



Using Artificial Bias to Assist Evasive Maneuvering of Aircrafts in Combat Situations

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Agenda

- Introduction
- Background
- Methodology Development
- Numerical Simulations
- Discussion
- Future Direction
- Conclusion



Introduction

- **Air combat requires the pilot to evade heat seeking missiles specifically designed to collide with the fighter aircrafts**
 - **missiles are running on solid fuel and therefore are much faster**
 - **missiles have smaller winglets and therefore have less maneuverability**



Background

- **Collision avoidance has been done with free-moving robots**
 - intelligent robots can navigate along its preplanned path while avoiding both stationary and moving obstacles
 - it is easy to model obstacles as sources of artificial field repelling the robot (against an obstacle)



Background



Background



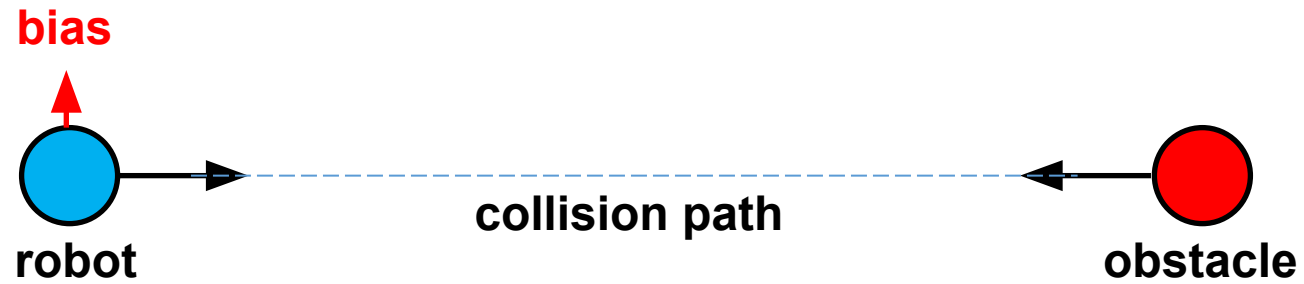
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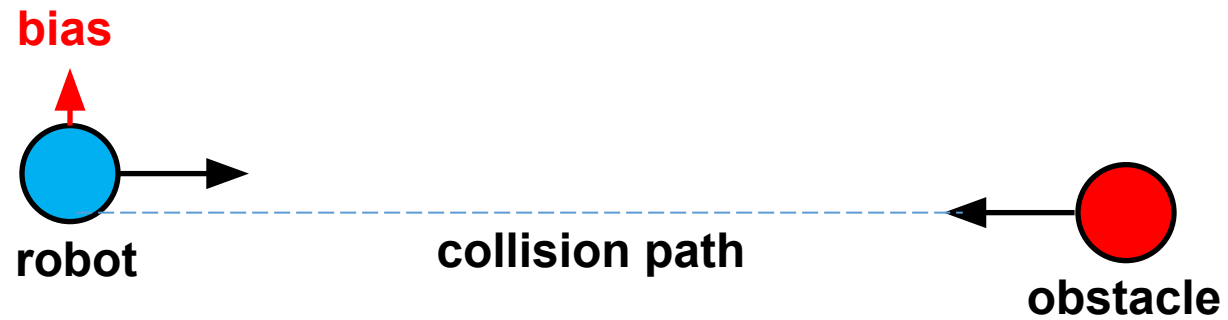
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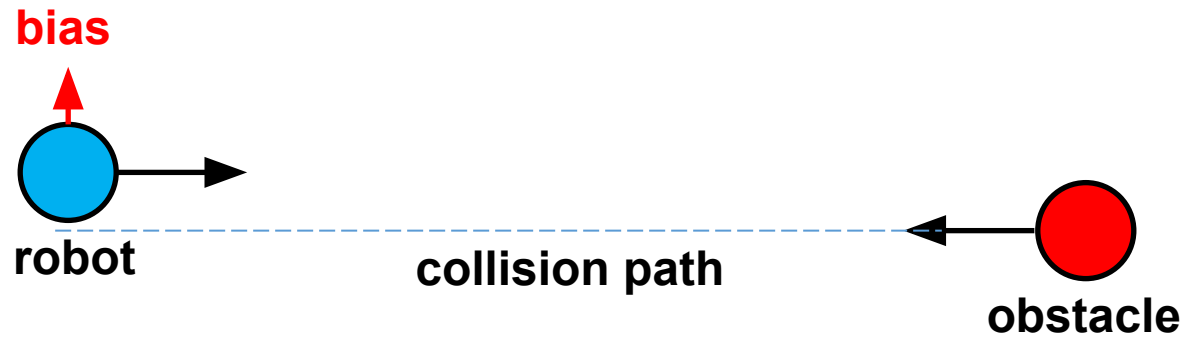
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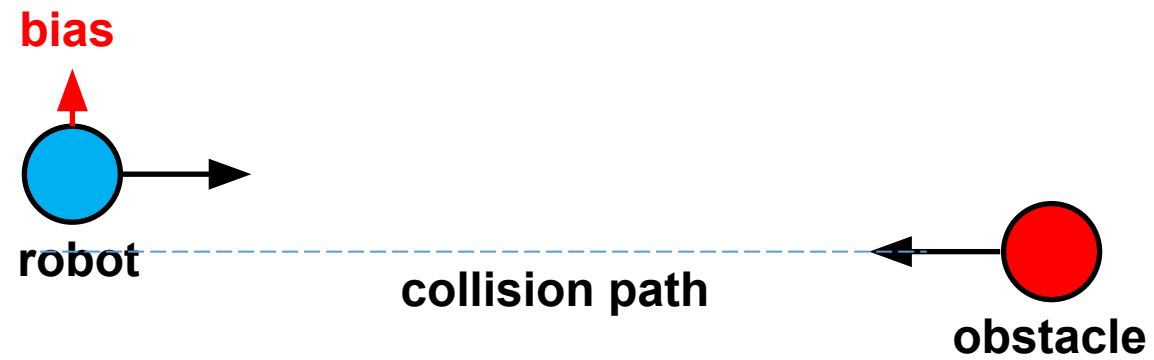
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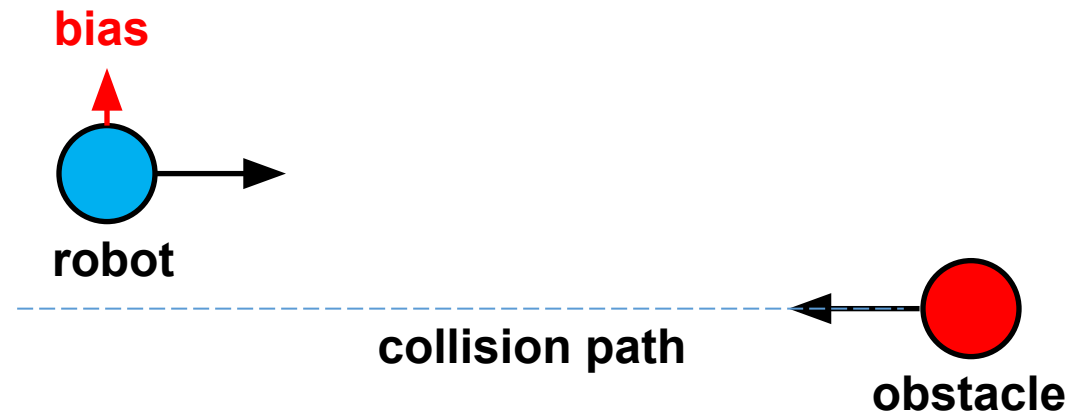
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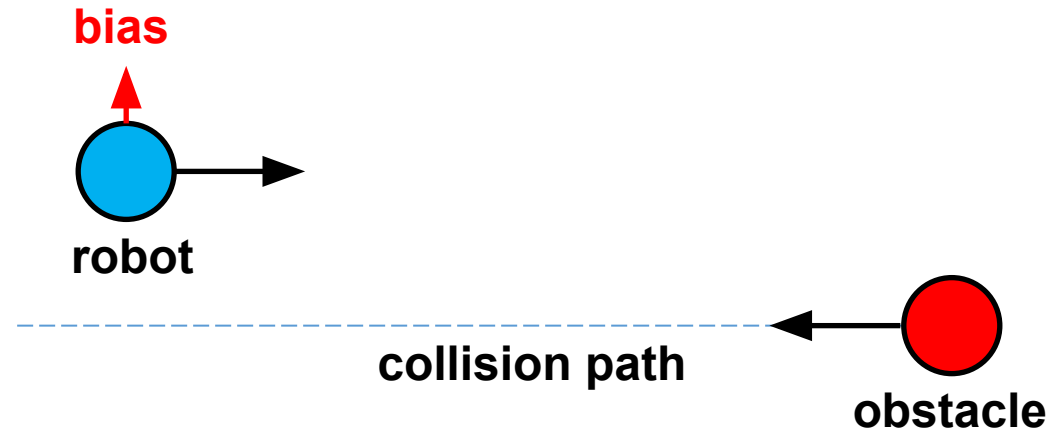
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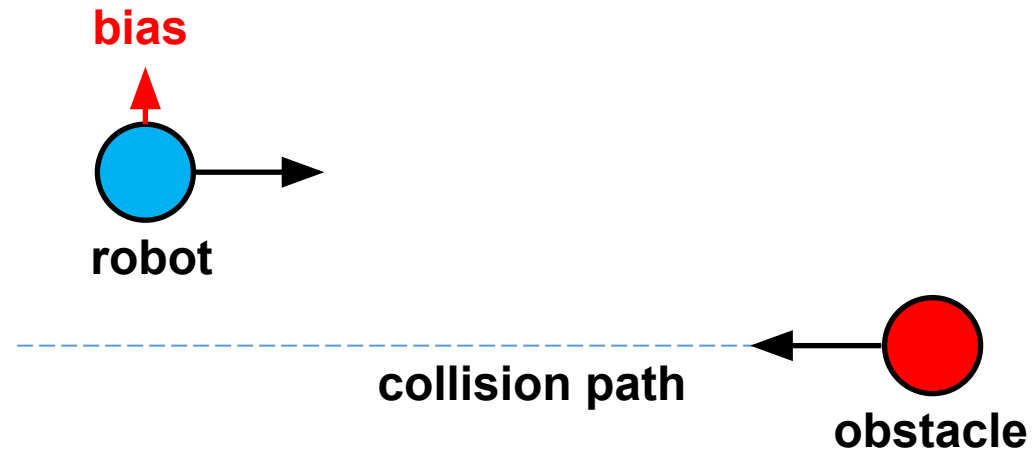
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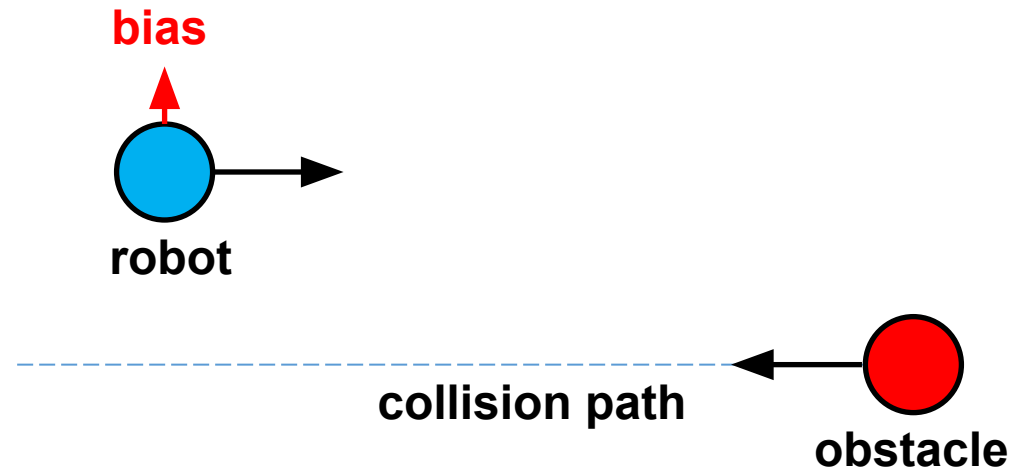
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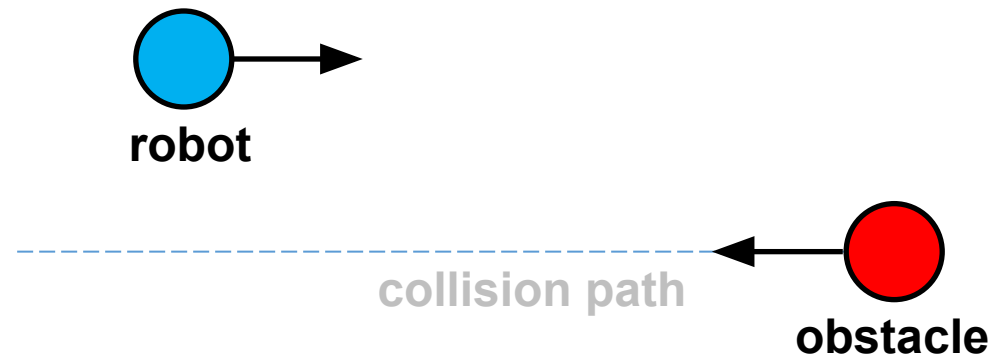
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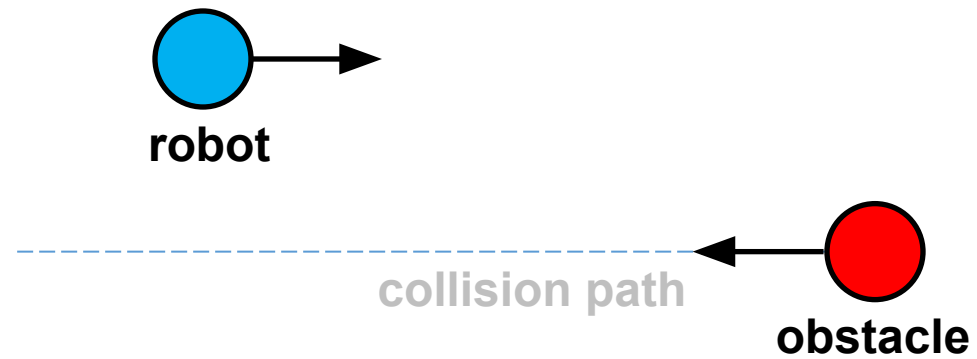
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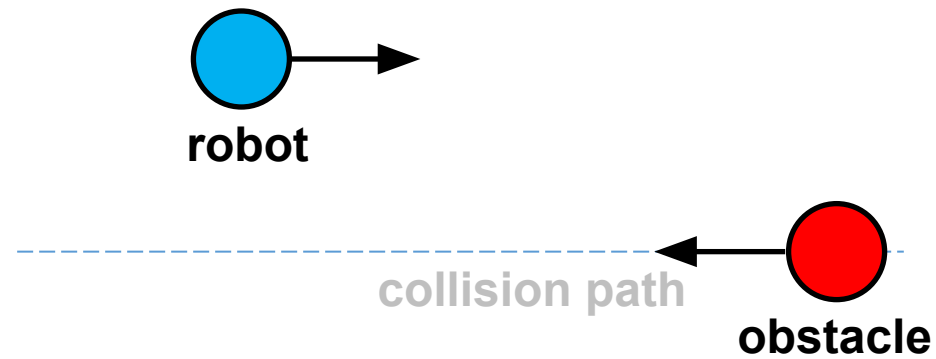
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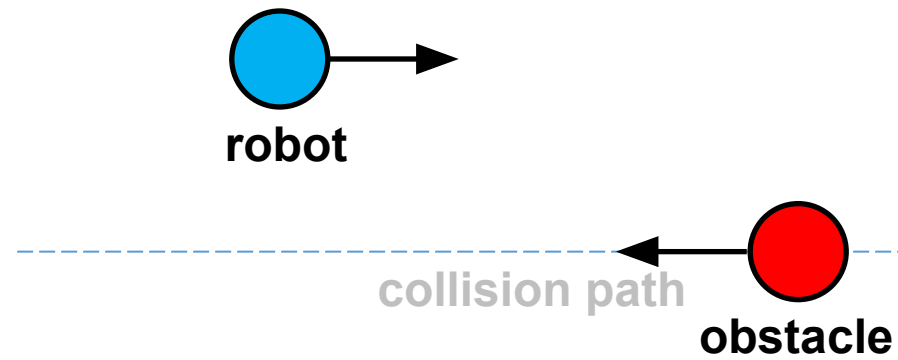
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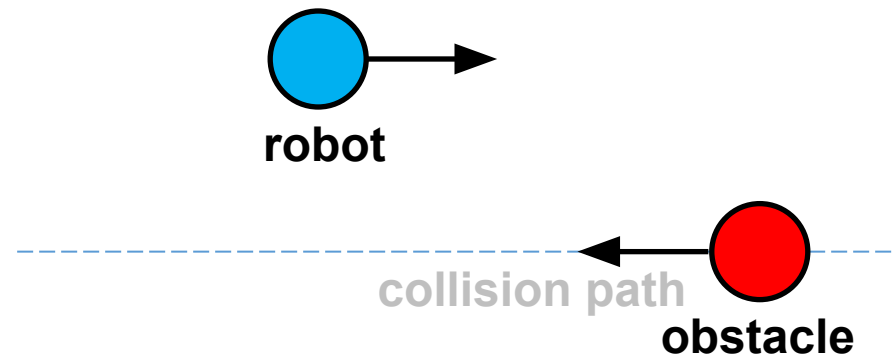
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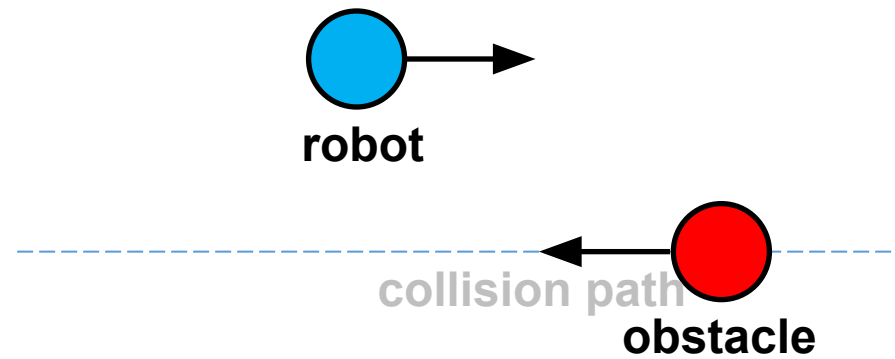
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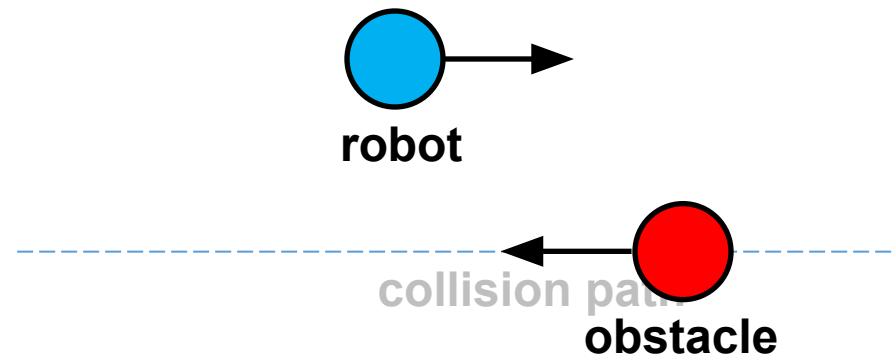
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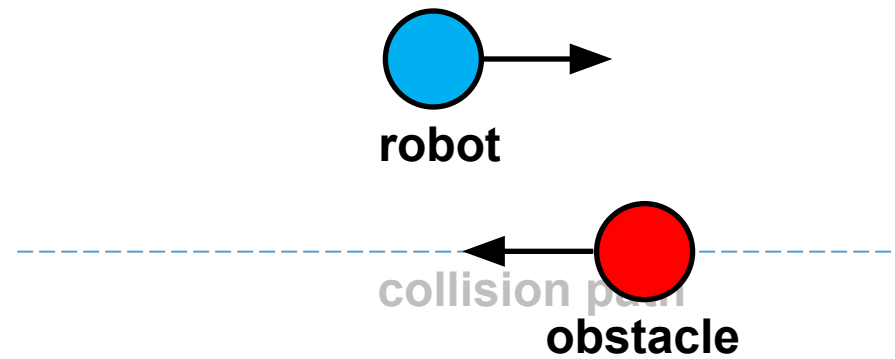
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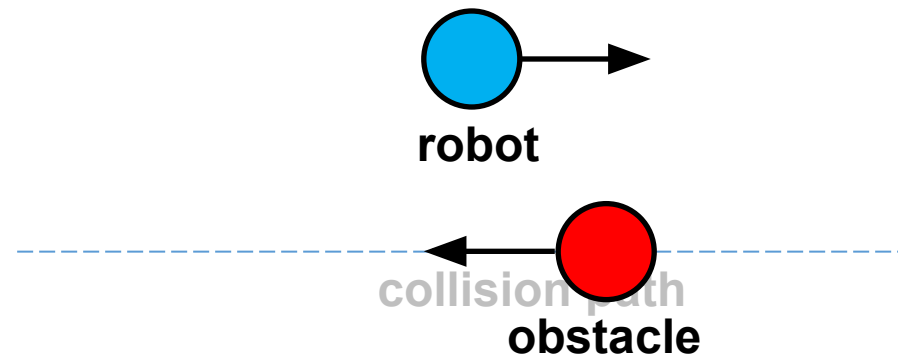
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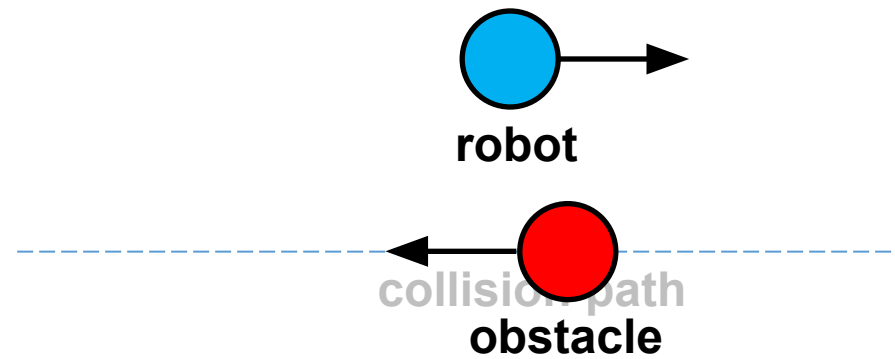
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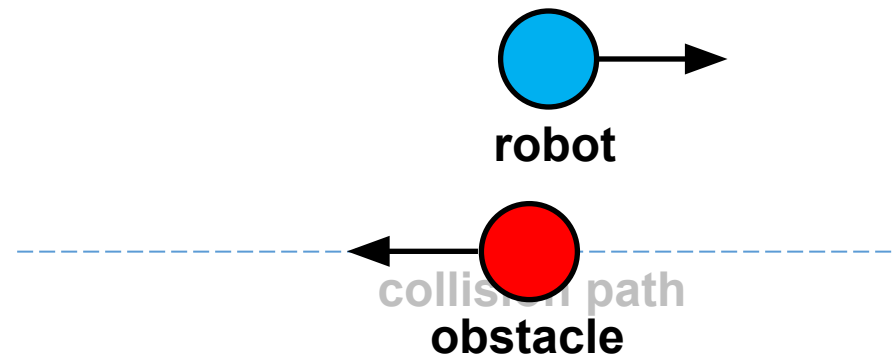
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Background



Background



Background

- **When an obstacle is designed to react and follow the robot to intentionally create a collision, the previous approach does not work!**
 - **RQ1: Can artificial bias be modified to avoid collision with heat seeking missile?**
 - **RQ2: Can an aircraft avoid more than one heat seeking missile?**
 - **RQ3: What are the limitations of an AI algorithm that avoids heat seeking missile?**



Methodology Development

- **Collision avoidance in jet fighter requires**
 - collision indicator
 - calculation of artificial bias force to push aircraft away from collision path
 - coexistence of AI control and human control



Methodology Development

- **Collision Indicator: a numerical value that indicates the likelihood of a collision**

$$\cos(\theta) = \frac{\Delta r(t) \bullet \dot{\Delta r}(t)}{\|\Delta r(t)\| \cdot \|\dot{\Delta r}(t)\|}$$

θ is the angle between the relative position vector and relative velocity vector:

$\theta = \pm 180^\circ \rightarrow$ imminent collision

$\theta = 0^\circ \rightarrow$ no collision



Methodology Development

- **Artificial Bias:** a modeling process that treats each missile as a source of artificial magnetic field that pushes a moving aircraft in the direction perpendicular to its velocity

$$\max_{\phi} \frac{\Delta r(t) \cdot [r_{\text{missile}}(t) - \mathfrak{R}(\phi) r_{\text{aircraft}}(t)]}{\|\Delta r(t)\| \cdot \|\dot{\Delta} r(t)\|}$$

s.t.

$$0 \leq \phi \leq$$

$$\phi_{\text{max}}$$



Methodology Development

- **Artificial Bias:** a modeling process that treats each missile as a source of artificial magnetic field that pushes a moving aircraft in the direction perpendicular to its velocity

$$\phi^* = \min \left\{ 180^\circ - \frac{\Delta r(t) \bullet \dot{\Delta} r(t)}{\|\Delta r(t)\| \cdot \|\dot{\Delta} r(t)\|}, \phi_{\max} \right\}$$



Methodology Development

- **Coexistence:** an AI algorithm should be only in an assisting mode as the last resort
 - pilots in combat situation prefer to control their aircraft instead of yielding to an AI algorithm when their lives are at stake
 - user's trust in an AI algorithm is difficult to establish



