

A Traveling Salesman Solution For The Capitals of All African Nations

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Abstract

A Traveling Salesman Problem is the task of finding the shortest round trip path a traveling salesperson can take to visit each vertex of a given graph. They are usually implemented using a genetic algorithm. Our salesperson happens to be traveling to the capitals of every country in Africa that is a recognized member of the United Nations.

1 The Problem

Attempt to find the shortest i.e. cheapest complete path around all African Nations so our sales person can travel the most efficient route possible.

- | | | |
|--|--------------------------------|------------------------------|
| 1. Algeria - Algiers | 17. Equatorial Guinea - Malabo | 36. Namibia - Windhoek |
| 2. Angola - Luanda | 18. Eritrea - Asmara | 37. Niger - Niamey |
| 3. Benin - Porto-Novo | 19. Ethiopia - Addis Ababa | 38. Nigeria - Abuja |
| 4. Botswana - Gaborone | 20. Gabon - Libreville | 39. Rwanda - Kigali |
| 5. Burkina Faso - Ouagadougou | 21. The Gambia - Banjul | 40. Senegal - Dakar |
| 6. Burundi - Bujumbura | 22. Ghana - Accra | 41. Seychelles - Victoria |
| 7. Cameroon - Yaounde | 23. Guinea - Conakry | 42. Sierra Leone - Freetown |
| 8. Cape Verde - Praia | 24. Guinea-Bissau - Bissau | 43. Somalia - Mogadishu |
| 9. Central African Republic - Bangui | 25. Kenya - Nairobi | 44. South Africa - Pretoria |
| 10. Chad - N'Djamena | 26. Lesotho - Maseru | 45. Sudan - Khartoum |
| 11. Comoros - Moroni | 27. Liberia - Monrovia | 46. Swaziland - Mbabane |
| 12. Congo, Republic of the - Brazzaville | 28. Libya - Tripoli | 47. Tanzania - Dar es Salaam |
| 13. Congo, Democratic Republic of the - Kinshasa | 29. Madagascar - Antananarivo | 48. Togo - Lome |
| 14. Cote d'Ivoire - Yamoussoukro | 30. Malawi - Lilongwe | 49. Tunisia - Tunis |
| 15. Djibouti - Djibouti | 31. Mali - Bamako | 50. Uganda - Kampala |
| 16. Egypt - Cairo | 32. Mauritania - Nouakchott | 51. Zambia - Lusaka |
| | 33. Mauritius - Port Louis | 52. Zimbabwe - Harare |
| | 34. Morocco - Rabat | |
| | 35. Mozambique - Maputo | |



Figure 1: Capitals of African Nations

2 Overview

The traveling salesman problem (TSP) is a thoroughly researched problem in theoretically computer-science. TSP is classified as NP-Hard e.g. it is as hard or harder to solve than a problem solvable in nondeterministic polynomial time. This means the worst case performance for a TSP algorithm will likely increase exponentially with the numbers of cities to traverse. The big-O complexity of a brute force TSP algorithms (check all vertices against all other vertices) is $O(n!)$.

I attempted to solve the TSP with both a brute force method initially and eventually a simulated annealing algorithm. Both implementation's rely on the pythong programming language and it's random number implementation to generate new routes. The brute force algorithm simply attempts all combinations, giving priority to each new best performing route. This algorithm

performed well, yielding great results, but I felt it would be beneficial to try another approach. Simulated annealing is often cited as a relatively easy way to improve TSP performance.

“Simulated annealing starts with the cities connected in a random order, and then considers making random changes in that order. If changing the order of cities leads to a shorter path, we accept that change. If the modification yields a longer path, we give ourselves a certain probability of accepting the modification – less likely the larger the proposed increase in path length. We then gradually reduce this probability over time, in order to rule out shorter and shorter path increases – thereby converging toward a path length close to the absolute minimum.” [5]

3 Programs

1. The Python 2.6 [1] programming language and interpreter.
2. Wikipedia provides a convenient list of latitude/longitude pairs for all major cities in the world. This was cross referenced with the list of African nations and capitals recognized by the United Nations. [2]
3. Software originally written by John Montgomery [3] in 2007. It was a general exercise in implementing different types of TSP algorithms. At this point it's been heavily modified to meet my needs for this project.
4. The results were then visualized using Google maps static mapping API. [4]
5. A general algorithm for computing the distance between two latitude/longitude points. [6]

