Informatik-Kolloquium

der
Friedrich-Schiller-Universität Jena
Regionalgruppe Ostthüringen der Gesellschaft für Informatik (GI)
Fachhochschule Jena

Markus Wagner

School of Computer Science, The University of Adelaide, Australia

"A Fast and Effective Local Search Algorithm for Optimizing the Placement of Wind Turbines"

21. August 2012, 14:00 Uhr
Ernst-Abbe-Platz 2, Raum 3319

University: The University of Adelaide

Field: Computer Science

(Jena to Adelaide:
ca. 15,000 km)

School of Computer Science

4 professors, ca. 60 (Senior) lecturers and research staff, ca. 40 PhD students

Topics: Computer Vision, Distributed High-Performance Computing, **Evolutionary Computation**, Software Engineering, …

Evolutionary Computation

Prof. Zbigniew Michalewicz
Dr. Frank Neumann
→ EC theory/applications

My Focus

EC theory: genetic programming
(time to evolve programs, w.c. runtime analysis)

Multi-objective optimization: continuous domains
(many objectives, quality measurements)

Applications: cycling, wind energy

…

A Fast and Effective Local Search Algorithm for Optimizing the Placement of Wind Turbines

or

How to Produce more Wind Energy

Markus Wagner
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University of Adelaide
Adelaide, Australia

Joint work with Jareth Day (UoA), Frank Neumann (UoA),
Una-May O'Reilly (MIT), Kalyan Veeramachaneni (MIT)

Other joint work with Tobias Friedrich (FSU), Katya Vladislavleva (EA)

Motivation

Renewable Energy

- Has gained increasing interest
- Is clean
- Substantial to decrease CO_2 emission
- Is a huge market
- Large developing effort
- Has many challenging questions

Wind Energy

- Major player in renewable energy
- Since 2005 the cumulative installed capacity of wind energy within the EU has almost doubled till 2010 (from 40 GW to 74 GW).
- In 2009, 39% of all new energy capacity installed in the EU was based on wind.
- Roughly 8800 wind turbines in Europe which helped to save 180 Mio tons of CO_2 since the beginning of 2009.

Largest Wind Farms

- Roscoe Wind Farm (Texas, 627 turbines, 781 MW)
- Vlorë Wind Farm (Albania, 250 turbines, 500 MW)

Recent News

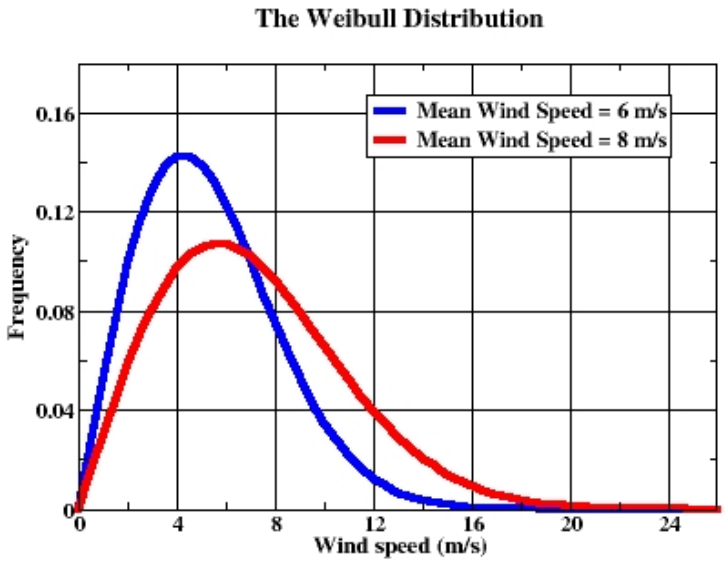
- Thanet Wind Farm (Offshore (UK), 100 turbines, 300 MW)
- Ontario's 21,000 Megawatts Offshore Potential
- Google invests 38.8 Mio. USD in Wind Energy
- Special Report on Renewable Energy Sources and Climate Change Mitigation 2011: 77% renewable energy in 2050

Source: Wind Power Ninja

Wind Speed and Energy

Wind Speed

- Most crucial for energy production
- Varies over time
- Depends on seasonal effects
- Weibull distribution gives a good representation of the variation in hourly mean wind speed over a year at many typical sites