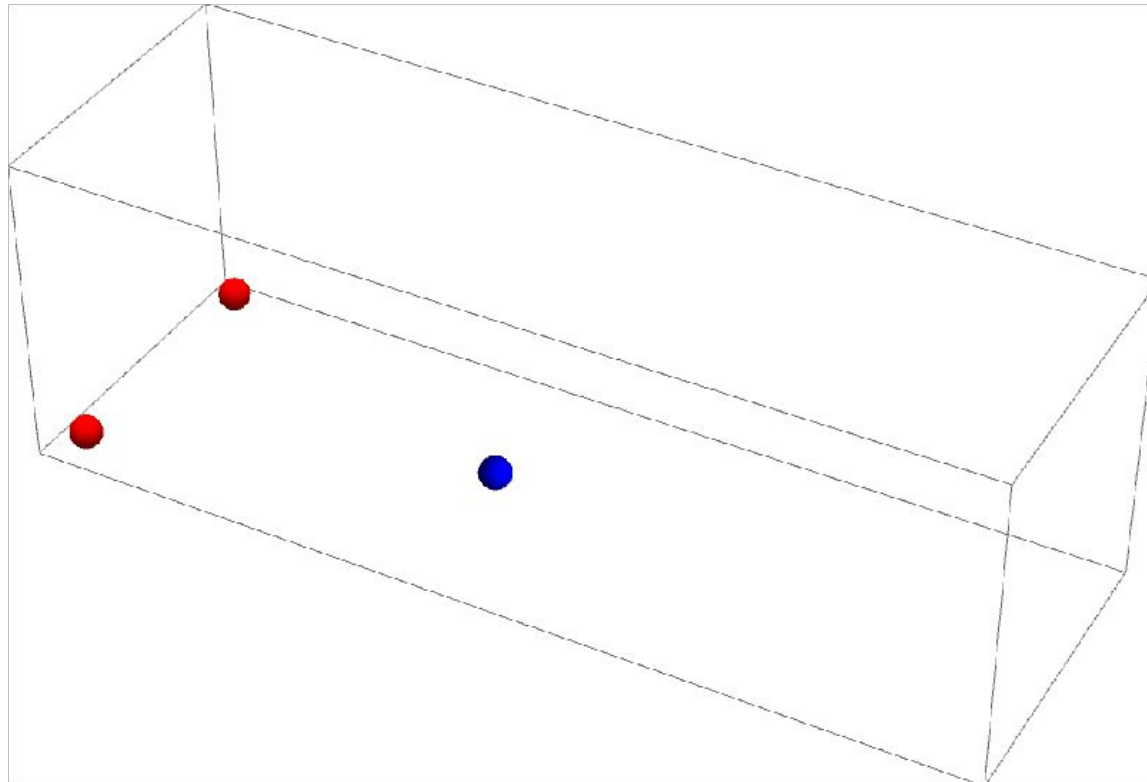
Numerical Simulations

- **Scenario 1: two air to air missiles attacking an aircraft at the same time**



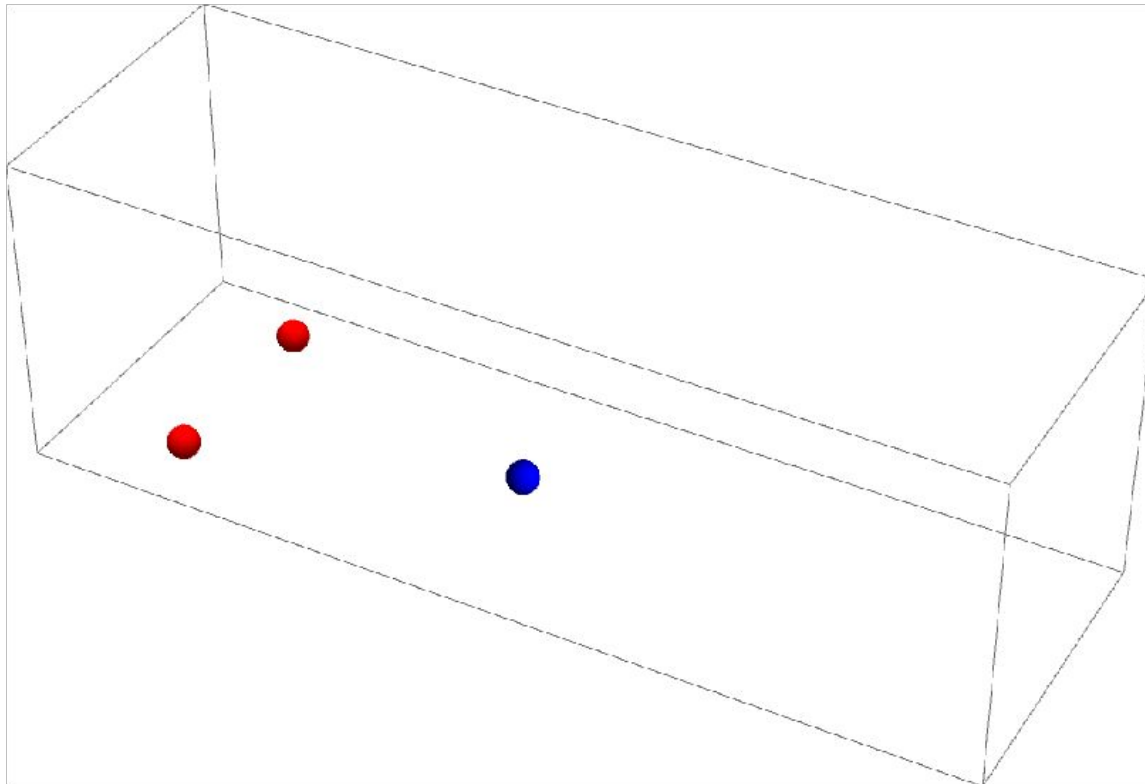
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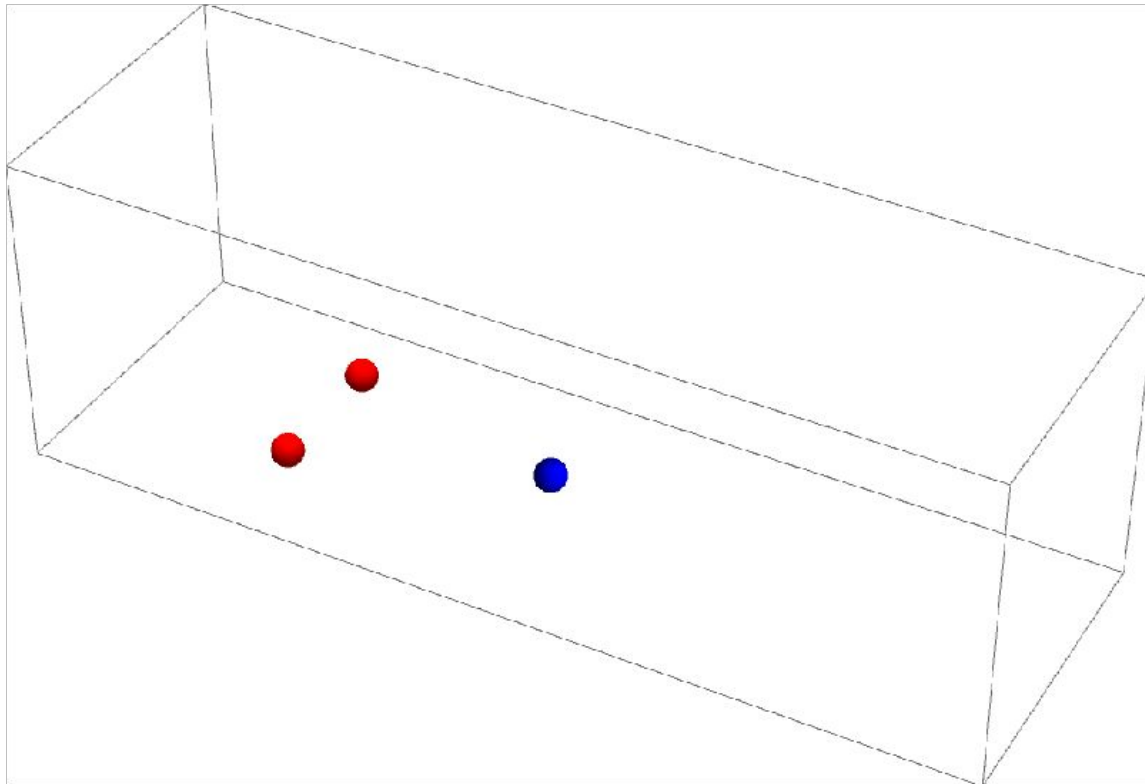
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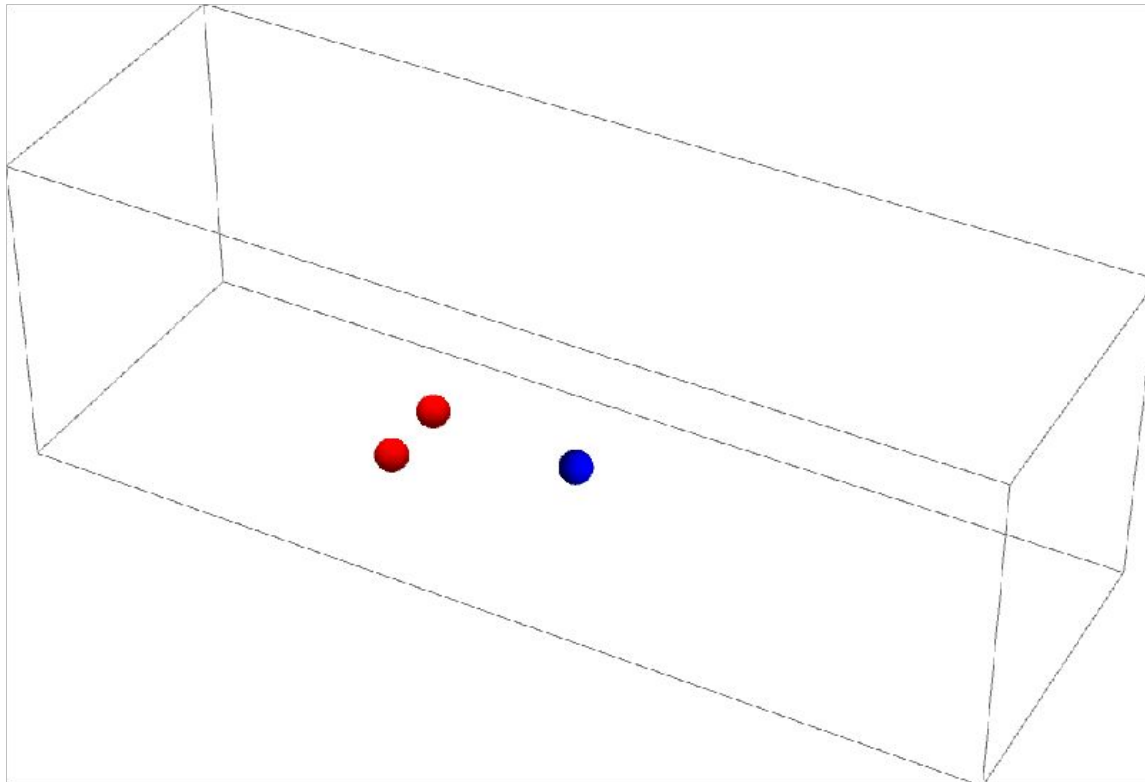
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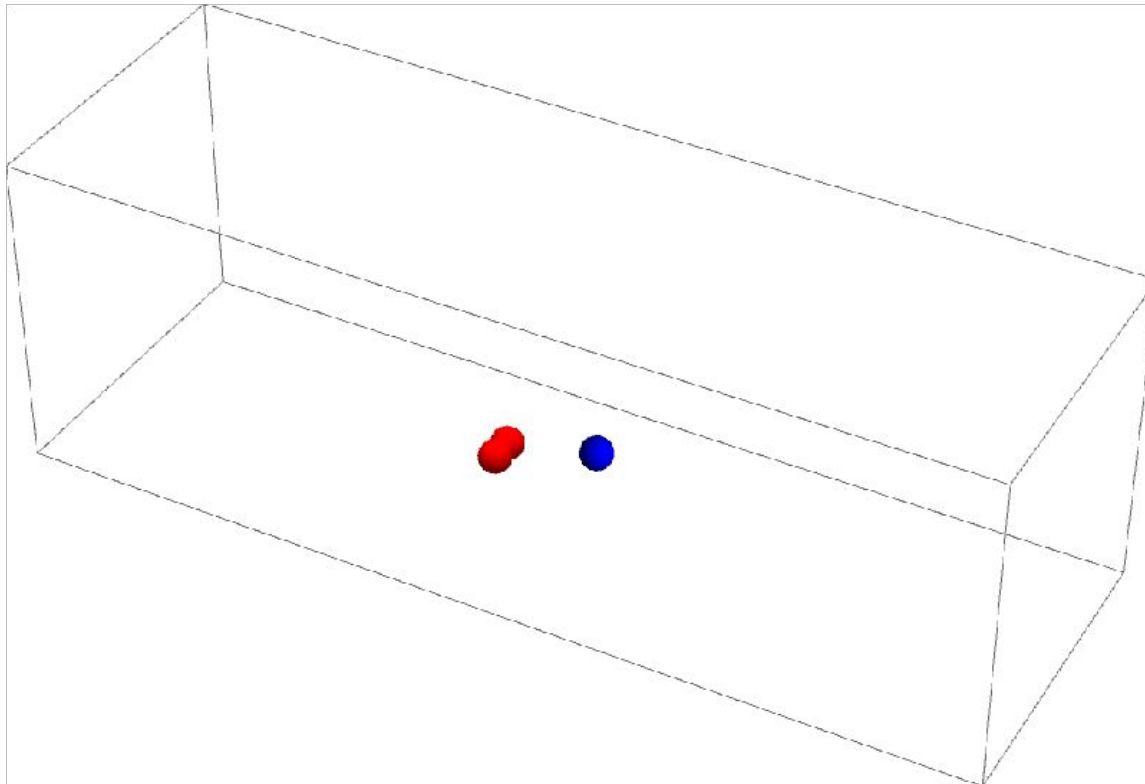
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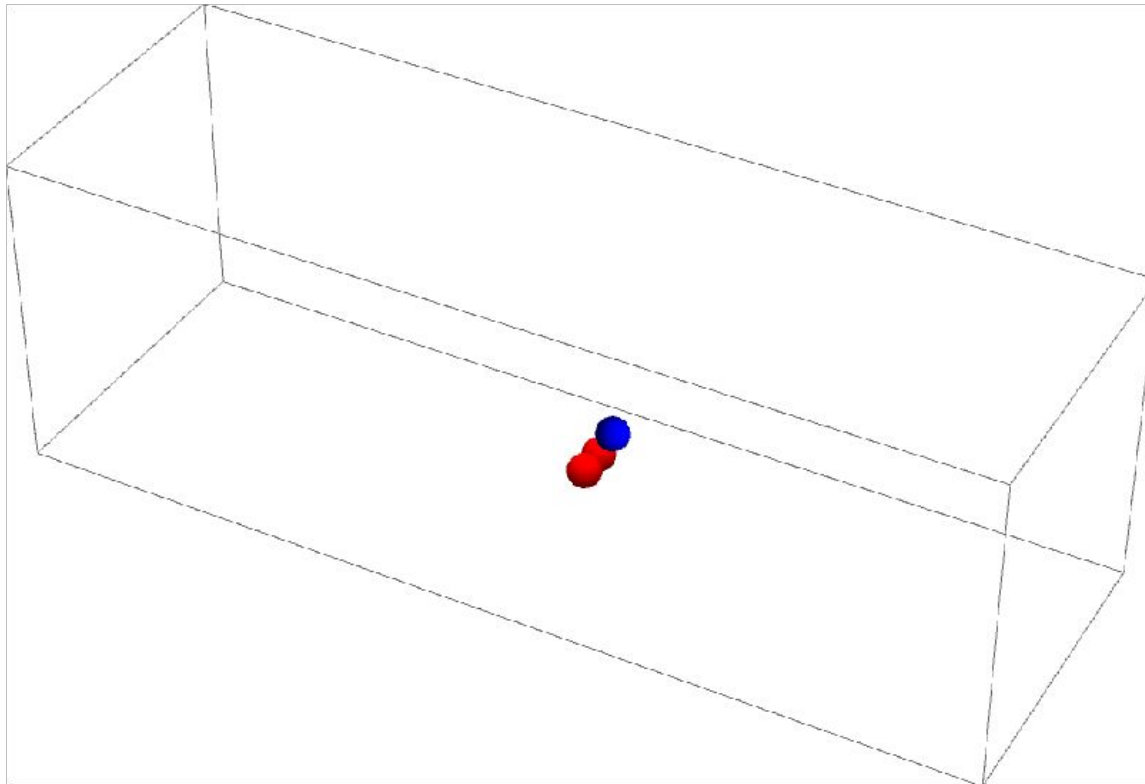
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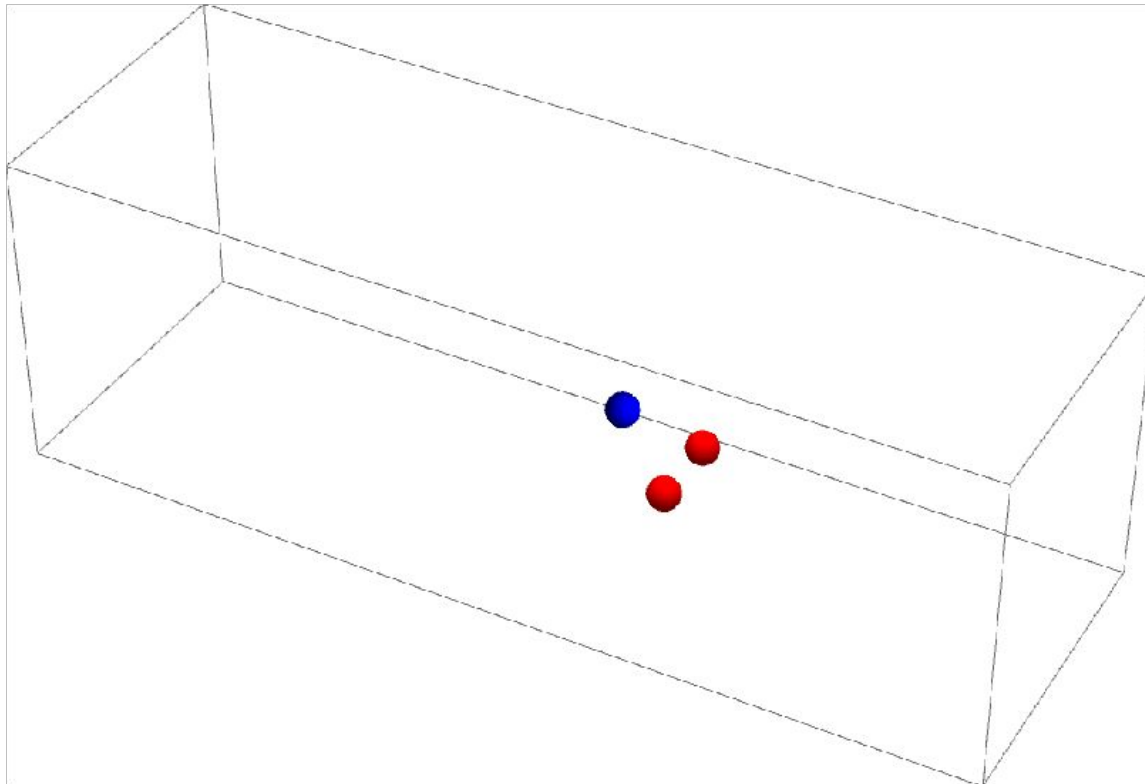


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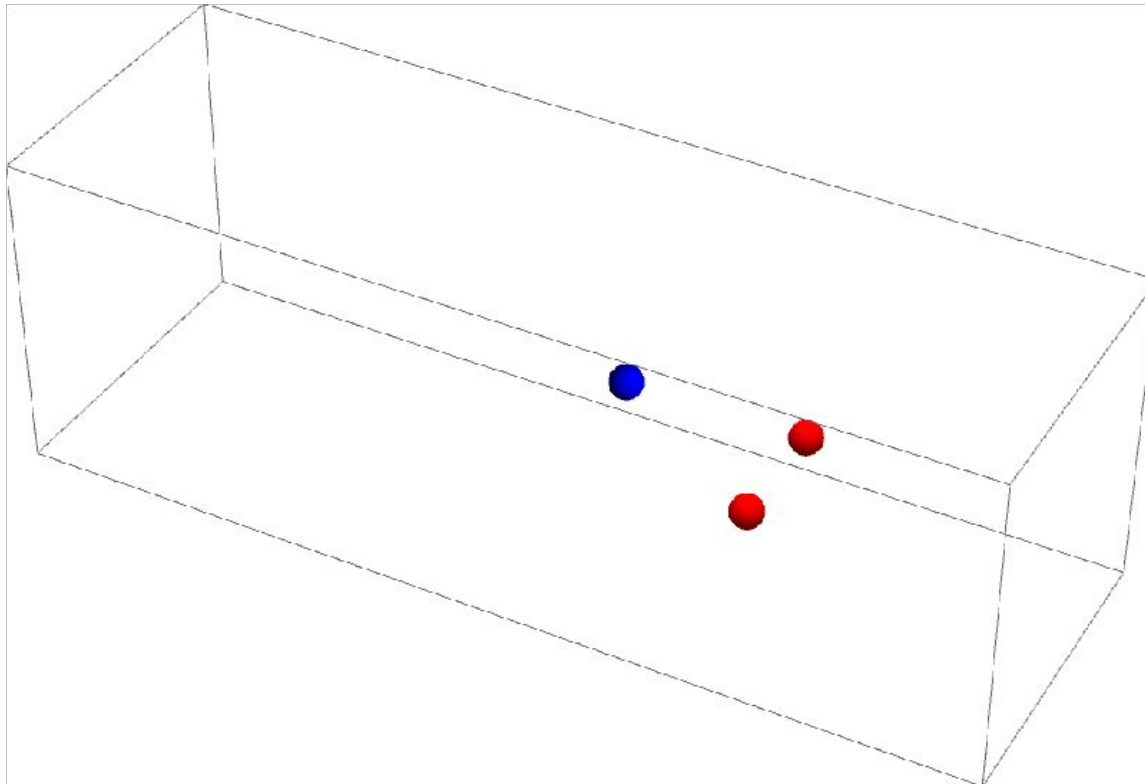
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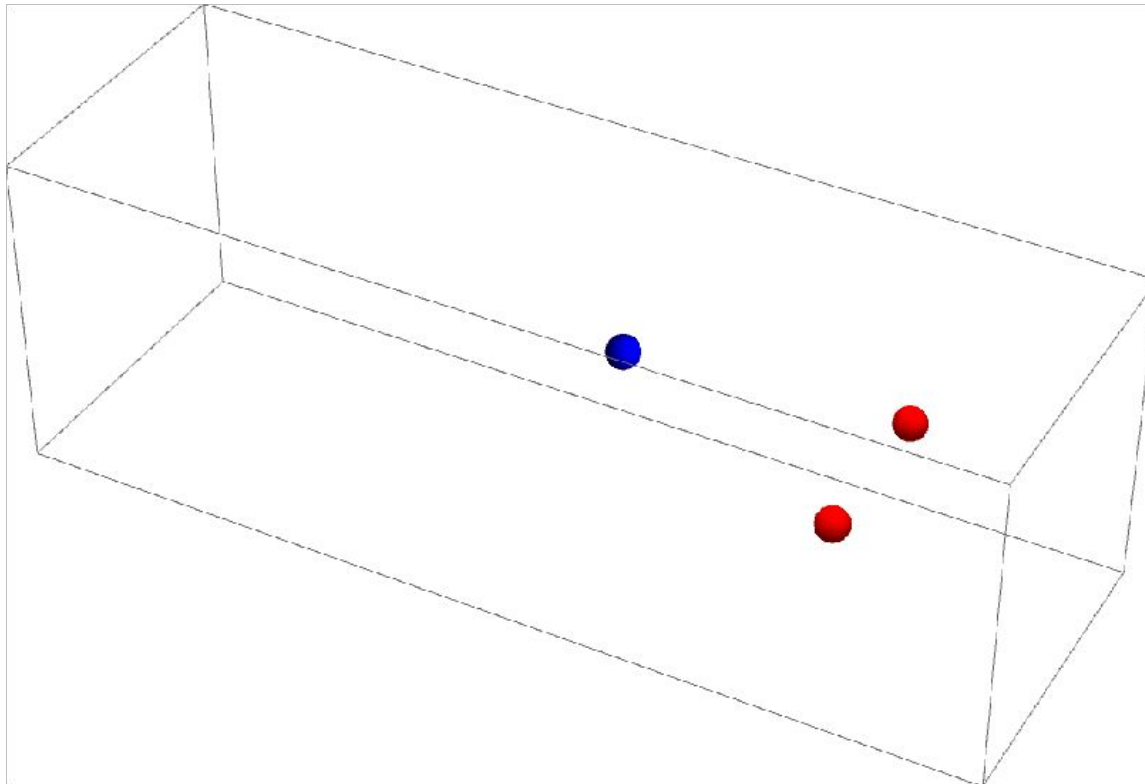
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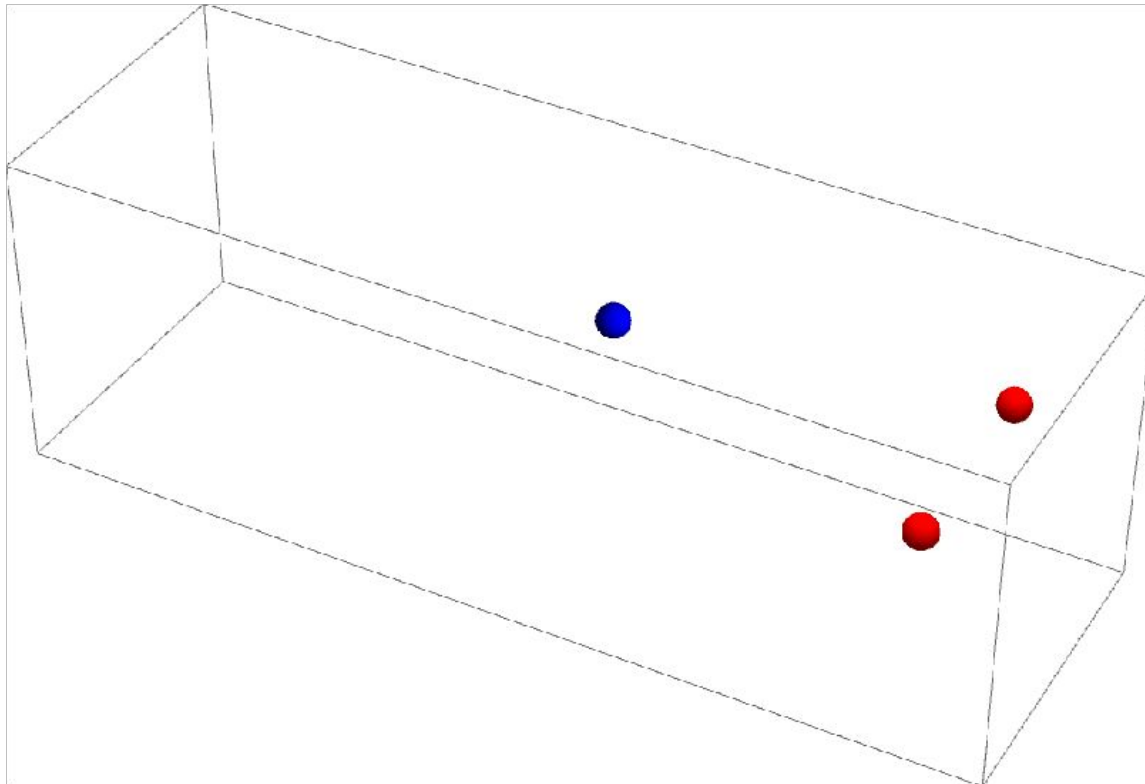
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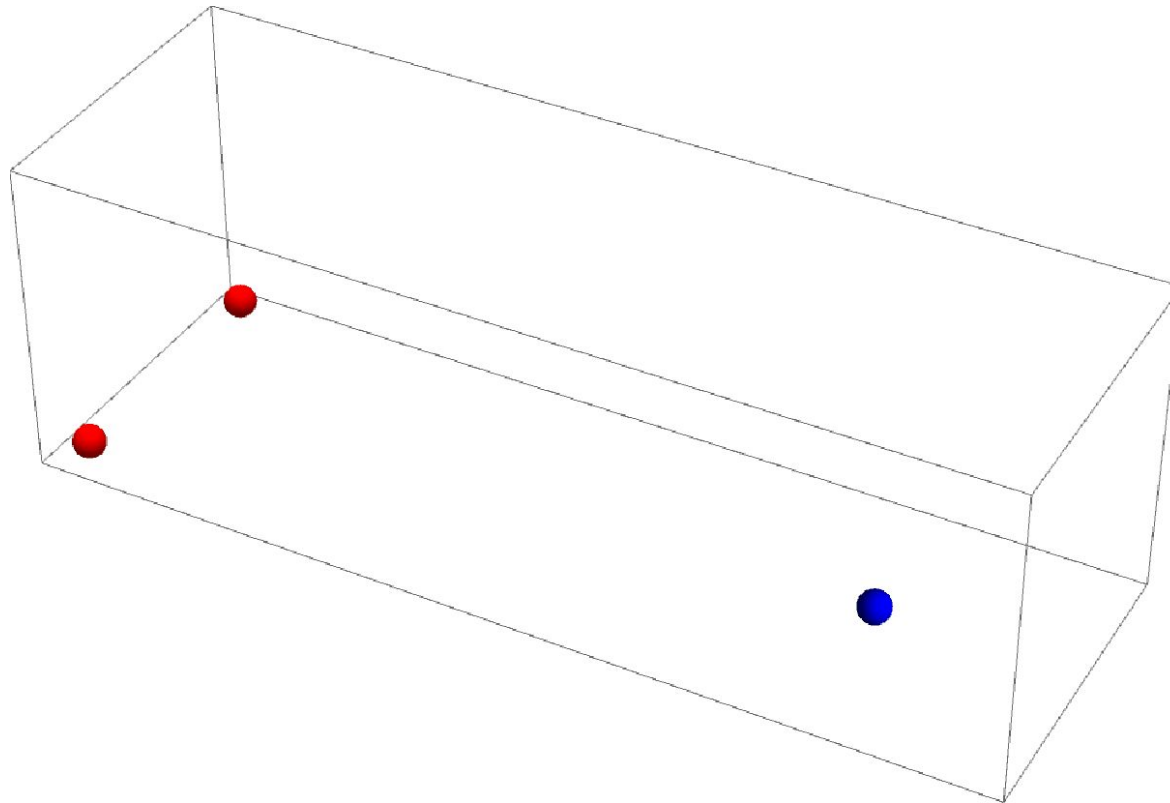
Numerical Simulations

- **Scenario 2: two surface to air missiles attacking an aircraft at the same time**



