MAKING DARWIN PROUD

Coding Evolutionary Algorithms

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Let me introduce myself…

- Bas W. Knopper
- Dutch
- JavaOne, J-Fall, GeeCon, JFokus Speaker
- AI enthousiast
  - Soft spot for Evolutionary Algorithms
- Java Developer
- Managing Partner @ JCore

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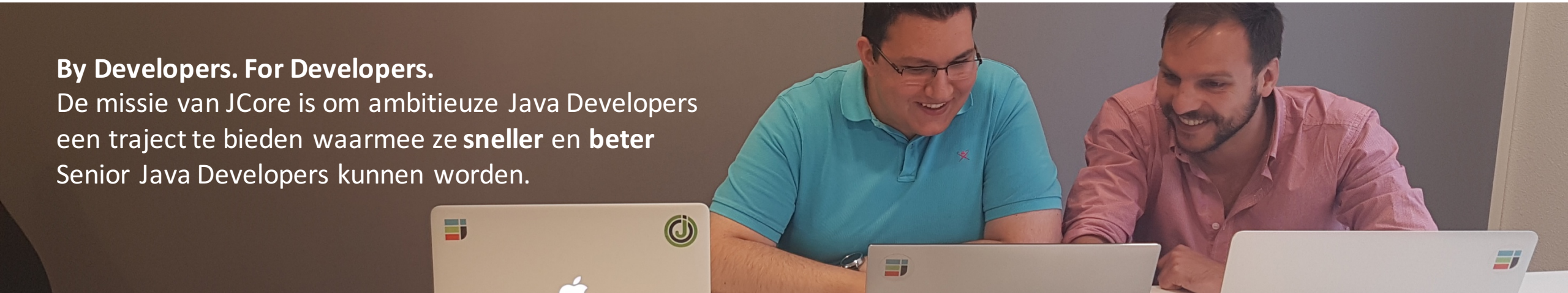
Versnel je carrière als Java Consultant

Wat
(Java Consultancy) ->
We helpen klanten met het realiseren van complexe IT projecten.

Hoe
Met ambitieuze en enthousiaste Java Consultants die een bijdrage leveren bij de klant.

Waarom
Vanuit een passie voor IT en het oplossen van complexe problemen.



By Developers. For Developers.
De missie van JCore is om ambitieuze Java Developers een traject te bieden waarmee ze **sneller** en **beter** Senior Java Developers kunnen worden.

What I would like to accomplish…

- Interest
- Understanding
- How & when
- Add to toolbox
- Attention

@utrechtjug #EvolutionaryAlgorithms @BWKnopper

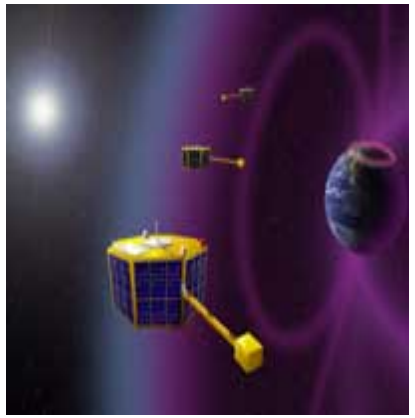
Agenda

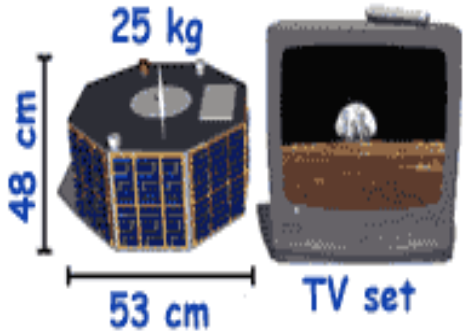
- Introduction
- NASA
- Evolution Concepts
- Puzzle Solving Time: Traveling Salesman Problem
  - Evolutionary Algorithm Design
  - Plain Java Code
  - Demo!
- Frameworks
- Checklist

NASA

- Space Technology 5 mission
  - launched March 22, 2006, and completed June 20, 2006

- Three full service 25-kilogram-class spacecraft





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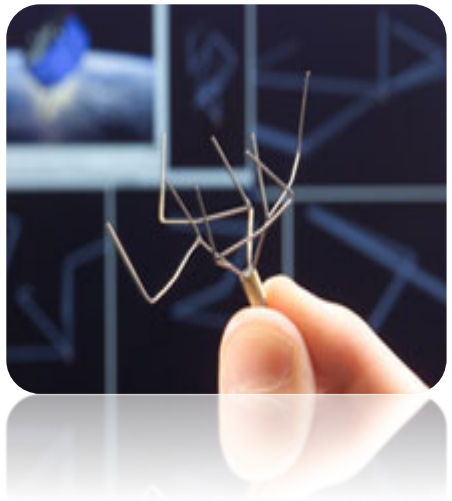
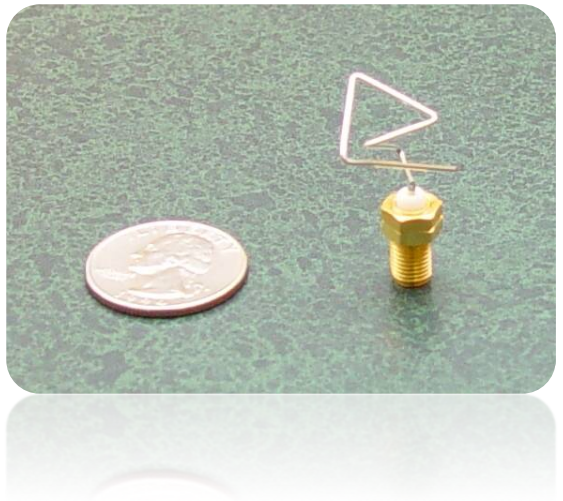
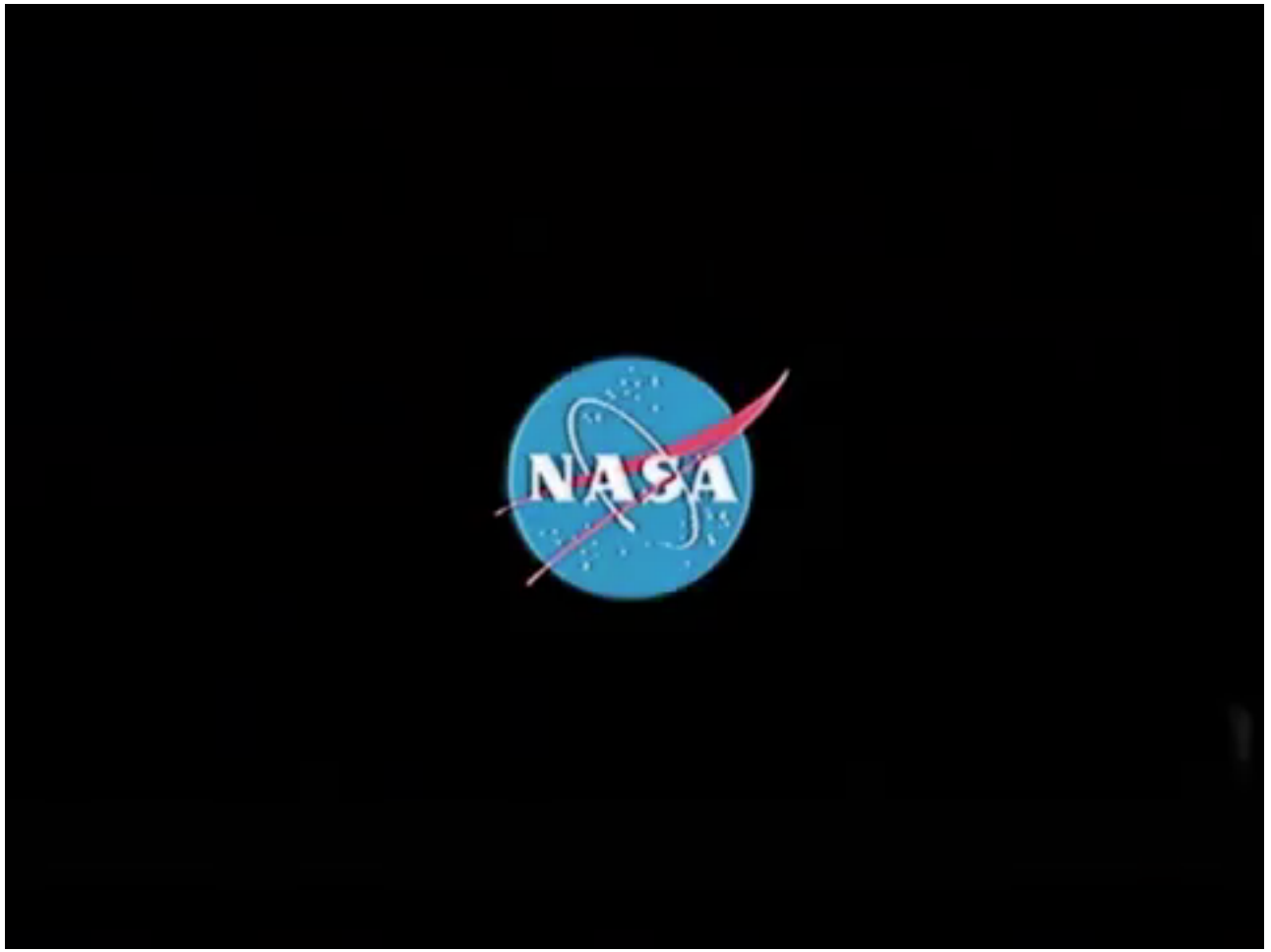
NASA Continued