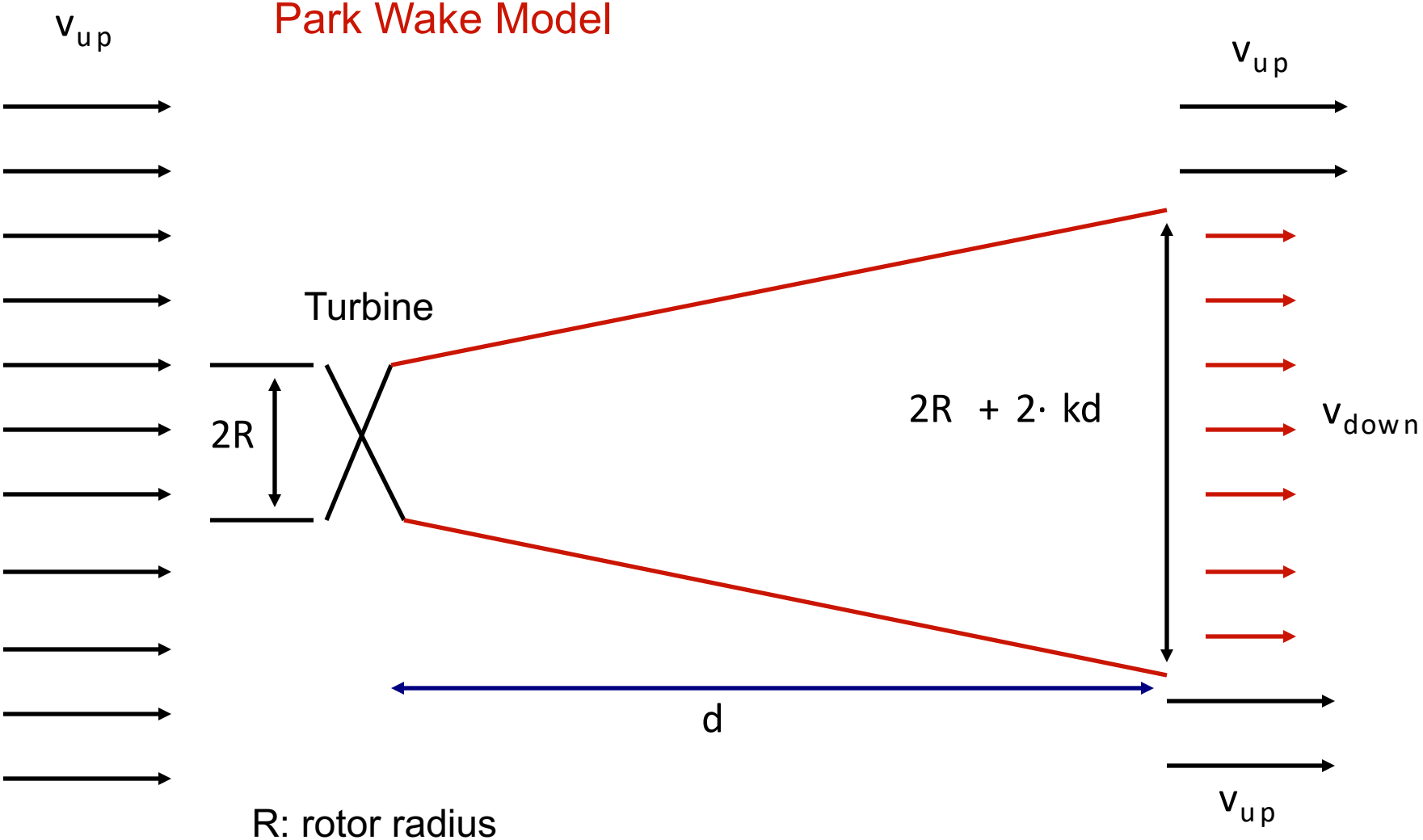


Source: Canadian Wind Energy Atlas

Wake

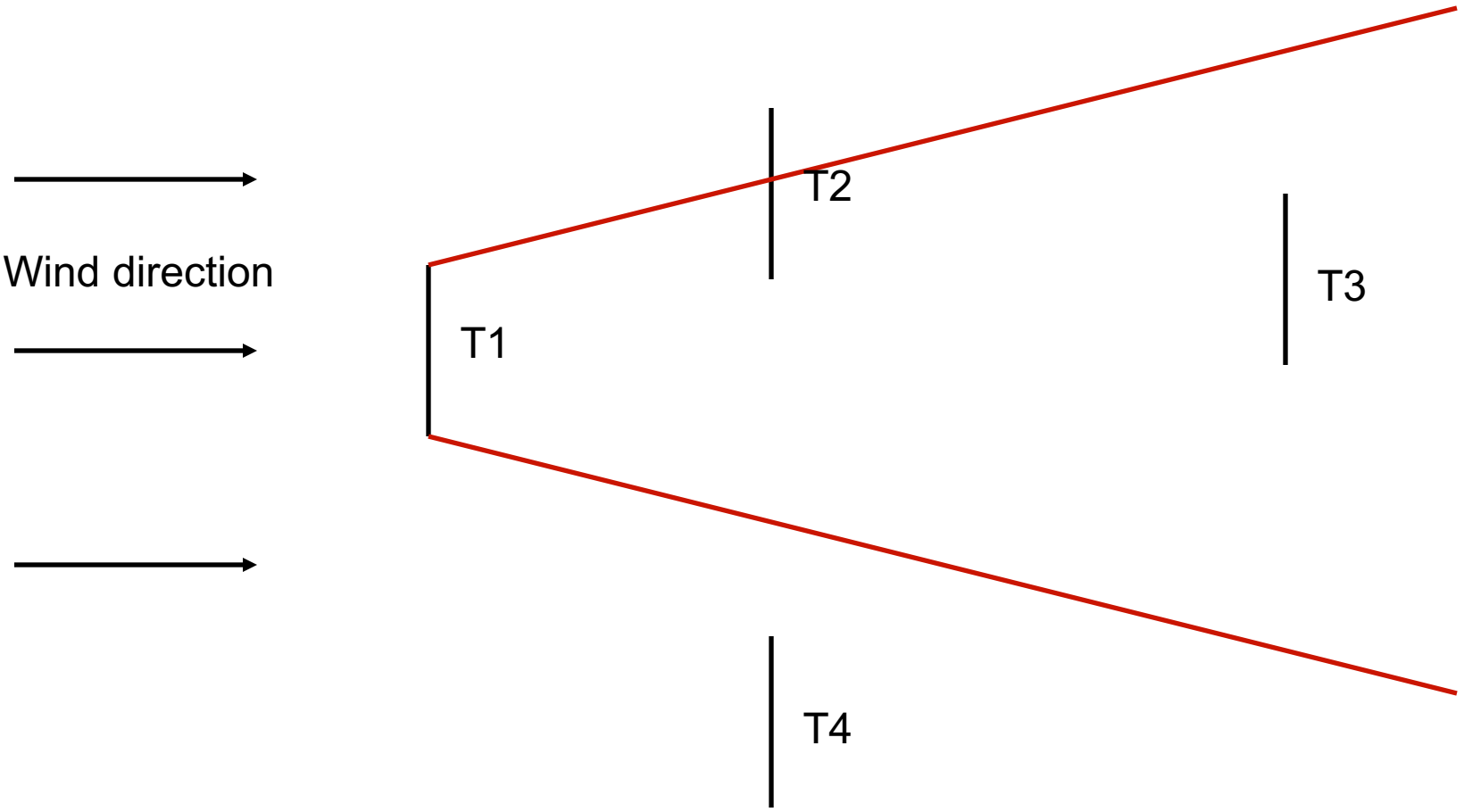
Source: Cooperative Institute for Research in Environmental Science

Park Wake Model



R: rotor radius

Wake effect



Computation of the wake effect (Kusiak and Song 2010)

Let $X = \{x_1, \ldots, x_n\}$ and $Y = \{y_1, \ldots, y_n\}$ be x and y coordinates of the n turbines

for $i = 1$ to number of turbines **do**
  for $\theta = 0^0$ to 360^0 **do**
    for $j = 1$ to n-1 and $j \neq i$ **do**

$$\delta_{i,j} = cos^{-1}\{\frac{o+R/\kappa}{\sqrt{(x_i - x_j + (R/\kappa)cos\theta)^2 + (y_i - y_j + (R/\kappa)sin\theta)^2}}\}$$