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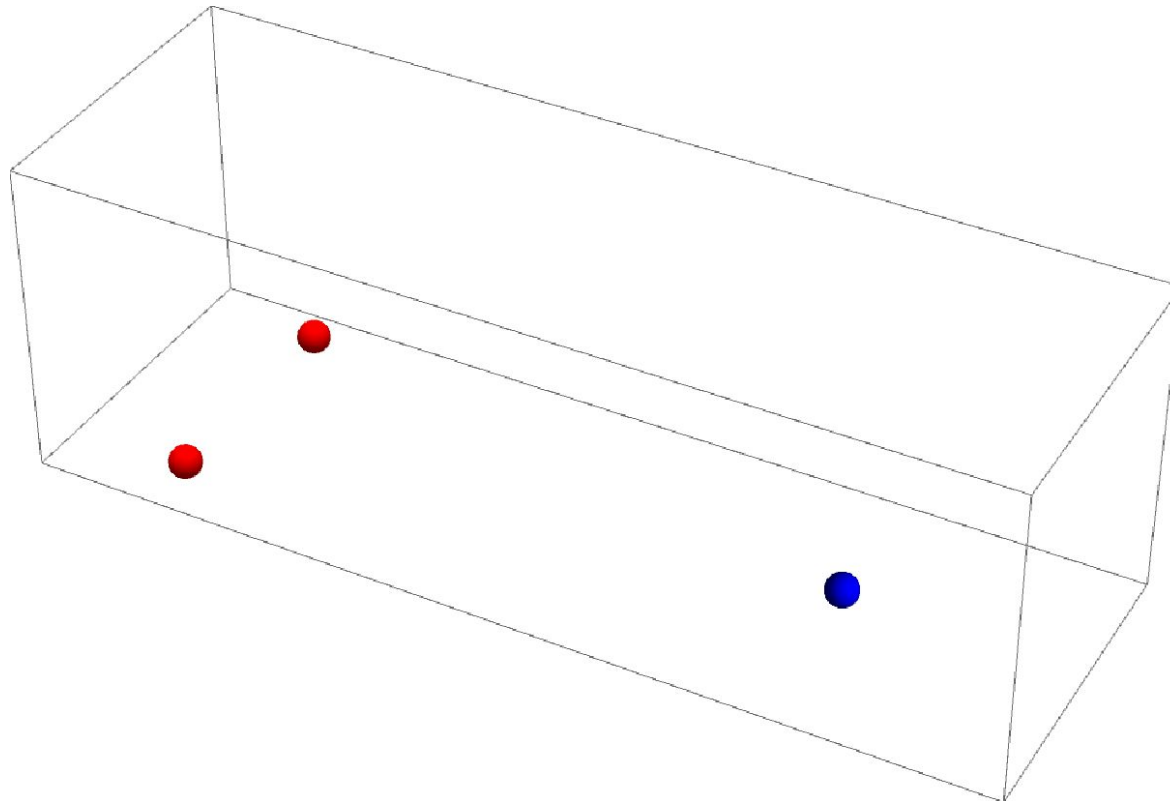


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Numerical Simulations

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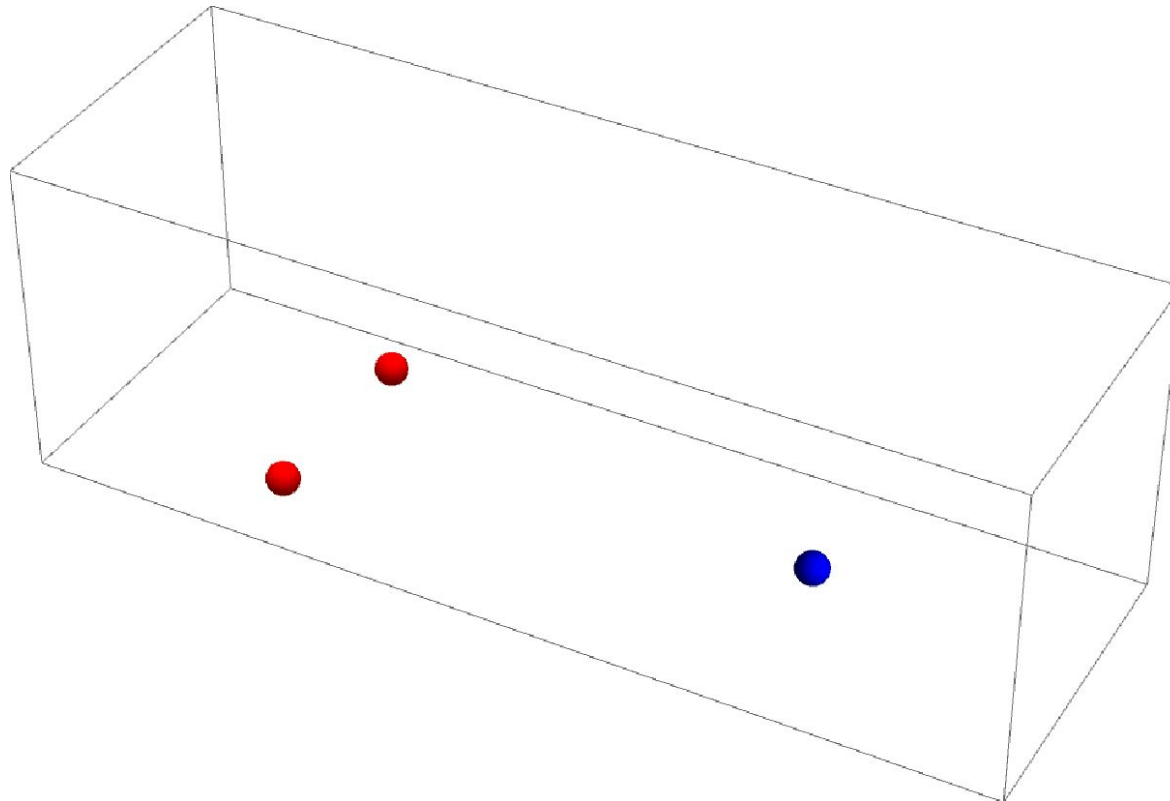


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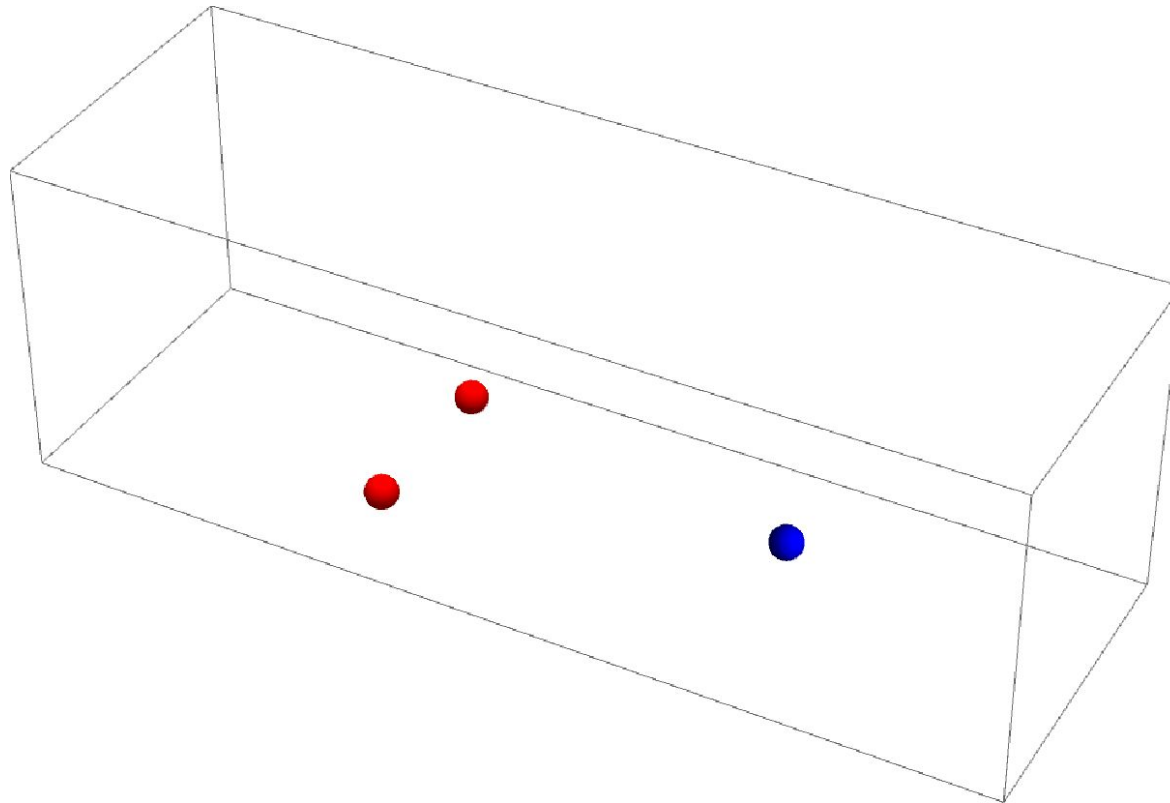


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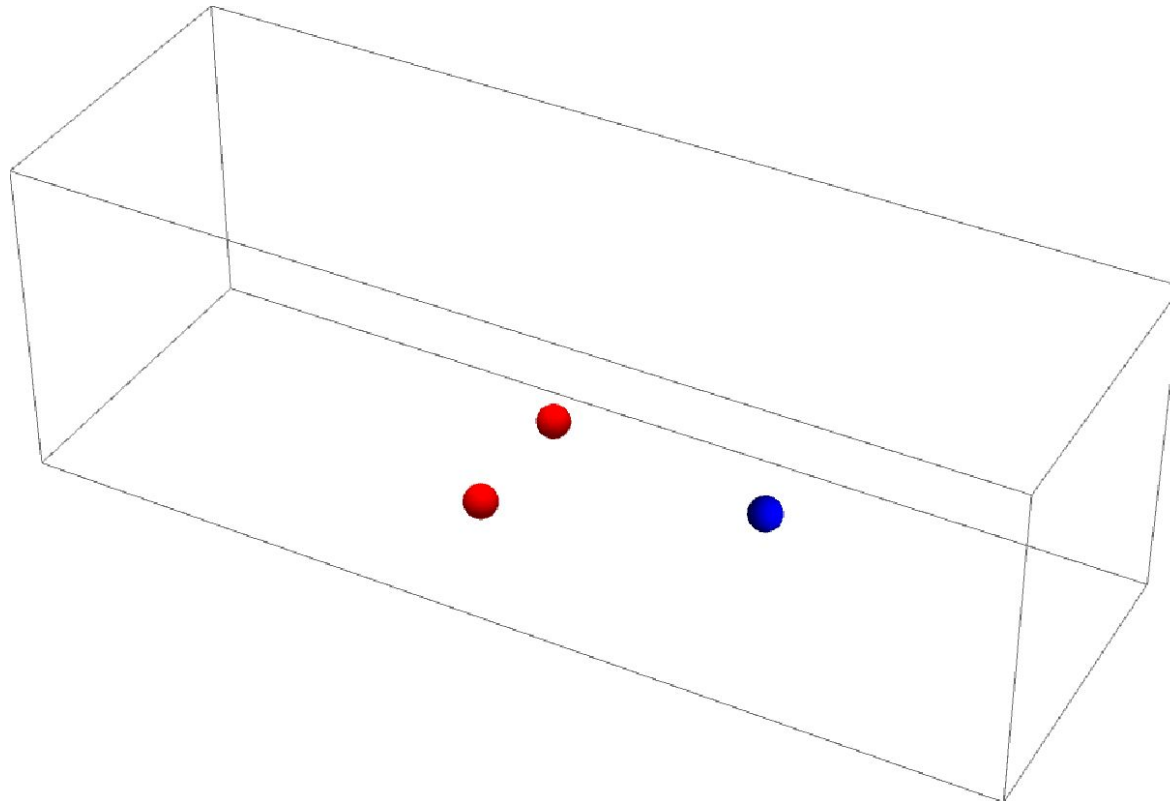
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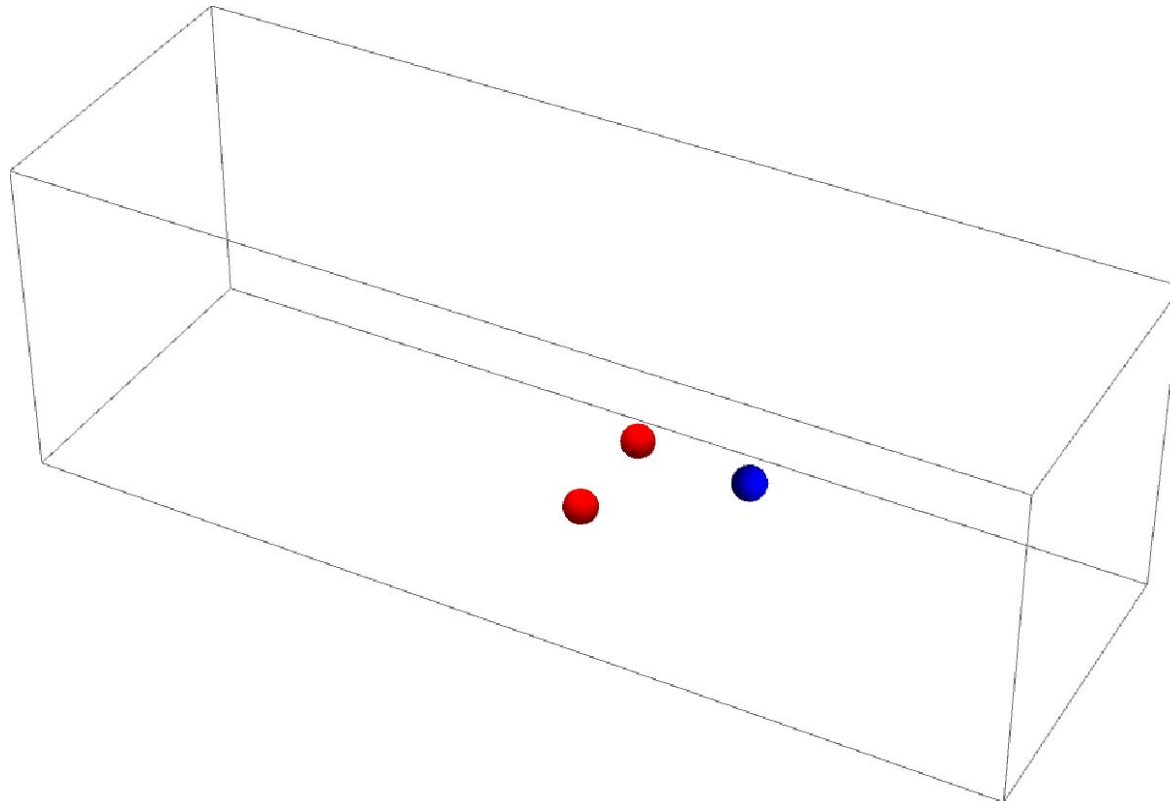


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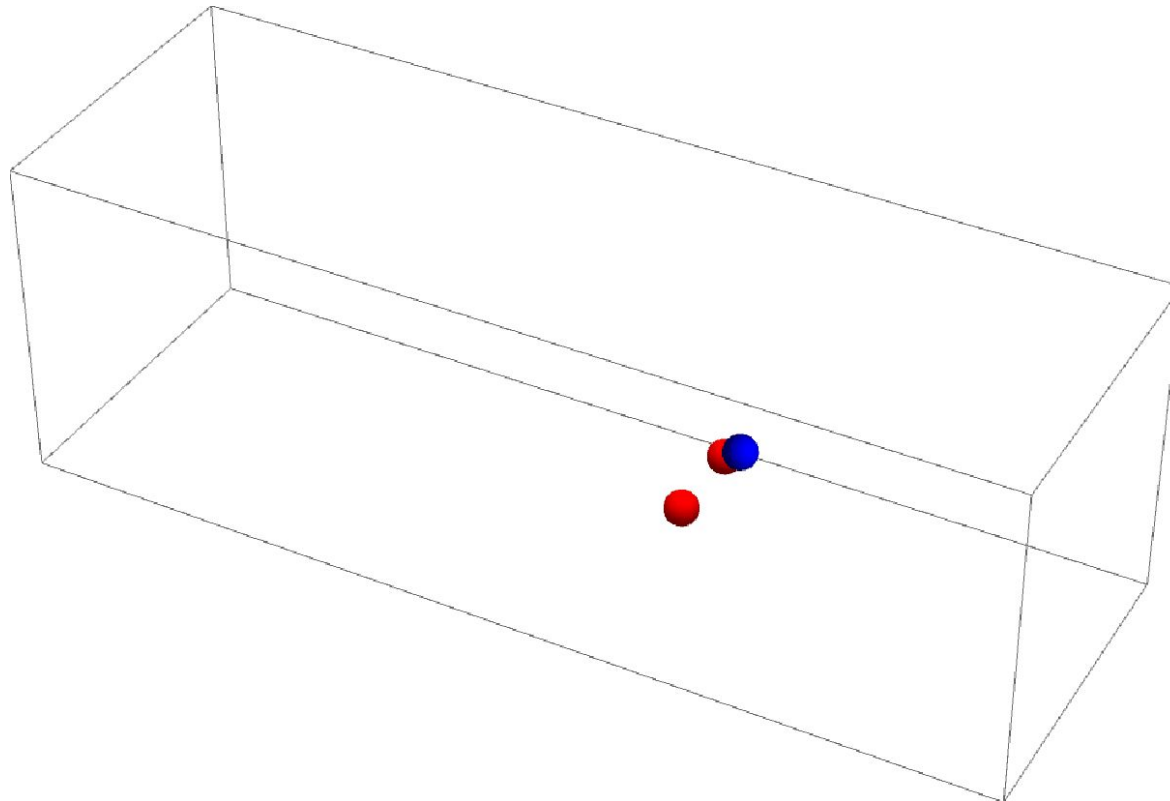
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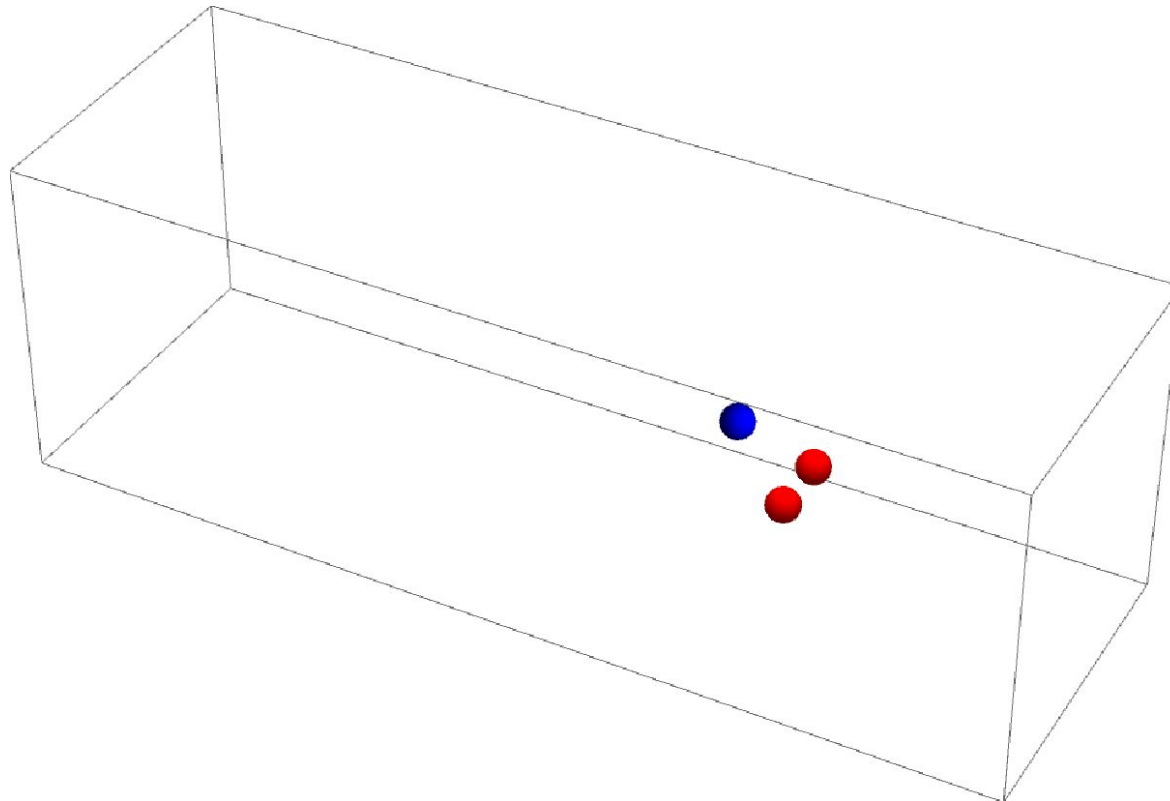


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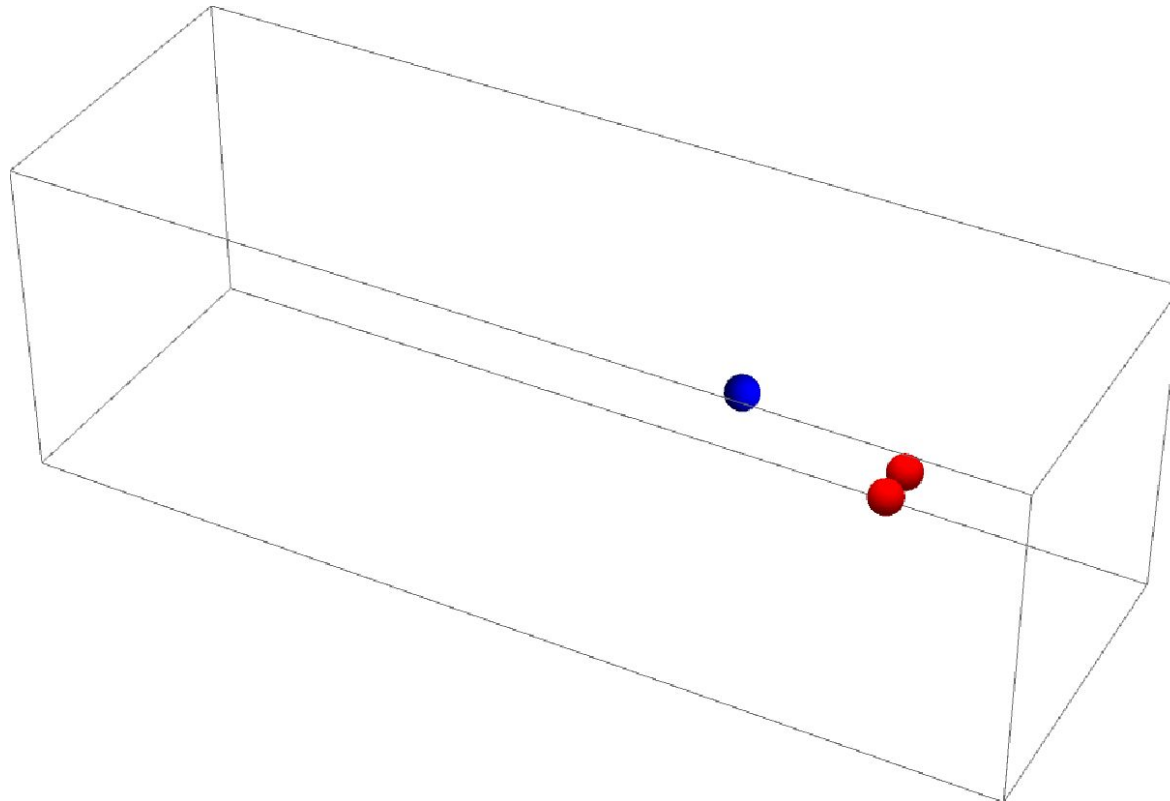


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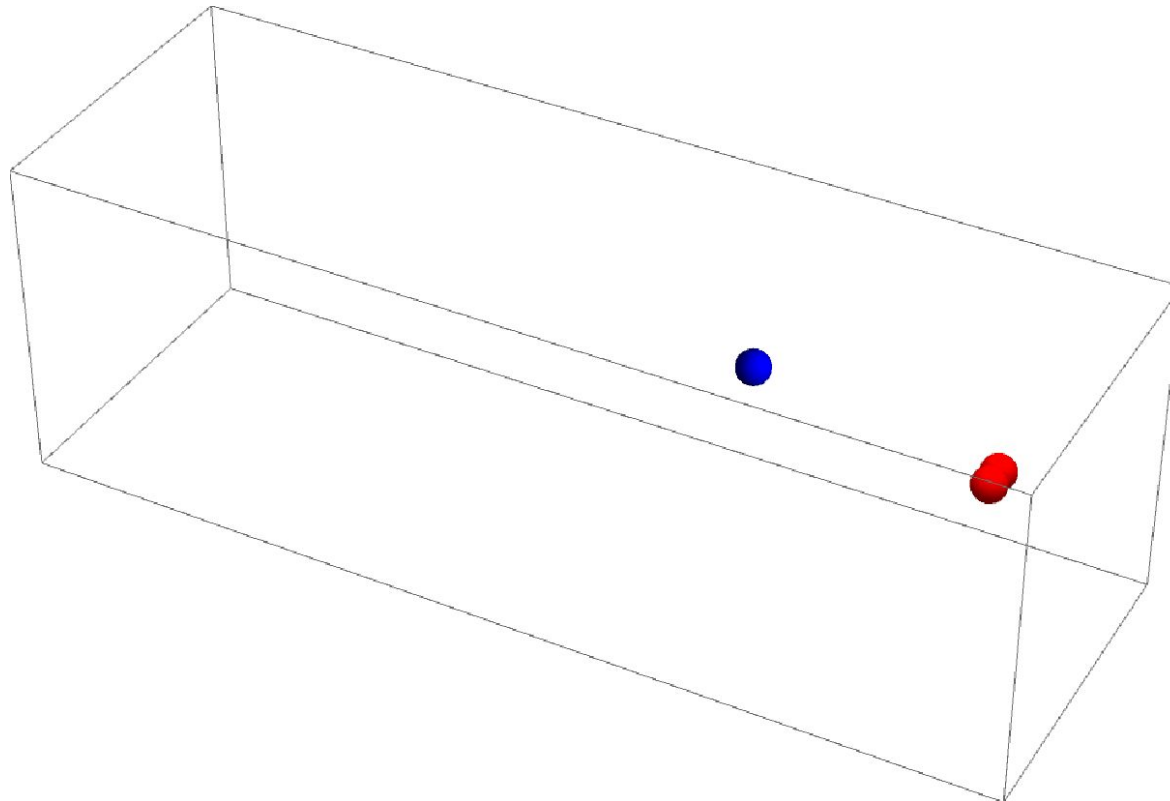
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Numerical Simulations

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Discussion

- **No matter how effective the avoidance algorithm is, pilots always prefer putting their lives in their control, not yielding the aircraft to an algorithm**
 - **implementation: the algorithm is used as the last resort when human reaction cannot escape the heat seeking missile**
 - **future direction: formulate the threshold of imminent collision for human reaction time to determine when to activate the algorithm**



Future Direction

- **In asymmetric warfare, when one side is gaining a tactical advantage the other side will work to neutralize it**
 - **missile attack: to coordinate many missiles to attack a target in fashion similar to that of a pack of animals hunting its prey**
 - **missile avoidance (again): to figure out how to out smart a coordinated attack by many missiles**
 - **missile attack: to increase maneuverability and range of missiles**
 - **missile avoidance (again):**
 - **life cycle of missile attack missile avoidance continues forever**



