A Guided Tour of Several New and Interesting Routing Problems

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Outline of Lecture

- The close enough traveling salesman problem (CETSP)
- The CETSP over a street network
- The colorful traveling salesman problem (CTSP)
- The consistent vehicle routing problem (CVRP)
- Conclusions

My Student Collaborators

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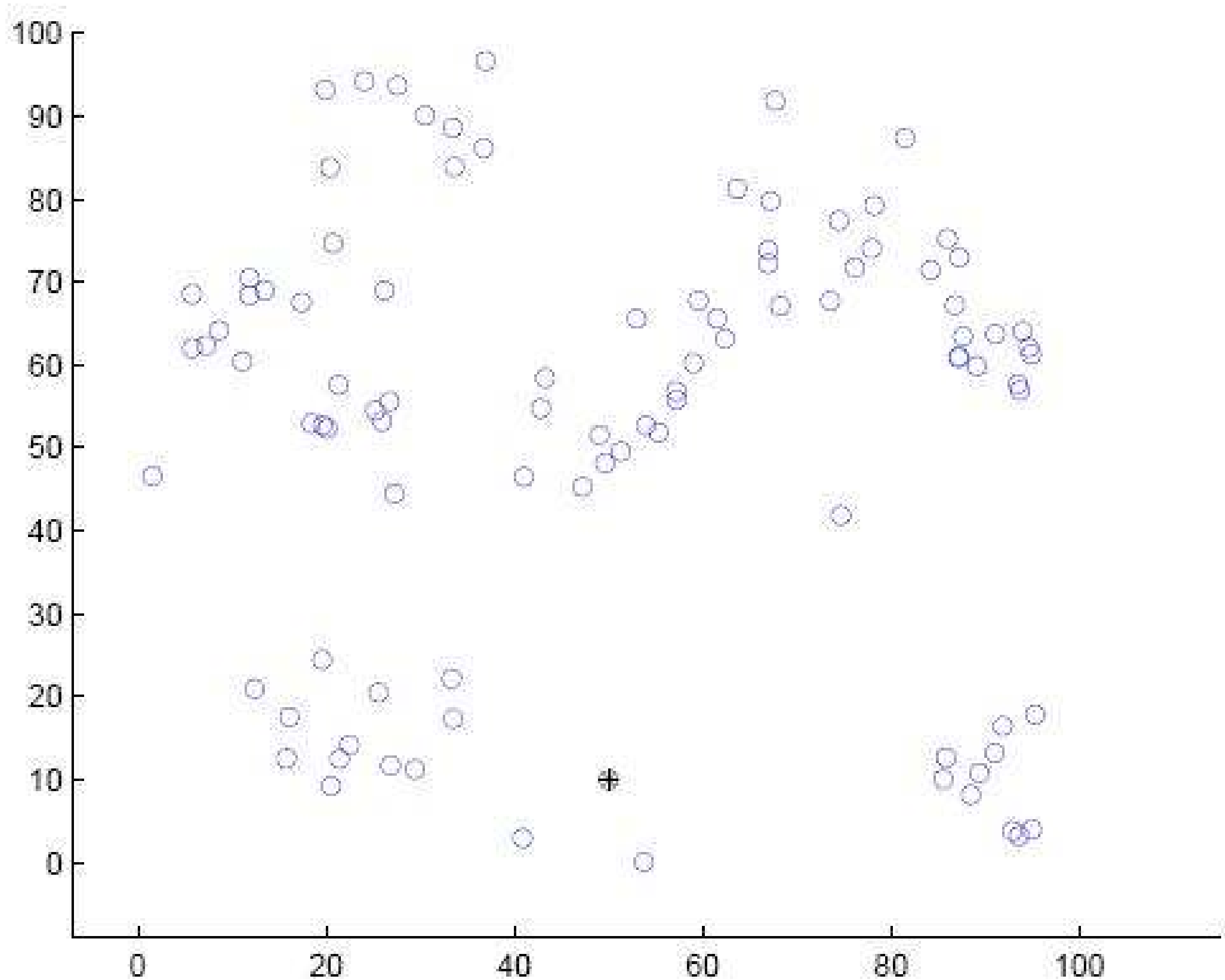
The Close Enough Traveling Salesman Problem

- Until recently, utility meter readers had to visit each customer location and read the meter at that site
- Now, radio frequency identification (RFID) technology allows the meter reader to get close to each customer and remotely read the meter
- A simple model
  - Customers are points in Euclidean space
  - There is a central depot
  - There is a fixed radius r which defines "close enough"
  - The goal is to minimize distance traveled

