# Adversarial Resilience Learning

## Analysis and Resilient Operation of Complex Systems without Domain Knowledge

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Our Infrastructures become more complex with every day.
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*“Machine Learning: The High Interest Credit Card of Technical Debt”*
*— Sculley, et al. (Google), 2014*

# The Power Grid

A Pervasive Example

**Power Grids: A Critical Infrastructure**

> Basis for our society!

**Spanning Continents**

> From Scandinavia to North Africa, from Ireland to Asia

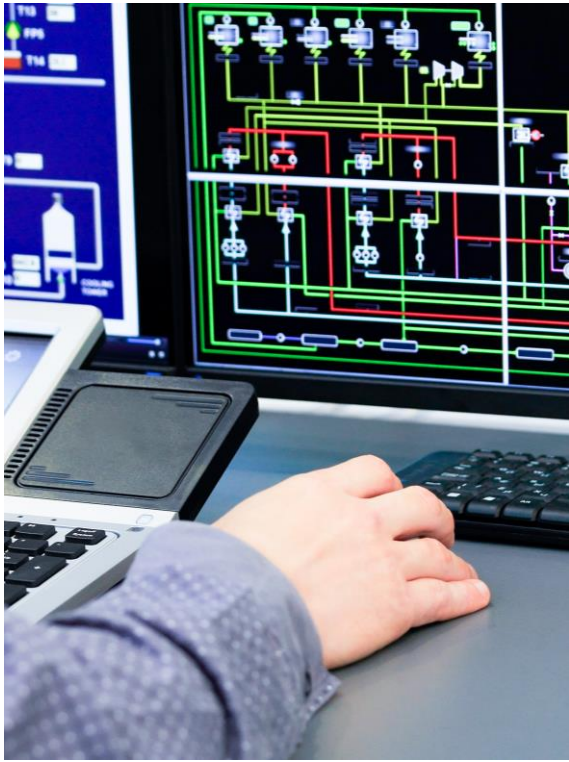
**Effects ubiquitously visible**

> Instabilities spread almost instantaneously

**Conflicting goals**

> Monetary, technical, and political interests not congruent

**Caught in a fast and turbulent change**



# Major Trends

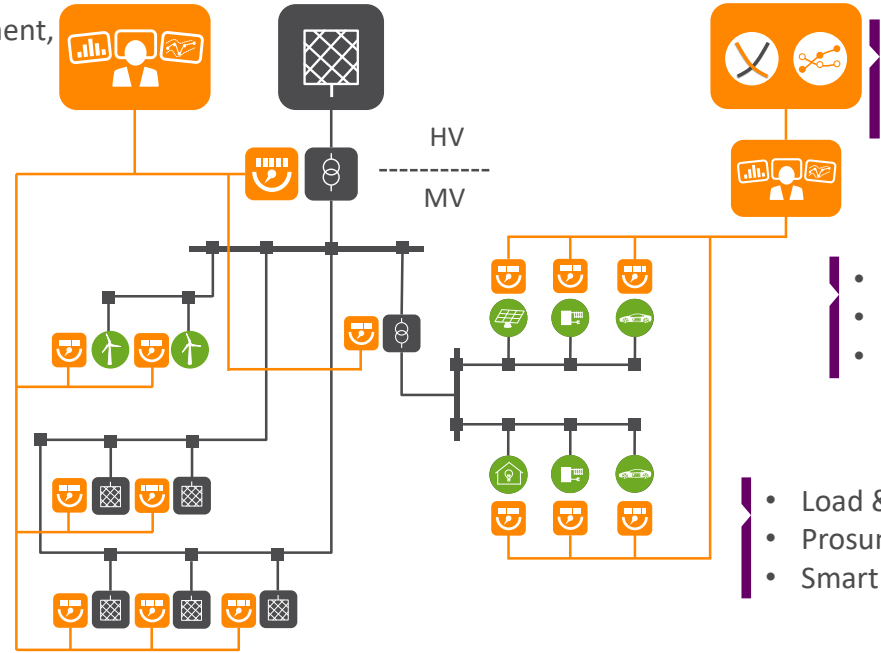
Influencing the Cyber-Physical System Power Grid

1. **Evolution of the Power Grid,**
   - > Many small generators, critical in sum
   - > Competition & business model innovations
   - > Growing complexity only mangeable through more digitalization – vicious circle!
2. **Digitalization**
   - > IoT trends: Many thousand “intelligent” devices (Nest, baby monitors, Smart TV, etc.) connect to the grid *“In IoT, the ‘S’ stands for ‘Security’.”*
   - > Buzzword Bingo: Smart Services, Cloud, Outsourcing, AI, Big Data, …
3. **New Threats through Cyber Attacks**
   - > State-sponsored attacks (*Grey Wars*)
   - > Ever more sophisticated tools
   - > Strong pressure for backdoors

# AI in the Power Grid

## A Complex System Indeed

- Grid State Prognosis,
- Optimized Reactive Power Management,
- Anomaly Detection in Power Grid and ICT.




- Algorithmic Power Trading,
- Market Integration of Renewables.

- Virtual Power Plants,
- Multi-Modal Optimization,
- Sector Coupling.

- Asset Monitoring,
- Automated Grid Interaction Stage,
- Decentralized Ancillary Services.