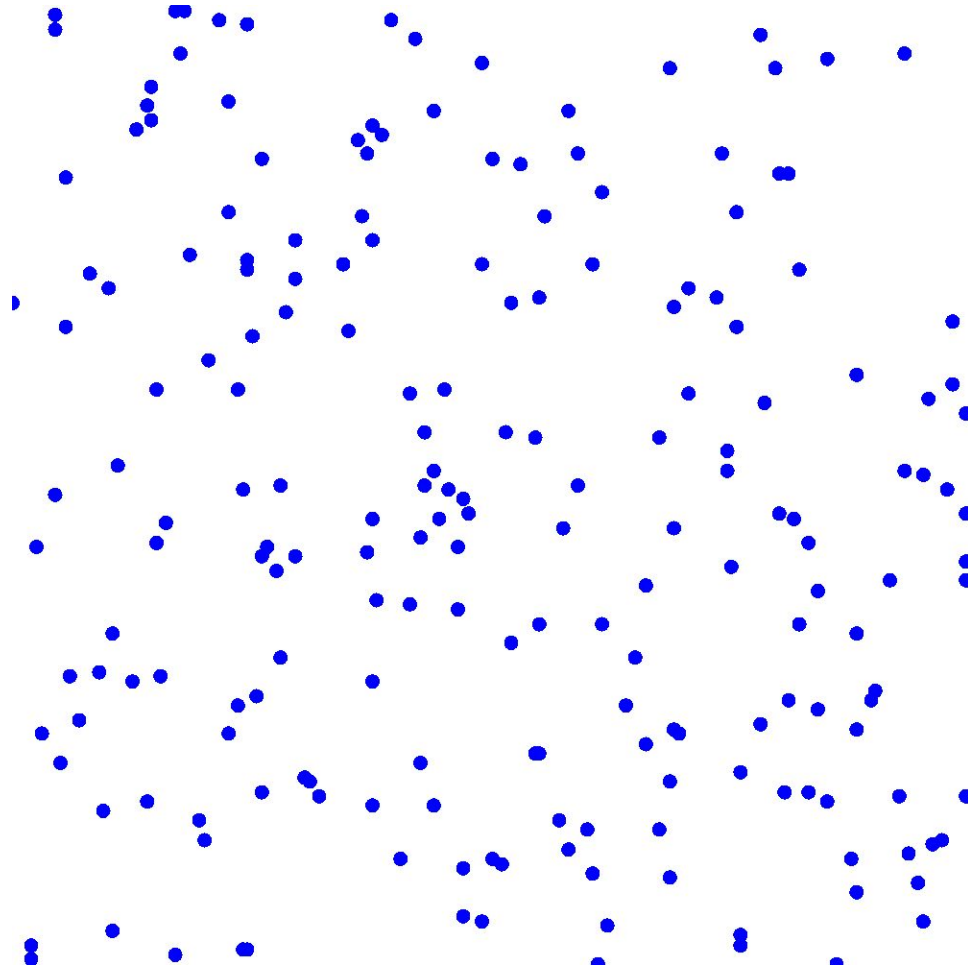
Future Direction

- **Using swarm intelligence to coordinate many missiles to attack**
 - **forming an attacking envelope to trap an aircraft inside instead of aiming at the aircraft directly**
 - **coordinating missiles to cover the area where the aircraft might out-manuever one missile**



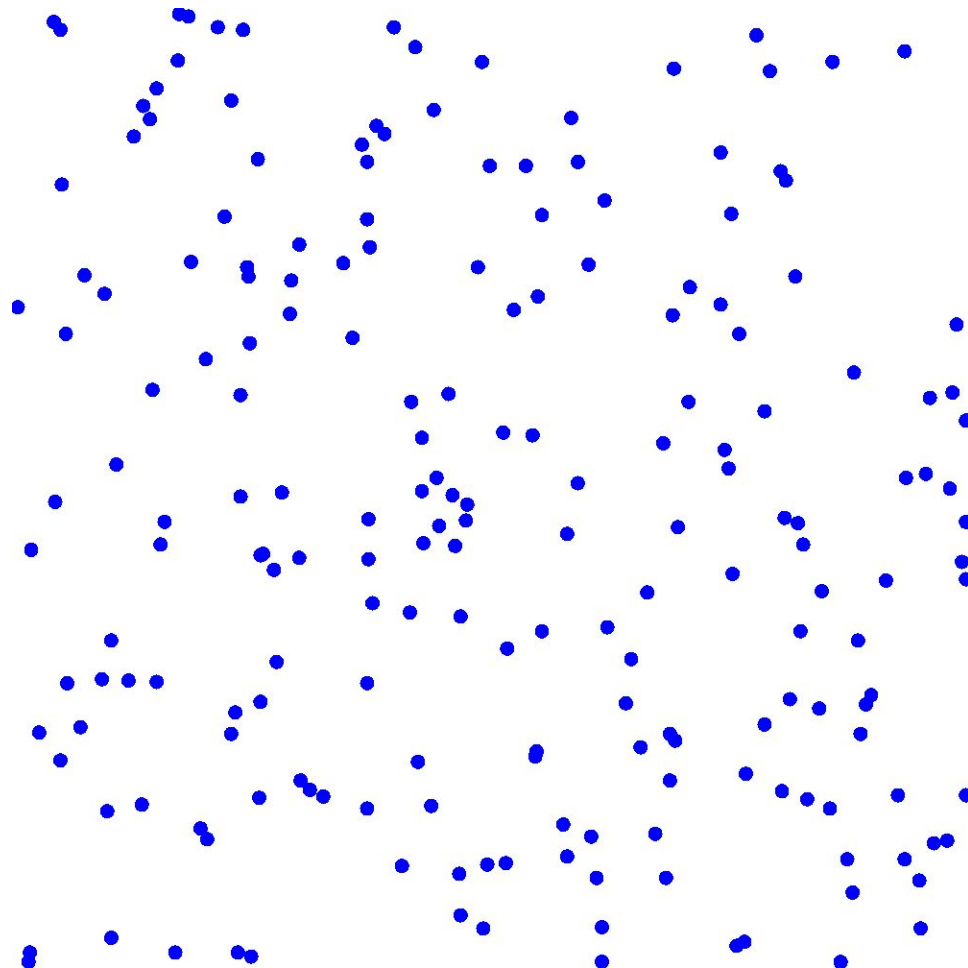
Future Direction

- Brief introduction to swarm intelligence



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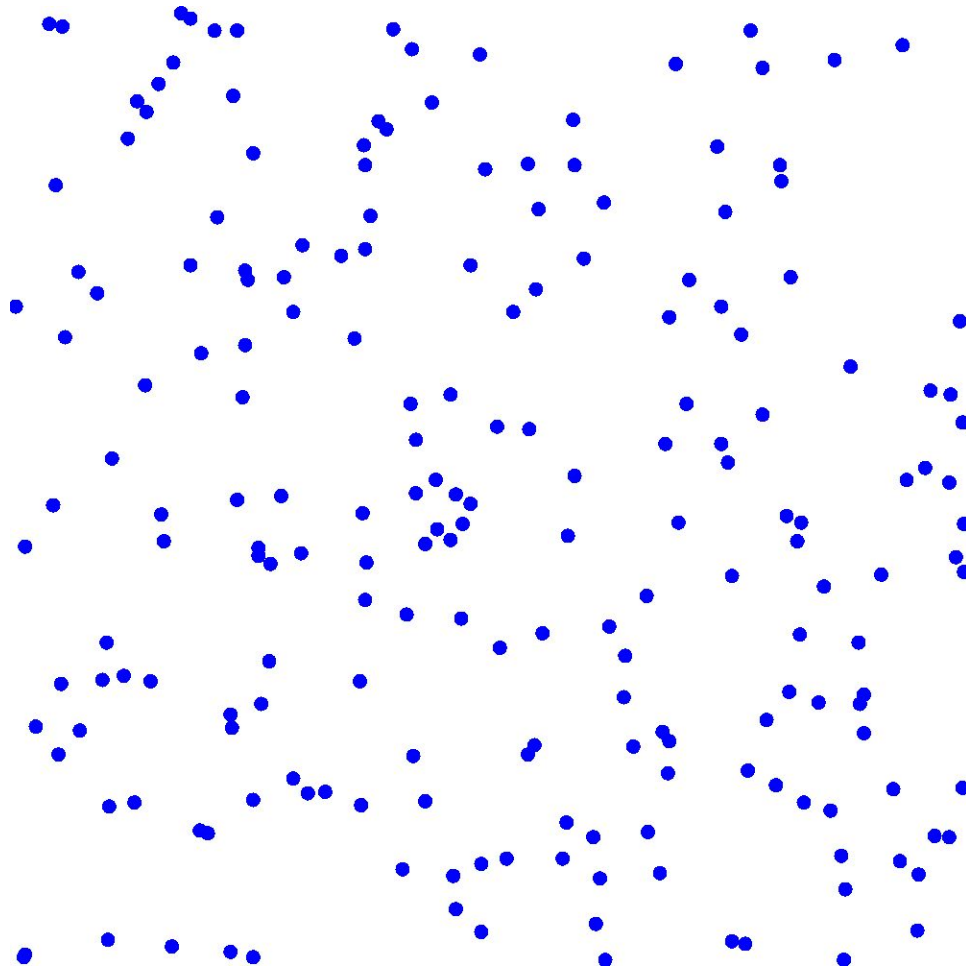


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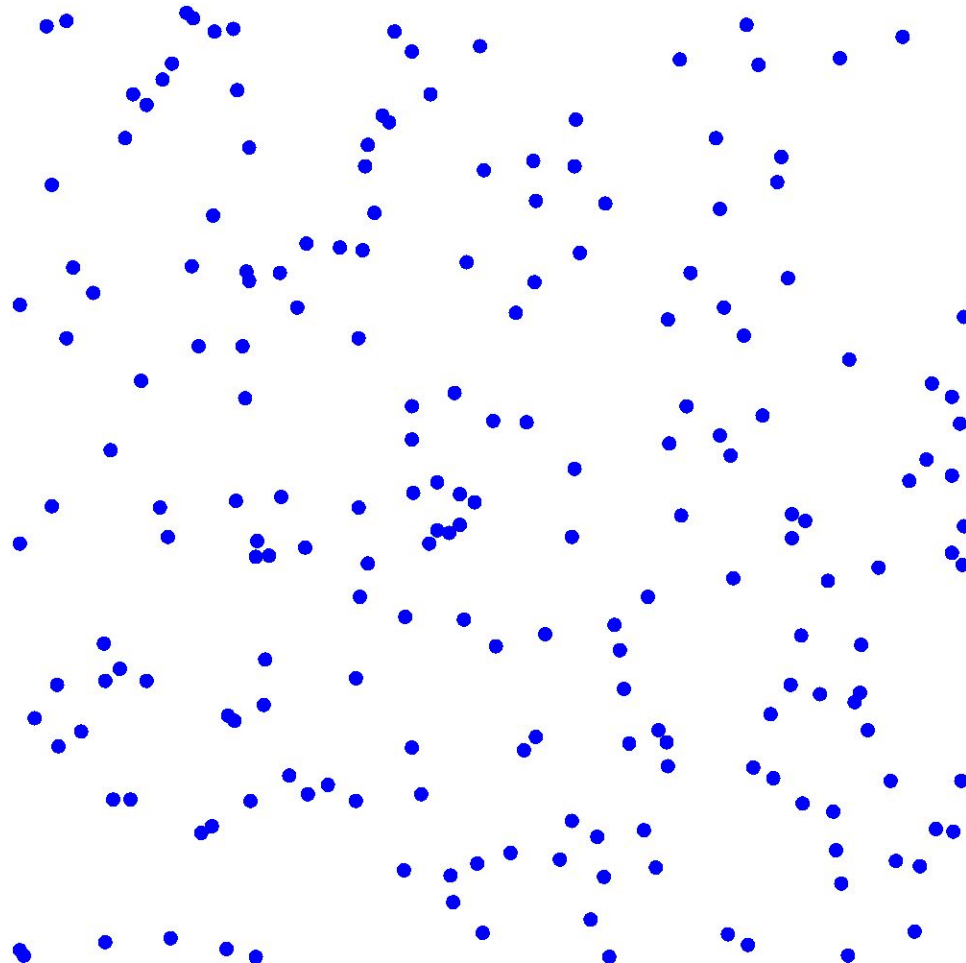


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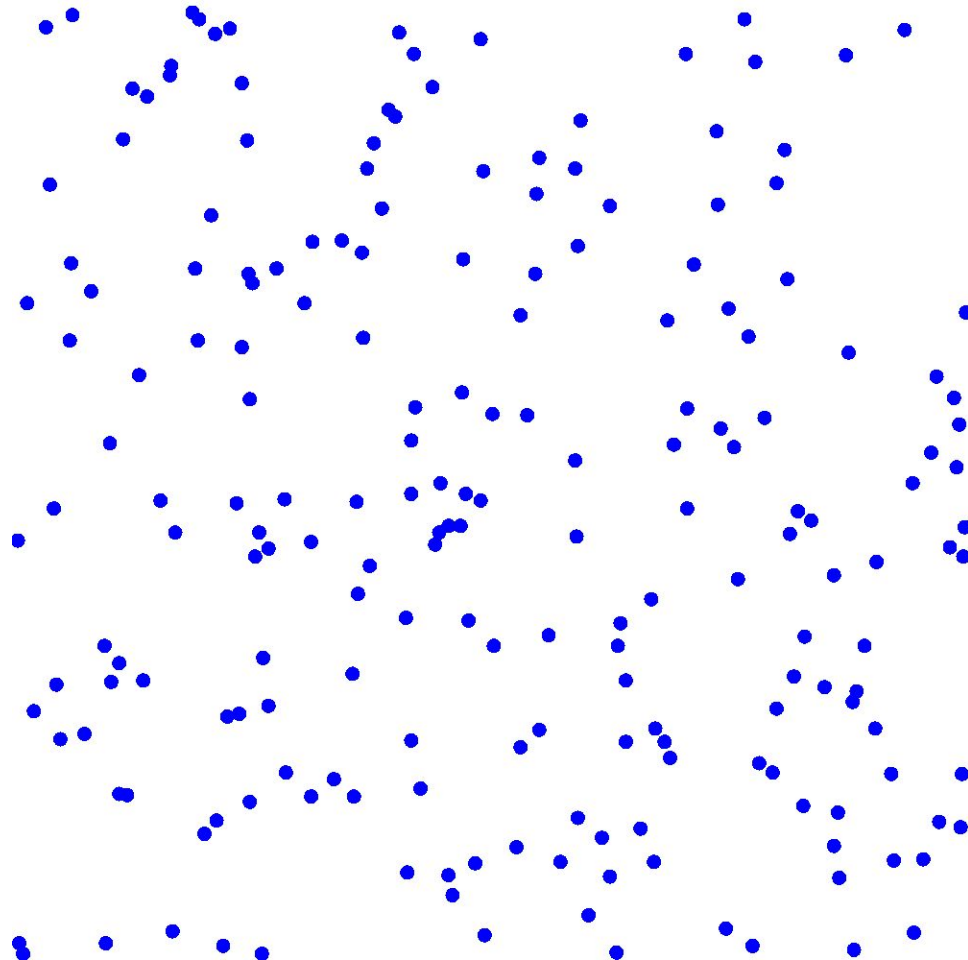


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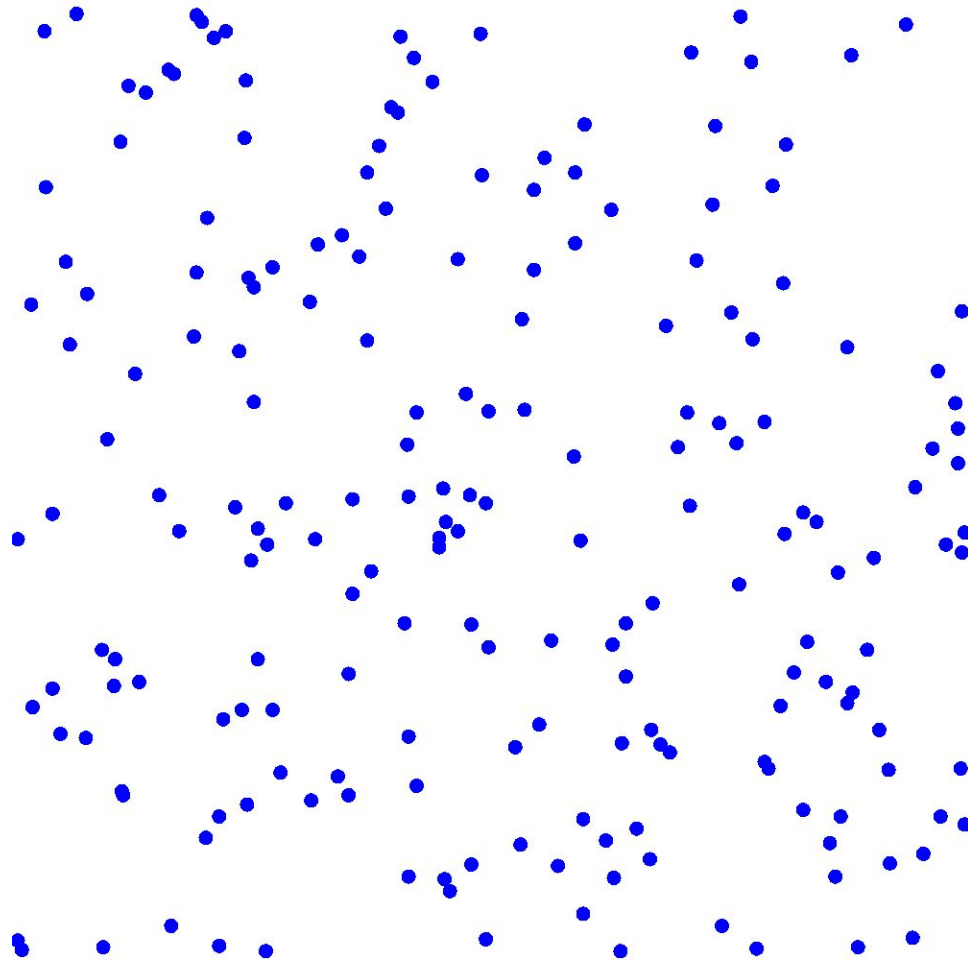


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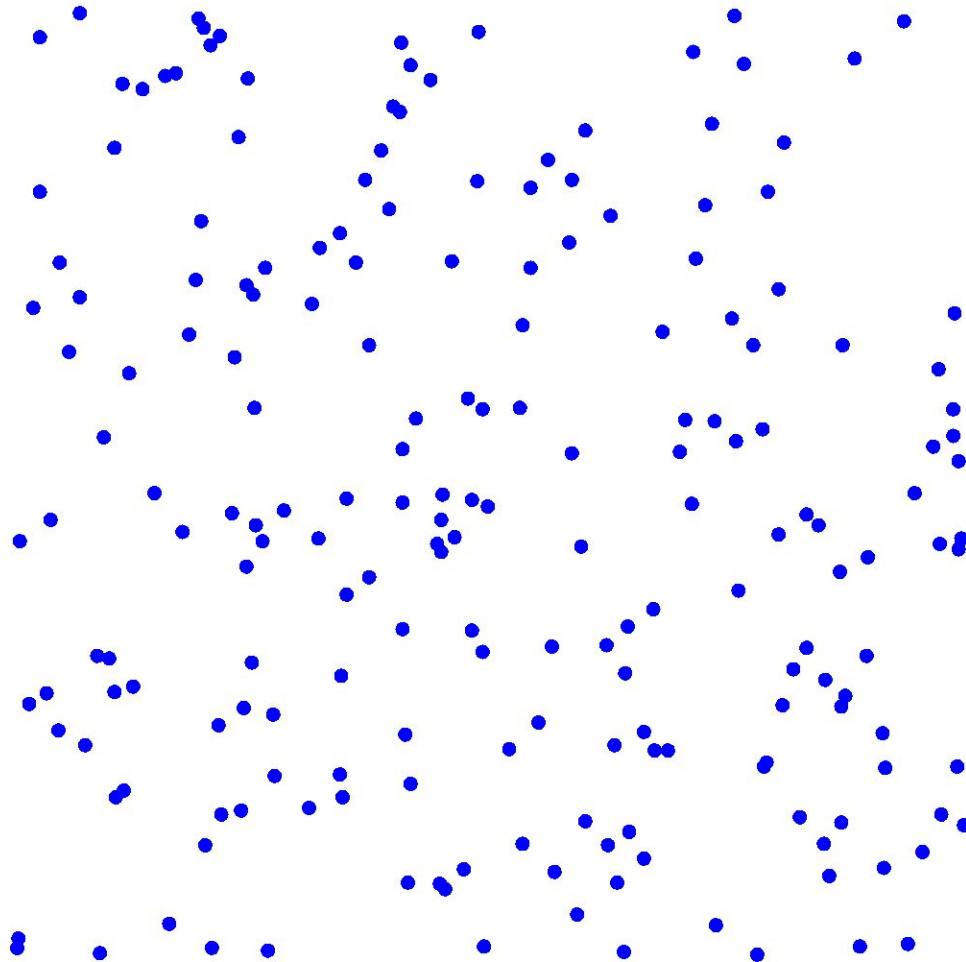
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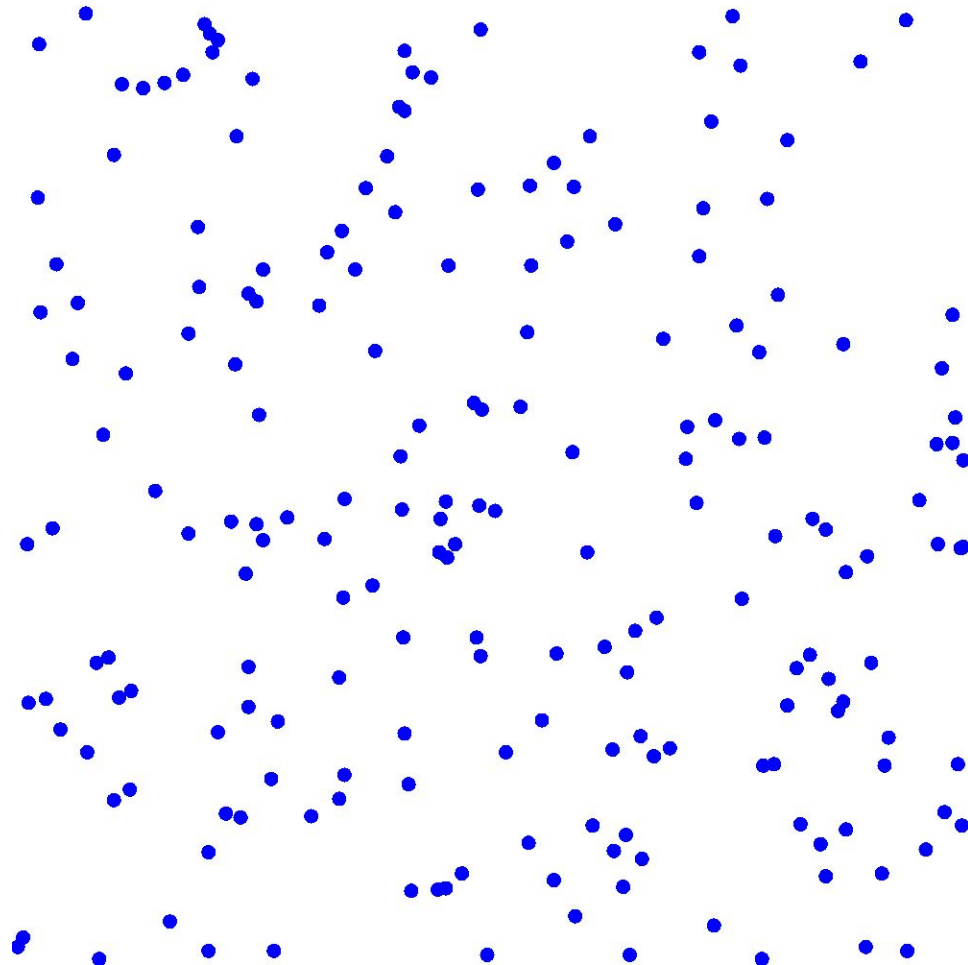
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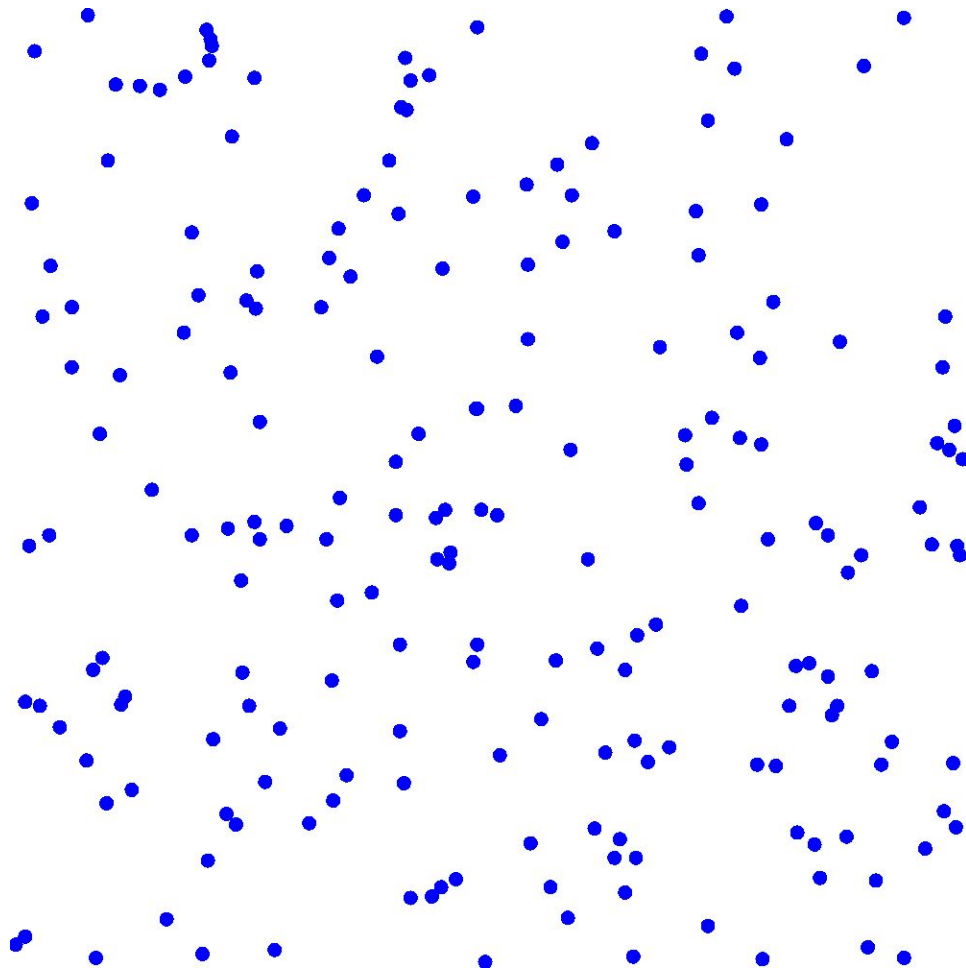


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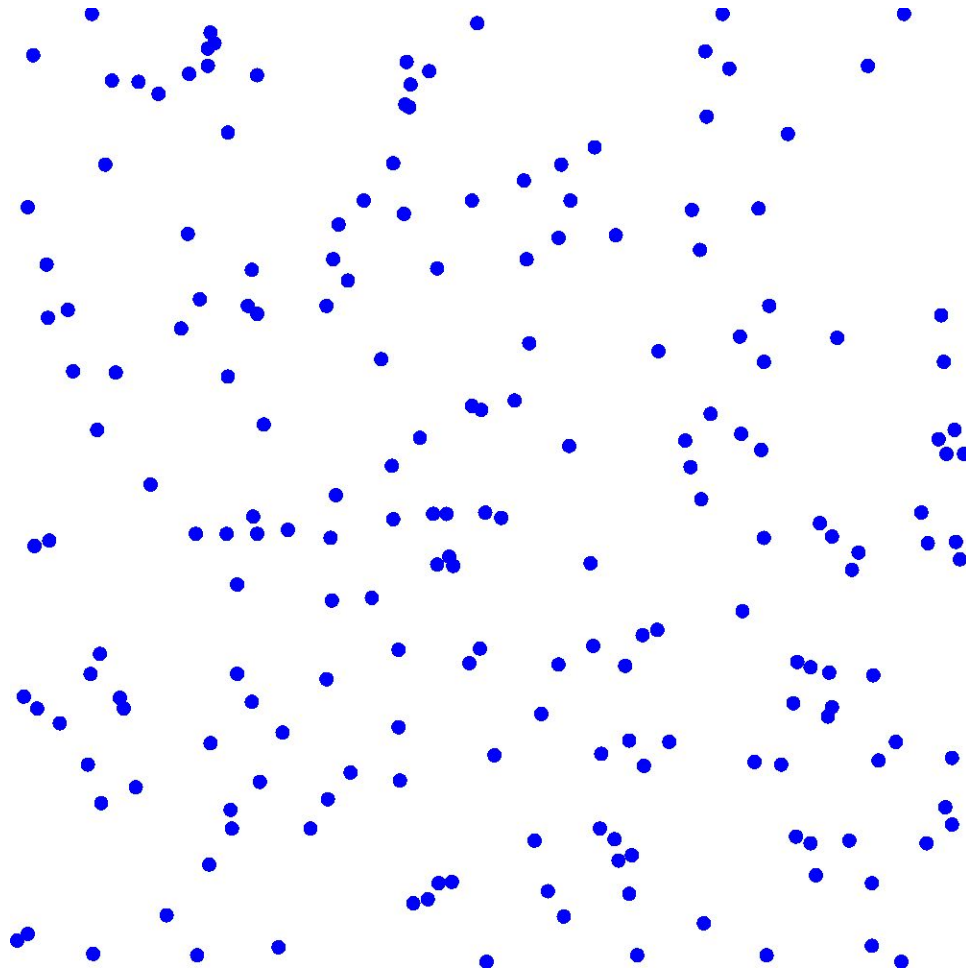
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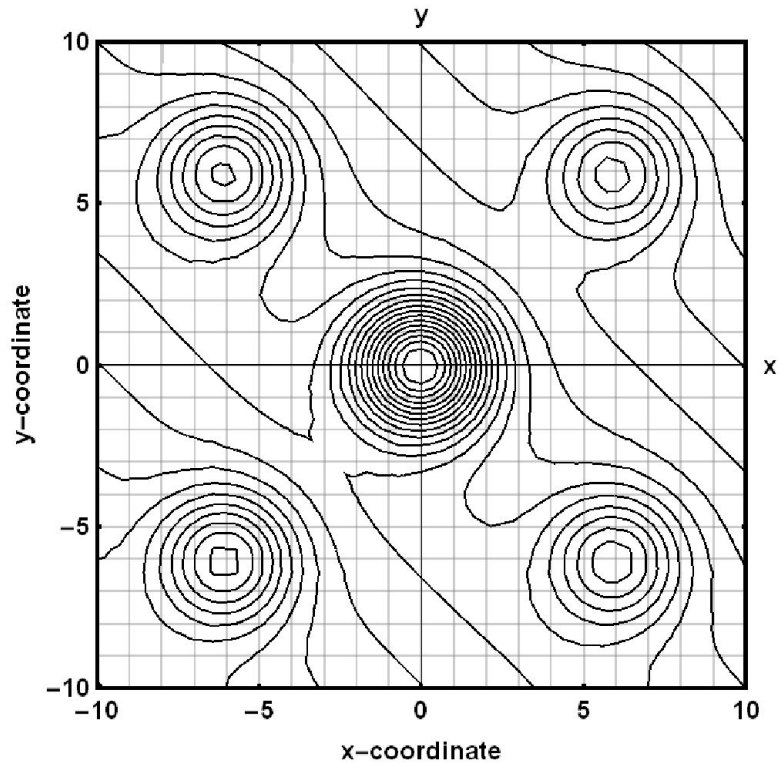
Future Direction