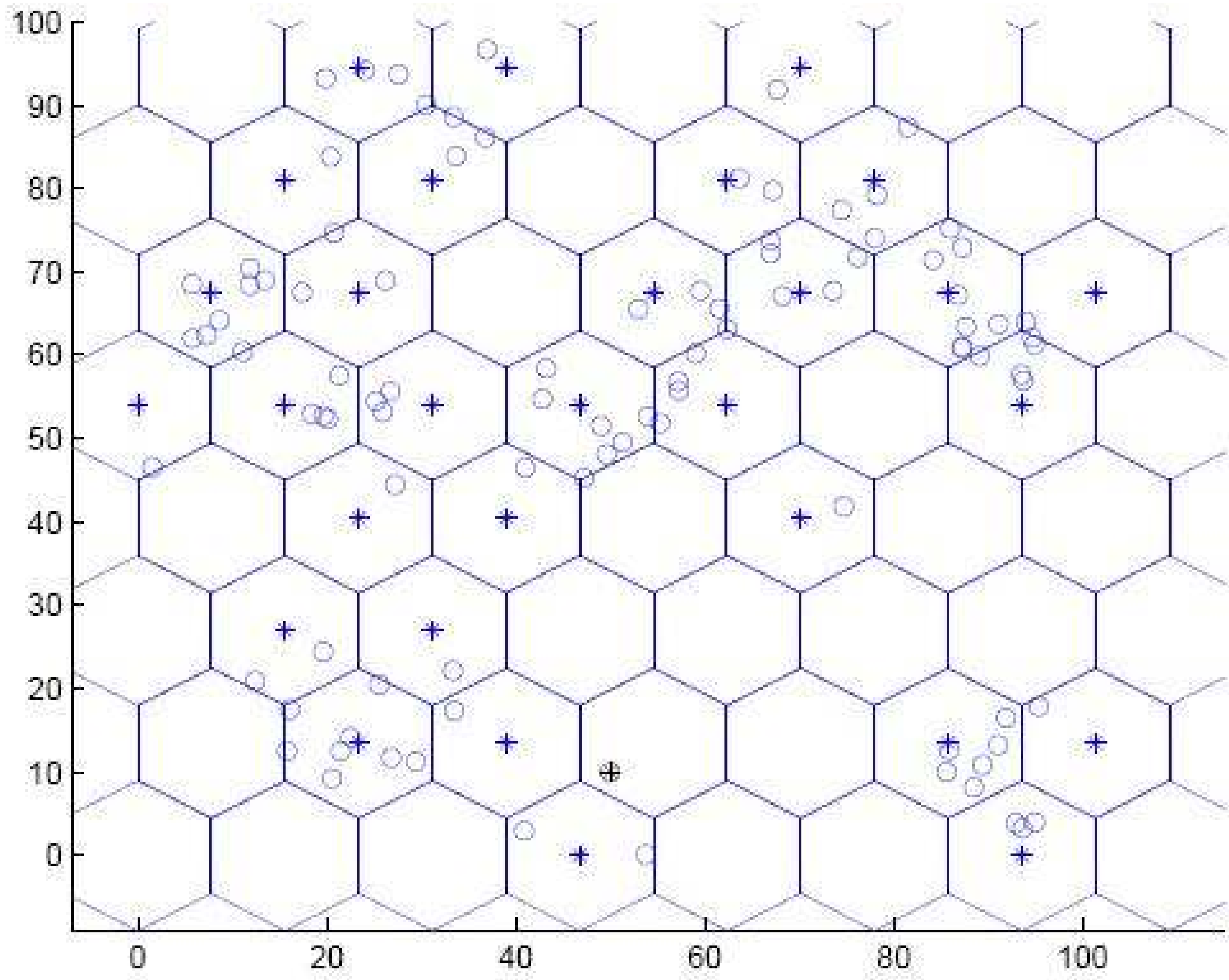
CETSP Heuristic

- Create a set S of “supernodes” such that each customer is within r units of at least one supernode
- This set should be as small in cardinality as possible
- Solve the TSP over S and the central depot
- Use post-processing to reposition the supernodes in order to reduce total distance
- An illustration follows

