EMERGING OPTIMIZATION PROBLEMS AND MODERN OPTIMIZATION ALGORITHMS

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TORRENS UNIVERSITY AUSTRALIA

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AIRO: Centre for Artificial Intelligence Research and Optimisation

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AIRO

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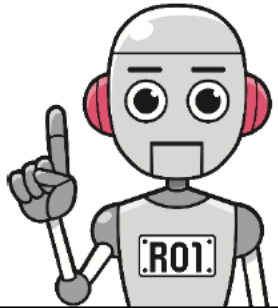
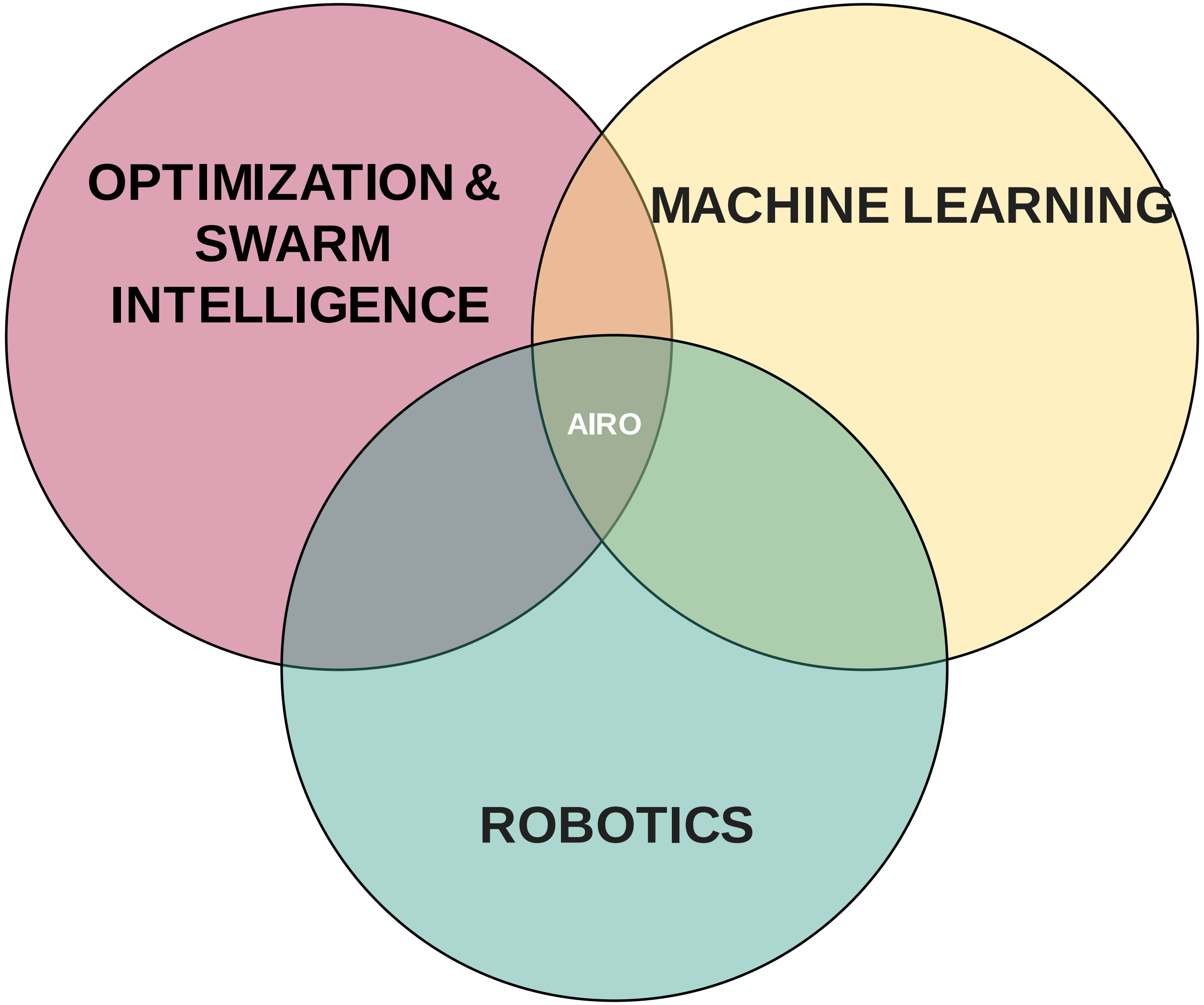


RESEARCH FOCUS AREAS IN AIRO CENTRE



MY STORY

- Dad's Pentium 3
- Bee hives and ant nests in our backyard

OUTLINES

- **Optimization problems**
  - Components
  - Inputs
  - Constraints
  - Objectives

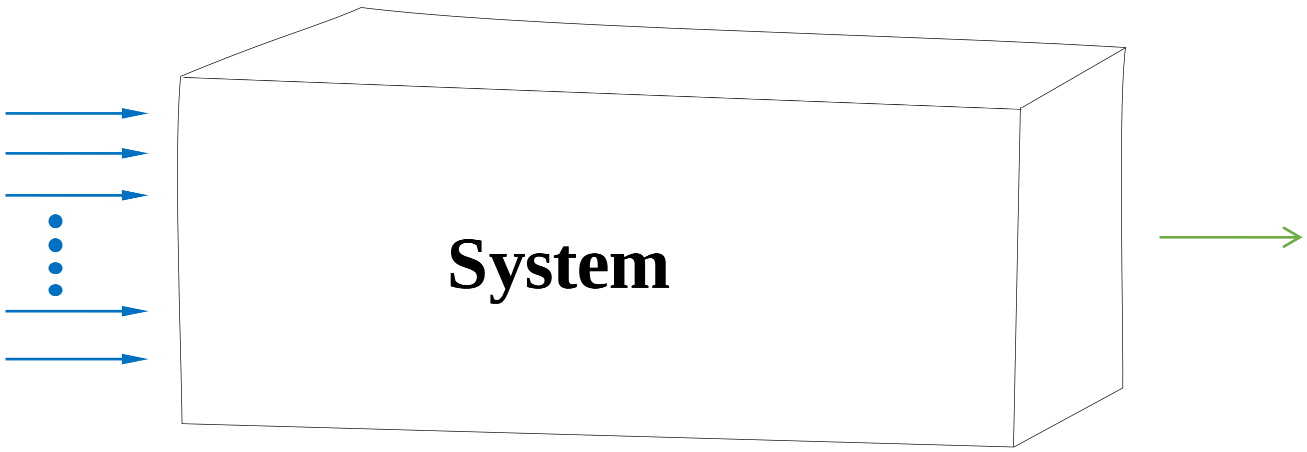
- **Optimization algorithms**
  - Conventional
  - Emergent complexity
  - Swarm-based & evolutionary algorithms