- **Particle Swarm Optimization: coordinate many search agent to find a solution to an optimization problem**

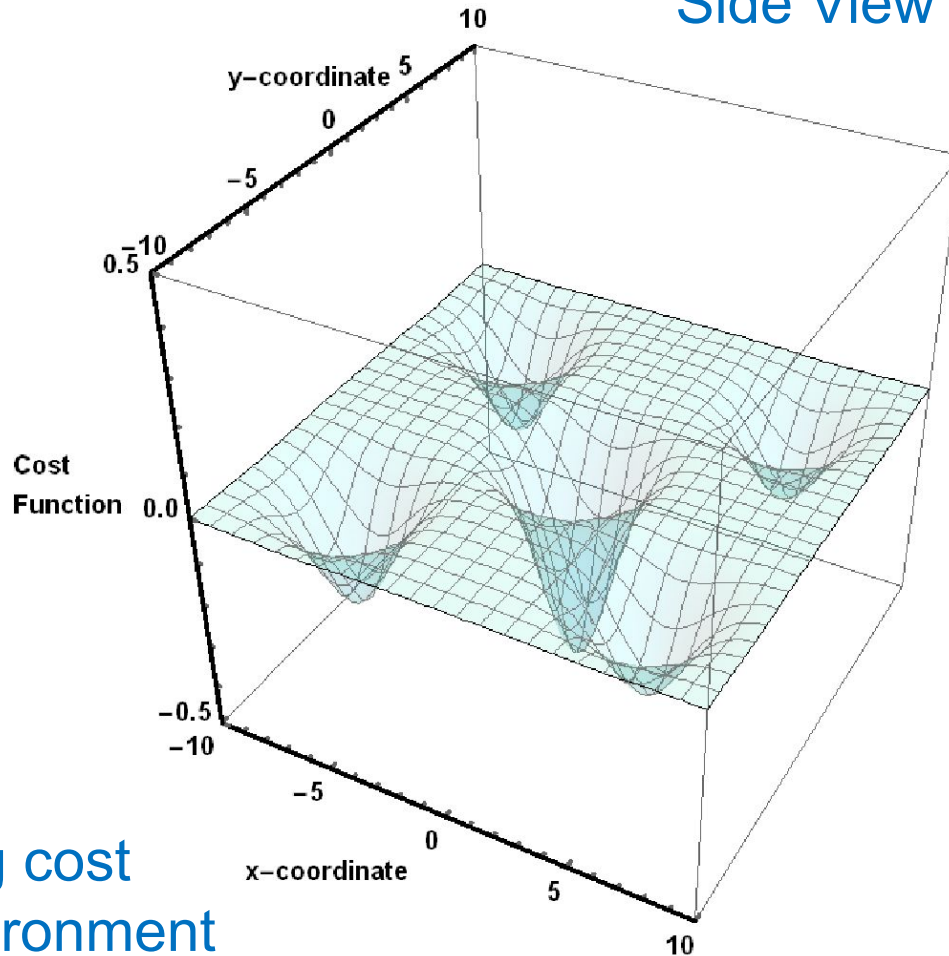


Future Direction

Top View



Side View

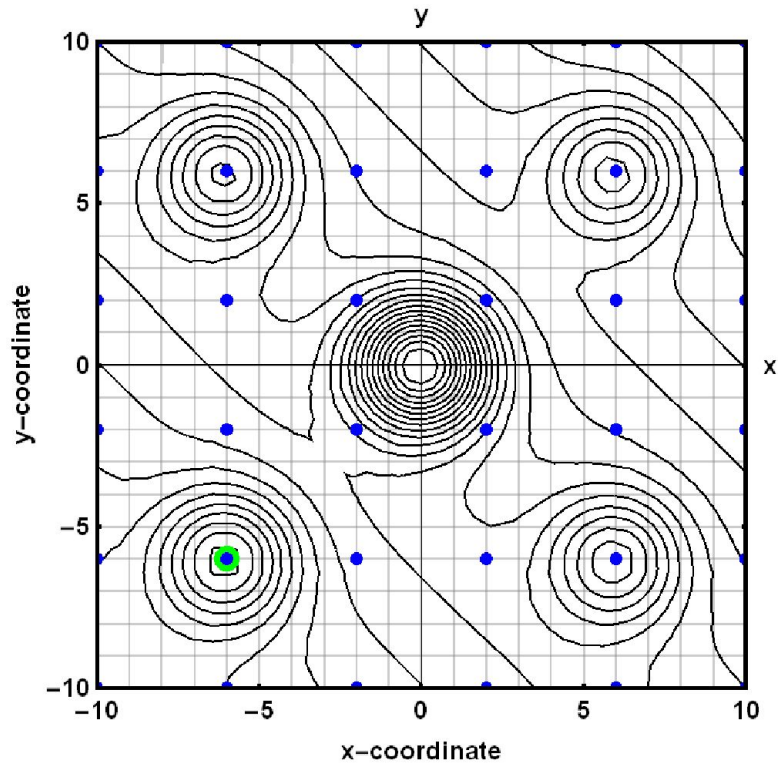


Starting Point 1: Constructing cost function to represent the environment

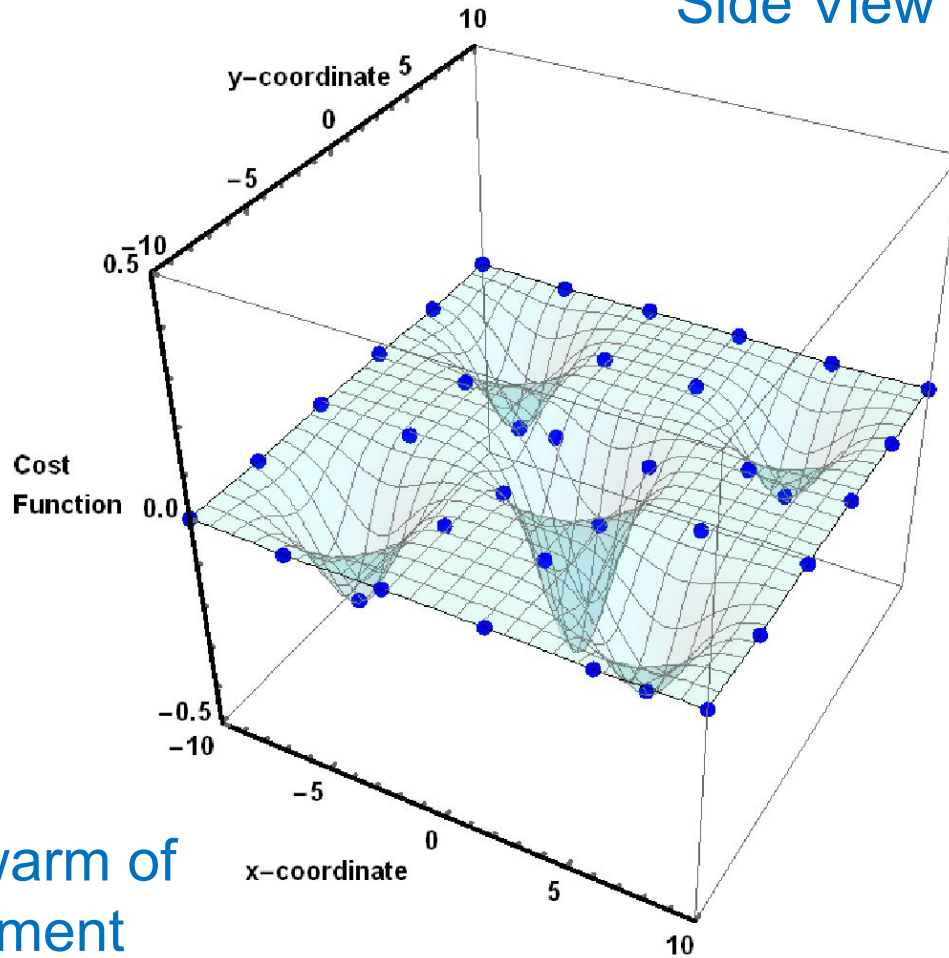


Future Direction

Top View



Side View

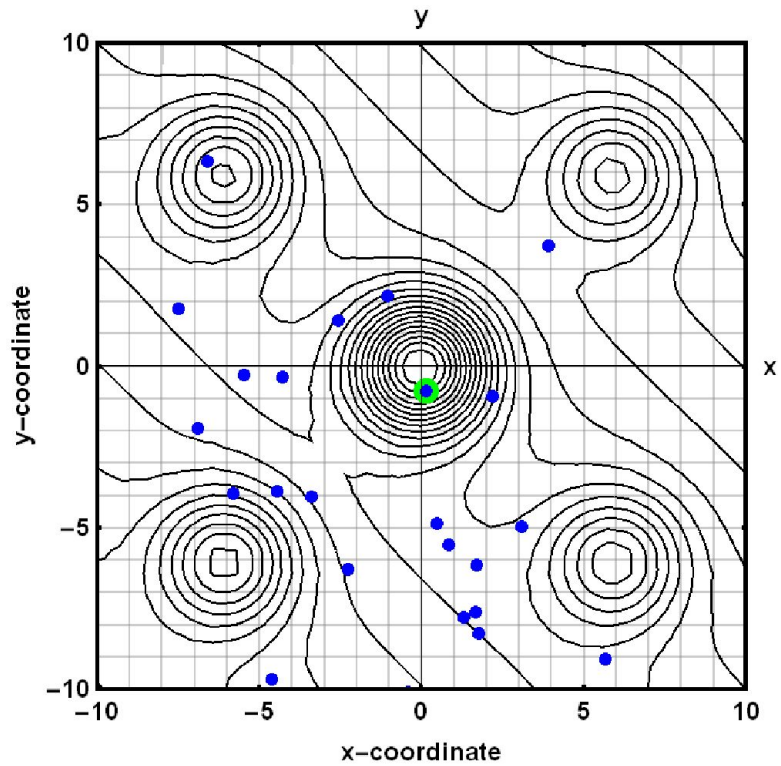


Starting Point 2: Generate swarm of particle agents in the environment

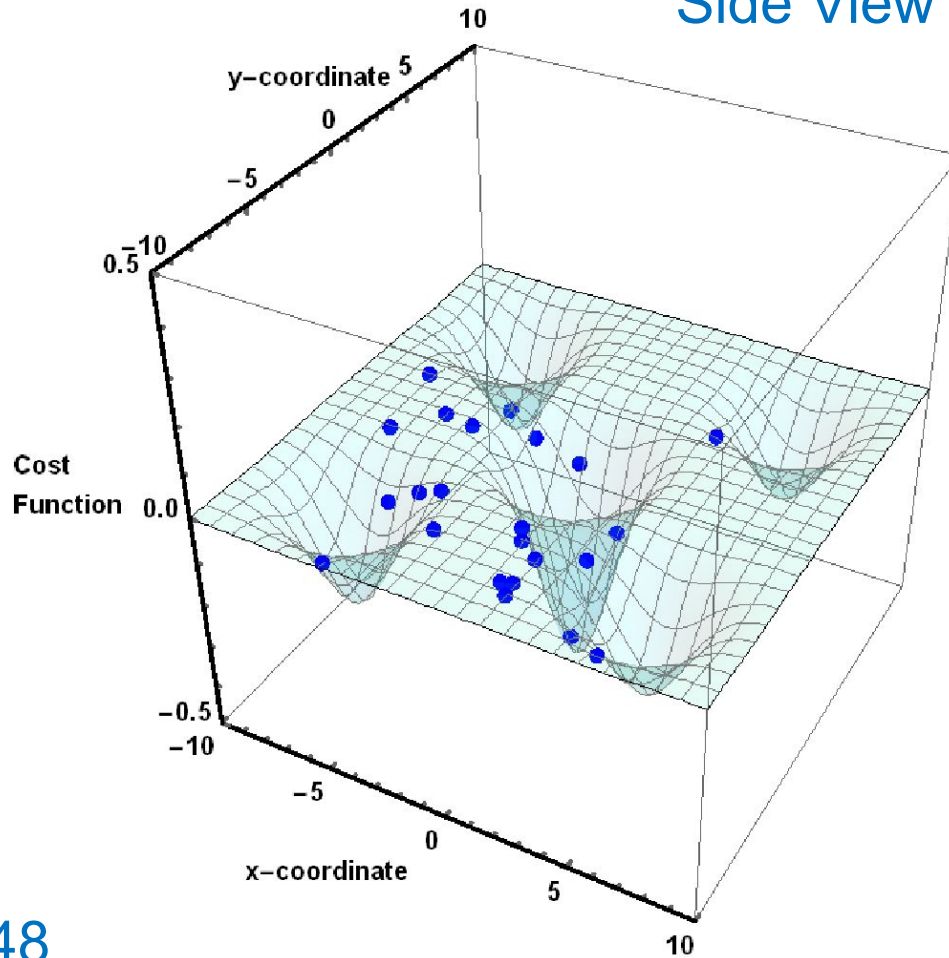


Future Direction

Top View



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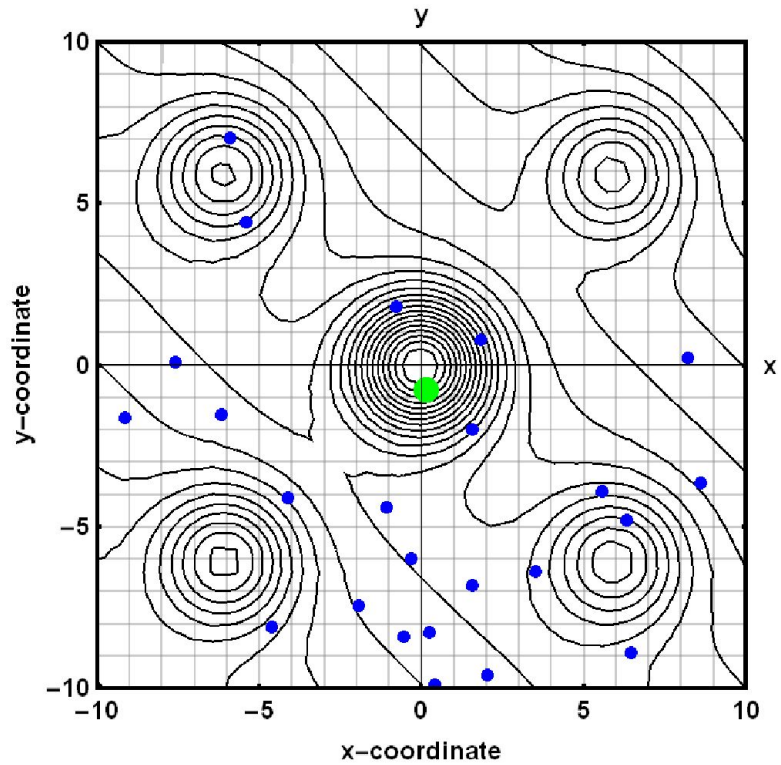
Searching Iteration 01

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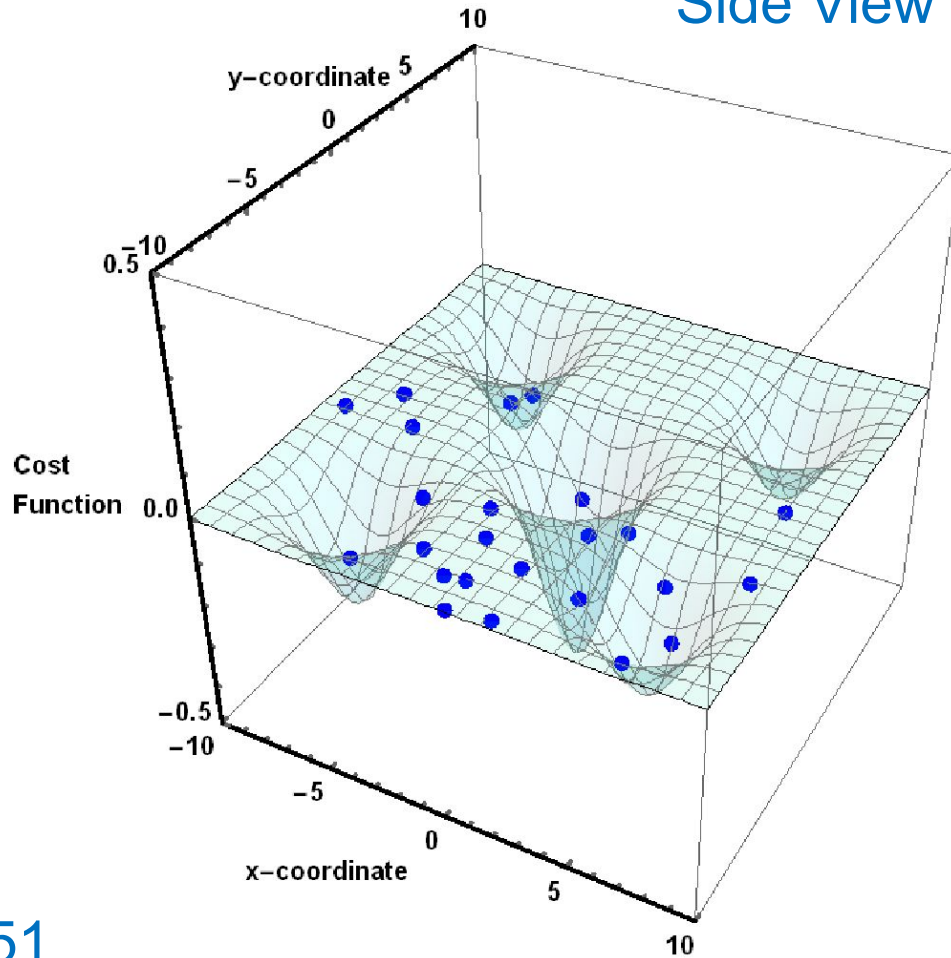


Future Direction

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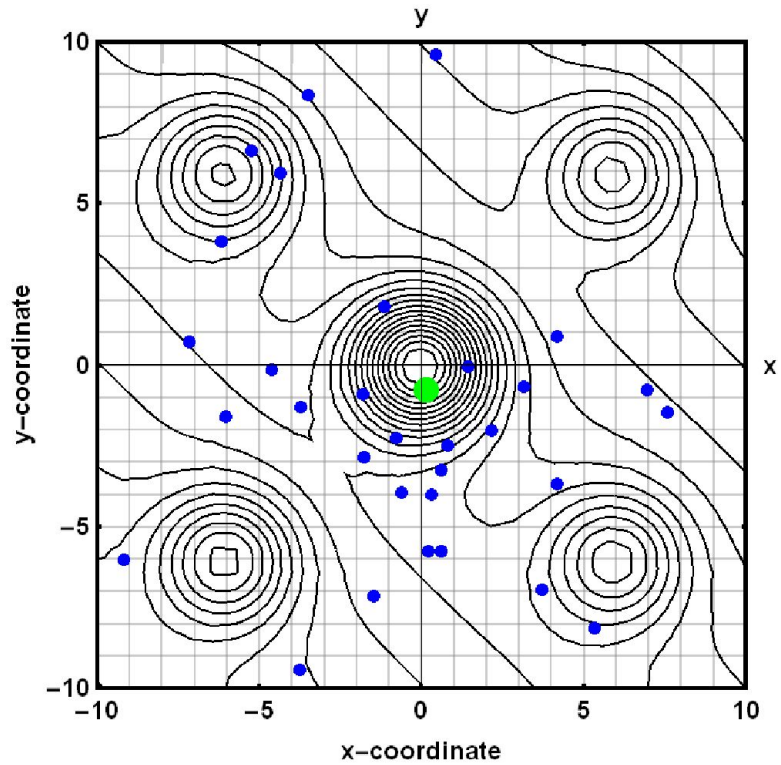
Searching Iteration 02

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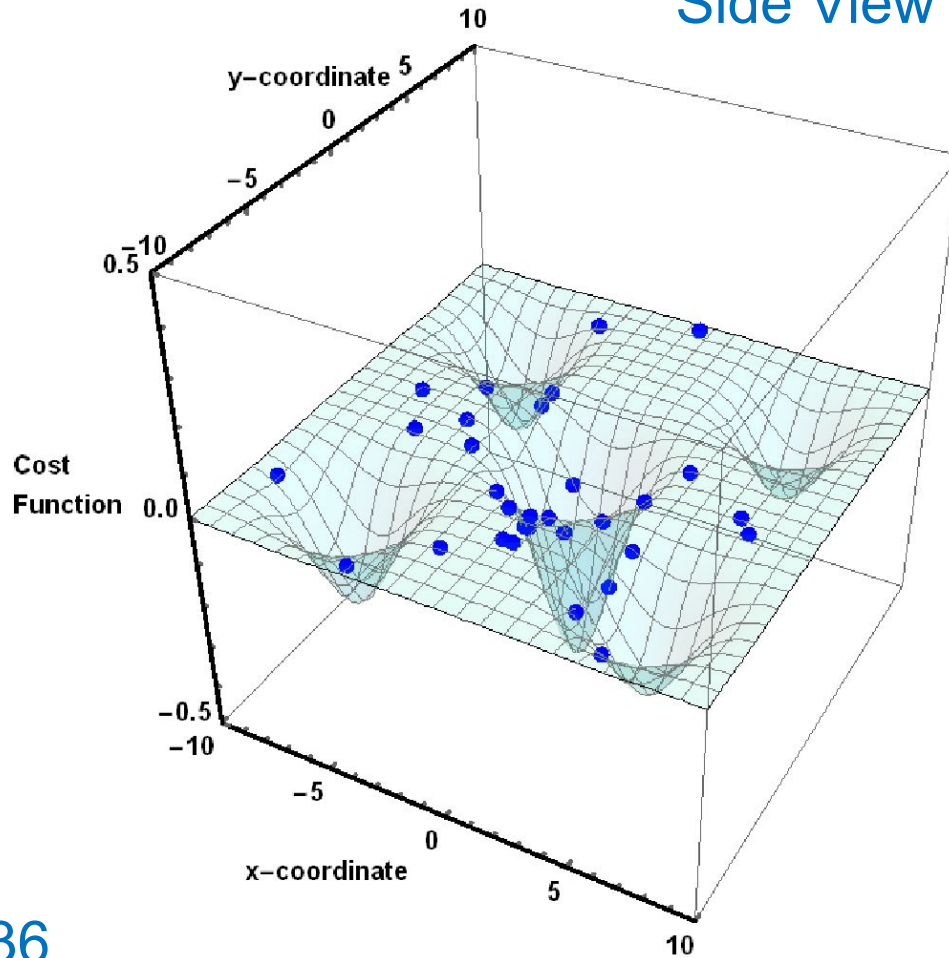


Future Direction

Top View



Side View



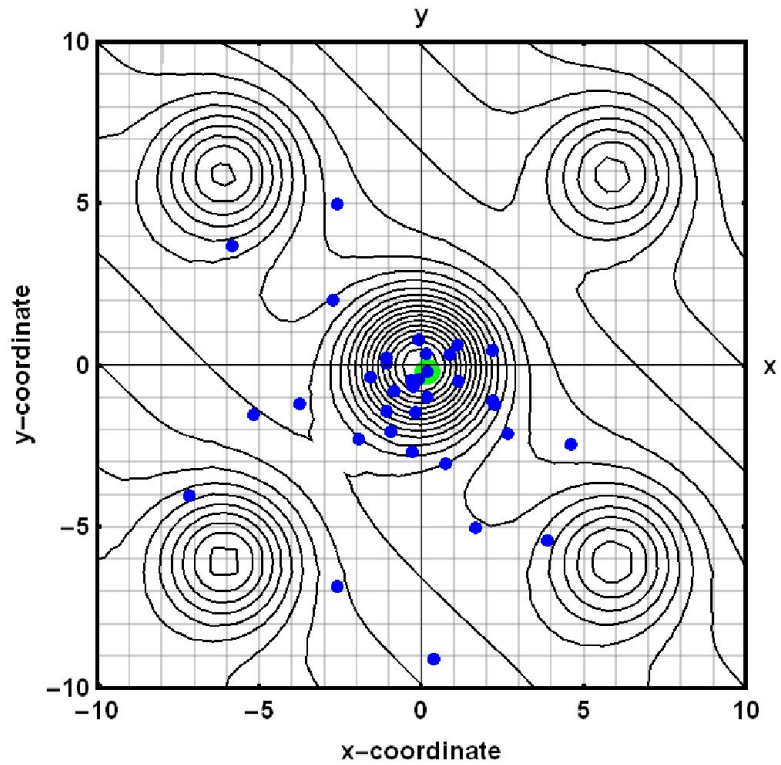
Searching Iteration 03

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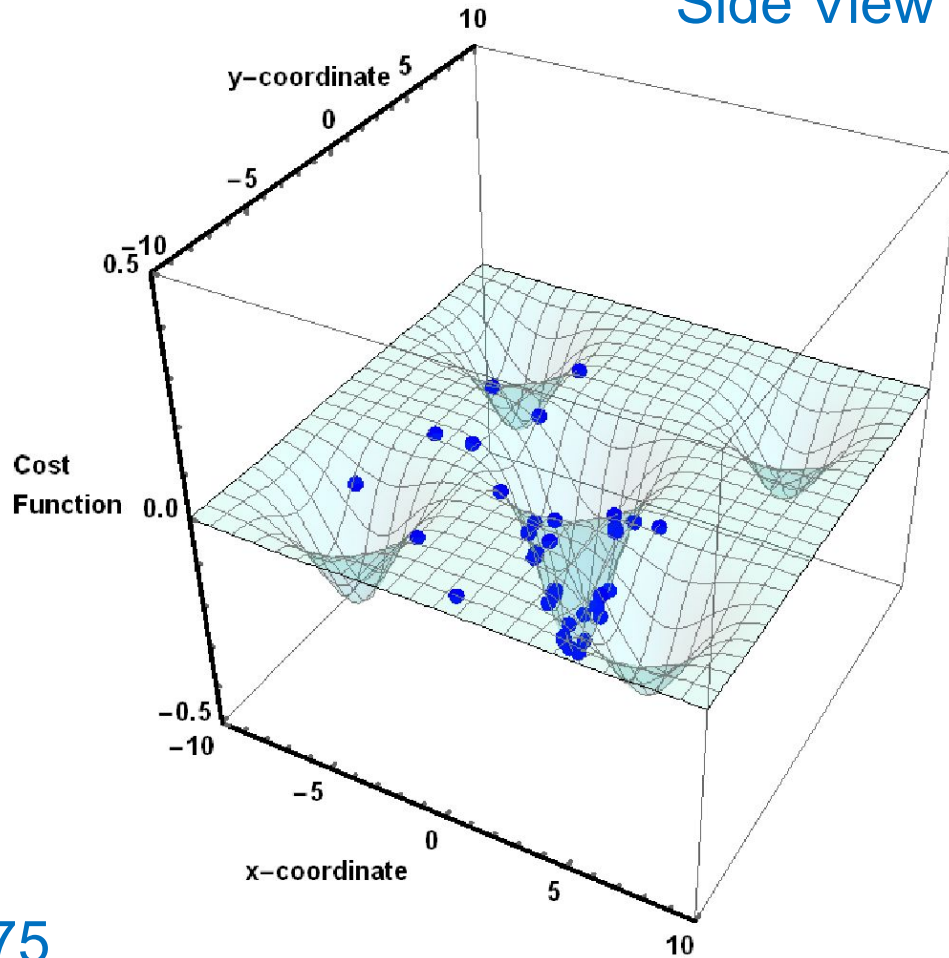