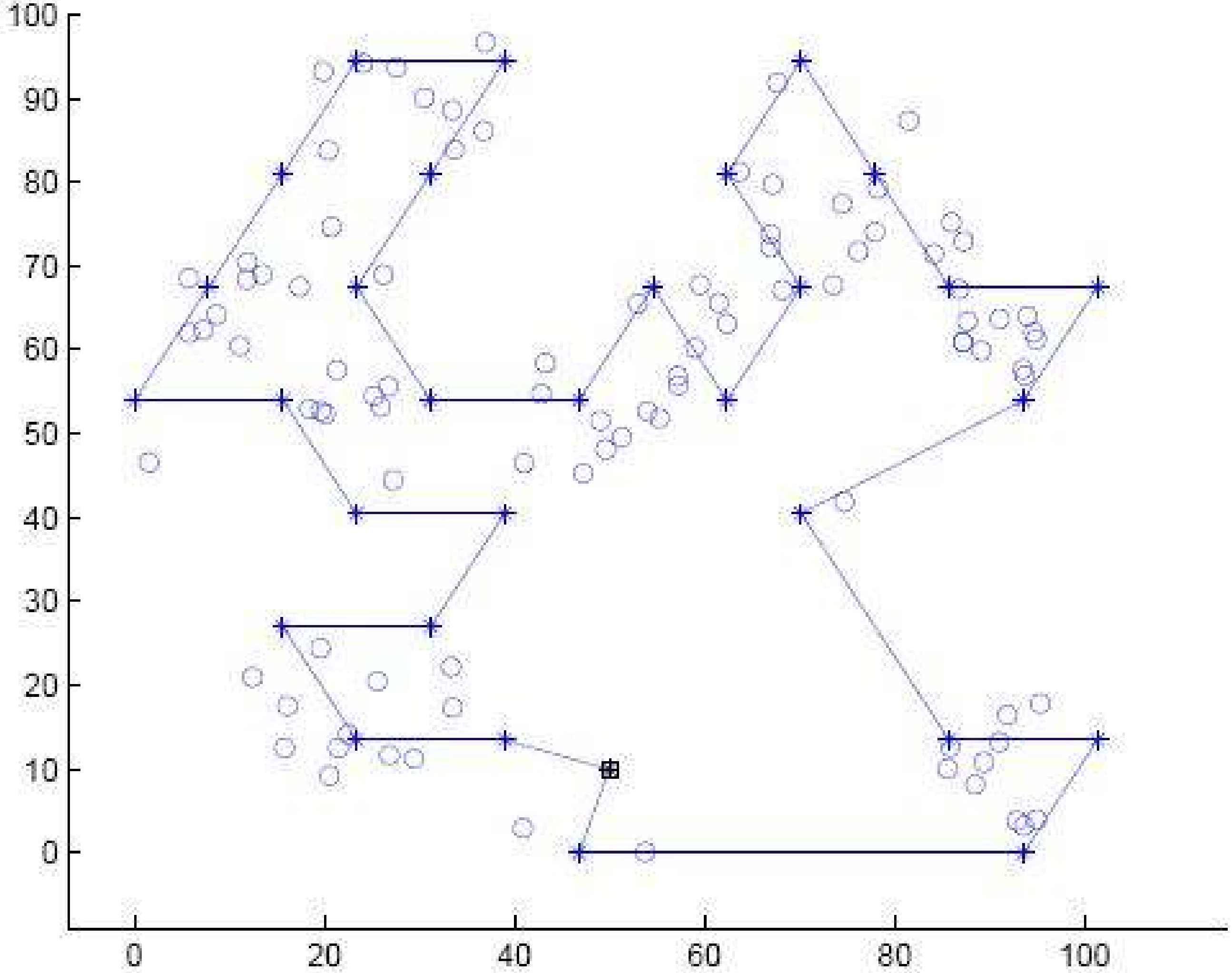
The Central Depot and Customers



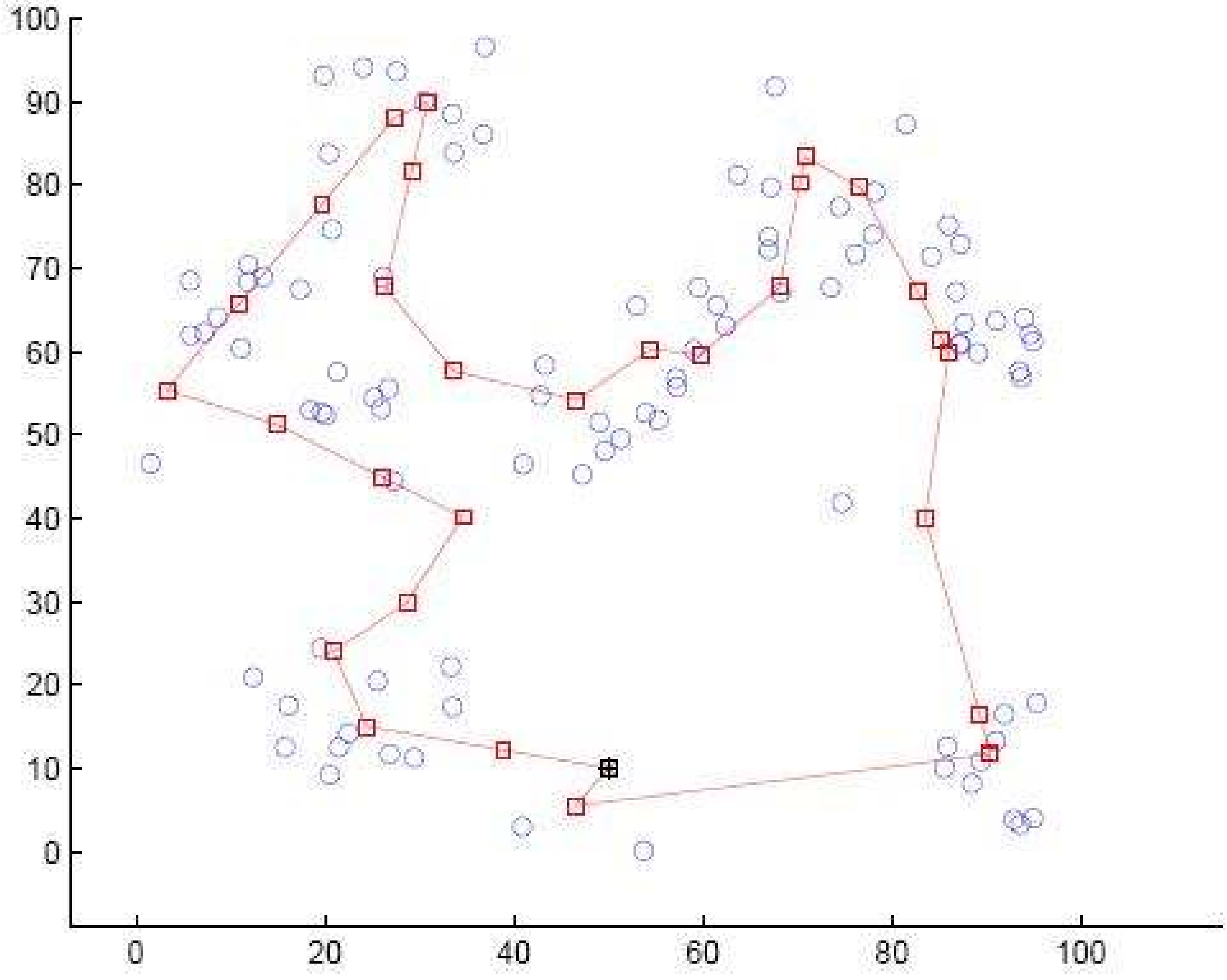
Use Geometry to Find Supernodes



Solve the TSP



Reposition Supernodes and Solve Again



Computational Experiments

- We focused on the location and relocation of the supernodes
- Several heuristics were compared
- Random and clustered data sets were tested
- The number of customers and the radius were varied
- The best heuristic seems to work well
- In the real-world, meter reading takes place over a street network

