RUNAMIC: Dynamic Generation of Personalized Running Routes

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Keywords: Dynamic Routing, Points of Interest (POI) Collection, POI Mapping, Route Poisoning, Personalization, Feedback, Crowdsourcing.

Abstract: In this paper, we present a novel mobile running application, Runamic. Runamic allows to generate dynamic routes, starting from any point in the city, whilst taking user preferences into account. A user can choose how long he would like to run alongside his preferred points of interest, such as waterways, parks and/or tourist hotspots. Based on these preferences, the characteristics of the road network/environment and feedback on previous runs, a route is generated. The suggested routes are smooth, avoiding too many turns and overlapping route segments. The generated routes can be changed dynamically. After the run, the user has the ability to rate the generated route, which will influence future route generation. In most cases, the graph and R-tree based algorithm generates nice smooth routes, leading to very positive user feedback on the dynamic routing aspect.

1 INTRODUCTION

Recreational running and walking are amongst the most popular sports in the world. Both activities have a very low entry-level as anyone can literally go outside and just start running or walking. Apart from these, there are other sport activities such as cycling, skateboarding, roller skating etc. that are very similar. People engage themselves in these kinds of sports activities for variety of reasons, ranging from health and fitness to fun, entertainment and relaxation. A wide range of research studies across the years (Ulrich, 1979; Mitchell, 2013; Triguero-Mas et al., 2015; Olafsdottir et al., 2017) portrays the effect of the role played by the environment, while performing outdoor activities. Thus, taking time for oneself and exploring the outdoor whilst not being restricted to a redundant, not so comfortable environment forms the vital part of all the above activities. This motivates the need for personalized routing.

To facilitate navigation and log the running performance, a variety of applications and devices are available. Routes can be planned in different ways and using a variety of already existing tools & applications. Based on their Route Planning ability, these applications could be broadly classified into two categories namely Database based Route Planning and Automized Route Planning. Of course, instead of using one of these digital tools, users can also consult the route books or leaflets that are offered by tourist offices (Figure 1a).

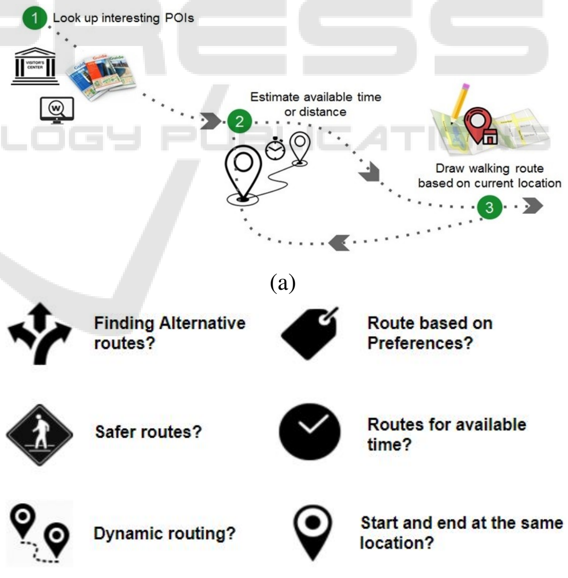


Figure 1: (*a.*) Traditional route planning methodology (*b.*) List of problems in traditional route planning applications.

The above mentioned traditional route planners are useful and definitely facilitate recreational running and walking, but they all have several problems

Chandrasekar, K., Arroubai, R., Dox, G., Nop, S., Stroobant, P., Stragier, J., Mey, K. and Verstockt, S.
RUNAMIC: Dynamic Generation of Personalized Running Routes.
DOI: 10.5220/0006889600980105
In *Proceedings of the 6th International Congress on Sport Sciences Research and Technology Support (icSPORTS 2018)*, pages 98-105
ISBN: 978-989-758-325-4

limiting the user experience. As shown in Figure 1b, the user is always limited to a couple of predefined routes passing by a preselected set of points of interest (POI). If they want to change these routes (e.g., shorten or extend their length), they need to estimate the time and distance of the new route segments themselves. Routes might have been created months or even years ago which would not be suitable for running or walking anymore. Furthermore, you have the lack of themed routes. Users don't always want to pass by neighborhoods or parts of the city that look bland. They would like to have some variation in their routes so they can be excited and motivated to start a new run or hike. For example, not many people would prefer a route near a busy motorway when compared to a route around a more pleasant neighborhood with enthralling landscapes (Ulrich, 1979). Thus, it would be better if people are presented with a list of different themes, allowing to generate a route according to their preferences. Lastly, the path and route conditions also play a vital role with regards to overall running experience. Better experiences not only result in more fun, but have also proven to be a form of motivation that paves way for an improved interaction and involvement (Mitchell, 2013).

