

Wind farm layout optimization via evolutionary algorithm

Jonathan Haag

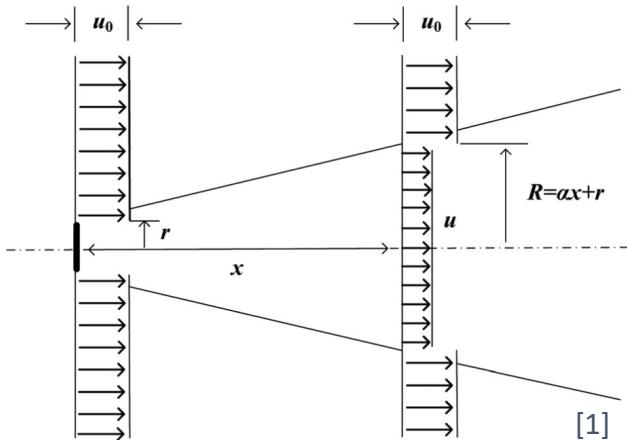
DD2365 Advanced Computation in Fluid Mechanics

KTH VT23



General setup

- How to place turbines to maximize the annual energy production?
- Problem: wake effect



Objective

- How much can we increase the production compared to a random layout?
- How does this scale with the number of turbines?
- Does the mesh resolution affect the findings? Can we contain the computational cost?

Method

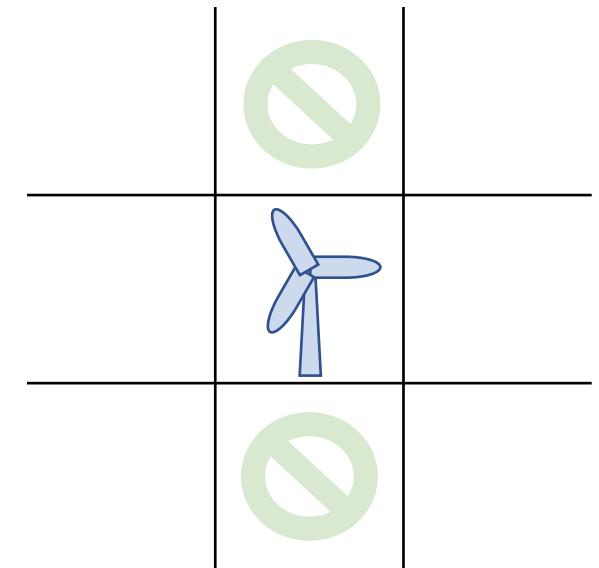
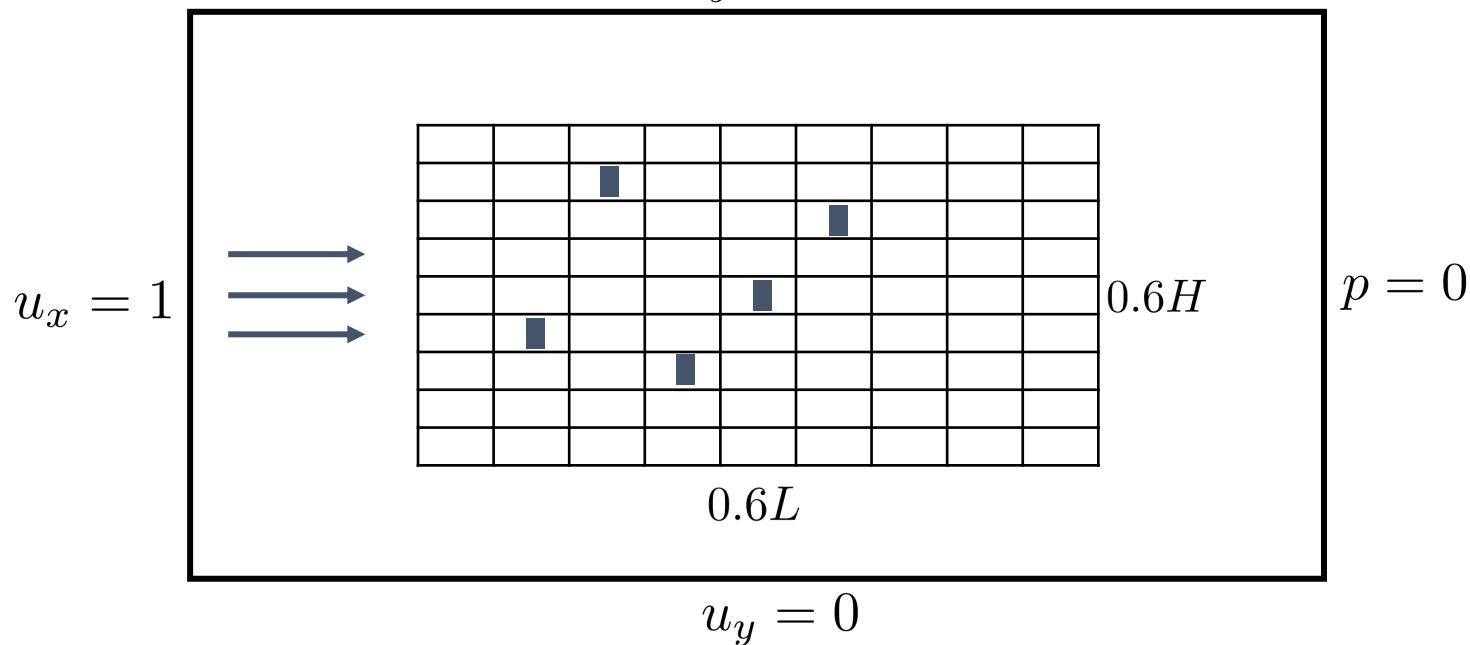
Wind farm model

