MetaHeuristics

INF273

#1:Introduction

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Optimization Group
Dept. of Informatics
University of Bergen

Spring Semester
2022

Agenda

- Practical information
- Course plan
- Why (Meta) heuristics?
- Applications

- Warning: Today's lecture contains many different subjects, and it is easy to get lost somewhere on the way. Don't despair, as we will repeat the important points several times!

Practical Info

- The lecturer:
  - E-mail: Ahmad.Hemmati@uib.no
  - Office: 410M2, Thormøhlens Gate 55
  - Drop by or email if you have any questions!

- Lectures:
  - Wednesdays 14:15 – 16:00
  - Fridays 10:15 – 12:00

- Group sessions:
  - Tuesdays 12:15 – 14:00

- Course plan on mitt.uib.no

Practical Info

- Reading material
  - Mainly lecture slides, published on MittUiB (after the lecture)
  - In case you need more! → Handbook of Metaheuristics (available @Digital litteratur-liste)
- Assignments
  - 5 mandatory assignments and they are related to each other and to the final project
    (need to get it approved, → resubmit)
- Programming language (C++, java, Python, Matlab, …)
- Final Grade
  - Being active in discussions and being creative in assignments
  - Project results and oral presentation of the project

Course Plan

Week #03:	**Wed Jan 19:** **Fri Jan 21:**	*Lecture#01:* *Lecture#02:*	*Intro* *Heuristics*
Week #04:	**Wed Jan 26:** **Fri Jan 28:**	*Lecture#03:* *Lecture#04:*	*Components of Metaheuristics* *Introducing advanced combinatorial optimization problems*
Week #05:	**Wed Feb 2:** **Fri Feb 4:**	*No lecture*	*Work on the assignments #1 and #2*
Week #06:	**Wed Feb 9:** **Fri Feb 11:**	*Lecture#05:* *Lecture#06:*	*Local Search* *Simulated Annealing*
Week #07:	**Wed Feb 16:** **Fri Feb 18:**	*No lecture*	*Work on the assignments #3*
Week #08:	**Wed Feb 23:** **Fri Feb 25:**	*Lecture#07:* *Lecture#08:*	*Tabu search* *Genetic Algorithm*
Week #09:	**Wed Mar 2:** **Fri Mar 4:**	*Lecture#09:* *Lecture#10:*	*Ant-colony and Particle Swarm* *Case study #1*
Week #10:	**Wed Mar 9:** **Fri Mar 11:**	*No lecture*	*Work on the assignments #4*
Week #11:	**Wed Mar 16:** **Fri Mar 18:**	*Lecture#11:* *Lecture#12:*	*VNS and ALNS* *Non randomized Metaheuristic, Case study #2*
Week #12:	**Wed Mar 23:** **Fri Mar 25:**	*No lecture*	*Work on the assignments #5*
Week #13:	**Wed Mar 30:** **Fri Apr 1:**	*One to One Individual Feedback Session*	
Week #14:	**Wed Apr 6:** **Fri Apr 8:**	*Lecture#13:* *Lecture#14:*	*General feedback session* *Sweep and Clustering algorithm, case study #3*
Week #15:	**Wed Apr 13:** **Fri Apr 15:**	*No lecture*	*Easter*
Week #16:	**Wed Apr 20:** **Fri Apr 22:**	*Lecture#15:* *Lecture#16:*	*Hybrid Algorithms and Mathheuristic, case study #4* *Hyper-Heuristics, Case Study #5*
Week #17:	**Wed Apr 27:** **Fri Apr 29:**	*Lecture#17:* *Lecture#18:*	*Case Study #6* *Practical information for the exam*

Optimization

What is optimization?

- Objective + fulfilling the constraints
  - Fastest way to reach school/Skyss.no (that departs in 15min)
  - Cheapest flight (from Bergen to somewhere that doesn't rain)
  - Biggest TV (that fits in a $10m^2$ dorm)
  - Fastest laptop (that fits in your bag)
  - Smallest laptop (that fits to your budget)
  - Minimum calorie (when you bake and the output is supposed to be a cupcake!)
  - Best courses for this semester (to learn sth., not to be difficult)
  - …

Applications

➢ Many other optimization problems in real life!

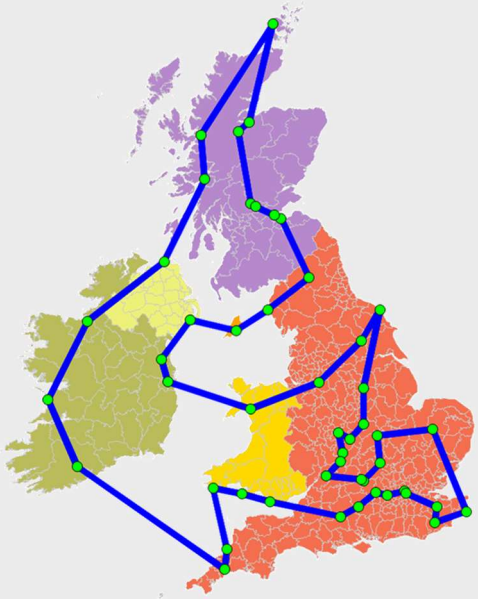
- ✓ Blending: Determine which raw materials from different sources to blend to produce a substance with certain desired qualities at minimum cost
- ✓ Capital Budgeting
- ✓ Inventory Management
- ✓ Capacity Planning
- ✓ Portfolio Optimization
- ✓ Product Mix
- ✓ Machine Allocation
- ✓ Process Selection
- ✓ Cutting Stock
- ✓ Cash Management
- ✓ Healthcare
- ✓ Transportation Model
- ✓ Facility Location
- ✓ Inventory Stocking/Reordering
- ✓ Media Planning
- ✓ Crew Scheduling
- ✓ Office Assignment
- ✓ Employee Scheduling
- ✓ Fleet Routing and Assignment
- ✓ Revenue Management
- ✓ Gasoline Blending
- ✓ Gas Contract Purchase
- ✓ Pipeline Capacity Auction
- ✓ Marketing
- ✓ …

Combinatorial Optimization Problems

Combinatorial optimization problems are optimization problems which have finitely many and discrete solutions.

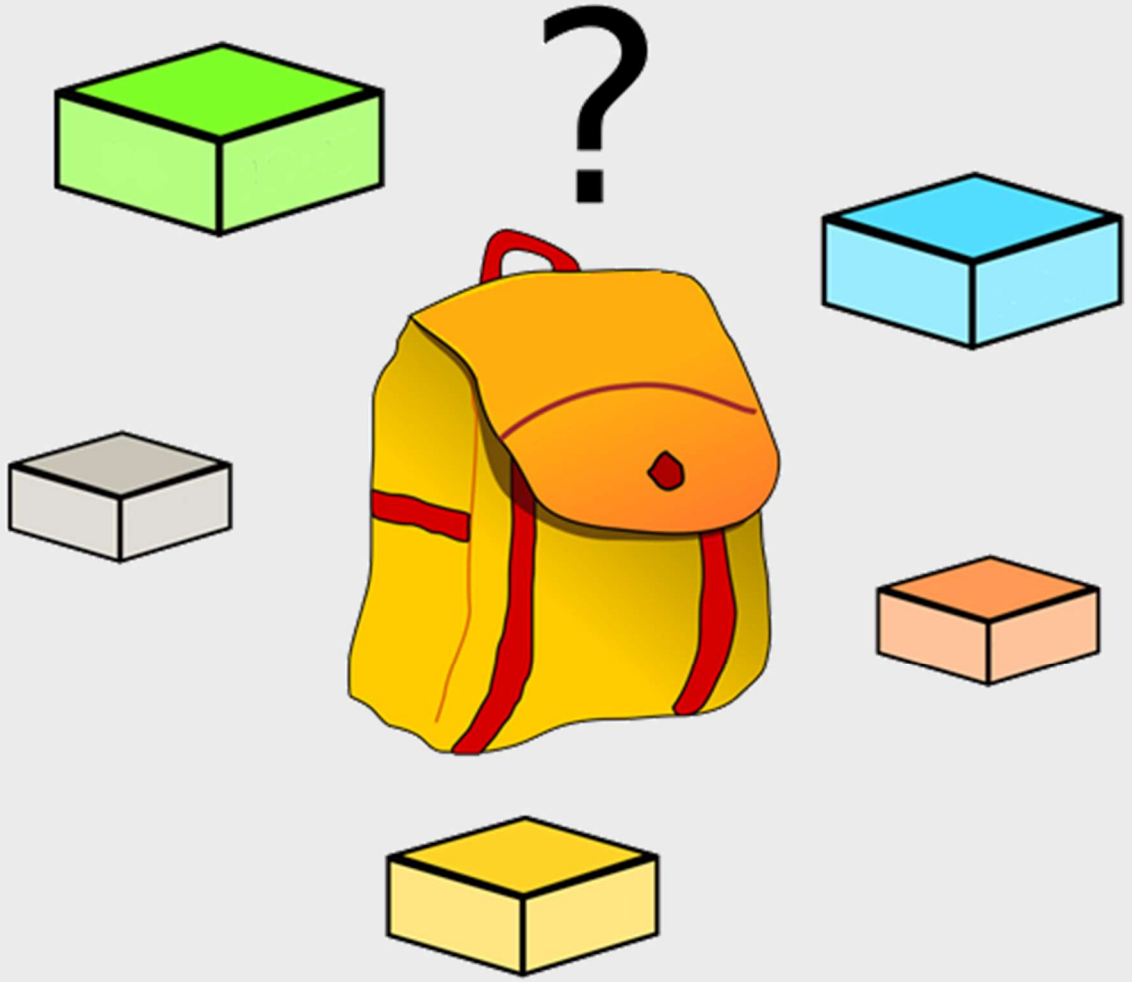
- Bit strings
  (i.e., many yes-no decisions)