4 Solution

Final Round Trip Order:



Figure 2: Final Round Trip Path Through Africa

- | | | |
|---|-------------------------------|---------------------------------------|
| 1. Congo, Republic of the - Brazzaville | 18. Comoros - Moroni | 37. Guinea - Conakry |
| 2. Congo, Democratic Republic of the - Kinshasa | 19. Madagascar - Antananarivo | 38. Sierra Leone - Freetown |
| 3. Angola - Luanda | 20. Mauritius - Port Louis | 39. Liberia - Monrovia |
| 4. Namibia - Windhoek | 21. Seychelles - Victoria | 40. Cote d'Ivoire - Yamoussoukro |
| 5. Botswana - Gaborone | 22. Somalia - Mogadishu | 41. Mali - Bamako |
| 6. South Africa - Pretoria | 23. Ethiopia - Addis Ababa | 42. Burkina Faso - Ouagadougou |
| 7. Lesotho - Maseru | 24. Djibouti - Djibouti | 43. Niger - Niamey |
| 8. Swaziland - Mbabane | 25. Eritrea - Asmara | 44. Ghana - Accra |
| 9. Mozambique - Maputo | 26. Sudan - Khartoum | 45. Togo - Lome |
| 10. Zimbabwe - Harare | 27. Egypt - Cairo | 46. Benin - Porto-Novo |
| 11. Zambia - Lusaka | 28. Libya - Tripoli | 47. Nigeria - Abuja |
| 12. Malawi - Lilongwe | 29. Tunisia - Tunis | 48. Chad - N'Djamena |
| 13. Burundi - Bujumbura | 30. Algeria - Algiers | 49. Central African Republic - Bangui |
| 14. Rwanda - Kigali | 31. Morocco - Rabat | 50. Cameroon - Yaounde |
| 15. Uganda - Kampala | 32. Mauritania - Nouakchott | 51. Equatorial Guinea - Malabo |
| 16. Kenya - Nairobi | 33. Cape Verde - Praia | 52. Gabon - Libreville |
| 17. Tanzania - Dar es Salaam | 34. Senegal - Dakar | |
| | 35. The Gambia - Banjul | |
| | 36. Guinea-Bissau - Bissau | |

Total Length Of Round Trip Route $\approx 35,813km$

Route Without Round Trip Stipulation:

- | | | |
|---------------------------------|-------------------------------|--|
| 1. Benin - Porto-Novo | 20. Egypt - Cairo | 39. Swaziland - Mbabane |
| 2. Togo - Lome | 21. Sudan - Khartoum | 40. Lesotho - Maseru |
| 3. Ghana - Accra | 22. Eritrea - Asmara | 41. South Africa - Pretoria |
| 4. Niger - Niamey | 23. Djibouti - Djibouti | 42. Botswana - Gaborone |
| 5. Burkina Faso - Ouagadougou | 24. Ethiopia - Addis Ababa | 43. Namibia - Windhoek |
| 6. Mali - Bamako | 25. Somalia - Mogadishu | 44. Angola - Luanda |
| 7. Cote d'Ivoire - Yamoussoukro | 26. Seychelles - Victoria | 45. Congo, Democratic Republic of the - Kinshasa |
| 8. Liberia - Monrovia | 27. Mauritius - Port Louis | 46. Congo, Republic of the - Brazzaville |
| 9. Sierra Leone - Freetown | 28. Madagascar - Antananarivo | 47. Central African Republic - Bangui |
| 10. Guinea - Conakry | 29. Comoros - Moroni | 48. Chad - N'Djamena |
| 11. Guinea-Bissau - Bissau | 30. Tanzania - Dar es Salaam | 49. Cameroon - Yaounde |
| 12. The Gambia - Banjul | 31. Kenya - Nairobi | 50. Gabon - Libreville |
| 13. Senegal - Dakar | 32. Uganda - Kampala | 51. Equatorial Guinea - Malabo |
| 14. Mauritania - Nouakchott | 33. Rwanda - Kigali | 52. Nigeria - Abuja |
| 15. Cape Verde - Praia | 34. Burundi - Bujumbura | |
| 16. Morocco - Rabat | 35. Malawi - Lilongwe | |
| 17. Algeria - Algiers | 36. Zambia - Lusaka | |
| 18. Tunisia - Tunis | 37. Zimbabwe - Harare | |
| 19. Libya - Tripoli | 38. Mozambique - Maputo | |

Total Length Of Non-Round-trip Route $\approx 34,096km$

5 Runtime

The two algorithms, simulated annealing and brute force random permutations where both run in numerous instances over the life of the project. In combined total they were run upwards of fifty times a piece.

