

Development of Route30

A Free and Open-Source Software Client-Side Routing Library

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Texas GIS Forum

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Generated Route
Distance: 5.7 km (click to toggle tour)

Recommended Tour:

- 3: St. Louis Catholic Church
- 2: Jungman Haus
- 16: Patterson/Renken/Bourquin/Higdon House
- 13: Henry Vonflie House
- 14: Joseph Naegelin House
- 28: Joseph Schorp House
- 7: The Charles Naegelin House
- 24: Arcadius Steinle House

Leaflet | Map data © OpenStreetMap contributors

Overview

Objective:

- To develop a user-configurable* client-side routing library
- Demonstrate its functionality in an historical walking-tour web app

Characteristics of Route30:

- Free and open-source software (FOSS)
- Easy, affordable solution
- Client-side library
- Dynamic route generation



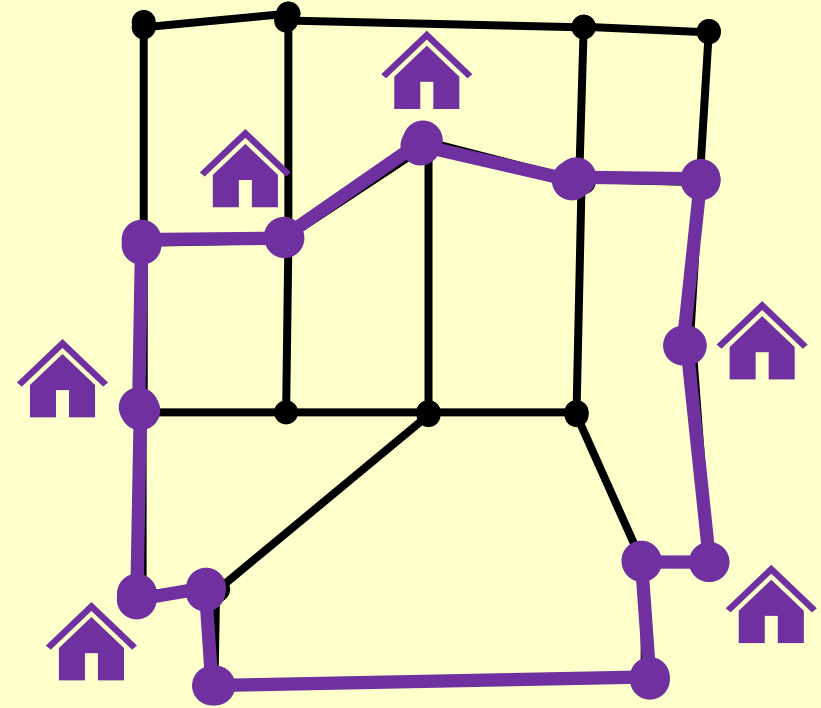
Henri Castro Homestead in Castroville, Texas - 1845

*User-configurable: the library allows an app user (or tourist) to filter points of interest (POIs) and constrain the route.

Outline

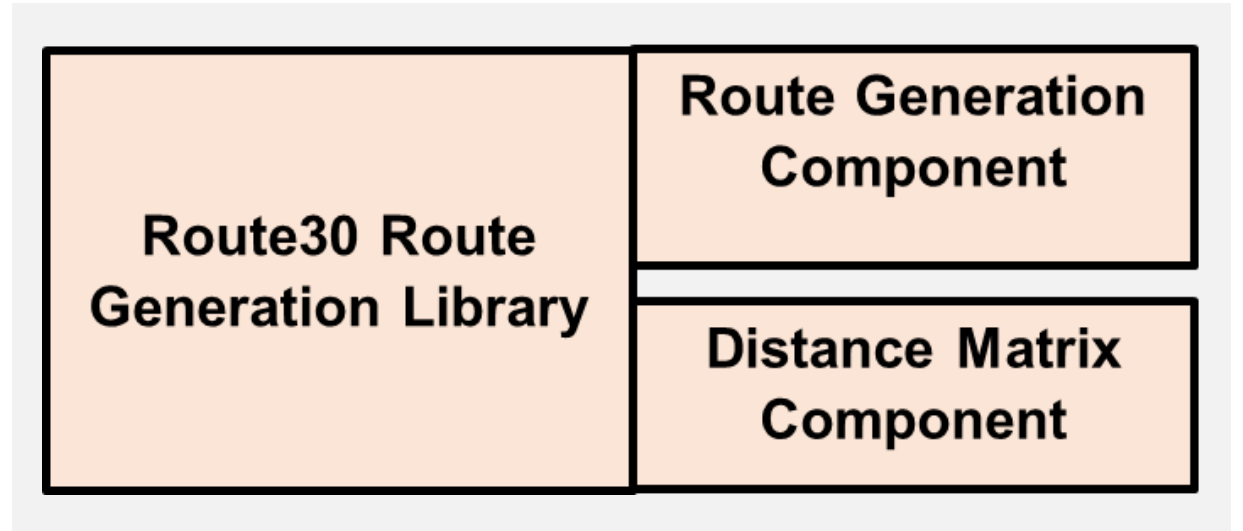
- **Background on routing**
- Routing library design
- Web app implementation
- How you can use the library
- Benefits to using the library

Routing: An optimal path is defined in a real-world geographical space through user-defined points of interest.



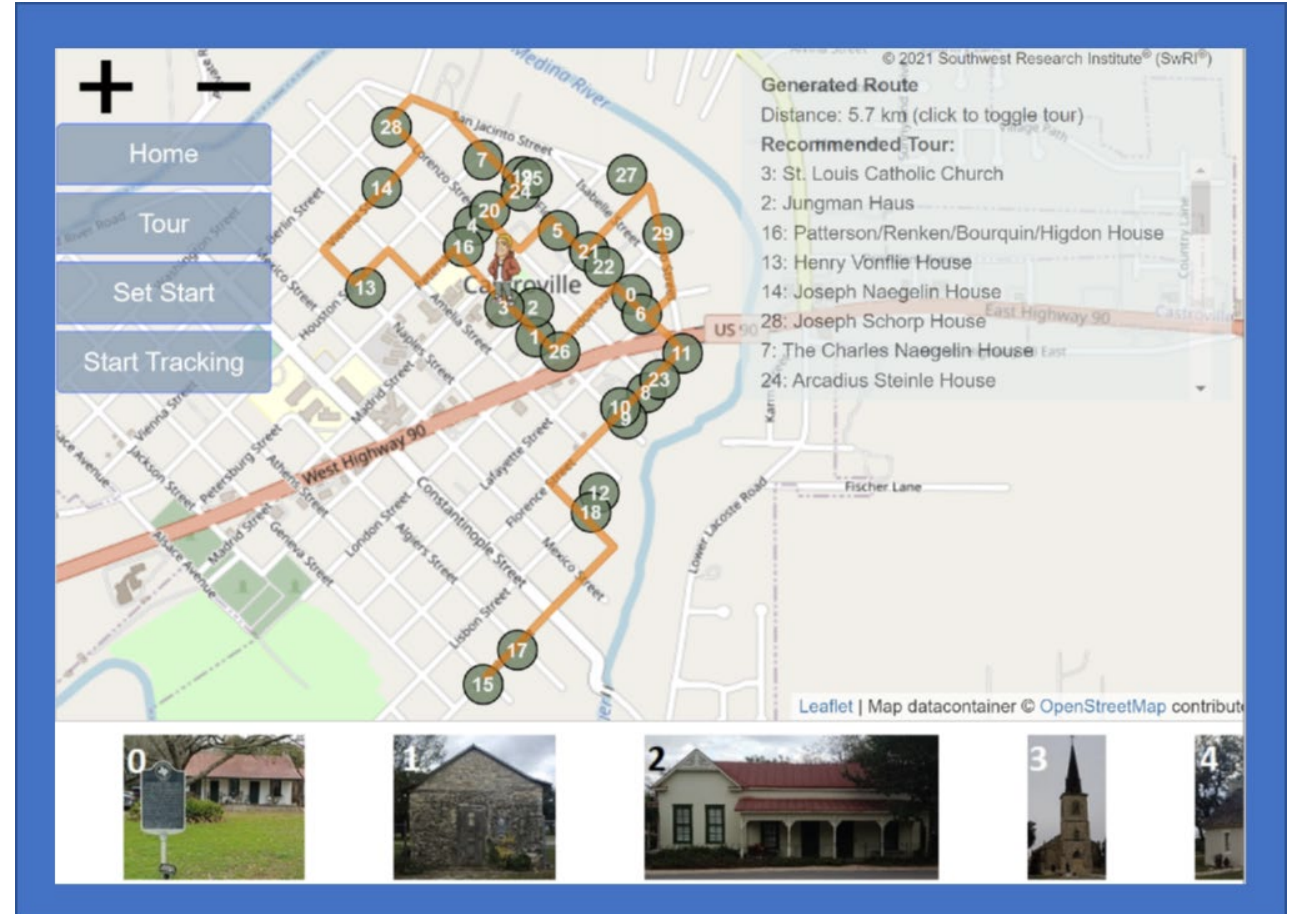
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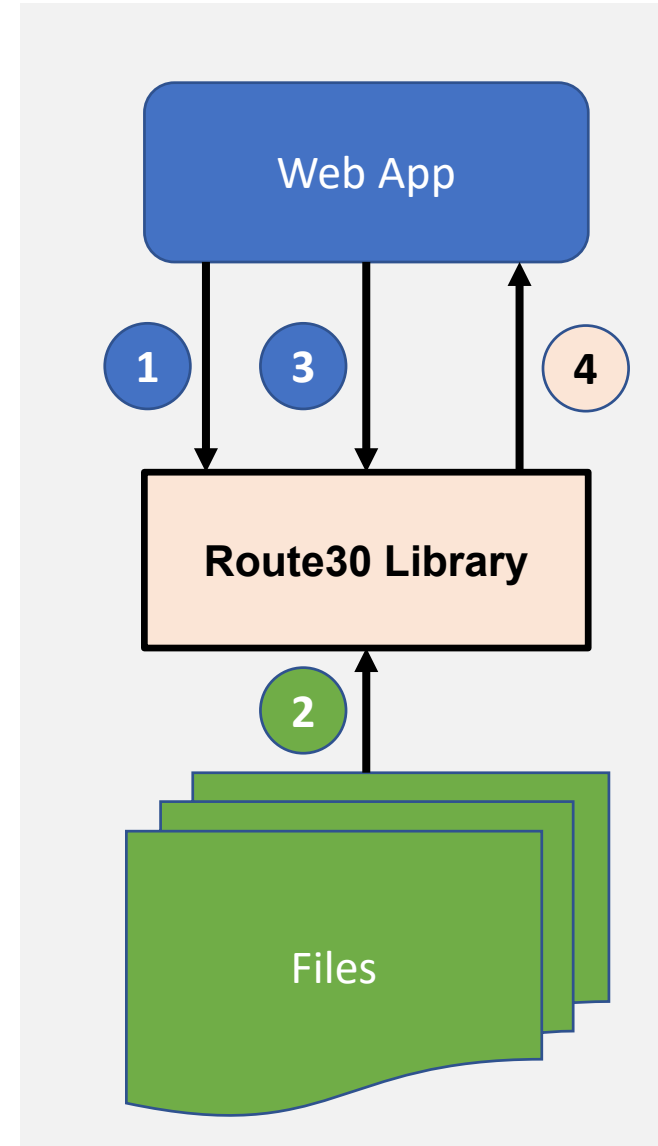
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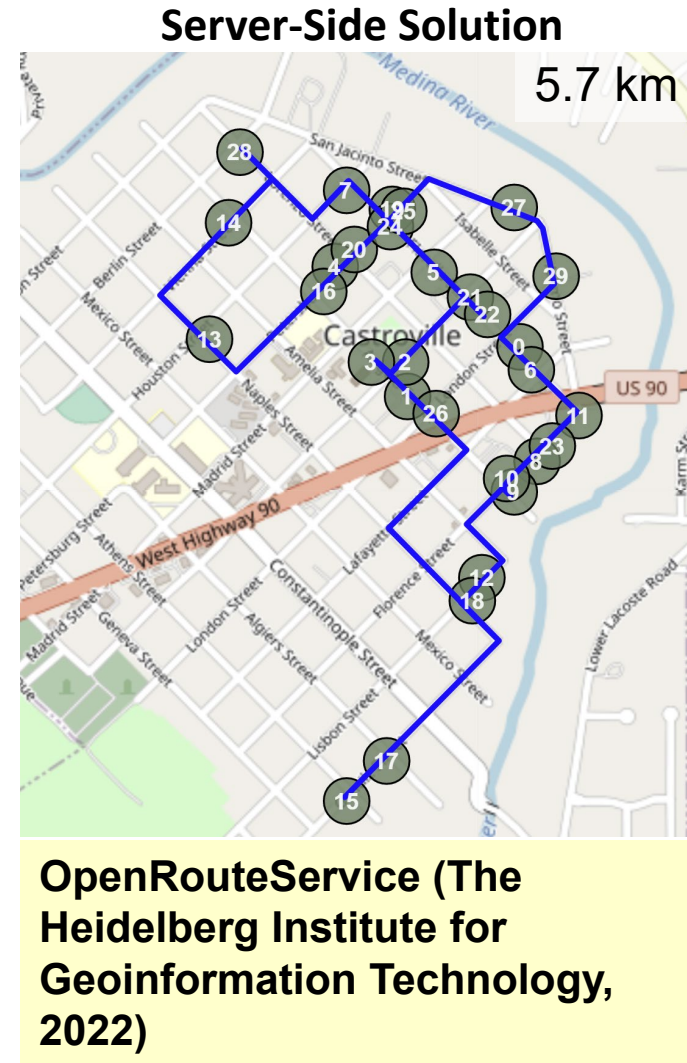
Outline

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Outline

- Background on routing
- Routing library design
- Web app implementation
- How you can use the library
- **Benefits to using the library**



Background

Routing Library Design

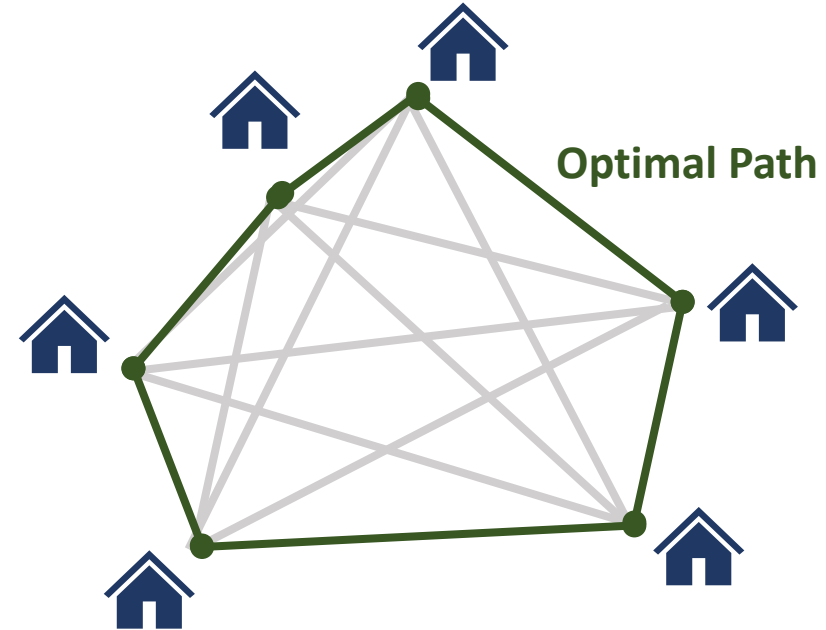
Web App Implementation

How You can use the Library

Benefits to using the Library

The Traveling Salesman Problem

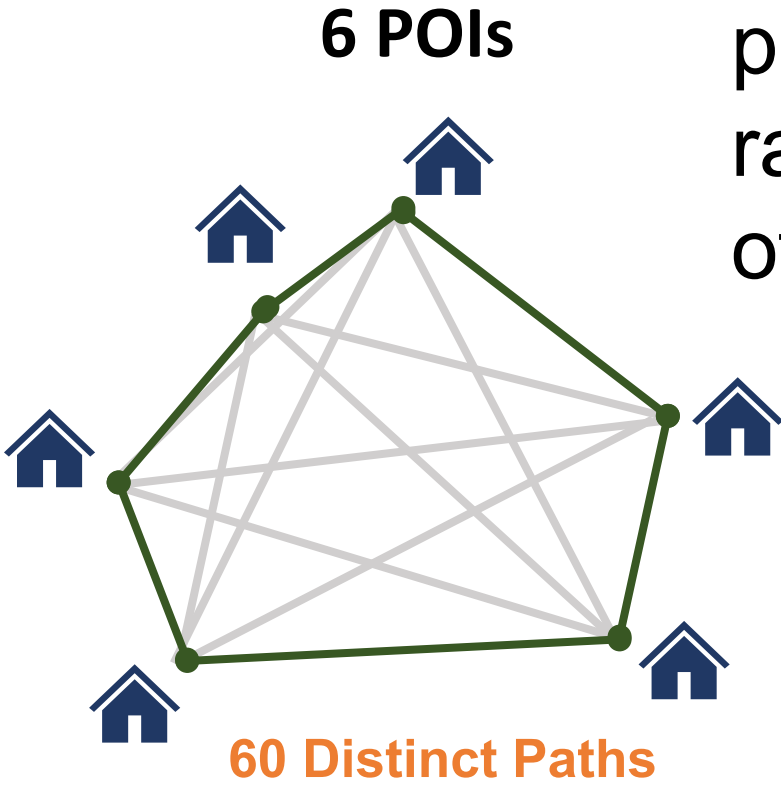
Given a set of Points of Interest (POIs), find the optimal (i.e., shortest) path among those POIs.