Navier Stokes Brinkman:

$$\frac{\partial}{\partial t} u + u \cdot \nabla u - \frac{1}{\rho} \nabla \cdot \sigma(u, p) + \frac{\nu}{K} (u - u_s) = 0$$

$$\nabla \cdot u = 0$$

$$u_y = 0$$



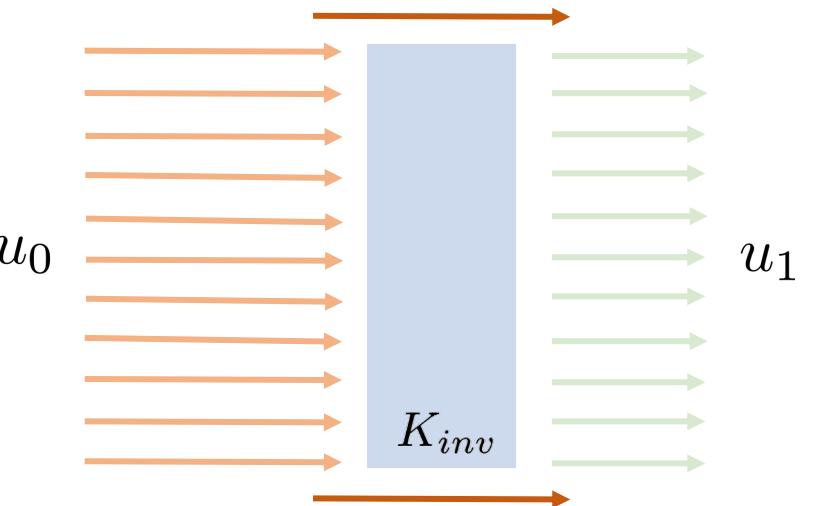
Wind farm model - Permeability

$$K(x, y) = \begin{cases} 1/K_{inv}, & \text{if } (x, y) \in \text{turbines} \\ \infty, & \text{else} \end{cases}$$

