runners to share their experiences of the trails. In addition, the increasing popularity of trail running and the application of social media is additive to the trend of Web 2.0 and the implication of volunteer geographic information.

In the future, it is recommended that further research into the availability of reliable and low cost satellite imagery or aerial photography will benefit trail race visualizations. Additionally, it is because the GPS data we received are recorded from a secondary source, additional ground truthing of GPS data is necessary to ensure data is accurate. Lastly, our project members were not experienced trail runners, therefore, our visualizations are limited to the knowledge of our geovisualization background. The implementation of our four visualizations will need to be tested with a group of various experienced trail runners to identify further improvements and refinements.

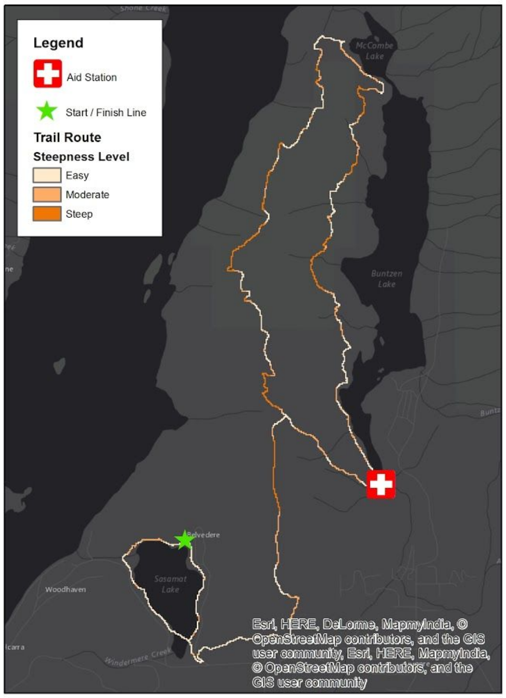
Acknowledgements

This project would not have been conducted without the guidance and assistance of Dr. Nadine Schuurman and David Swanlund and for that we owe our sincere appreciation. We would also like to thank the Coast Mountain Trail Series organizing team, Gary Robbins and Ryan Robertson, for providing the data required for our project and quality advice. In addition, we would also like to thank Julie Jones of SFU Research Commons for providing data. We hope that this project will help the future of trail races and inspire GIS users, trail race organizers, and academics to explore the vast opportunities of geovisualization.

