



Solving the Travelling Salesman Problem in Continuous Phase Domain with Neuromorphic Oscillatory Neural Networks

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► To cite this version:

Corentin Delacour, Aida Todri-Sanial. Solving the Travelling Salesman Problem in Continuous Phase Domain with Neuromorphic Oscillatory Neural Networks. AI, Neuroscience and Hardware: From Neural to Artificial Systems and Back Again, Sep 2022, Bonn, Germany. . hal-03846335

HAL Id: hal-03846335

<https://hal.science/hal-03846335>

Submitted on 10 Nov 2022

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Solving the Travelling Salesman Problem in Continuous Phase Domain with Neuromorphic Oscillatory Neural Networks



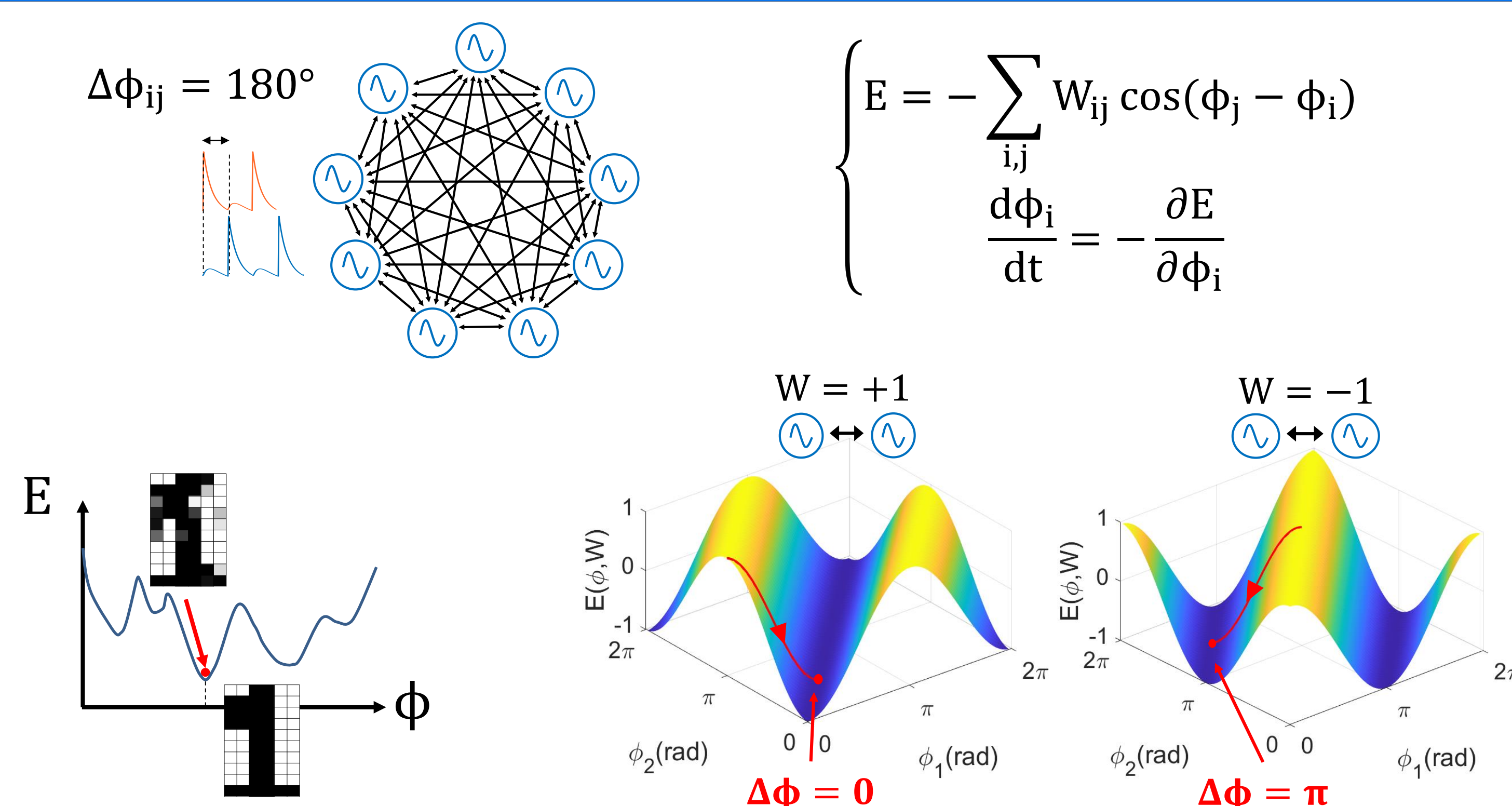
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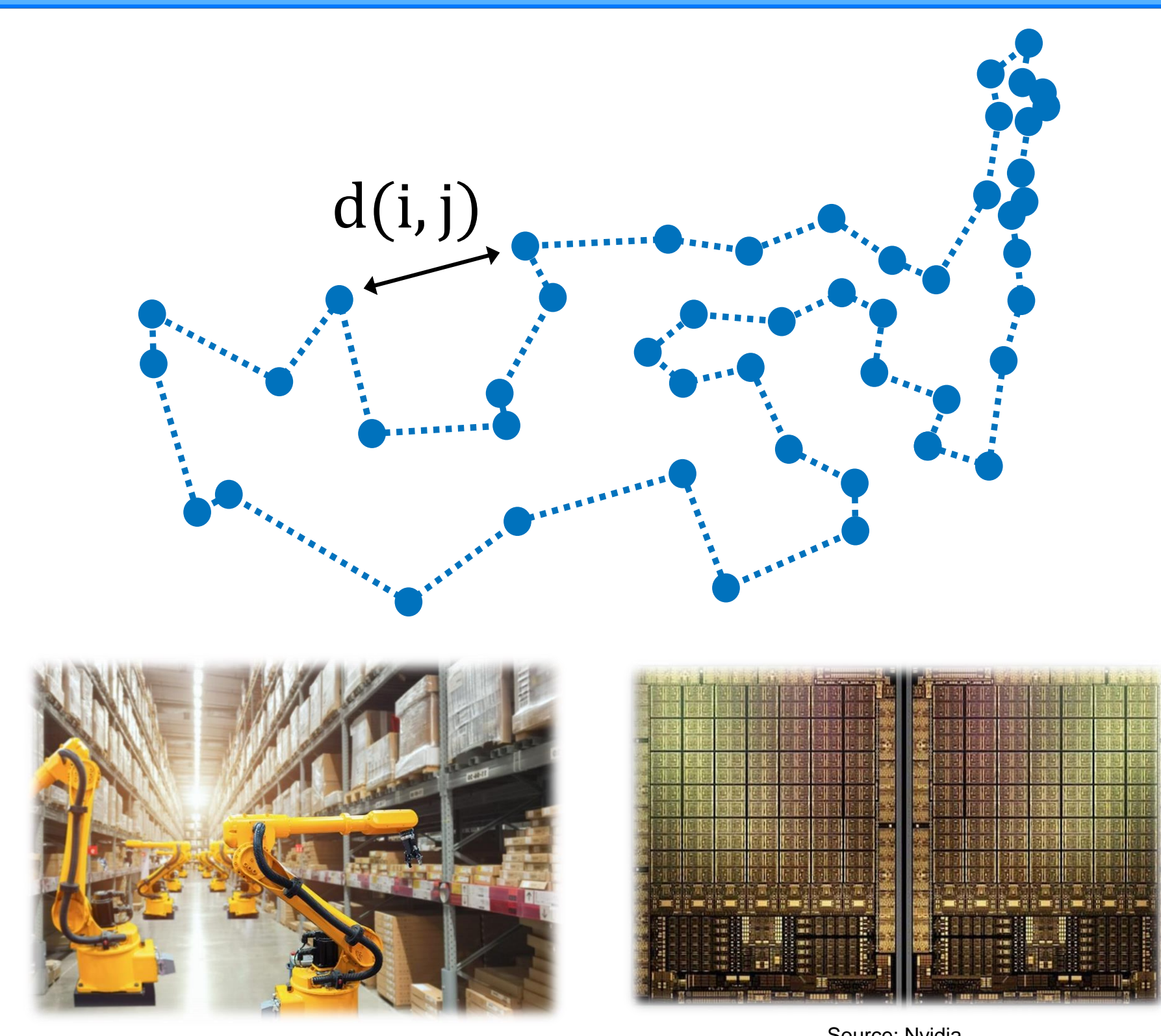
OSCILLATORY NEURAL NETWORKS