PART I - OPTIMIZATION PROBLEMS

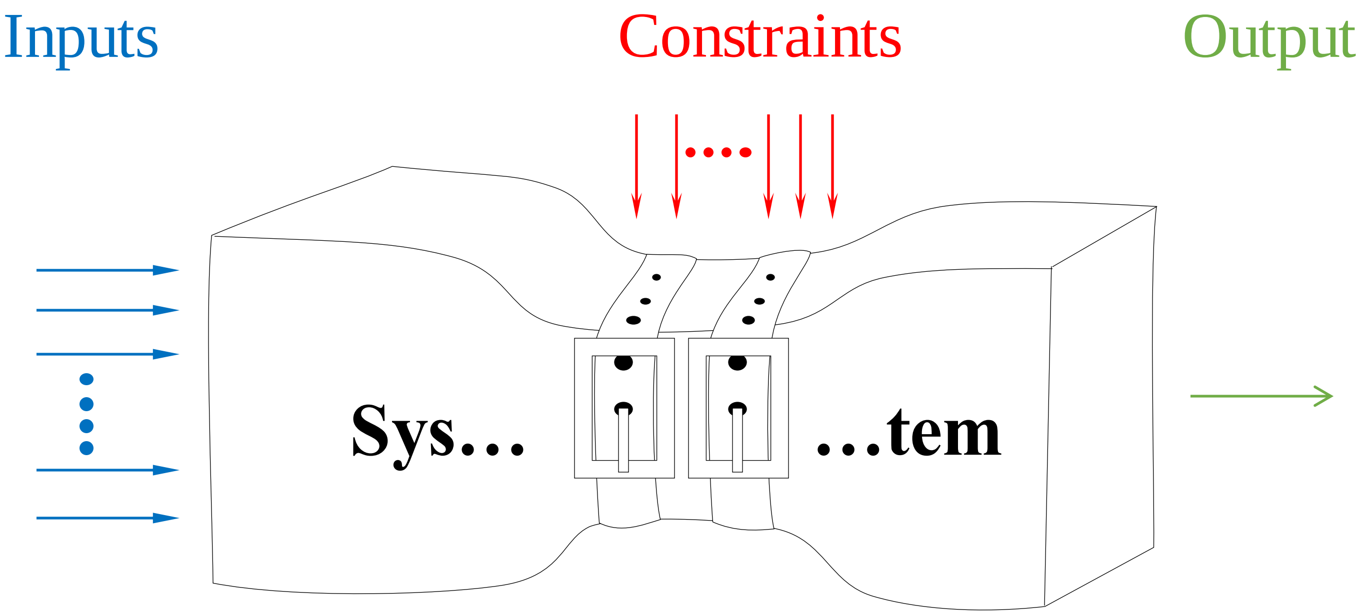
MAIN COMPONENTS OF AN OPTIMIZATION PROBLEM

Inputs (variables)

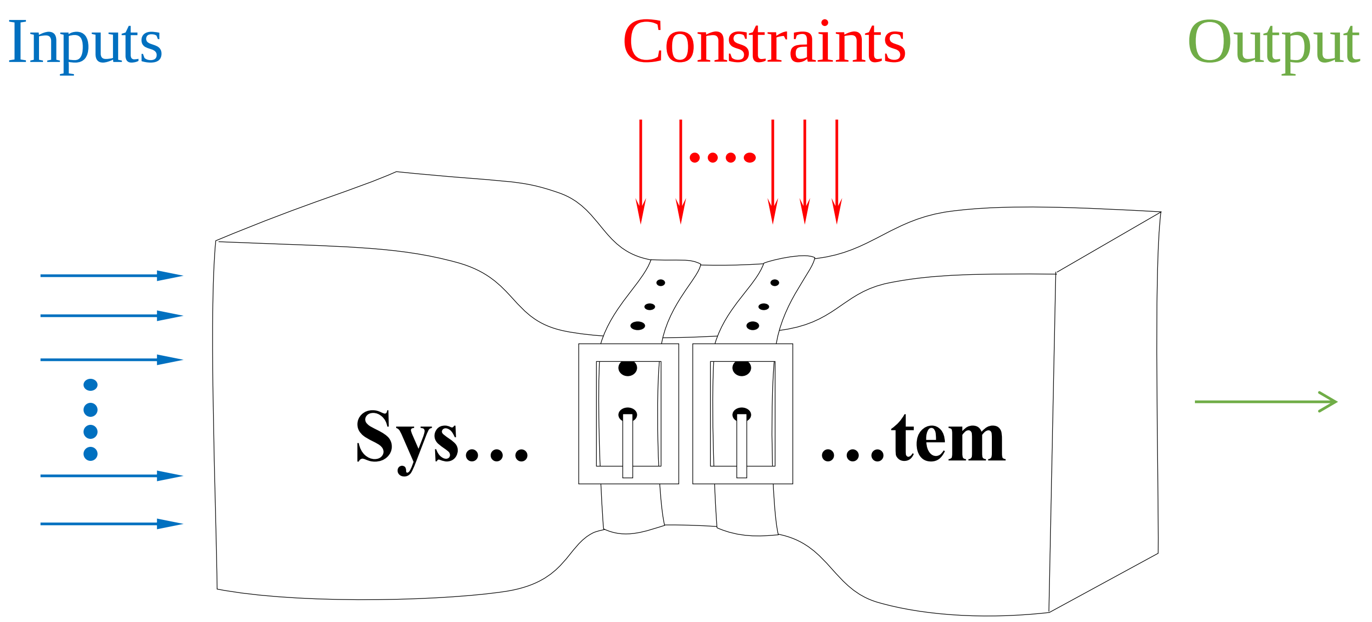
Output (objective)