The version of the algorithm which used simulated annealing on average found the optimal solution in 6 seconds. While the brute force method often took upwards of

6 Analysis

I believe the final optimal path's are within a reasonable uncertainty of the actual path. Given the big-O of the brute force algorithm, $O(n!)$ or $O(8.065 \times 10^{67})$, a runtime complexity of this magnitude is obviously out of my league for finding exact values. At a maximum I was able to attempt 100,000,000 permutations of the path.

Two area's of possible improvement I can pinpoint are:

1. The language itself. I chose the python programming language for my TSP implementation. The language is interpreted and it's runtime speed can at times be 20% slower than an equivalent C program.

2. The random.shuffle implementation. Given how python's random.shuffle API is implemented it takes a set of values and shuffles them based on a random number between 0,1 generated by the operating system. However given the size of the set , 52 individual points, the likely hood that random.shuffle will generated all permutations without excessive doubles is incredibly unlikely. This is the cause of a lot of useless computation time, however because of the size of the data set, caching data sets is not plausible let alone if even possible.

Re-writing the algorithm in C would be a great performance benefit. Also having a proper resources to cache routes or a effective random route generator I believe a more accurate optimal route might be found.

It is also worth mentioning that after completing a large part of the project I discovered the LHK [7] high performance TSP solver. It's written in straight C and requires the dataset to be in a very specific format. Given more time to organize the dataset into the proper format, I believe the LHK solver might produce a more accurate route given a much larger number of iterations.

References

- [1] <http://python.org>
- [2] http://en.wikipedia.org/wiki/Latitude_and_longitude_of_cities
- [3] Montgomery, John *Tackling The Travelling Salesman Problem* <http://www.psychicorigami.com/category/tsp/> , 2007
- [4] <http://code.google.com/apis/maps/documentation/staticmaps/>
- [5] <http://www.svengato.com/salesman.html>
- [6] <http://www.geesblog.com/2009/01/calculating-distance-between-latitude-longitude-pairs-in-python/>
- [7] <http://www.akira.ruc.dk/~keld/research/LKH/>

