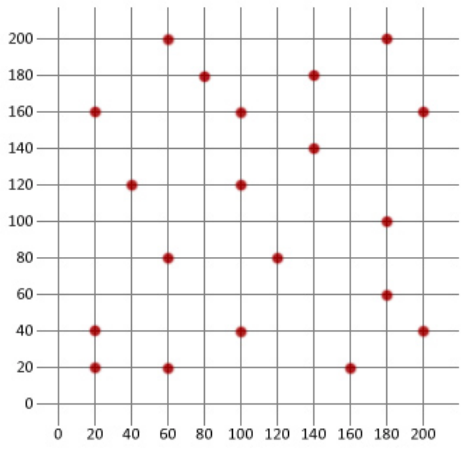
20TH AUGUST 2012 · BY LEE JACOBSON

Applying a genetic algorithm to the traveling salesman problem

To understand what the traveling salesman problem (TSP) is, and why it's so problematic, let's briefly go over a classic example of the problem.



Imagine you're a salesman and you've been given a map like the one opposite. On it you see that the map contains a total of 20 locations and you're told it's your job to visit each of these locations to make a sell.

Before you set off on your journey you'll probably want to plan a route so you can minimize your travel time. Fortunately, humans are pretty good at this, we can easily work out a reasonably good route without needing to do much more than glance at the map. However, when we've found a route that we believe is optimal, how can we test if it's really the optimal route?

Well, in short, we can't - at least not practically.

To understand why it's so difficult to prove the optimal route let's consider a similar map with just 3 locations instead of the original 20. To find a single route, we first have to choose a starting location from the three possible locations on the map. Next, we'd have a choice of 2 cities for the second location, then finally there is just 1 city left to pick to complete our route. This would mean there are 3 x 2 x 1 different routes to pick in total.

That means, for this example, there are only 6 different routes to pick from. So for this case of just 3 locations it's reasonably trivial to calculate each of those 6 routes and find the shortest. If you're good at maths you may have already realized what the problem is here. The number of possible routes is a factorial of the number of locations to visit, and trouble with factorials is that they grow in size remarkably quick!

For example, the factorial of 10 is 3628800, but the factorial of 20 is a gigantic, 2432902008176640000.

So going back to our original problem, if we want to find the shortest route for our map of 20 locations we would have to evaluate 2432902008176640000 different routes! Even with modern computing power this is terribly impractical, and for even bigger problems, it's close to impossible.

Finding a solution

Although it may not be practical to find the best solution for a problem like ours, we do have

Twitter Feed

"😂 https://t.co/fbpPYtnOfX"
6th November 2017, 03:56:43 | Link

"The best thing about visiting
parents... https://t.co/U3x89O
4th November 2017, 11:55:14 | Link

"@gnome_wandering Depend
risk tolerance I guess, but I pe
love $sq"
27th October 2017, 19:42:50 | Link

"@gnome_wandering Why pi
in all of these 😂"
27th October 2017, 19:39:44 | Link

"Hope is important"
27th October 2017, 19:30:40 | Link

"In @ 11.52 boii. https://t.co
/vatyQZjWPG"
27th October 2017, 19:12:27 | Link

@leejacobson

Popular Tags

space genetic-algorithm perceptron-le artificial-neural-networks javascr multilayer-perceptron tsp interviews ant-colony-optimization self-improvement artificial-intelligence neural-networks simulated-anneali algorithm bionics multi-layer- node node-js

Hire Me

I'm available for freelance work, lee@cwpstudios[dot]com algorithms that let us discover close to optimum solutions such as the nearest neighbor algorithm and swarm optimization. These algorithms are capable of finding a 'good-enough' solution to the travelling salesman problem surprisingly quickly. In this tutorial however, we will be using genetic algorithms as our optimization technique.

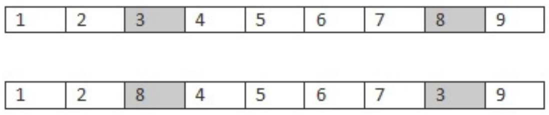
If you're not already familiar with genetic algorithms and like to know how they work, then please have a look at the introductory tutorial below:
[Creating a genetic algorithm for beginners]

Finding a solution to the travelling salesman problem requires we set up a genetic algorithm in a specialized way. For instance, a valid solution would need to represent a route where every location is included at least once and only once. If a route contain a single location more than once, or missed a location out completely it wouldn't be valid and we would be valuable computation time calculating it's distance.