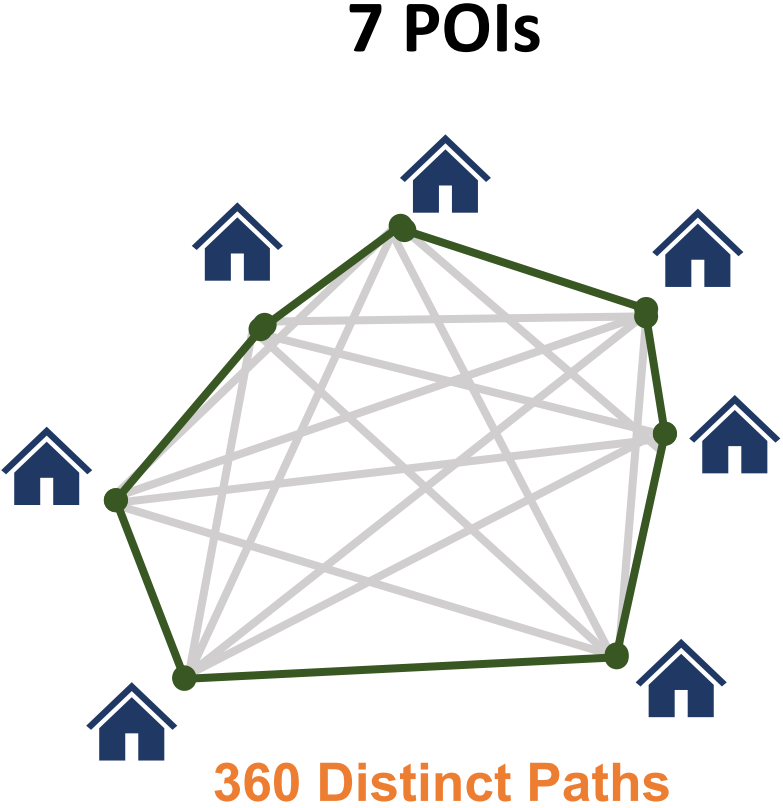
Optimal Path through Six POIs

The Traveling Salesman Problem

Number of distinct paths goes up rapidly with Points of Interest (POIs)



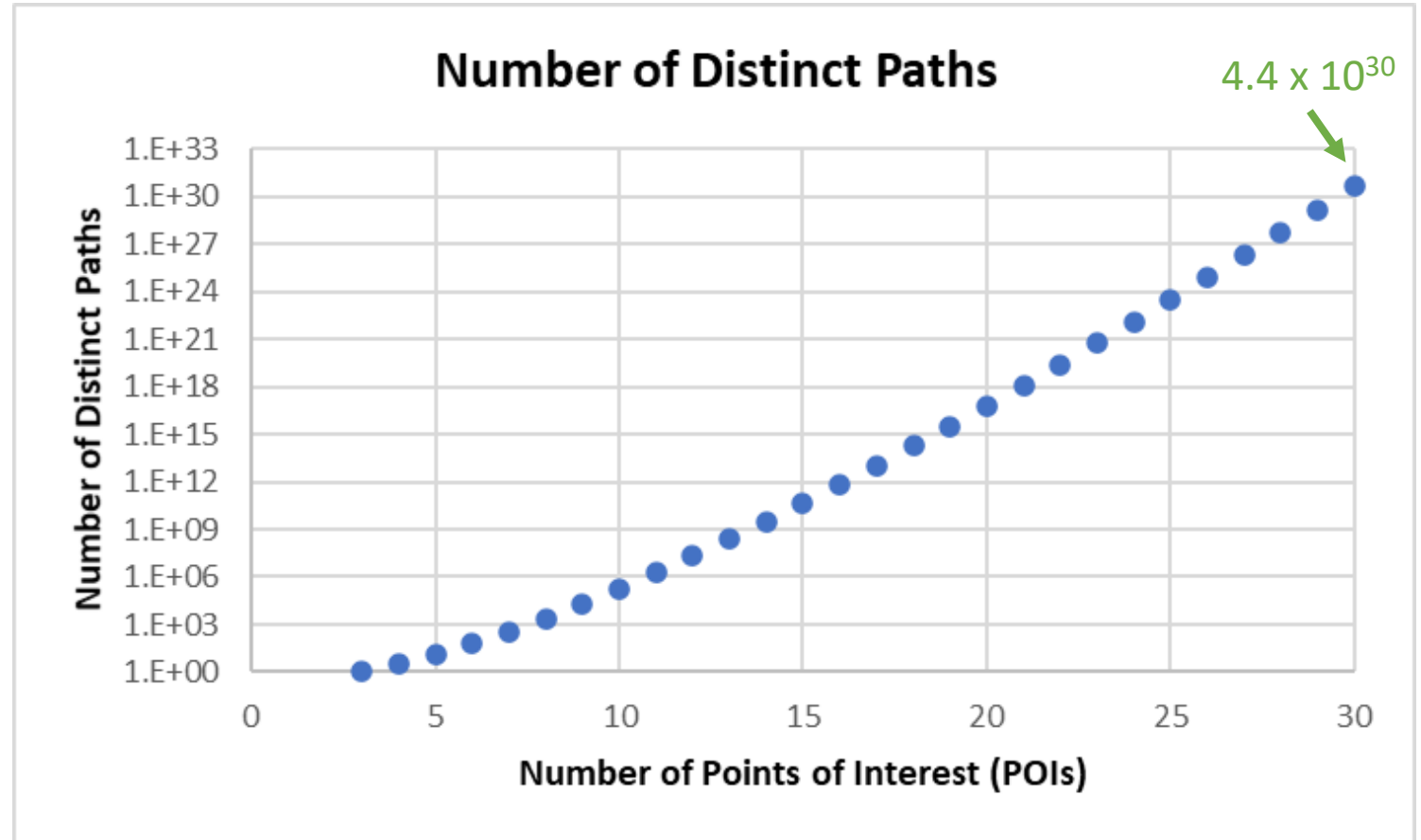
Add one more POI



The Traveling Salesman Problem

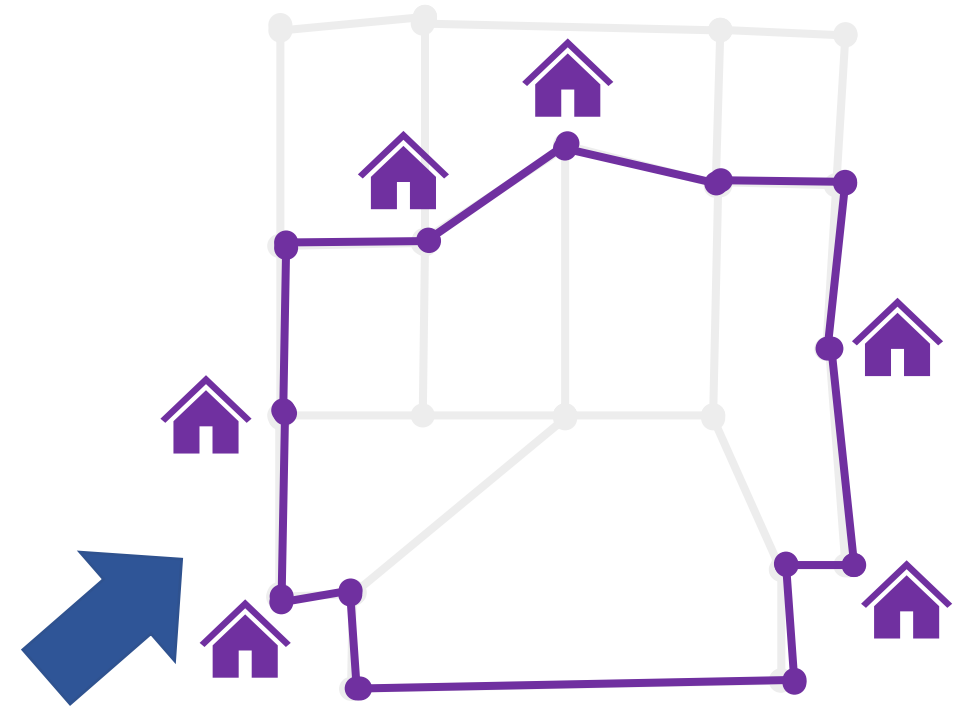
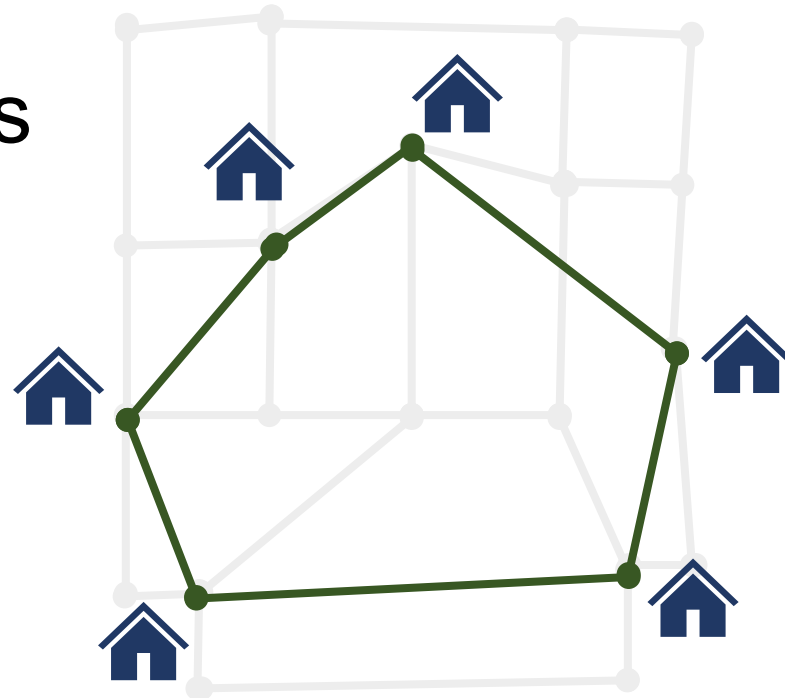
Paths increase as $(n-1)!/2$, where n is the number of POIs (Curry, 2020)

- Brute force solution quickly becomes infeasible
- Find a solution close to the optimal (i.e., shortest) route



The Traveling Salesman Problem

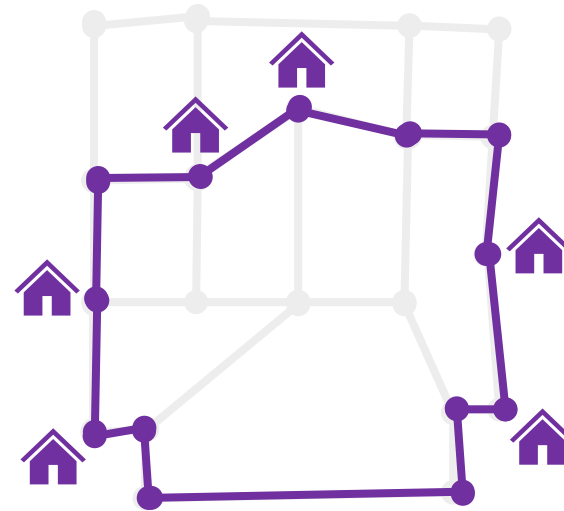
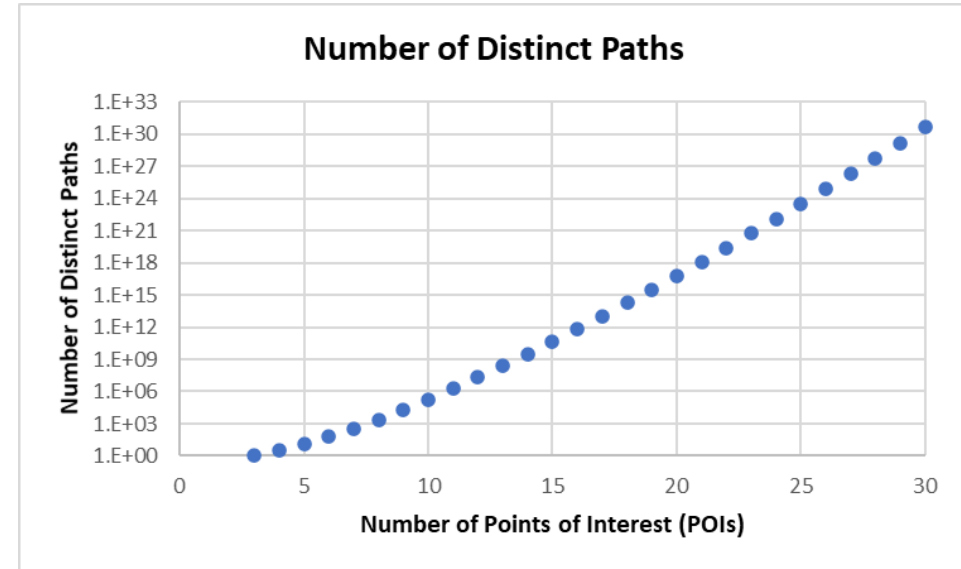
Also, paths are frequently not simple straight lines between POIs



Paths follow a street network

Goals for the Route30 Routing Library

- Find a solution close to optimal, efficiently
- Build the path along a street network
- Manage constraints
 - User
 - Street network



Background

Routing Library Design

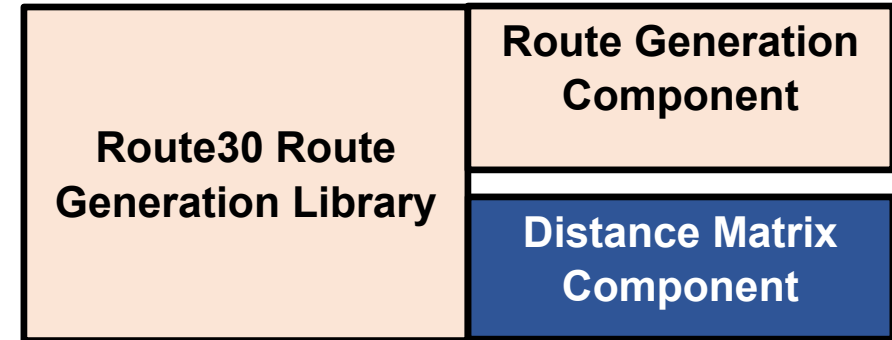
Web App Implementation

How You can use the Library

Benefits to using the Library

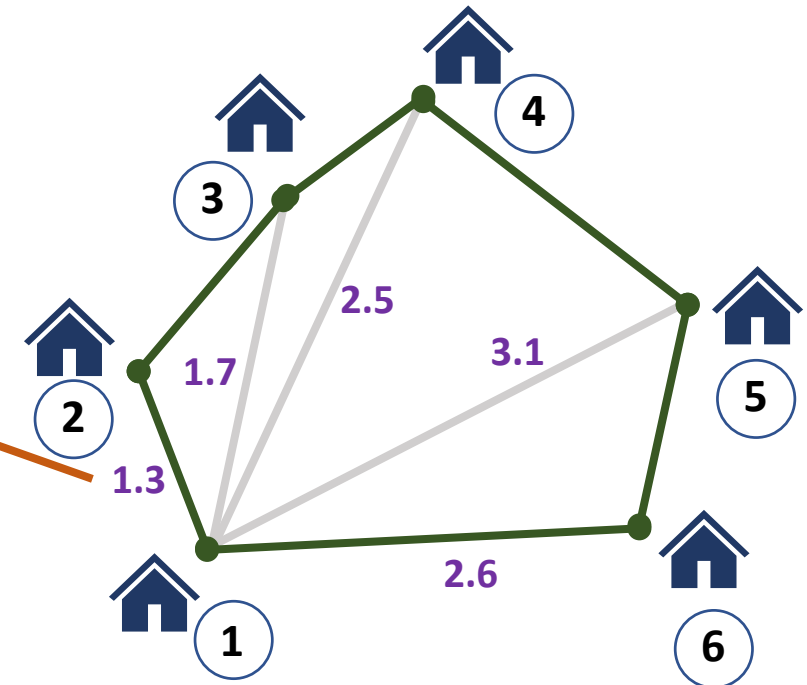
Distance Matrix Component

Find the shortest path between every pair of POIs



| POI → | 1 | 2 | 3 | 4 | 5 | 6 |
|-------|------|------|------|------|------|------|
| ↓ 1 | Null | 1.3 | 1.7 | 2.5 | 3.1 | 2.6 |
| 2 | 1.3 | Null | 1.2 | 1.8 | 2.1 | 1.9 |
| 3 | 1.7 | 1.2 | Null | 0.9 | 1.4 | 1.7 |
| 4 | 2.5 | 1.8 | 0.9 | Null | 1.9 | 1.2 |
| 5 | 3.1 | 2.1 | 1.4 | 1.9 | Null | 0.7 |
| 6 | 2.6 | 1.9 | 1.7 | 1.2 | 0.7 | Null |