MAIN COMPONENTS OF AN OPTIMIZATION PROBLEM

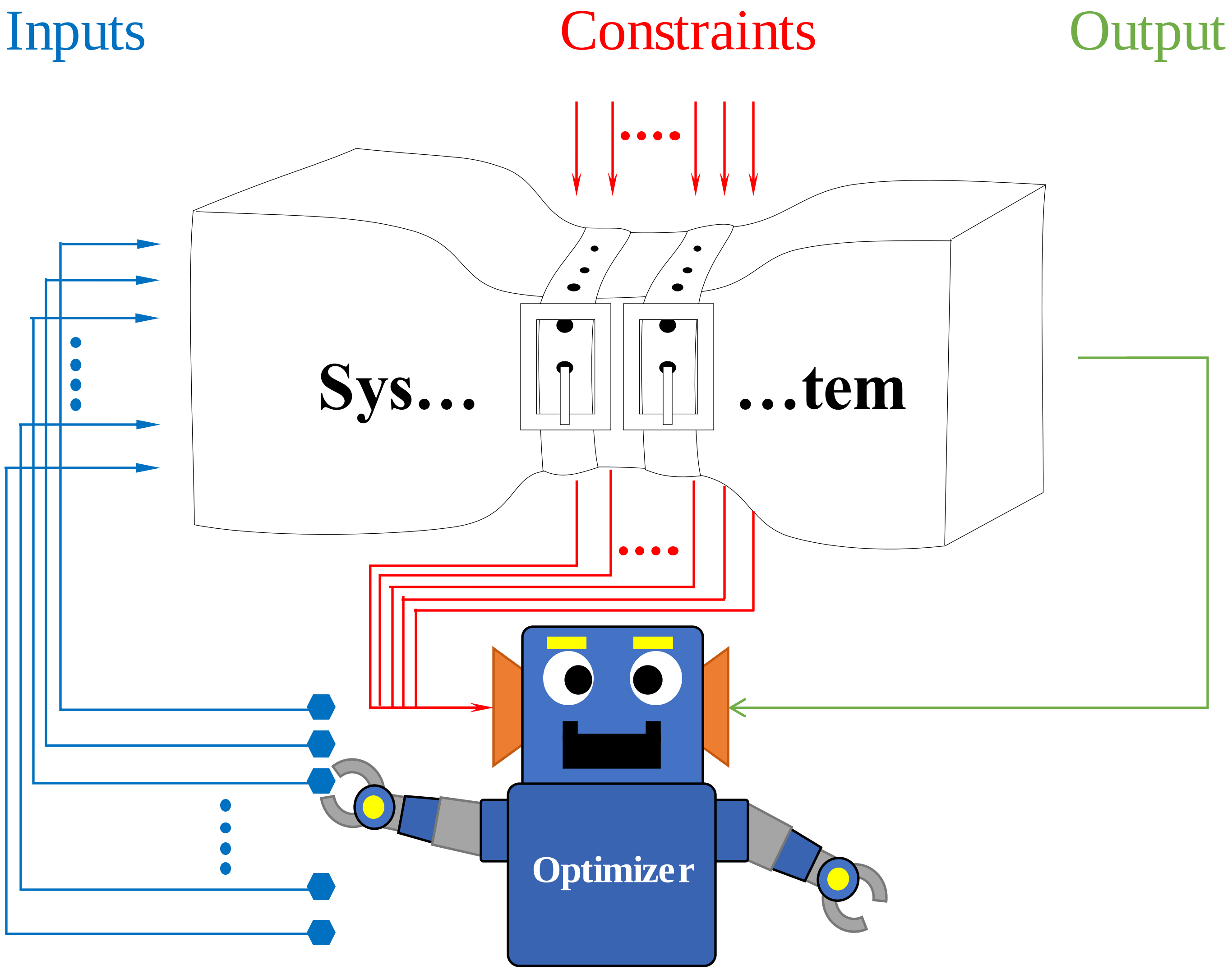


FORMULATING AN OPTIMIZATION PROBLEM

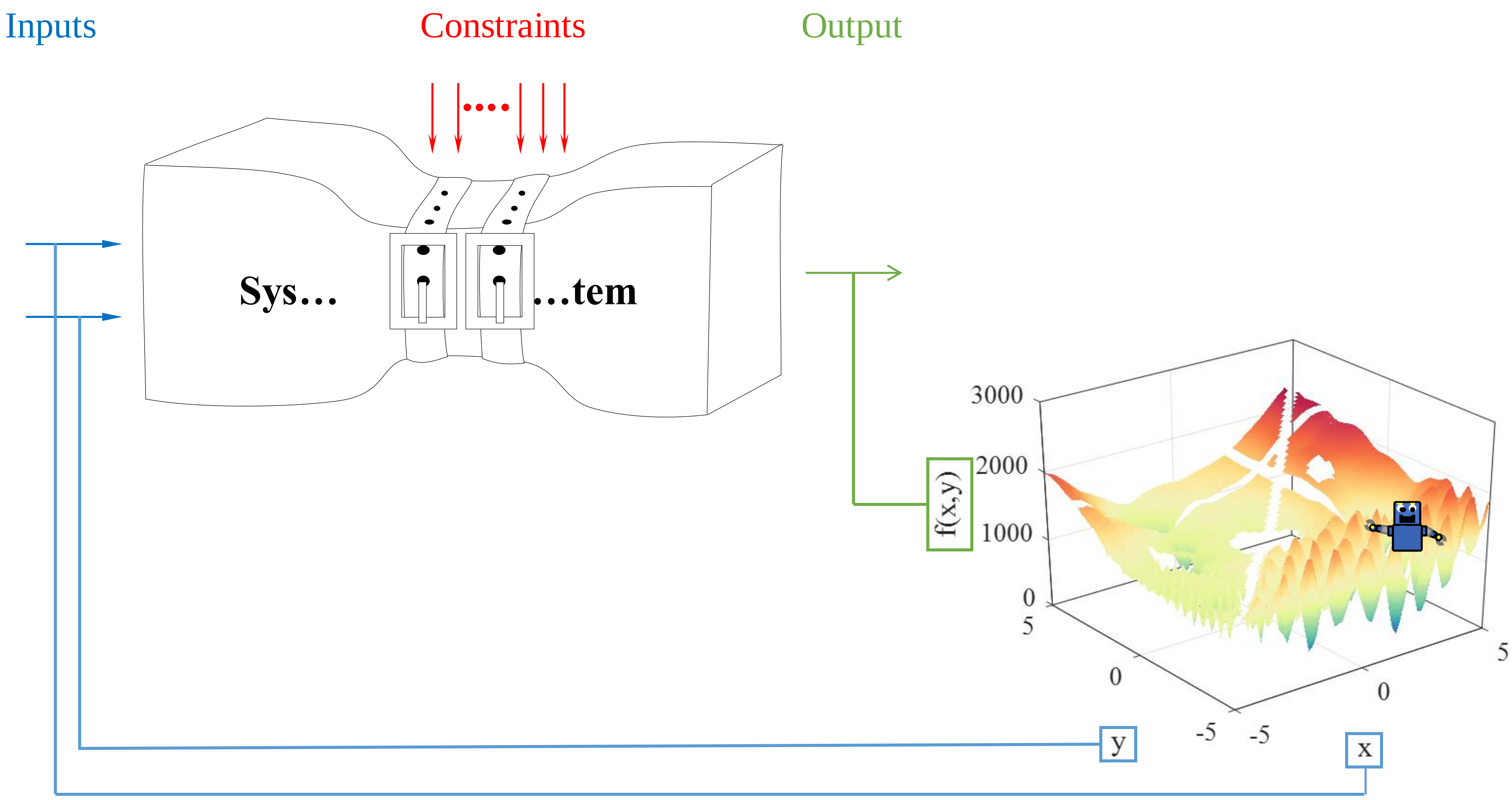


$$Minimise: \quad f(x_1, x_2, \ldots, x_n)$$
$$Suject\ to: \quad Constraints$$

OPTIMIZATION ALGORITHM