In literature: $u_1 \approx \frac{2}{3} \cdot u_0$

Experimental finding: $K_{inv} = 8 \cdot 10^4$

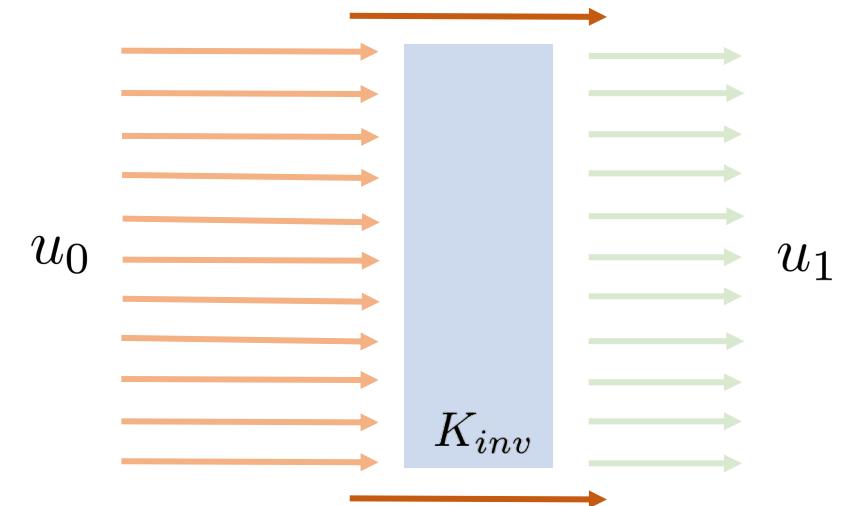
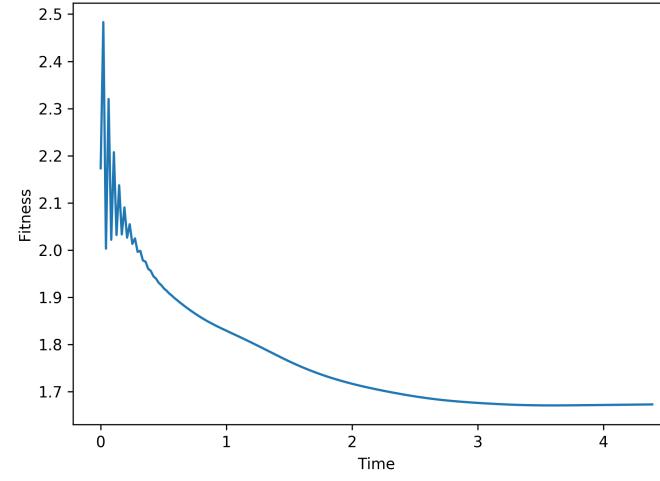
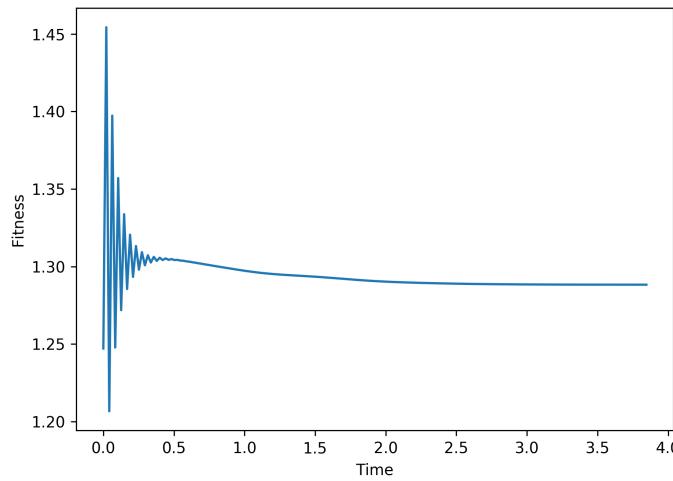
Production estimate: integrating $u_{0,x}$ for all turbines



Wind farm model – Production

Production estimate: integrating $u_{0,x}$ for all turbines

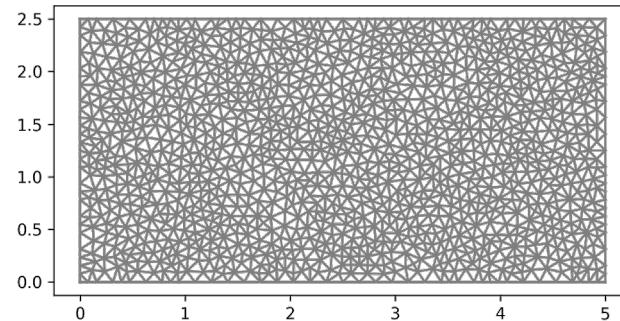
Choose T based on convergence of the production