Future Direction

Top View



Side View



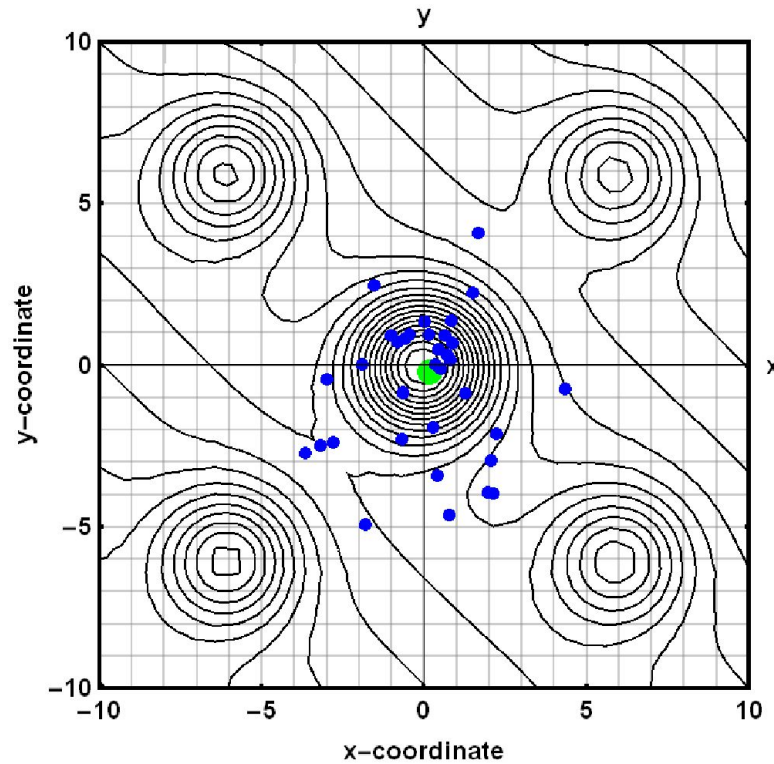
Searching Iteration 04

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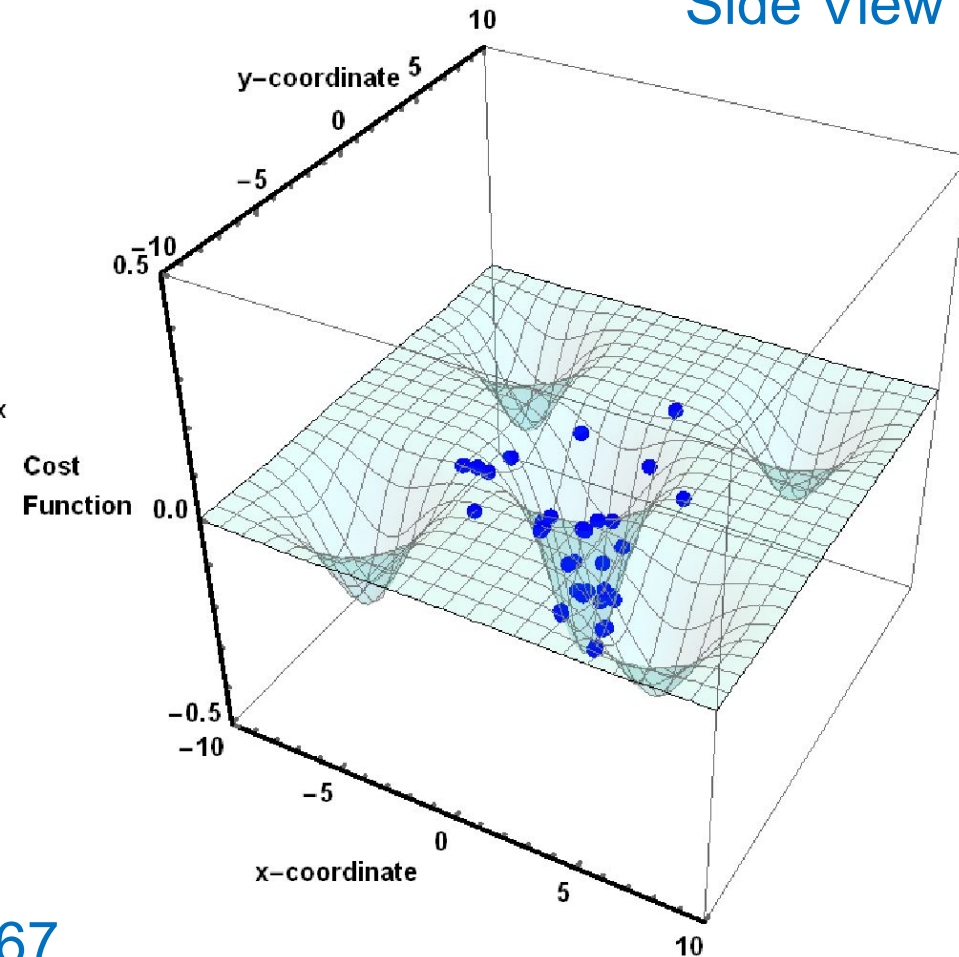


Future Direction

Top View



Side View



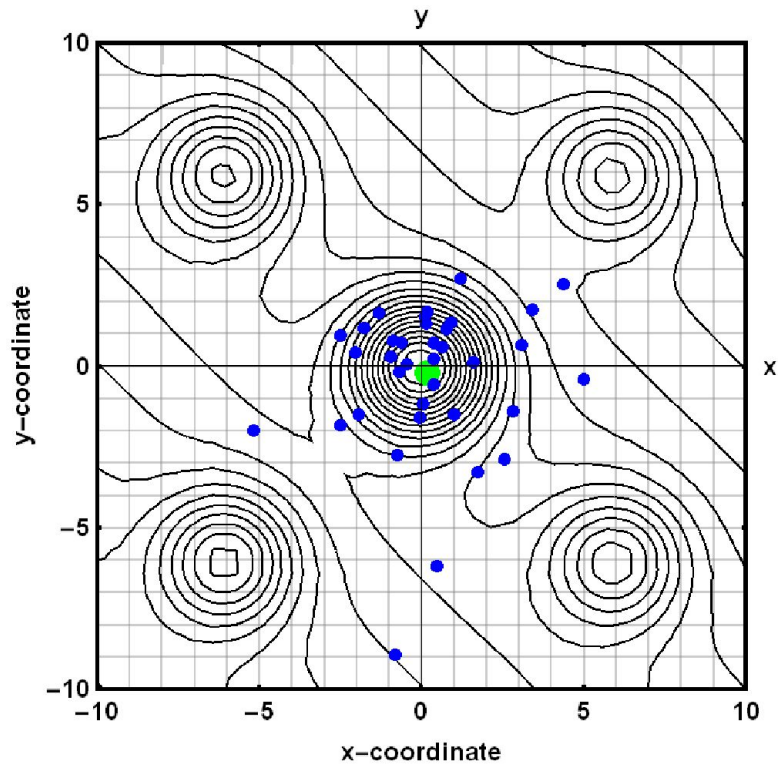
Searching Iteration 05

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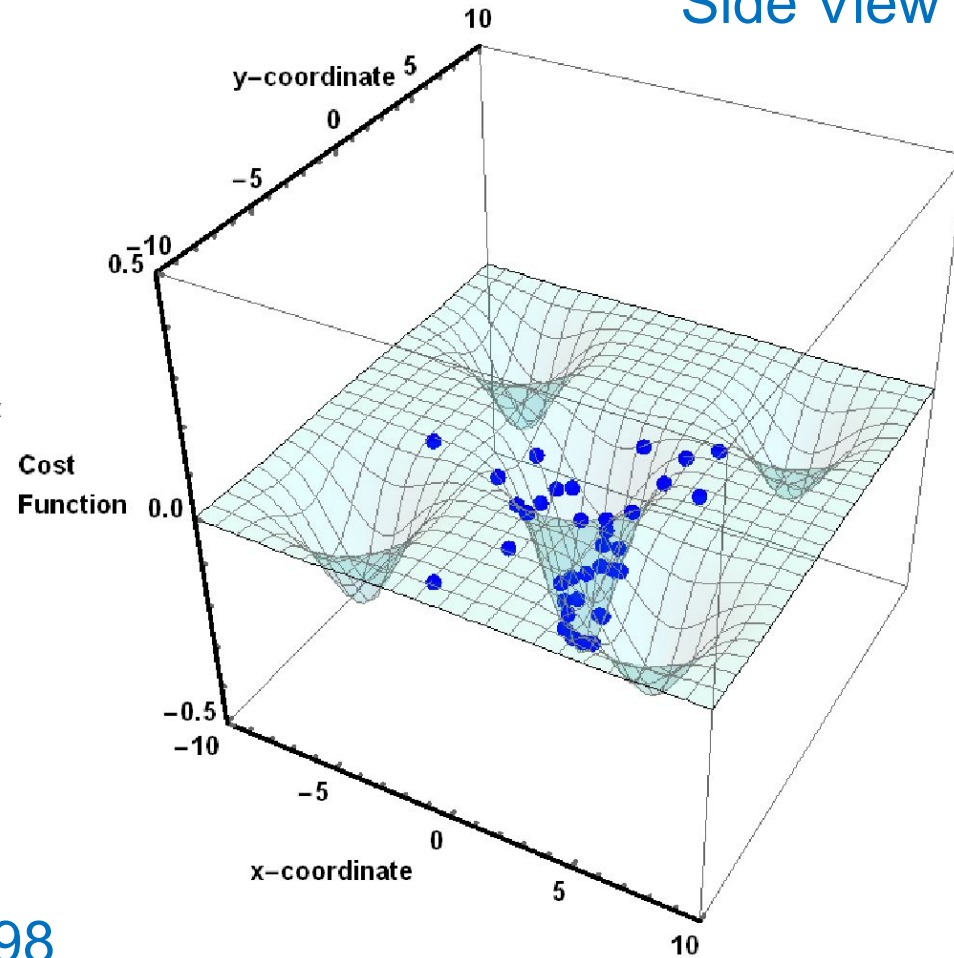


Future Direction

Top View



Side View



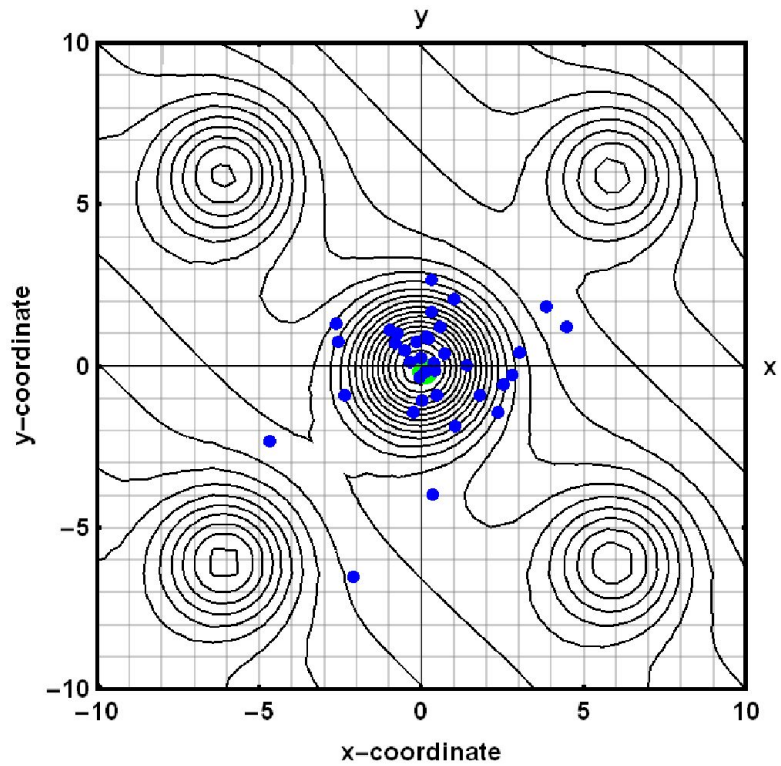
Searching Iteration 06

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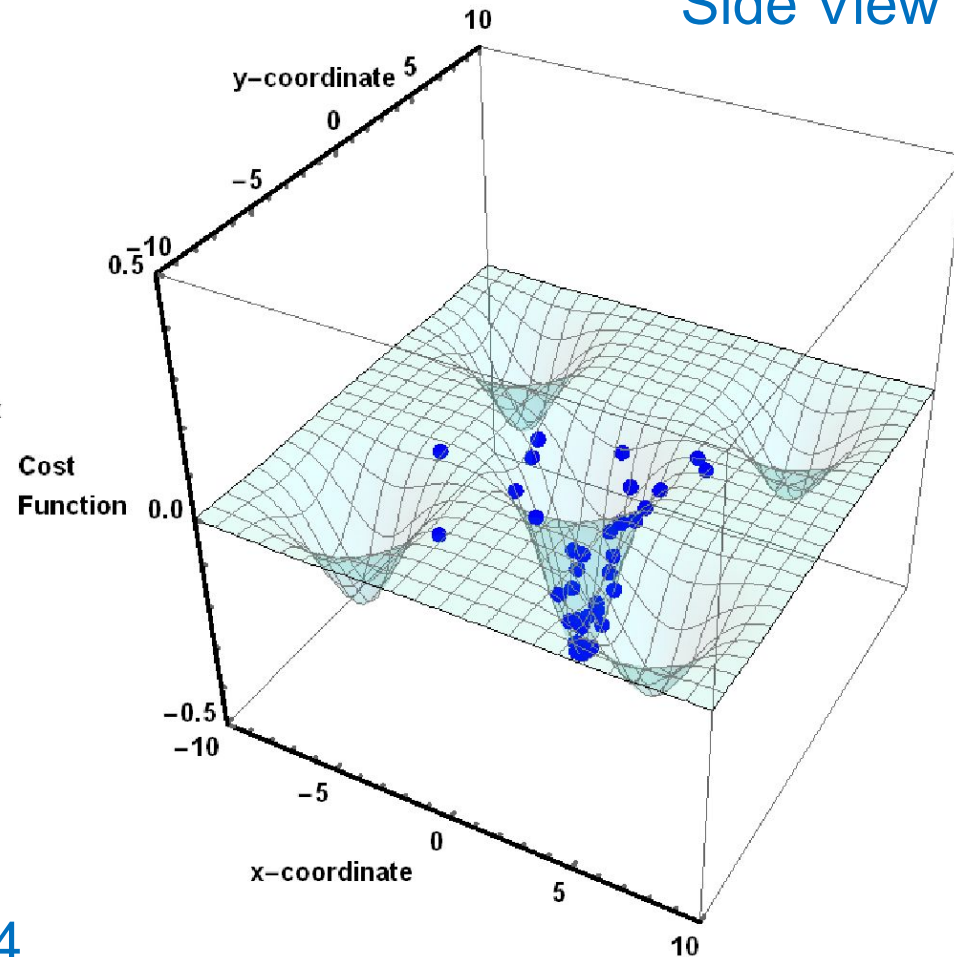