- Permutation of elements
  (order something)



Knapsack Problem

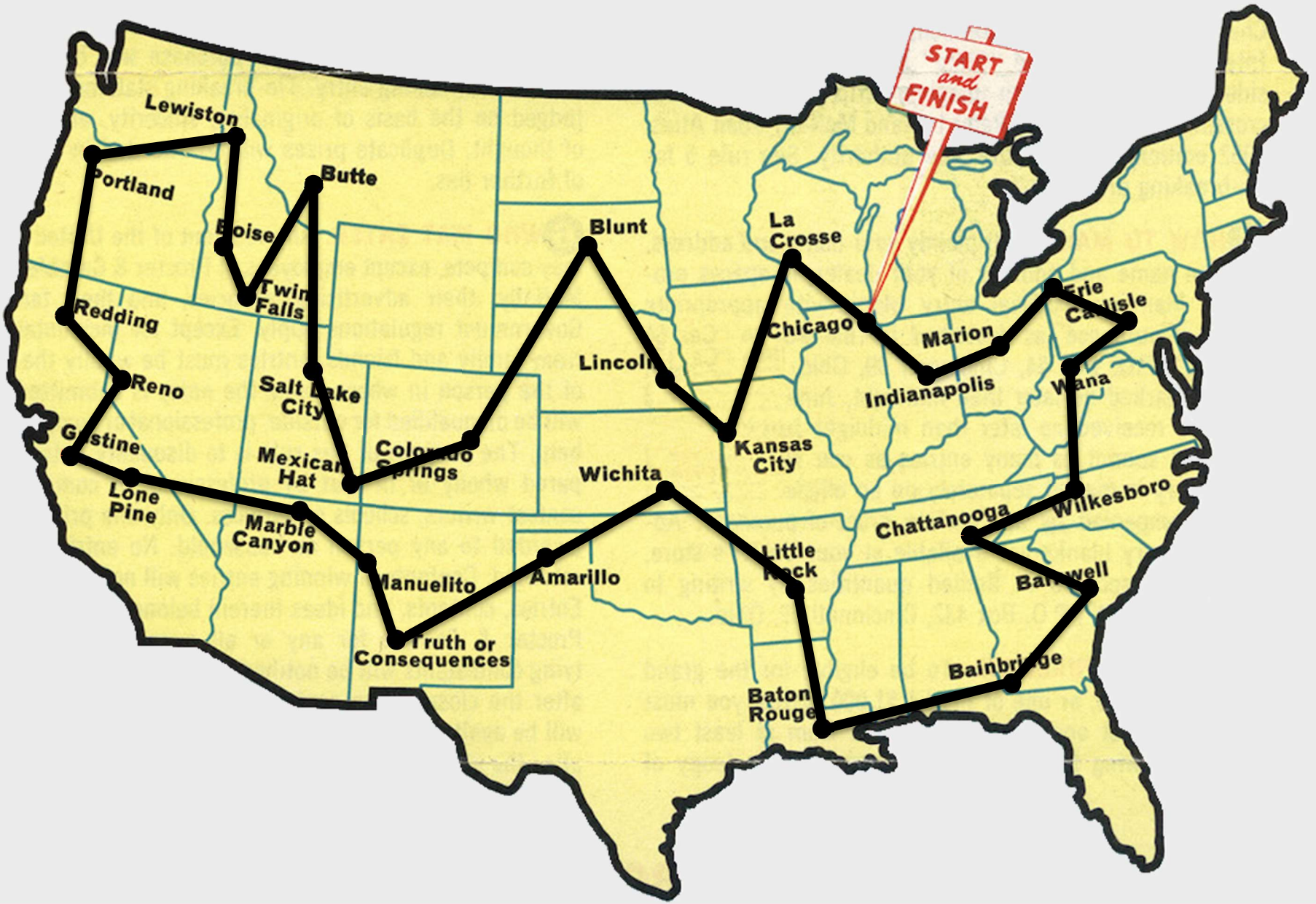
- How many solutions?!



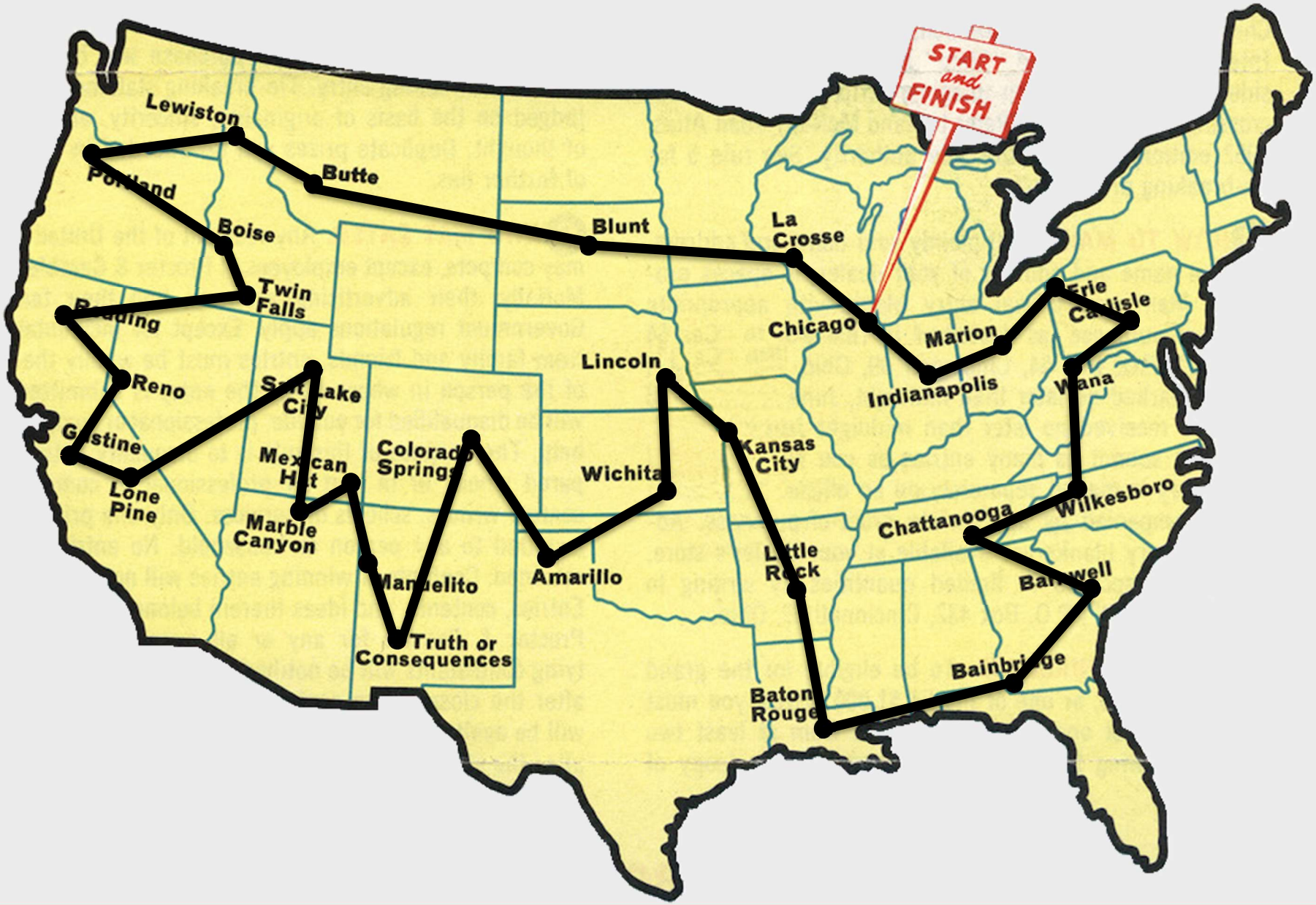
Travelling Salesman Problem (TSP)

- A saleswoman located in Chicago wants to visit all 33 locations on the map to sell her wares
- What is shortest way of visiting all and then returning to Chicago?

Travelling Salesman Problem (TSP)



Travelling Salesman Problem (TSP)



TRAVELLING SALESMAN PROBLEM (TSP)

- A saleswoman located in Chicago wants to visit all 33 locations on the map to sell her wares
- What is shortest way of visiting all and then returning to Chicago?