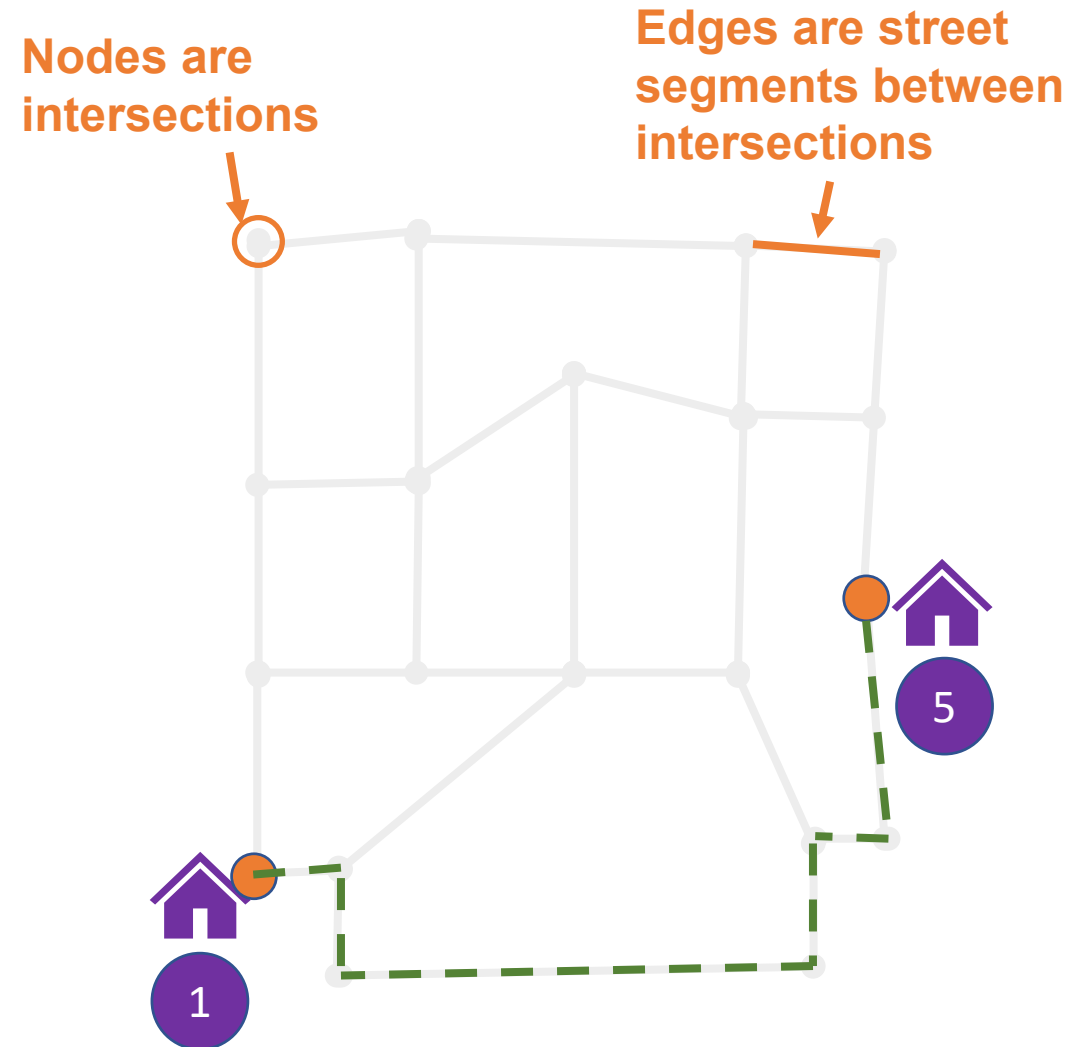
1.3 km from POI 1 to POI 2



A-Star Algorithm

Finds the shortest path between two POIs

Searches along the nodes and edges of a street network

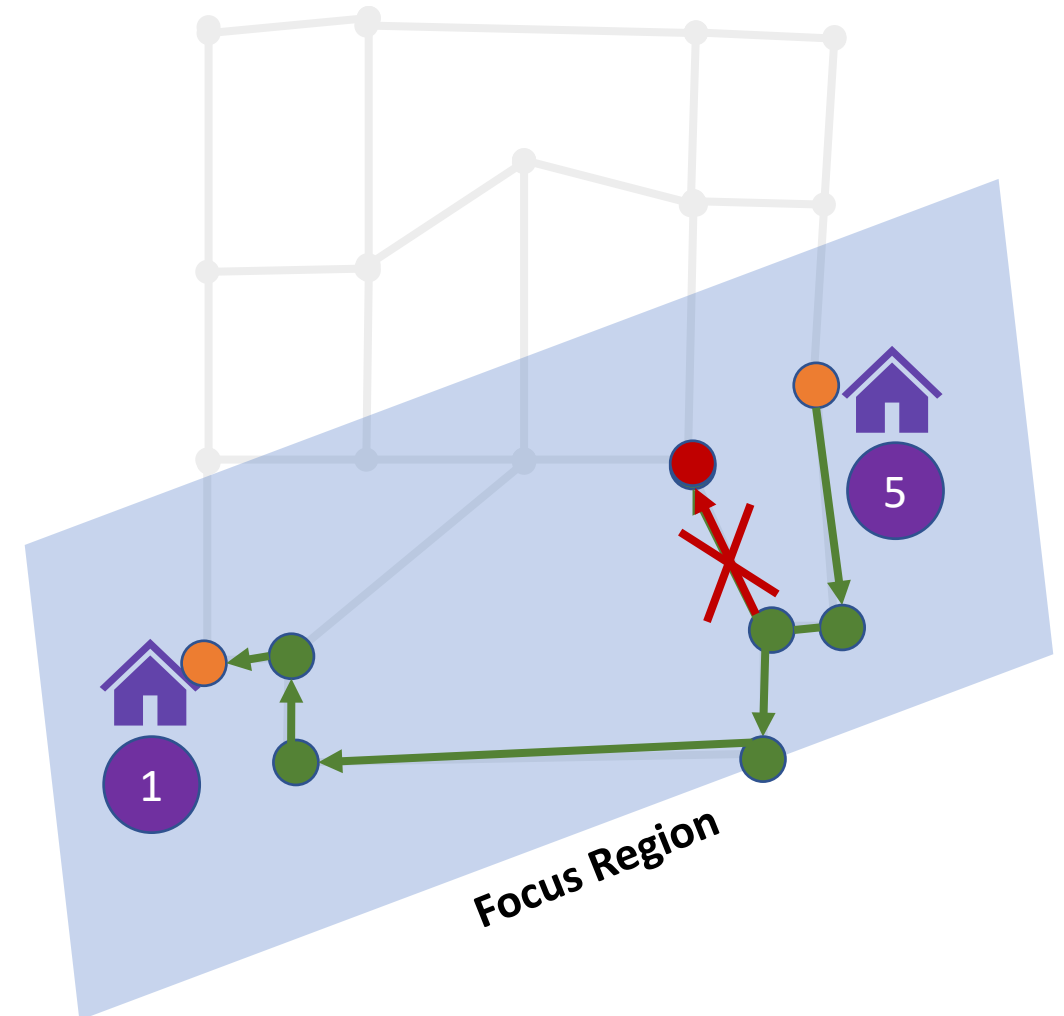


Lester (2005), Roy (2019), and Swift (2017) describe the A-Star algorithm.

A-Star Algorithm

Focuses on paths directly between the two points

Can backtrack to identify alternative, better paths



Barriers Exist on Street Networks

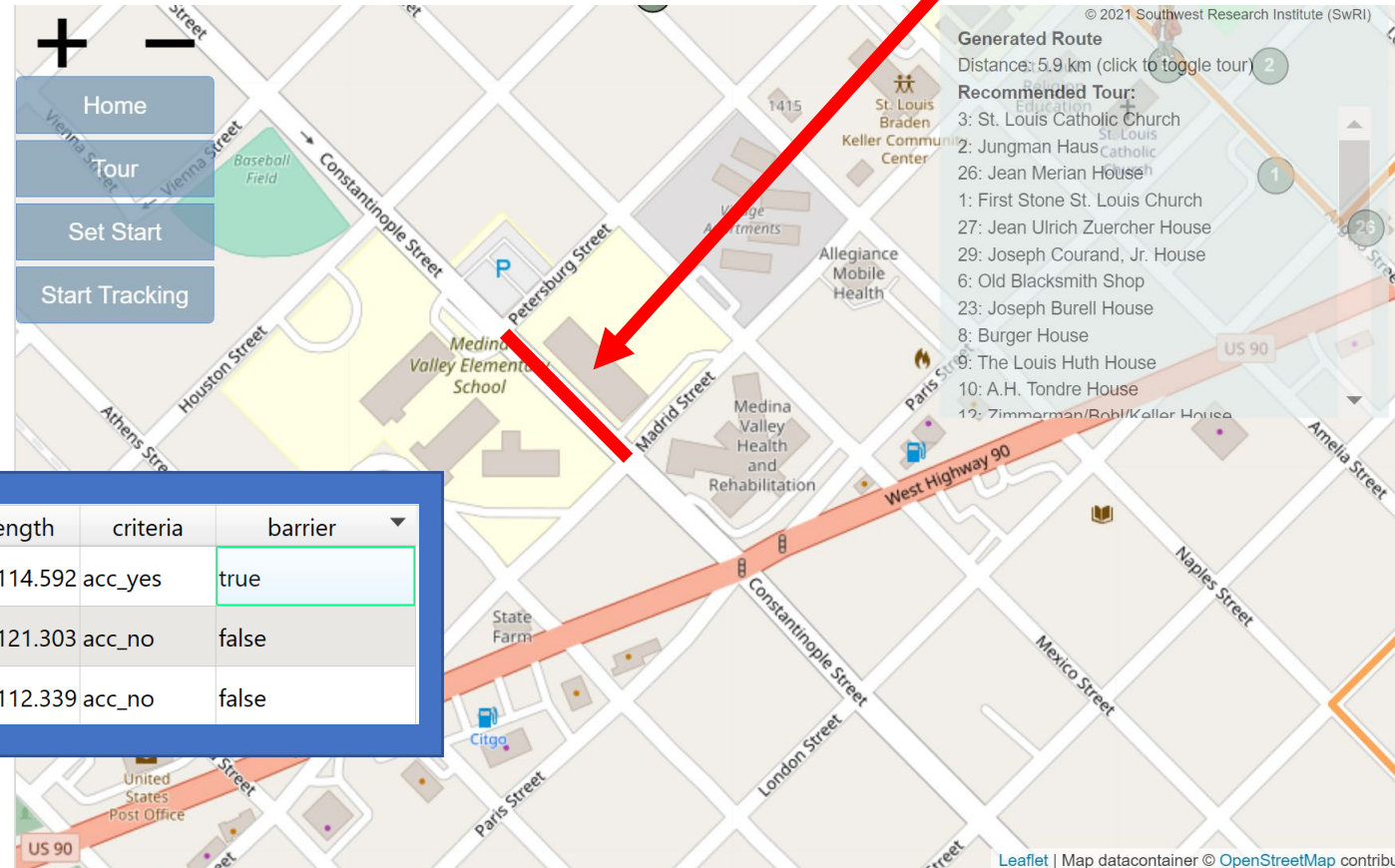
1. Street segment (edge) barriers

2. Intersection (node) barriers

Street segment (edge) passes through elementary school campus and is fenced off.

| | id | from | name | to | length | criteria | barrier |
|---|-----|-----------|--------------------|-----------|---------|----------|---------|
| 1 | 297 | 227263518 | Constantinople ... | 227202084 | 114.592 | acc_yes | true |
| 2 | 230 | 227263502 | Paris Street | 227190341 | 121.303 | acc_no | false |
| 3 | 231 | 227234010 | Paris Street | 227190341 | 112.339 | acc_no | false |

Edges File



Street network is from Harvard Dataverse (Boeing, 2017).

Barriers Exist on Street Networks

1. Street segment
(edge) barriers

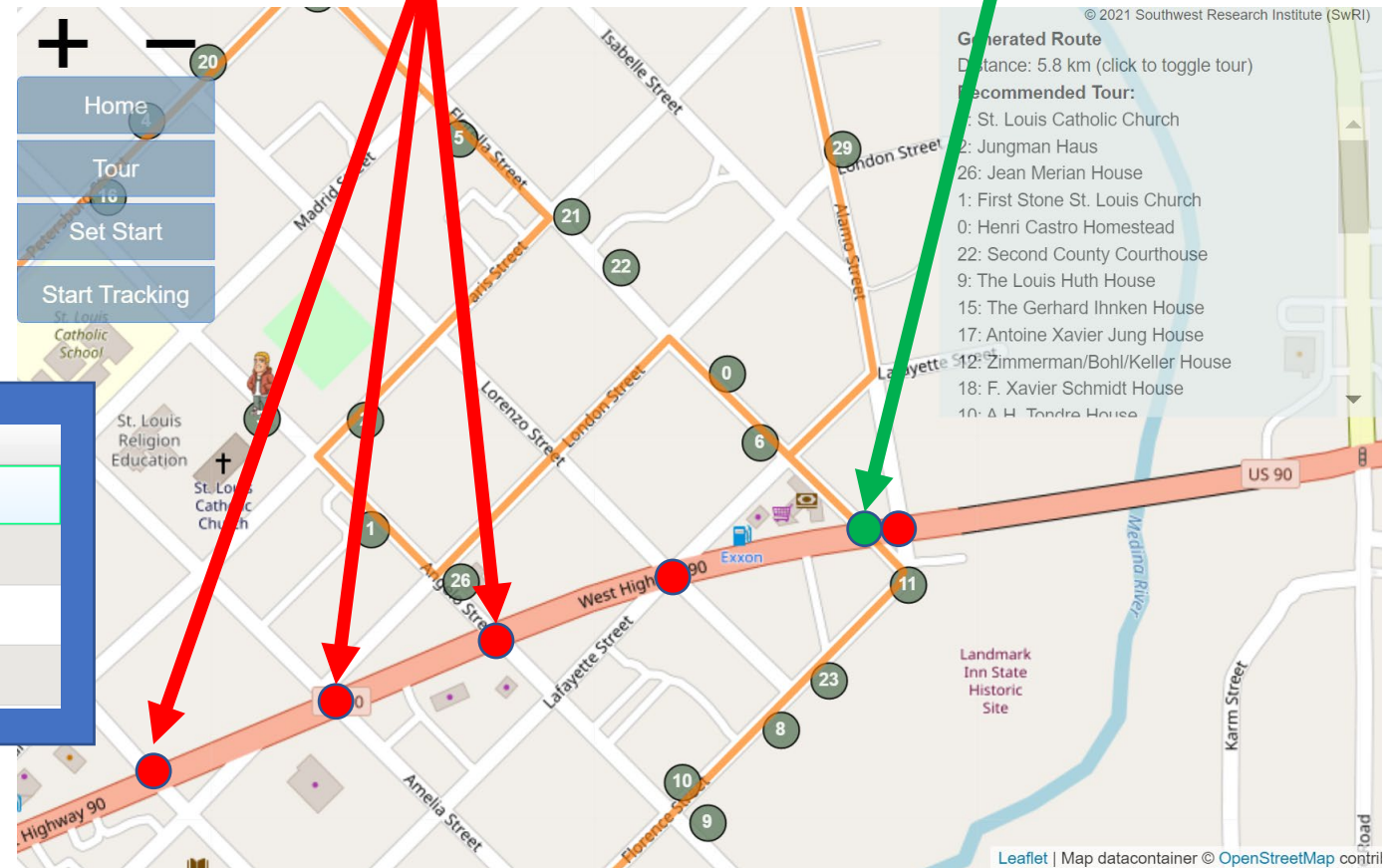
2. Intersection
(node) barriers

| | id | barrier |
|---|-----------|---------|
| 1 | 226969131 | true |
| 2 | 226969135 | false |
| 3 | 227004194 | false |
| 4 | 227004212 | false |

Nodes File

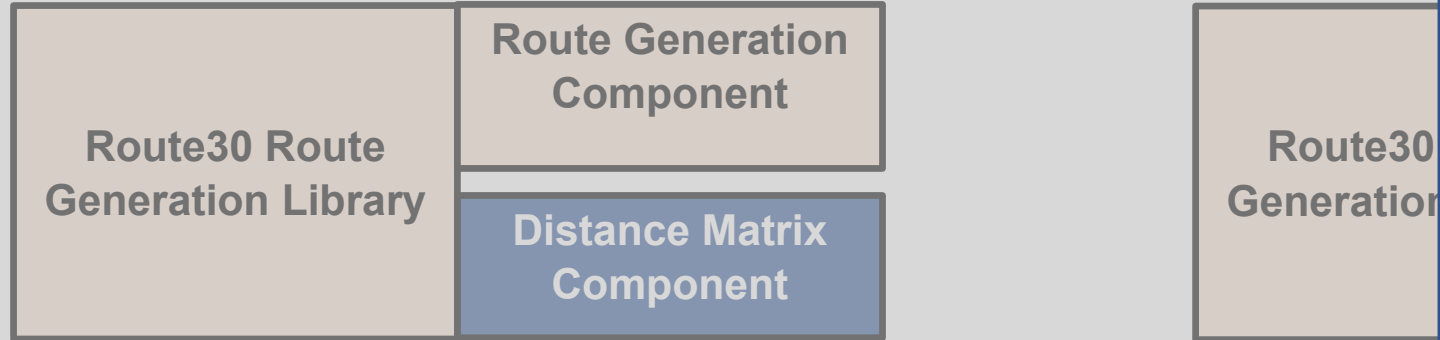
Highway 90
splits the
historic district.

One of two
crosswalks



Street network is from Harvard Dataverse (Boeing, 2017).