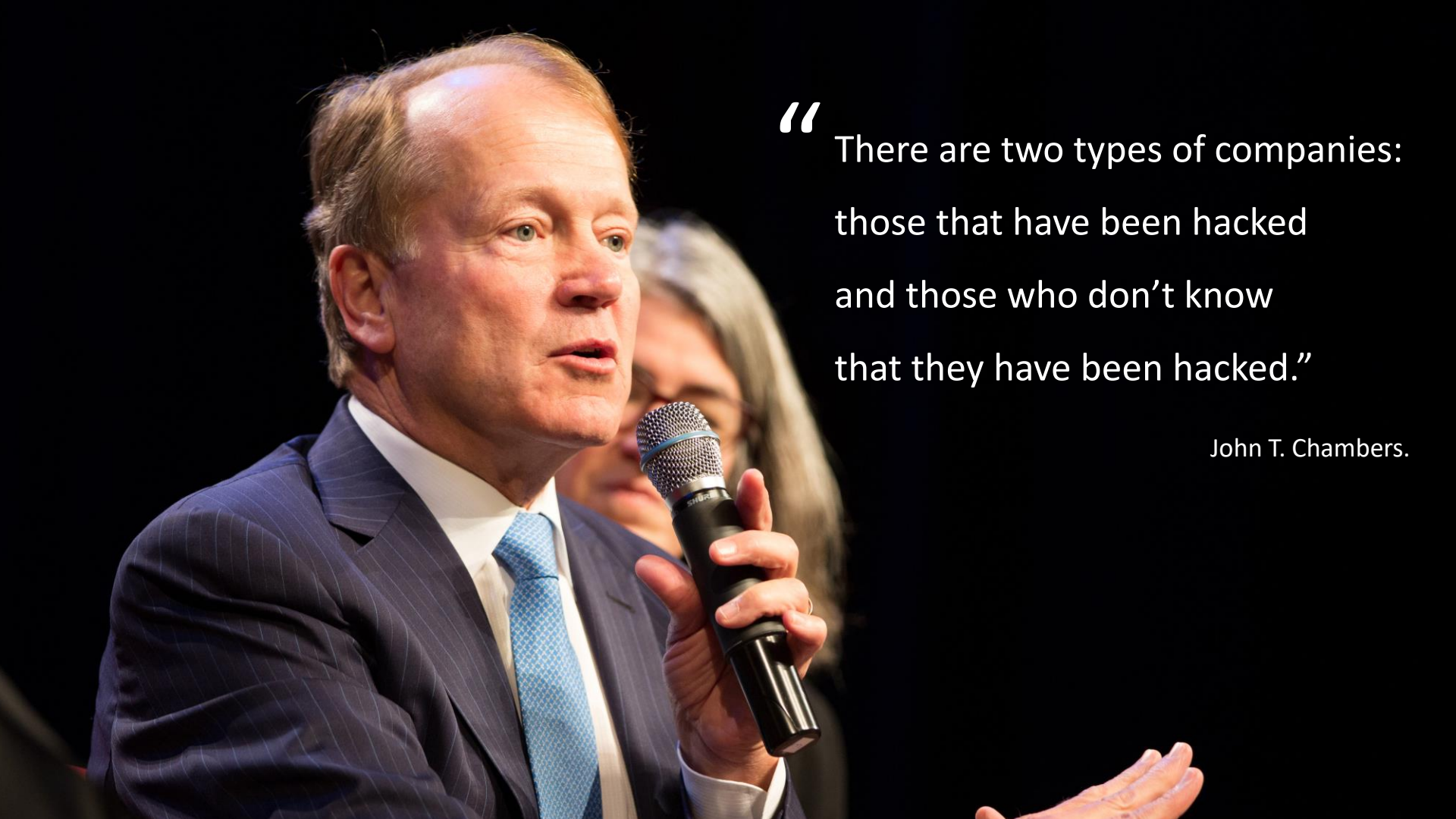
- Load & Flexibility Management,
- Prosumer,
- Smart Metering.

# What follows?

Obvious Conclusions Drawn from the Current State of Affairs

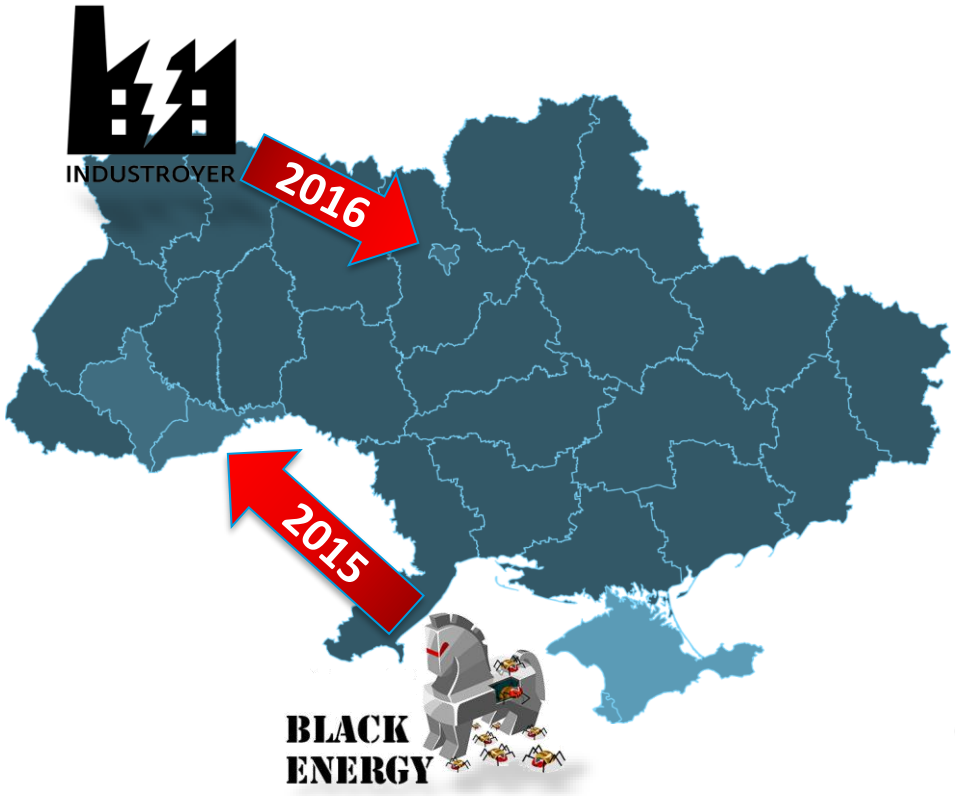
1. Trends in digitalization from other areas will flood into our critical infrastructures.
2. Digitalization of our power supply, transportation, etc., will lead to a new threat level – damage potential unfathomable.
3. Digitalization & machine learning are neccessary  for sustainable, environment-friendly infrastractures: Not only a threat, but also a great potential, even for security!

*We don’t really understand the interdependent effects between digitalization and critical infrastructures yet.*


“There are two types of companies:
those that have been hacked
and those who don’t know
that they have been hacked.”
John T. Chambers.