- Needs even smaller antenna
- That still functions according to spec
- Need for solution that's not easy to engineer
- So they used an EA that made these:







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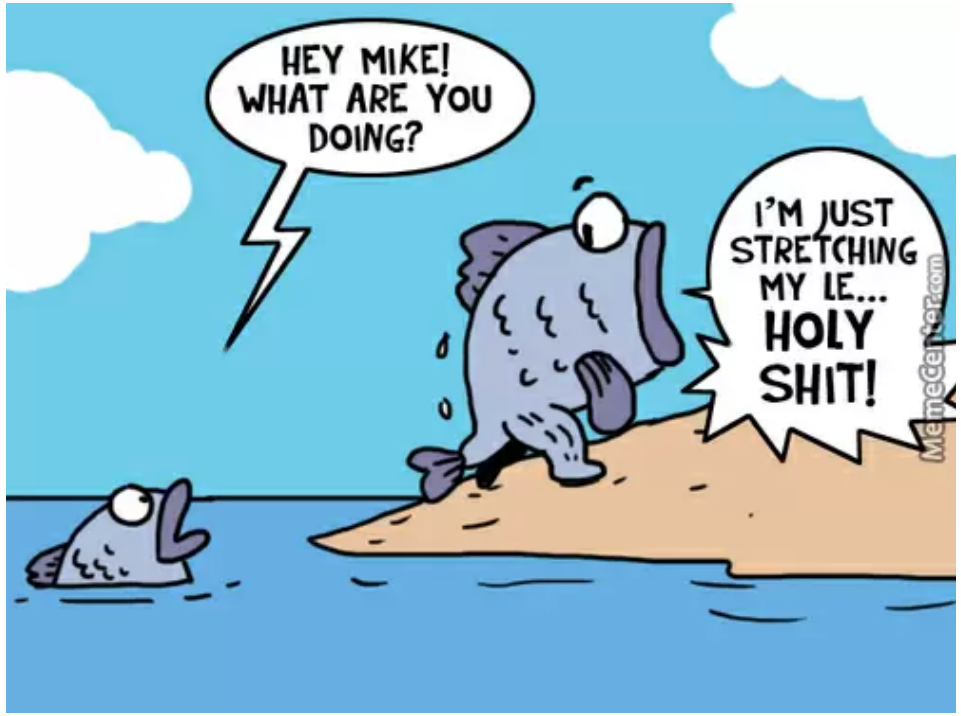
Recap

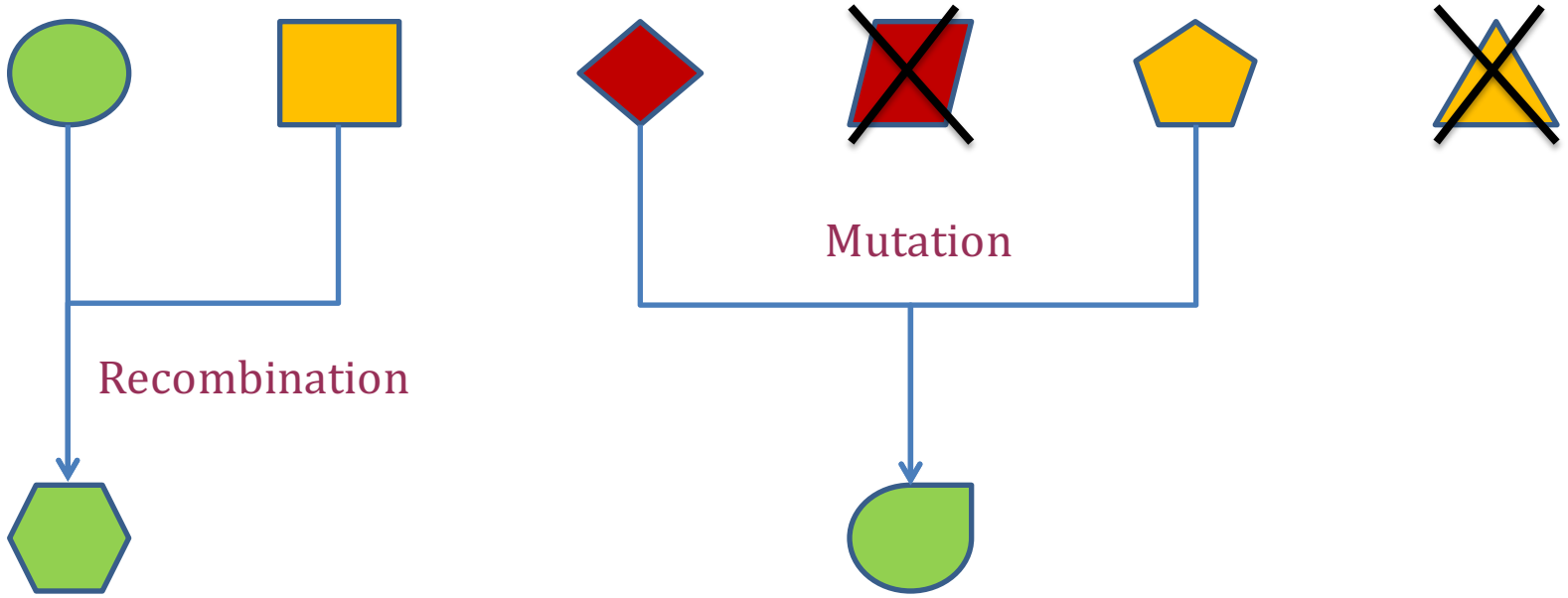
- Powerful example
- First evolved object to travel through space