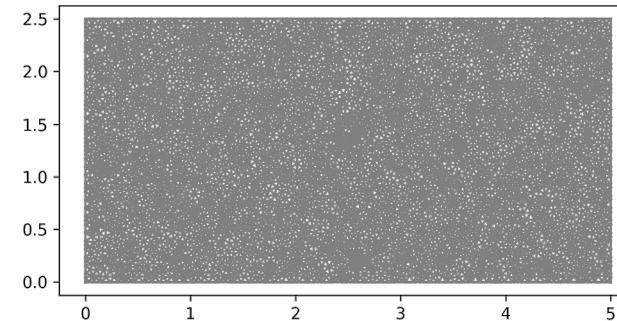
Wind farm model - Mesh

As always: balancing accuracy and computational burden

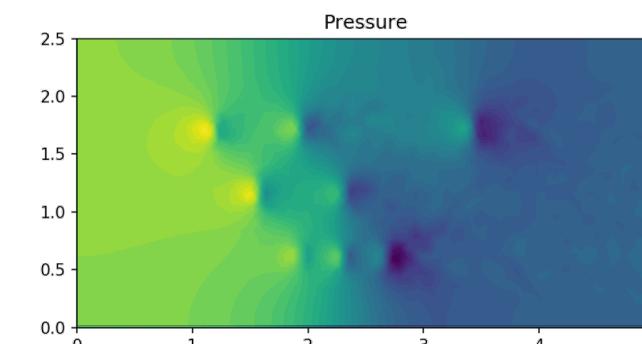
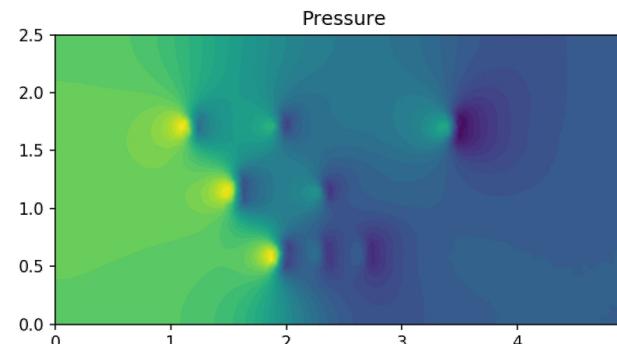
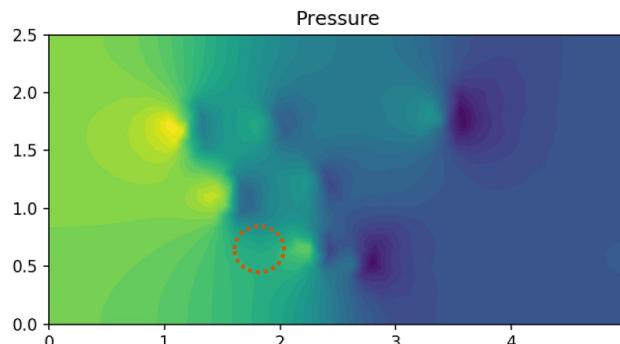
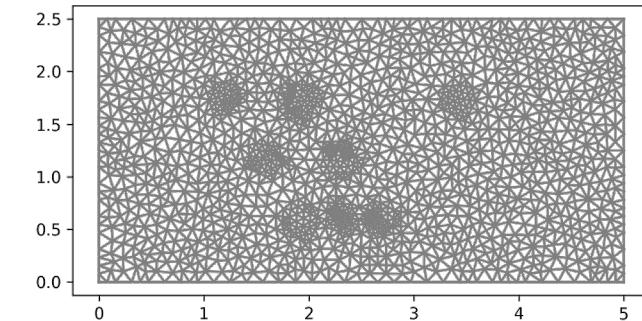
Resolution = 32



Resolution = 64



Locally refined



CFD – Optimization Coupling



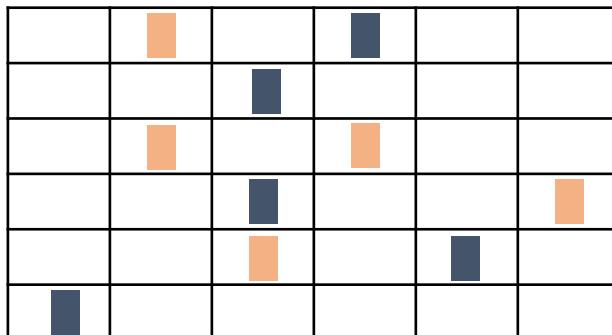
Evolutionary algorithm

Algorithm 1 Evolutionary Optimization Metaheuristic

```
Set parameters, create initial population
while termination condition not met do
    Evaluate fitness of individuals
    Select best individuals
    Crossover to create offspring
    Mutate offspring and survivors
end while
```