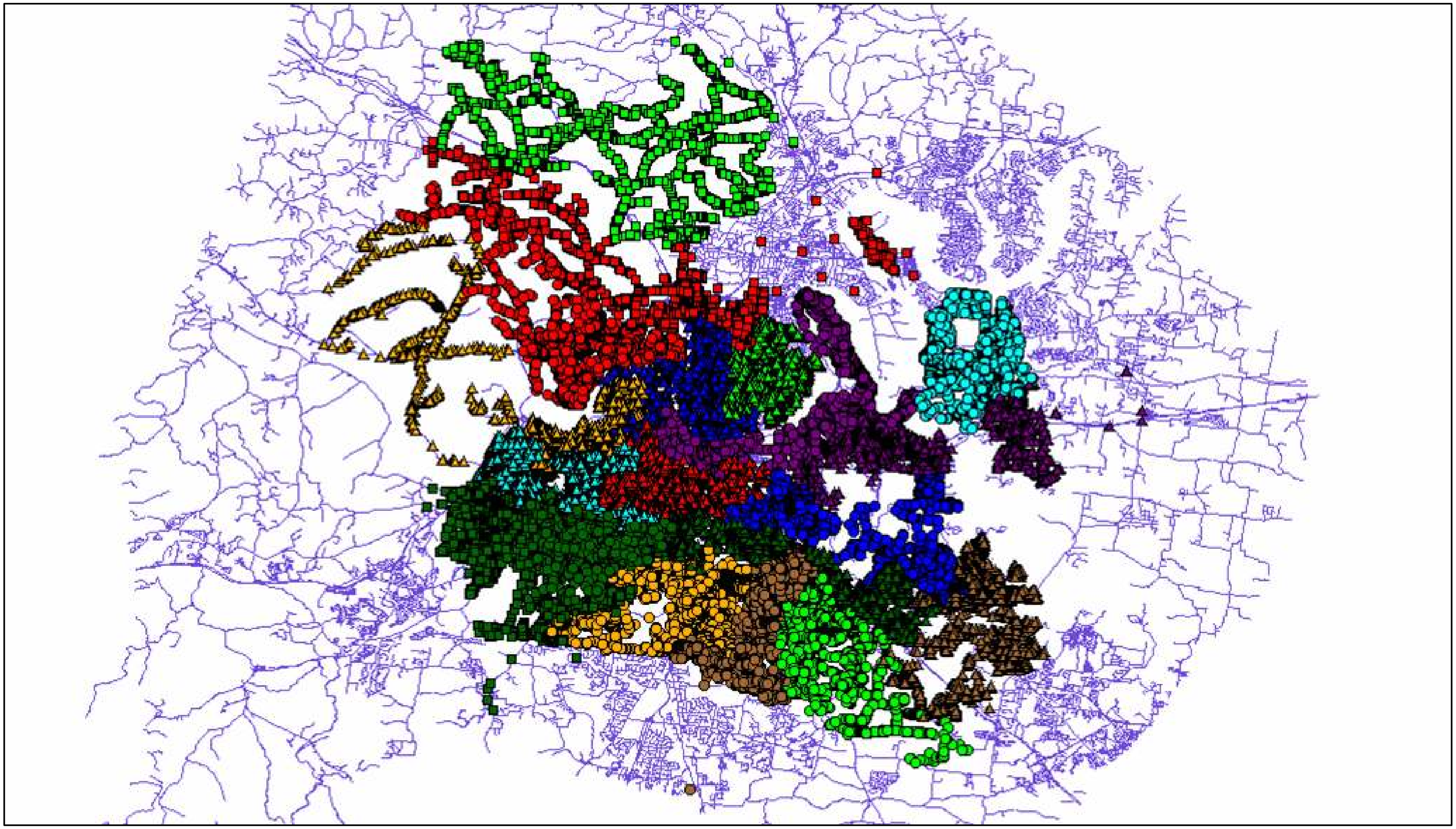
The CETSP over a Street Network

- We used RouteSmart (RS) with ArcGIS
  - Real-world data and constraints
  - Address matching
  - Side-of-street level routing
  - Solved as an arc routing problem
- Our heuristic selects segments (analogous to supernodes) to exploit the "close enough" feature of RFID
- RS routes over the chosen segments to obtain a cycle
- Currently, RS solves the problem as a Chinese (or rural) Postman Problem

Heuristic Implementation

- How do we choose the street segments to feed into RS?
- We tested several ideas
- Two are simple greedy procedures
  - Greedy A: Choose the street segment that covers the most customers, remove those customers, and repeat until all customers are covered
  - Greedy B: Same as above, but order street segments based on the number of customers covered per unit length