- ONNs dynamics are driven by an energy function
- Training the ONN consists in shaping the energy landscape
- ONNs can solve Ising problems or image processing tasks in robotics [1,2,3]



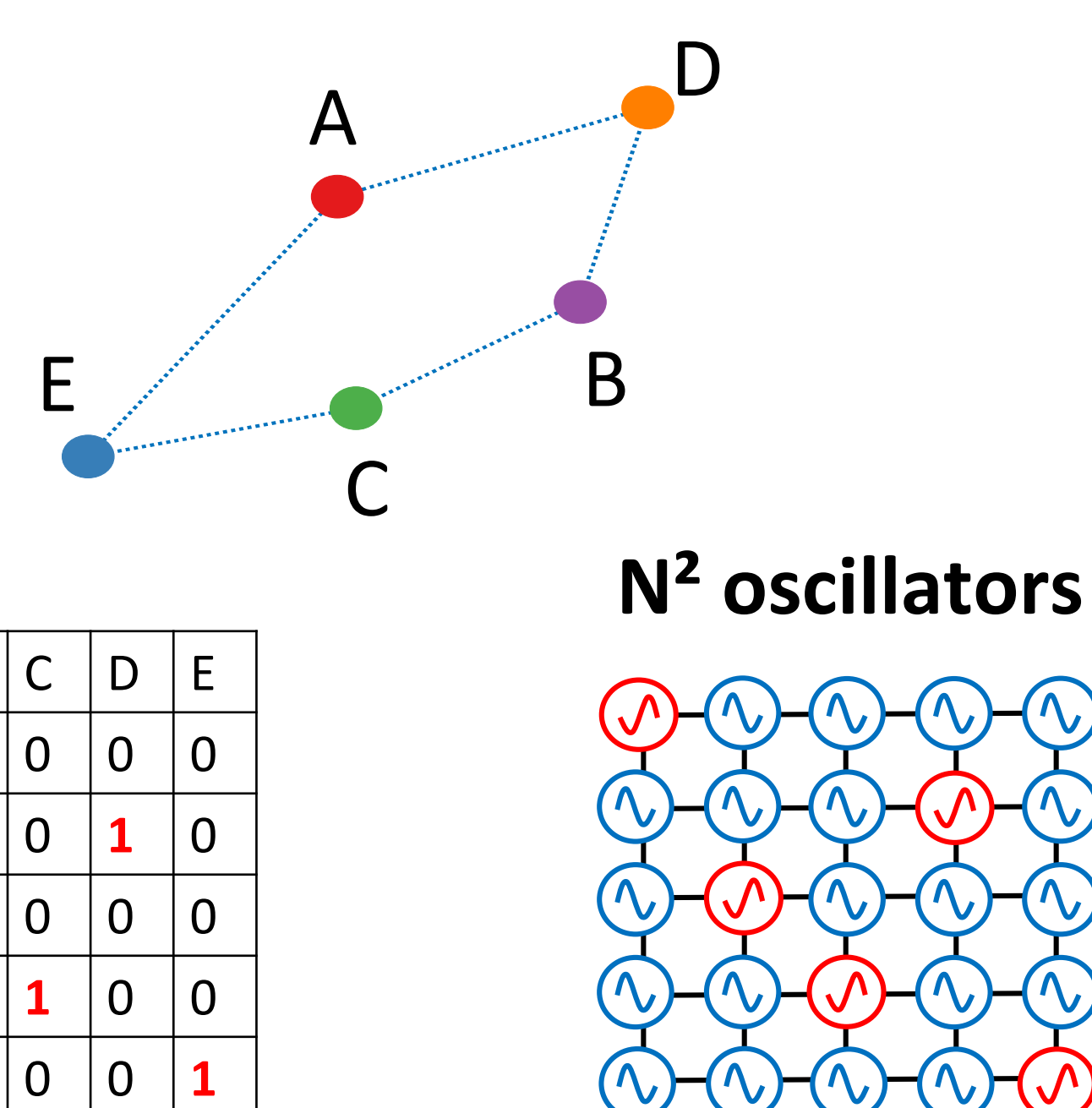
THE TRAVELLING SALESMAN PROBLEM

- Given a list of cities and their inter distances $d(i, j)$, find the shortest tour that visits each city only once
- Solving TSP is NP-hard:
 $(N - 1)!/2$ possible solutions
- State-of-the-art:
3/2 approximation algorithm from Christofides [4]
- Many applications such as Machine scheduling, warehouse pickup, VLSI routing...