Population: set of layouts
Fitness: production of single layout

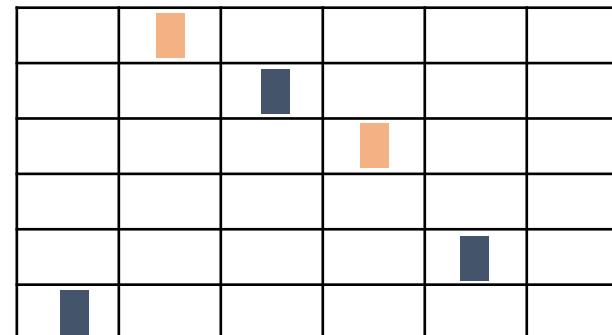
Best individuals



Layout 1

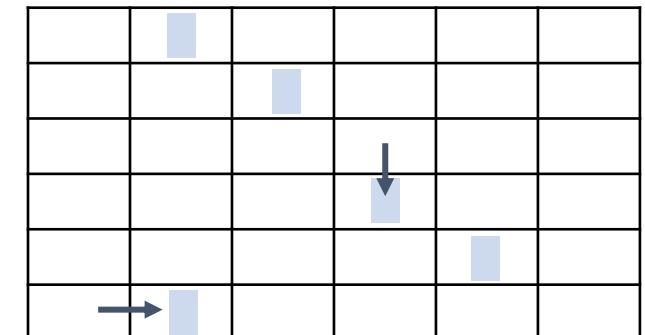
Layout 2

Crossover



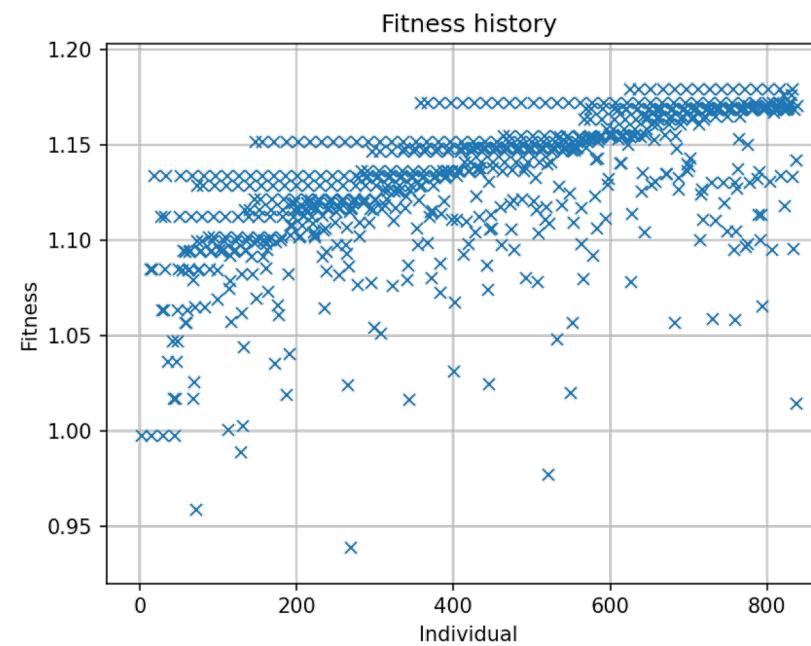
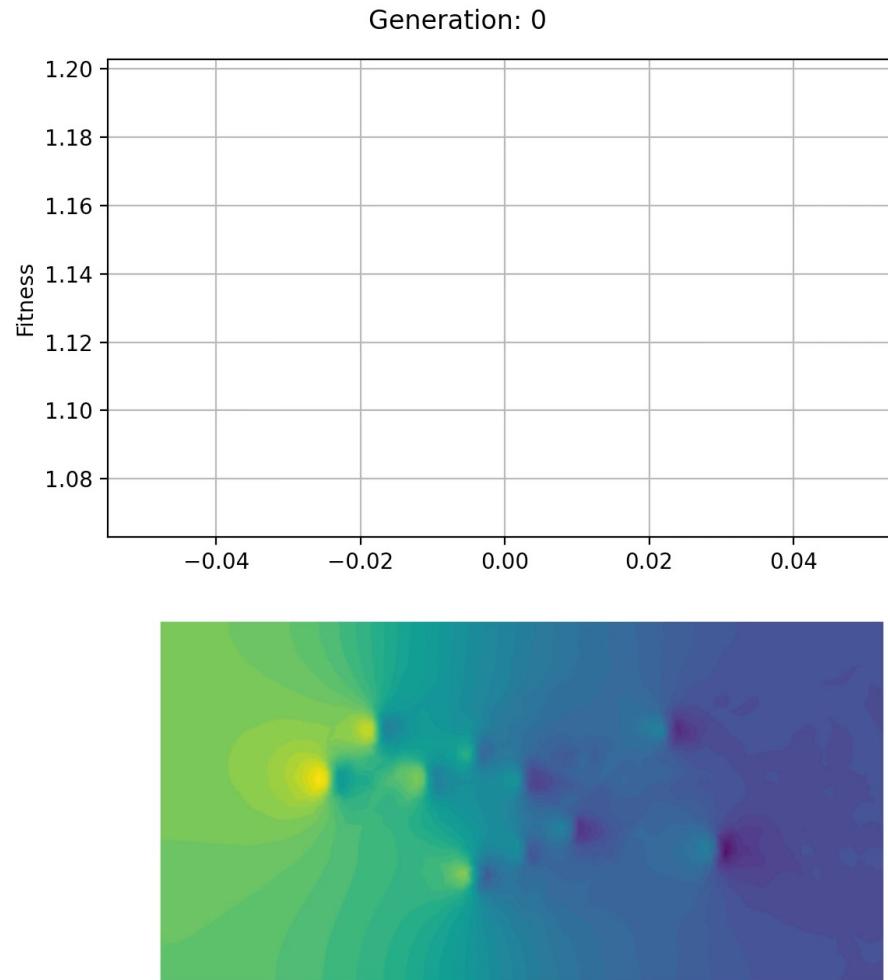
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Mutation