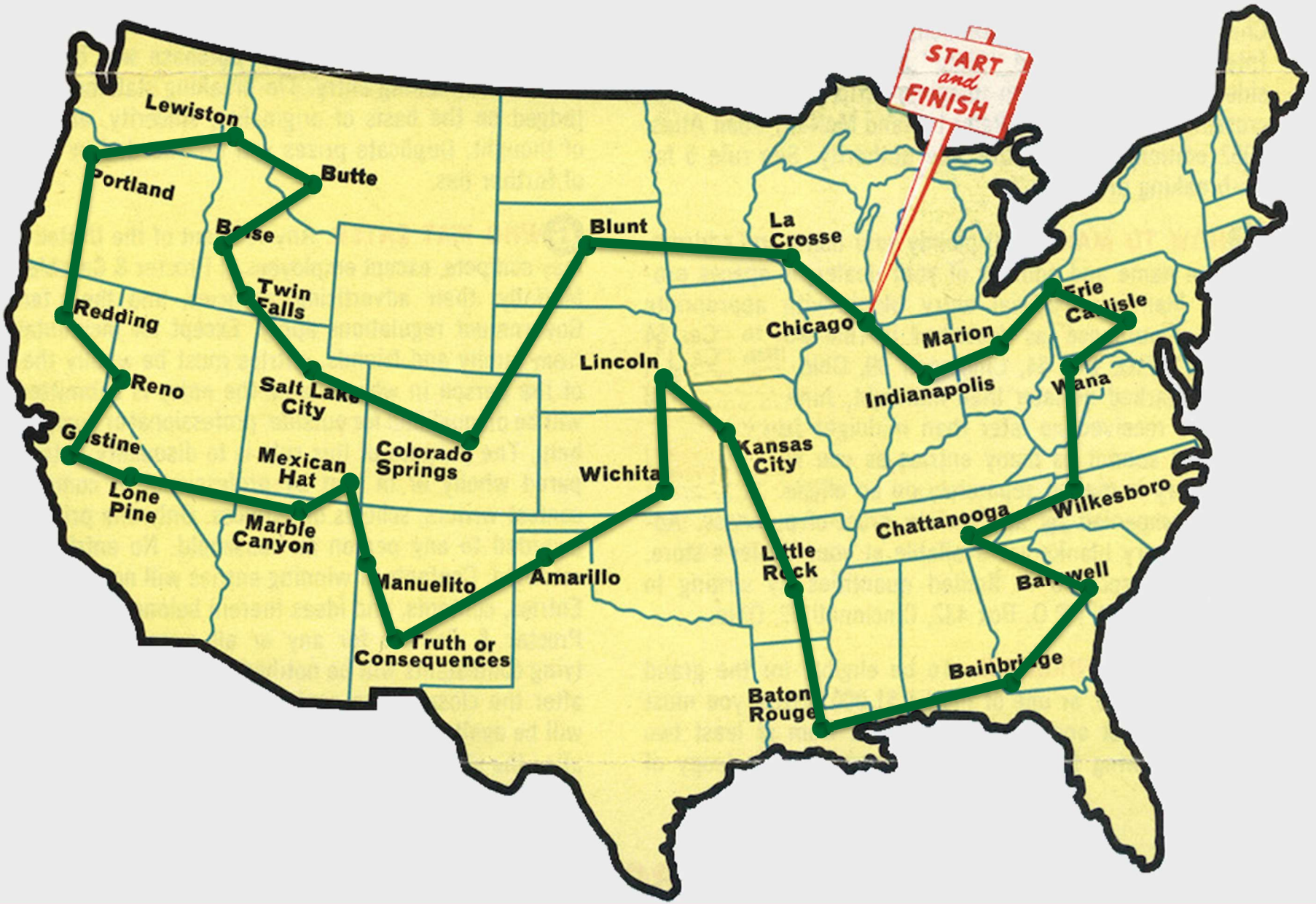
TRY TO SOLVE IT!

Travelling Salesman Problem (TSP)

Travelling Salesman Problem (TSP)

- Proctor and Gamble Contest
  - 1962

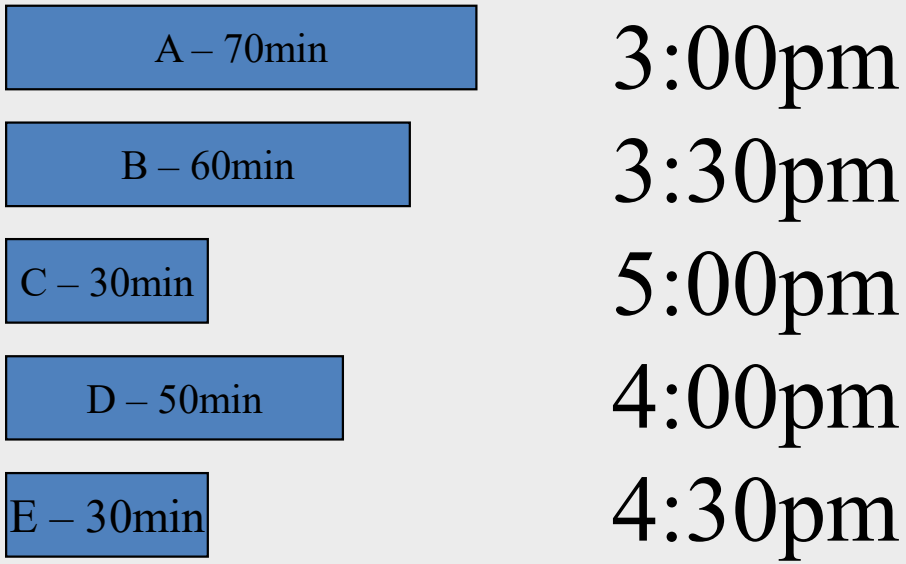
Travelling Salesman Problem (TSP)



TSP IS EVERYWHERE!

- These jobs have to be done; their length represents the time they will take. We can start at 2:00pm

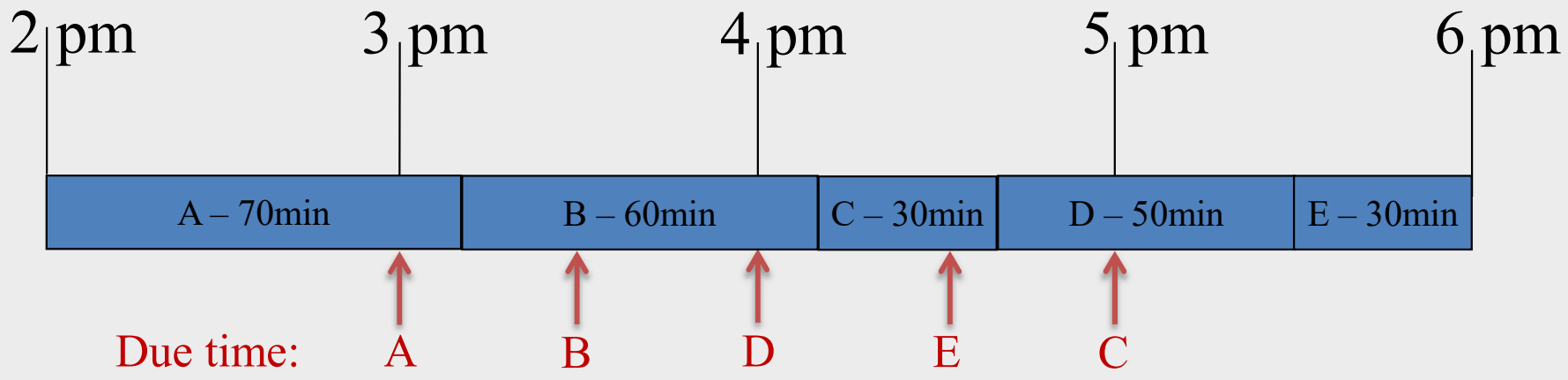
Each has a 'due date', when it needs to be finished



Only one 'machine' is available to process these jobs, so can do just one at a time.

[e.g. photocopier, …]

TSP IS EVERYWHERE!

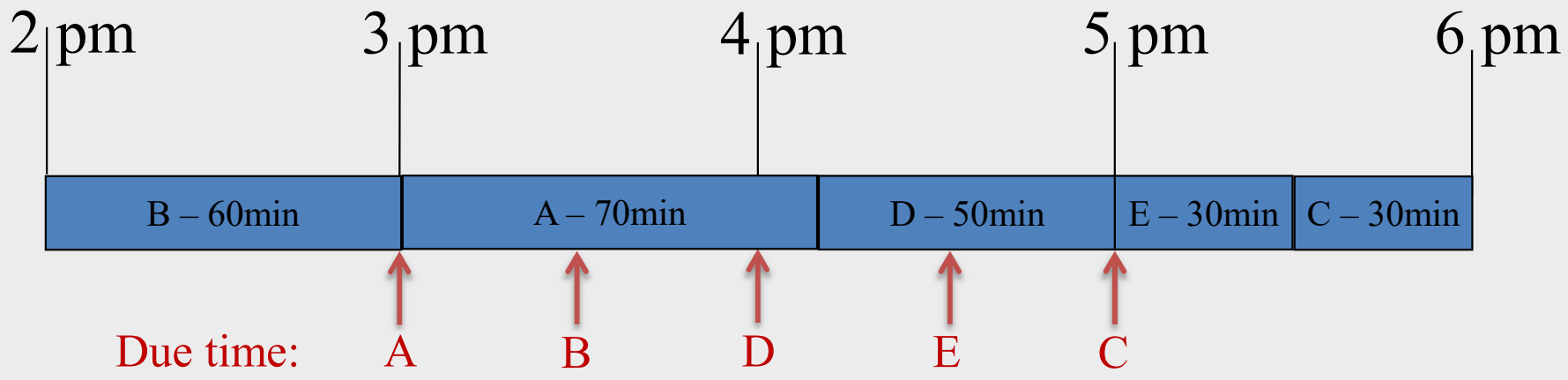


A is 10min late
B is 40min late
C is 20min early (lateness = 0)
D is 90min late
E is 90min late

Fitness might be average lateness;
in this case 46min

or fitness could be Max lateness,
in this case 90min

TSP IS EVERYWHERE!