$$Vdef_{(i,j)} = u(\delta_{i,j} - \alpha)\frac{a}{(1+bd_{i,j})^2}$$

    end for

$$Vdef_i^{\theta} = \sqrt{\sum_j (Vdef_{(i,j)})^2}$$

$$c_i(\theta) = c_i(\theta) \times (1 - Vdef_i)$$

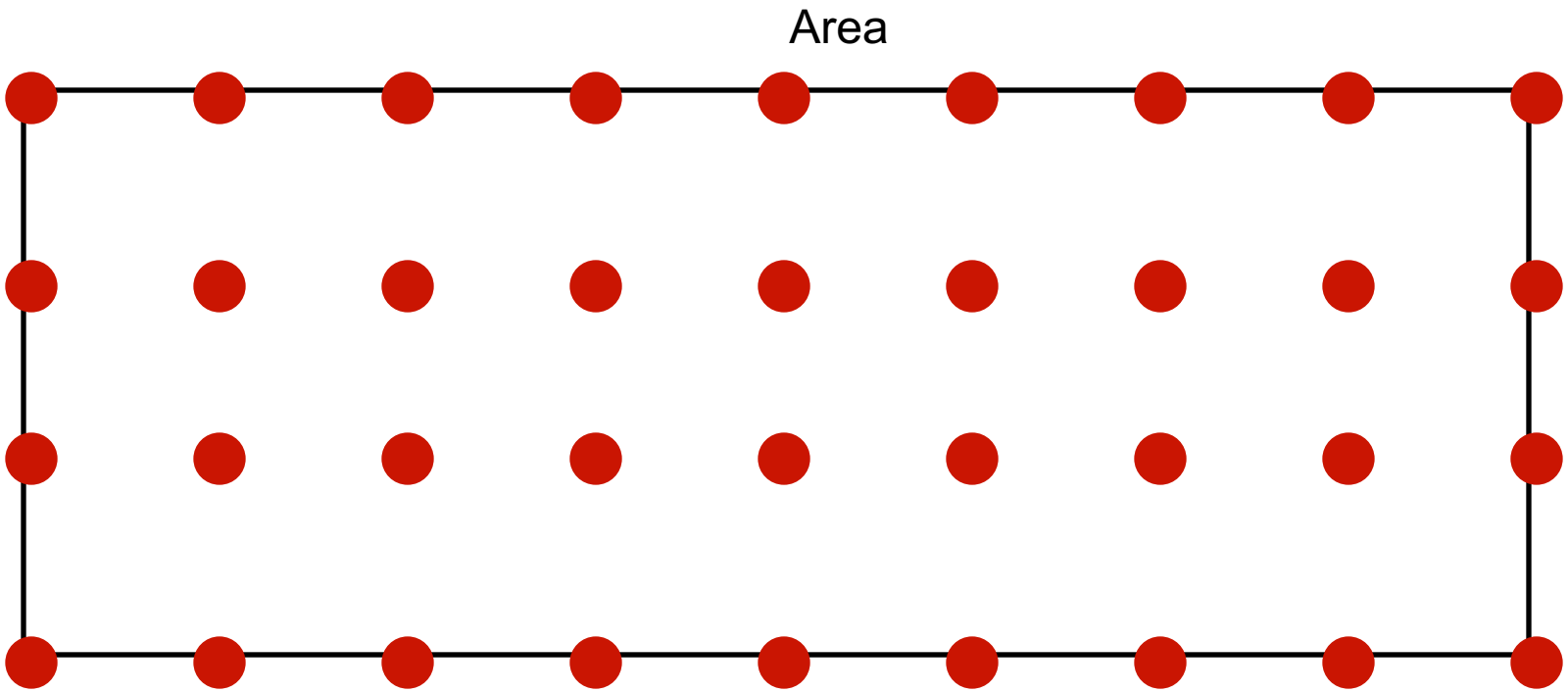
  end for
end for

Wake effect only changes scaling parameter of Weibull distribution

Experimental Study

Turbine Placement on wind farm

Maximal spacing initialization



Wind Scenario (Kusiak and Song, Renewable Energy 2010)

θ^{l-1}	θ^{l}	k	c	$P(\theta)$
0	15	2	7	0.0002
15	30	2	5	0.008
30	45	2	5	0.0227
45	60	2	5	0.0242
60	75	2	5	0.0225
75	90	2	4	0.0339
90	105	2	5	0.0423
105	120	2	6	0.029
120	135	2	7	0.0617
135	150	2	7	0.0813
150	165	2	8	0.0994
165	180	2	9.5	0.1394