# Applies to Critical Infrastructures, too

Attack against the Ukrainian Power Grid




**Dec 23rd, 2015**

> Cyber Attack leads to **Blackout**
> **3 Grid Operators** targeted
> Operative **Intrusion into Control Systems**
> Disconnect of **several Transformers**
> Several Months in Preparation

**2016**

> **Highly automated** Variant

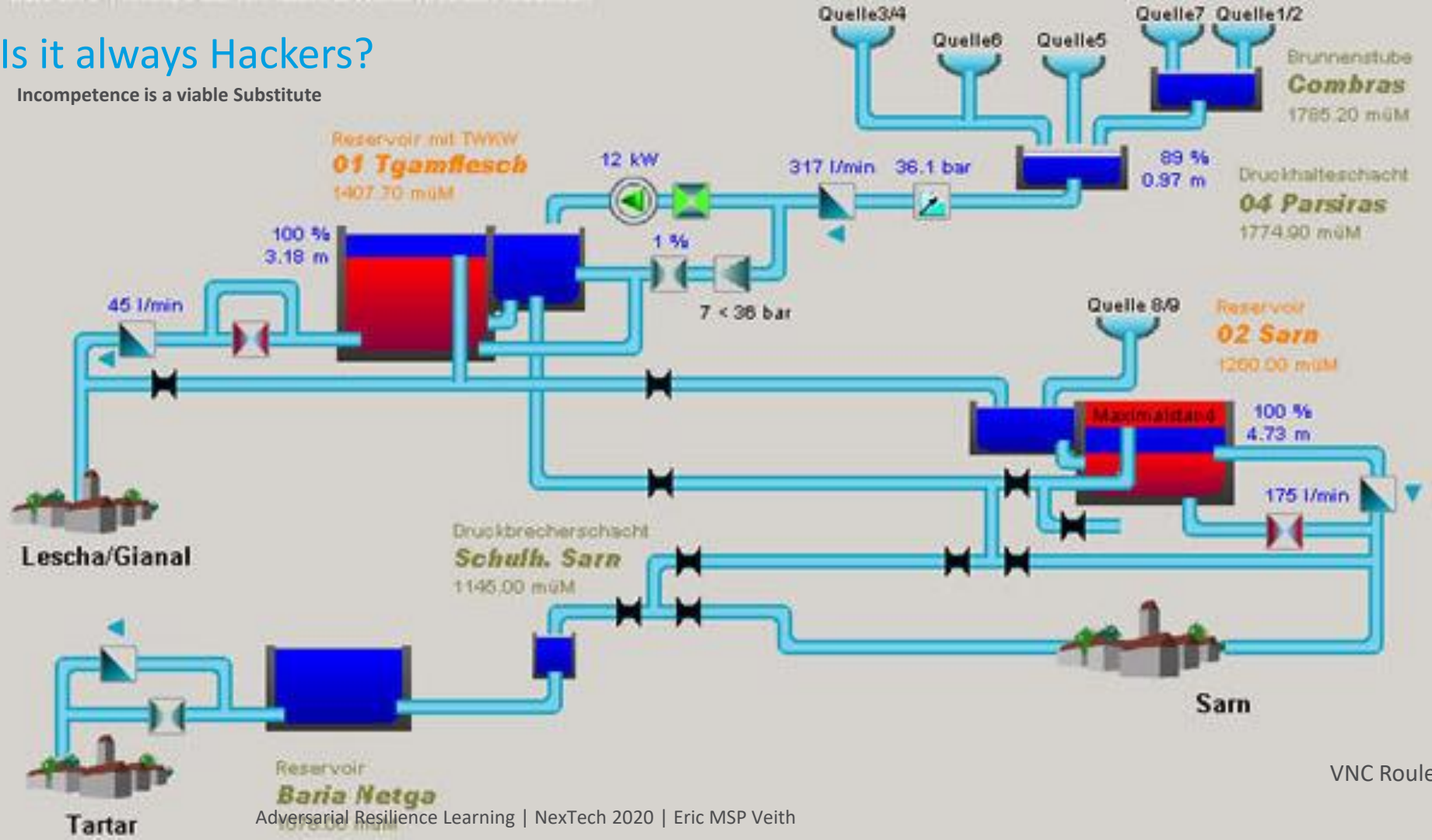
**Our infrastructures are valuable targets.**