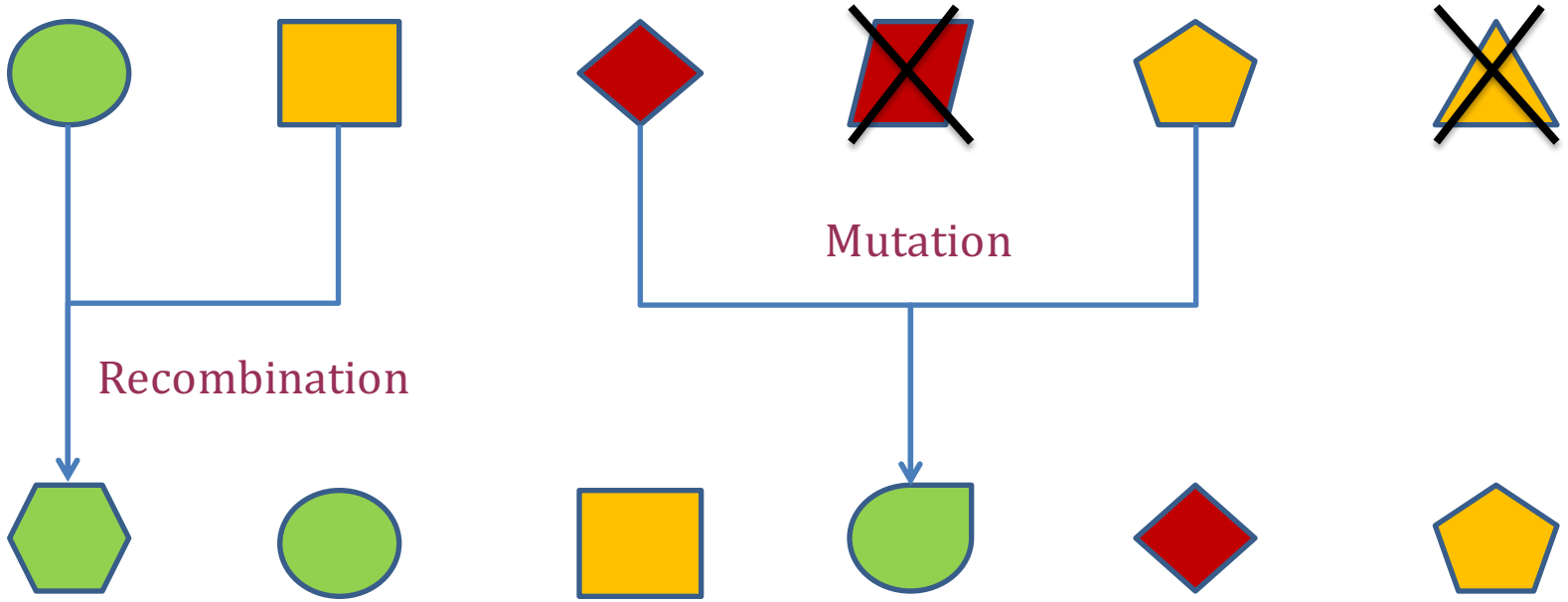
- How?