7 Program Output

```
burny ~/src/traveling-salesman $ python tsp.py -v -a anneal -n 1000000 --cooling 10:.9991 ../latlon
2009-11-02 00:43:38,822 INFO using move_operator: <function reversed_sections at 0x745f0>
2009-11-02 00:43:38,860 INFO new best score: -111551.944723
2009-11-02 00:43:38,861 INFO anneal started: score=-111551.944723
2009-11-02 00:43:38,861 INFO current run at 2 runs
2009-11-02 00:43:38,861 INFO current run at 4 runs
2009-11-02 00:43:38,861 INFO new best score: -108938.423206
2009-11-02 00:43:38,862 INFO new best score: -108255.962603
2009-11-02 00:43:38,862 INFO current run at 8 runs
2009-11-02 00:43:38,862 INFO new best score: -107174.578311
2009-11-02 00:43:38,862 INFO new best score: -107174.578311
2009-11-02 00:43:38,862 INFO new best score: -106843.737327
2009-11-02 00:43:38,863 INFO current run at 16 runs
2009-11-02 00:43:38,864 INFO new best score: -105825.989448
2009-11-02 00:43:38,864 INFO new best score: -105805.630085
2009-11-02 00:43:38,864 INFO new best score: -105428.930412
2009-11-02 00:43:38,864 INFO new best score: -103871.898541
2009-11-02 00:43:38,865 INFO new best score: -99956.329397
2009-11-02 00:43:38,865 INFO current run at 32 runs
2009-11-02 00:43:38,865 INFO new best score: -99252.982749
2009-11-02 00:43:38,865 INFO new best score: -96688.656537
2009-11-02 00:43:38,866 INFO new best score: -94637.985111
2009-11-02 00:43:38,866 INFO new best score: -92809.021849
2009-11-02 00:43:38,866 INFO new best score: -92567.648622
2009-11-02 00:43:38,867 INFO new best score: -92341.764572
2009-11-02 00:43:38,867 INFO new best score: -92019.656620
2009-11-02 00:43:38,867 INFO new best score: -91759.417996
2009-11-02 00:43:38,867 INFO new best score: -91657.533796
2009-11-02 00:43:38,867 INFO new best score: -91615.252931
2009-11-02 00:43:38,868 INFO new best score: -91510.009964
2009-11-02 00:43:38,868 INFO new best score: -91409.900530
2009-11-02 00:43:38,868 INFO new best score: -88486.992310
2009-11-02 00:43:38,869 INFO new best score: -87865.530081
2009-11-02 00:43:38,869 INFO current run at 64 runs
2009-11-02 00:43:38,870 INFO new best score: -84271.022595
2009-11-02 00:43:38,871 INFO new best score: -83806.794411
2009-11-02 00:43:38,871 INFO new best score: -83541.482139
2009-11-02 00:43:38,873 INFO new best score: -83230.783927
2009-11-02 00:43:38,873 INFO new best score: -82737.304308
2009-11-02 00:43:38,874 INFO new best score: -81484.288842
2009-11-02 00:43:38,874 INFO new best score: -78113.454255
2009-11-02 00:43:38,875 INFO new best score: -78076.761685
2009-11-02 00:43:38,876 INFO current run at 128 runs
2009-11-02 00:43:38,876 INFO new best score: -77590.182221
2009-11-02 00:43:38,876 INFO new best score: -77048.097861
2009-11-02 00:43:38,876 INFO new best score: -75684.545805
2009-11-02 00:43:38,877 INFO new best score: -75404.373749
2009-11-02 00:43:38,877 INFO new best score: -75171.746424
2009-11-02 00:43:38,878 INFO new best score: -74321.762810
2009-11-02 00:43:38,879 INFO new best score: -73252.833808
2009-11-02 00:43:38,879 INFO new best score: -73104.514189
2009-11-02 00:43:38,881 INFO new best score: -72788.614518
2009-11-02 00:43:38,881 INFO new best score: -72591.656921
2009-11-02 00:43:38,881 INFO new best score: -70578.358239
2009-11-02 00:43:38,882 INFO new best score: -68799.506394
2009-11-02 00:43:38,883 INFO new best score: -68619.887877
2009-11-02 00:43:38,884 INFO new best score: -67121.606526
2009-11-02 00:43:38,884 INFO new best score: -66626.493200
2009-11-02 00:43:38,884 INFO new best score: -64344.816135
2009-11-02 00:43:38,884 INFO new best score: -64230.900991
2009-11-02 00:43:38,885 INFO new best score: -64101.038316
2009-11-02 00:43:38,885 INFO new best score: -63926.594272
2009-11-02 00:43:38,886 INFO new best score: -63639.151393
2009-11-02 00:43:38,886 INFO new best score: -63342.571435
2009-11-02 00:43:38,886 INFO new best score: -62883.123482
2009-11-02 00:43:38,886 INFO new best score: -60493.251630
2009-11-02 00:43:38,887 INFO new best score: -58493.381705
2009-11-02 00:43:38,888 INFO new best score: -58364.904831
2009-11-02 00:43:38,888 INFO new best score: -57861.729512
2009-11-02 00:43:38,889 INFO new best score: -57785.659587
2009-11-02 00:43:38,889 INFO new best score: -56237.272807
2009-11-02 00:43:38,889 INFO current run at 256 runs
2009-11-02 00:43:38,890 INFO new best score: -52752.018487
2009-11-02 00:43:38,890 INFO new best score: -52058.361255
```