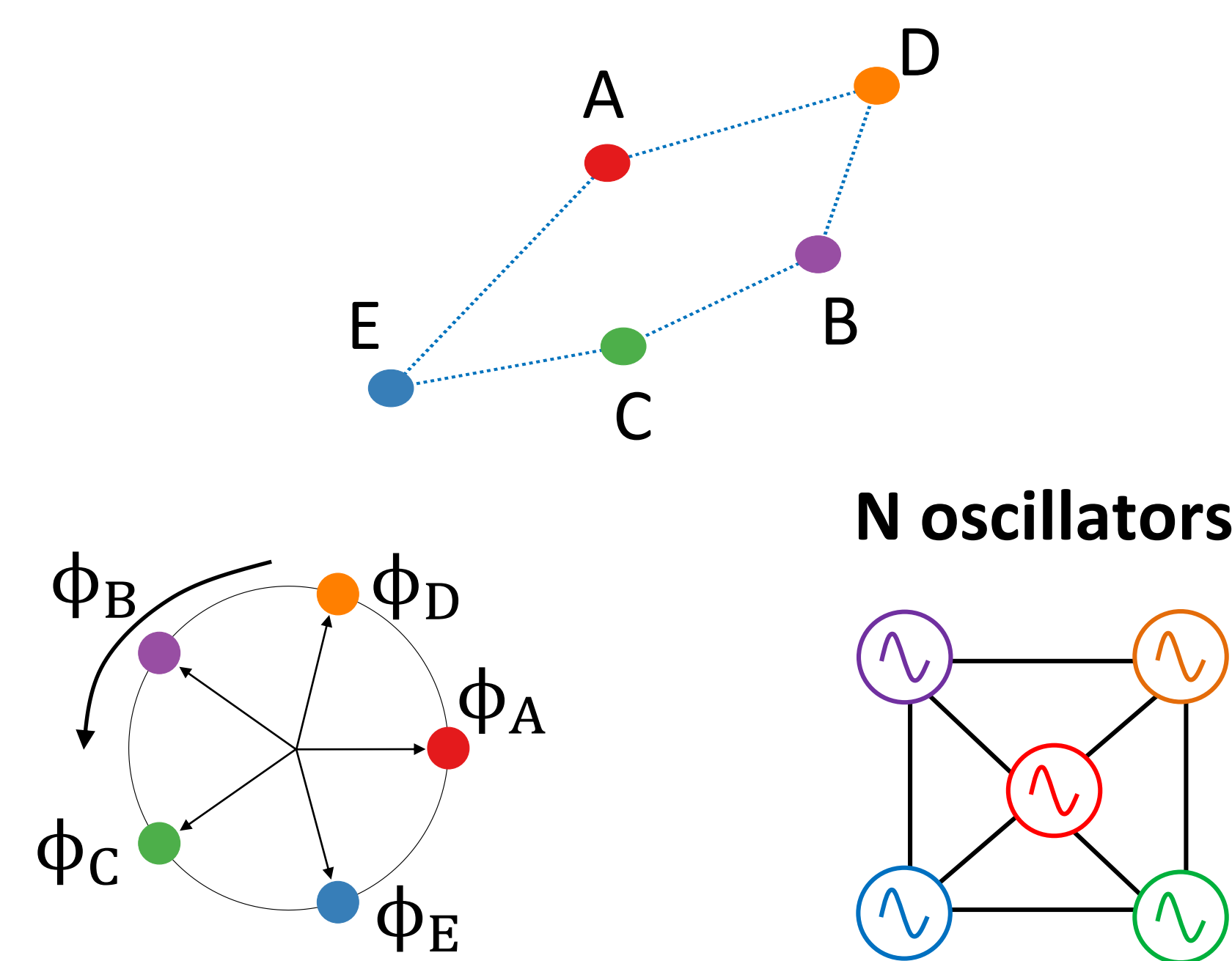


SOLVING TSP WITH ONN

WITH BINARY PHASES (ISING)