Routing Library Design



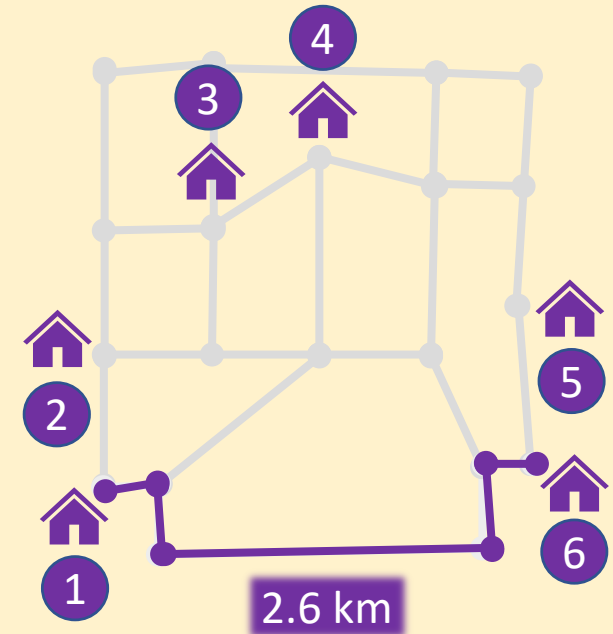
Creates distance matrix for
Route Generation
Component

Input is a POI file and a
street network (nodes and
edges files)

| POI → | 1 | 2 | 3 | 4 | 5 | 6 |
|-------|------|------|------|------|------|------|
| ↓ 1 | Null | 1.3 | 1.7 | 2.5 | 3.1 | 2.6 |
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| 5 | 3.1 | 2.1 | 1.4 | 1.9 | Null | 0.7 |
| 6 | 2.6 | 1.9 | 1.7 | 1.2 | 0.7 | Null |

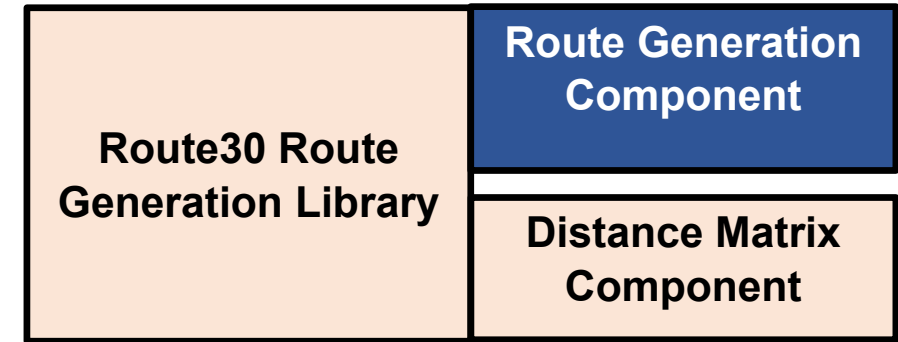
Distance Matrix

Each cell contains the
shortest path and its
associated distance

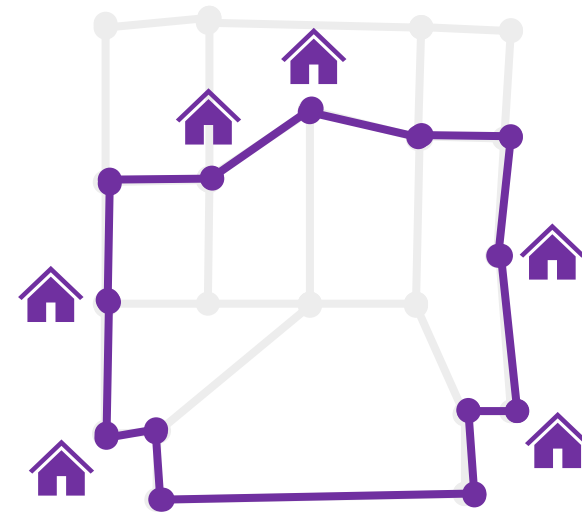


Route Generation Component

Finds a best solution
and generates a route
that is close to optimal

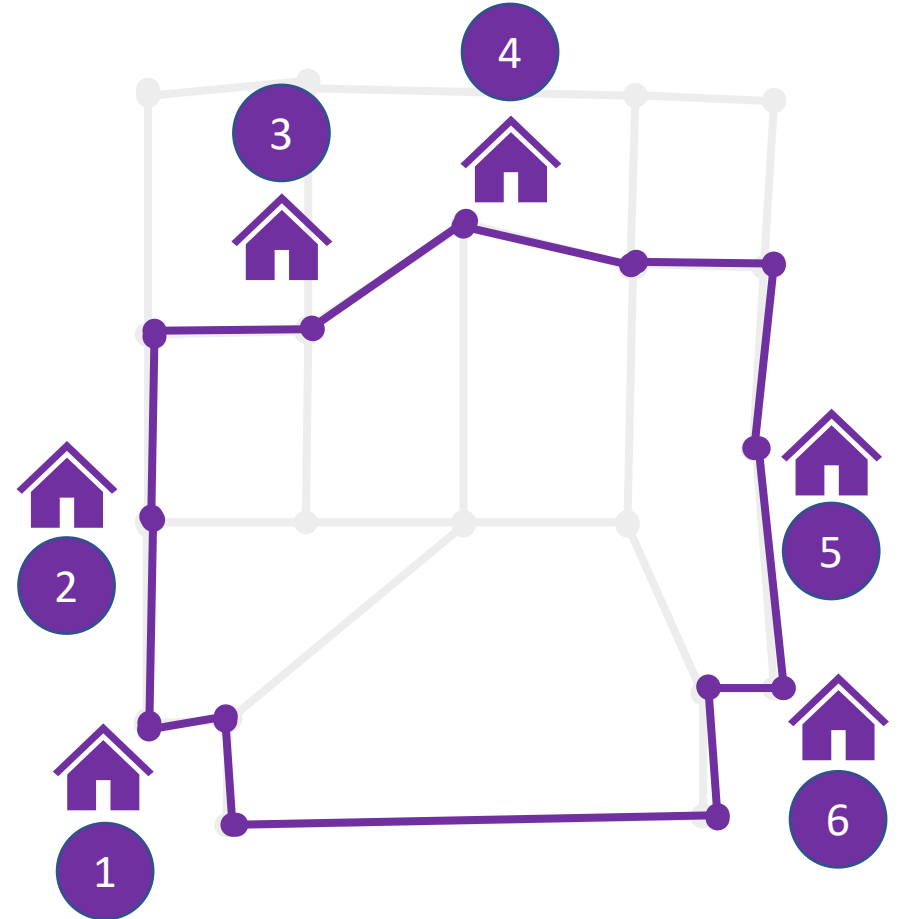


Simulated annealing



Simulated Annealing

- Analogy to metallurgy – lower the temperature slowly
- At each “temperature” test alternatives
 - Perform transport or reversal
 - Check the new total distance
 - Accept a better solution
 - Maybe accept a solution that is not better
- Goal is to find a global minimum where many local minima may exist



Lojkin (2018), Jacobson (2013), Press et al. (1992), Schneider (2014), and Walker (2018) describe the simulated annealing approach.

Simulated Annealing - Example

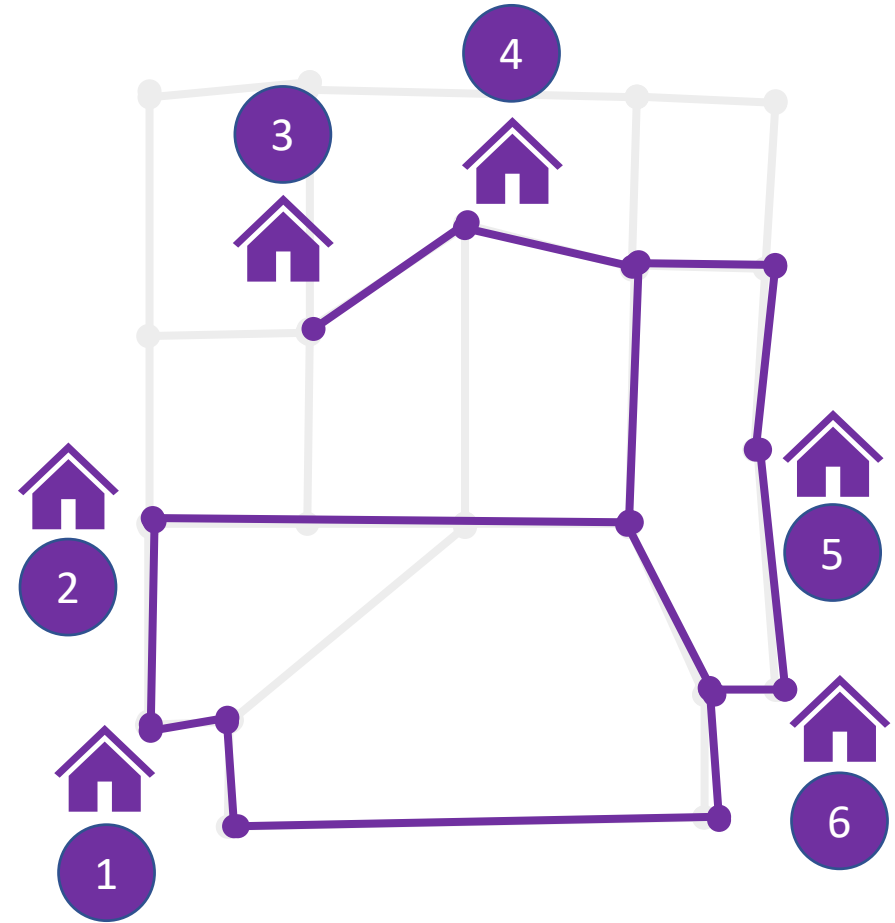
1. Pick a route at random
2. Calculate the distance

Original Route

3,5,2,1,6,4

Distance

4.8 km



Simulated Annealing - Example

Pick a transformation. Flip a coin and select either:

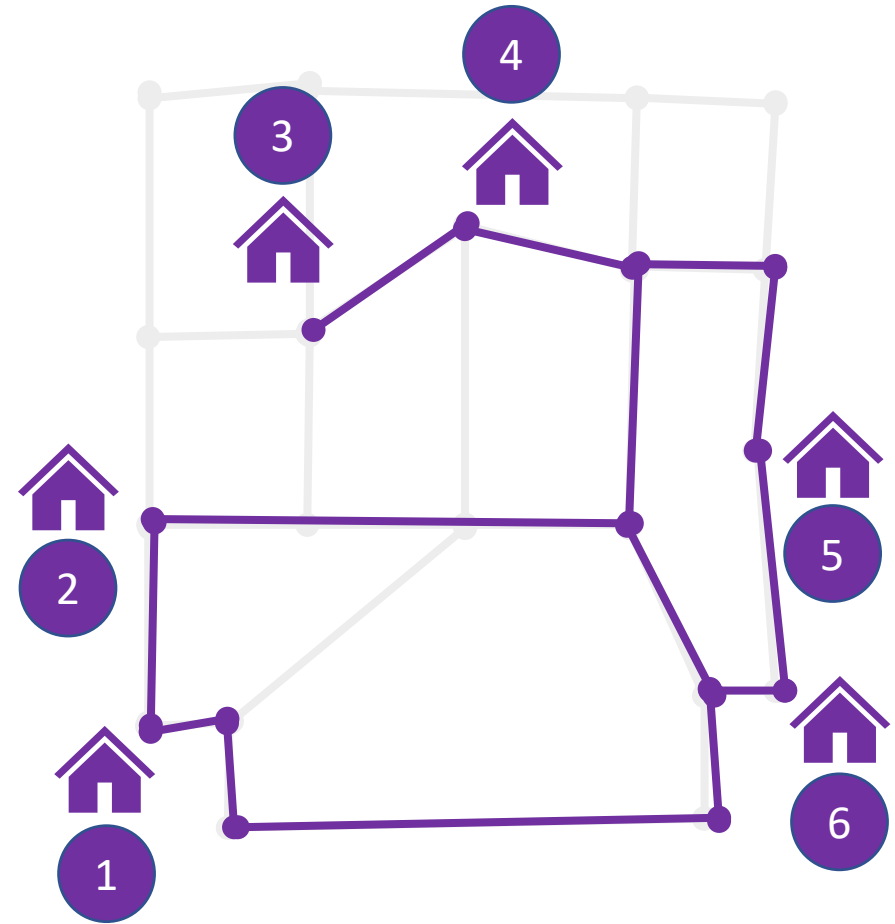
- Reverse or
- Transport

Original Route

3,5,2,1,6,4

Distance

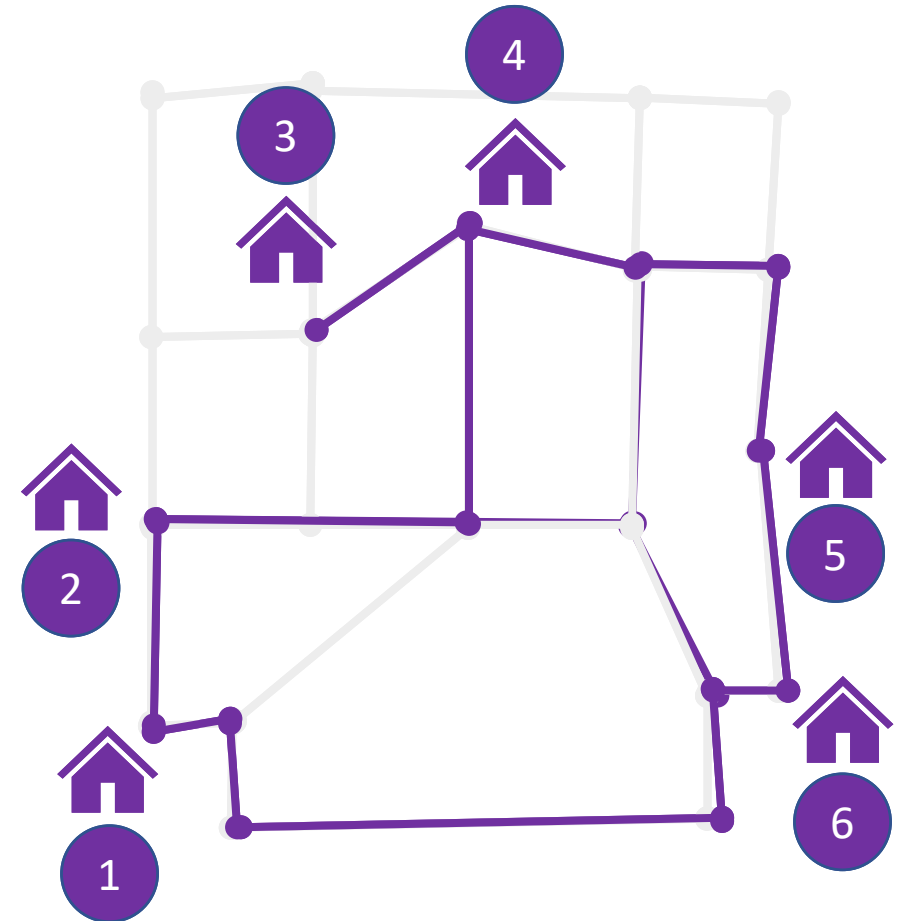
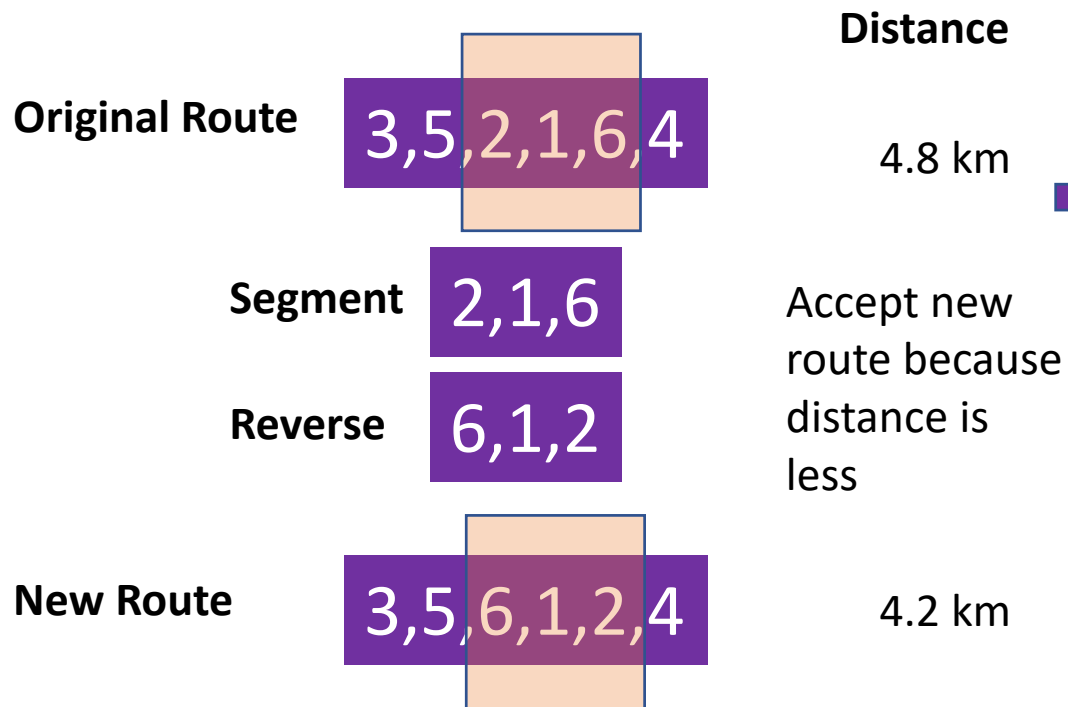
4.8 km