2009-11-02 00:43:38,890 INFO new best score: -51827.173423
 2009-11-02 00:43:38,891 INFO new best score: -50650.559834
 2009-11-02 00:43:38,894 INFO new best score: -50540.078096
 2009-11-02 00:43:38,895 INFO new best score: -50317.193191
 2009-11-02 00:43:38,895 INFO new best score: -48975.975547
 2009-11-02 00:43:38,896 INFO new best score: -48849.972600
 2009-11-02 00:43:38,898 INFO new best score: -48838.291771
 2009-11-02 00:43:38,902 INFO new best score: -48368.567964
 2009-11-02 00:43:38,903 INFO new best score: -46559.324605
 2009-11-02 00:43:38,904 INFO new best score: -46558.360448
 2009-11-02 00:43:38,905 INFO new best score: -46522.611077
 2009-11-02 00:43:38,905 INFO new best score: -46422.331395
 2009-11-02 00:43:38,906 INFO new best score: -44981.634651
 2009-11-02 00:43:38,907 INFO new best score: -44820.384544
 2009-11-02 00:43:38,907 INFO new best score: -44643.673209
 2009-11-02 00:43:38,909 INFO new best score: -44004.657313
 2009-11-02 00:43:38,909 INFO new best score: -43563.669128
 2009-11-02 00:43:38,910 INFO new best score: -43510.757103
 2009-11-02 00:43:38,912 INFO current run at 512 runs
 2009-11-02 00:43:38,916 INFO new best score: -42977.735342
 2009-11-02 00:43:38,916 INFO new best score: -41456.278999
 2009-11-02 00:43:38,917 INFO new best score: -41383.345365
 2009-11-02 00:43:38,918 INFO new best score: -40087.086741
 2009-11-02 00:43:38,919 INFO new best score: -39434.670603
 2009-11-02 00:43:38,919 INFO new best score: -39219.990542
 2009-11-02 00:43:38,921 INFO new best score: -38293.656546
 2009-11-02 00:43:38,924 INFO new best score: -36738.445888
 2009-11-02 00:43:38,926 INFO new best score: -36649.112566
 2009-11-02 00:43:38,932 INFO new best score: -36591.647201
 2009-11-02 00:43:38,933 INFO new best score: -36238.421358
 2009-11-02 00:43:38,935 INFO new best score: -36196.494534
 2009-11-02 00:43:38,938 INFO new best score: -36014.634524
 2009-11-02 00:43:38,940 INFO new best score: -35991.037879
 2009-11-02 00:43:38,941 INFO new best score: -35889.038030
 2009-11-02 00:43:38,946 INFO new best score: -35667.660601
 2009-11-02 00:43:38,953 INFO new best score: -35491.868203
 2009-11-02 00:43:38,955 INFO current run at 1024 runs
 2009-11-02 00:43:38,958 INFO new best score: -35322.422385
 2009-11-02 00:43:38,971 INFO new best score: -35296.389295
 2009-11-02 00:43:38,972 INFO new best score: -34799.198370
 2009-11-02 00:43:38,974 INFO new best score: -34655.194786
 2009-11-02 00:43:38,977 INFO new best score: -34608.069227
 2009-11-02 00:43:38,979 INFO new best score: -34539.947513
 2009-11-02 00:43:38,979 INFO new best score: -33247.031299
 2009-11-02 00:43:38,979 INFO new best score: -32367.878943
 2009-11-02 00:43:38,987 INFO new best score: -31805.170969
 2009-11-02 00:43:38,996 INFO new best score: -31465.390351
 2009-11-02 00:43:38,996 INFO new best score: -31399.347724
 2009-11-02 00:43:38,999 INFO new best score: -30749.273747
 2009-11-02 00:43:39,003 INFO new best score: -30425.747441
 2009-11-02 00:43:39,005 INFO new best score: -29257.455498
 2009-11-02 00:43:39,006 INFO new best score: -29215.783892
 2009-11-02 00:43:39,008 INFO new best score: -28975.291472
 2009-11-02 00:43:39,012 INFO new best score: -28192.624760
 2009-11-02 00:43:39,018 INFO new best score: -27934.421265
 2009-11-02 00:43:39,026 INFO new best score: -27688.247659
 2009-11-02 00:43:39,035 INFO current run at 2048 runs
 2009-11-02 00:43:39,037 INFO new best score: -27390.644387
 2009-11-02 00:43:39,057 INFO new best score: -26793.922438
 2009-11-02 00:43:39,057 INFO new best score: -26696.244150
 2009-11-02 00:43:39,061 INFO new best score: -26404.136400
 2009-11-02 00:43:39,083 INFO new best score: -26404.136400
 2009-11-02 00:43:39,094 INFO new best score: -25926.038197
 2009-11-02 00:43:39,108 INFO new best score: -25368.028231
 2009-11-02 00:43:39,115 INFO new best score: -25312.586966
 2009-11-02 00:43:39,132 INFO new best score: -25251.911826
 2009-11-02 00:43:39,137 INFO new best score: -25202.999277
 2009-11-02 00:43:39,145 INFO new best score: -24692.239918
 2009-11-02 00:43:39,158 INFO new best score: -24692.239918
 2009-11-02 00:43:39,187 INFO new best score: -24206.877575
 2009-11-02 00:43:39,195 INFO current run at 4096 runs
 2009-11-02 00:43:39,223 INFO new best score: -24159.595396
 2009-11-02 00:43:39,231 INFO new best score: -24088.719891
 2009-11-02 00:43:39,245 INFO new best score: -23972.734353
 2009-11-02 00:43:39,260 INFO new best score: -23906.426074
 2009-11-02 00:43:39,289 INFO new best score: -23901.325907
 2009-11-02 00:43:39,305 INFO new best score: -23286.130255