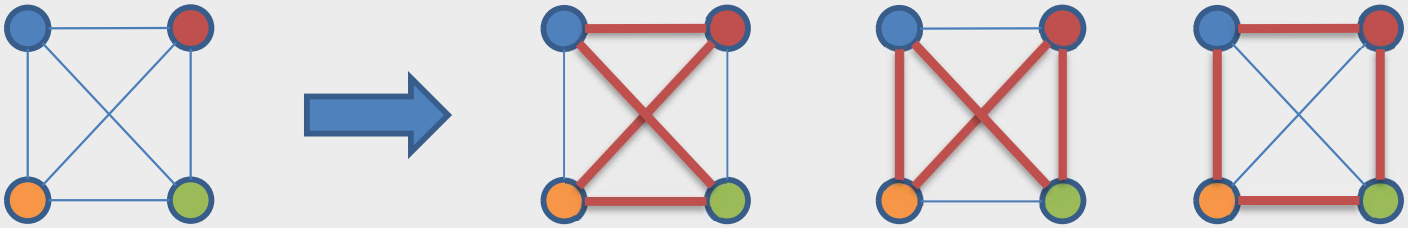
A is 70min late
B is 30min early (0 lateness)
C is 60min late
D is 60min late
E is 60min late

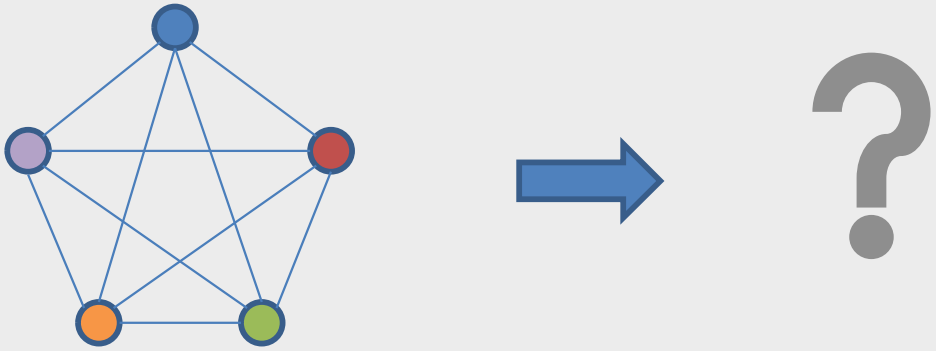
Fitness might be average lateness;
in this case 50min

or fitness could be Max lateness,
in this case 70min

Travelling Salesman Problem (TSP)

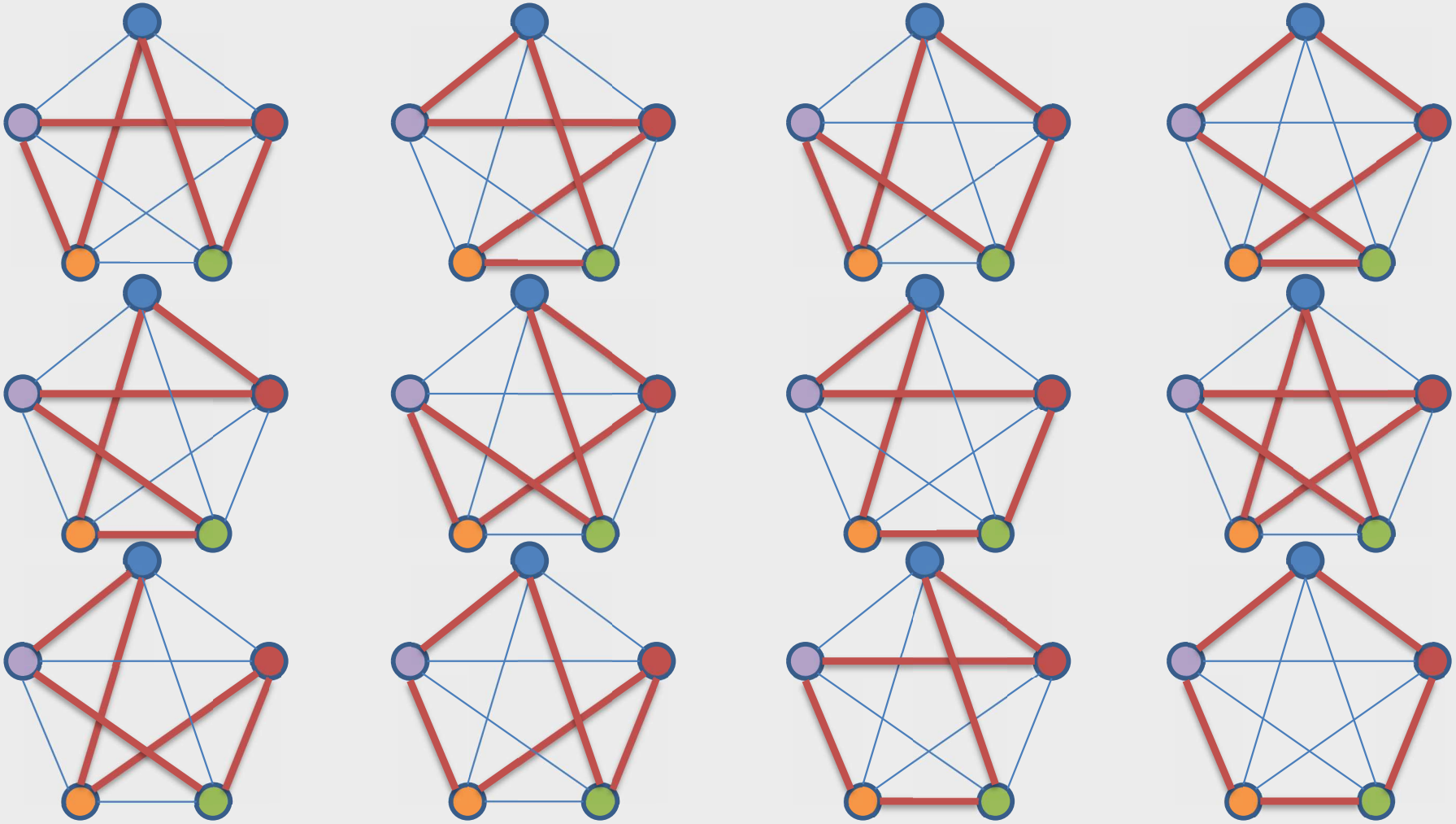
- How many solutions?!





Travelling Salesman Problem (TSP)

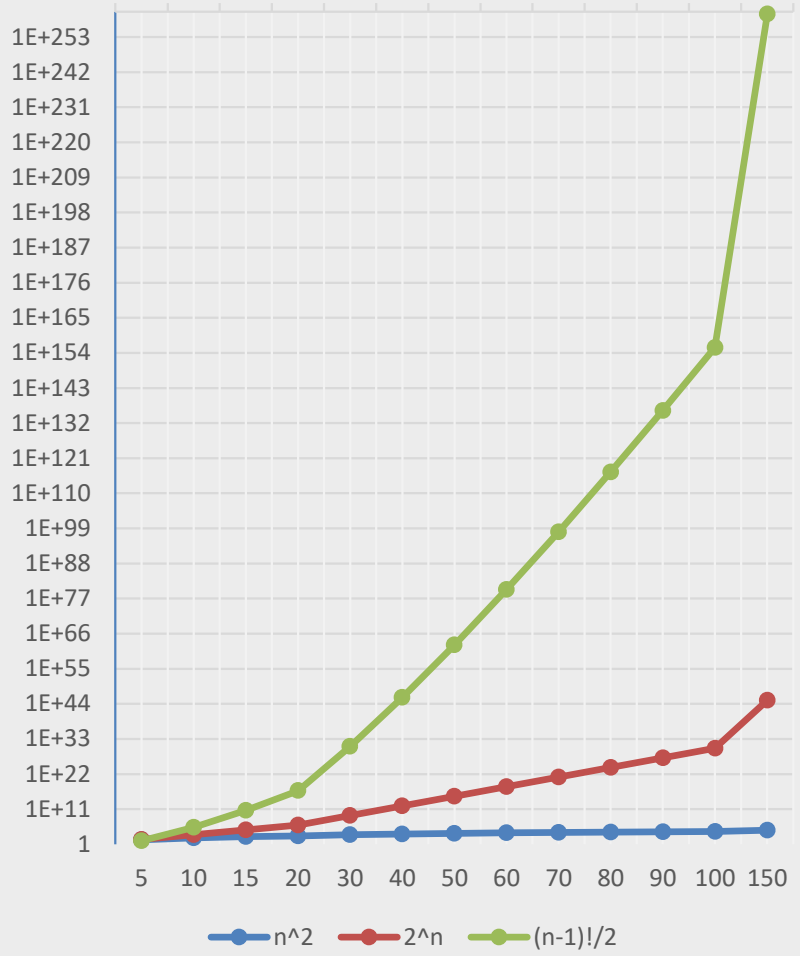
- ½(n-1)!