Future Direction

Top View



Side View



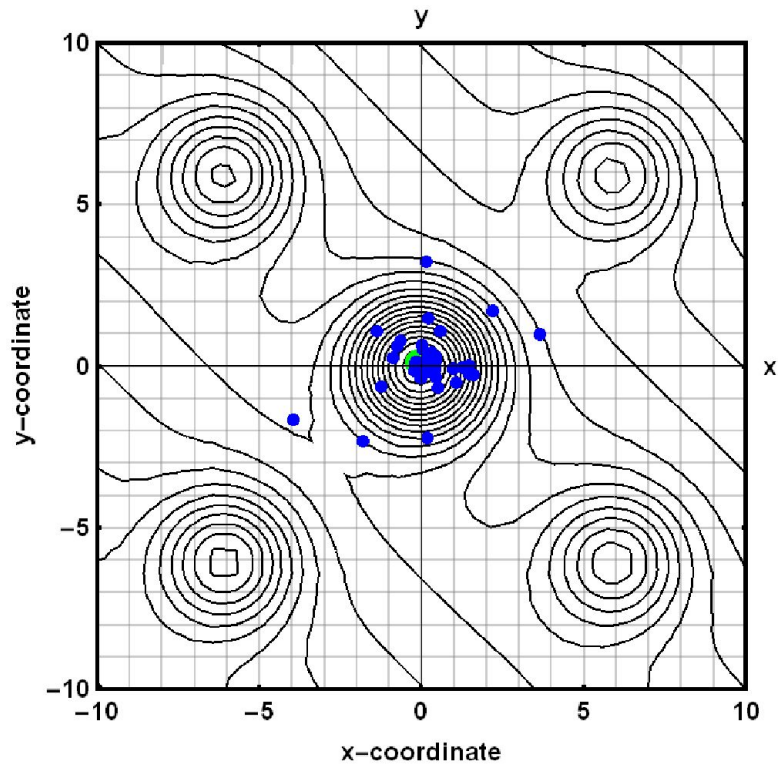
Searching Iteration 07

Pos. Var. = 4.3599379278214

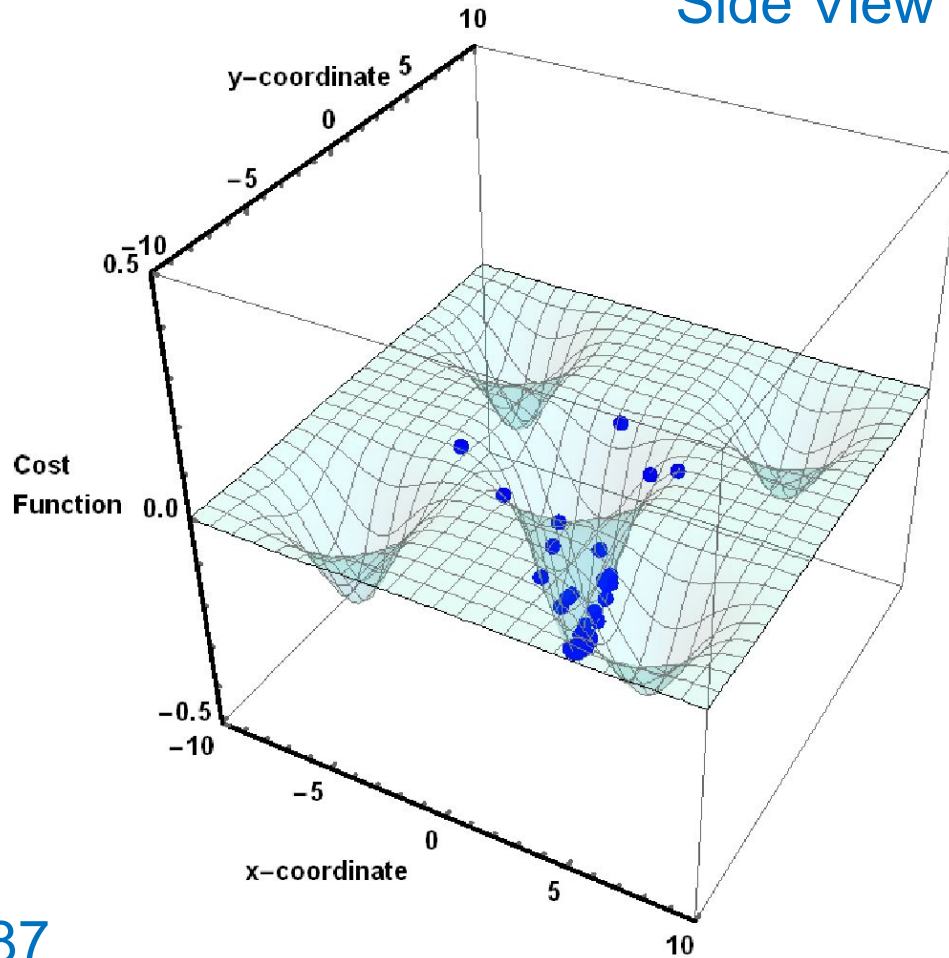


Future Direction

Top View



Side View



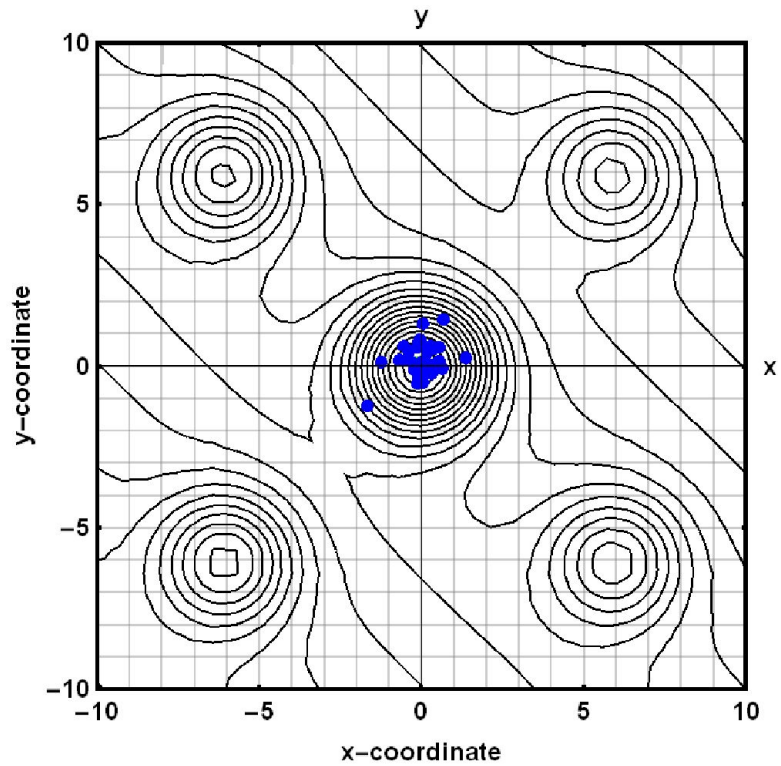
Searching Iteration 08

Pos. Var. = 1.78485476442887

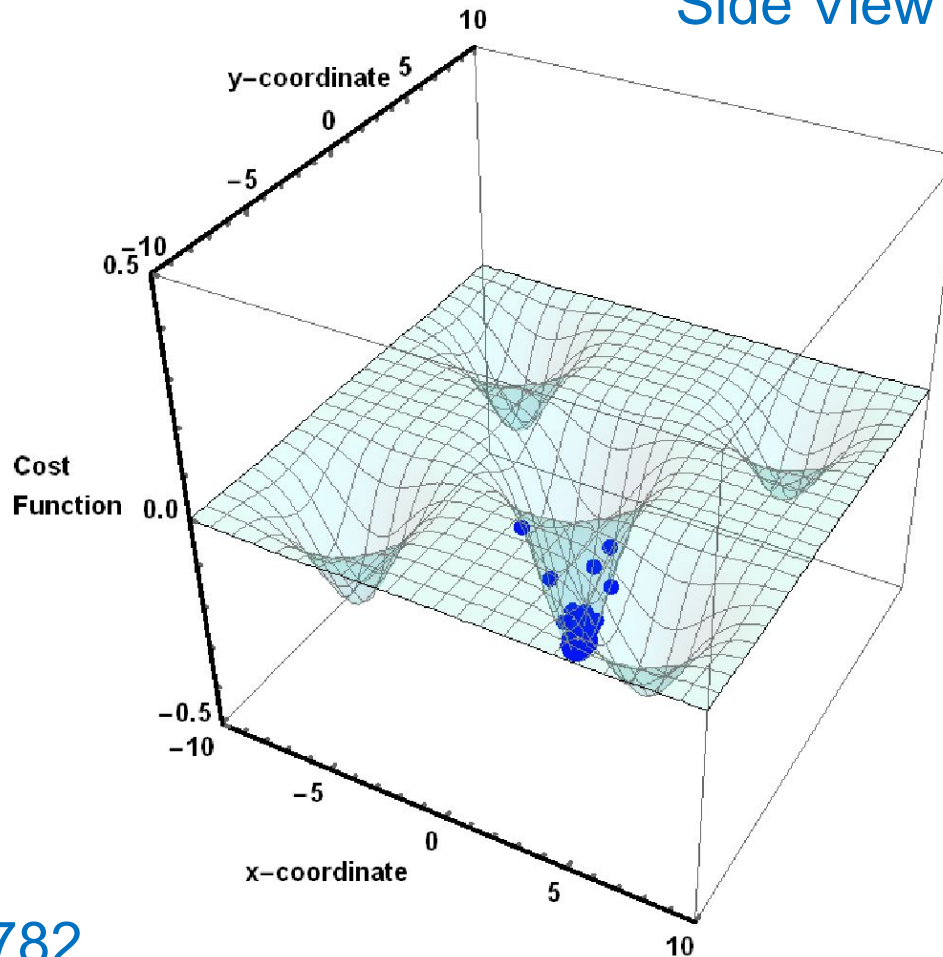


Future Direction

Top View



Side View



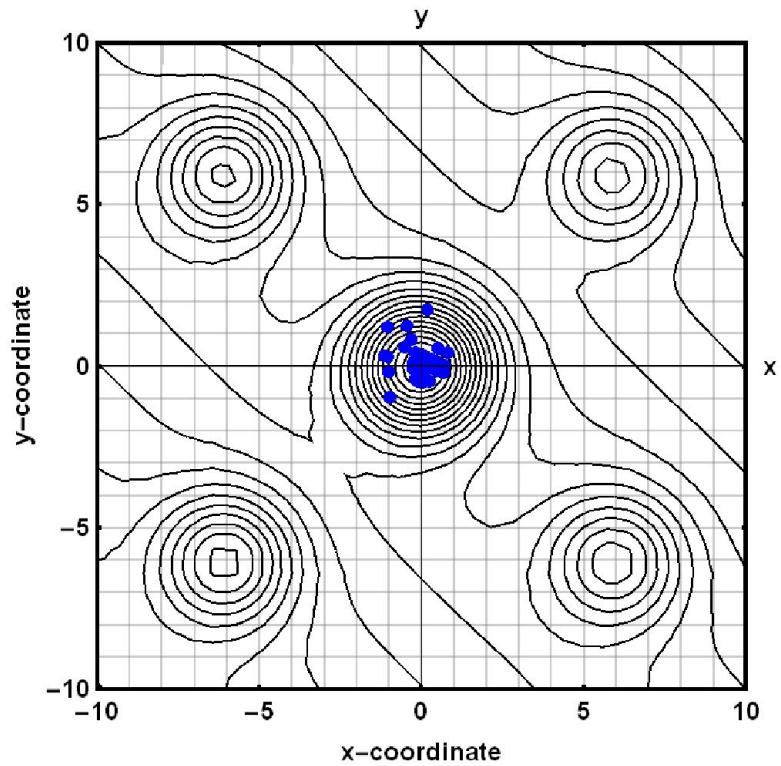
Searching Iteration 09

Pos. Var. = 0.389367537093782

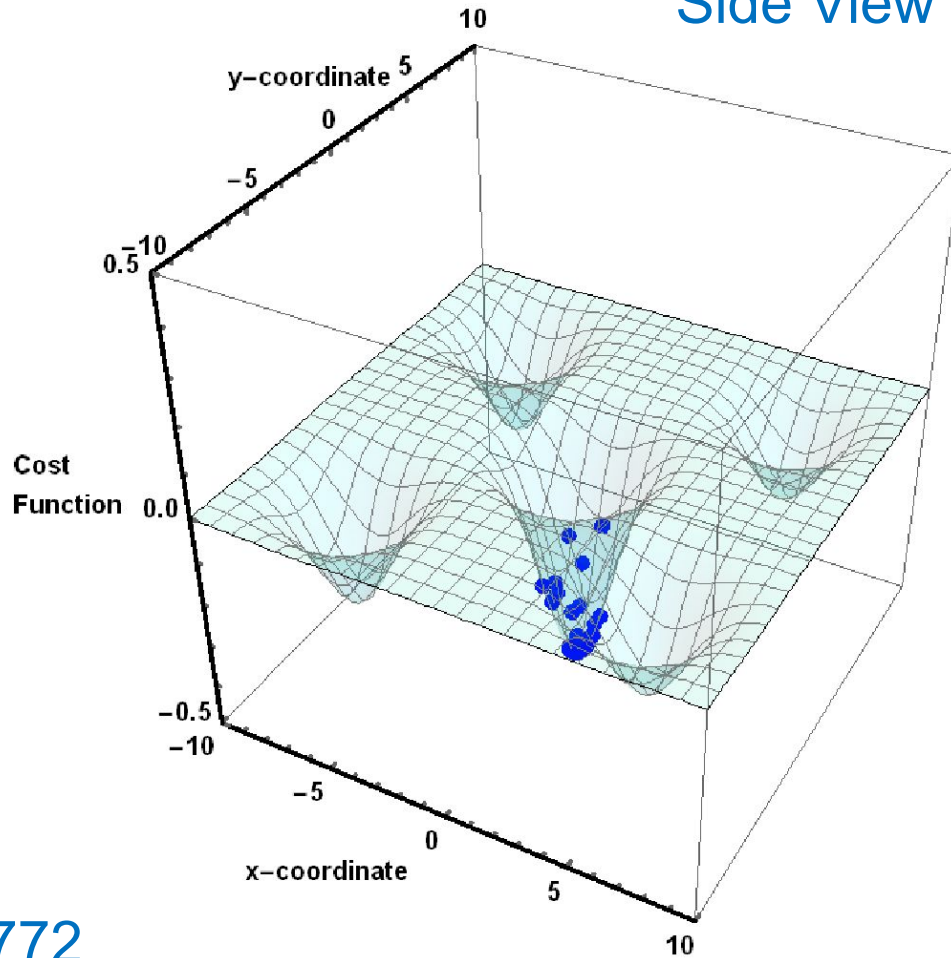


Future Direction

Top View



Side View



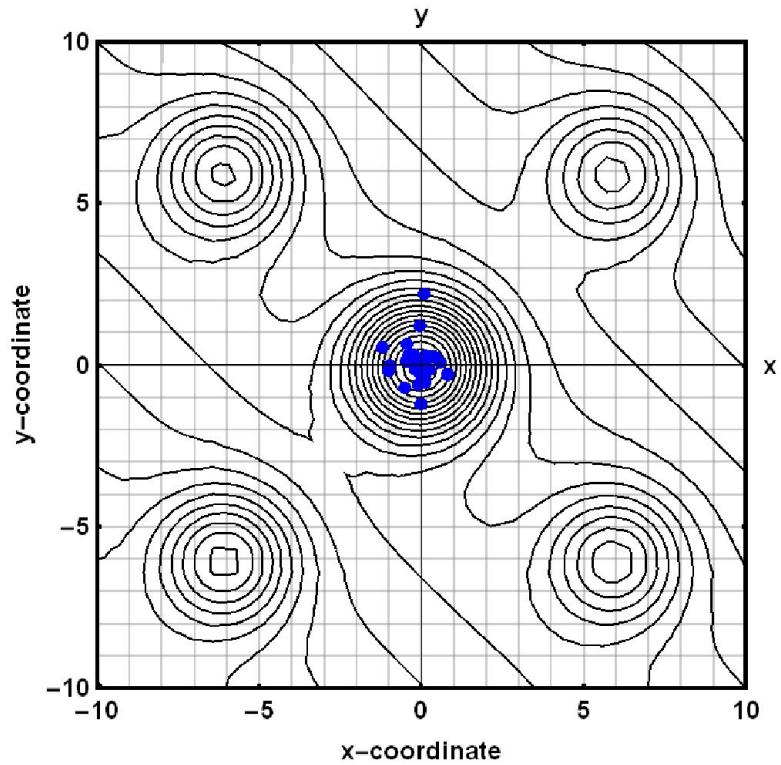
Searching Iteration 10

Pos. Var. = 0.373266255096772

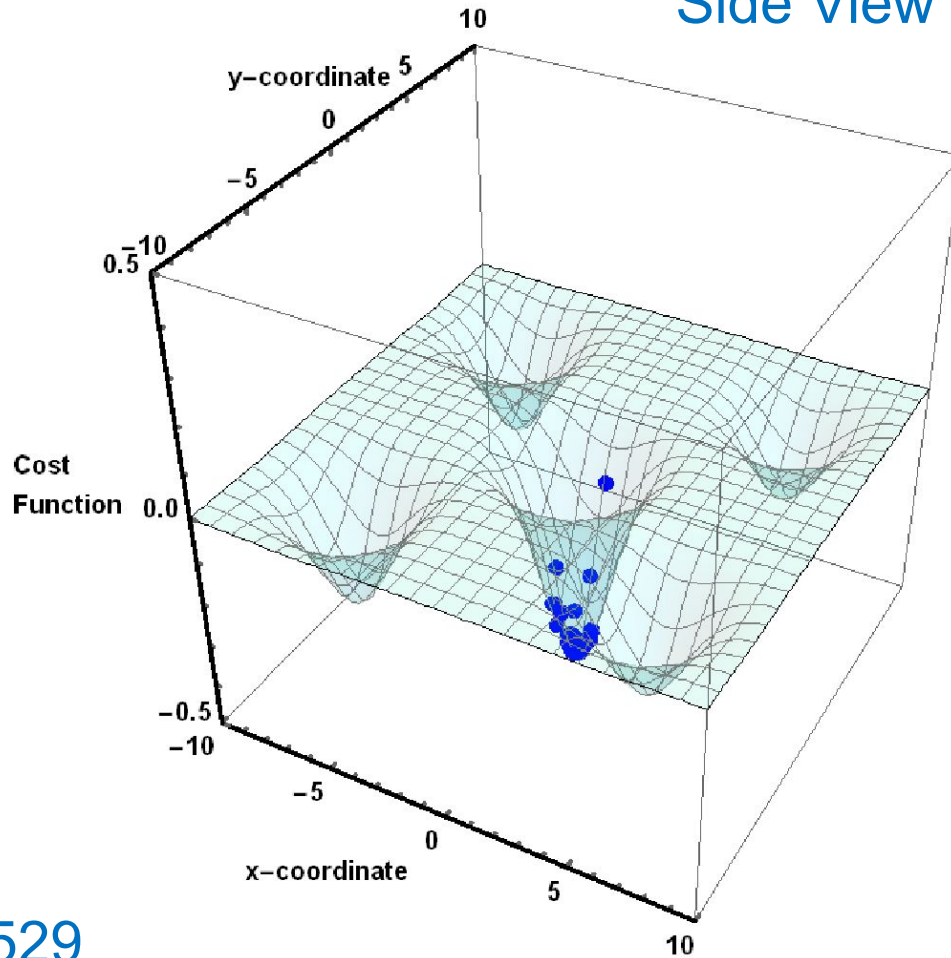


Future Direction

Top View



Side View



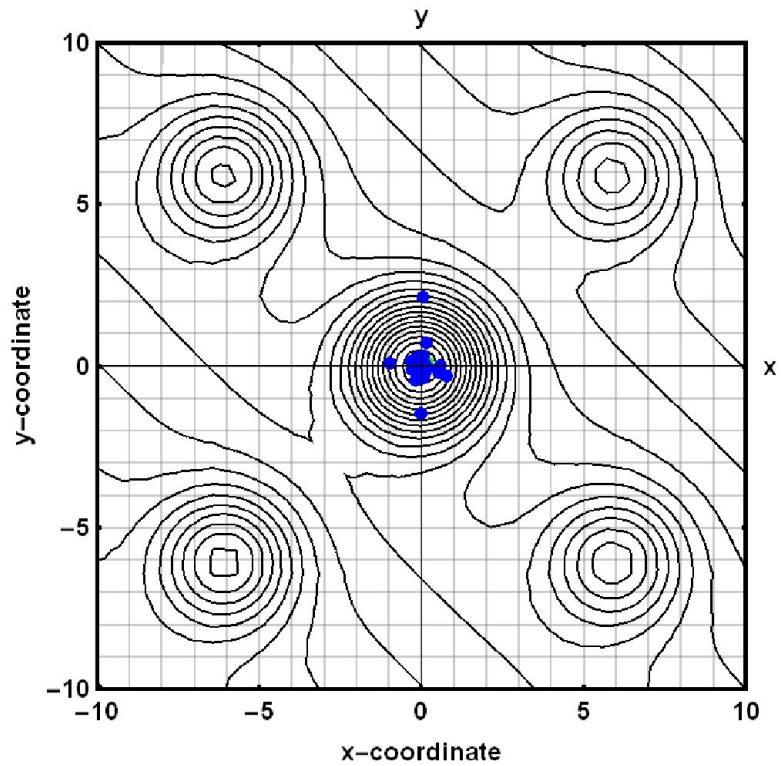
Searching Iteration 11

Pos. Var. = 0.349279444849529

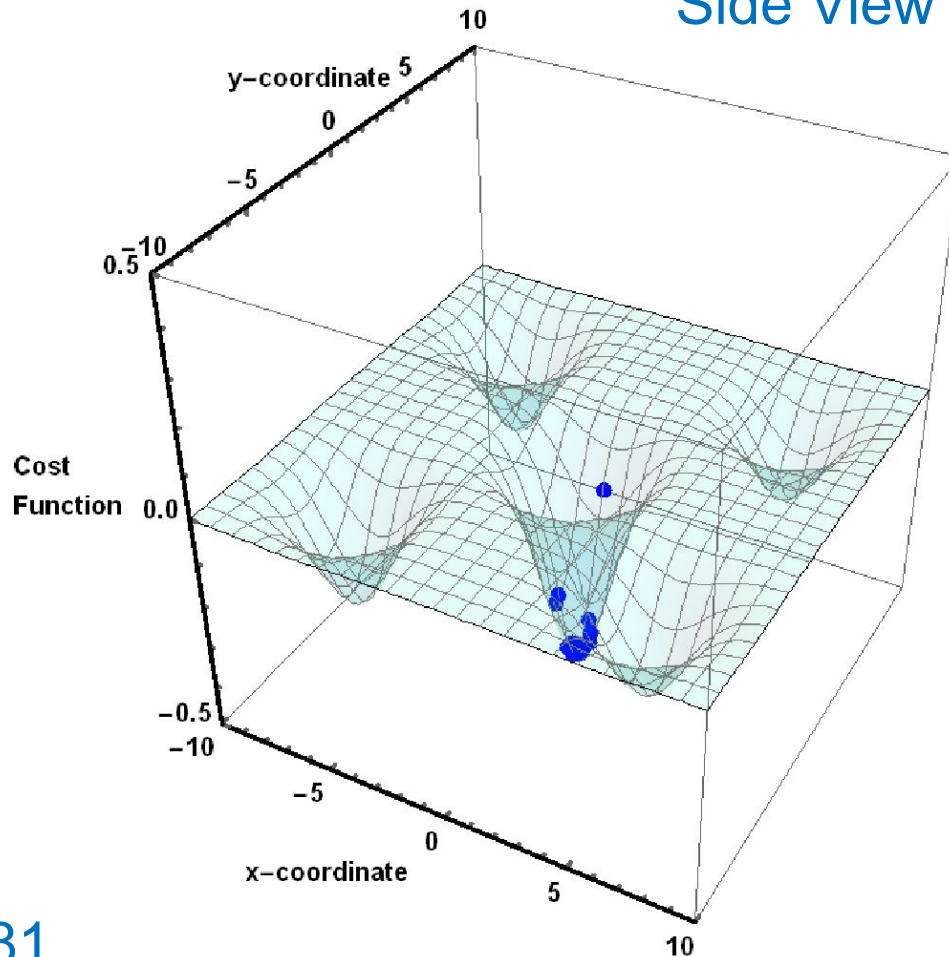


Future Direction

Top View



Side View



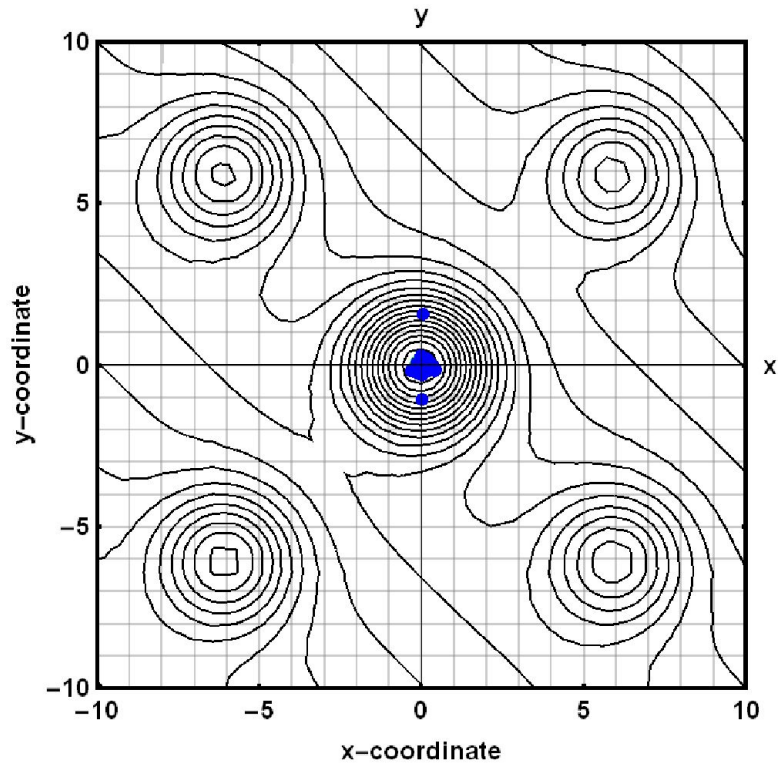
Searching Iteration 12

Pos. Var. = 0.24747560396581

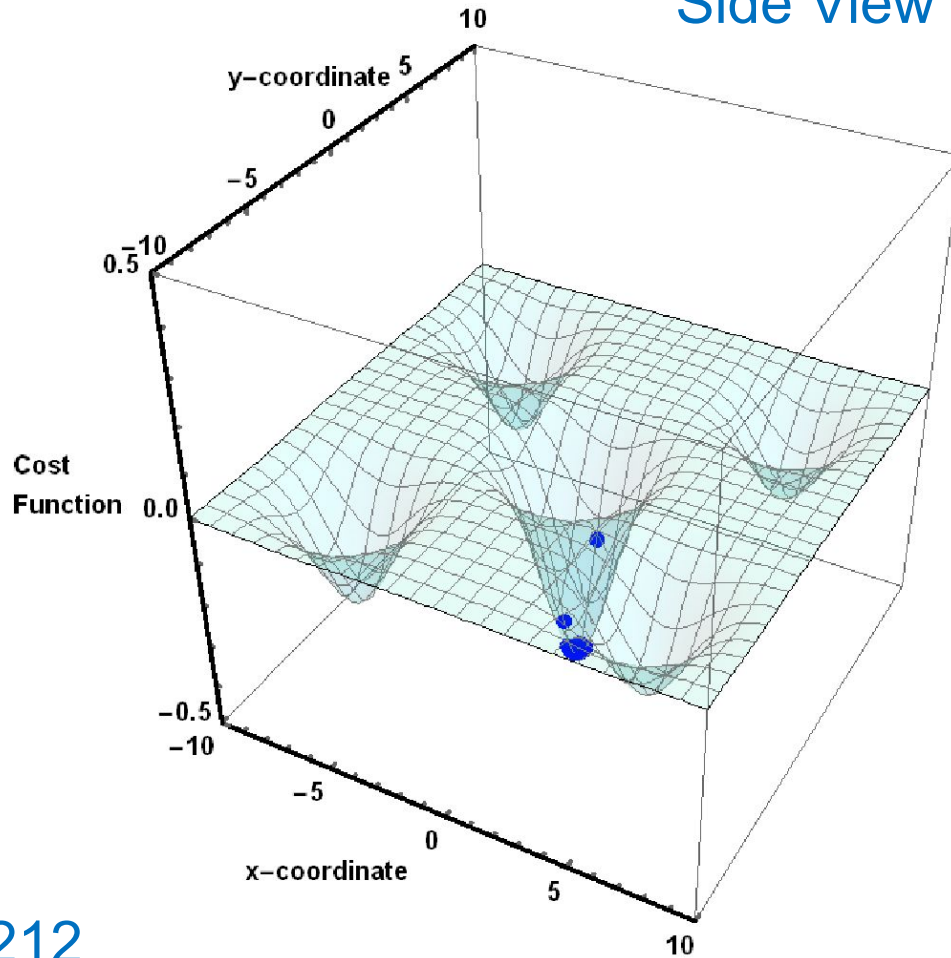


Future Direction

Top View



Side View



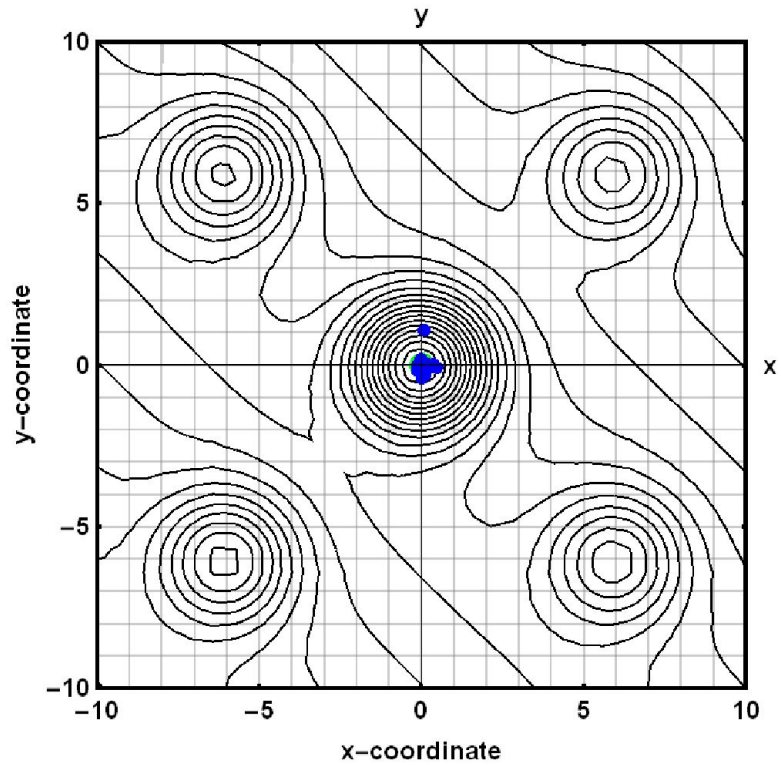
Searching Iteration 13

Pos. Var. = 0.123437269484212

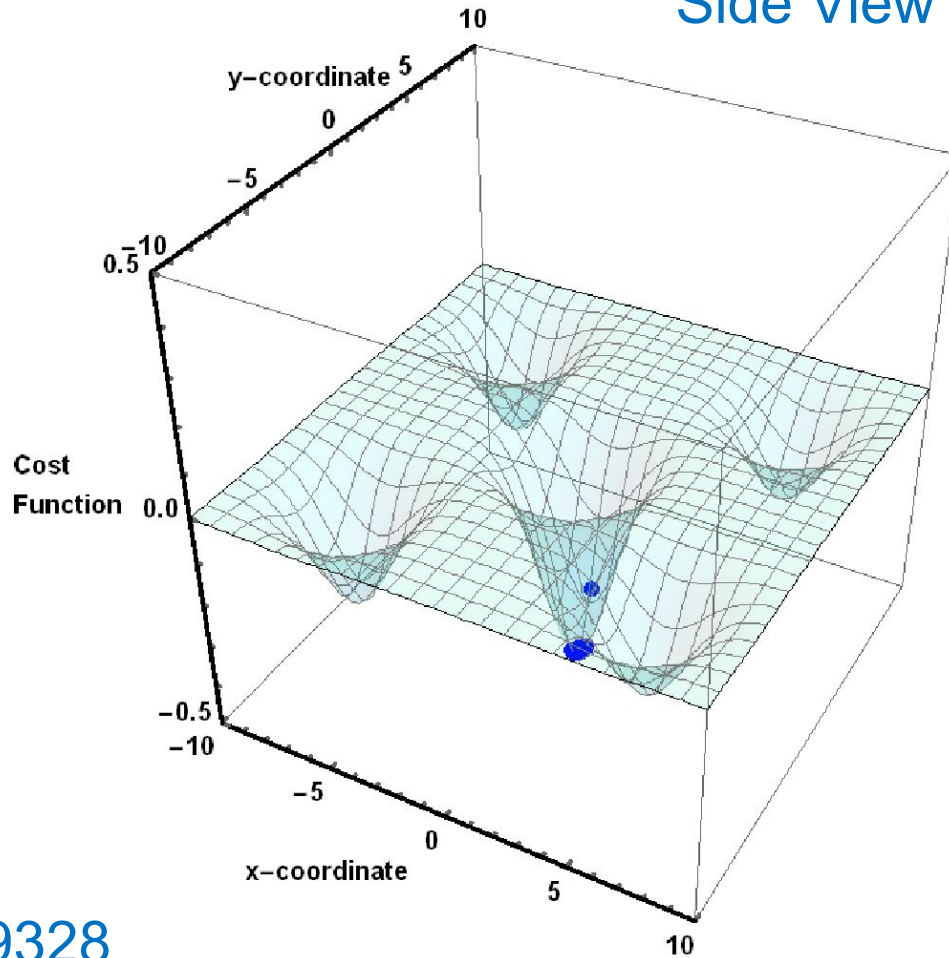


Future Direction

Top View



Side View



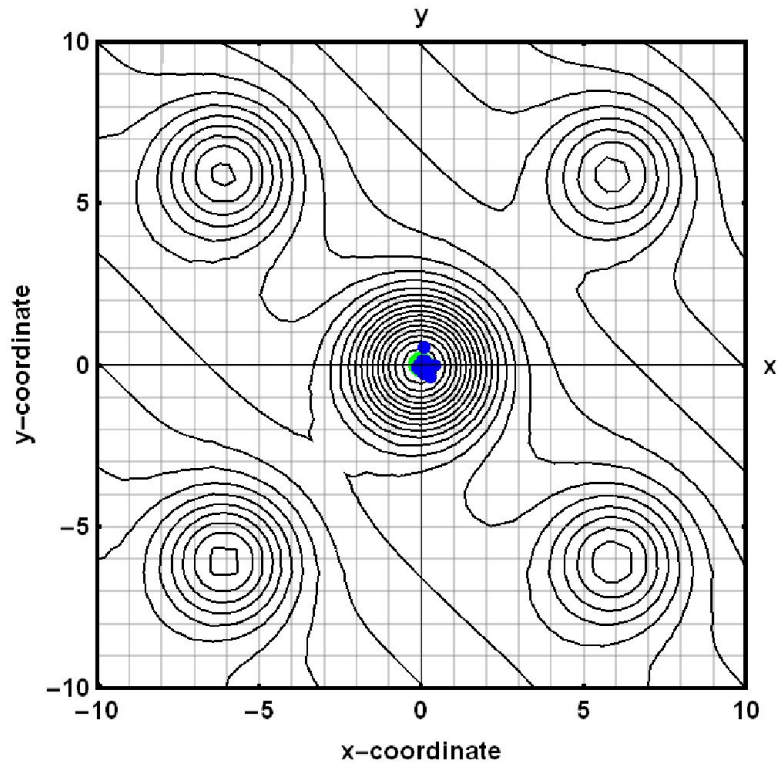
Searching Iteration 14

Pos. Var. = 0.0521151277099328

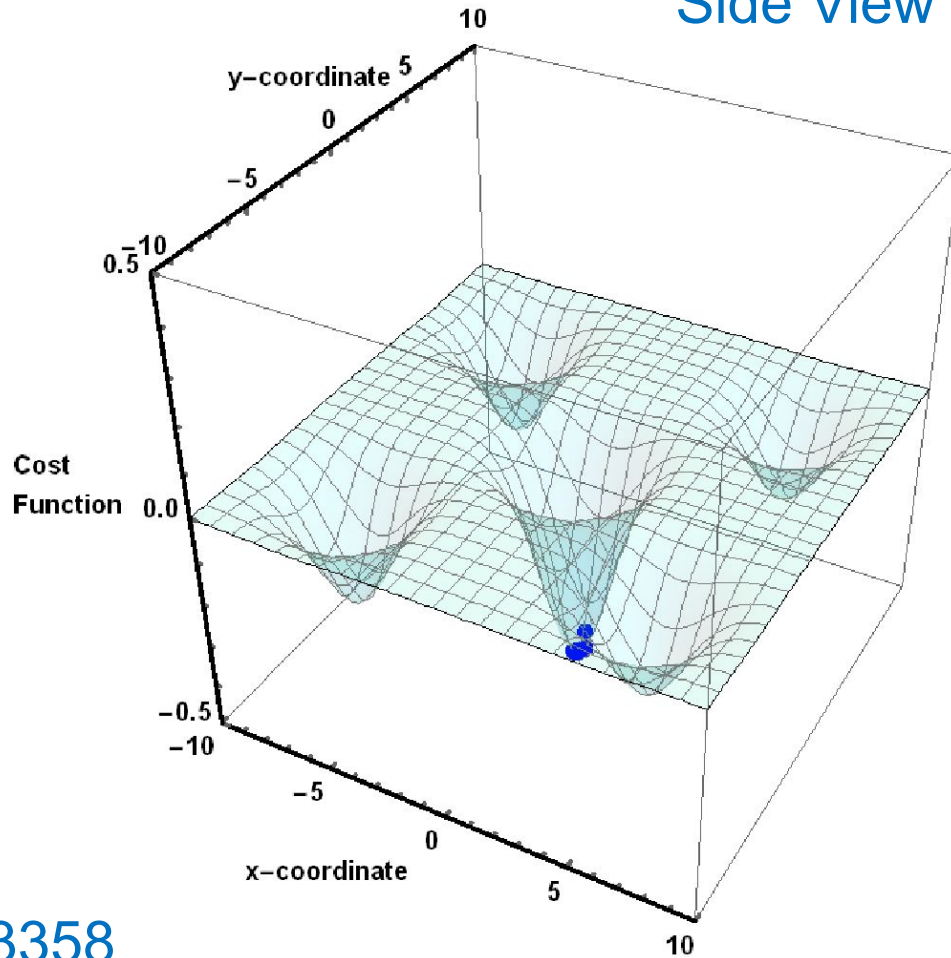


Future Direction

Top View



Side View



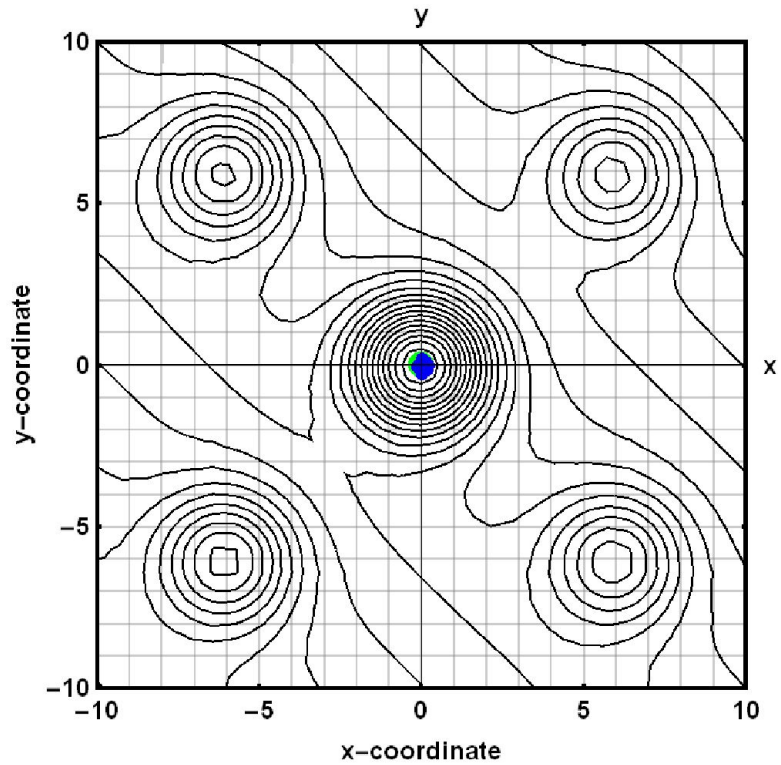
Searching Iteration 15

Pos. Var. = 0.0223415055133358

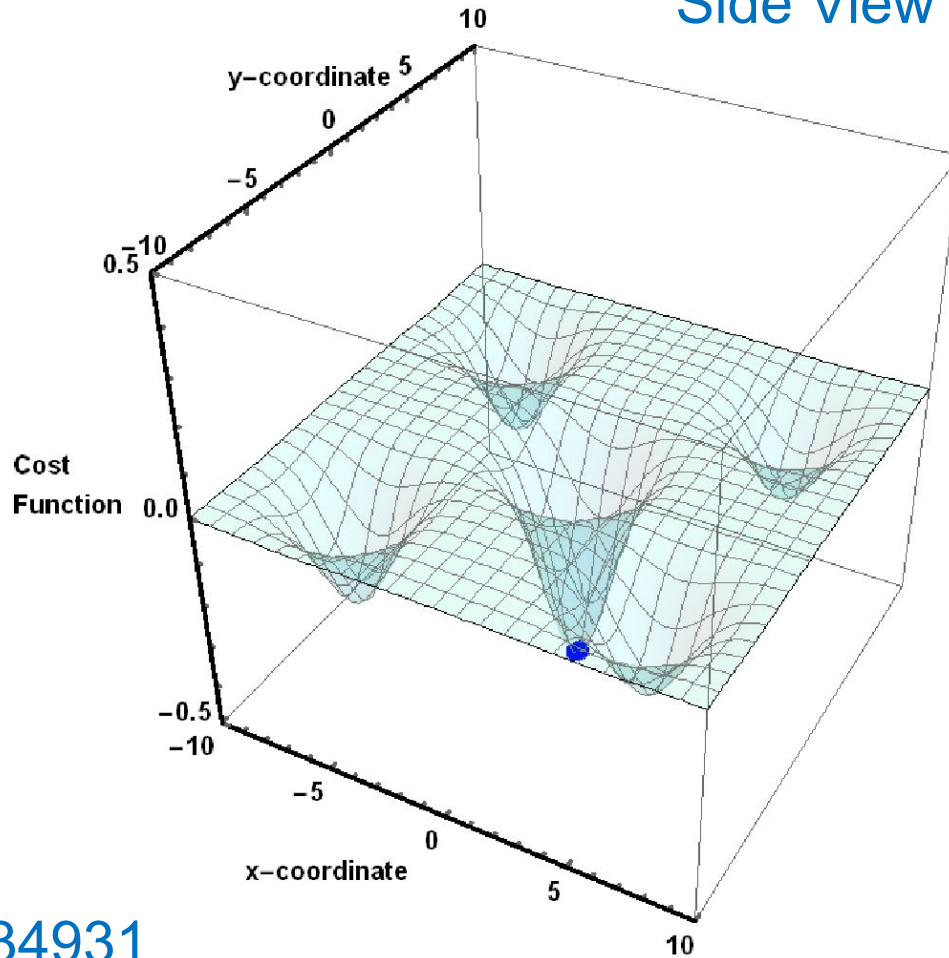


Future Direction

Top View



Side View



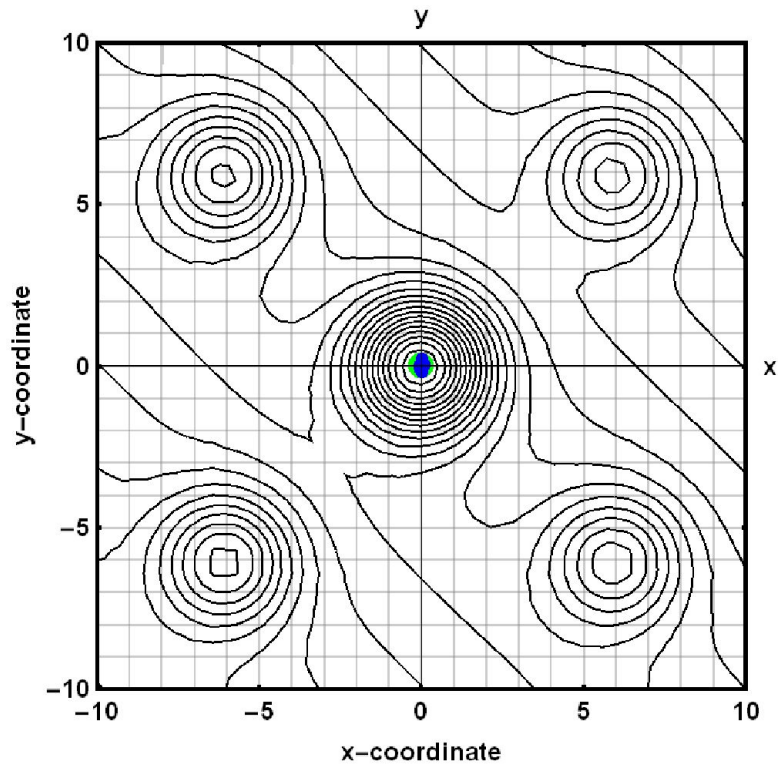
Searching Iteration 16

Pos. Var. = 0.00763218886734931

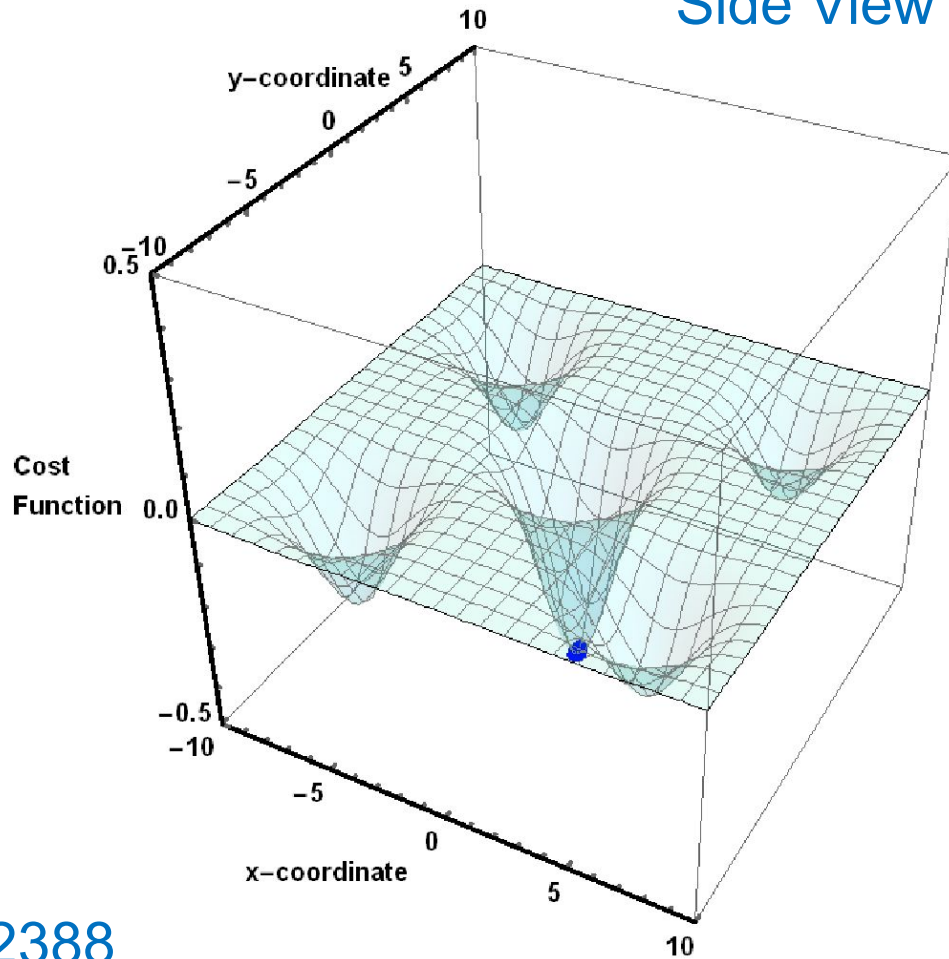


Future Direction

Top View



Side View



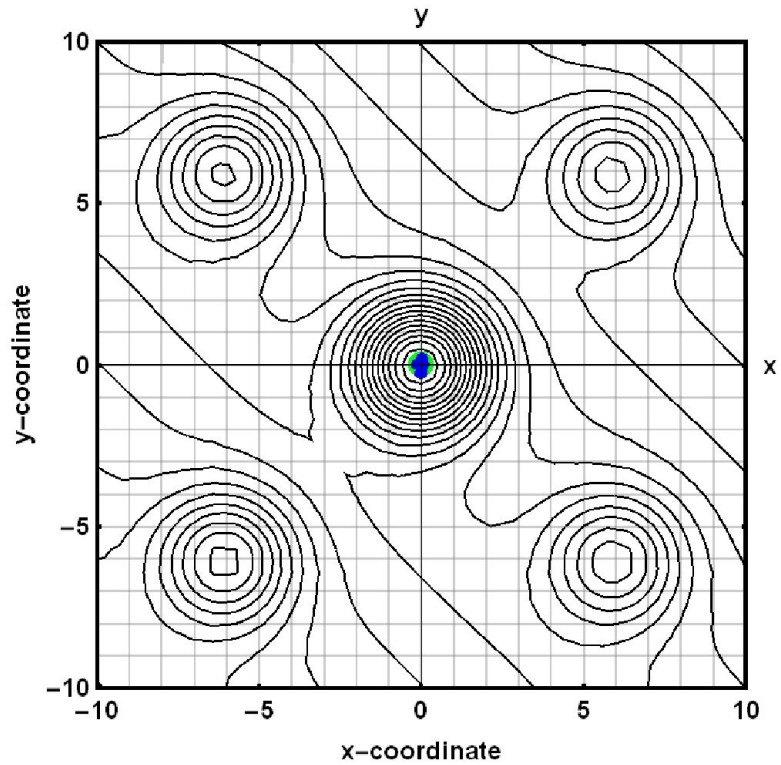
Searching Iteration 17

Pos. Var. = 0.0037816567382388

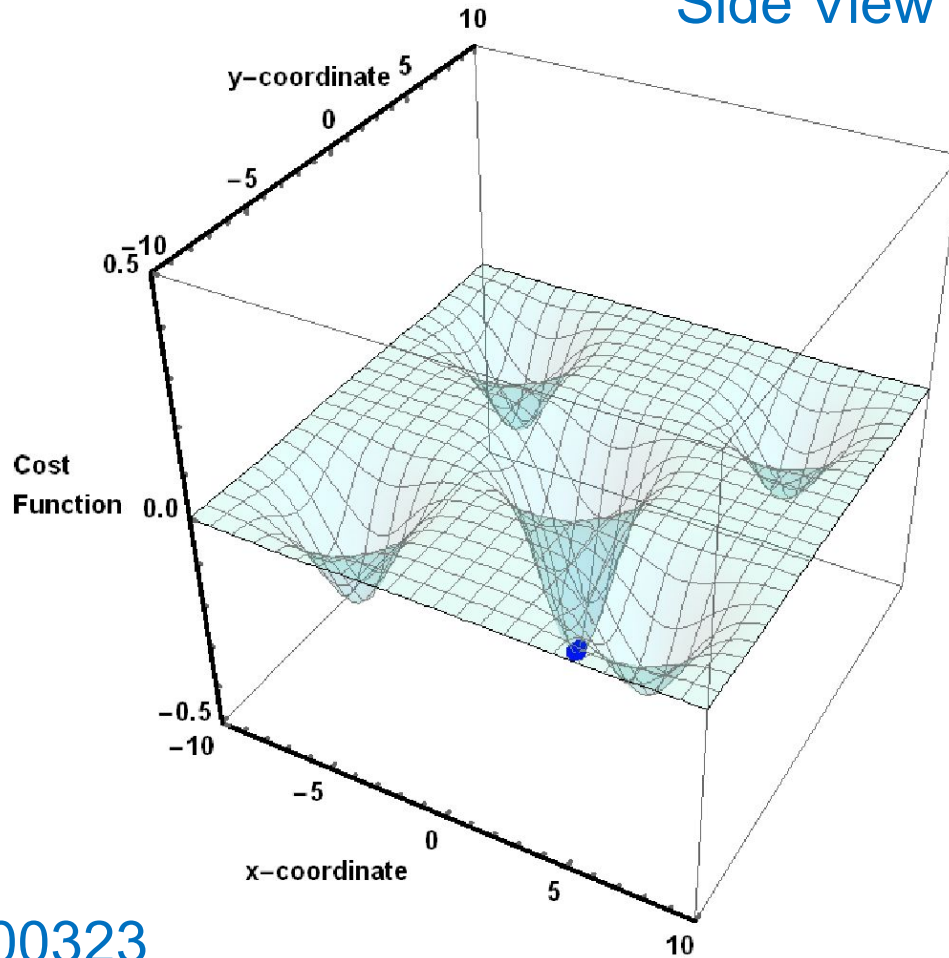


Future Direction