Manually planning a route takes a lot of time and may prove to be difficult as the user may not be familiar with the region. In this paper we present the Runamic application, shown in Figure 2, that automates this tedious process and offers dynamic rerouting abilities. The remainder of this paper is organized as follows. The following Section 2 compares the existing related work in our context of usage. Section 3 presents the different types of data that are used as input for the route generation algorithm. Next, Section 4 presents the routing algorithm and discusses the optimizations that were investigated to improve its performance. Subsequently, Section 5 discusses our one-step process to add new types of (dynamic) POIs and section 6 focuses on the Android app. Finally, user engagement and evaluation is covered in section 7 and section 8 concludes this paper and points out directions for future work.

2 RELATED WORK

A user can, for example, create a route using a route plotting application and share this route with the user base like in (RouteYou, 2017) or the user can also choose between various databases of predefined/shared routes such as in (Contours, 2017) for walking or (RunKeeper, 2017; Runtastic, 2017; MapMyRun, 2017) for running. Another possibility is to use

Figure 2: *Runamic: A Dynamic Route Generation Application.* The figure shows an active running screen of the application. The green line segment in the figure denotes the currently followed running route while the blue one denotes a shorter route, requested dynamically during the run.

a smartphone or a GPS tracker to log the runners location and upload the route to a database (Gavin Maurice, 2011). Such database based route planning applications work on high quality existing routes, but they are inflexible and not personalized. Availability of these routes may differ strongly between urbanized and rural areas.

A more intelligent method of planning one's route would be a logical choice for the problems discussed above. Existing automized route planning solutions have some flexibility, but this is typically limited to some predefined user profiles (Stroobant, 2016). The user can draw a route by adding route markers on the map, which are then connected by a shortest path algorithm that can be configured to prefer or avoid certain types of roads (PlotARoute, 2017). These types of methods are not very user friendly for dynamic changes, since this scheme requires moving/adding markers while running. Google Maps is also a similar type of application that gives a simple algorithm-based point to point route generation, where the user provides his start position and destination. It is dynamic, yet customisation is still limited to only trans-

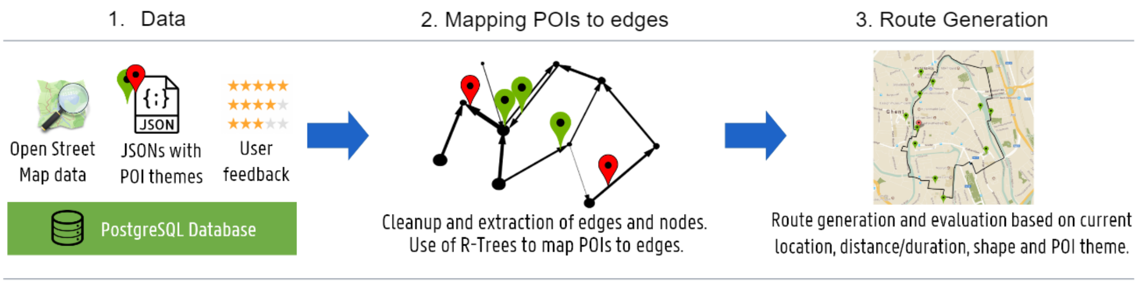


Figure 3: General workflow of Runamic.

portation modes. Finally, there are applications like route suggestions in (RouteYou, 2017) and (RouteLoops, 2017) that generate routes based on the theme or the preference of the user profile. The route planning is completely automatic, yet it is not dynamic.

Apart from these existing applications, there are a number of theoretical solutions such as (Hochmair and Fu, 2009; Hrncir et al., 2014; Su et al., 2010; Turverey et al., 2010), that find the shortest path between two nodes based on user-specified preferences or properties. Works like (Hrncir et al., 2015; Song et al., 2014) addresses the multi-criteria aspect of bicycle routing by looking for a set of Pareto optimal routes. (Storandt, 2012) focuses on the problem of finding Pareto optimal routes by prioritizing one of the many routing criteria. This application, on the other hand uses a weighted combination of criteria to search for optimal paths between two nodes.

