Network Digital Twins

Concepts, Requirements, and Applications

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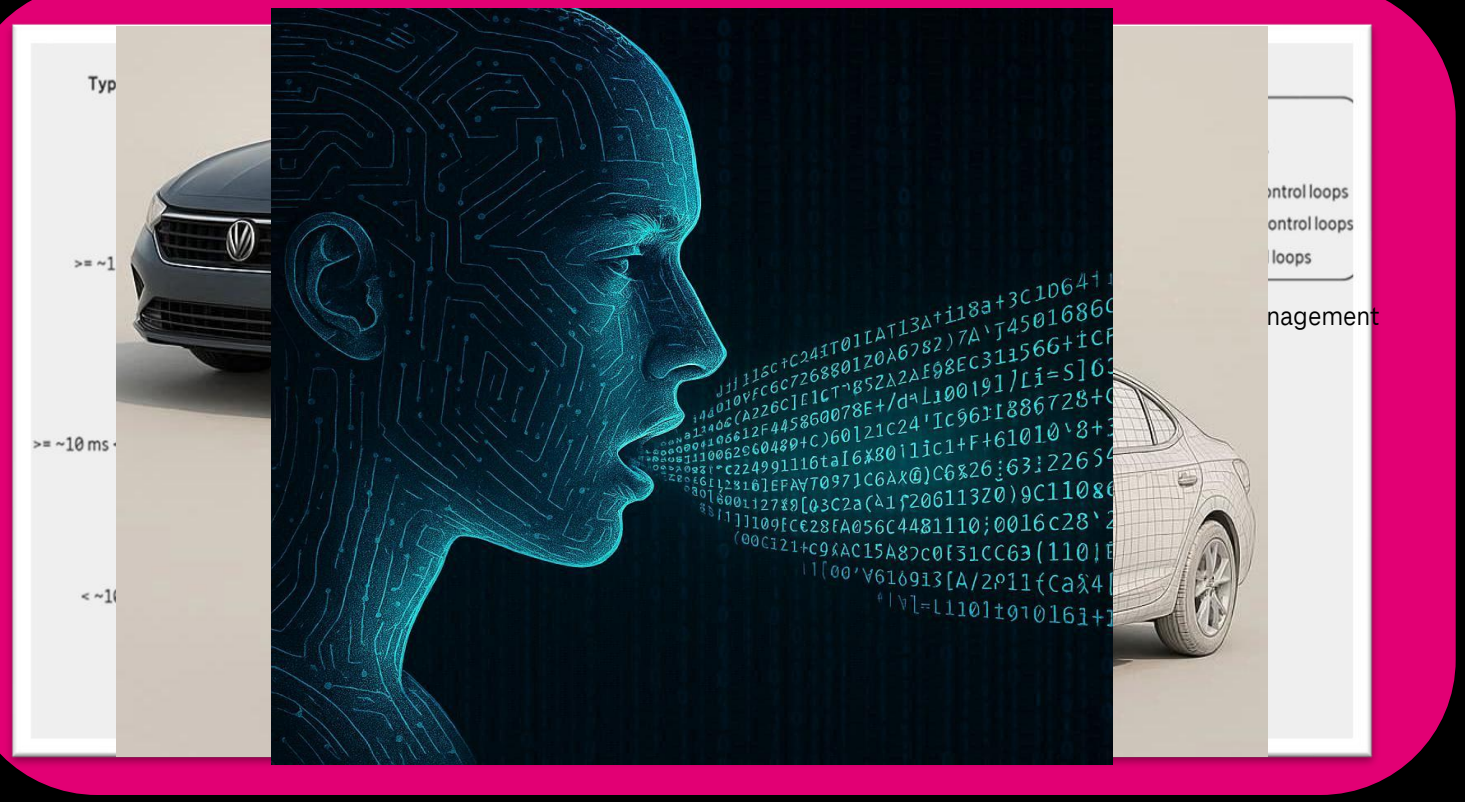
GROUP **TECHNOLOGY**

(Network) Digital Twins – Short Introduction

- Future of telecommunication networks
- Exploring behavior of agents in the network