θ^{l-1}	θ^{l}	k	c	$P(\theta)$
180	195	2	10	0.1839
195	210	2	8.5	0.1115
210	225	2	8.5	0.0765
225	240	2	6.5	0.008
240	255	2	4.6	0.0051
255	270	2	2.6	0.0019
270	285	2	8	0.0012
285	300	2	5	0.001
300	315	2	6.4	0.0017
315	330	2	5.2	0.0031
330	345	2	5	0.0097
345	360	2	3.9	0.0317

Kusiak and Song use evolution strategy

Only results for up to 6 turbines.

Experimental Studies:

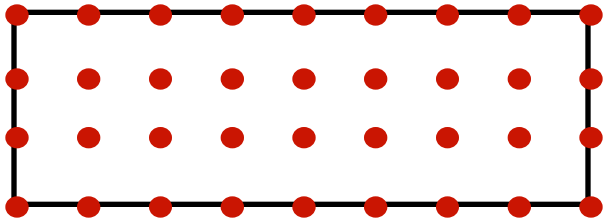
- Use maximal spacing
- Include mechanism to deal with boundary constraints
- Improves results of Kusiak and Song
- What results do we get for large wind farms?

Problem:

- Evaluation is very costly for large number of turbines (single optimization: two weeks for 1000 turbines)

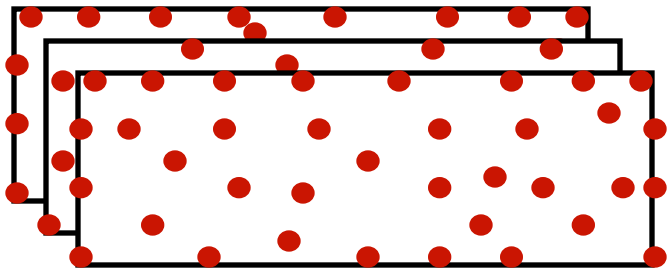
Algorithms - 1. Approach [EWEA 2011]

Covariance Matrix Adaptation Evolution Strategy (CMA-ES)



f(s)

Sample 20x from multivariate normal distribution

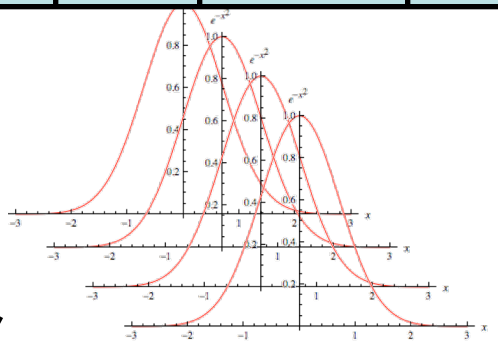


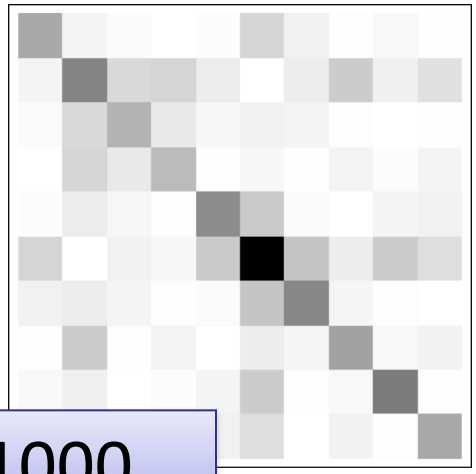
$f(s_1), f(s_2), \ldots, f(s_{20})$

update

update

X_1=0	Y_1=0	X_2=200	Y_2=350



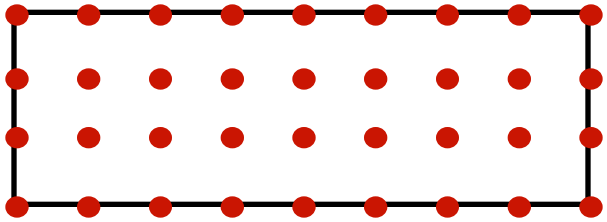


Result: pushed from 10-30 turbines to 1000

Collaboration: Hasso-Plattner-Institute Potsdam

Algorithms - 2. Approach (problem-specific) [under review]