Simulated Annealing – Reverse Process

Reverse Selected

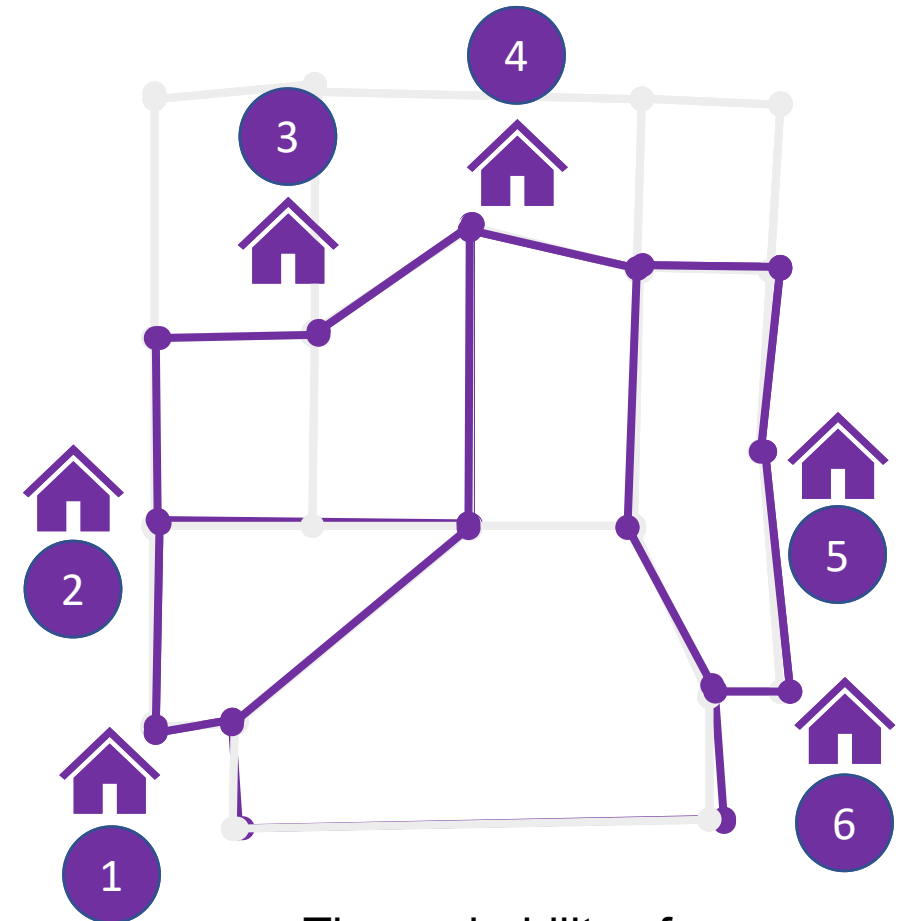
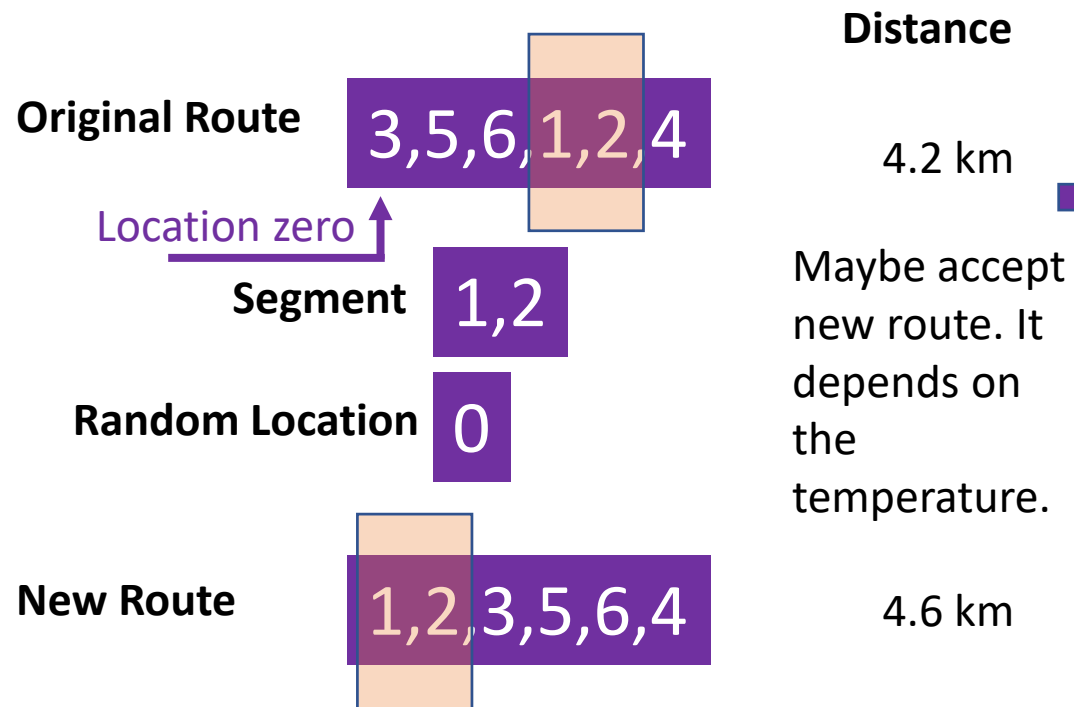
1. Pick a segment at random
2. Reverse the nodes
3. Calculate new distance



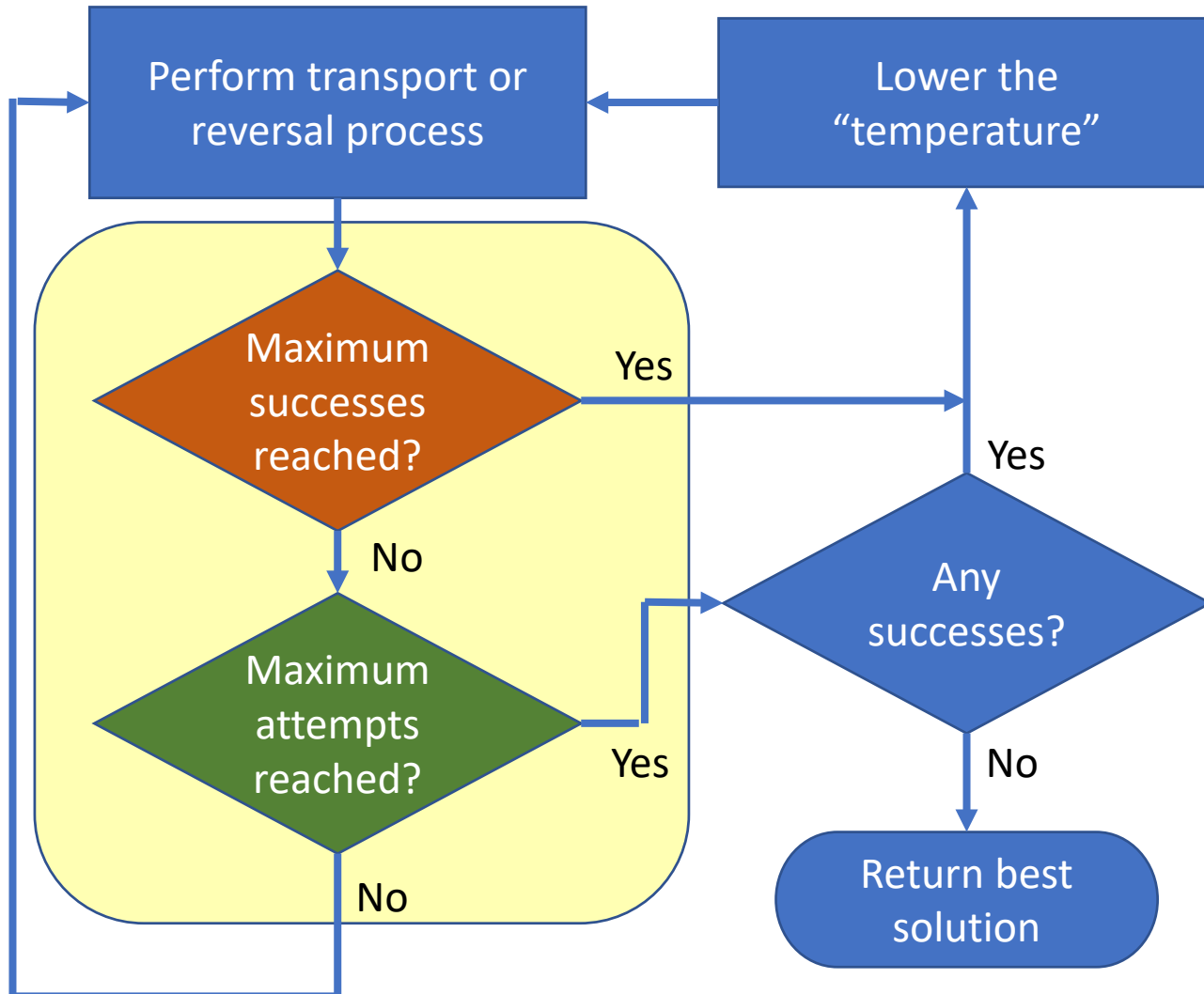
Simulated Annealing – Transport Process

Transport Selected

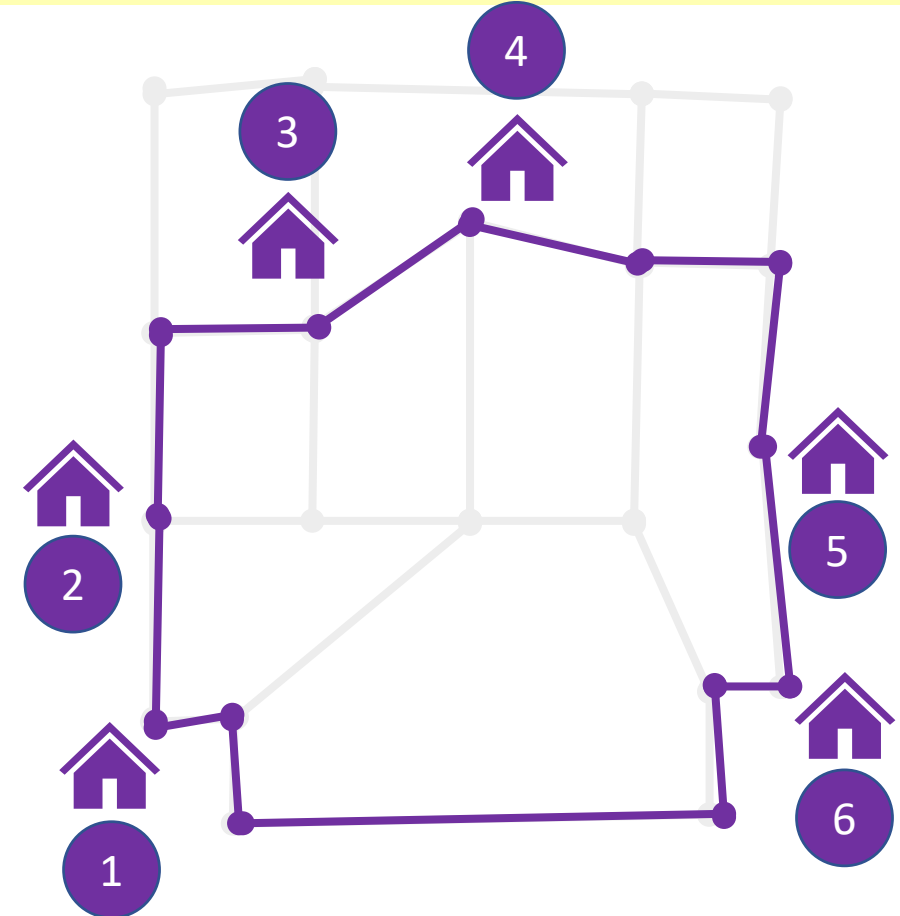
1. First, pick a random segment. Then, pick a random location on the remaining route.
2. Transport the segment to that location
3. Calculate new distance



Simulated Annealing



**Configuration parameters:
Maximum Successes and
Maximum Attempts**



Final Route

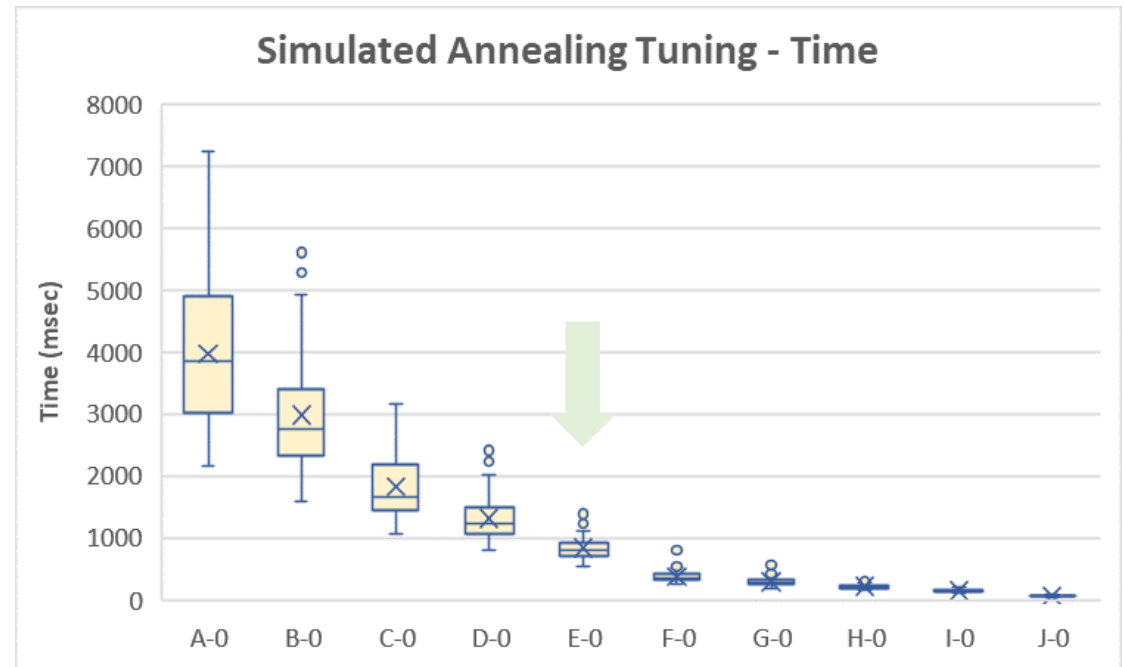
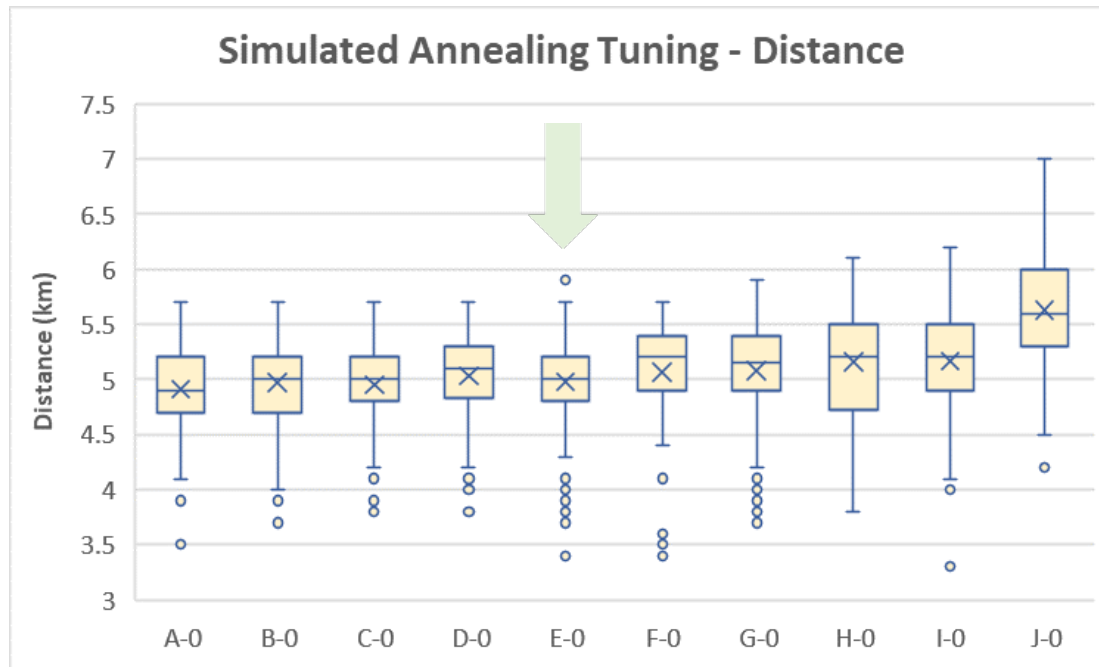
3,4,5,6,1,2

Note: A success is a new route accepted by the algorithm.