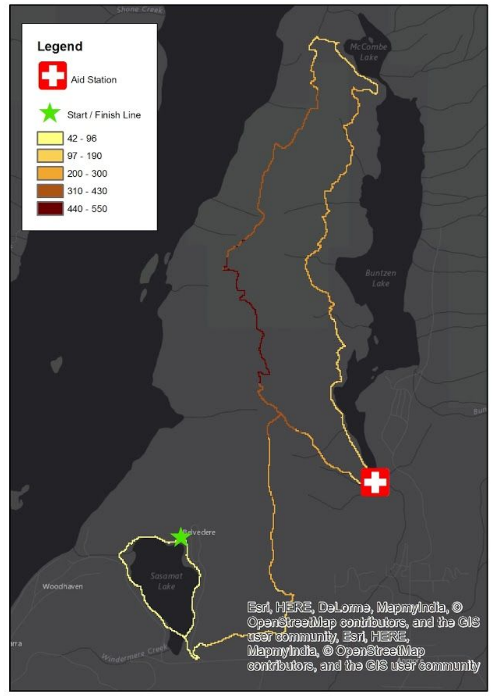
Figures and Maps

Run Ridge Run

N



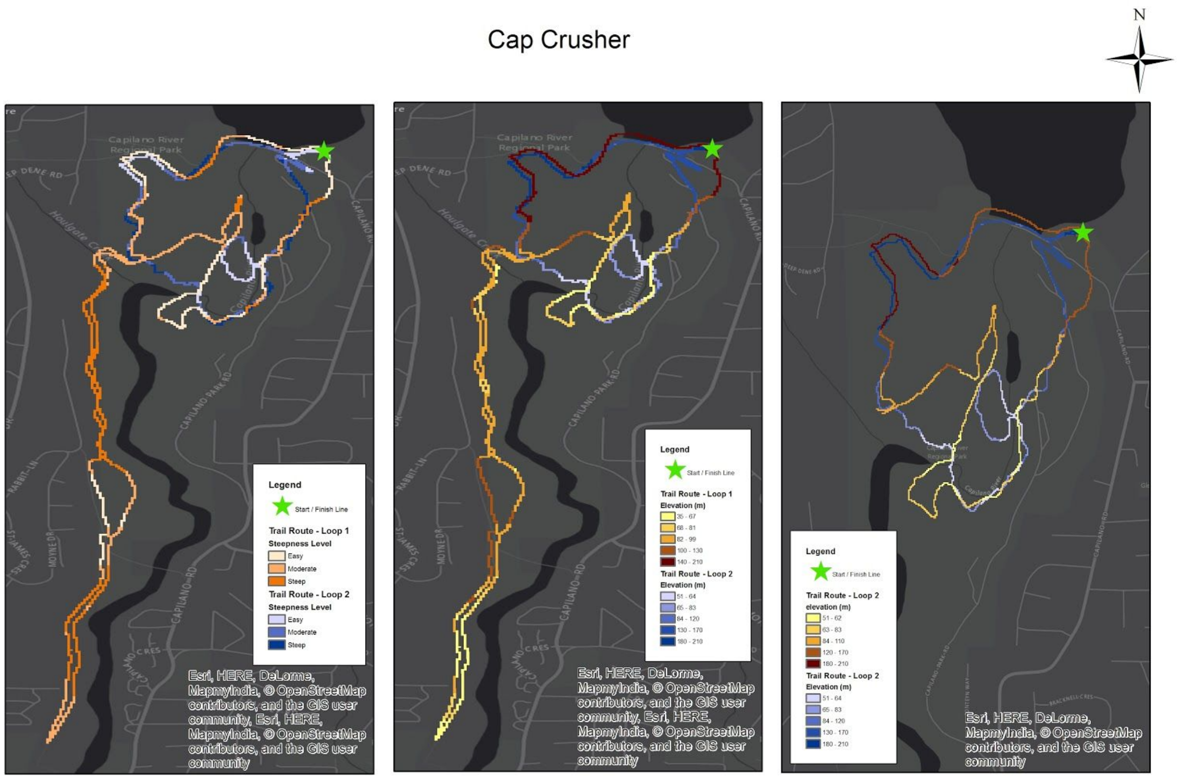
Map 1: 25km trail route indicating steepness level



Map 2: 25km trail route indicating the elevation

0 500 1,000 2,000 Meters

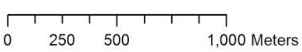
Cap Crusher



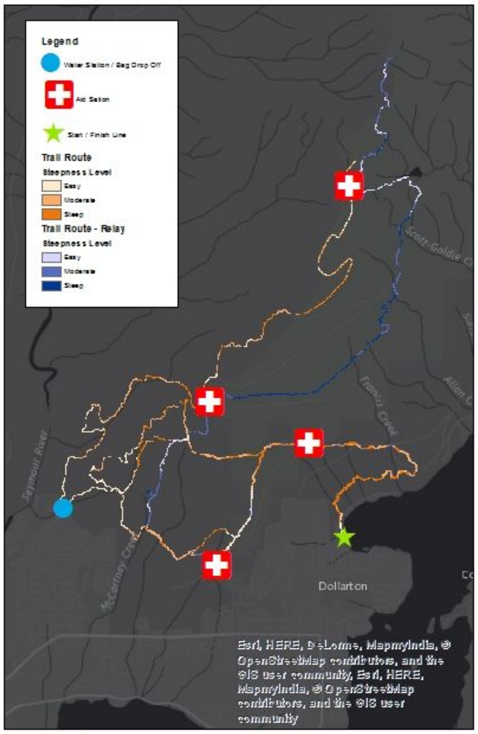
Map 3: 13km trail route indicating the steepness level