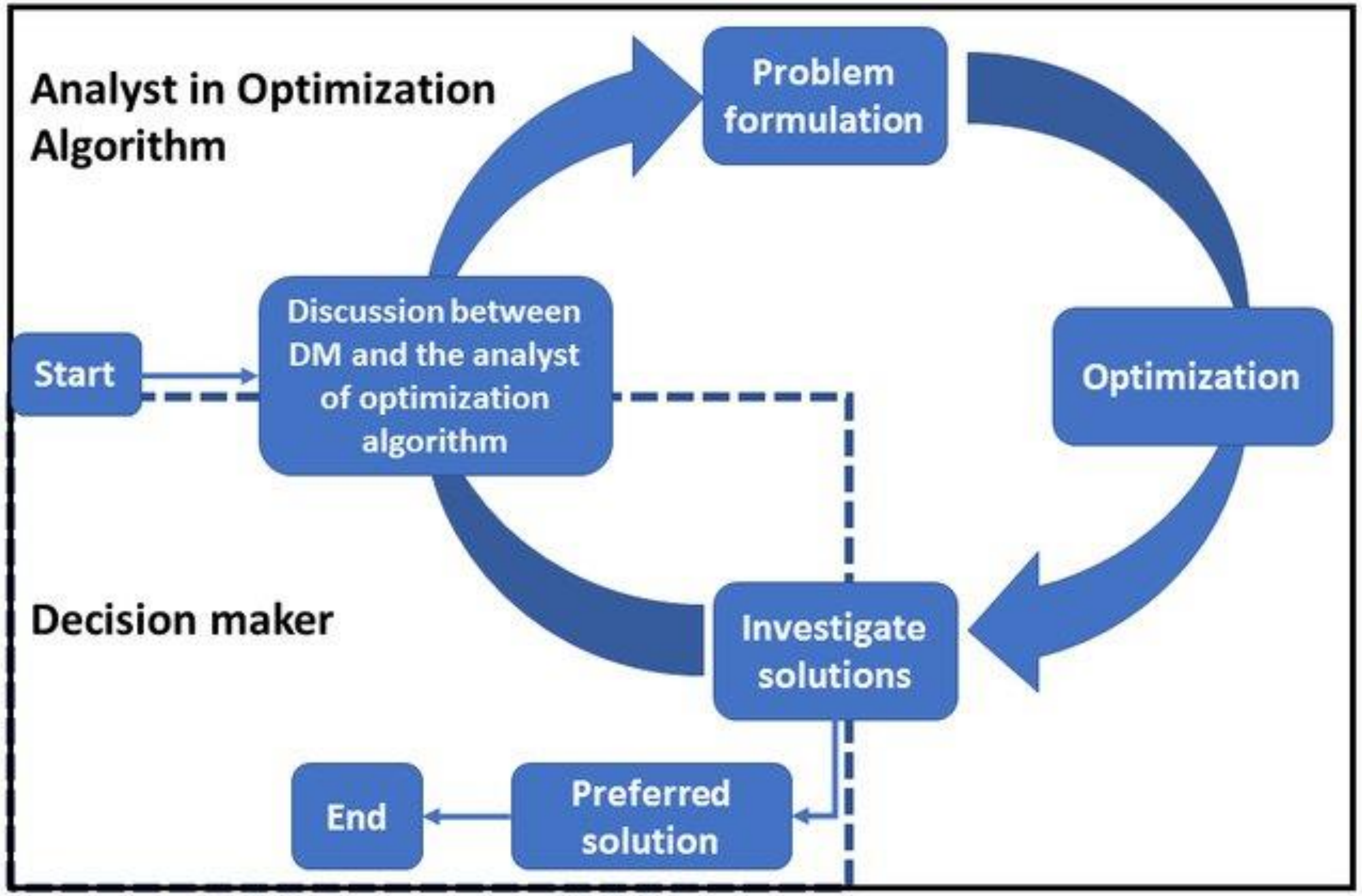


A SEARCH SPACE

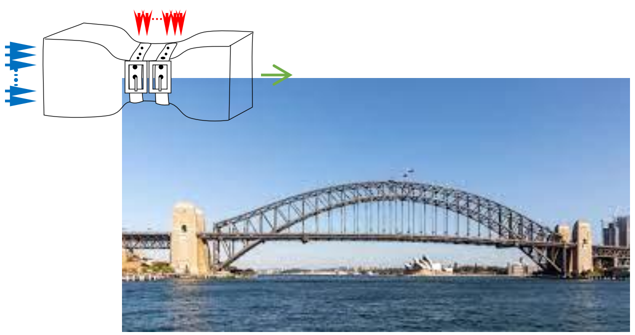


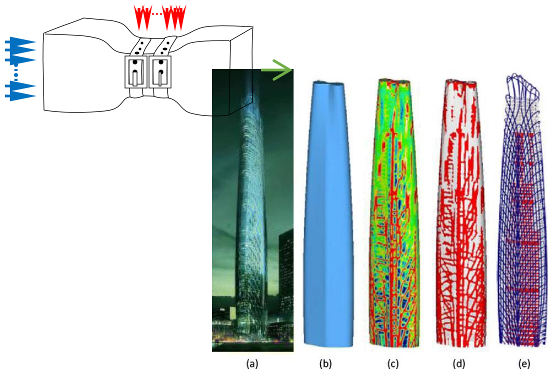
EXISTING FRAMEWOKS TO WORK WITH PROBLEM OWNERS

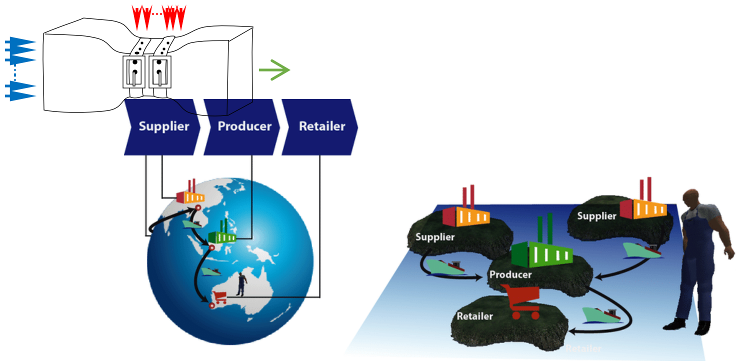
- Iterative process
- Simplification over optimization