→ Digital Twin

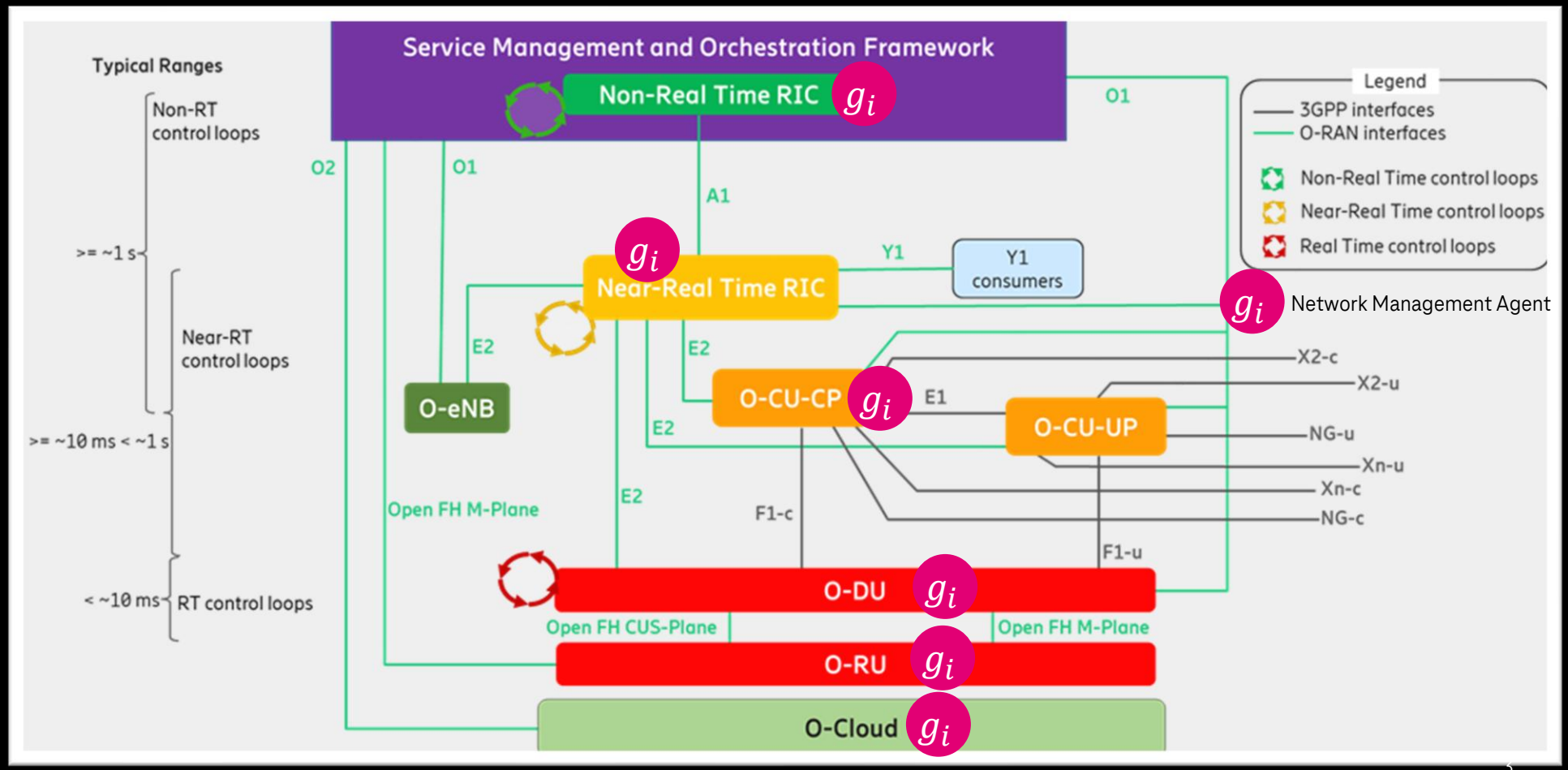
- Network Digital Twins
- Buzz word
- Planning tools, simulators
- What about a personal digital twin?



Future Networks & Autonomy

- **Heterogeneous agents** g_i
- **Network (architecture & topology)**
- **Openness required**
- **Self-organization: synergies, oscillations, conflicts**
- **Operator policies {OP}**

Can even be extended with agents in the UE and air interface (RIS).