The Combinatorial Explosion

- Knapsack problem: 2^n
- TSP: ½(n-1)!

n	n^2	2^n	½(n-1)!
5	25	32	12
10	100	1024	181440
20	400	1048576	6.08E+16
30	900	1.07E+09	4.42E+30
50	2500	1.13E+15	3.04E+62
100	10000	1.27E+30	4.70E+155
150	22500	1.43E+45	1.90E+260

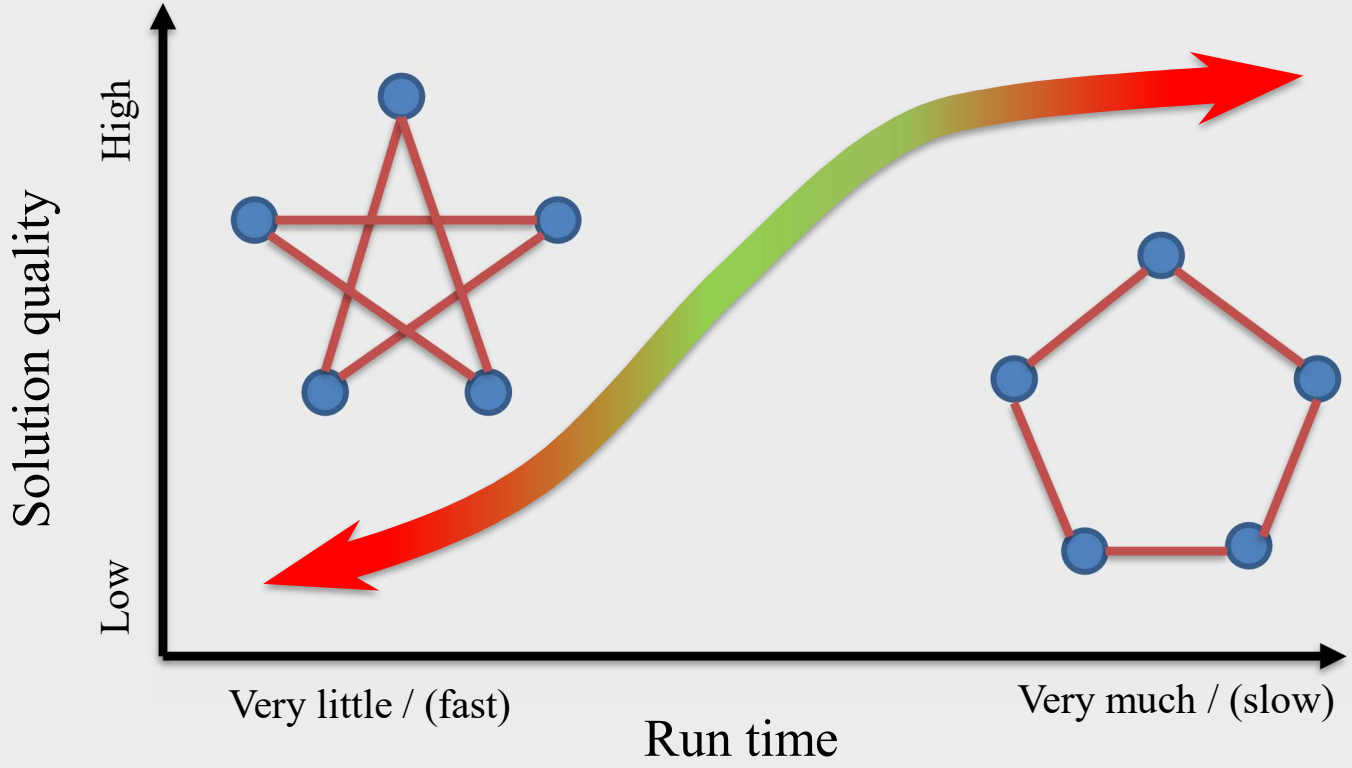


Solution Approaches

- Exact
  - INF170/270/271/272
  - Gives you the best solution but may take forever!
  - Less practical for realistic problems
- Approximation
  - Gives a bound!
  - To get a rough idea about the cost for strategic decisions
  - Reducing the complexity
- (Meta)Heuristics
  - Gives good solutions in a short time
  - No need to simplify the problem
  - Very practical for realistic problems
  - Does not guarantee to give the best solution!

Runtime vs. Solution Quality

- (Meta)Heuristics optimization algorithms try to find solutions that are as good as possible in a reasonable time.



MetaHeuristics vs. Heuristics

- Heuristics are often specialized algorithms
- However, there are many different optimization problems and often we won't see a "pure" TSP in practice, there usually will be additional constraints and restrictions or multiple cars etc.
- We want general algorithms that can be adapted to different problems.
- A metaheuristic is a high-level problem-independent algorithmic framework that combines operators/heuristics intelligently and provide a sufficiently good solution!

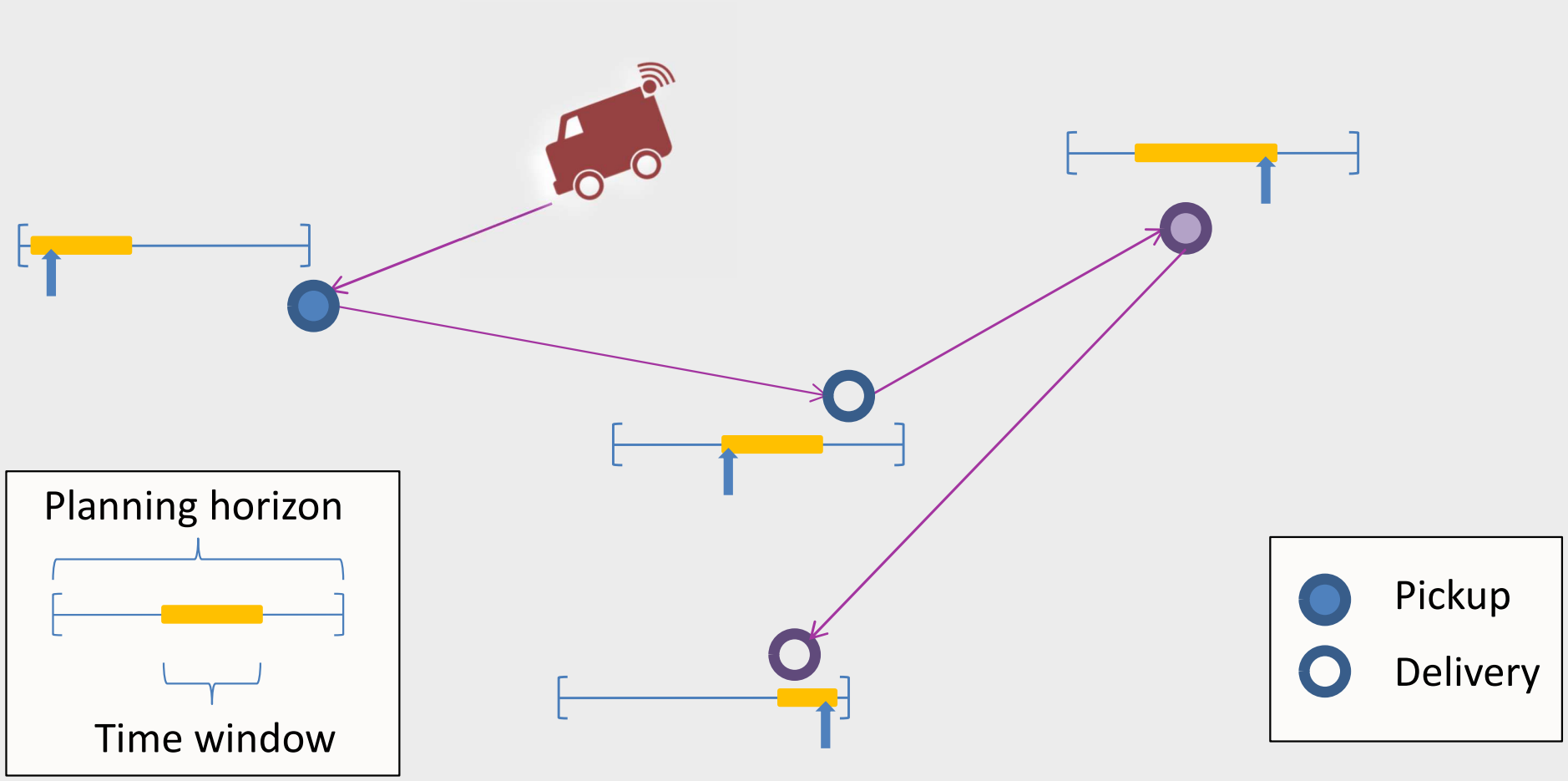
ALGORITHMS THAT WE LEARN…

- Local search
- Genetic Algorithm
- Simulated Annealing
- Tabu search
- Ant-colony
- Particle Swarm
- Variable Neighborhood Search
- Adaptive Large Neighborhood Search
- …

Transportation and Logistics

- Using Metaheuristics to solve the practical problems!