To ensure the genetic algorithm does indeed meet this requirement special types of mutation and crossover methods are needed.

Firstly, the mutation method should only be capable of shuffling the route, it shouldn't ever add or remove a location from the route, otherwise it would risk creating an invalid solution. One type of mutation method we could use is swap mutation.

With swap mutation two location in the route are selected at random then their positions are simply swapped. For example, if we apply swap mutation to the following list, [1,2,3,4,5] we might end up with, [1,2,5,4,3]. Here, positions 3 and 5 were switched creating a new list with exactly the same values, just a different order. Because swap mutation is only swapping pre-existing values, it will never create a list which has missing or duplicate values when compared to the original, and that's exactly what we want for the traveling salesman problem.



1	2	3	4	5	6	7	8	9

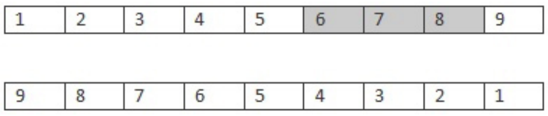
1	2	8	4	5	6	7	3	9

Now we've dealt with the mutation method we need to pick a crossover method which can enforce the same constraint.

One crossover method that's able to produce a valid route is ordered crossover. In this crossover method we select a subset from the first parent, and then add that subset to the offspring. Any missing values are then adding to the offspring from the second parent in order that they are found.

To make this explanation a little clearer consider the following example:

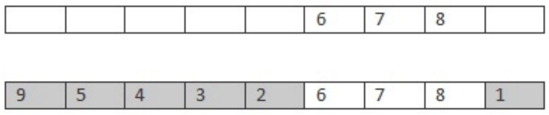
Parents



1	2	3	4	5	6	7	8	9

9	8	7	6	5	4	3	2	1

Offspring



					6	7	8	

9	5	4	3	2	6	7	8	1

Here a subset of the route is taken from the first parent (6,7,8) and added to the offspring's route.

Next, the missing route locations are adding in order from the second parent. The first location in the second parent's route is 9 which isn't in the offspring's route so it's added in the first available position. The next position in the parents route is 8 which is in the offspring's route so it's skipped. This process continues until the offspring has no remaining empty values. If implemented correctly the end result should be a route which contains all of the positions it's parents did with no positions missing or duplicated.

Creating the Genetic Algorithm

In literature of the traveling salesman problem since locations are typically refereed to as cities, and routes are refereed to as tours, we will adopt the standard naming conventions in our code.

To start, let's create a class that can encode the cities.

City.java

```
/*
* City.java
* Models a city
*/

package tsp;

public class City {
    int x;
    int y;

    // Constructs a randomly placed city
    public City(){
        this.x = (int)(Math.random()*200);
        this.y = (int)(Math.random()*200);
    }

    // Constructs a city at chosen x, y location
    public City(int x, int y){
        this.x = x;
        this.y = y;
    }

    // Gets city's x coordinate
    public int getX(){
        return this.x;
    }

    // Gets city's y coordinate
    public int getY(){
        return this.y;
    }

    // Gets the distance to given city
    public double distanceTo(City city){
        int xDistance = Math.abs(getX() - city.getX());
        int yDistance = Math.abs(getY() - city.getY());
        double distance = Math.sqrt( (xDistance*xDistance) + (yDistance*yDistance) );

        return distance;
    }

    @Override
    public String toString(){
        return getX()+", "+getY();
    }
}
```

Now we can create a class that holds all of our destination cities for our tour

TourManager.java

```
/*
* TourManager.java
* Holds the cities of a tour
*/

package tsp;

import java.util.ArrayList;

public class TourManager {
    // Holds our cities
    private static ArrayList destinationCities = new ArrayList<City>();

    // Adds a destination city
    public static void addCity(City city) {
        destinationCities.add(city);
    }

    // Get a city
    public static City getCity(int index){
        return (City)destinationCities.get(index);
    }

    // Get the number of destination cities
    public static int numberOfCities(){
        return destinationCities.size();
    }
}
```

Next we need a class that can encode our routes, these are generally referred to as tours so we'll stick to the convention.