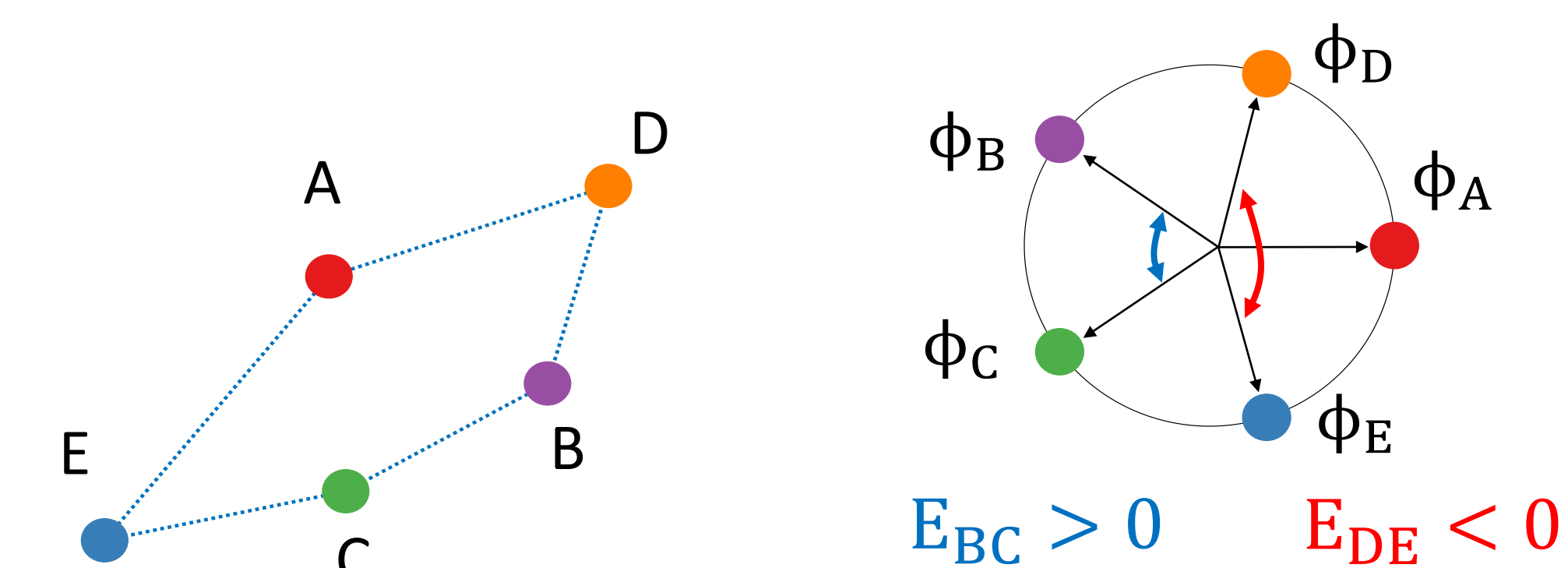
WITH CONTINUOUS PHASES



ONN ENERGY FUNCTION AND TSP

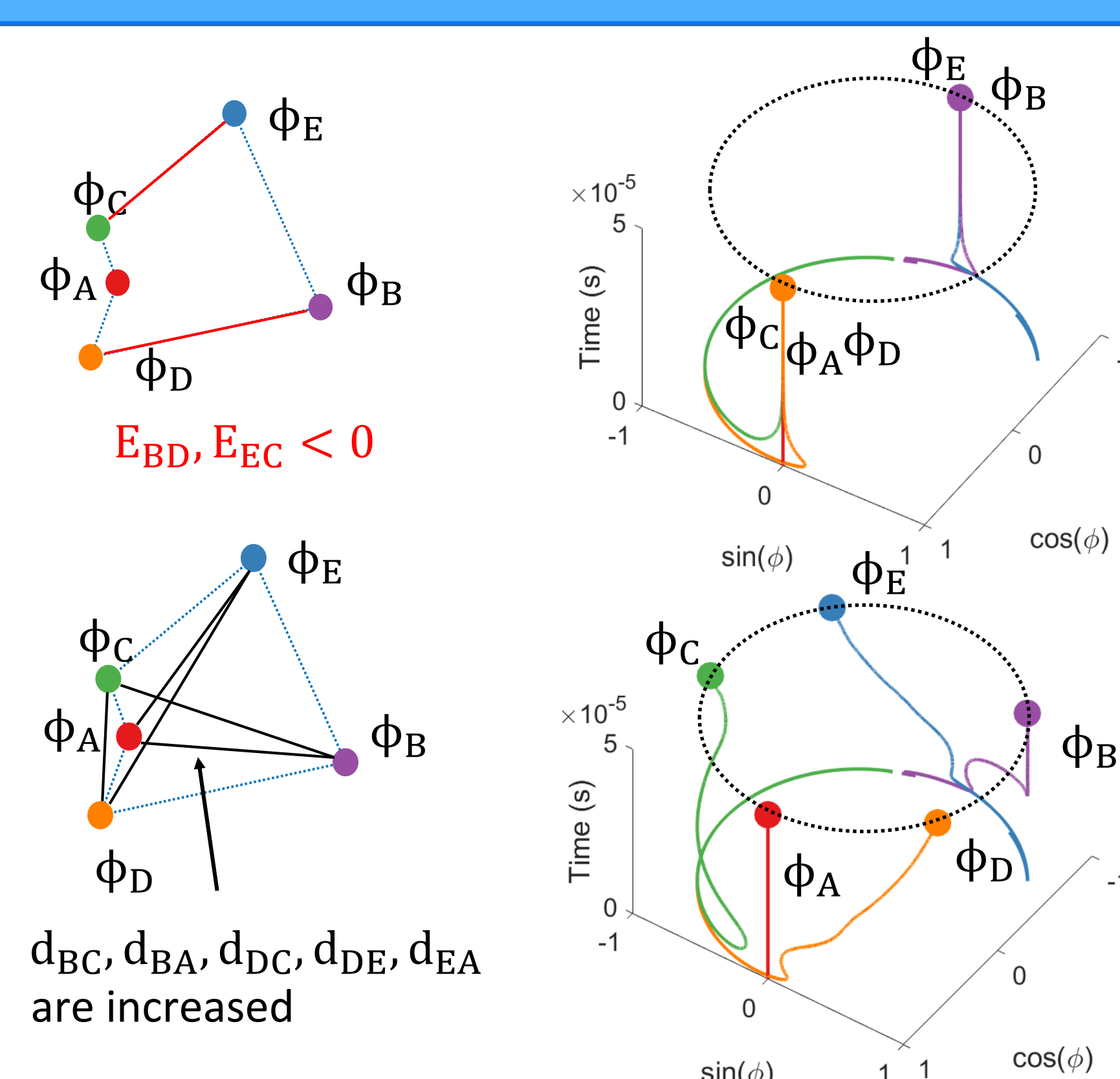
- With negative coupling coefficients encoding distances, the ONN « pushes » **all possible phases** apart to minimize E
- Energy terms can be classified in two subsets:
 - $E_{\leq 0} = d_{ij} \cos(\phi_j - \phi_i) \leq 0$
 - $E_{> 0} = d_{ij} \cos(\phi_j - \phi_i) > 0$
- ONN prioritizes cities with long distances ($E_{\leq 0}$) and **minimizes distances between adjacent cities ($E_{> 0}$)**, i.e. the TSP tour