# Digitalized Critical Infrastructures: A Threat?

Newspaper Collection

# Is it always Hackers?

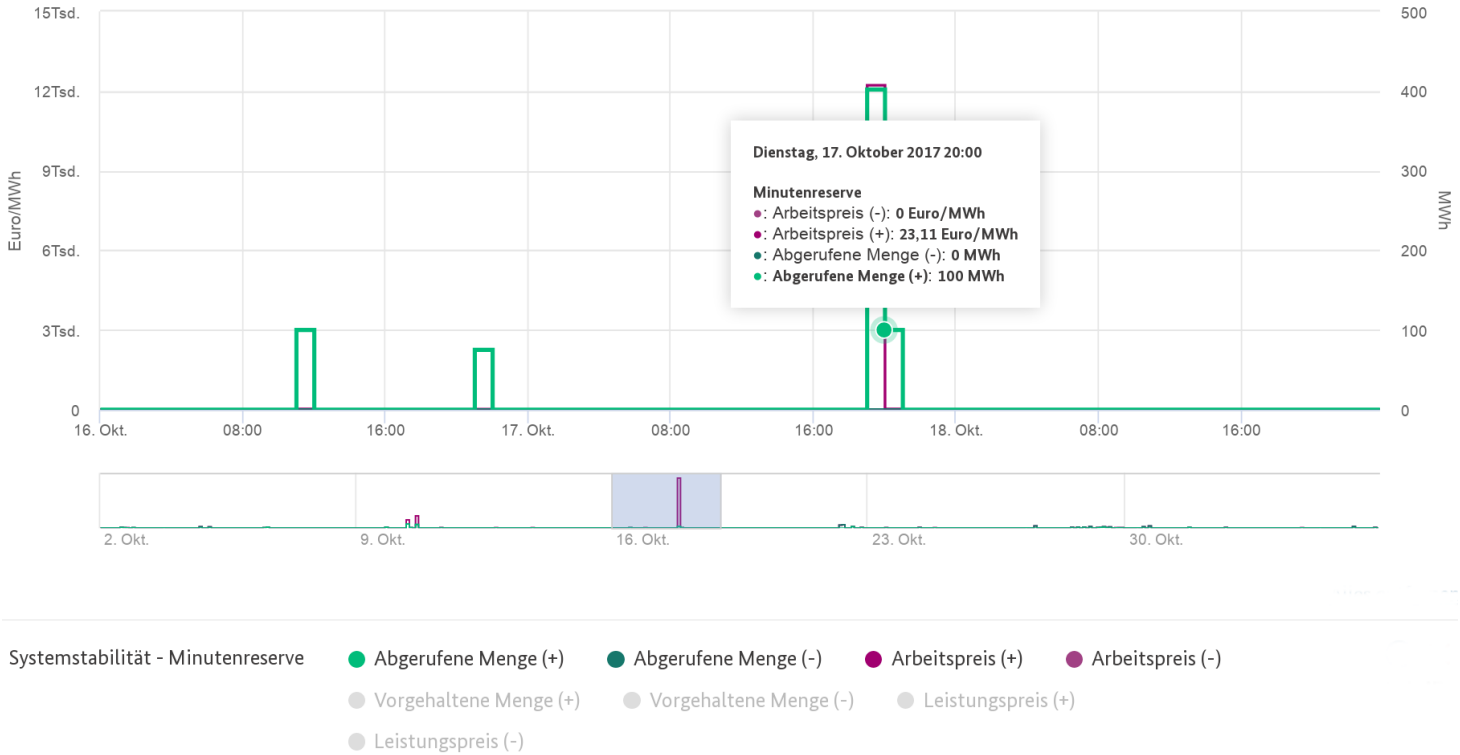
**Incompetence is a viable Substitute**




VNC Roulette

# Market can also be the Culprit

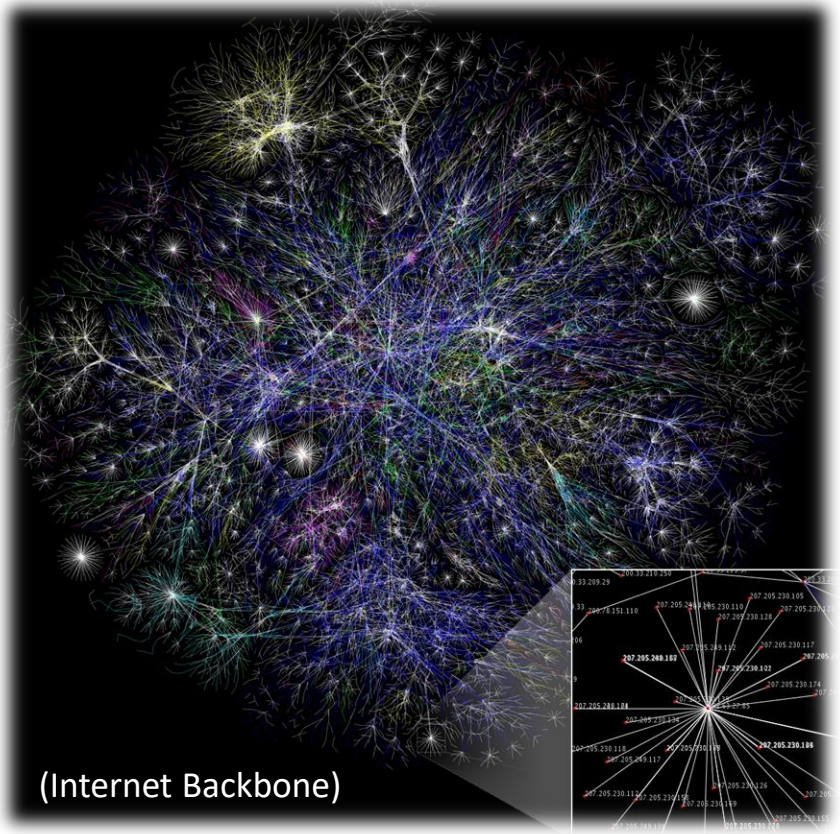
## Gaming a Critical Infrastructure?