3 RUNAMIC DATA

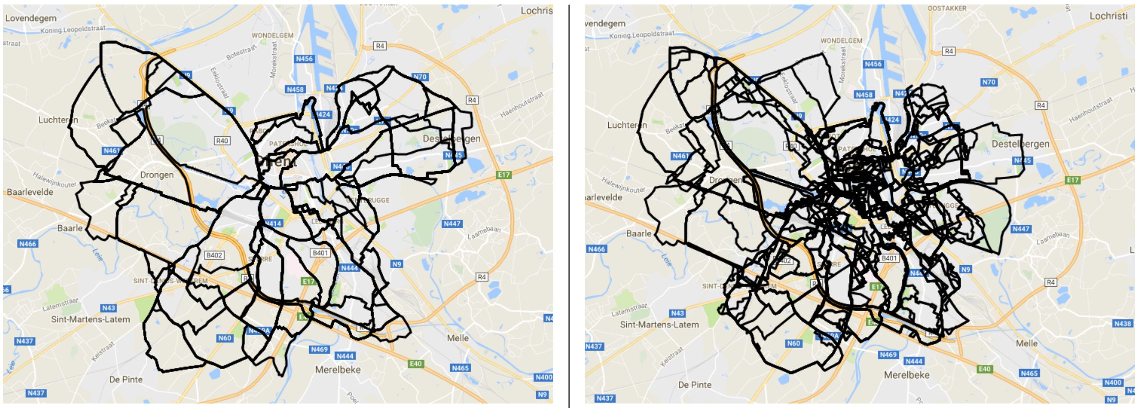
3.1 Map Data

The first part of the workflow, shown in Figure 3, is collecting data of the road network and processing this data so that it can be used within the route generation algorithm. Open map data of Open Street Map (OSM, 2018) is utilized to obtain the required nodes and edges structure of the road network such that an appropriate city graph could be generated. For acquiring the OSM data of a specific region (e.g., the city of Ghent), we use the OSM - Osmosis tool (OSM-OSMOSIS, 2018). This tool serves as an access point for OSM map data and allows to generate custom selected parts of the OSM-map based on the coordinates of the bounding box of the preferred region. The result of this query is the OSM-map data (nodes, ways, relations and tags) for the selected region that gets stored in a temporary XML-file. This XML file contains the following elements: *Nodes* represent locations or points on the map. *Ways* represent a polyline referencing the nodes that exist on the polyline. *Tags* describe specific features of map elements (highways, parks etc). *Relations* represent relationships that can't be described by nodes and ways.

On acquiring the data, pre-processing of the data is started by filtering out all the roads which are not suitable for pedestrians. We use the OSM tags associated with the "highway" tag to filter out all the unnecessary data. This is done with the help of the sub tags such as "motorway", which corresponds to extremely busy roads that are not suited for pedestrians. Further optimizations, such as using the activity loggings/heatmaps of a large database of recreational activities (e.g. RouteYou) are currently under development. The result is saved in a new XML-file which is then migrated to our PostgreSQL-database. In this migration step the nodes and the ways are added to two separate tables as nodes and edges in our database. Since roads can intersect other roads at non-end nodes, they are transformed by splitting them at intersections before they are added to the database. As a last step, we also remove intermediary node information and only keep the start and ending node of the segments.

3.2 Points of Interest (POIs)

To solve the lack of information required to generate themed routes or touristic routes, POIs were added to the database. Some of the common interest points, like waterways or green region points, can be acquired from the OSM tags. However, the OSM data does not have tags for all possible points of interest in the city. Thus, to enrich the "interest points" data, a new platform was developed which allow stakeholders to upload their own set of custom POI points in the provided json structure. For example, the tourist administration of the city could upload all tourist attractions points as themed sets for specific types of attractions. The upload to the POI database is also a simple one step process. Furthermore, additional tools were also developed for automatically generating these POI-data from popular existing open data formats, as further discussed in Section 5.



Without road burn | With road burn.

Figure 4: Comparison of 100 generated routes with and without road burn.