2009-11-02 00:43:39,309 INFO new best score: -23076.669258
 2009-11-02 00:43:39,310 INFO new best score: -22945.476729
 2009-11-02 00:43:39,320 INFO new best score: -22943.882305
 2009-11-02 00:43:39,370 INFO new best score: -22097.219253
 2009-11-02 00:43:39,378 INFO new best score: -21951.069041
 2009-11-02 00:43:39,512 INFO current run at 8192 runs
 2009-11-02 00:43:39,769 INFO new best score: -21949.474618
 2009-11-02 00:43:40,134 INFO current run at 16384 runs
 2009-11-02 00:43:40,367 INFO new best score: -21819.103878
 2009-11-02 00:43:40,368 INFO new best score: -21814.003710
 2009-11-02 00:43:40,430 INFO new best score: -21812.409286
 2009-11-02 00:43:40,442 INFO new best score: -21812.409286
 2009-11-02 00:43:41,231 INFO new best score: -21729.582347
 2009-11-02 00:43:41,262 INFO new best score: -21604.015041
 2009-11-02 00:43:42,573 INFO new best score: -21549.955257
 2009-11-02 00:43:43,565 INFO current run at 32768 runs
 2009-11-02 00:43:43,652 INFO new best score: -21549.955257
 2009-11-02 00:43:45,122 INFO new best score: -21549.955257
 2009-11-02 00:43:48,326 INFO current run at 65536 runs
 2009-11-02 00:43:54,024 INFO current run at 131072 runs
 2009-11-02 00:44:05,620 INFO current run at 262144 runs
 2009-11-02 00:44:29,461 INFO current run at 524288 runs
 2009-11-02 00:45:13,352 INFO final temperature: 1.232621
 2009-11-02 00:45:13,352 INFO anneal finished: num_evaluations=1000000, best_score=-21549.955257
 Benin - Porto-Novo
 Togo - Lome
 Ghana - Accra
 Niger - Niamey
 Burkina Faso - Ouagadougou
 Cote d'Ivoire - Yamoussoukro
 Liberia - Monrovia
 Sierra Leone - Freetown
 Guinea - Conakry
 Guinea-Bissau - Bissau
 The Gambia - Banjul
 Senegal - Dakar
 Mauritania - Nouakchott
 Cape Verde - Praia
 Morocco - Rabat
 Algeria - Algiers
 Tunisia - Tunis
 Libya - Tripoli
 Egypt - Cairo
 Sudan - Khartoum
 Eritrea - Asmara
 Djibouti - Djibouti
 Ethiopia - Addis Ababa
 Somalia - Mogadishu
 Seychelles - Victoria
 Mauritius - Port Louis
 Madagascar - Antananarivo
 Comoros - Moroni
 Tanzania - Dar es Salaam
 Kenya - Nairobi
 Uganda - Kampala
 Rwanda - Kigali
 Burundi - Bujumbura
 Malawi - Lilongwe
 Zambia - Lusaka
 Zimbabwe - Harare
 Mozambique - Maputo
 Swaziland - Mbabane
 Lesotho - Maseru
 South Africa - Pretoria
 Botswana - Gaborone
 Namibia - Windhoek
 Angola - Luanda
 Congo, Democratic Republic of the - Kinshasa
 Congo, Republic of the - Brazzaville
 Central African Republic - Bangui
 Chad - N'Djamena
 Cameroon - Yaounde
 Gabon - Libreville
 Equatorial Guinea - Malabo
 Nigeria - Abuja
 21186.3444977 mi