Pickup and Delivery

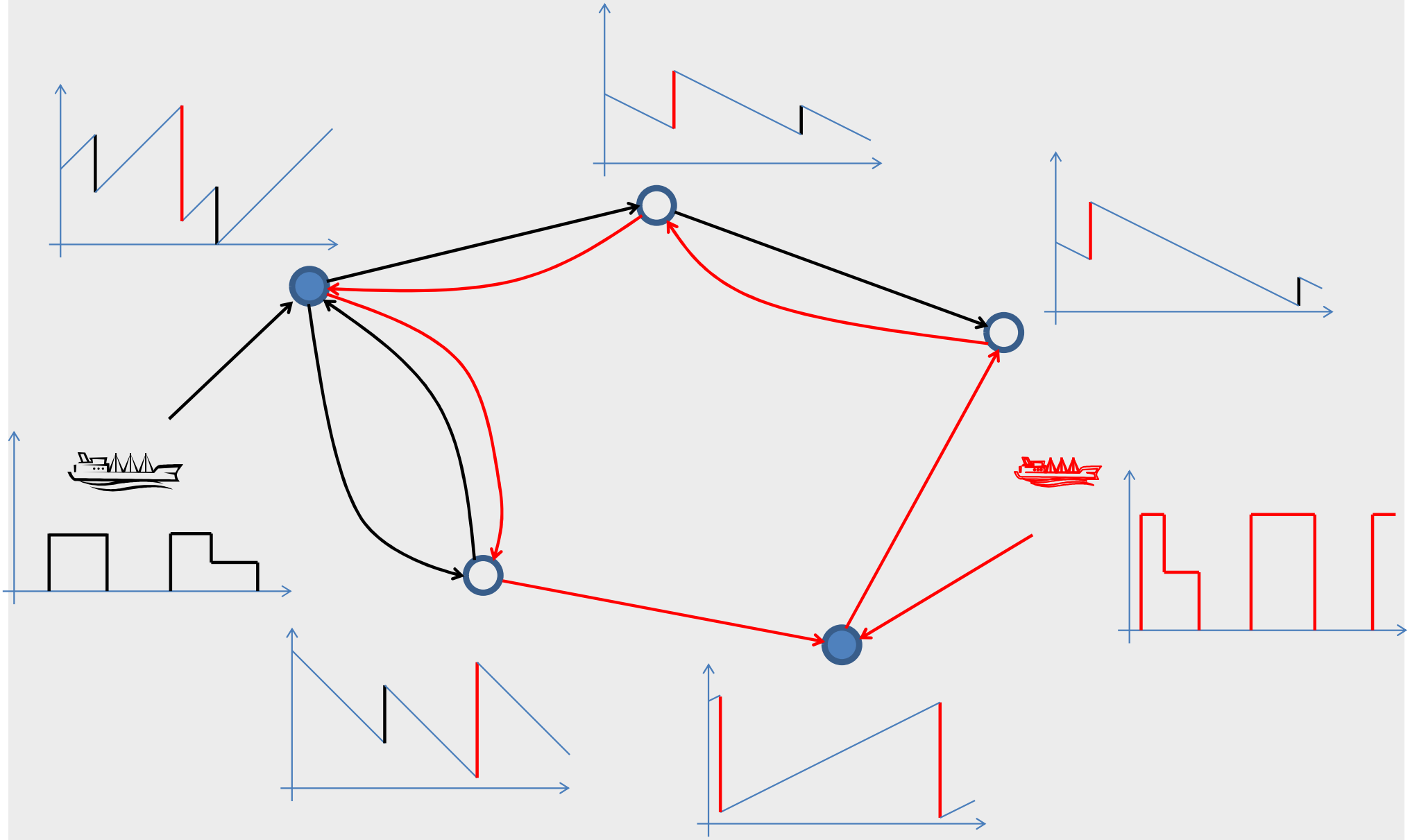


Request: Origin, Destination, Size, Time windows at origin and destination

Maritime Inventory Routing

- Multiple products
- Products are produced and/or consumed at any number of ports
- Heterogeneous fleet
- Fully flexible system (many-to-many)
- Designing routes & schedules
- Determining the quantities handled at each port call
- Not exceeding the storage limits