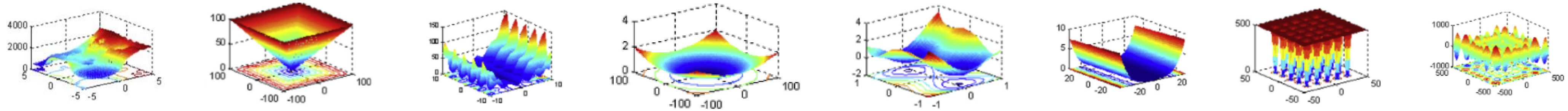


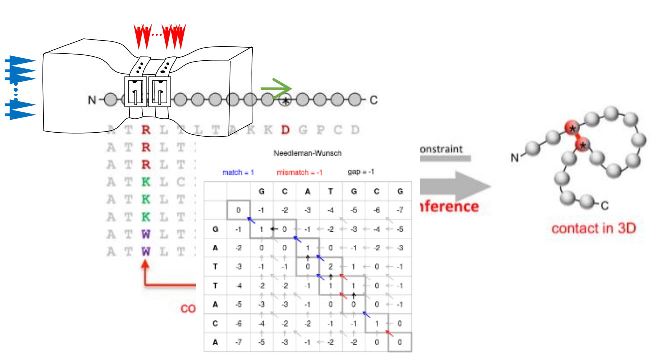
WELCOME TO OUR WORLD

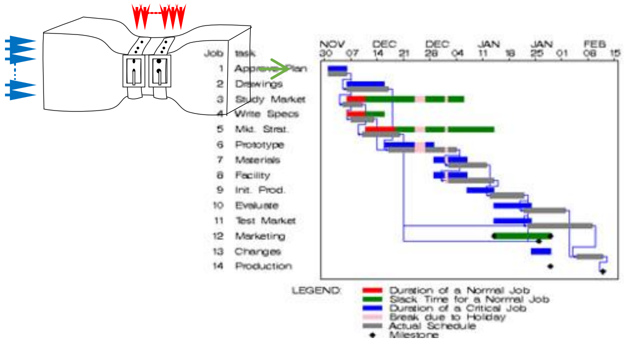


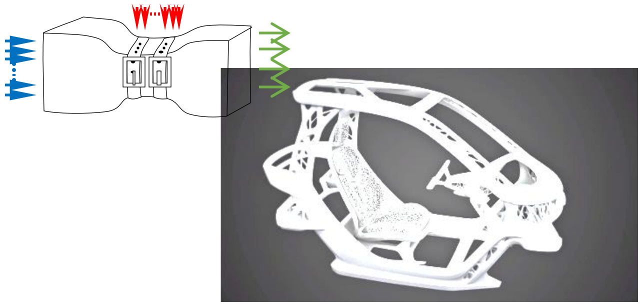


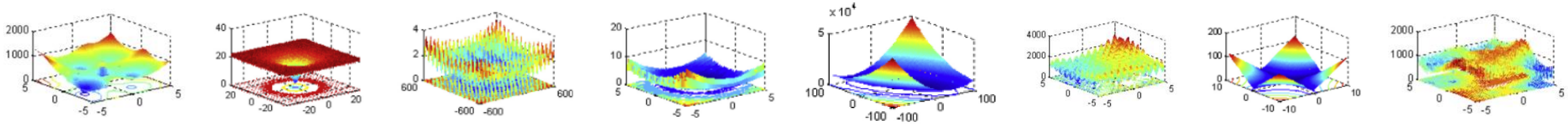








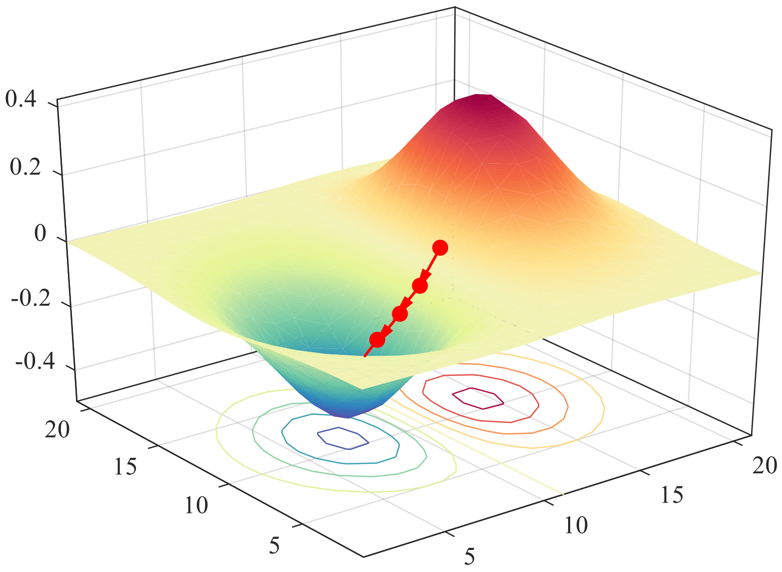


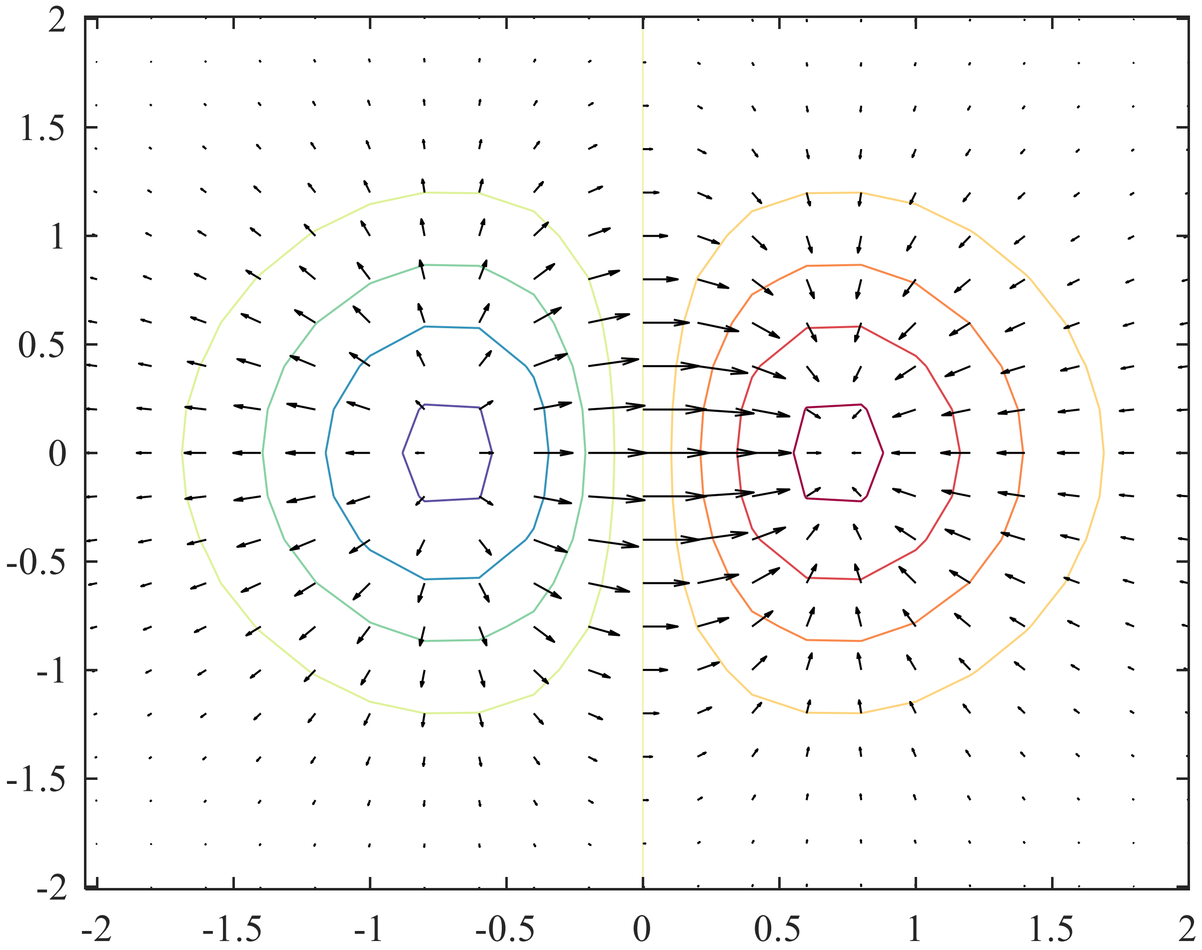


PART II - OPTIMIZATION ALGORITHMS

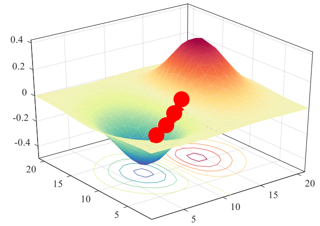
GRADIENT-BASED OPTIMIZATION ALGORITHMS

- Gradient descent algorithm

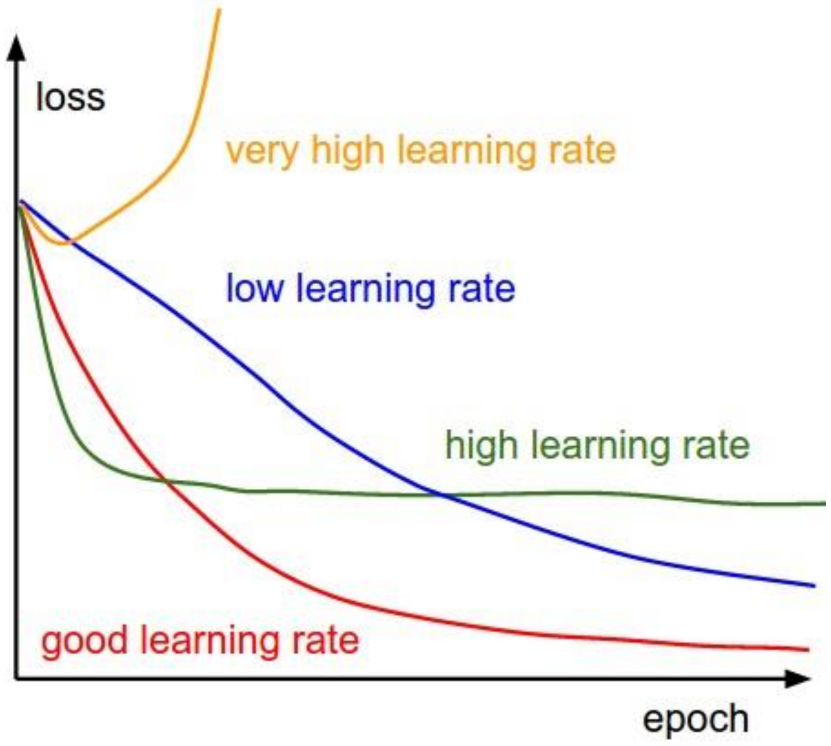




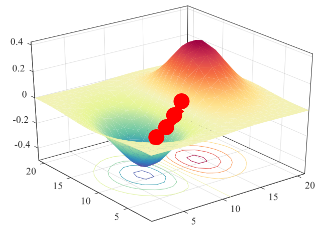
RECENT ADVANCES TO TACKLE THESE CHALLENGES



- Mostly developed by the **Deep Learning community**
  - Momentum
  - Nesterov accelerated gradient (NAG)
  - Adagrad
  - Adadelta
  - RMSprop (Geoff Hinton)
  - Adaptive Moment Estimation (Adam)
  - AdaMax
  - Nadam
  - AMSGrad
  - …



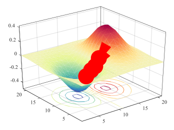
CHALLENGES



- Choosing a proper learning rate can be difficult.
- Learning rate schedules try to adjust the learning rate during training
- The same learning rate applies to all parameter updates.
- Avoiding getting trapped in their numerous suboptimal local minima
- Not practical for problems that are not differentiable