Each Color is a Separate Partition

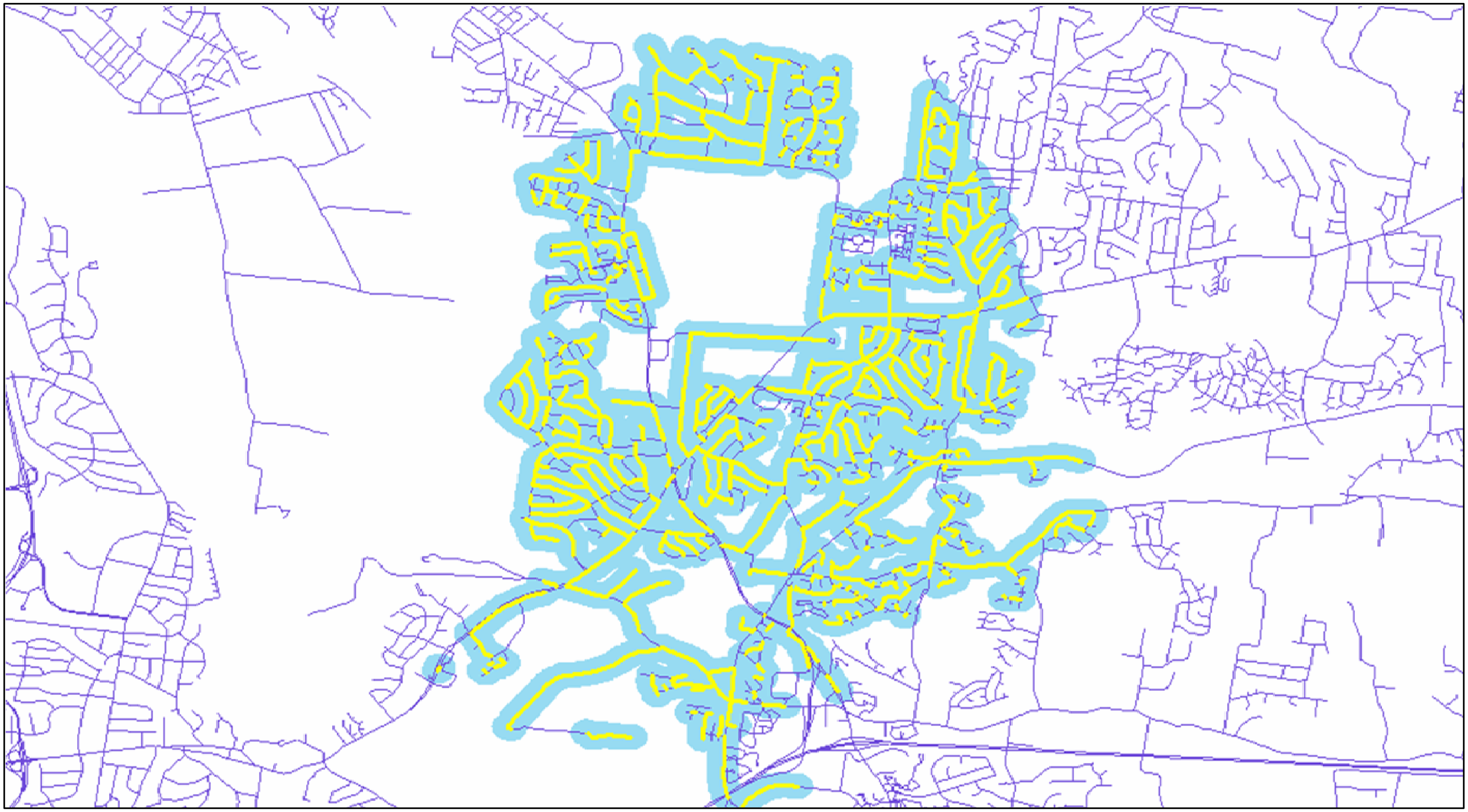


A Single Partition

A Closer Look at a Partition

The Area Covered with RFID

The Area Covered by the Entire Partition



Some Preliminary Results

500 foot radius

Method	Miles	Hours	Number of Segments	Miles of Segments	Deadhead Miles
RS	204.8	9:22	1099	107.3	97.5
Greedy A	161.8	7:16	485	66.3	95.5
Greedy B	158.5	7:06	470	64.4	94.1
Essential	–	–	256	47.9	–