Tuning the Simulated Annealing Algorithm

Tune Maximum Attempts

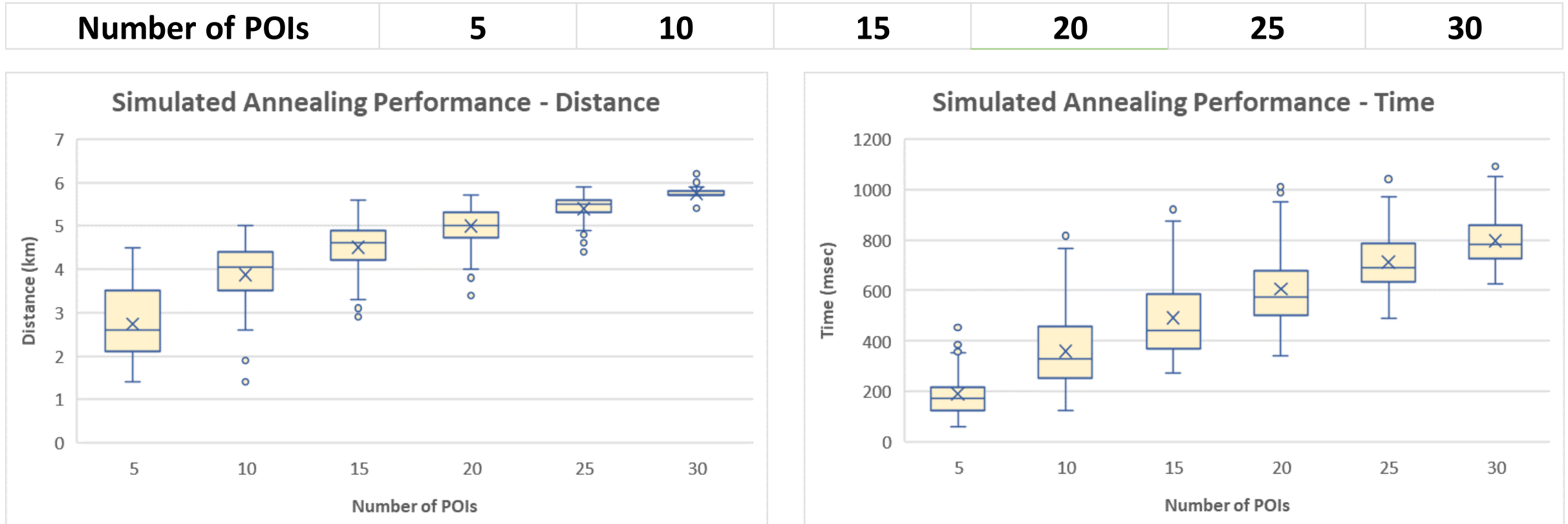
| | | | | | | | | | | |
|---------------|------|------|------|-----|-----|-----|-----|-----|-----|-----|
| Max Attempts | 2000 | 1500 | 1000 | 750 | 500 | 250 | 200 | 150 | 100 | 50 |
| Max Successes | 2000 | 1500 | 1000 | 750 | 500 | 250 | 200 | 150 | 100 | 50 |
| | A-0 | B-0 | C-0 | D-0 | E-0 | F-0 | G-0 | H-0 | I-0 | J-0 |



Selected 20 random POIs out of 30 for each repetition – 100 repetitions total

Examine the Performance

Change the number of POIs



Selected POIs randomly out of 30 for each repetition – 100 repetitions total

Background

Routing Library Design

Web App Implementation

How You can use the Library

Benefits to using the Library

Demo Web App

Demonstrates a walking tour through the historical district in Castroville, Texas

The tourist can

- Build a tour
- Set their start position
- Track their position

Build a Tour

Constrain Tour

Accessible Length: 2 km

Filter Points of Interest

Structures

Houses Churches Commercial

Era

1800s 1900s

Close Clear Tour Generate Tour

0 1 2 3 4

Web app URL: <https://personal.psu.edu/gra35/GEOG596B/tourR30.html>

Demo Web App

Demonstrates a walking tour through the historical district in Castroville, Texas

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Web app URL: <https://personal.psu.edu/gra35/GEOG596B/tourR30.html>

Demo Web App

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The tourist can

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Generated Route
Distance: 5.7 km (click to toggle tour)

Recommended Tour:

- 3: St. Louis Catholic Church
- 2: Jungman Haus
- 16: Patterson/Renken/Bourquin/Higdon House
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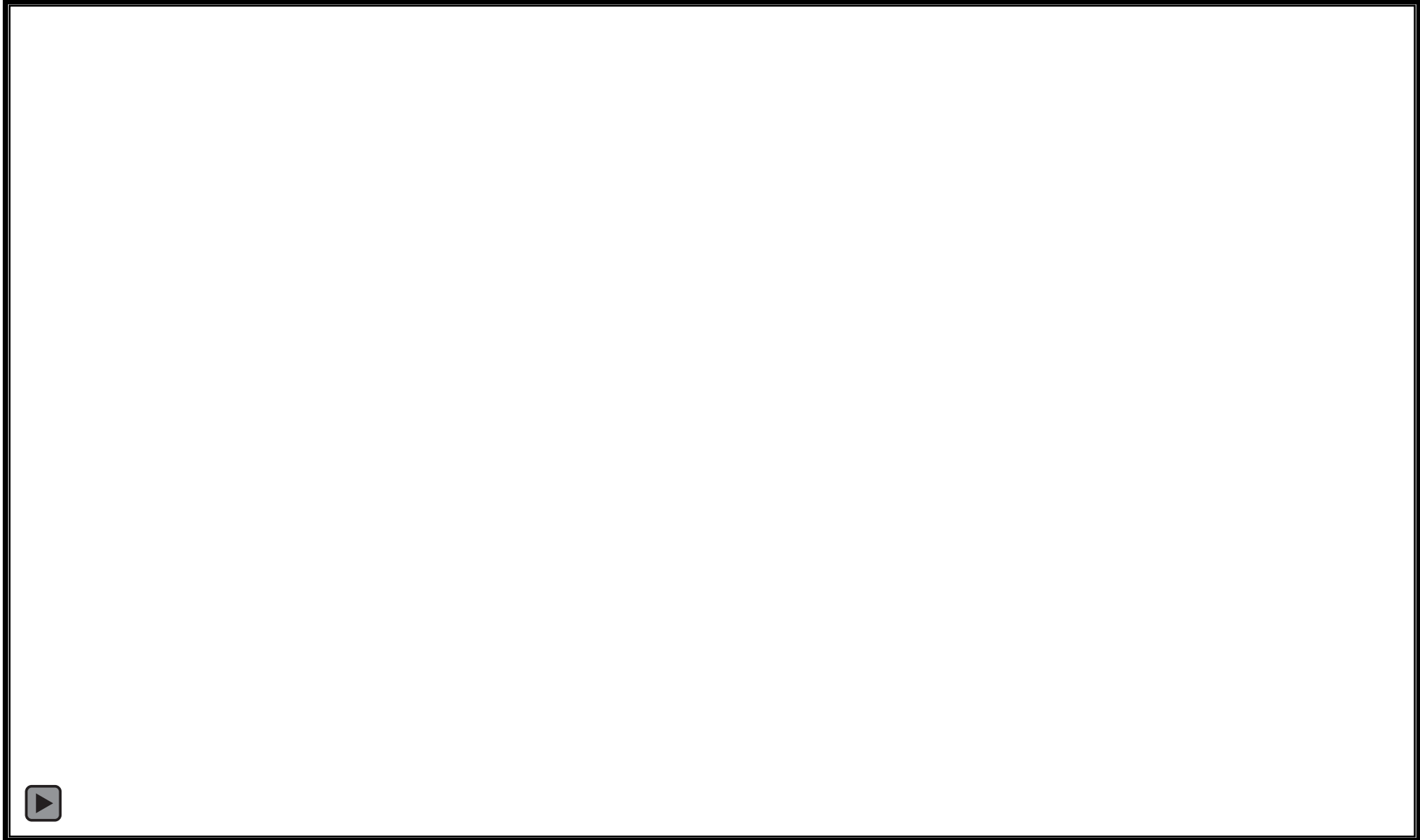
Leaflet | Map datacontainer © OpenStreetMap contributors

Web app URL: <https://personal.psu.edu/gra35/GEOG596B/tourR30.html>

Demo Web App

Web app URL:

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Background

Routing Library Design

Web App Implementation

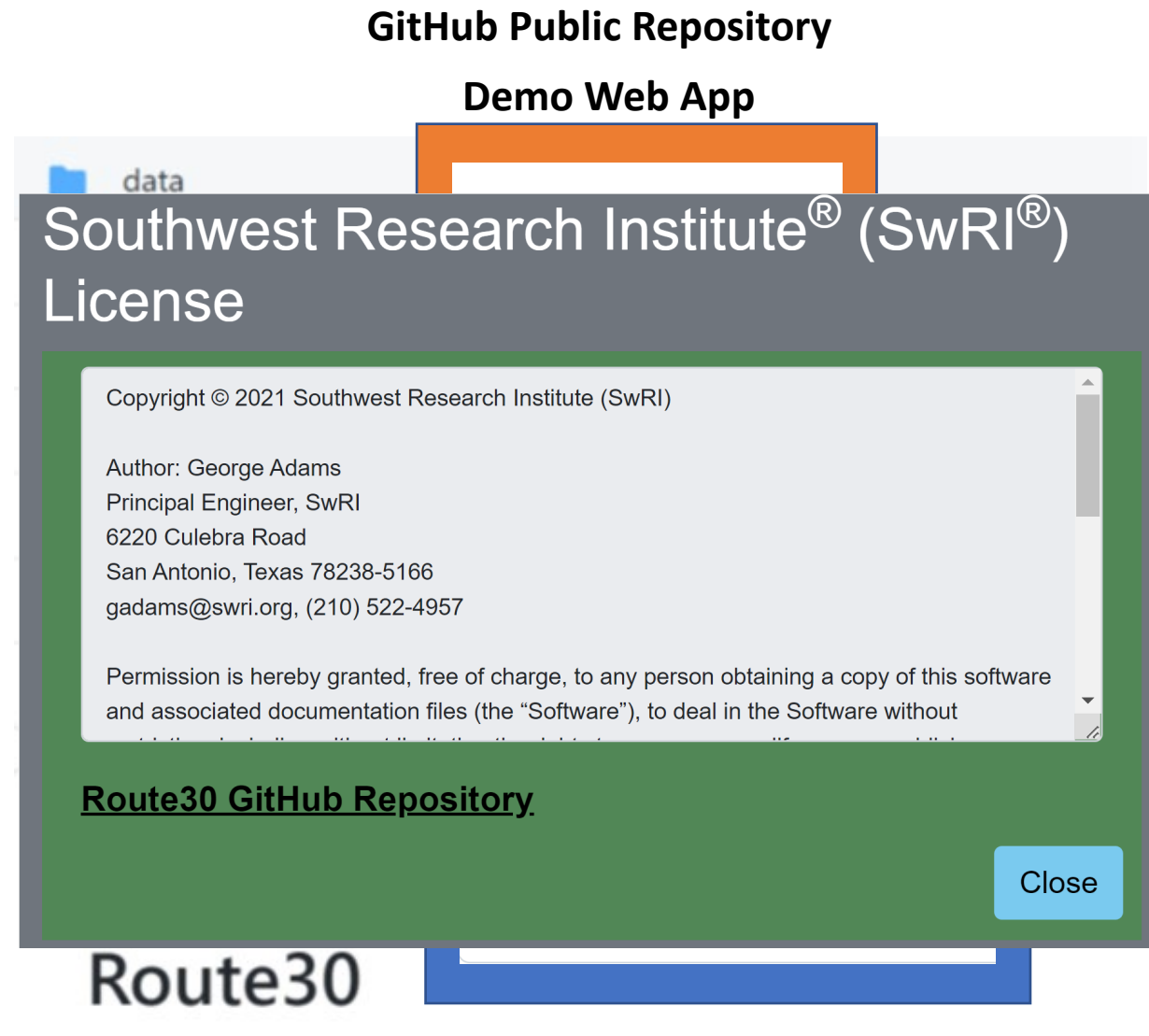
How You can use the Library

Benefits to using the Library

Distribution

Public repository on GitHub

- Available under an MIT-Type license
- Free for commercial and non-commercial uses



Data Files – Points of Interest

Historical properties from the Castroville Tour Guide (CACCC, 2017) as well as finding them on my own

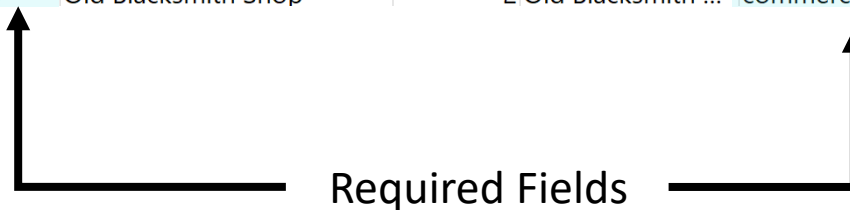
- POIs file

Street Network from Harvard Dataverse (Boeing, 2017)

- Nodes file
- Edges file

POIs

| | id | name | priority | popup | criteria | Year | Address |
|---|----|------------------------------|----------|-----------------------|-------------------|------|-----------------------|
| 1 | 0 | Henri Castro Homestead | 1 | Henri Castro Ho... | house, 1800s | 1845 | 1109 Fiorella Street |
| 2 | 1 | First Stone St. Louis Church | 2 | First Stone St. Lo... | church, 1800s | 1849 | Angelo Street |
| 3 | 2 | Jungman Haus | 2 | Jungman Haus -... | house, 1800s | 1860 | 512 Paris Street |
| 4 | 3 | St. Louis Catholic Church | 2 | St. Louis Catholi... | church, 1800s | 1870 | Angelo Street |
| 5 | 4 | The Pingenot House | 2 | The Pingenot H... | house, 1800s | 1845 | 507 Petersburg Street |
| 6 | 5 | The Tarde Hotel | 2 | The Tarde Hotel ... | commercial, 1800s | 1852 | 1310 Fiorella |
| 7 | 6 | Old Blacksmith Shop | 2 | Old Blacksmith ... | commercial, 1900s | 1920 | 1102 Fiorella Street |



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| 5 | 4 | The Pingenot House | | | | | rsburg Street |
| 6 | 5 | The Tarde Hotel | | | | | ella |
| 7 | 6 | Old Blacksmith Shop | | | | | ella Street |

Filter Criteria

↓

Build a Tour

Constrain Tour

Accessible Length: 2 km

Filter Points of Interest

Structures

Houses Churches Commercial

Era

1800s 1900s

Close Clear Tour Generate Tour

→

Data Files – Points of Interest

Historical properties from the Castroville Tour Guide (CACCC, 2017) as well as finding them on my own

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- Nodes file
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GeoJSON Points of Interest Feature Collection

```

{
  "type": "FeatureCollection",
  "features": [
    {
      "type": "Feature",
      "id": "0",
      "properties": {
        "name": "Henri Castro Homestead",
        "priority": 1,
        "popup": "Henri Castro Homestead - 1845",
        "criteria": ["house", "1800s"],
        "Year": 1845,
        "Address": "1109 Fiorella Street"
      },
      "geometry": {
        "type": "Point",
        "coordinates": [-98.882, 29.351]
      }
    },
    {
      .... Additional features follow the same format as above....
    }
  ]
}

```

One POI

Data Files – Points of Interest

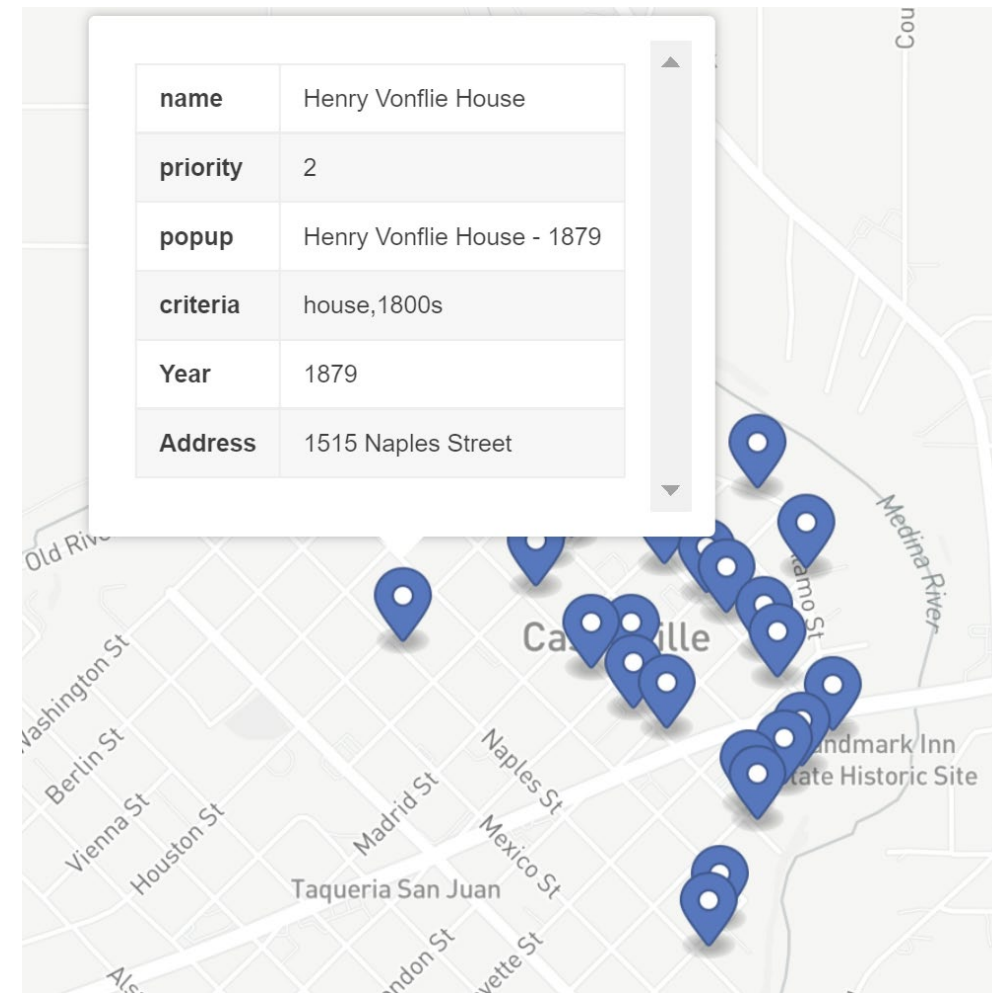
Historical properties from the Castroville Tour Guide (CACCC, 2017) as well as finding them on my own

- POIs file

Street Network from Harvard Dataverse (Boeing, 2017)

- Nodes file
- Edges file

POI File Displayed in GitHub



Data Files – Street Network

Historical properties from the Castroville Tour Guide (CACCC, 2017) as well as finding them on my own

- POIs file

Street Network from Harvard Dataverse (Boeing, 2017)

- Nodes file
- Edges file

Edges

| | id | from ▼ | name | to | length | criteria | barrier |
|---|-----|-----------|---------------------|-----------|---------|----------|---------|
| 1 | 89 | 376356515 | Vienna Street | 227156001 | 111.026 | acc_yes | false |
| 2 | 218 | 376356515 | Alsace Avenue | 227183789 | 75.589 | acc_yes | false |
| 3 | 271 | 376356515 | Alsace Avenue | 227201879 | 120.548 | acc_yes | false |
| 4 | 392 | 376356330 | United States Hi... | 227296729 | 332.827 | acc_yes | false |