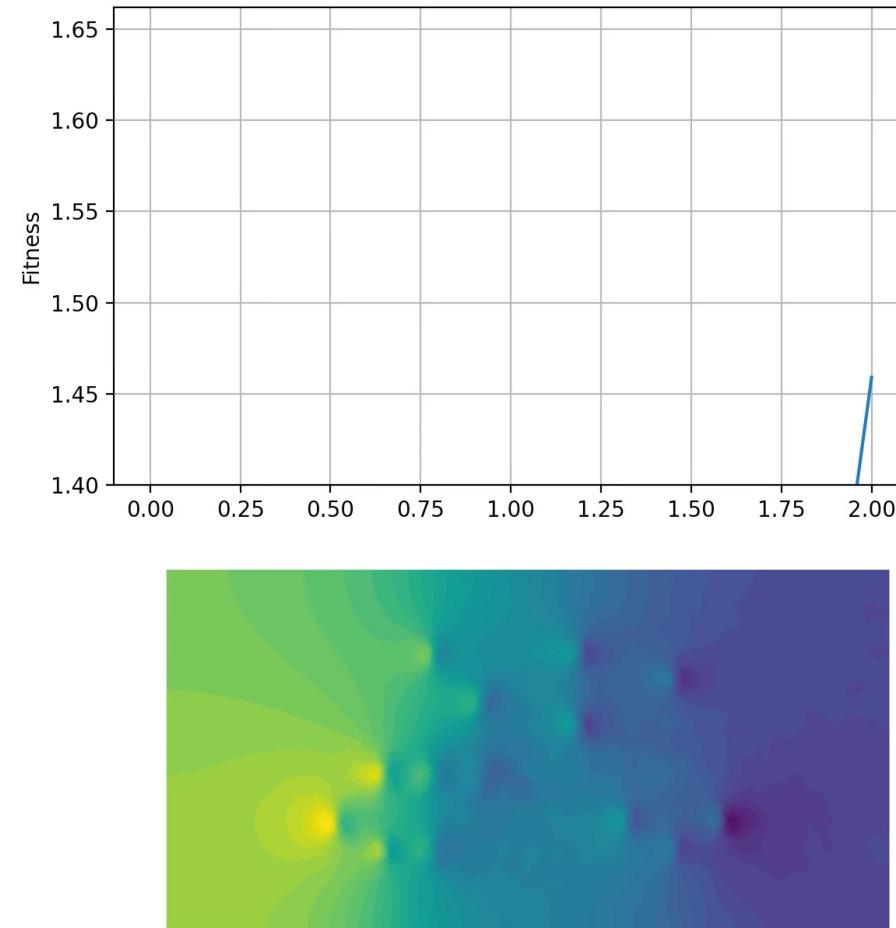
Results

10 Turbines

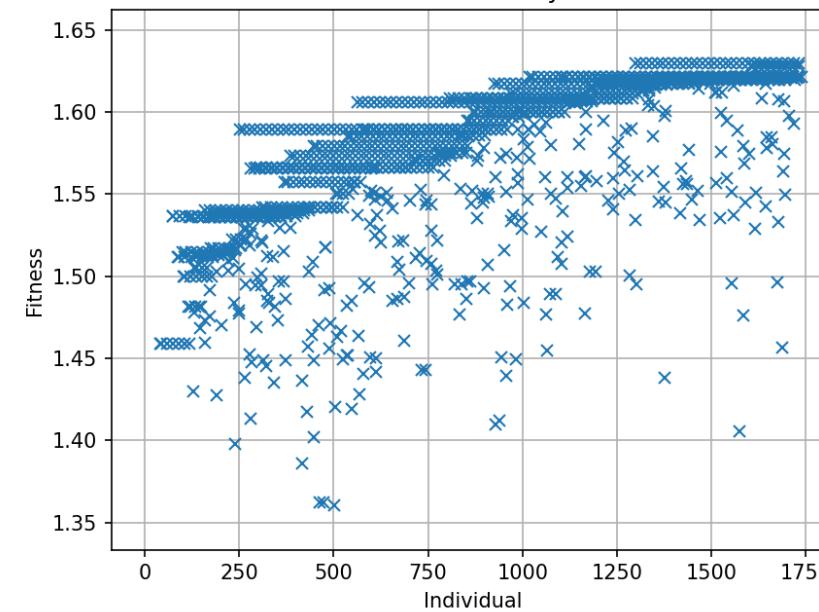


14 Turbines

Generation: 2

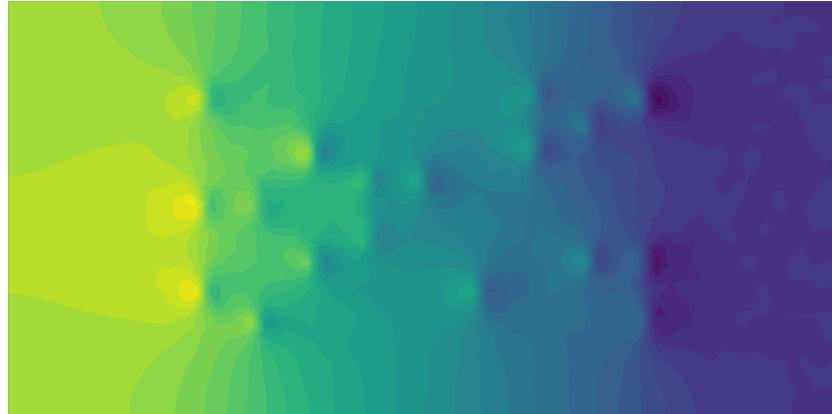


Fitness history

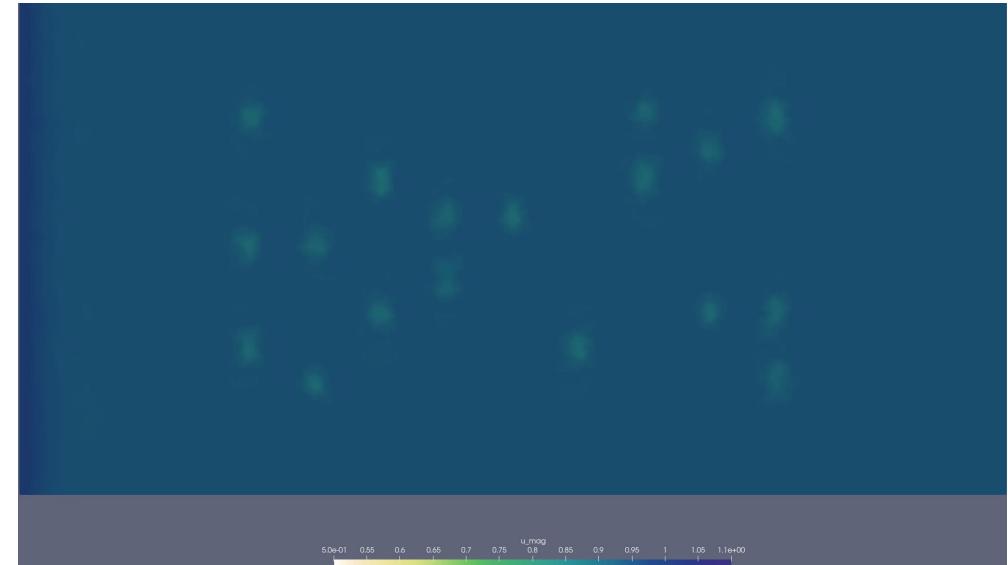


18 Turbines

Best layout



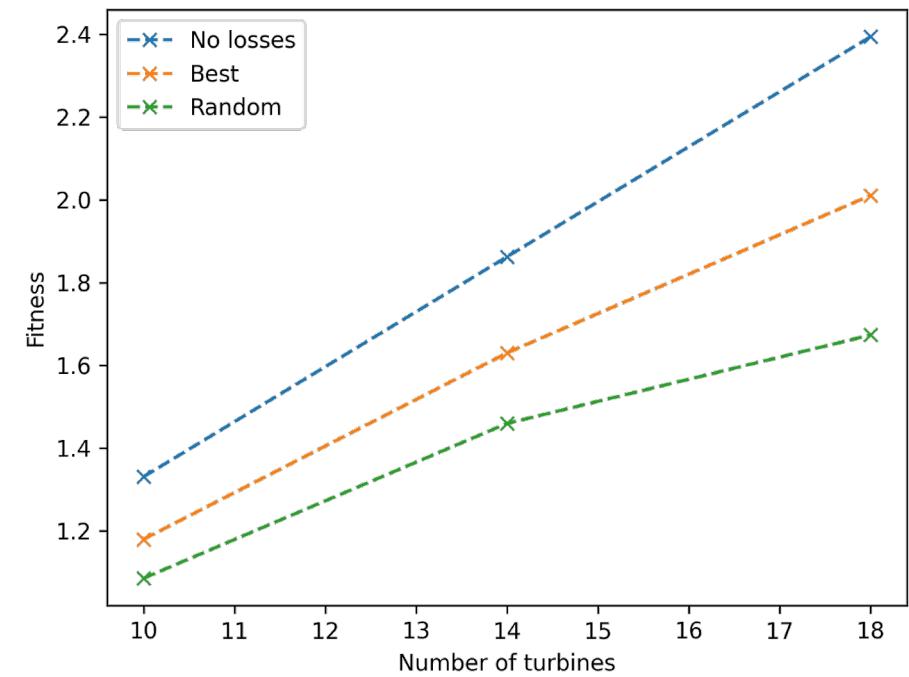
Third best layout



Discussion

Results Overview

- Local mesh refinement necessary
- Production increase of up to 20% compared to random layout
- Production per turbine decreases for larger farm
- Runs took between 6 and 18 hours
- Generally diagonal layouts are favorable



Outlook

- Parallelization of fitness evaluation
- Extend to or compare with 3D, use wake model
- Larger and more complex domain
- Varying wind directions

References

- [1] Chen, K., Song, M. X., He, Z. Y., & Zhang, X. (2013). Wind turbine positioning optimization of wind farm using greedy algorithm. *Journal of Renewable and Sustainable Energy*, 5(2), 023128.
- [2] Cruz, L. E. B., & Carmo, B. S. (2020). Wind farm layout optimization based on CFD simulations. *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, 42, 1-18.