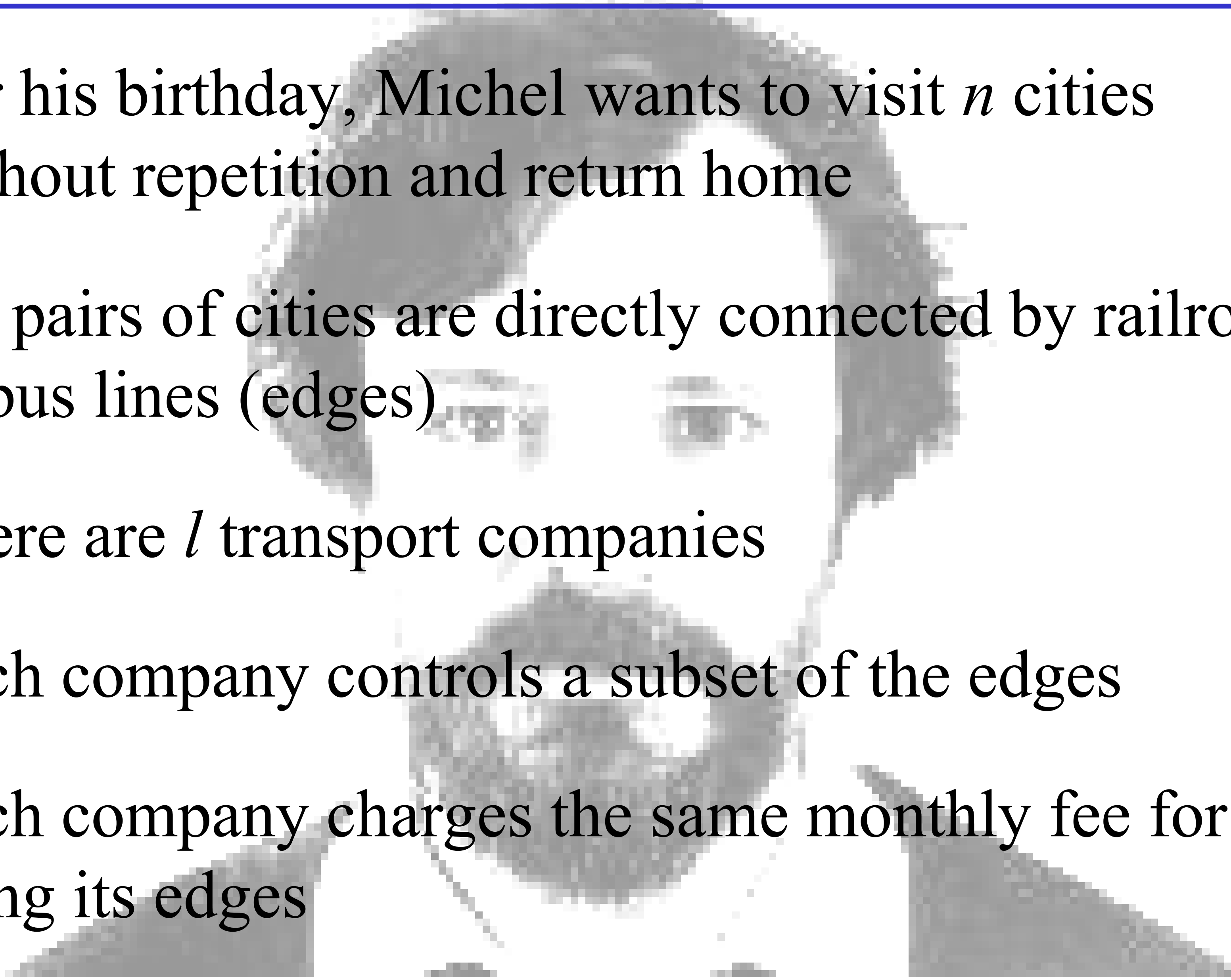
350 foot radius

RS	204.8	9:22	1099	107.3	97.5
Greedy A	171.9	7:45	621	78.1	93.8
Greedy B	171.2	7:43	610	78.0	93.2
Essential	–	–	451	67.9	–

The Colorful Traveling Salesman Problem

- Given an undirected complete graph with colored edges as input
- Each edge has a single color
- Different edges can have the same color
- Find a Hamiltonian tour with the minimum number of colors
- This problem is related to the Minimum Label Spanning Tree problem
- A hypothetical scenario follows

CTSP Motivation



- For his birthday, Michel wants to visit *n* cities without repetition and return home
- All pairs of cities are directly connected by railroad or bus lines (edges)
- There are *l* transport companies
- Each company controls a subset of the edges
- Each company charges the same monthly fee for using its edges

CTSP Motivation - - continued

- We can think of the edges owned by Company 1 as red, those owned by Company 2 as blue, and so on
- The objective is to construct a Hamiltonian tour that uses the smallest number of colors
- After much thought, Michel realizes that the CTSP is NP-complete since if he could solve the CTSP optimally, he could determine whether a graph has a Hamiltonian tour
- He then solves the CTSP using his favorite metaheuristic and his birthday journey begins
- Joyeux Anniversaire Michel!