Map 4: 13km trail route indicating the elevation

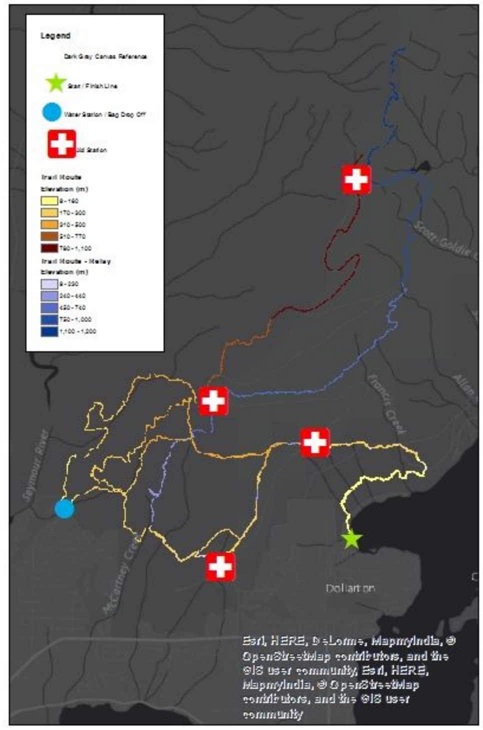
Map 5: 8km trail route indicating the elevation



Buckin Hell



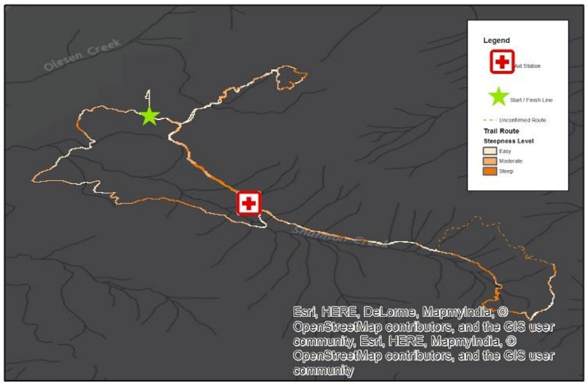
Map 6: 50km relay trail route indicating steepness level



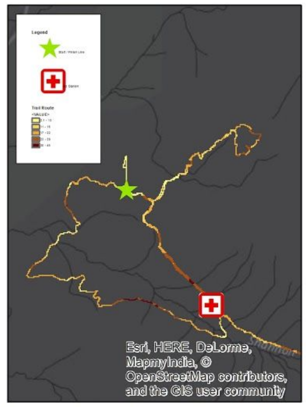
Map 7: 50km relay trail route indicating elevation

0 500 1,000 2,000 Meters

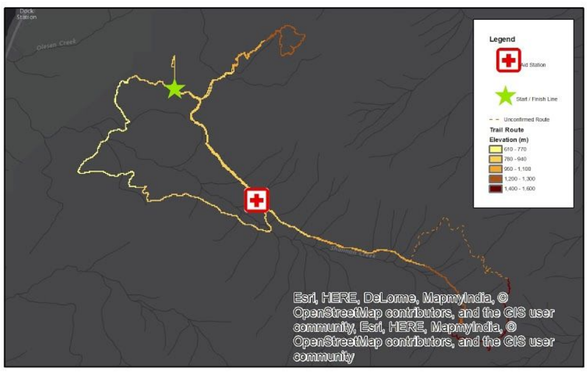
Sky Pilot



Map 8: 25km trail route indicating steepness level



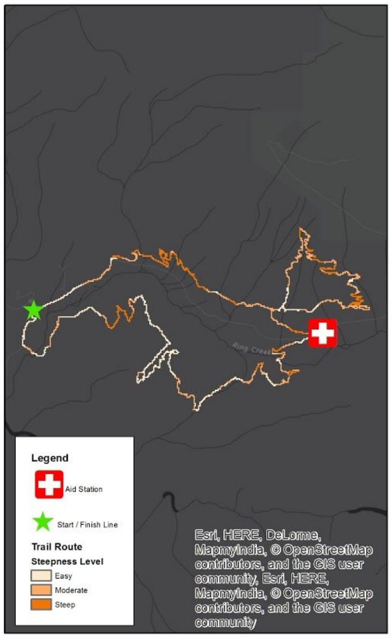
Map 10: 14km trail route indicating elevation