$$W_{ij} = -d_{ij} \rightarrow E = \sum_{i,j} d_{ij} \cos(\phi_j - \phi_i)$$



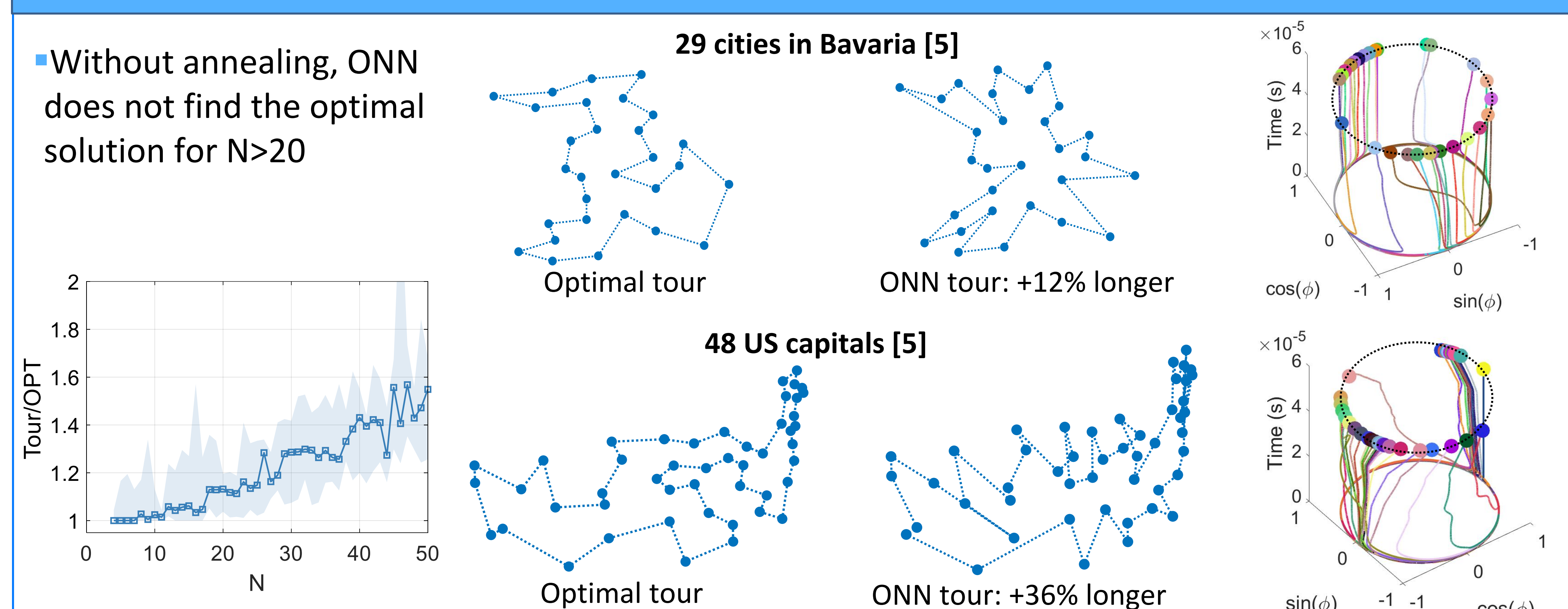
SHAPING THE ONN ENERGY LANDSCAPE

- ONN needs more constraints to better estimate the TSP tour
- Unconstrained, some pairs of adjacent cities can negatively contribute to the total tour distance ($\in E_{\leq 0}$)
- To mitigate this issue, we shape in real-time the energy landscape as:
If $\Delta\phi_{ij} > \frac{2\pi}{N}$
Increase $|d_{ij}|$ for non adjacent cities (which do not contribute to the final tour)



RESULTS

- Without annealing, ONN does not find the optimal solution for $N > 20$



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- [3] M. Abernot et. al., "Digital Implementation of Oscillatory Neural Network for Image Recognition Applications", Front. In Neuroscience, 2021
- [4] N. Christofides, "Worst-case analysis of a new heuristic for the travelling salesman problem", Report 388, Graduate School of Industrial Administration, CMU, 1976
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ACKNOWLEDGEMENTS AND FUNDING



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 871501.