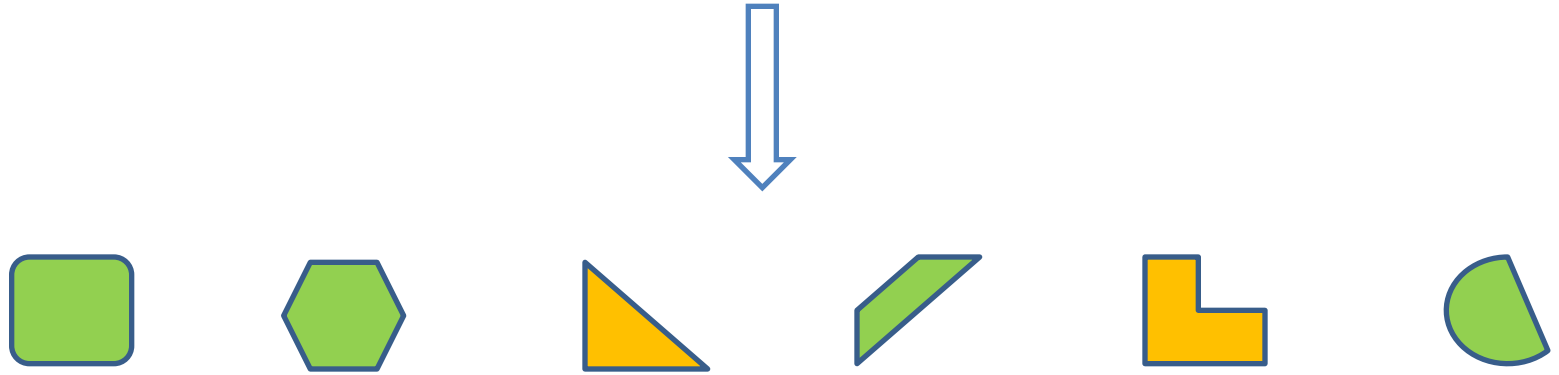
Evolution


HEY MIKE! WHAT ARE YOU DOING?
I'M JUST STRETCHING MY LE... HOLY SHIT!
MemeCenter.com

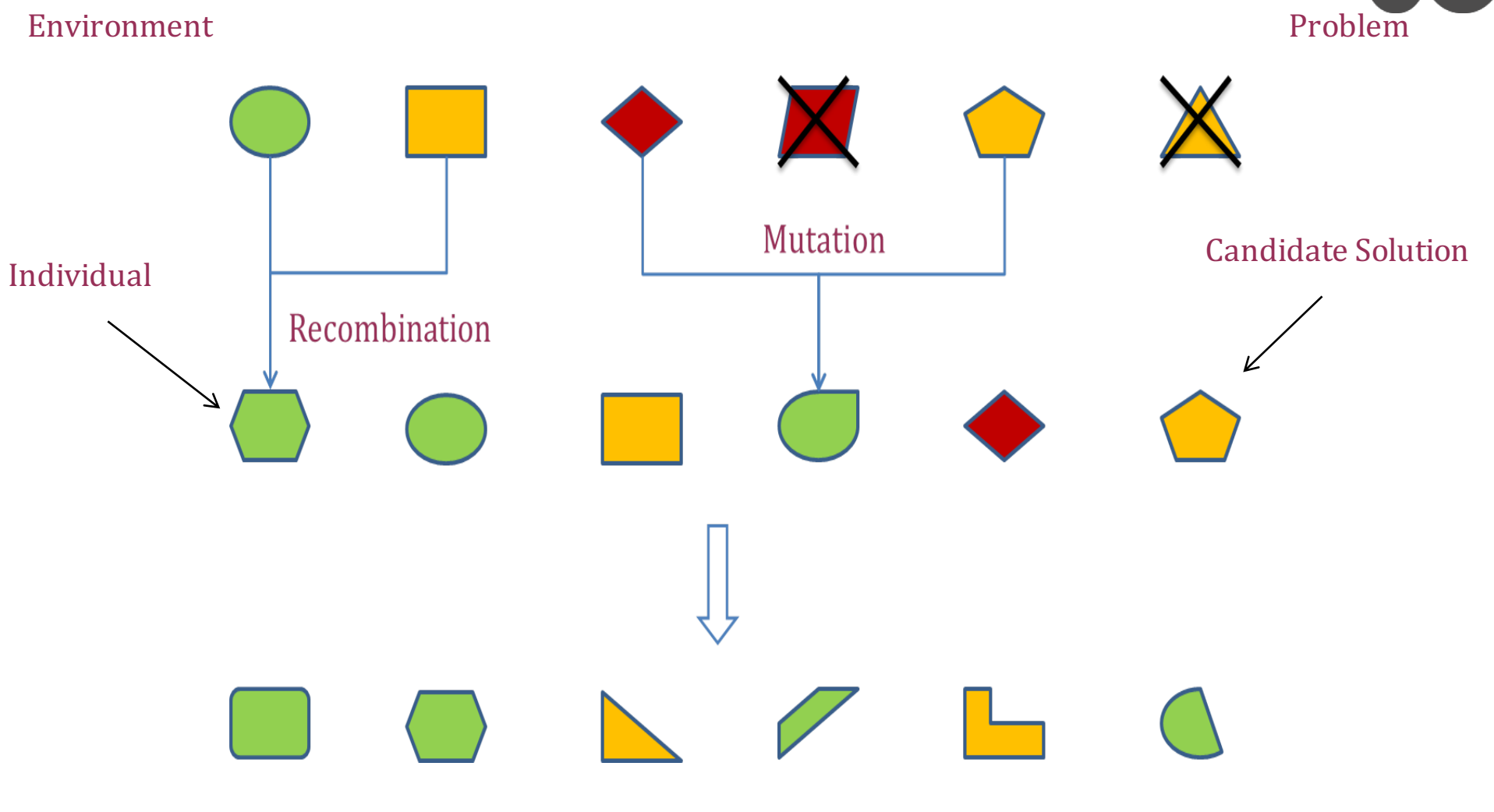
Evolution - “Survival of the fittest”


Recombination
Mutation


Mutation
Recombination



From evolution to problem solving

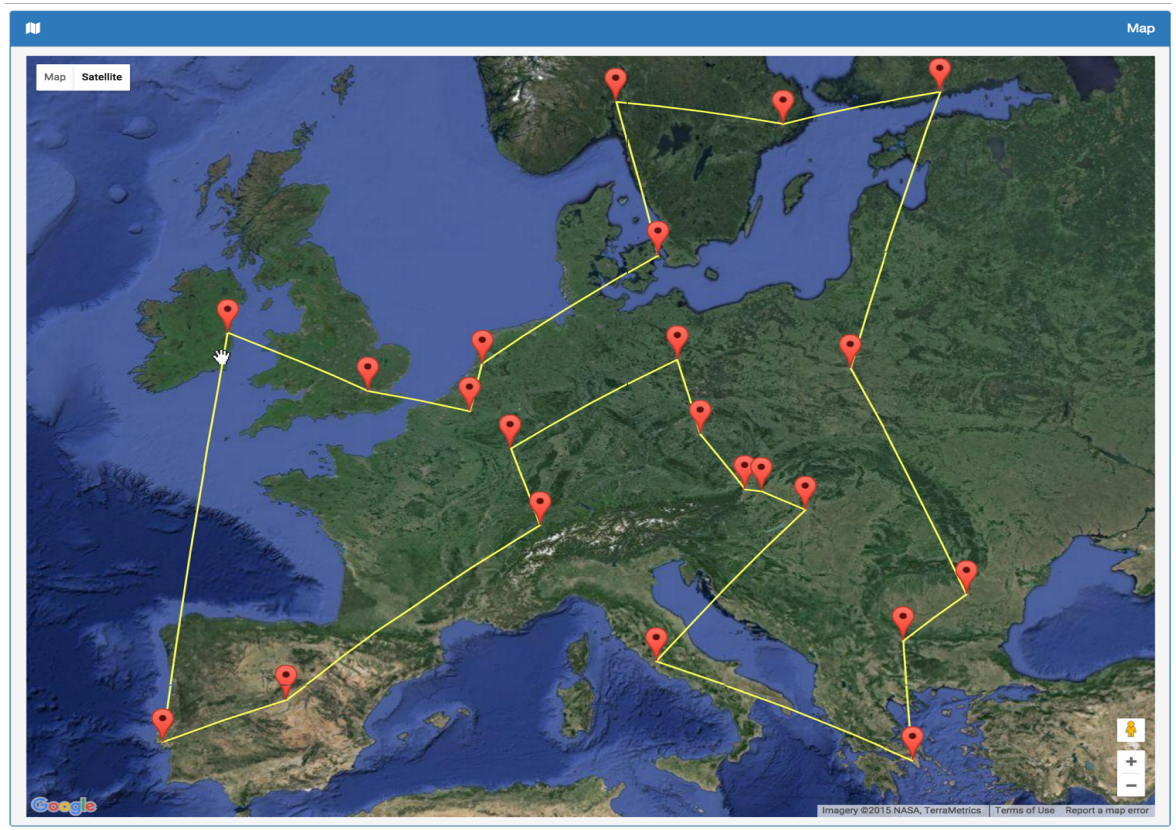


Puzzle solving time!

- More down to earth example
  - Travelling Salesman Problem

Travelling Salesman Problem

- Given *n* cities
  - *n = number of cities to visit*
- Find (optimal) route for visiting all cities
  - Visit every city only once
  - Return to origin city
- Search space is huge
  - For 30 cities there are 30! ≈ 10^32 possible routes



That's 100.000.000.000.000.000.000.000.000.000.000 possible routes!

Brute force might not be the best solution…

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Puzzle solving time!