Top View



Side View



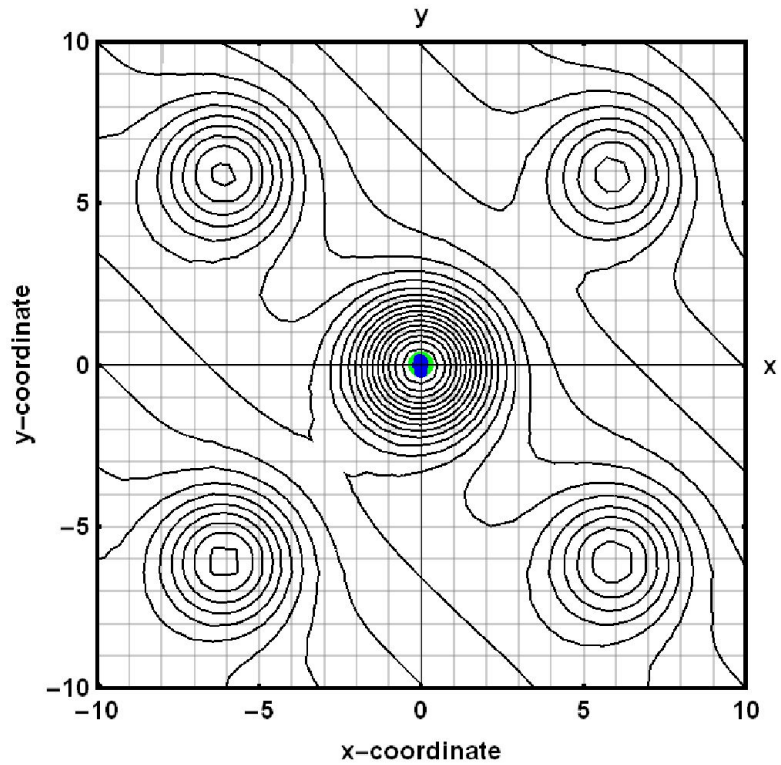
Searching Iteration 18

Pos. Var. = 0.00337919200600323

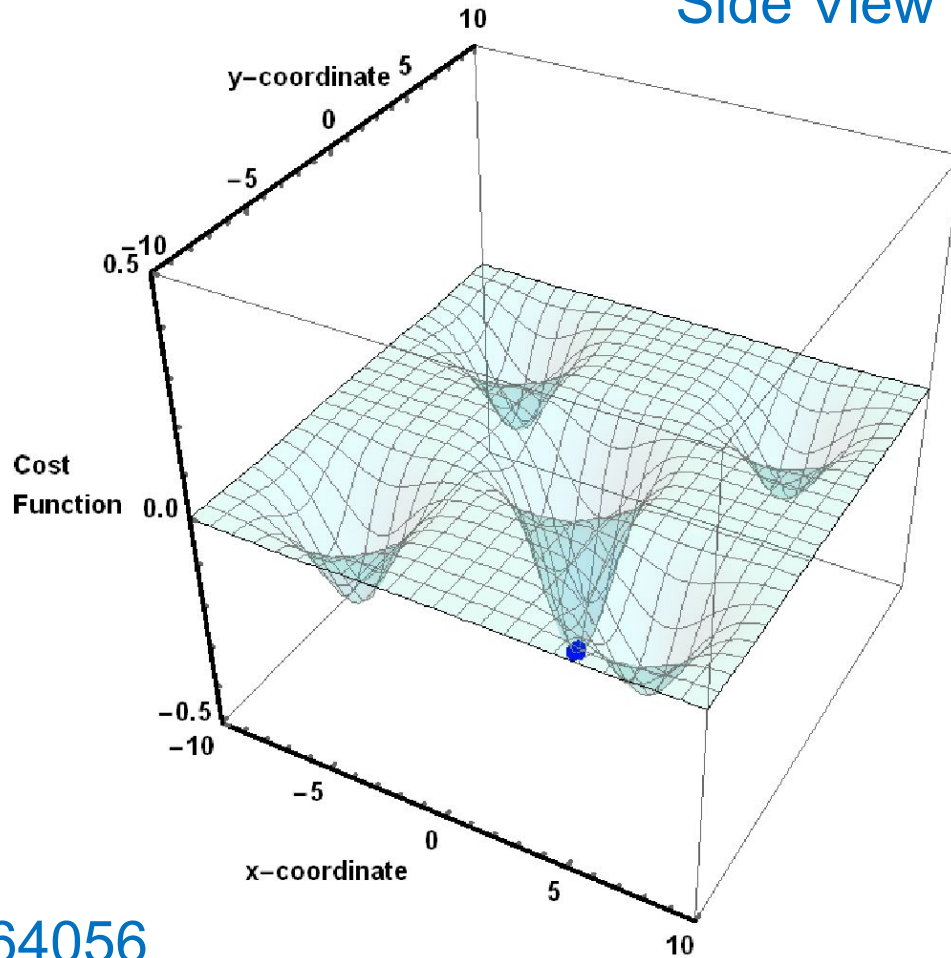


Future Direction

Top View



Side View



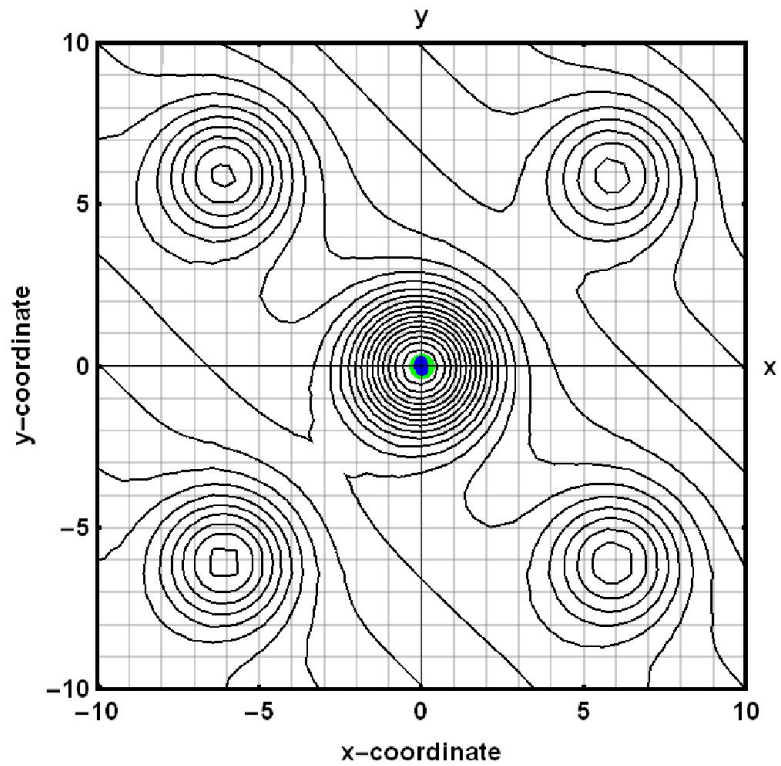
Searching Iteration 19

Pos. Var. = 0.00230846509564056

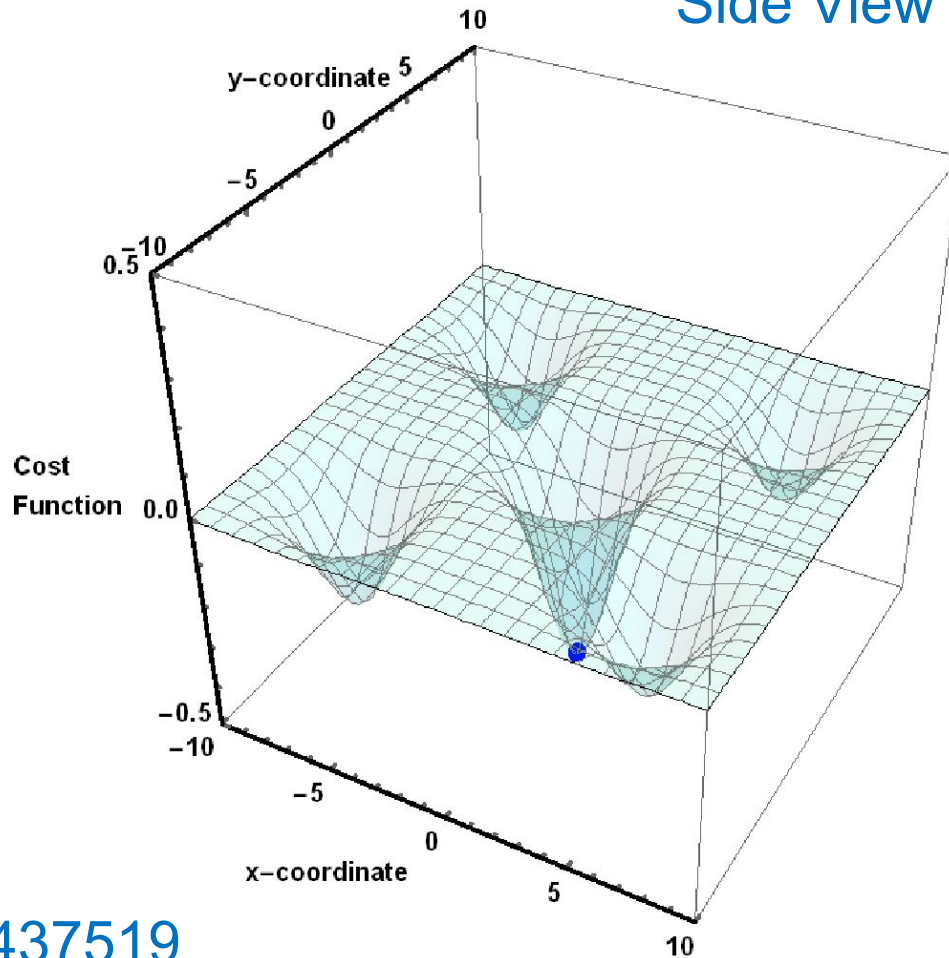


Future Direction

Top View



Side View



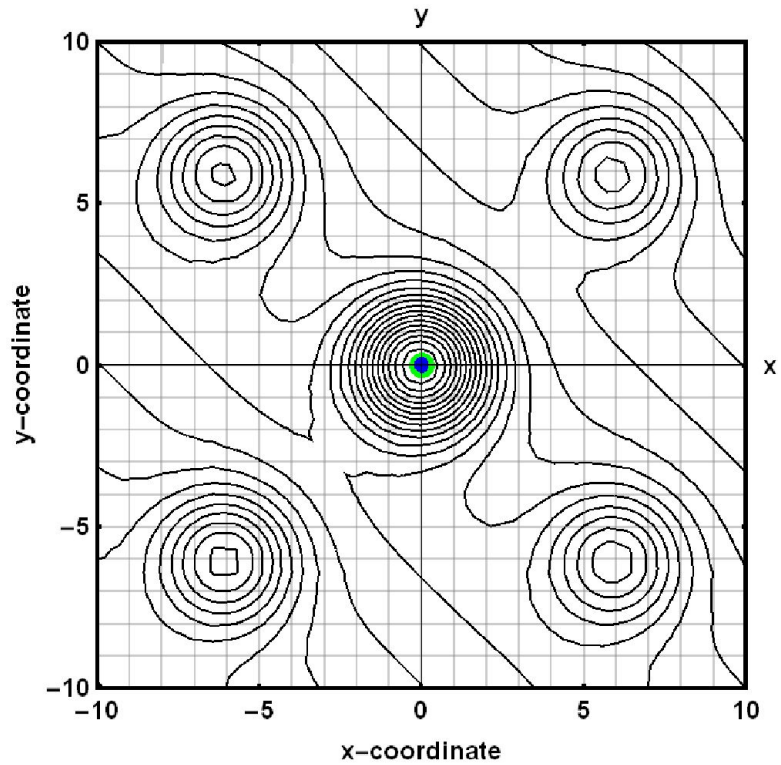
Searching Iteration 20

Pos. Var. = 0.000906775945437519

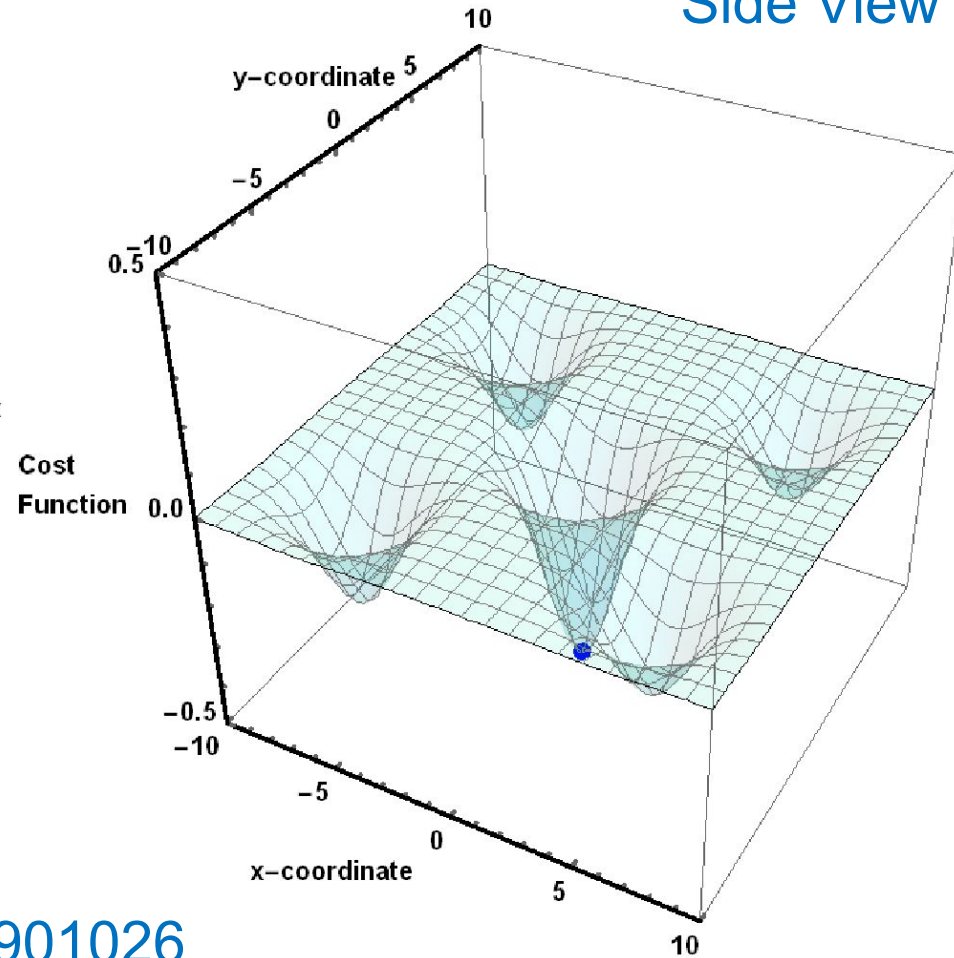


Future Direction

Top View



Side View



Searching Iteration 21

Pos. Var. = 0.000365528942901026



Future Direction

- **Applications for PSO**

- **search & rescue mission: group of soldiers moving constantly while drones are coordinated to search for them**
- **missile attack: an aircraft is moving evasively while missiles are coordinated to create a collision**



Future Direction

- PSO depends on the optimal point being static (stationary) so that the collective memory can be share among search agents
 - in real-life application, target is moving and sometimes splitting for survivability
 - PSO must be modified to address this changing factor that depends on time



Future Direction

- **IEEE IoT, Seattle, WA, June 2022**
 - **Pham, T. “Using Swarm Intelligence for Search & Recue Mission”**

- **IEEE/ISMCR, Rio, Brazil, September 2022**
 - **Pham, T., Marine, L., & K. Krishen. “Using Swarm Intelligence to Coordinate Missiles to Attack an Aircraft”**



Conclusion

- **It has been shown that an AI algorithm can push an aircraft in a pitch rotation to avoid collision with a heat seeking missiles**
 - **the algorithm was extended to avoid multiple missiles attacking at the same time**
 - **the advantage of the algorithm is the human-like behavior at the much faster reaction time of a computing machine**



Thank you very much

Merci beaucoup

Muchas gracias

Cám ơn rất nhiều

非常感謝

Grazie mille

Muito obrigado

Moltes gràcies

आपका बहुत बहुत धन्यवाद