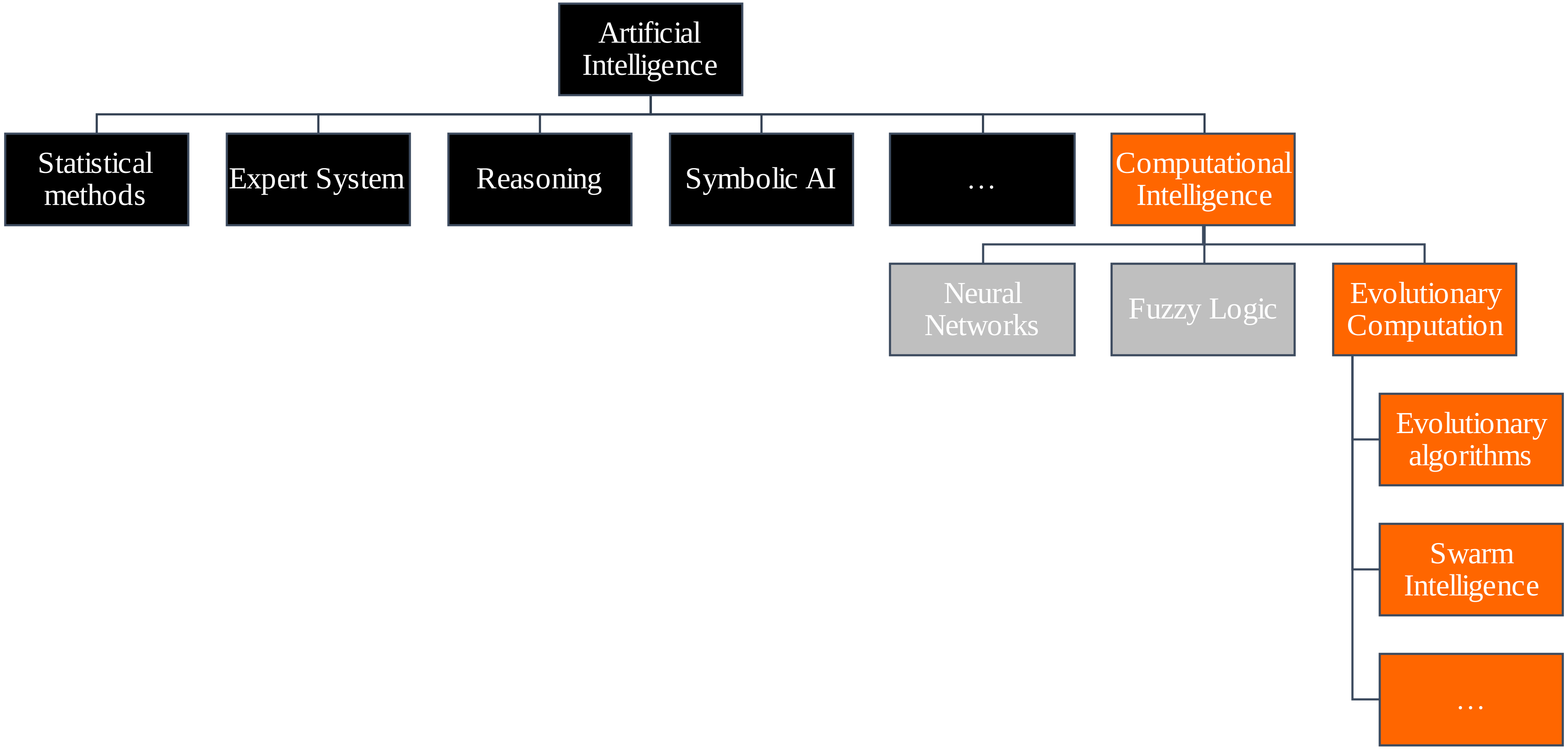
ISSUES WITH CLASSICAL ALGORITHMS

- Optimization algorithms
  - Gradient
    - Gradient-based
    - Gradient fee
  - Search model
    - Local search
    - Global search
  - Behaviour
    - Deterministic
    - Stochastic
  - Number of solutions
    - Single solution based
    - Population based



Mitigation

POSITION IN AI FIELD



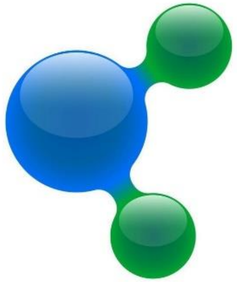
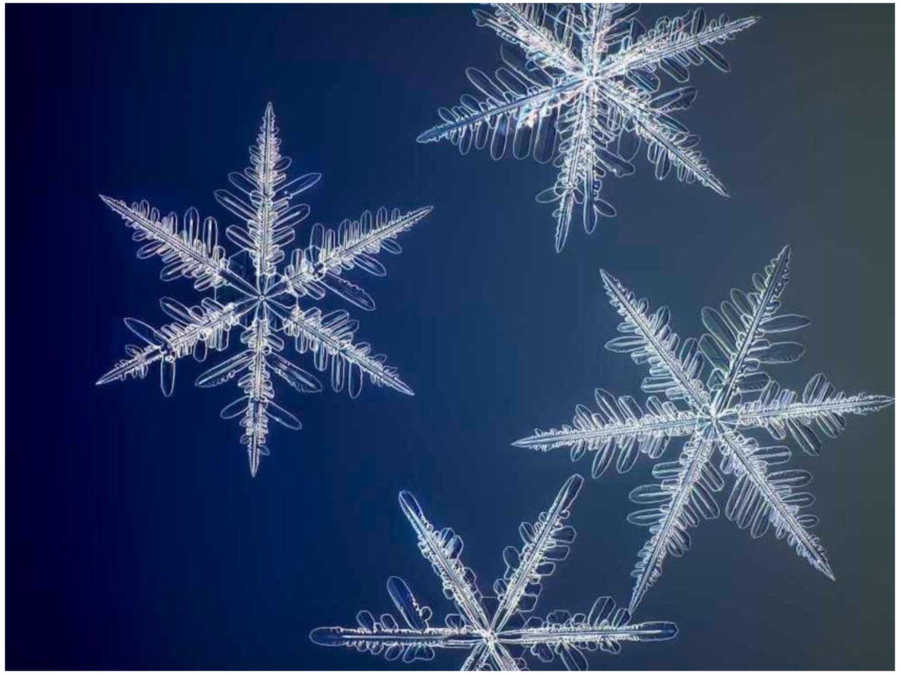
WHY DO NATURE-INSPIRED ALGORITHMS WORK?

Emergent complexity

- **Emergent complexity:** "a phenomenon whereby larger entities arise through interaction among smaller or simpler entities "
- Necessary components:
  - Units with simple behaviors
  - External force for cooperation
- What we get is some complex behavior resulting from an optimization process