- More down to earth example
  - Travelling Salesman Problem

- Use case to show you
  - Evolutionary Algorithm Design
  - Plain Java Code
  - Demo

EA Algorithm (Pseudocode)

INITIALISE population with random candidate solutions;

EA Algorithm (Pseudocode)

INITIALISE population with random candidate solutions;

Candidate Solution - Representation

- $n = 6$

- Label cities 1,2,3,4,5,6
- And base city 1

- Candidate Solution
  - Signifying the route

- for $n = 10$

- Enables
  - Calculating distance (fitness function)
  - Mutation
  - Recombination

EA Algorithm (Pseudocode)

INITIALISE population with random candidate solutions;

EA Algorithm (Pseudocode)

INITIALISE population with random candidate solutions;
EVALUATE each candidate;

Evaluation Function (Fitness Function)

- Summed distance:
  - d1,2 + d2,4 + … + d5,1
  - Used NASA WorldWind
- Minimize!

```java
/**
 * Calculates the total distance of the whole route and stores it as this
 * candidate solution's fitness
 */
private void calculateFitness() {









}
```

```java
/**
 * Calculates the total distance of the whole route and stores it as this
 * candidate solution's fitness
 */
private void calculateFitness() {

   /* initialize total distance */
   double totalDistance = 0;









   /* calculate total distance */









   /* store totalDistance as this candidate solution's fitness */
   this.fitness = totalDistance;
}
```

```java
/**
 * Calculates the total distance of the whole route and stores it as this
 * candidate solution's fitness
 */
private void calculateFitness() {

   /* initialize total distance */
   double totalDistance = 0;

   /*
    * For all Cities in the route (except the last one) get the distance between this
    * City and the next and add it to the totalDistance
    */
   for (int i = 0; i < route.size() - 1; i++) {




   }

   /* store totalDistance as this candidate solution's fitness */
   this.fitness = totalDistance;
}
```

```java
/**
 * Calculates the total distance of the whole route and stores it as this
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private void calculateFitness() {

   /* initialize total distance */
   double totalDistance = 0;

   /*
    * For all Cities in the route (except the last one) get the distance between this
    * City and the next and add it to the totalDistance
    */
   for (int i = 0; i < route.size() - 1; i++) {

      City city = route.get(i);
      City nextCity = route.get(i + 1);
      totalDistance += city.calculateDistance(nextCity);
   }

   /* store totalDistance as this candidate solution's fitness */
   this.fitness = totalDistance;
}
```

EA Algorithm (Pseudocode)

INITIALISE population with random candidate solutions;
EVALUATE each candidate;

EA Algorithm (Pseudocode)

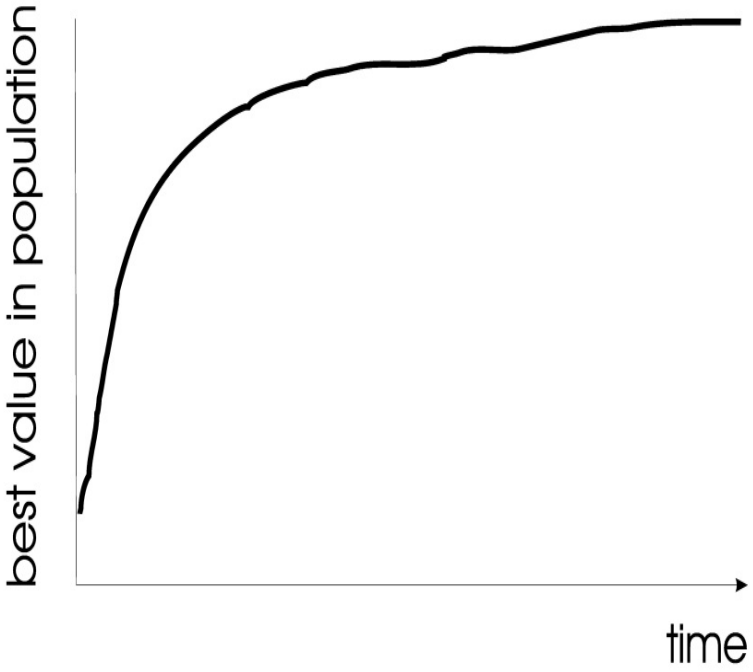
```
INITIALISE population with random candidate solutions;
EVALUATE each candidate;
WHILE ( TERMINATION CONDITION is not satisfied ) {




}
```

Termination Condition

- EA's are stochastic
  - May never find optimum



Figures from "Introduction to Evolutionary Computing" by A.E. Eiben & J.E. Smith (Springer)

Termination Condition

- Combination
- Sure to terminate
  - Time
  - Max number of runs (generations)
- Goal
  - Fitness threshold
  - Fitness improvement stagnation

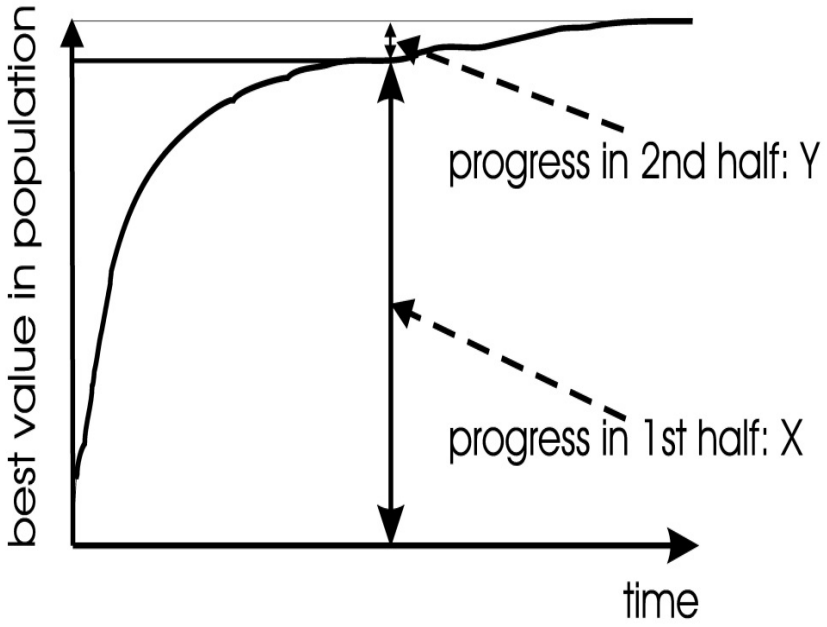


Figure from "Introduction to Evolutionary Computing" by A.E. Eiben & J.E. Smith (Springer)

EA Algorithm (Pseudocode)

```
INITIALISE population with random candidate solutions;
EVALUATE each candidate;
WHILE ( TERMINATION CONDITION is not satisfied ) {




}
```

EA Algorithm (Pseudocode)

```
INITIALISE population with random candidate solutions;
EVALUATE each candidate;
WHILE ( TERMINATION CONDITION is not satisfied ) {
  1 SELECT parents;




}
```

Parent Selection

- Where *x* is the number of parents:
  - Pick *x* best
  - Random *x*
  - Best *x* out of random *y*

- In our example:
  - Best x out of random y

```
private List<CandidateSolution> parentSelection() {




}
```

```
private List<CandidateSolution> parentSelection() {

    List<CandidateSolution> tempPopulation = new ArrayList<>(population);
    List<CandidateSolution> randomCandidates = new ArrayList<>();




}
```

```
private List<CandidateSolution> parentSelection() {

    List<CandidateSolution> tempPopulation = new ArrayList<>(population);
    List<CandidateSolution> randomCandidates = new ArrayList<>();

    /* create parent pool */
    for(int i = 0; i < parentPoolSize; i++)
    {









    }




}
```

```
private List<CandidateSolution> parentSelection() {

    List<CandidateSolution> tempPopulation = new ArrayList<>(population);
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    /* create parent pool */
    for(int i = 0; i < parentPoolSize; i++)
    {
       /* select a random candidate solution from the temp population */
       int randomlySelectedIndex = random.nextInt(tempPopulation.size());
       CandidateSolution randomSelection = tempPopulation.get(randomlySelectedIndex);
       randomCandidates.add(randomSelection);



    }




}
```