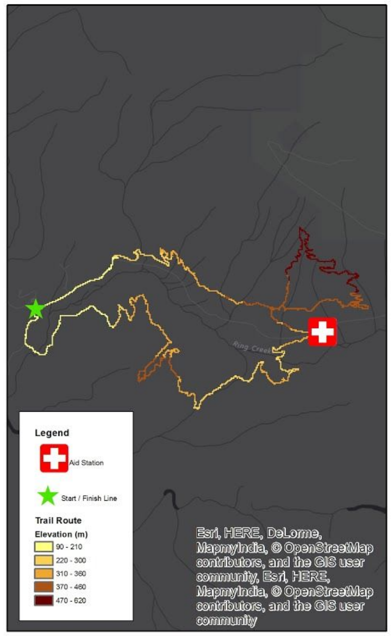
Map 9: 25km trail route indicating elevation

0 625 1,250 2,500 Meters

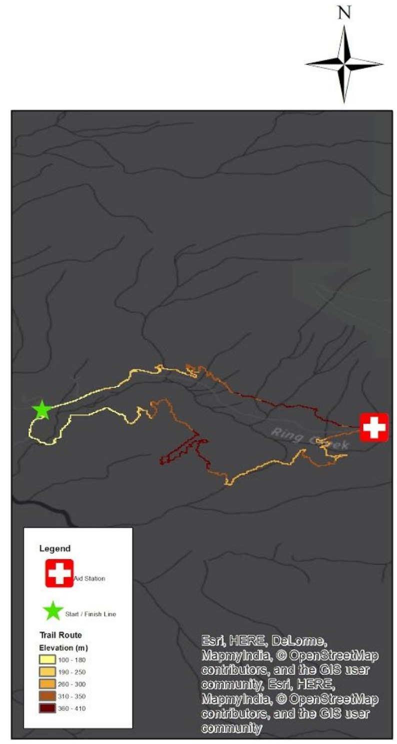
Survival of the Fittest



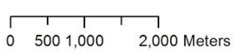
Map 11: 18km trail route indicating steepness level



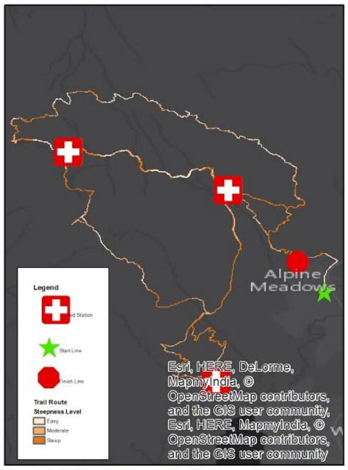
Map 12: 18km trail route indicating elevation



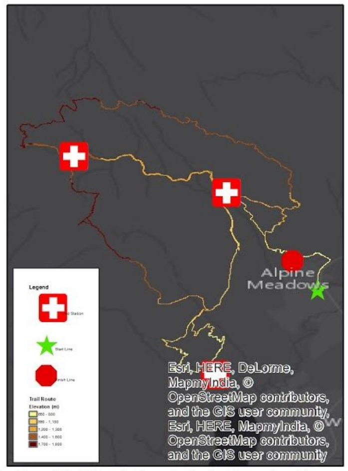
Map 13: 13km trail route indicating elevation



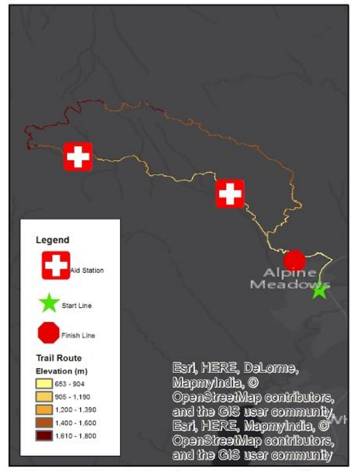
Whistler Alpine Meadows



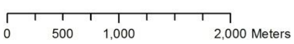
Map 14: 55km trail route indicating steepness level