# LearnsingResilient Control

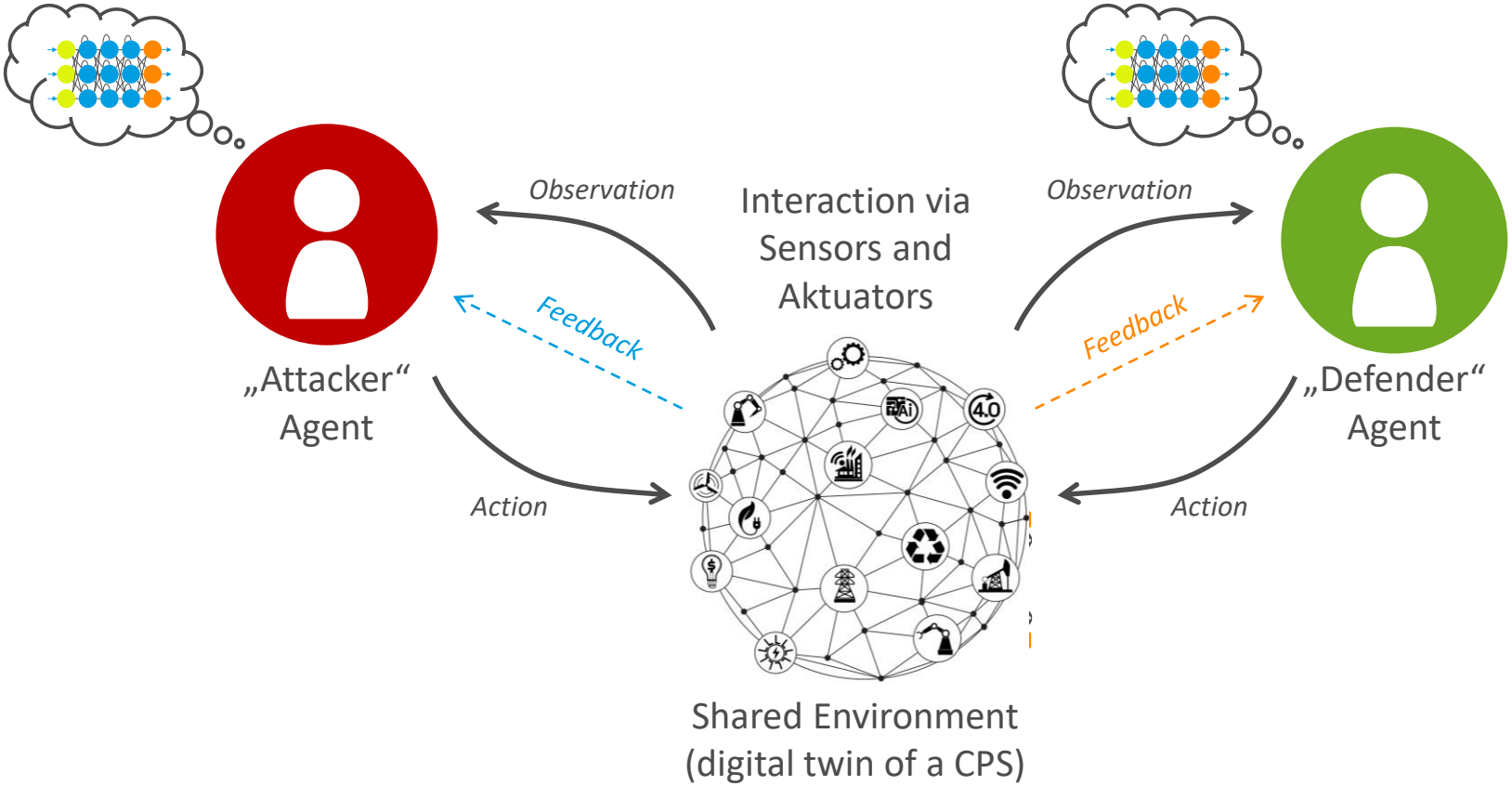
## CPS inherently vulnerable

- Interconnected CPS have always attack surface **due to their inherent complexity**
  - Low latency of ICT and OT
  - High interdependence
  - Complexity in breadth and depth
  - Cricital Services as SPOF (DNS, BGP, *SCADA, SDL*)
- Learning Stratgies for **automatic issue mangement**



# Adversarial Resilience Learning Concept

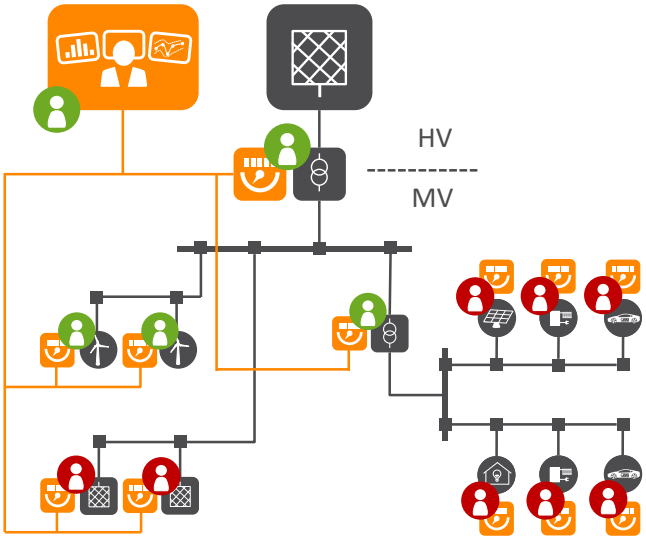
## Competing Agents Learn in a Shared Environment



# Demo: Attack on a Power System

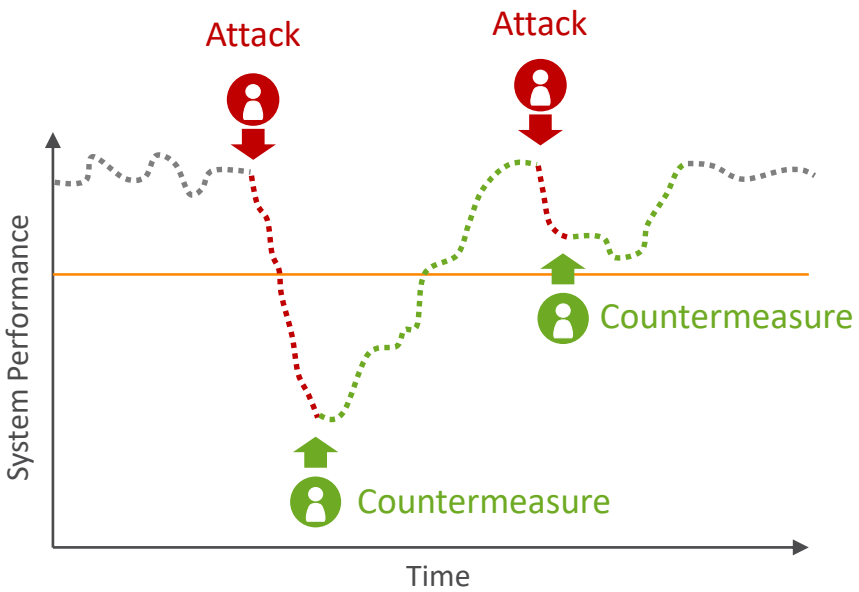
Prevention of (sub-)system takeover as a secondary problem