EXAMPLES OF EMERGENT COMPLEXITY

Units → EMERGENCE → **Complex behaviour**

 H_2O → EMERGENCE → 

EXAMPLES OF EMERGENT COMPLEXITY

Units

EMERGENCE

Complex behaviour

EMERGENCE

EMERGENCE

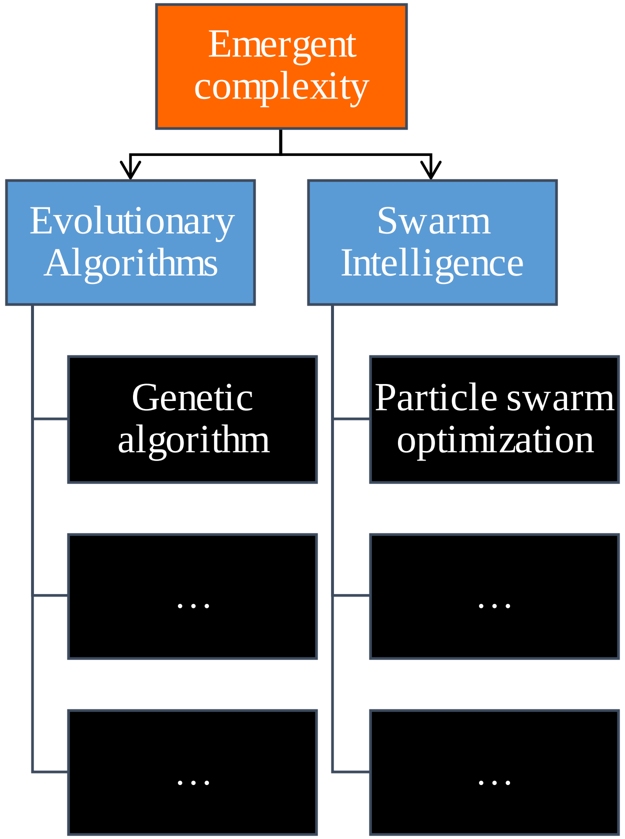
EMERGENCE

EMERGENCE

EMERGENCE

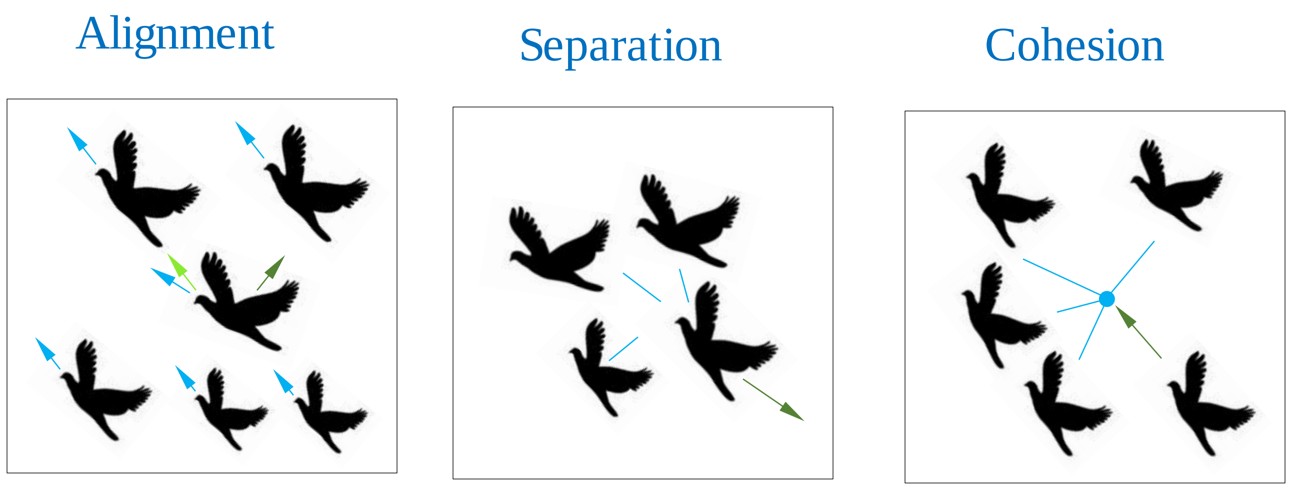
EMERGENT COMPLEXITY

- Emergent complexity is not fundamentally natural. We can develop artificial systems that show complex behavior (e.g. game of life)
- So we can achieve complexity, the question is so what? Not every complex system is useful but what about complexity in natural systems?
- **Evolution tends to select complex systems for good reasons: OPTIMIZATION**
- So if there is a complexity in nature, it might be a good reason for that
  - **Evolutionary algorithms and swarm intelligence** techniques are useful applications of emergent complexity
- So it is wise to inspire from natural systems:
  1. Complex behavior in nature MUST solve problems efficiently
  2. A lot of problems in computer science are quite similar to problems in nature (path planning, scheduling, ..)
  3. They are scalable

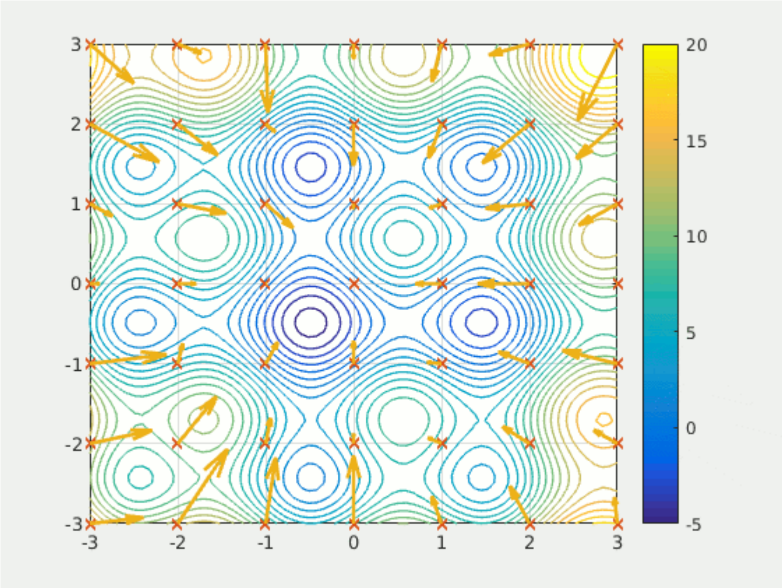


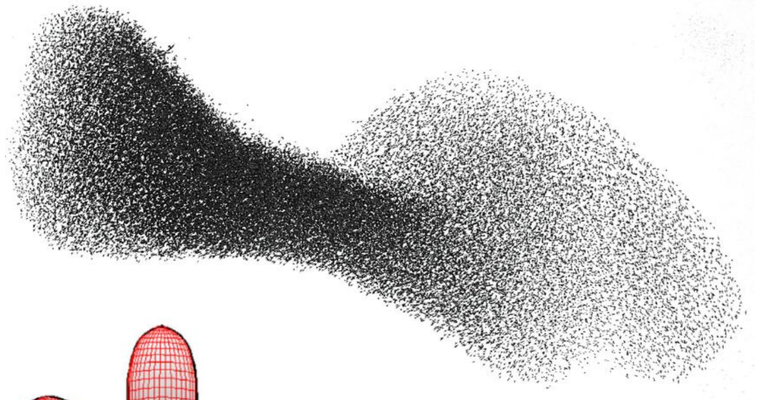
FLOCK OF BIRDS

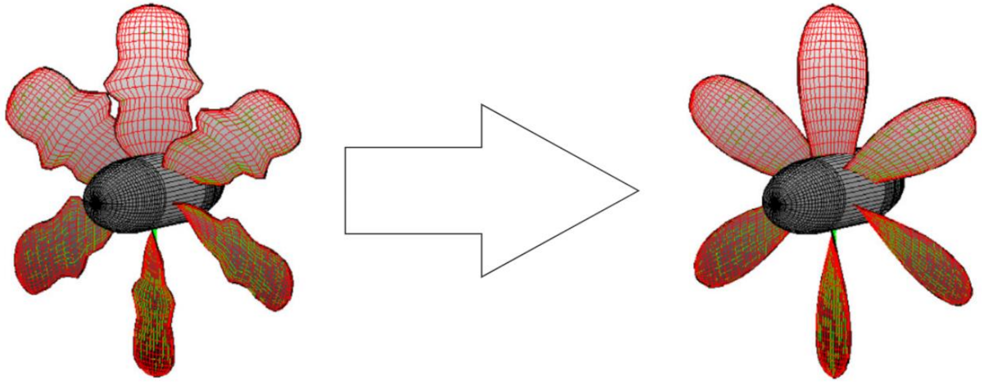
- Example: migration in a flock by birds in an unknown environment to minimize energy consumption is similar to flying in an unknown search space of a problem to minimize the cost function.