3.3 Mapping POIs to Edges

The POIs are uploaded to the server in the form of JSON and represented as nodes in the database. Since nodes cannot refer to ways (roads) directly, these POIs are stored as locations without any association to nearby roads. To connect these two elements, we need to match each of the POI nodes to the closest way. We realize this by using an R-tree data structure (Guttman, 1984) by which imaginary bounding boxes are built around the ways. These boxes form the base of the R-tree structure. This is used to speed up the search for the road that is closest to the POI.

4 ROUTE GENERATION

The actual creation of randomized cycles has been implemented as a server application, in order to be able to deal with increasing map sizes, to report on the usage, and to improve the running time of the algorithm.

4.1 Basic Generation

The cycle generation algorithm is based on several recent papers (Stroobant, 2016; Stroobant et al., 2018), which specify how cycles can be generated by first generating a path from the origin to a random point at a distance (the "rod"), and then generating a new path that connects the origin alongside a detour with the rod ("closing" the rod). This algorithm works in essence, but a few issues appeared not long after implementation, which are described in the subsequent subsections.

4.2 Feeding Extra Costs to Prevent Going Back the Same Way (Poisoning)

In order to create a detour that isn't identical to the rod itself, we mark the rod and the space around it with an extra cost. The paper (Stroobant, 2016) computes the distances using a graph search, saving all edges in a certain radius. This is memory expensive. Instead, the server uses a linear approximation between the nodes at 12% and 37% of the rod, since they convey the general position and direction of the rod the most accurately. In the second step of the algorithm, only a part of the rod is reused, and statistically this part is exactly half as long as the original rod. Therefore, the 2 selected nodes are the first and third quartile of the expected useful sub rod. Additionally, instead of using a linear function for poisoning, corresponding to

$$\frac{L_{\text{perceived}}}{L_{\text{actual}}} = 1 + \max\left(0, \frac{D_{max} - D}{D_{max}} \cdot \alpha\right)$$

we use an exponential decay function for poisoning:

$$\frac{L_{\text{perceived}}}{L_{\text{actual}}} = \exp\left(\left(1 - \frac{D}{D_{max}}\right) \cdot \alpha\right)$$

Originally this change was made to create larger cycles, but this choice also turned out to be the cheaper option when increasing the coverage.

4.3 Increasing the Coverage

We enhanced Dijkstra's algorithm (Cormen, 2001) with Pareto fronts: instead of saving a best cost for every node in the graph, a vector of Pareto optimal solutions is stored for every node. This allows us to use multidimensional cost functions and to find the shortest path from start to end for every linear combination of the input. This is done because sometimes the usage of an algorithm only yields routes that are slightly too large or too small, and adding a second dimension yields an increased amount of routes with a higher variance, and thus a higher probability of generating a cycle that satisfies our constraints.

As the cost function, we use two randomly chosen instantiations of the hyper parameters, which are a small distance apart, namely 8% of the total route length. Larger differences than that will slow down the execution too much.

4.4 Routing through POI's

When we try to route through POI's, a first attempt would be to reduce the cost of the road that contains the POI. However, if this road is short, then reducing the already low cost of going through that road would not influence the cycle generation. A first attempt to fix this is to set the cost to a negative value. Unfortunately, in this case the routing algorithm will stop working, especially when a negative cost cycle is created. Alternatively, we could reduce the cost of all routes close to the POI as well, but this would encourage the routing algorithm to route close to the POI but potentially miss it, which might not be what we want. So, an alternative technique is proposed: whenever a POI is hit, a potential cost is saved in the cost structure, and every subsequent road hit will be cheapened and the potential cost reduced. This forces the algorithm to route through the POI's without introducing negative cycles. In practice, we use a potential with an exponential decay. This has the added advantage that we can simply approximate the cost factor using the potential function itself.

4.5 Randomisation

Since we don't want to navigate the user(s) by the same routes over and over, we decided to add a randomisation aspect to our routing methodology. At this point, it is possible to create a random cycle, and if we look at the randomness from the perspective of the route itself, we see that most routes only have a small part in common, and that they are quite distributed. However, if we look at the randomness from the perspective of the distinct roads, we observe that some roads are included quite often in the routes, while other roads are never included at all. To address this issue, we introduce two features:

- The cost of traversing a road in Dijkstra's algorithm is multiplied with a random number between 0.1 and 0.9. This change allows the algorithm to create shortcuts through small alleys;
- Every route creates road burn, i.e., a small cost that is added to the route segments to avoid repetitive usage of a central road.