Smart Grid
Cyber-Resilience Lab




Attacker AI

Defender AI



## Defender Points

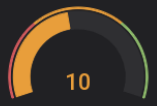
2656

### Loads Connected


### Generators Connected


### Buses Connected

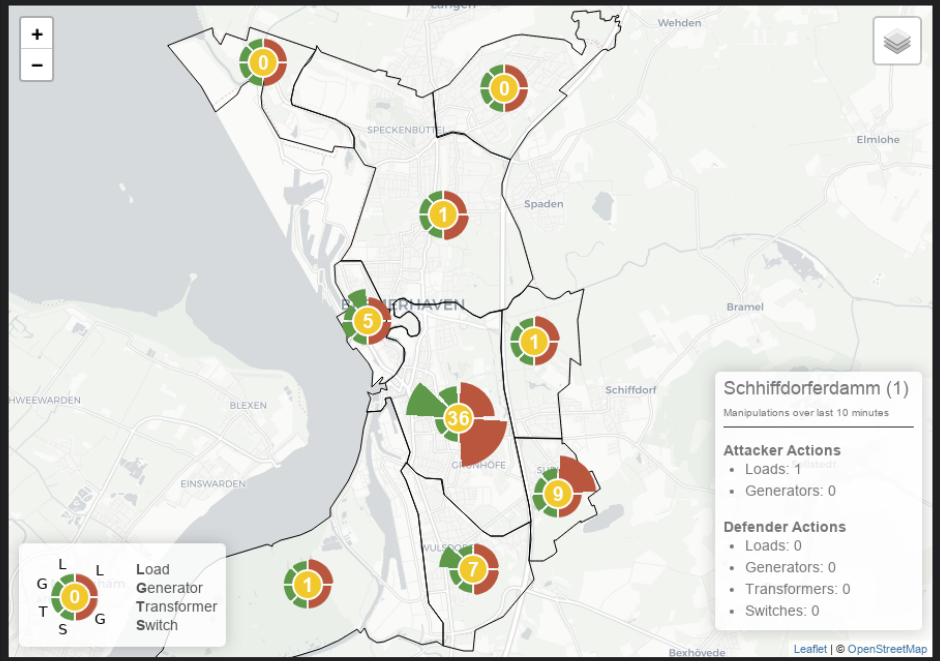

### Transformers Connected...



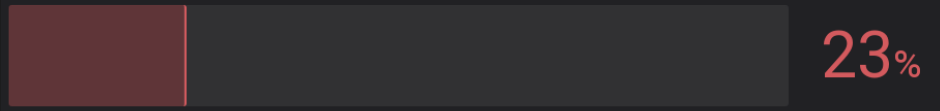

### Most Valuable Actions (Defender)

| Info | Time | Points |
|---|---|---|
| Changed Scaling from Lehe Households - 4 to 0.6667 | 2018-01-01 02:00:10 | -0.25 |
| Changed Scaling from Leherheide Industrielast to 0.8889 | 2018-01-01 02:26:10 | -0.07 |
| Changed Tap_pos from trafo to 1.0000 | 2018-01-01 01:47:50 | -0.07 |
| Changed Scaling from PV Fischereihafen to 0.0000 | 2018-01-01 02:14:30 | -0.07 |
| Changed Tap_pos from trafo to 1.0000 | 2018-01-01 01:45:30 | -0.06 |

## Map



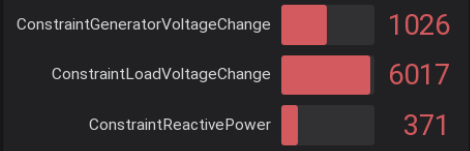

### Time Left (Coins Left in %)



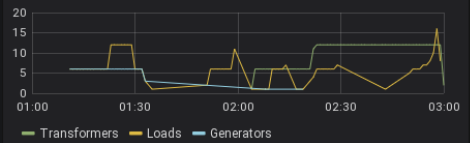

## Attacker Points

7344

### Constraint Violations




### Malfunctions




### Most Valuable Actions (Attacker)

| Info | Time | Points |
|---|---|---|
| Changed Scaling from Geestemünde Households - 0 to 0.5000 | 2018-01-01 01:00:00 | 0.96 |
| Changed Scaling from Geestemünde Households - 0 to 0.5000 | 2018-01-01 01:00:00 | 0.93 |
| Changed Scaling from Geestemünde Households - 0 to 0.5000 | 2018-01-01 01:00:00 | 0.91 |

# Adversarial Learning

ARL != AL

- Attempt to modify input data slightly in order to yield extremely different output from ANN
- Modification of data not or only slightly visible to humans
- Ex: RGB noise on a picture, small textual changes in spam messages
- AL: Finding mechanisms against these attacks

# Generative Adversarial Networks

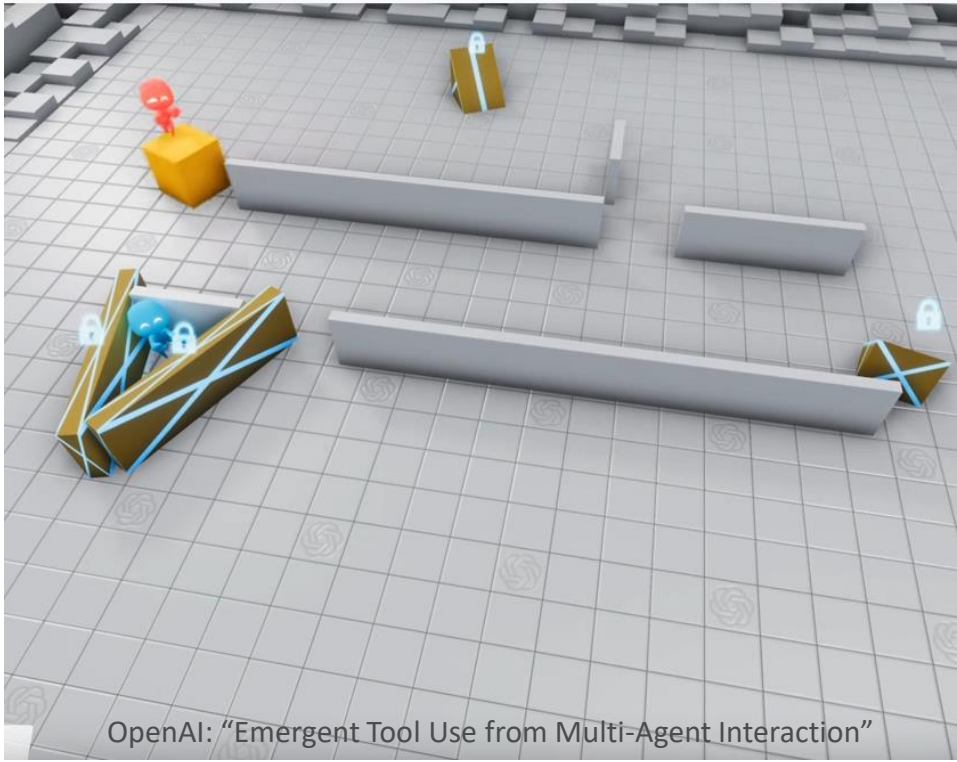
ARL != GAN

- Two ANNs with **different roles**: Generator and Discriminator
- Zero-sum game
- Generator maps vector of latent variables to feature space; Discriminator evaluates the result
- Error measure: Ability of the Discriminator to differentiate between real and generated data's distribution