Nodes

| | id ▼ | barrier |
|---|-----------|---------|
| 1 | 376356515 | false |
| 2 | 376356330 | false |
| 3 | 376356312 | false |
| 4 | 376356296 | false |

Data Files – Street Network

Historical properties from the Castroville Tour Guide (CACCC, 2017) as well as finding them on my own

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- Edges file

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Nodes

| | id | barrier |
|---|-----------|---------|
| 1 | 376356515 | false |
| 2 | 376356330 | false |
| 3 | 376356312 | false |
| 4 | 376356296 | false |

Correspond

Data Files – Street Network

Historical properties from the Castroville Tour Guide (CACCC, 2017) as well as finding them on my own

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Filter Criteria



Edges

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Build a Tour

Constrain Tour

Accessible Length: 2 km

Filter Points of Interest

Structures

Houses Churches Commercial

Era

1800s 1900s

Close Clear Tour Generate Tour

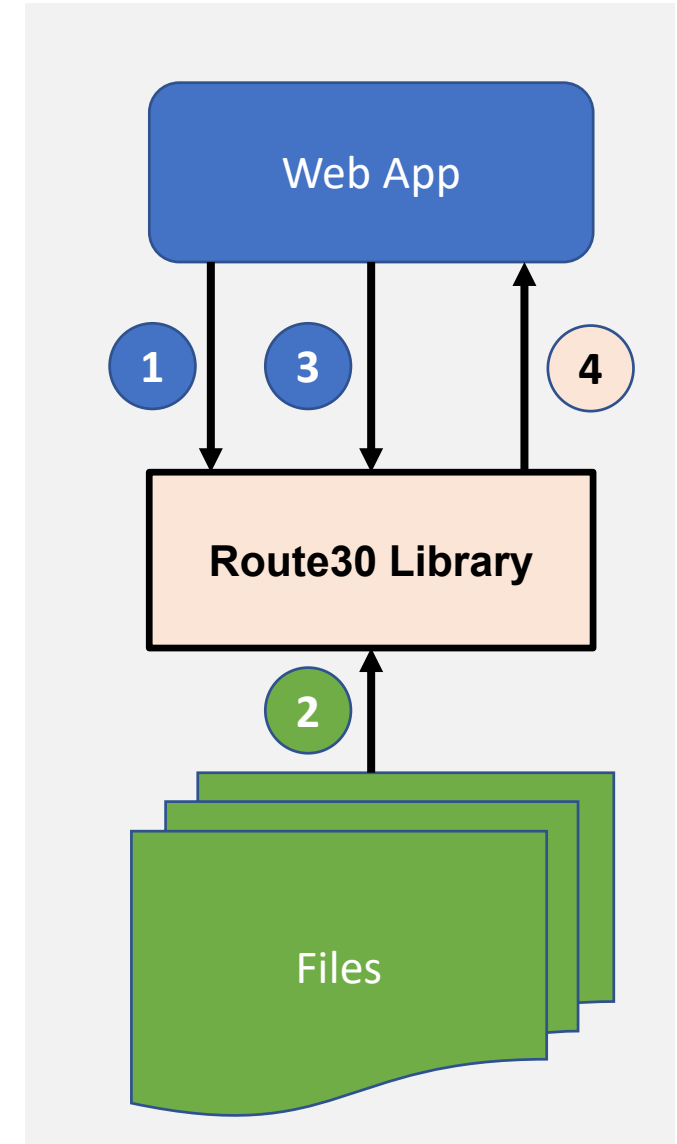
Nodes

| | id | barrier |
|---|-----------|---------|
| 1 | 376356515 | false |
| 2 | 376356330 | false |
| 3 | 376356312 | false |
| 4 | 376356296 | false |

Invoking the Library

Four Steps:

1. **Web app commands library to initialize**
2. Library initializes
3. **Web app commands library to generate route**
4. Library responds with best solution found



Step 1: Command: Initialize Library

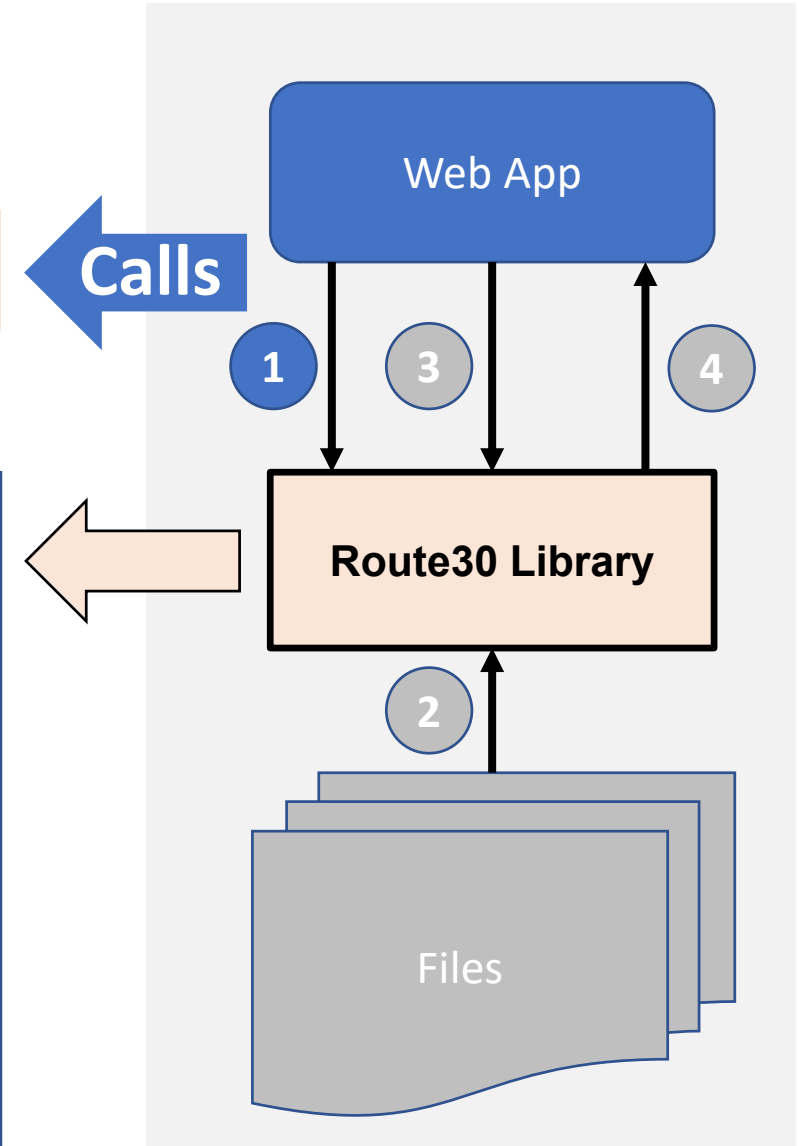
“R30LoadData(POI, Nodes, Edges)”

First
Entry Point

Route30 Library

..

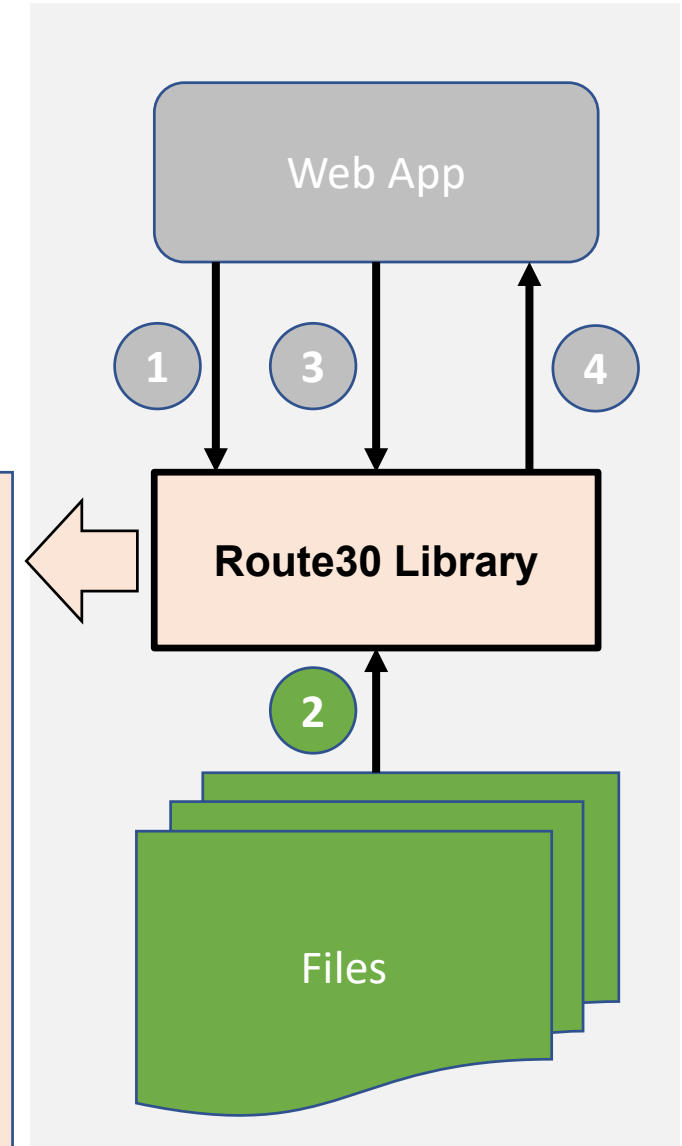
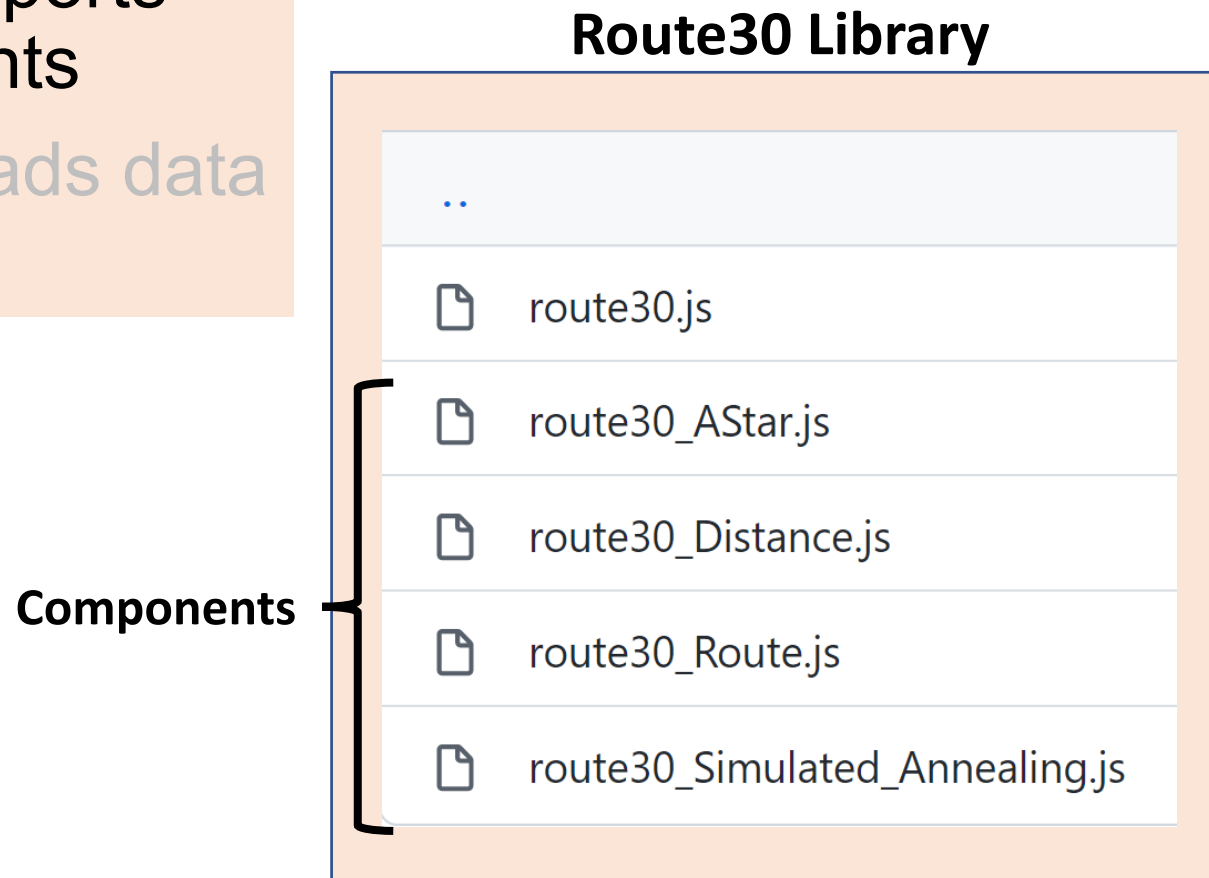
- route30.js
- route30_AStar.js
- route30_Distance.js
- route30_Route.js
- route30_Simulated_Annealing.js



Step 2: Response: Library Initializes

“R30LoadData(POI, Nodes, Edges)” executes

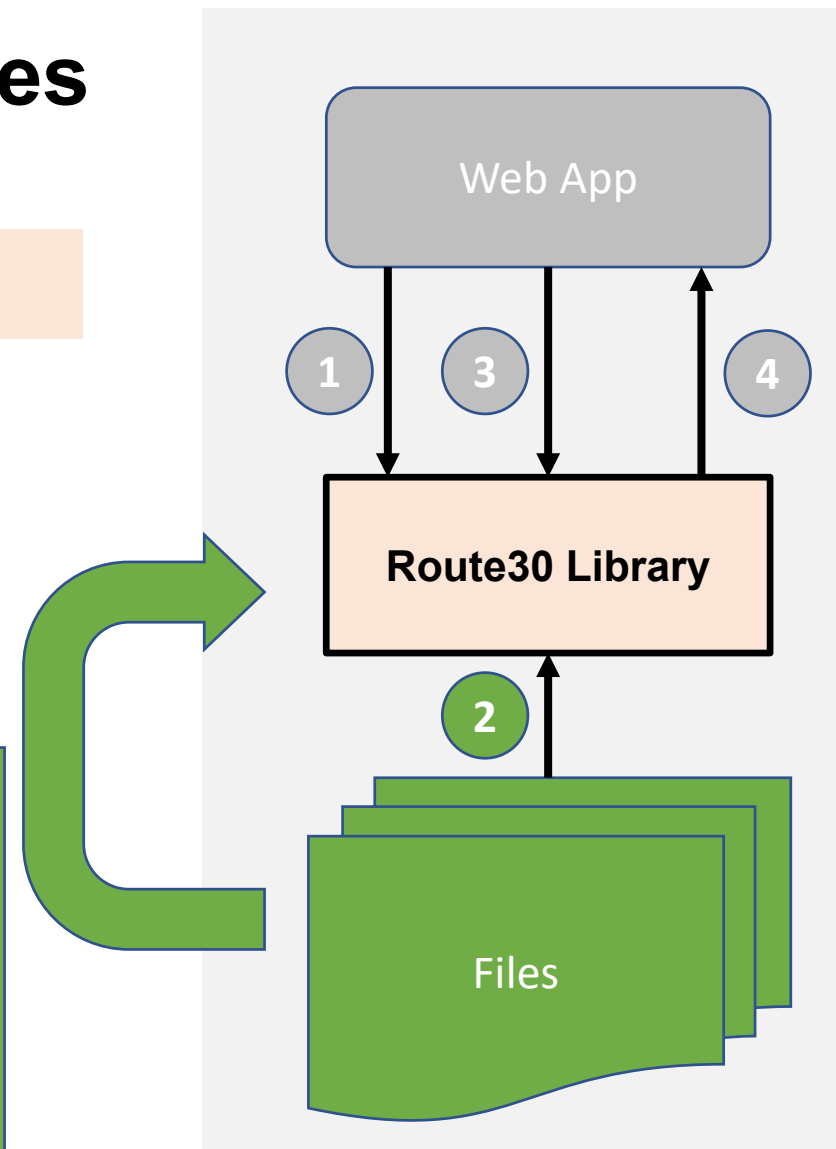
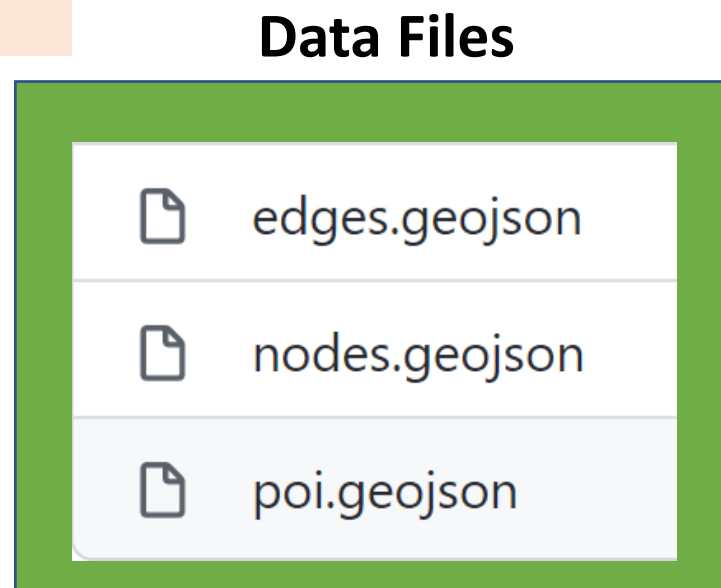
- Library imports components
- Library loads data files