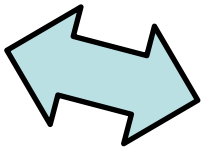
Turbine Distribution Algorithm (TDA)



X_1=0	Y_1=0	X_2=200	Y_2=350

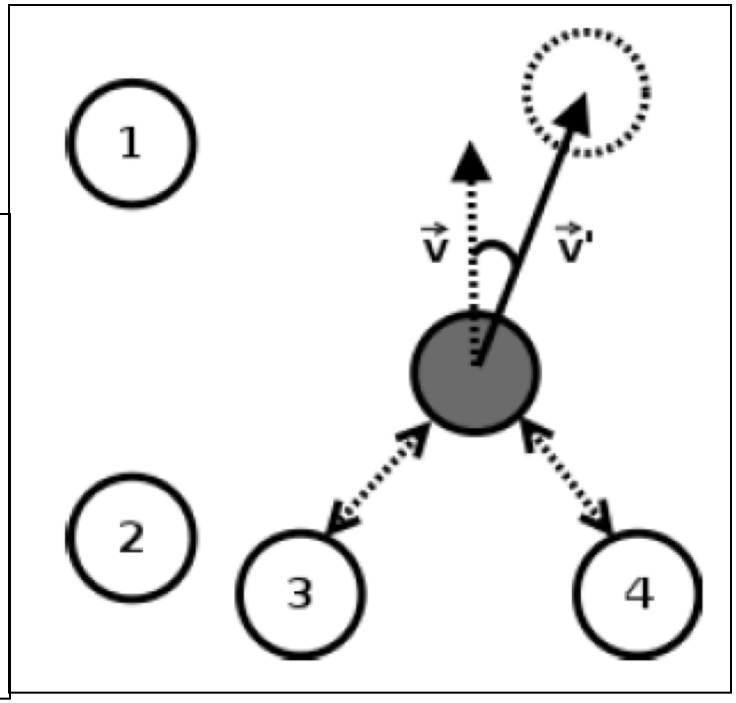
f(s)

Move 1 randomly chosen turbine



V
- direction resulting from k NN

V'
- Sampled normal distributed around V
- length is turbine specific (sampled normal distributed)



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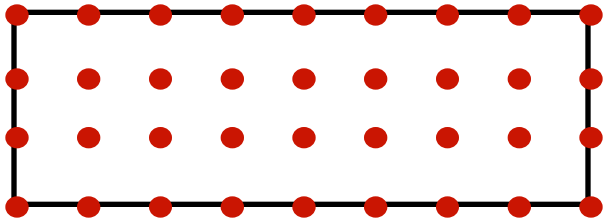

f(s)

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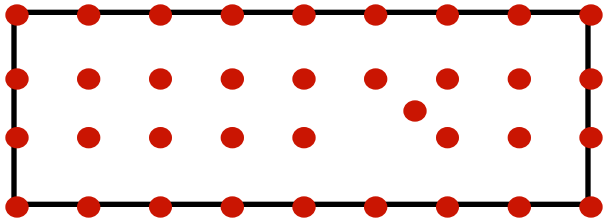
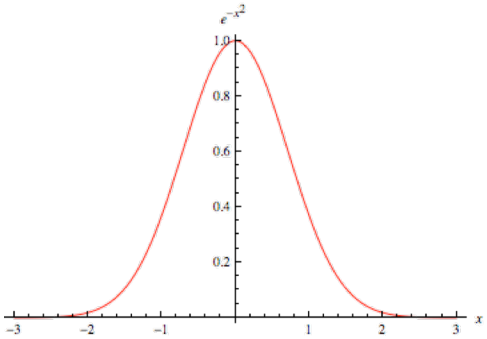