# Why does it work?

RL Agents discover bugs in the engine

- Setup: Two groups of agents play *hide and seek*
- No domain information; agents learn strategies and tool use independently
- Result: Agents learn to exploit bugs in the underlying game engine
  - Holes in walls
  - Sliding boxes
  - Edge/corner jumps



OpenAI: “Emergent Tool Use from Multi-Agent Interaction”

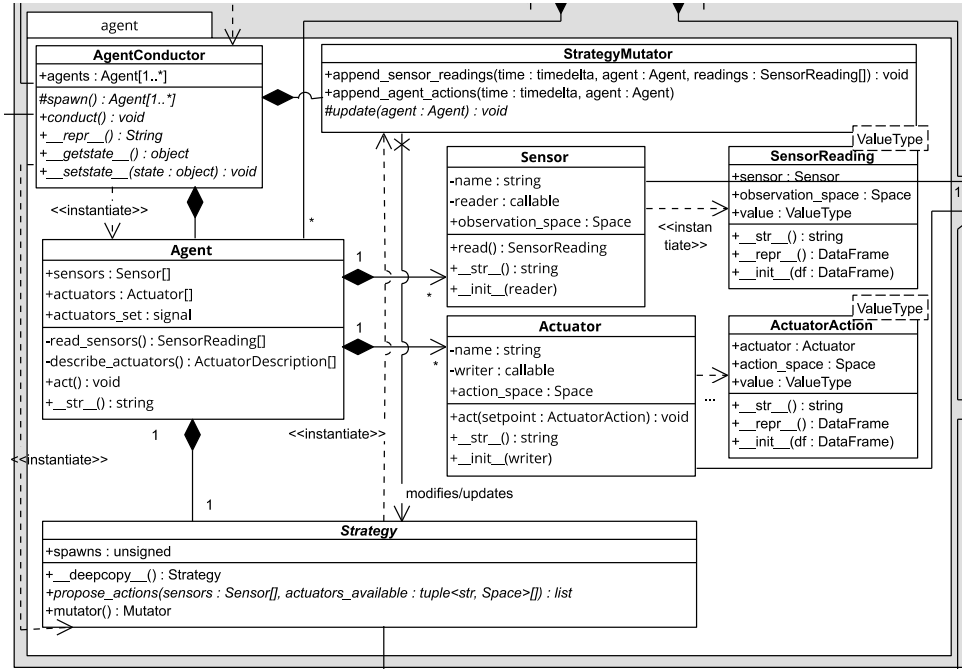
# Multi-Agent DRL

## Multi-Algorithm

- E.g., Q-learning vs. A3C (multiple workers)
- Conductor orchestrates worker-environment pairs
- Strategy: The “muscle” in an agent
- Mutator: The “brain” for several agents