As shown in Figure 4, this change improved the seeming randomness of the cycle generation by a large amount.

5 POI GENERATION AND UPLOAD

In order to facilitate the generation of POIs and to easily upload POI datasets to the RUNAMIC server, three POI management tools were developed. The first tool, shown in Figure 5, allows stakeholders to draw dynamic POI regions (e.g. regions that can only be run during the day because of safety reasons). Both positive and negative POI regions can be created and additional metadata can be added to define the validness information of the particular polygon or rectangular region.

Subsequently, this tool automatically creates the POI data (in JSON format) that can be uploaded to our server. The second tool extracts location entities from text data with a geographic entity recognition (GER) algorithm and transforms the location data into POI coordinates using a geocoder. Figure 6 shows some results of evaluating this tool on a collection of historic pictures from the CegeSoma dataset. As seen, this tool allows us to easily map non-spatial data when it contains sufficient location information in its textual descriptions. Finally, some scripts were also developed to automatically generate RUNAMIC POI datasets from some popular open data formats (e.g. csv, kml and geoJSON).

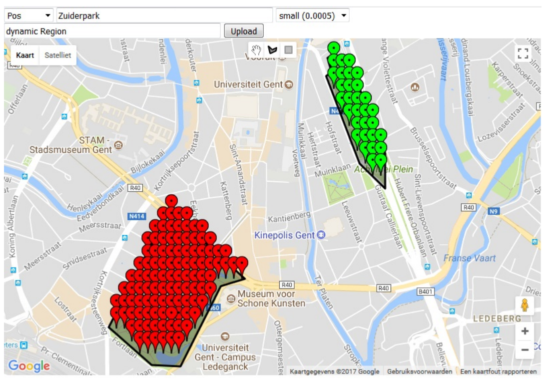


Figure 5: Tool for drawing dynamic POI regions.

6 ANDROID APPLICATION

To test out and visualize route generation, an Android application was developed (shown in Figure 7). The application has been published to the Google Play Store for user testing and provides all the tools to go running/walking. Apart from the normal routing capabilities, the app also allows users to link their heart rate monitors for a wholesome interaction. The general flow of the app is as follows: first there is a main screen where the map gets rendered. Then there is a route settings tab where the user specifies his preferences (Figure 7a) and POIs for the route generation (Figure 7b). Previous runs are stored in the application and get shown in the history tab. Finally, a profile tab is present, where the user can see all his statistics (speed,distance,average heart rate) and can change the settings of the application.

6.1 Route Preferences

The route preferences in the route settings tab consist of two main elements. The first element is the distance/time the user would like to run. The user can

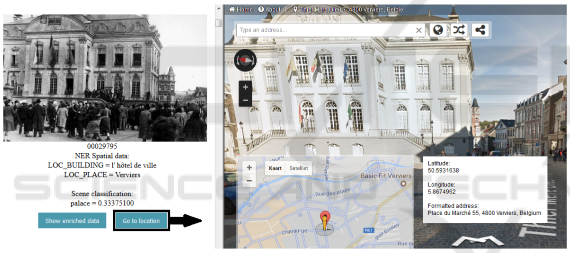
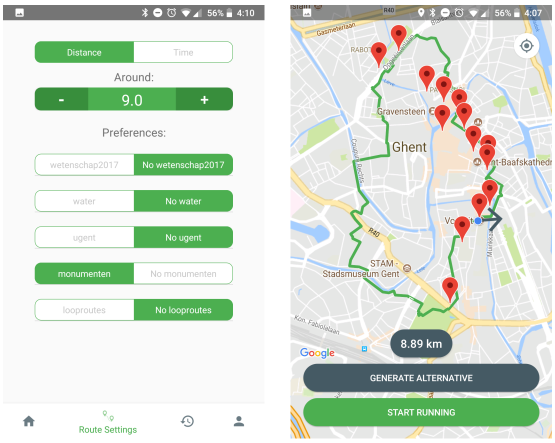


Figure 6: Geographic entity recognition (GER) tool to extract locations from textual metadata of images.