Maritime Inventory Routing

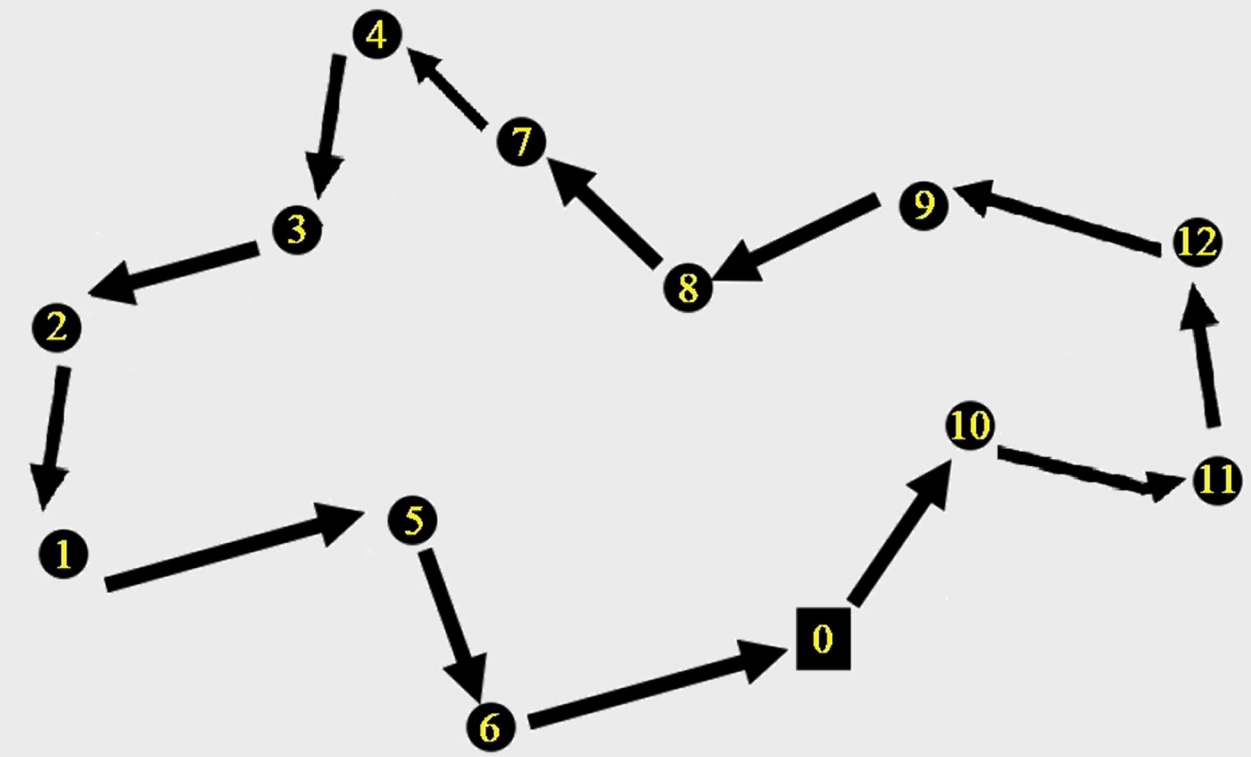


Truck–Drone Delivery

Truck–Drone Delivery

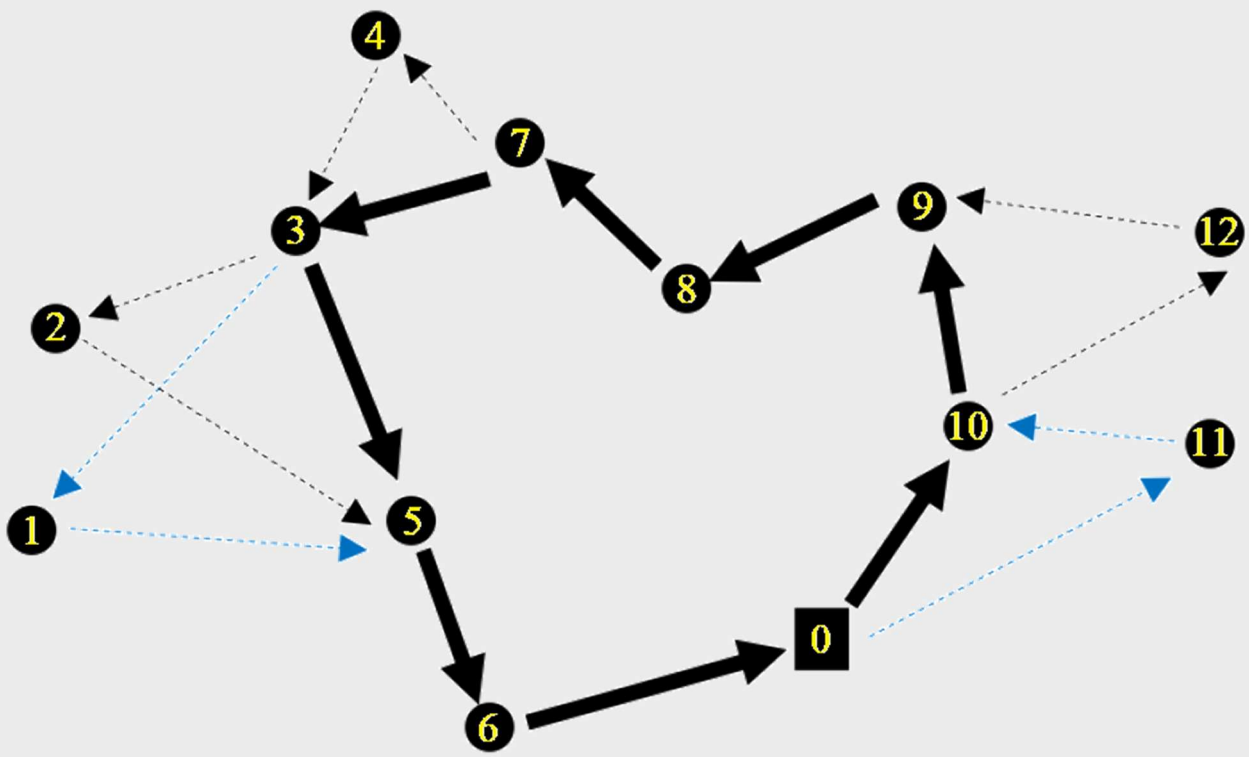
Drone Routing

- Instead of a vehicle routing …

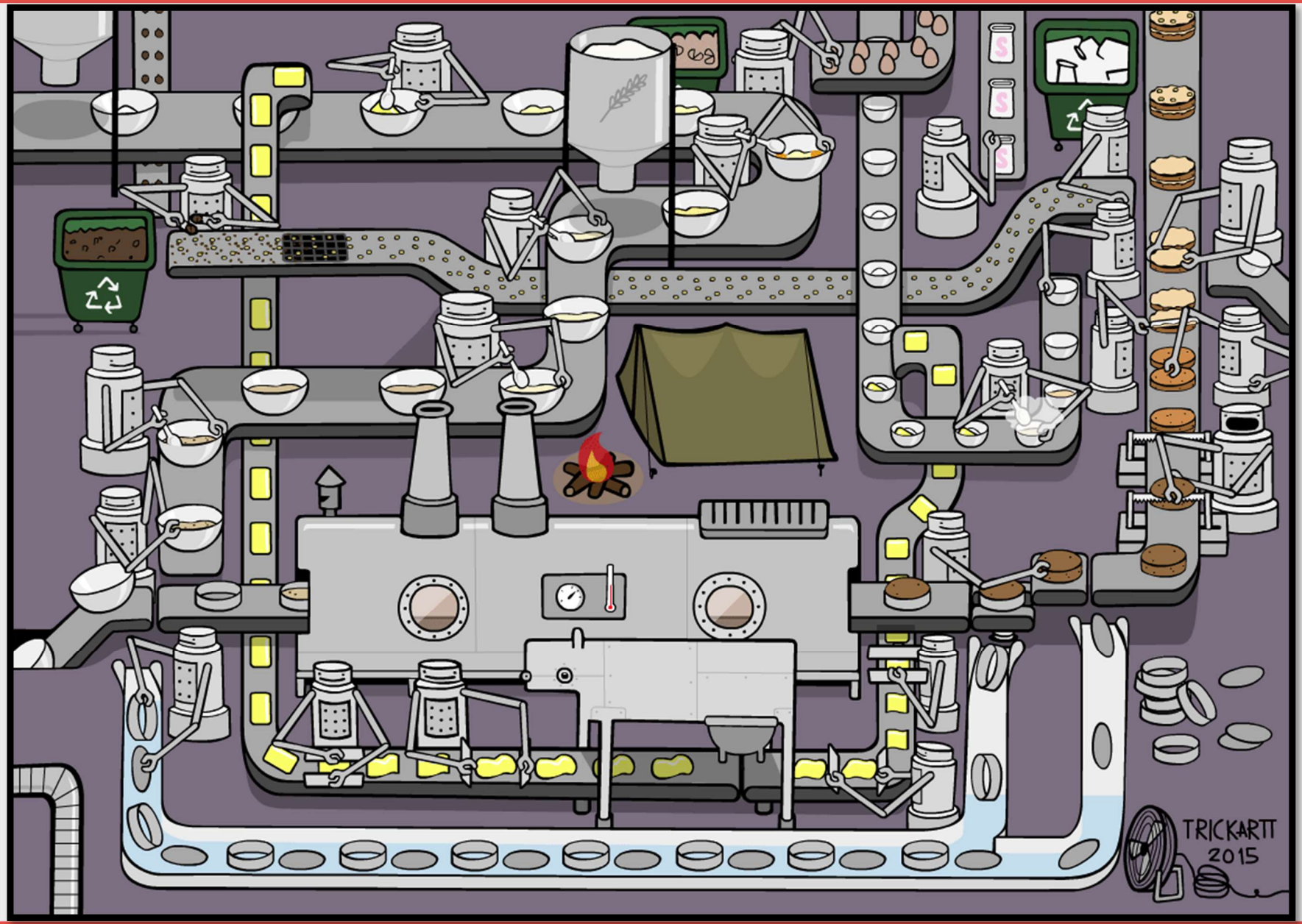


Drone Routing

- Let's assign some customers to drones!

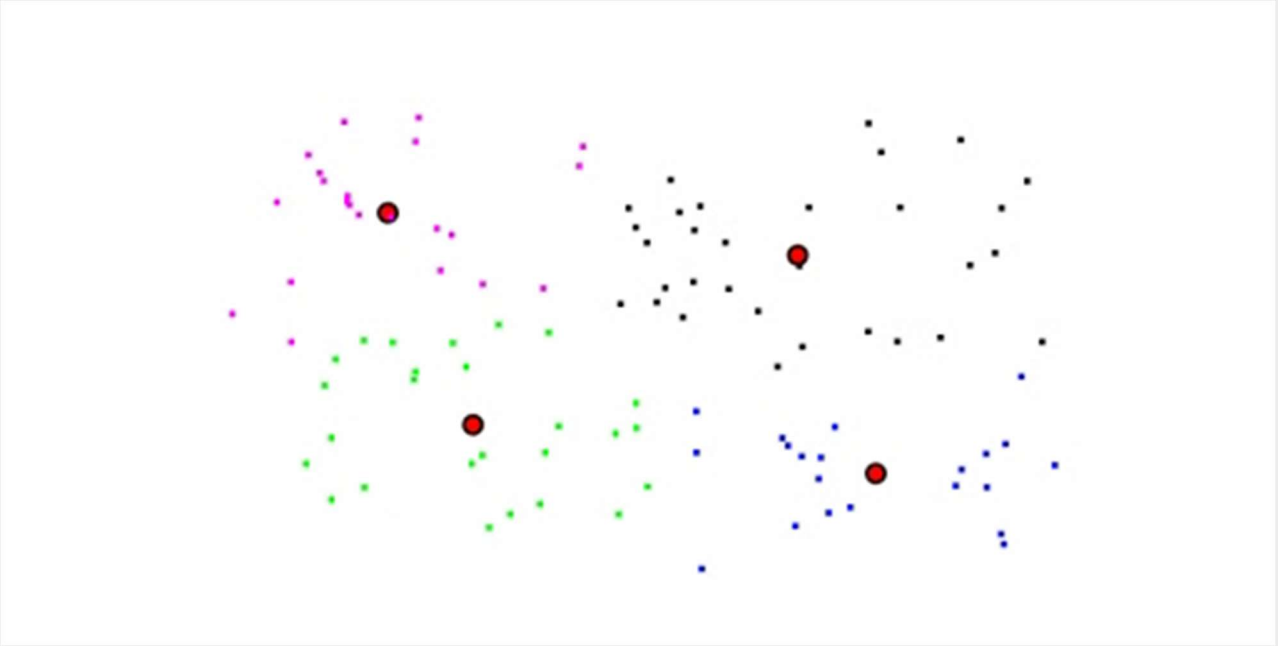


Production Scheduling

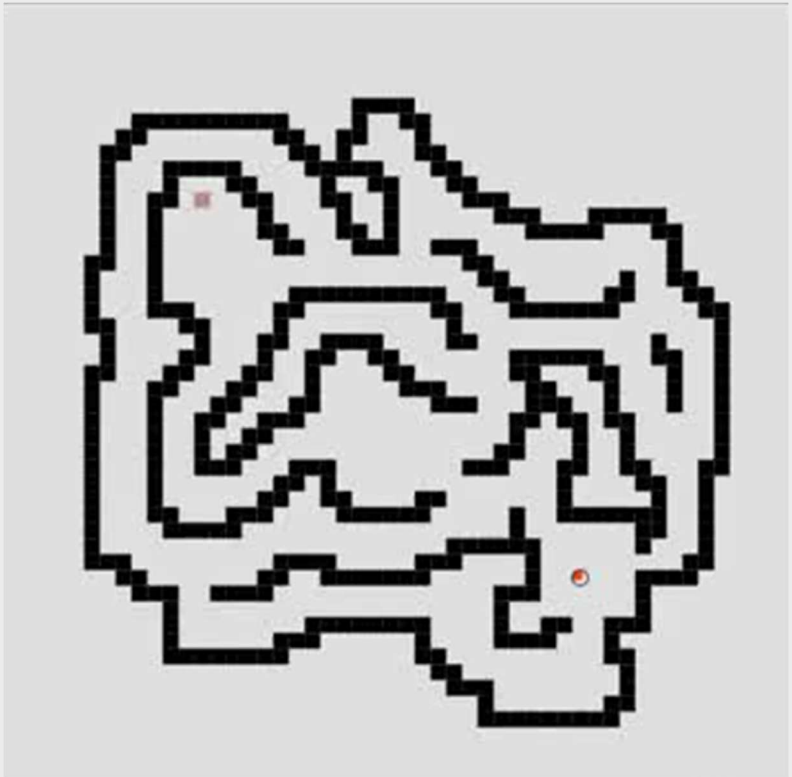


Covering Location

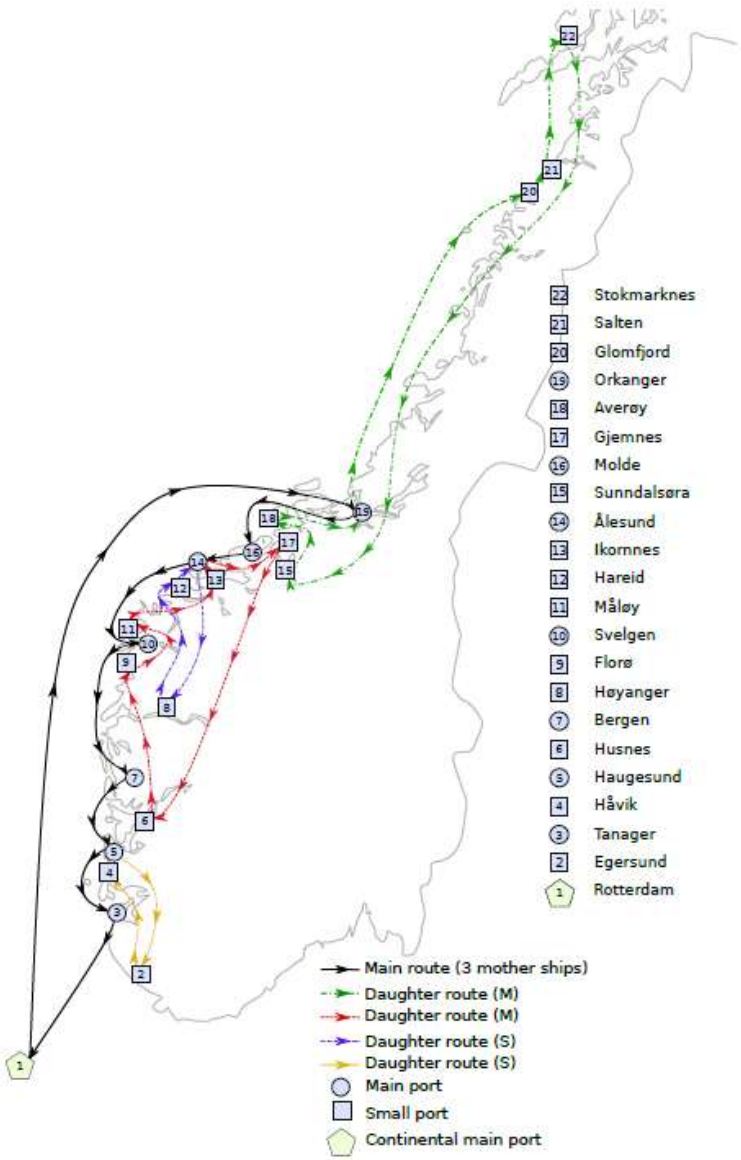
- How to cover moving demands!