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private List<CandidateSolution> parentSelection() {

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    /* create parent pool */
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       CandidateSolution randomSelection = tempPopulation.get(randomlySelectedIndex);
       randomCandidates.add(randomSelection);

       /* delete the candidate from the temp population, so we can't pick it again */
       tempPopulation.remove(randomlySelectedIndex);
    }




}
```

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private List<CandidateSolution> parentSelection() {

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       randomCandidates.add(randomSelection);

       /* delete the candidate from the temp population, so we can't pick it again */
       tempPopulation.remove(randomlySelectedIndex);
    }

    /* Sort the population so that the best candidates are up front */
    Collections.sort(randomCandidates);



}
```

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private List<CandidateSolution> parentSelection() {

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       randomCandidates.add(randomSelection);

       /* delete the candidate from the temp population, so we can't pick it again */
       tempPopulation.remove(randomlySelectedIndex);
    }

    /* Sort the population so that the best candidates are up front */
    Collections.sort(randomCandidates);

    /* return a list with size parentSelectionSize with the best CandidateSolutions   */
    return randomCandidates.subList(0, parentSelectionSize);
}
```

EA Algorithm (Pseudocode)

```
INITIALISE population with random candidate solutions;
EVALUATE each candidate;
WHILE ( TERMINATION CONDITION is not satisfied ) {
  1 SELECT parents;




}
```

EA Algorithm (Pseudocode)

```
INITIALISE population with random candidate solutions;
EVALUATE each candidate;
WHILE ( TERMINATION CONDITION is not satisfied ) {
  1 SELECT parents;
  2 RECOMBINE pairs of parents;



}
```

Recombination

- In our example:
  - half-half does not work
  - “Cut-and-crossfill”

```
public List<CandidateSolution> recombine(CandidateSolution otherParent) {




}
```

```
public List<CandidateSolution> recombine(CandidateSolution otherParent) {
    /* get routes of both parents */
    List<City> parentRoute1 = getRoute();
    List<City> parentRoute2 = otherParent.getRoute();









}
```

```
public List<CandidateSolution> recombine(CandidateSolution otherParent) {
    /* get routes of both parents */
    List<City> parentRoute1 = getRoute();
    List<City> parentRoute2 = otherParent.getRoute();
    /* initialize the routes for the children */
    List<City> childRoute1 = new ArrayList<City>();
    List<City> childRoute2 = new ArrayList<City>();









}
```

```
public List<CandidateSolution> recombine(CandidateSolution otherParent) {
    /* get routes of both parents */
    List<City> parentRoute1 = getRoute();
    List<City> parentRoute2 = otherParent.getRoute();
    /* initialize the routes for the children */
    List<City> childRoute1 = new ArrayList<City>();
    List<City> childRoute2 = new ArrayList<City>();

    /* randomize cutIndex for "cross-and-fill point" */
    int cutIndex = new Random().nextInt(parentRoute1.size());









}
```

```
public List<CandidateSolution> recombine(CandidateSolution otherParent) {
    /* get routes of both parents */
    List<City> parentRoute1 = getRoute();
    List<City> parentRoute2 = otherParent.getRoute();
    /* initialize the routes for the children */
    List<City> childRoute1 = new ArrayList<City>();
    List<City> childRoute2 = new ArrayList<City>();

    /* randomize cutIndex for "cross-and-fill point" */
    int cutIndex = new Random().nextInt(parentRoute1.size());

    /* copy the first part of the parents cut into the children */
    childRoute1.addAll(parentRoute1.subList(0,  cutIndex));
    childRoute2.addAll(parentRoute2.subList(0,  cutIndex));









}
```

```
public List<CandidateSolution> recombine(CandidateSolution otherParent) {
    /* get routes of both parents */
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    /* randomize cutIndex for "cross-and-fill point" */
    int cutIndex = new Random().nextInt(parentRoute1.size());

    /* copy the first part of the parents cut into the children */
    childRoute1.addAll(parentRoute1.subList(0, cutIndex));
    childRoute2.addAll(parentRoute2.subList(0, cutIndex));

    /* perform crossfill for both children */
    crossFill(childRoute1, parentRoute2, cutIndex);
    crossFill(childRoute2, parentRoute1, cutIndex);



}
```

```
public List<CandidateSolution> recombine(CandidateSolution otherParent) {
    /* get routes of both parents */
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    childRoute1.addAll(parentRoute1.subList(0,  cutIndex));
    childRoute2.addAll(parentRoute2.subList(0,  cutIndex));

    /* perform crossfill for both children */
    crossFill(childRoute1, parentRoute2, cutIndex);
    crossFill(childRoute2, parentRoute1, cutIndex);

    /* create new children using the new children routes */
    CandidateSolution child1 = new CandidateSolution(childRoute1);
    CandidateSolution child2 = new CandidateSolution(childRoute2);


}
```

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    childRoute1.addAll(parentRoute1.subList(0, cutIndex));
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    /* perform crossfill for both children */
    crossFill(childRoute1, parentRoute2, cutIndex);
    crossFill(childRoute2, parentRoute1, cutIndex);

    /* create new children using the new children routes */
    CandidateSolution child1 = new CandidateSolution(childRoute1);
    CandidateSolution child2 = new CandidateSolution(childRoute2);

    /* put the children in a list and return it (omitted for layout reasons) */
}
```
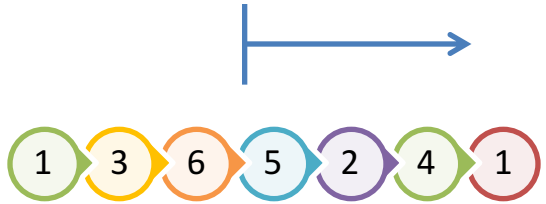

```java
/**
 * Check the rest of the route in the crossing parent and add the cities
 * that are not yet in the child (in the order of the route of the crossing
 * parent)
 */
private void crossFill(List<City> childRoute, List<City> parentRoute, int cutIndex) {









}
```

```java
/**
 * Check the rest of the route in the crossing parent and add the cities
 * that are not yet in the child (in the order of the route of the crossing
 * parent)
 */
private void crossFill(List<City> childRoute, List<City> parentRoute, int cutIndex) {

   /* traverse the parent route from the cut index on and add every city not yet in the child to the child */
   for (int i = cutIndex; i < parentRoute.size(); i++) {



   }



}
```



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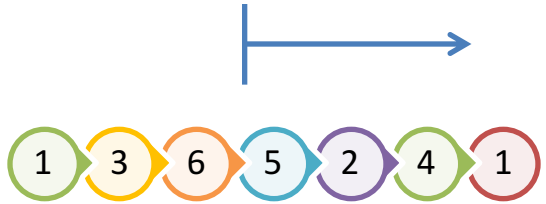
 * parent)
 */
private void crossFill(List<City> childRoute, List<City> parentRoute, int cutIndex) {