$f(s_1)$

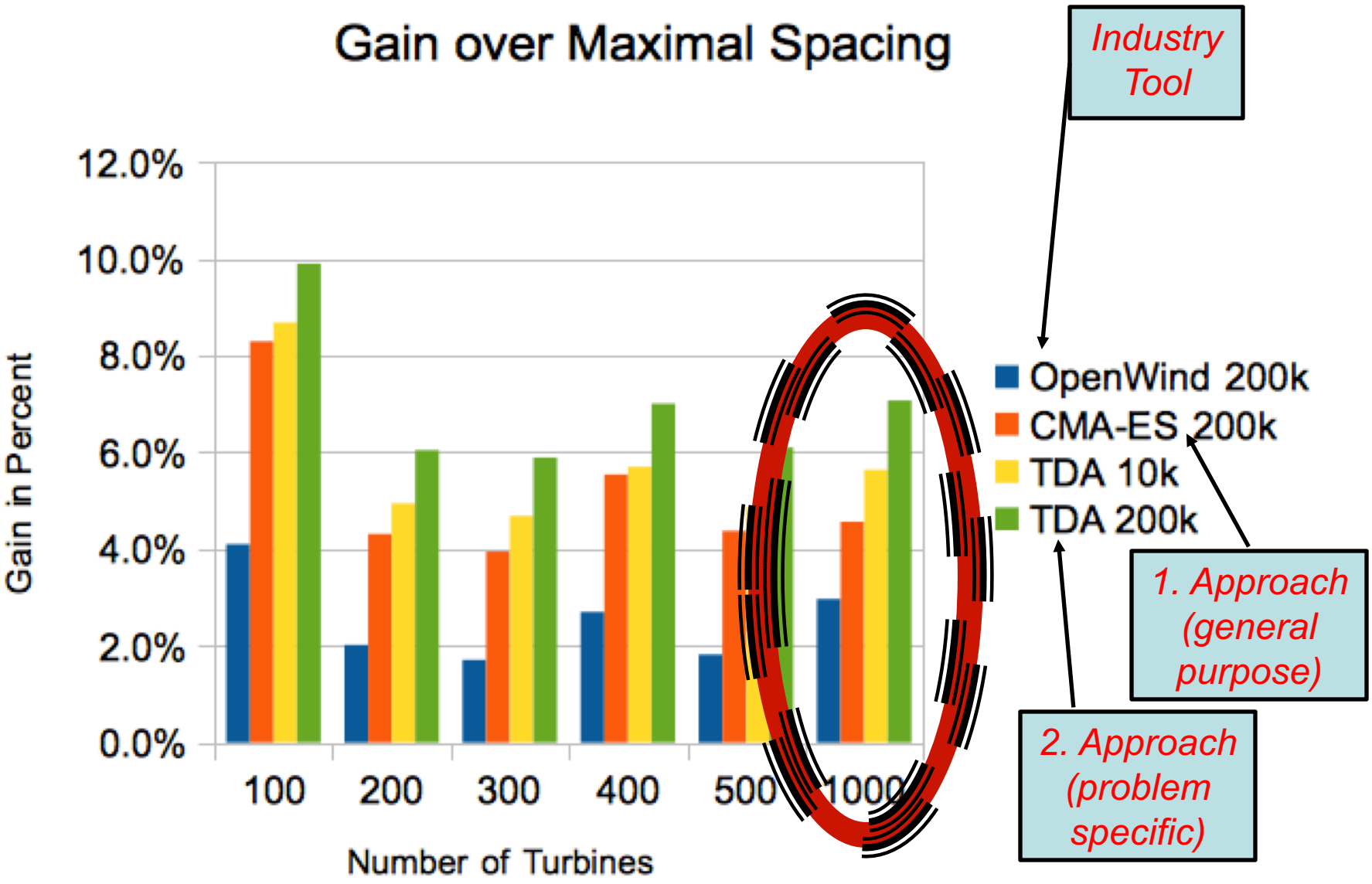
update

X_1=0	Y_1=0	X_2=200	Y_2=350



Dislocation length (per turbine) used for exploitation/exploration

Result: higher quality and speed



Can translate in **millions** of additional EUR per year

Summary

- Renewable energy is an interesting field with challenging optimization problems
- Problems are very complex
- Evolutionary algorithms *(our key technology)* are well suited for tackling these problems
- There is a lot of money in this field (grants, government support, industry funding)
- Computer Science/Mathematics should play a key role

Future Work

- Improve simulator: nonlinear power curves, mixed wind farms, more complex wake models
- Combination with other design parameters (cable length)
- Multi-objective problems
- Project at Future SOC Lab of the Hasso-Plattner-Institut (again?)

- **Use contact with industry!**

Thank you!

TODO

- insert plots WOOLNORTH from technical report
- Say: turbines in the centre receive just 70% of the wind
- Potentially state something for theoreticians (circle packing, different algorithm: volume overlap minimisation)