Tour.java

```
/*
* Tour.java
* Stores a candidate tour
*/

package tsp;

import java.util.ArrayList;
import java.util.Collections;

public class Tour{

    // Holds our tour of cities
    private ArrayList tour = new ArrayList<City>();
    // Cache
    private double fitness = 0;
    private int distance = 0;

    // Constructs a blank tour
    public Tour(){
        for (int i = 0; i < TourManager.numberOfCities(); i++) {
            tour.add(null);
        }
    }

    public Tour(ArrayList tour){
        this.tour = tour;
    }

    // Creates a random individual
    public void generateIndividual() {
        // Loop through all our destination cities and add them to our tour
        for (int cityIndex = 0; cityIndex < TourManager.numberOfCities(); cityIndex++) {
          setCity(cityIndex, TourManager.getCity(cityIndex));
        }
        // Randomly reorder the tour
        Collections.shuffle(tour);
    }

    // Gets a city from the tour
    public City getCity(int tourPosition) {
        return (City)tour.get(tourPosition);
    }

    // Sets a city in a certain position within a tour
    public void setCity(int tourPosition, City city) {
        tour.set(tourPosition, city);
        // If the tours been altered we need to reset the fitness and distance
        fitness = 0;
        distance = 0;
    }

    // Gets the tours fitness
    public double getFitness() {
        if (fitness == 0) {
            fitness = 1/(double)getDistance();
        }
        return fitness;
    }

    // Gets the total distance of the tour
```

```java
    public int getDistance(){
        if (distance == 0) {
            int tourDistance = 0;
            // Loop through our tour's cities
            for (int cityIndex=0; cityIndex < tourSize(); cityIndex++) {
                // Get city we're travelling from
                City fromCity = getCity(cityIndex);
                // City we're travelling to
                City destinationCity;
                // Check we're not on our tour's last city, if we are set our
                // tour's final destination city to our starting city
                if(cityIndex+1 < tourSize()){
                    destinationCity = getCity(cityIndex+1);
                }
                else{
                    destinationCity = getCity(0);
                }
                // Get the distance between the two cities
                tourDistance += fromCity.distanceTo(destinationCity);
            }
            distance = tourDistance;
        }
        return distance;
    }

    // Get number of cities on our tour
    public int tourSize() {
        return tour.size();
    }

    // Check if the tour contains a city
    public boolean containsCity(City city){
        return tour.contains(city);
    }

    @Override
    public String toString() {
        String geneString = "|";
        for (int i = 0; i < tourSize(); i++) {
            geneString += getCity(i)+"|";
        }
        return geneString;
    }
}
```

We also need to create a class that can hold a population of candidate tours

Population.java

```java
/*
* Population.java
* Manages a population of candidate tours
*/

package tsp;

public class Population {

    // Holds population of tours
    Tour[] tours;

    // Construct a population
    public Population(int populationSize, boolean initialise) {
        tours = new Tour[populationSize];
        // If we need to initialise a population of tours do so
        if (initialise) {
            // Loop and create individuals
            for (int i = 0; i < populationSize(); i++) {
                Tour newTour = new Tour();
                newTour.generateIndividual();
                saveTour(i, newTour);
            }
        }
    }

    // Saves a tour
    public void saveTour(int index, Tour tour) {
        tours[index] = tour;
    }

    // Gets a tour from population
    public Tour getTour(int index) {
        return tours[index];
    }

    // Gets the best tour in the population
    public Tour getFittest() {
        Tour fittest = tours[0];
        // Loop through individuals to find fittest
        for (int i = 1; i < populationSize(); i++) {
            if (fittest.getFitness() <= getTour(i).getFitness()) {
                fittest = getTour(i);
            }
        }
        return fittest;
    }

    // Gets population size
    public int populationSize() {
        return tours.length;
    }
}
```

Next, the let's create a GA class which will handle the working of the genetic algorithm and evolve our population of solutions.