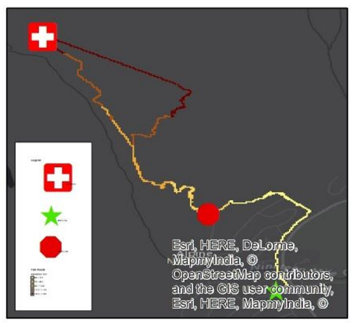


Map 15: 55km trail route indicating elevation

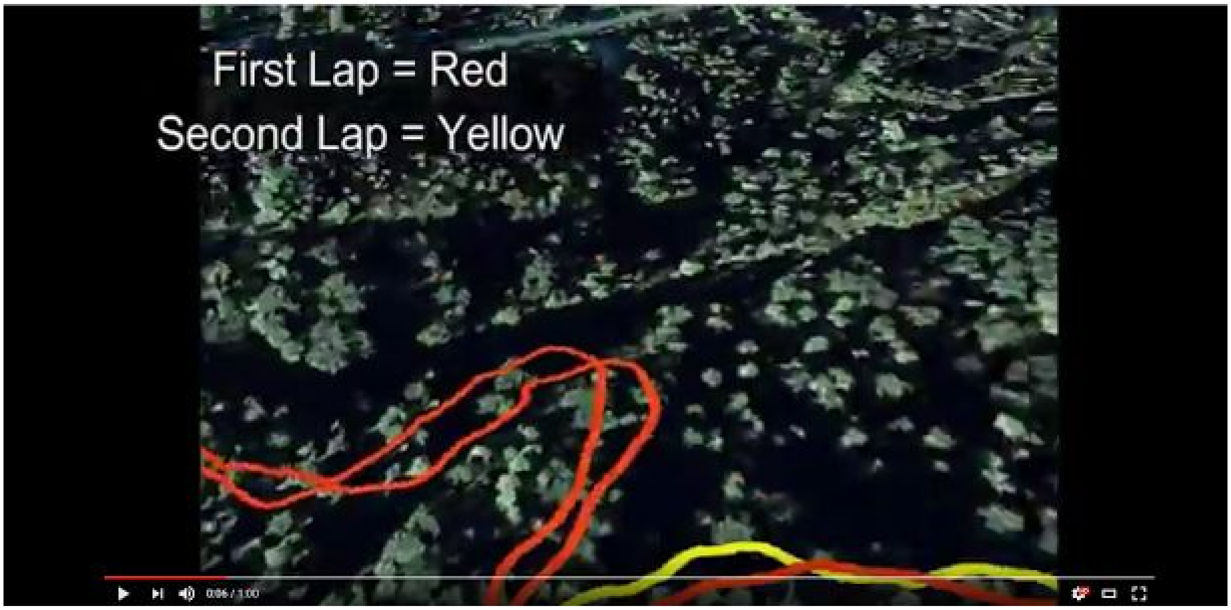


Map 16: 25km trail route indicating elevation

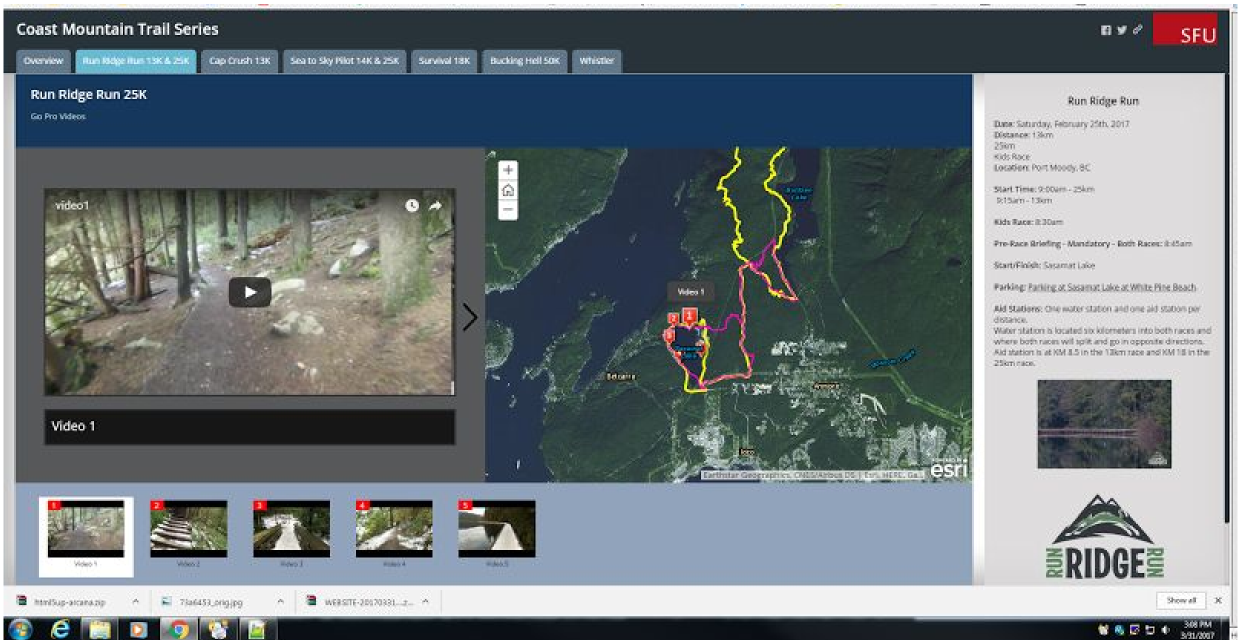




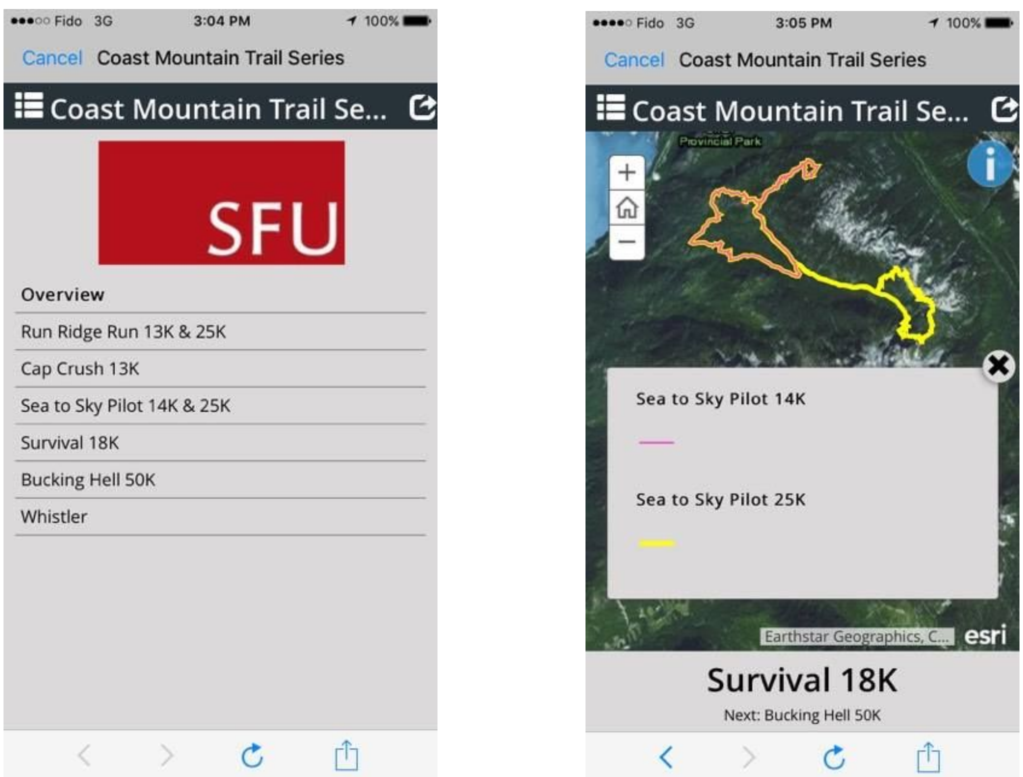
Map 17: 12km trail route indicating elevation



Screenshot example of the flyover with text description.



Desktop screenshot example of the Coast Mountain Trail Series ArcOnline Web App.



Mobile screenshot example of the Coast Mountain Trail Series ArcOnline Web App.

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