   /* traverse the parent route from the cut index on and add every city not yet in the child to the child */
   for (int i = cutIndex; i < parentRoute.size(); i++) {
      City nextCityOnRoute = parentRoute.get(i);

      if (!childRoute.contains(nextCityOnRoute)) {
         childRoute.add(nextCityOnRoute);
      }
   }

}
```



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private void crossFill(List<City> childRoute, List<City> parentRoute, int cutIndex) {

   /* traverse the parent route from the cut index on and add every city not yet in the child to the child */
   for (int i = cutIndex; i < parentRoute.size(); i++) {
      City nextCityOnRoute = parentRoute.get(i);

      if (!childRoute.contains(nextCityOnRoute)) {
         childRoute.add(nextCityOnRoute);
      }
   }
```
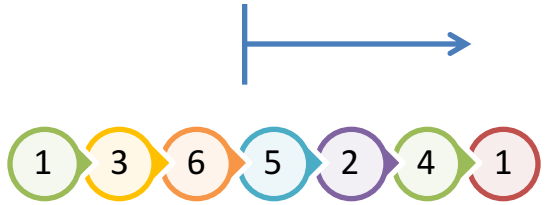
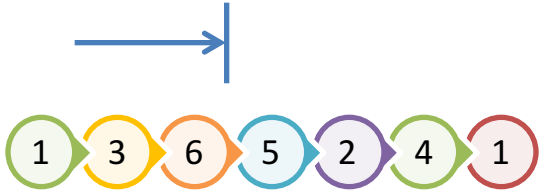




```java
   /* traverse the parent route from the start of the route and add every city not yet in the child to the child */
   for (int i = 0; i < cutIndex; i++) {
      City nextCityOnRoute = parentRoute.get(i);

      if (!childRoute.contains(nextCityOnRoute)) {
         childRoute.add(nextCityOnRoute);
      }
   }
}
```



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INITIALISE population with random candidate solutions;
EVALUATE each candidate;
WHILE ( TERMINATION CONDITION is not satisfied ) {
  1 SELECT parents;
  2 RECOMBINE pairs of parents;



}
```

EA Algorithm (Pseudocode)

```
INITIALISE population with random candidate solutions;
EVALUATE each candidate;
WHILE ( TERMINATION CONDITION is not satisfied ) {
   1 SELECT parents;
   2 RECOMBINE pairs of parents;
   3 MUTATE the resulting offspring;


}
```

Mutation

- Change of nr won't work
  - Infeasible candidate solution
- Swap to the rescue!

```java
/**
 * Mutates the current individual by swapping two random cities in its
 * route.
 */
public void mutate() {









}
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public void mutate() {

   Random random = new Random();

   /* randomly select two indices in the route */
   int indexFirstCity = random.nextInt(route.size());
   int indexSecondCity = random.nextInt(route.size());

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   int indexFirstCity = random.nextInt(route.size());
   int indexSecondCity = random.nextInt(route.size());

   /* Make sure they are different */
   while (indexFirstCity == indexSecondCity) {
      indexSecondCity = random.nextInt(route.size());
   }



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   /* Make sure they are different */
   while (indexFirstCity == indexSecondCity) {
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   }

   /* retrieve the Cities on the given indices */
   City firstCity = route.get(indexFirstCity);
   City secondCity = route.get(indexSecondCity);



}
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   }

   /* retrieve the Cities on the given indices */
   City firstCity = route.get(indexFirstCity);
   City secondCity = route.get(indexSecondCity);


   /* Changer! */
   route.set(indexFirstCity, secondCity);
   route.set(indexSecondCity, firstCity);

}
```

EA Algorithm (Pseudocode)

```
INITIALISE population with random candidate solutions;
EVALUATE each candidate;
WHILE ( TERMINATION CONDITION is not satisfied ) {
   1 SELECT parents;
   2 RECOMBINE pairs of parents;
   3 MUTATE the resulting offspring;


}
```

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   4 EVALUATE new candidates;
   5 SELECT individuals for the next generation;
}
```

Survivor Selection

- Replacement Strategy
- Do nothing
- Replace Worst

```
/**
 * Selects the survivors by removing the worst candidate
 * solutions from the list, so we have the original
 * population size again
 */
private void selectSurvivors() {



}
```

```
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 * solutions from the list, so we have the original
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private void selectSurvivors() {

  Collections.sort(population);

}
```

```
/**
 * Selects the survivors by removing the worst candidate
 * solutions from the list, so we have the original
 * population size again
 */
private void selectSurvivors() {

  Collections.sort(population);
  population = population.subList(0, populationSize);
}
```

EA Algorithm (Pseudocode)

```
INITIALISE population with random candidate solutions;
EVALUATE each candidate;
WHILE ( TERMINATION CONDITION is not satisfied ) {
   1 SELECT parents;
   2 RECOMBINE pairs of parents;
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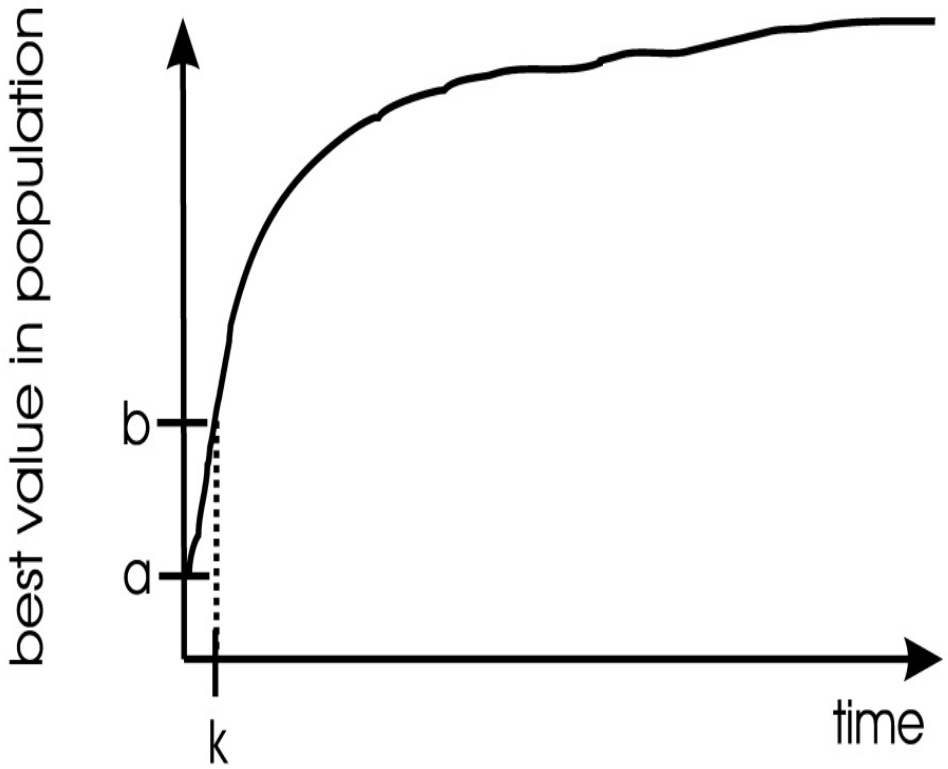
}
```

Tuning…

- Mutation probability
- Population size
- Nr of offspring
- Termination condition (# runs or fitness)
- Parent selection
- Survival selection
- Initialisation
  - Random

EA Behavior



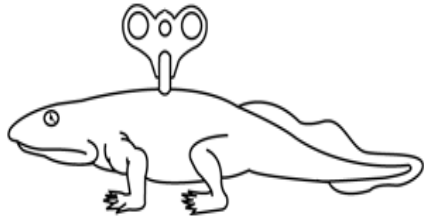
Figures from "Introduction to Evolutionary Computing" by A.E. Eiben & J.E. Smith (Springer)

JCORE

Demo!