GA.java

```
/*
* GA.java
* Manages algorithms for evolving population
*/

package tsp;

public class GA {

    /* GA parameters */
    private static final double mutationRate = 0.015;
    private static final int tournamentSize = 5;
    private static final boolean elitism = true;

    // Evolves a population over one generation
    public static Population evolvePopulation(Population pop) {
        Population newPopulation = new Population(pop.populationSize(), false);

        // Keep our best individual if elitism is enabled
        int elitismOffset = 0;
        if (elitism) {
            newPopulation.saveTour(0, pop.getFittest());
            elitismOffset = 1;
        }

        // Crossover population
        // Loop over the new population's size and create individuals from
        // Current population
        for (int i = elitismOffset; i < newPopulation.populationSize(); i++) {
            // Select parents
            Tour parent1 = tournamentSelection(pop);
            Tour parent2 = tournamentSelection(pop);
            // Crossover parents
            Tour child = crossover(parent1, parent2);
            // Add child to new population
            newPopulation.saveTour(i, child);
        }

        // Mutate the new population a bit to add some new genetic material
        for (int i = elitismOffset; i < newPopulation.populationSize(); i++) {
            mutate(newPopulation.getTour(i));
        }

        return newPopulation;
    }

    // Applies crossover to a set of parents and creates offspring
    public static Tour crossover(Tour parent1, Tour parent2) {
        // Create new child tour
        Tour child = new Tour();

        // Get start and end sub tour positions for parent1's tour
        int startPos = (int) (Math.random() * parent1.tourSize());
        int endPos = (int) (Math.random() * parent1.tourSize());

        // Loop and add the sub tour from parent1 to our child
        for (int i = 0; i < child.tourSize(); i++) {
            // If our start position is less than the end position
            if (startPos < endPos && i > startPos && i < endPos) {
                child.setCity(i, parent1.getCity(i));
            } // If our start position is larger
            else if (startPos > endPos) {
                if (!(i < startPos && i > endPos)) {
```

```java
                    child.setCity(i, parent1.getCity(i));
                }
            }
        }

        // Loop through parent2's city tour
        for (int i = 0; i < parent2.tourSize(); i++) {
            // If child doesn't have the city add it
            if (!child.containsCity(parent2.getCity(i))) {
                // Loop to find a spare position in the child's tour
                for (int ii = 0; ii < child.tourSize(); ii++) {
                    // Spare position found, add city
                    if (child.getCity(ii) == null) {
                        child.setCity(ii, parent2.getCity(i));
                        break;
                    }
                }
            }
        }
        return child;
    }

    // Mutate a tour using swap mutation
    private static void mutate(Tour tour) {
        // Loop through tour cities
        for(int tourPos1=0; tourPos1 < tour.tourSize(); tourPos1++){
            // Apply mutation rate
            if(Math.random() < mutationRate){
                // Get a second random position in the tour
                int tourPos2 = (int) (tour.tourSize() * Math.random());

                // Get the cities at target position in tour
                City city1 = tour.getCity(tourPos1);
                City city2 = tour.getCity(tourPos2);

                // Swap them around
                tour.setCity(tourPos2, city1);
                tour.setCity(tourPos1, city2);
            }
        }
    }

    // Selects candidate tour for crossover
    private static Tour tournamentSelection(Population pop) {
        // Create a tournament population
        Population tournament = new Population(tournamentSize, false);
        // For each place in the tournament get a random candidate tour and
        // add it
        for (int i = 0; i < tournamentSize; i++) {
            int randomId = (int) (Math.random() * pop.populationSize());
            tournament.saveTour(i, pop.getTour(randomId));
        }
        // Get the fittest tour
        Tour fittest = tournament.getFittest();
        return fittest;
    }
}
```

Now we can create our main method, add our cities and evolve a route for our travelling salesman problem.

TSP_GA.java

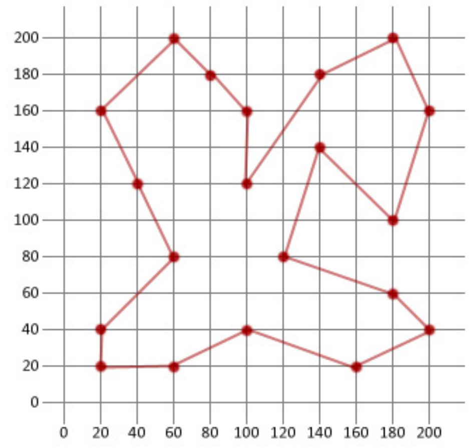
```java
/*
* TSP_GA.java
* Create a tour and evolve a solution
*/

package tsp;

public class TSP_GA {

    public static void main(String[] args) {

        // Create and add our cities
        City city = new City(60, 200);
        TourManager.addCity(city);
        City city2 = new City(180, 200);
        TourManager.addCity(city2);
        City city3 = new City(80, 180);
        TourManager.addCity(city3);
        City city4 = new City(140, 180);
        TourManager.addCity(city4);
        City city5 = new City(20, 160);
        TourManager.addCity(city5);
        City city6 = new City(100, 160);
        TourManager.addCity(city6);
        City city7 = new City(200, 160);
        TourManager.addCity(city7);
        City city8 = new City(140, 140);
        TourManager.addCity(city8);
        City city9 = new City(40, 120);
        TourManager.addCity(city9);
        City city10 = new City(100, 120);
        TourManager.addCity(city10);
        City city11 = new City(180, 100);
        TourManager.addCity(city11);
        City city12 = new City(60, 80);
        TourManager.addCity(city12);
        City city13 = new City(120, 80);
        TourManager.addCity(city13);
        City city14 = new City(180, 60);
        TourManager.addCity(city14);
        City city15 = new City(20, 40);
        TourManager.addCity(city15);
        City city16 = new City(100, 40);
        TourManager.addCity(city16);
        City city17 = new City(200, 40);
        TourManager.addCity(city17);
        City city18 = new City(20, 20);
        TourManager.addCity(city18);
        City city19 = new City(60, 20);
        TourManager.addCity(city19);
        City city20 = new City(160, 20);
        TourManager.addCity(city20);

        // Initialize population
        Population pop = new Population(50, true);
        System.out.println("Initial distance: " + pop.getFittest().getDistance());

        // Evolve population for 100 generations
        pop = GA.evolvePopulation(pop);
        for (int i = 0; i < 100; i++) {
            pop = GA.evolvePopulation(pop);
        }

        // Print final results
        System.out.println("Finished");
        System.out.println("Final distance: " + pop.getFittest().getDistance());
        System.out.println("Solution:");
        System.out.println(pop.getFittest());
    }
}
```