Preliminary Results

- We developed a path extension algorithm (PEA) and a genetic algorithm (GA) to solve the CTSP
- We solved problems with 50, 100, 150, and 200 nodes and from 25 to 250 colors
- Our experiments were run on a Pentium 4 PC with 1.80 GHz and 256 MB RAM
- In general, GA outperforms PEA
- Average running time for the GA on a graph with 200 nodes and 250 colors was 17.2 seconds

The Consistent Vehicle Routing Problem

- This problem comes from a major package delivery company in the U.S.
- Start with a capacitated vehicle routing problem (VRP)
- Add two service quality constraints
  - Each customer must receive service from the same driver each day
  - Each customer must receive service at roughly the same time each day

The Consistent Vehicle Routing Problem

- Assumptions
  - A week of service requirements is known in advance
  - An unlimited number of vehicles each with fixed capacity (or time limit) c
- The Goal
  - Produce a set of routes for each day such that total weekly cost is minimized subject to the capacity and consistency constraints

A Simple Heuristic for the CVRP

- Identify all customer locations requiring service on more than one day
- Solve a capacitated VRP (capacity = $(1 + \lambda)\, c$) over these locations using sweep, savings, and 2-opt procedures
- This results in a template of routes
- Create daily routes from the template
  - Remove customers who do not require service on that day
  - Insert all customers who require service only on that day

The Artificial Capacity

- If we expect the daily routes to involve more insertions than removals from the template, then we set $\lambda < 0$
- If we expect there to be more removals than insertions, then set $\lambda > 0$
- In our experiments, we found that $\lambda = 0.1$ worked well

Implicit Rules that Guide the Heuristic

- If customers *i* and *j* are on the same route on one day, then they must be on the same route every day both require service
- If customer *i* is visited before customer *j* on one day, then this precedence must be satisfied every day both customers require service
- Next, we examine how well these simple rules work

How Consistent are the Solutions?

- The "same driver" requirement is automatically satisfied
- The "same time" requirement is more complex
- Observation: The amount of service time variation depends on the amount of customer overlap amongst the five days
  - Large overlap → slight variation
  - Small overlap → increased variation
- We performed several computational experiments

Experiment #1

- Each customer requires service on each day with equal probability p
- We varied p from 0.7 to 0.9 in steps of 0.02
- Vehicle capacity is 500 minutes
- Vehicles travel one Euclidean unit of distance per minute
- It takes one minute to service a customer
- There are $k = 700$ customers in total
- This results in about 100 to 125 customers per route
- Ten repetitions for each value of p

Service Time Variation

p	Max Service Time Variation	Mean Service Time Variation	Mean Number Customers/Route	Mean Number Vehicles
0.7	44.5	14.6	106.4	4.8
0.8	39.7	13.8	114.2	5.0
0.9	30.8	10.6	124.4	5.2

- Bottom line: The level of consistency is quite high

Experiment #2

- This experiment is of greater practical interest
- Here we have business customers and residential customers
- Based on real-world data
  - 70% are business customers
  - 30% are residential customers
  - Business customers require service with probability 0.9 each day
  - Residential customers require service with probability 0.1 each day
- We generated five data sets, each with 1000 customers

Service Time Variation

Data Set	Max Service Time Variation	Mean Service Time Variation
1	43.7	18.7
2	42.7	22.3
3	47.1	17.1
4	34.6	17.5
5	51.7	24.9
Avg.	44.0	20.1

- Here, consistent service is important to business customers, not residential customers

The (Approximate) Cost of Consistency

- If we relax the consistency requirements, what would the solutions look like?
- We looked at 10 homogeneous data sets with $p = 0.7$ and $k = 800$
- On average, total cost is reduced by about 3.5%
- On the other hand, the mean service time variation increases from 15 minutes to 3 hours
- We looked at 10 heterogeneous data sets also, and the results were essentially the same
- Bottom line: The two simple rules ensure a high degree of consistency

Conclusions

- I have been working on vehicle routing problems since 1974
- But, the area is as fresh and exciting to me NOW as it was when I began
- Very interesting and practical new vehicle routing problems continue to emerge, as illustrated in this talk
- I expect this to continue for quite some time
- Clever metaheuristics can often be used to obtain excellent solutions to these new problems