(a) *Preference screen* (b) *Routing screen*

Figure 7: (*a.*) The *preferences screen* used for obtaining user preferences. (*b.*) The main *routing screen* where the generated route along with the nearest preferred POI points are displayed.

choose the preferred time or distance. For the time parameter, a level system (beginner, intermediate, expert) which determines the average speed is used. In a later stage this parameter would be determined based on the user base, but for now they are default parameters. The second element allows to make a selection among the available POI themes. When the application boots up it requests all the possible POI themes from the server. The user then chooses which ones he would like to add to generate his personalized request.

6.2 Route Generation

When the user has chosen the variables for his route, he can go back to the home screen and generate a route. The application sends a request to the server containing the current location and the preferences of the user. The server then generates a route and sends it to the application. The body of the response contains all the nodes for the route, directions and the nearby/used POI nodes. The application renders the route on the map, and allows the user to generate an alternative tour. Finally, if the user likes the route he can start running. While running, the app saves statistics and provides audio instructions. When the user finishes, he gets the option to give the route a rating. The application sends this rating to the server and the weight of the edges get updated for future route generations.

6.3 Dynamic Routing

In the application the user has the option to change his route while running. If a user changes his route, the application dynamically adapts the planned tour. For example, if the user takes another turn than instructed, a new route will be requested continuing from his current position but returning to the original end point. Other actuators for dynamic routing are:

- **Heart Rate:** When the heart rate of the user reaches a lower level than the minimum threshold, a longer route gets generated. When the heart rate of the user reaches a higher level than the maximum threshold, a shorter route gets generated.
- **Average Speed:** Similar to the heart rate the route can be manipulated based on the average speed of the user.
- **Buttons:** In the application, the user can also touch the plus or minus button to increase or decrease the length of the route dynamically whilst running.

7 EVALUATION

The first version of the application server was tested using a web-application that was used by the city of Ghent to navigate to various Ghent University locations, during the 200 years of Ghent University celebrations. Following the enormous support to the initiative, the android application was formally released and was made available for download in the Android Play Store from the 17th of October in order to perform a first hand evaluation on user engagement and performance. The app was limited to the region of Ghent for feedback and development purposes, but can easily be expanded to any area. The app had an extremely welcoming opening with approximately 1000 unique users logging in and using the app in the first two months (as can be seen in Figure 8). This in turn proves the necessity for a more personalized routing application in performing day to day running and walking activities. There were people of different age groups and the feedbacks obtained from them were greatly positive.

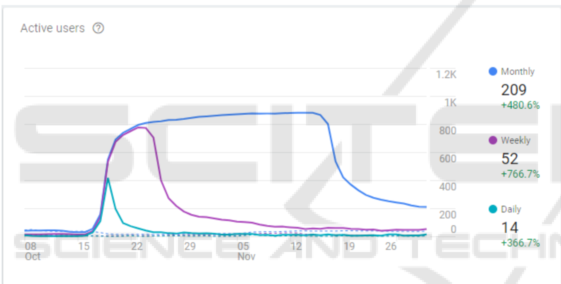


Figure 8: *Active Users graph* for the first evaluation period.

Between the first two months, there was on an average 105% increase in the utilization of running activity of the app. User feedback was crucial in rating unclassified roads, which makes the application constantly better. The tool for making POIs was also an advent of feedbacks. There is a lot more feedback coming in and evaluations are instrumental for the future prospects of the application. A more comprehensive user study has also been planned with the current set of users to obtain a more introspective review of the application from the end users.

8 CONCLUSION AND FUTURE WORK

In this paper we have introduced a mobile application which allows generation of dynamic routes starting from any point in the city based on user preferences. The application has been rolled out for public usage and its functionalities have been limited to the city of Ghent for evaluation, testing and developmental reasons. Currently the application contains a collection of POI datasets covering a variety of themes ranging from nature (parks, water) to tourism (monumenten) and special POI themes. In most cases, the graph and R-tree based algorithm generates nice smooth routes, leading to very positive user feedback on the dynamic routing aspect.

Currently, the application supports only one city - Ghent. In the future it would be expanded to multiple cities and eventually the whole country. Another working point would be adding a theme for safety (negative and positive points of interest) and more interesting points in general. Also, currently the functionalities have been limited to walking and running tasks but could also be extended to other activities involving similar routing requirements.

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