Output:

```
Initial distance: 1996
Finished
Final distance: 940
Solution:
|60, 200|20, 160|40, 120|60, 80|20, 40|20, 20|60, 20|100, 40|160, 20|200, 40|180, 60|120, 80|140
```

As you can see in just 100 generations we were able to find a route just over twice as good as our original and probably pretty close to optimum.

Final Results:



If you liked this tutorial you might also enjoy, Simulated Annealing for beginners

Author

Hello, I'm Lee.
I'm a developer from the UK who loves technology and business. Here you'll find articles and tutorials about things that interest me. If you want to hire me or know more about me head over to my about me page

Social Links

Tweet Like 146 Share Follow

Tags

genetic-algorithms artificial-intelligence java algorithm tsp

Related Articles

Solving the Traveling Salesman Problem Using Google Maps and Genetic Algorithms
Our Artificial World!
Ant Colony Optimization For Hackers
Introduction to Artificial Neural Networks - Part 1
Workplace Automation

Comments

105 Comments The Project Spot মীর ইমতিয়াজ মোসতা...

Recommend 6 Share Sort by Best

The Project Spot requires you to verify your email address before posting. Send verification email to imtiaz_naved@yahoo.com

Join the discussion…

abhishek • 3 years ago
where is package tsp,i m not getting output
7 • Reply • Share ›

Russita Lea • 2 years ago
Hello Lee,
thank you for the interesting article,

I have to apply a FUZZY genetic algorithm to the traveling salesman problem,
any explanation about that?

any body wrote the code of Lee on c++ ?

Best regards.
5 • Reply • Share ›

Kenny Liu → Russita Lea • a year ago
Hi, I plan on doing more research with this and I wonder if you re-wrote the code in c++?
Reply • Share ›

Adam Flammino → Kenny Liu • 2 months ago
Mine isn't identical, but I hope it's helpful to you https://github.com/Adam-Fla...
Reply • Share ›

Riccardo • 4 years ago
Hi! I have some problem with compilation:

```
javac -Xlint *.java
Tour.java:22: warning: [unchecked] unchecked call to add(E) as a member of the raw type
java.util.ArrayList
tour.add(null);
^
Tour.java:47: warning: [unchecked] unchecked call to set(int,E) as a member of the raw type
java.util.ArrayList
tour.set(tourPosition, city);
^
TourManager.java:17: warning: [unchecked] unchecked call to add(E) as a member of the raw
type java.util.ArrayList
destinationCities.add(city);
```

Where do I'm wrong?
Thanks!
5 • Reply • Share ›

Yuriy Chernyshov • 4 years ago
Good article but a little bit pure explanation.
Suppose I have 25 cities, following Your idea I do initialize they and set into TourManager.
Now, what I do need is to get exact answer for the question: the minimum cost of a traveling salesman tour for this instance.
Could You explain in more details about Population and GA classes. Running Your code every time I get different results.
4 • Reply • Share ›

the Project Spot.

Thanks for visiting!

Lets keep in touch,

Send me an email or follow me on Google+

Built by cwpStudios.com

Maintained and updated by Lee Jacobson