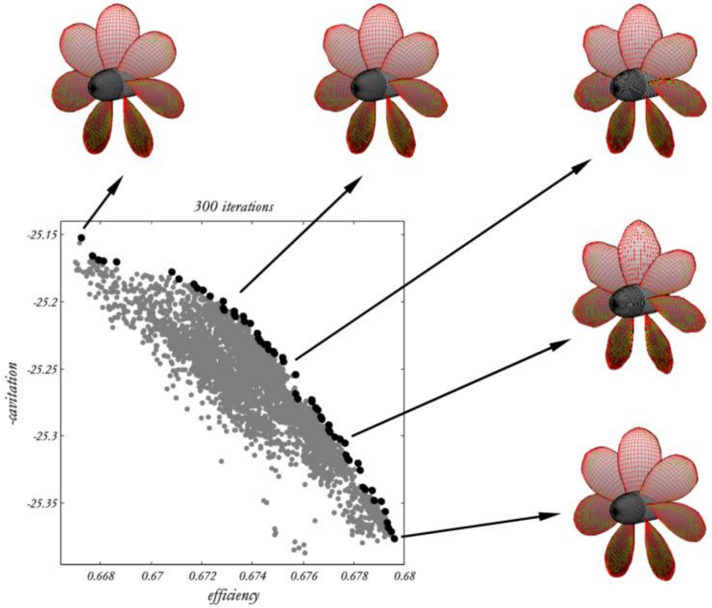


FLOCK OF BIRDS

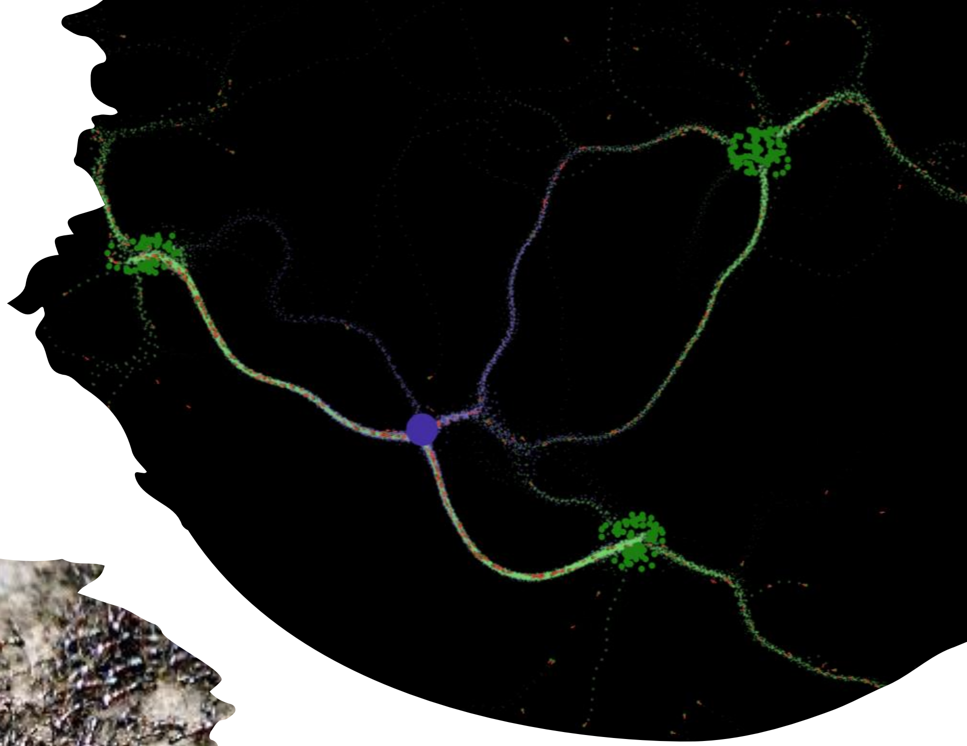


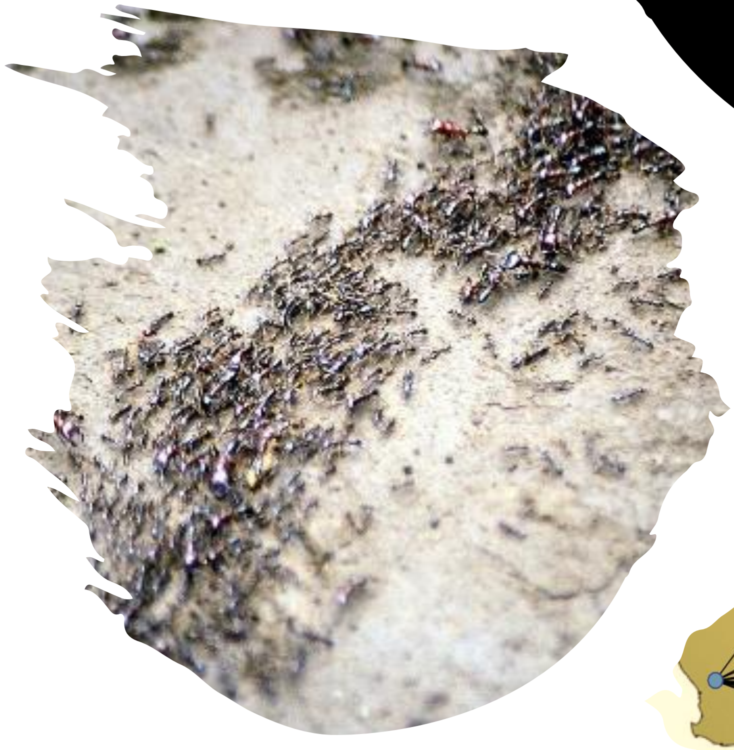


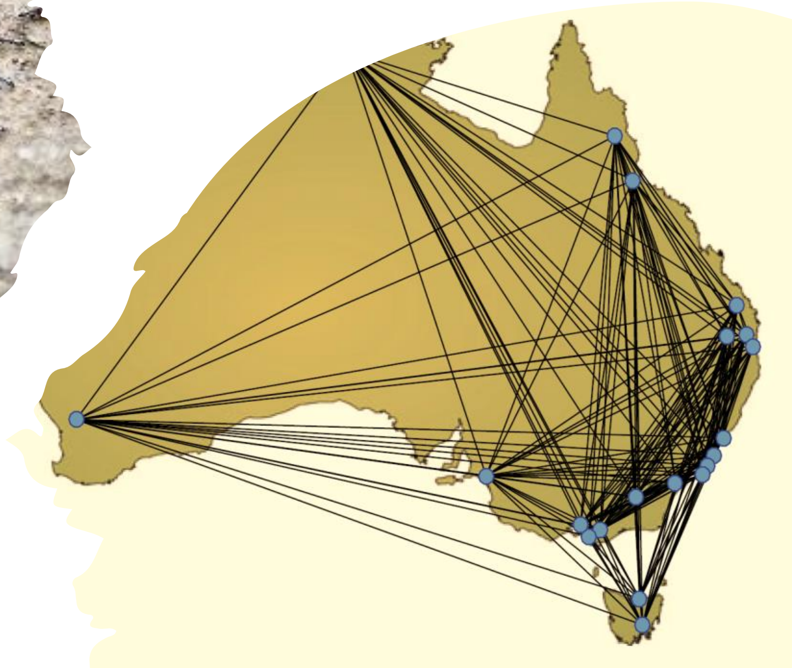




Finding an optimal path to a food source by ants in an unknown environment is similar to finding a global optimum in an unknown search space

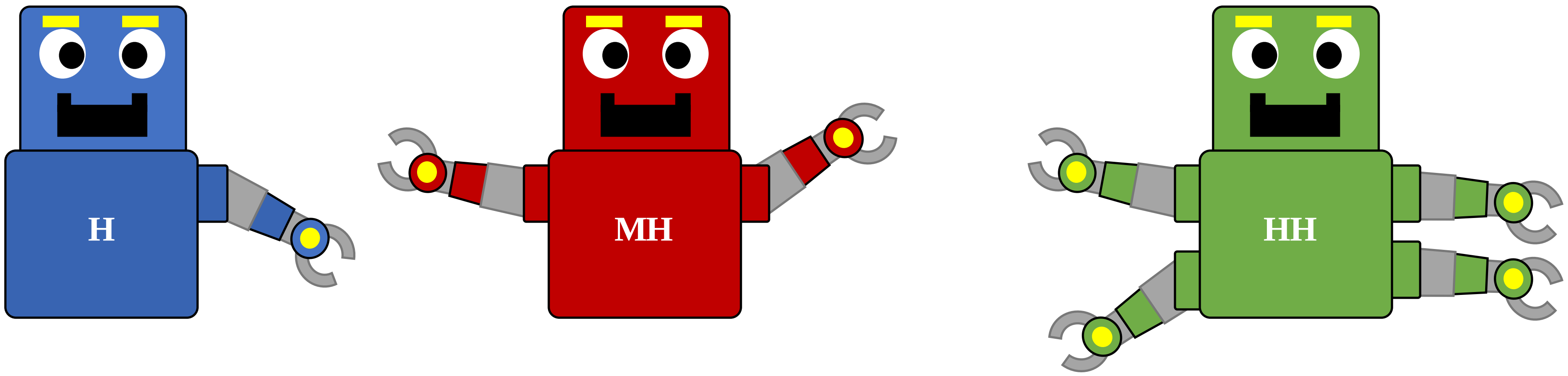






WHERE WE ARE HEADING

Heuristic → Meta-heuristic → Hyper-heuristic → …..



Increased Automation

MY PLAN AS A MEMBER OF ÓBUDA UNIVERSITY

- **ÓB Research capacity and culture**
  - Setting up and running a research group on optimization and evolutionary computing
  - HDR Student exchanged
  - Running a workshop every year on emerging areas in AI: machine learning, deep learning, and optimization
- **ÓB Research promotion and partnership**
  - Enabling collaboration between researchers in my centre at Torrens University Australia and ÓU's researchers
  - Collaboration with internal stakeholders
- **Research Output**
  - Academic publishing strategy in the focus area
  - Edited book, conference sessions, special issues, …
- **Research Funding**
  - Develop a strategy for obtaining research funding in the focus area of the research group

RESEARCH BENEFIT AND IMPACT

- Help businesses and organisations in Hungary to be more agile and efficient
- Facilitate data-driven decision making
- Help stakeholders to understand the underlying factors and their impact in their decision making
- Help scientists and practitioners in Hungary to solve computationally expensive optimization problems
- Help with better understanding of how nature solves problem
- Developing innovative problem solving techniques inspired from nature

Love what you do

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