- Backend
  - Java code shown
  - Used NASA World Wind to do calculations on the backend
- Frontend
  - AngularJs + Bootstrap + Google Maps ☺
- https://github.com/bknopper/TSPEvolutionaryAlgorithmsDemo.git

Java Frameworks & API's



WATCHMAKER FRAMEWORK

FOR EVOLUTIONARY COMPUTATION

JGAP

JAVA GENETIC ALGORITHMS PACKAGE

http://watchmaker.uncommons.org

http://jgap.sourceforge.net/

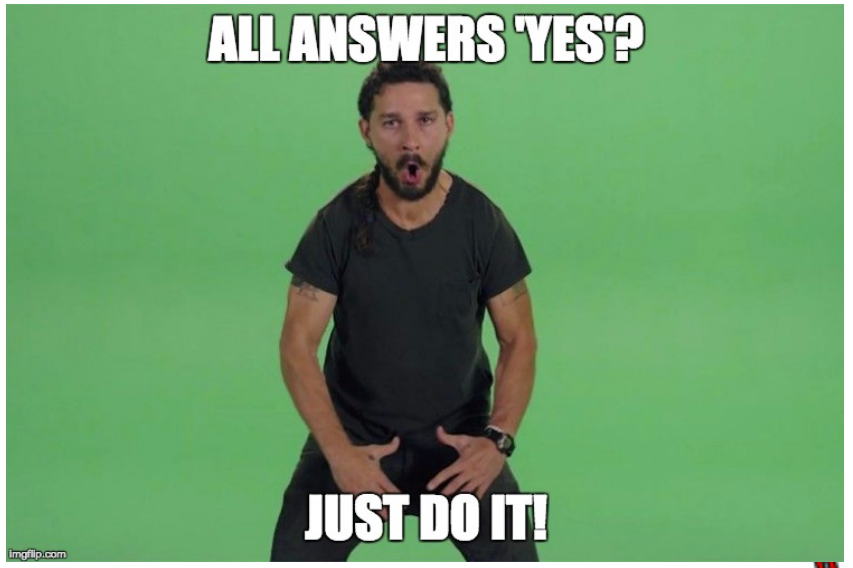
Java Frameworks & API's

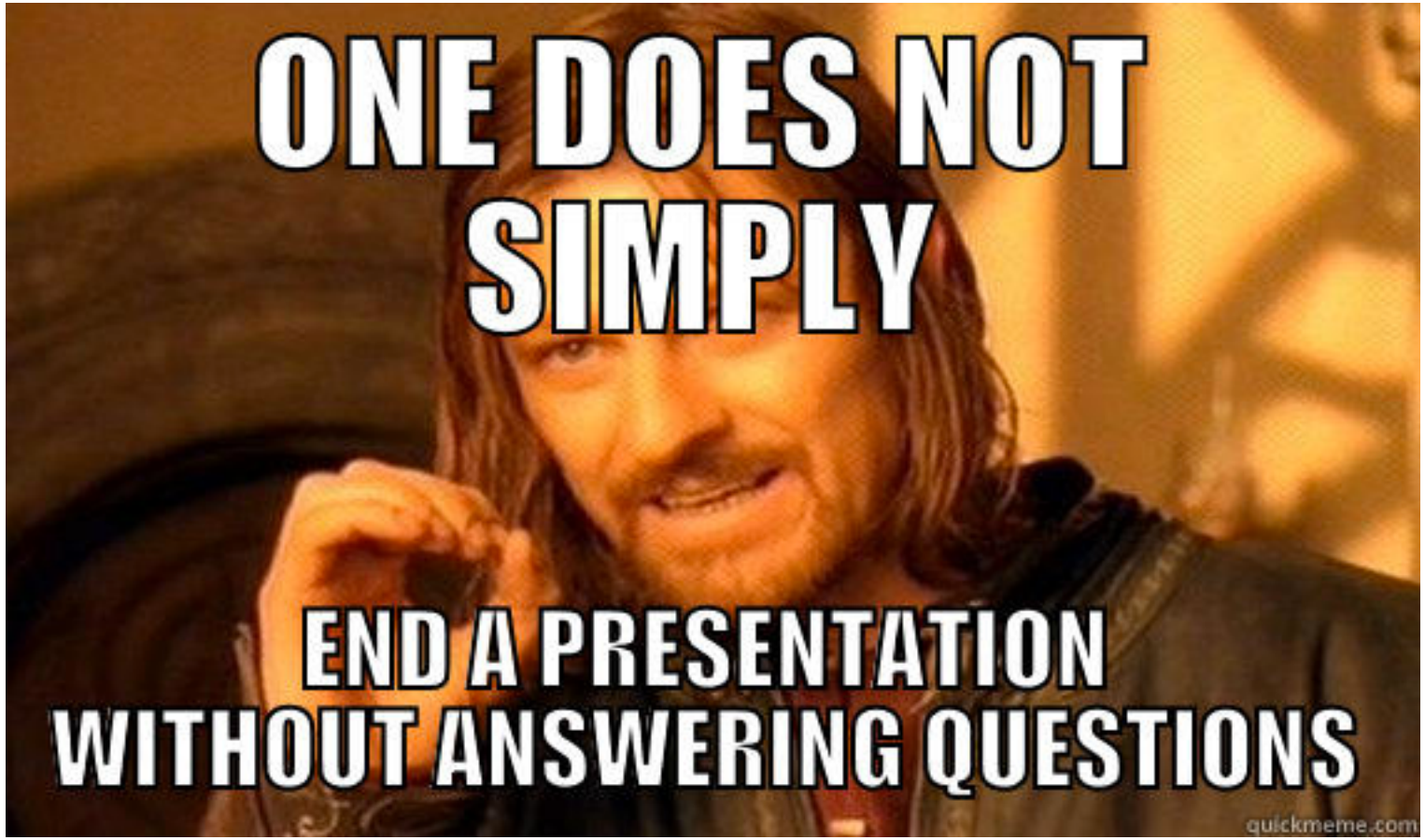
- ECJ
  - http://cs.gmu.edu/~eclab/projects/ecj/
- MOEA Framework
  - http://www.moeaframework.org
- JEAF
  - https://github.com/GII/JEAF
- …

With great power comes great responsibility

- I'm sure I cannot find a solution using a brute-force approach?
  - (within a reasonable amount of time)

- Am I facing an optimization or search problem?
- Can I encode a candidate solution to the problem?
  - Representation possible?
- Can I determine the fitness of a candidate solution?





bas.knopper@jcore.com @BWKnopper github.com/bknopper

Additional questions?

- Contact me on @BWKnopper
- Google it!
  - There's lots to find…
    - Papers
    - Demo's
    - Aforementioned Frameworks/API's


THANK
YOU