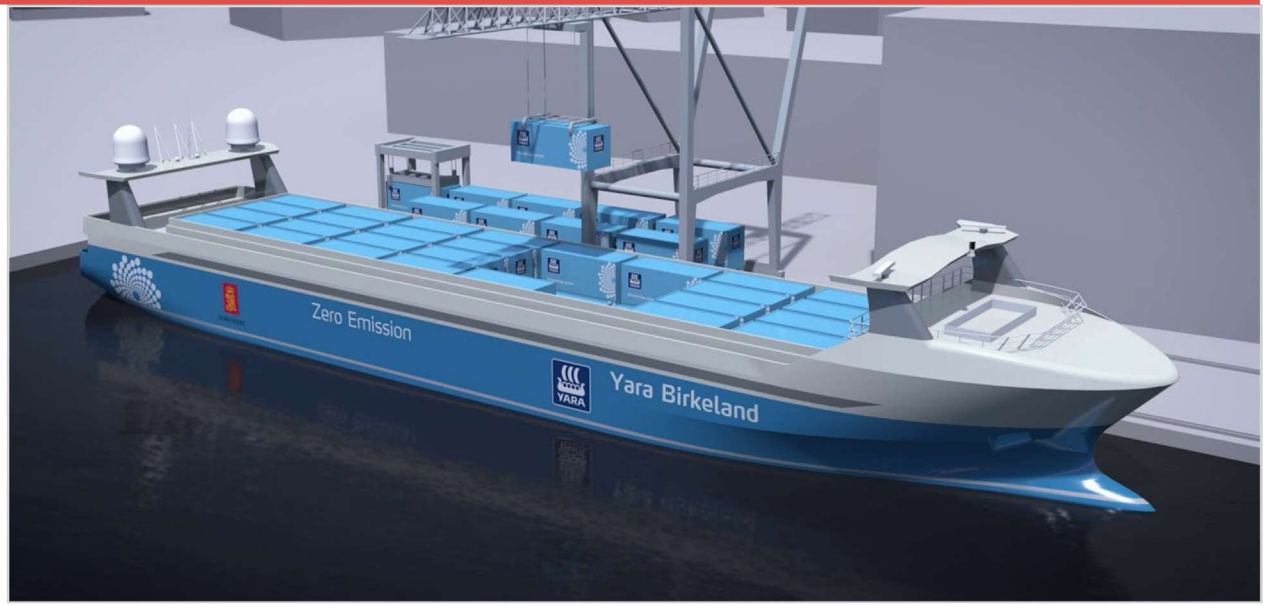


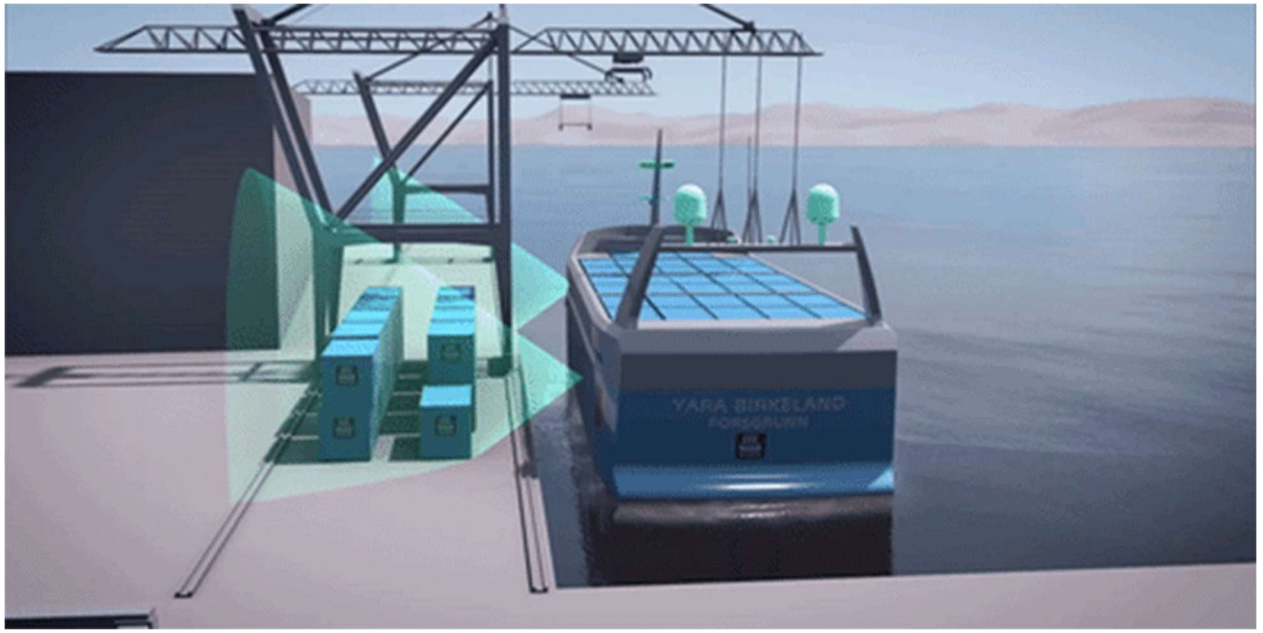
Maze



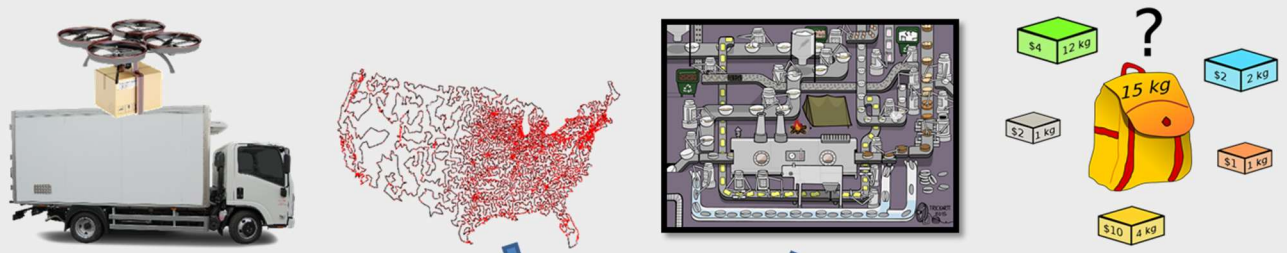
Zero Emission Autonomous Vessels







Optimization Process- Exact Approach

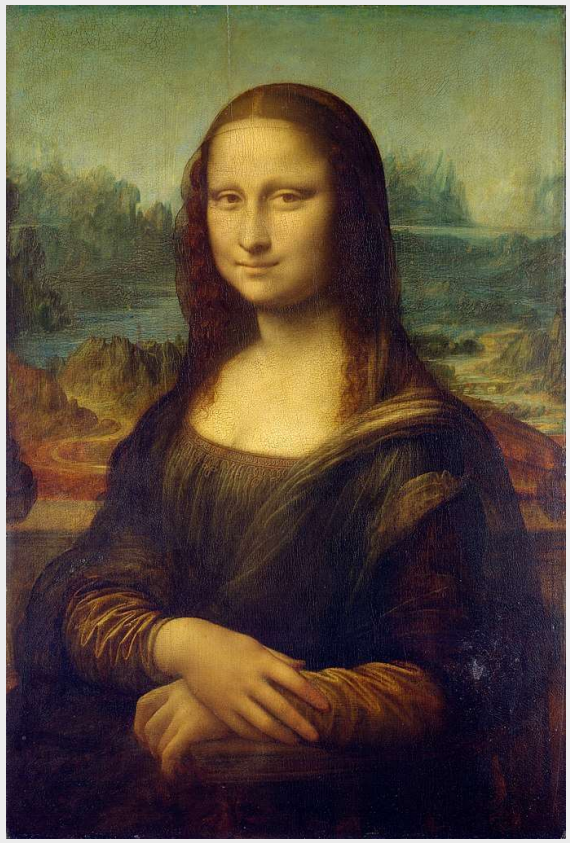


$$\min \; f(x)$$
$$st \;\; g(x) \le b$$
$$x \in X$$

Real problem → **Simplified problem** → **Optimization Model** → **Solution** → **Results**

Optimization Process with Metaheuristics

The Art of Design



Remarks

- Optimization, combinatorial optimization
- Growth of solution space!
- Solution methods
- Trade in solution quality for runtime, by finding very good (but not necessarily optimal) solutions within feasible time
- A powerful toolbox for solving practical (often very complicated) optimization problems
- The art of design!

#2: Heuristics