## Simple Implementation API

- Only “brain” and “muscle” need to be implemented for new algorithms



# Neuroevolution

**Motivation**

> Pre-defined policy network: Implicit domain knowledge

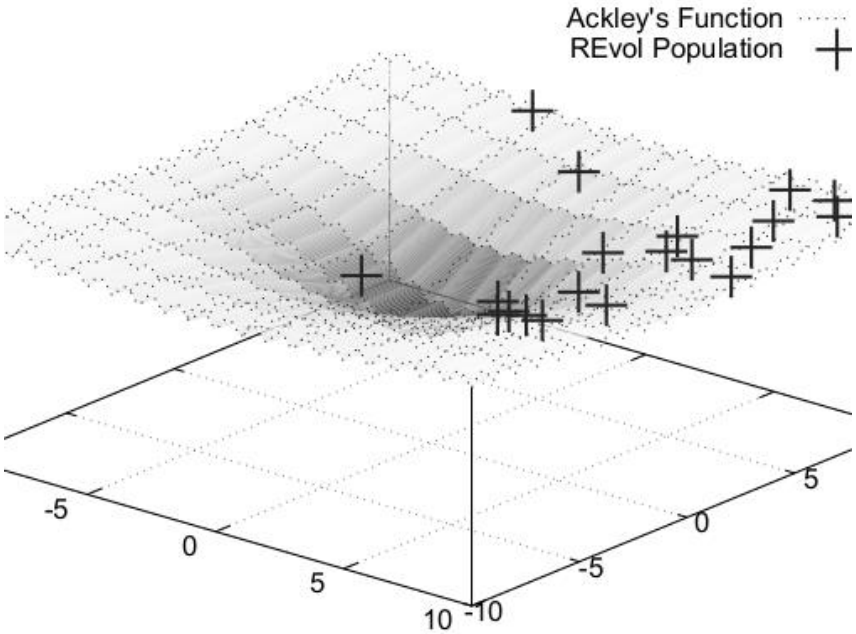
**Combination of Revol and NEAT**

> Implicit gradient information

> Dynamic reproduction PDF

> Speciation

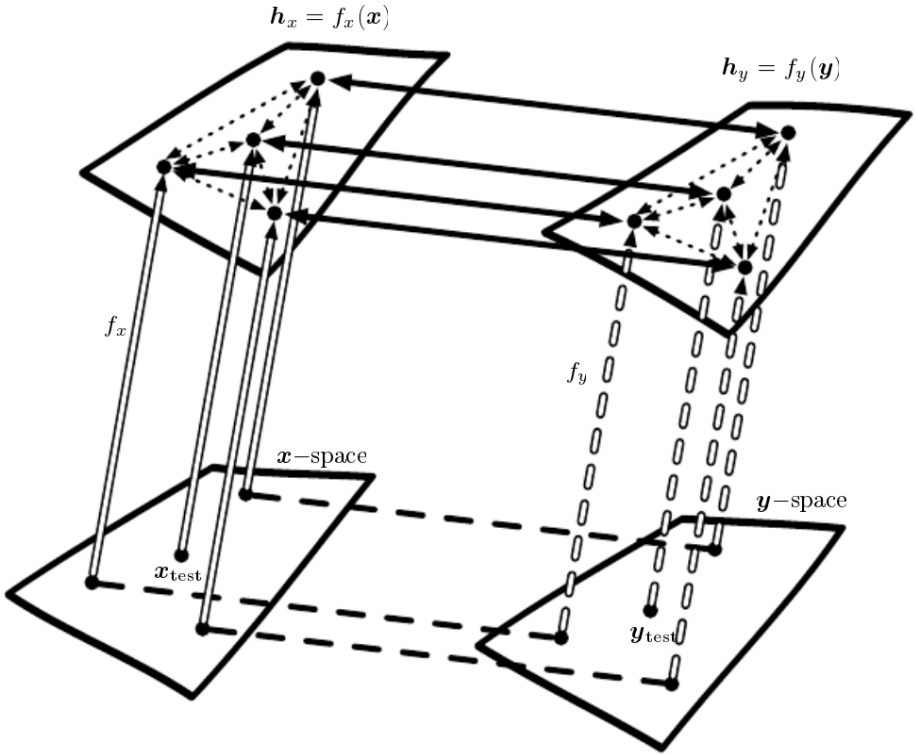
> Indirect encoding



# Transfer Learning for Multi-Agent DRL

Ensure transferability with minimal re-training

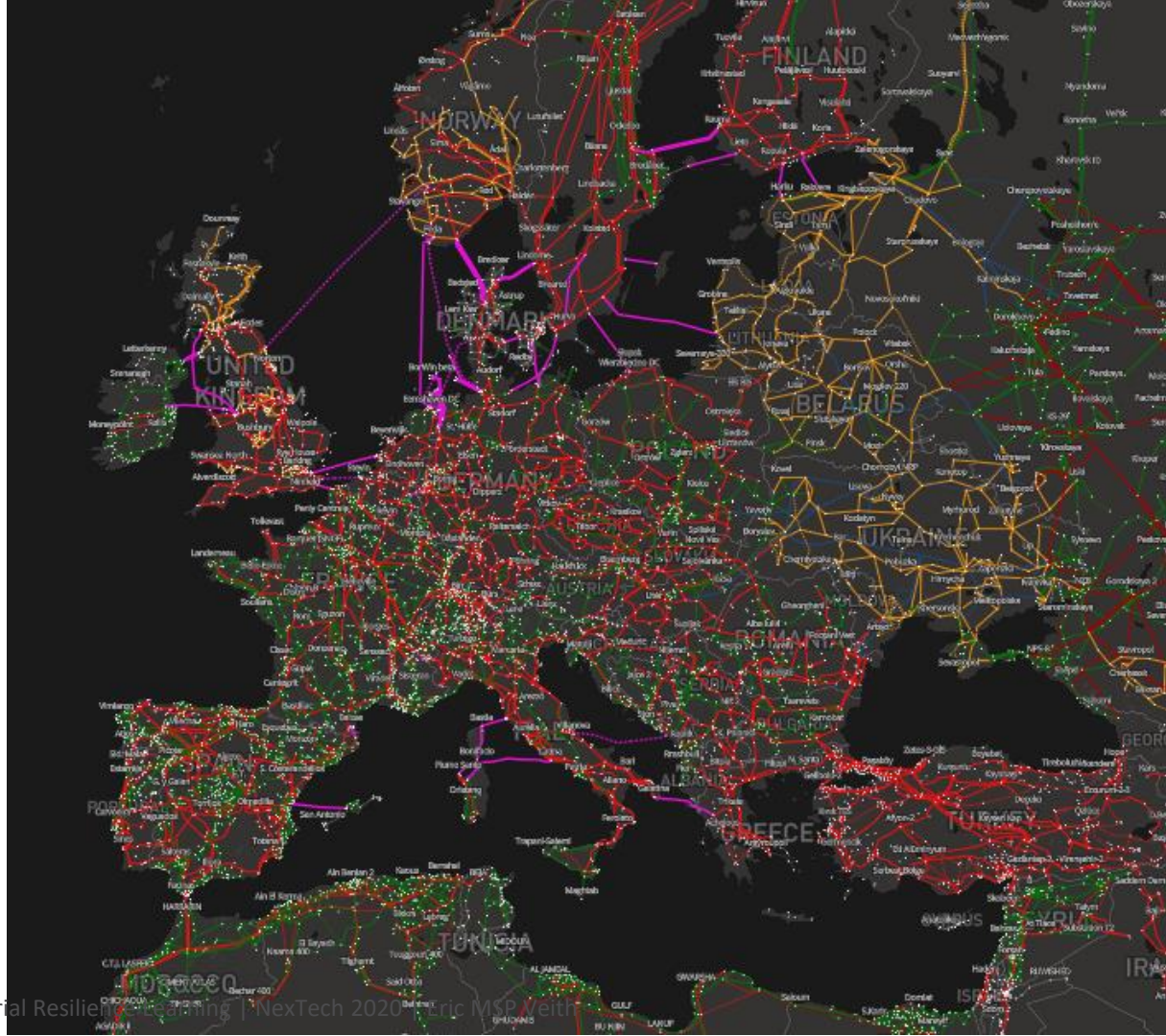
- Agents can “conquer” their environment (think CTF!)
- Different models in the same domain
- Transfer between similar domains
- Extraction of algorithms?



# Rigging the Game

Strategic Infrastructure Extension

- Weaknesses are indicator for strategic infrastructure investments
- Calculate risks & losses, motivate investments



# Analysis & Training of Resilient Systems

Flavors of ARL

**Analysis – attacker only**

> Resilient Systems Lab
> Attacker explores vulnerabilities
> „Conquest“ of a system
> Attack vectors & log as basis of traditional analysis

**Training – Attacker & Defender**

> AI for Grid Operation
> Resilient overall system
> Attacker trains defender
> Attacks can be environmental factors
  > Deviations in prognoses
  > Accidents, etc.


**Ethics of ARL**

> ARL a weapon?
> **Lizence a soluation**?
> **Laws of Robotics** possibly inherent?

# Conclusion

**ARL enables discovery of vulnerabilities and interdependencies**

> Even when conform to regularizations! (EnWG, GridCodes, TAB etc.)

**Development of defense (!) strategies**

> Ethic dilemma

**„Attacker-Defender-Games“**

> Impact analysis in „anomalie-sensitive State Estimation“

> Risk models, investment strategies (finding an equilibirum)

> Analyzing asymmetries („Rigging the Game“)

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