Step 2: Response: Library Initializes

“R30LoadData(POI, Nodes, Edges)” executes

- Library imports components
- Library loads data files



Step 3: Command: Generate Route

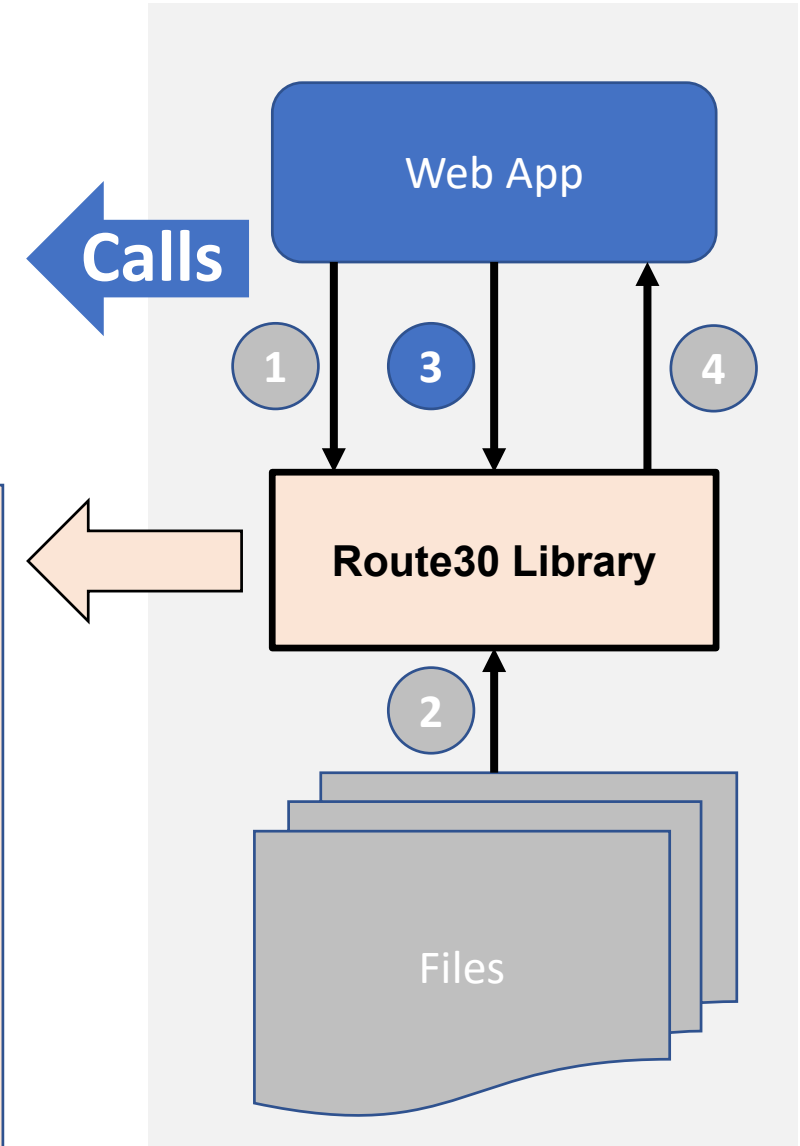
“R30Generate(routeParameter)”

Second
Entry Point

Route30 Library

..

- route30.js
- route30_AStar.js
- route30_Distance.js
- route30_Route.js
- route30_Simulated_Annealing.js



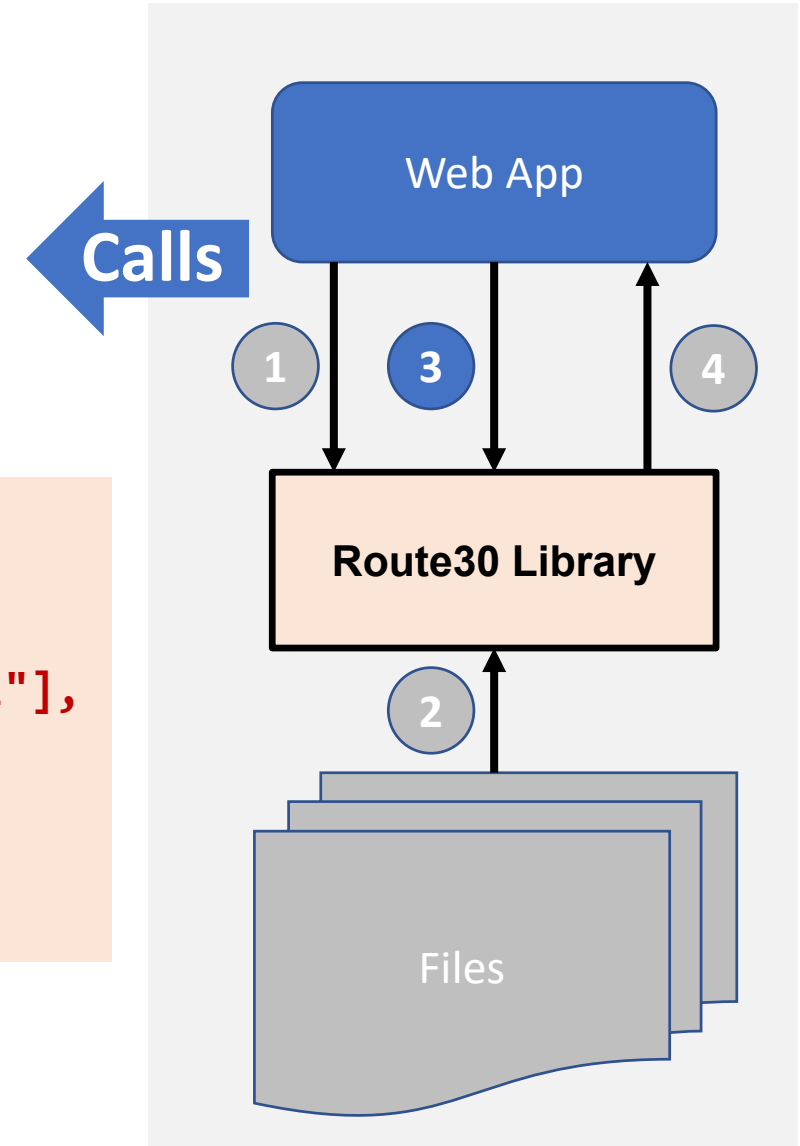
Step 3: Command: Generate Route

“R30Generate(routeParameter)”

Parameter Passed to Routing Library

```
var routeParameter = {  
  maxDistance: 3.5,  
  userStart: [-98.87934, 29.35596],  
  poiFilter: [ ["house", "church", "commercial"],  
              ["1800s", "1900s"] ],  
  edgeFilter: [ ["acc_yes", "acc no"] ],  
  algorithm: [5.0, 0.9, 200, 500, 150]  
}
```

Configuration
parameters from tuning



Step 4: Response: Library Generates Best Solution

Generated Route in GeoJSON Format:

Generated Route in GeoJSON Format

```

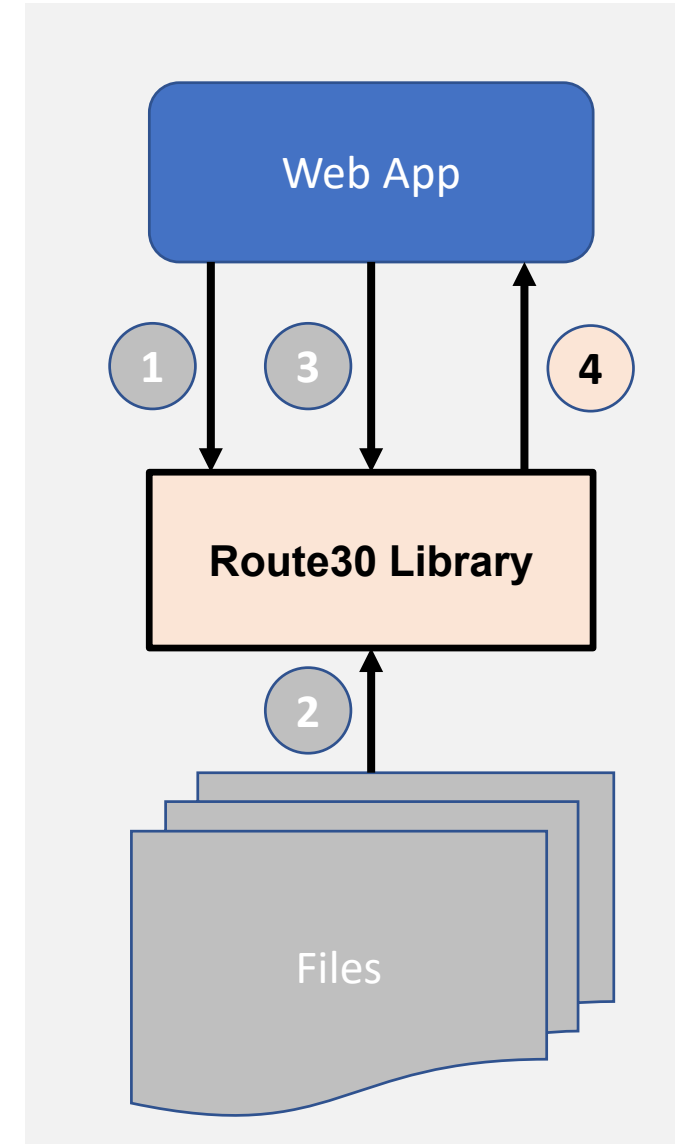
{
  "type": "Feature",
  "properties": {
    "distance": 5.734,
    "path": '3', '2', '1', '26', ...
  },
  "geometry": {
    "type": "MultiLineString",
    "coordinates": [
      [[-98.87894, 29.35572], [-98.87809, 29.35498]],
      [[-98.87809, 29.35498], [-98.87724, 29.35573]],
      [[-98.87473, 29.355], [-98.87477, 29.35492], [-98.87502, 29.3547]]
      .... Additional coordinate pairs follow the same format as above....
    ]
  }
}

```

1. Distance in kilometers

2. Sequential list of POIs

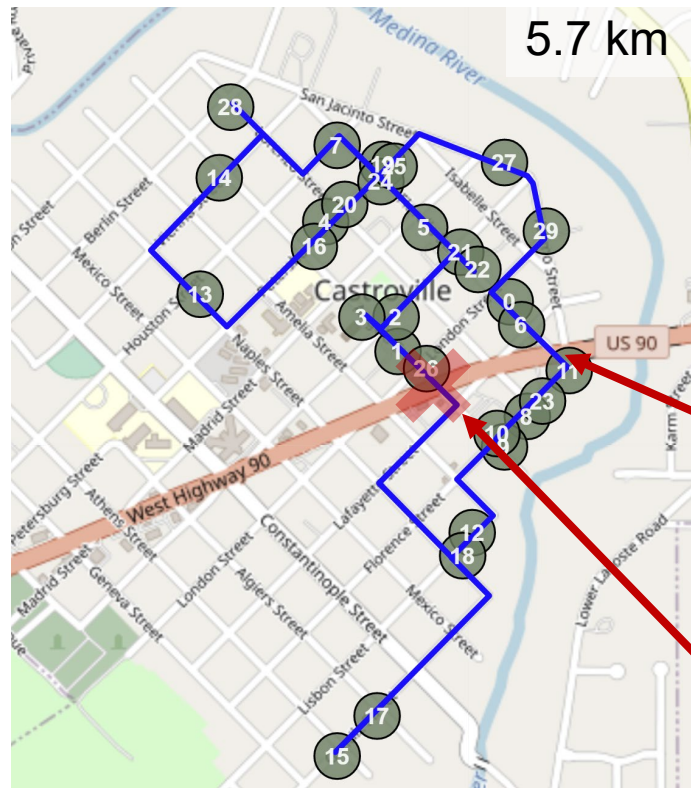
3. Paths Between POIs



Background
Routing Library Design
Web App Implementation
How You can use the Library
Benefits to using the Library

OpenRouteService Comparison

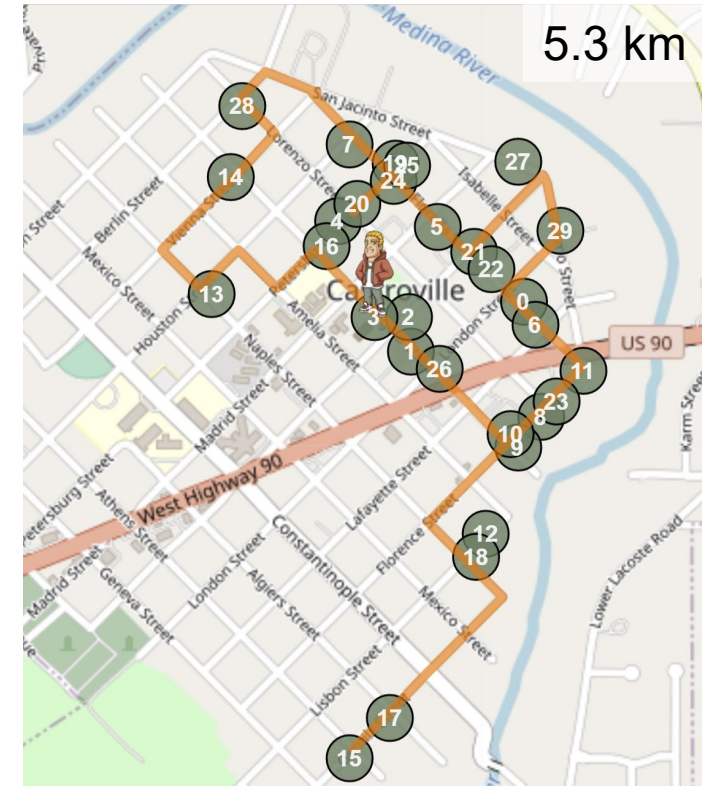
Compare unconstrained solutions



OpenRouteService (The Heidelberg Institute for Geoinformation Technology, 2022)

The route should only cross at this one location to the east.

Not here.

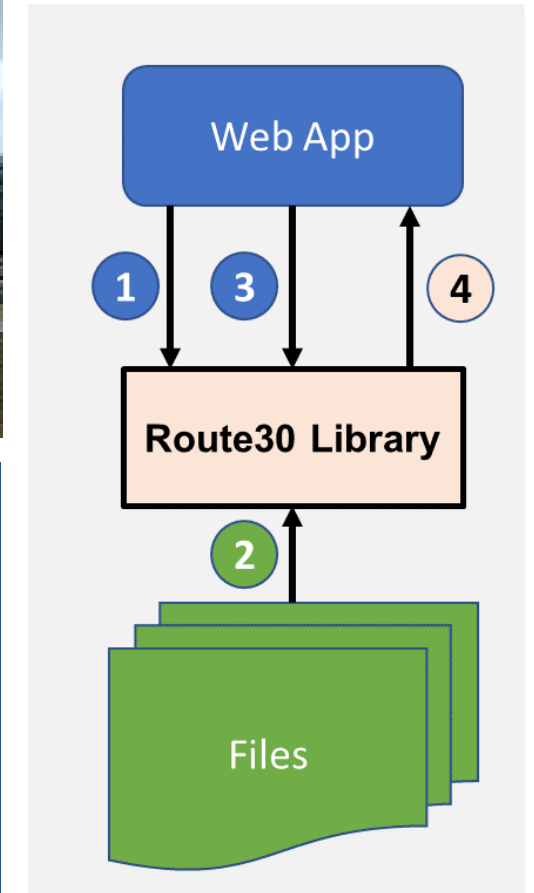
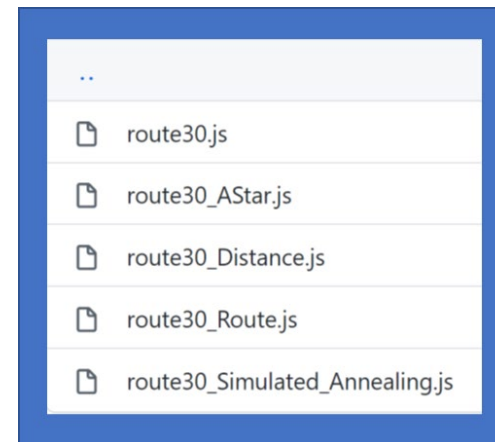


Route30

Benefits to Using Library

1. Direct control over inputs
2. Minimal data input
3. Library uses plug-ins
4. Library is free and easy to use
5. Can tune the algorithm
6. Library is expandable

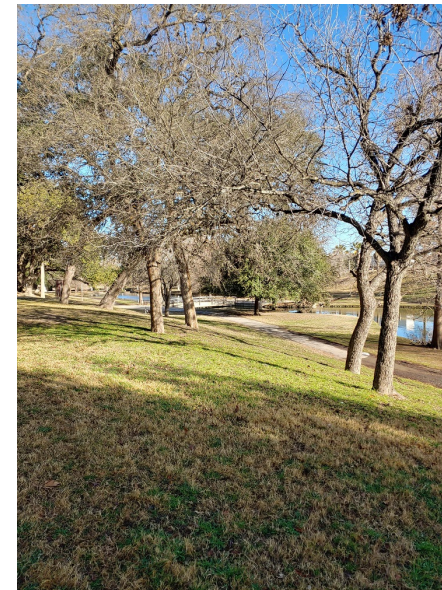
First Stone St. Louis Church - 1849



Future Uses

1. Public works department
2. Natural area where no street network exists
3. Museum or warehouse routing
4. Small business delivery operations
5. Experimental platform for testing new algorithms

Warehouse



Natural Areas with Trails

Summary

1. FOSS client-side routing library
 - a. Routing component
 - b. Distance matrix component
2. Demo web app
 - a. Demonstrates routing library
 - b. Displays filtered and constrained routes
3. How you can use the library
 - a. Deployed on GitHub
 - b. Uses standard data format
 - c. Called from your web app
4. Benefits
 - a. Greater control over inputs
 - b. Affordable/Easy to implement



Historical Significance Unknown

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Hans Meat Market - 1910

Questions?

GitHub Repository:

<https://github.com/savage507051/Route30>

Web app URL:

<https://personal.psu.edu/gra35/GEOG596B/tourR30.html>



Landmark Inn - 1849

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