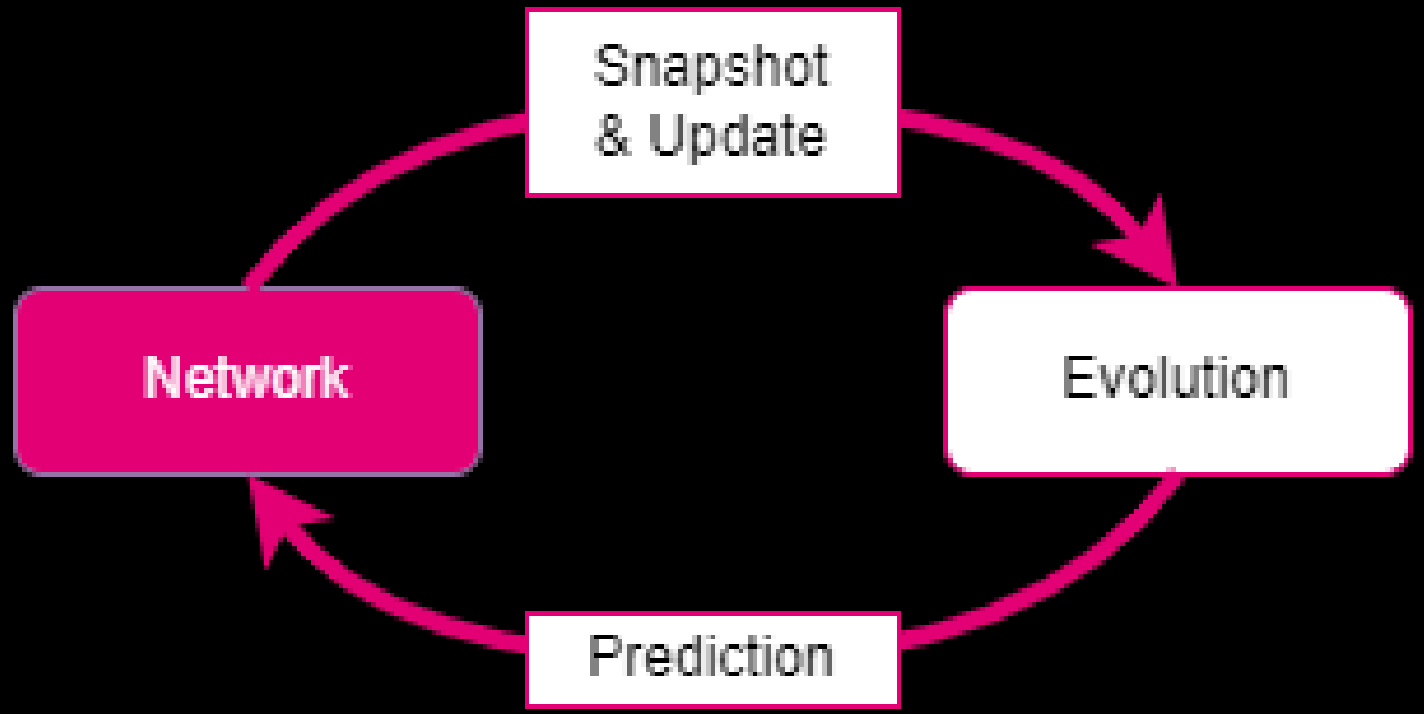
Network Digital Twins – Core Properties

- Network → Snapshot
- Propagation / Evolution engine

→ Moving forward in time → Prediction

- Decision in the network
- Update engine / continuous coupling

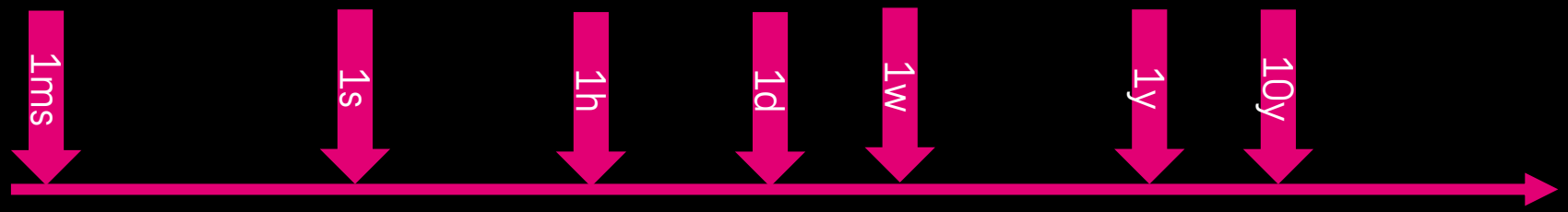
Should be more resource efficient than an exact twin.



Nothing is the network digital twin.

Scales in the network (10^11)

- **Time**
- **Space**
- **… and more**



Corollary

A Network Digital Twin can never be a monolithic, “one size fits all” system.

It will be a modular system which provides the elements to be combined for answering ***well-posed*** *questions.*

Well-Posed Problems

Objective:

- coverage, slicing, energy, …
- plan, operate, optimize, …

Constraints: architecture, resources, topology, service, …

Domains: world, site, RAN, core, transport, E2E, …

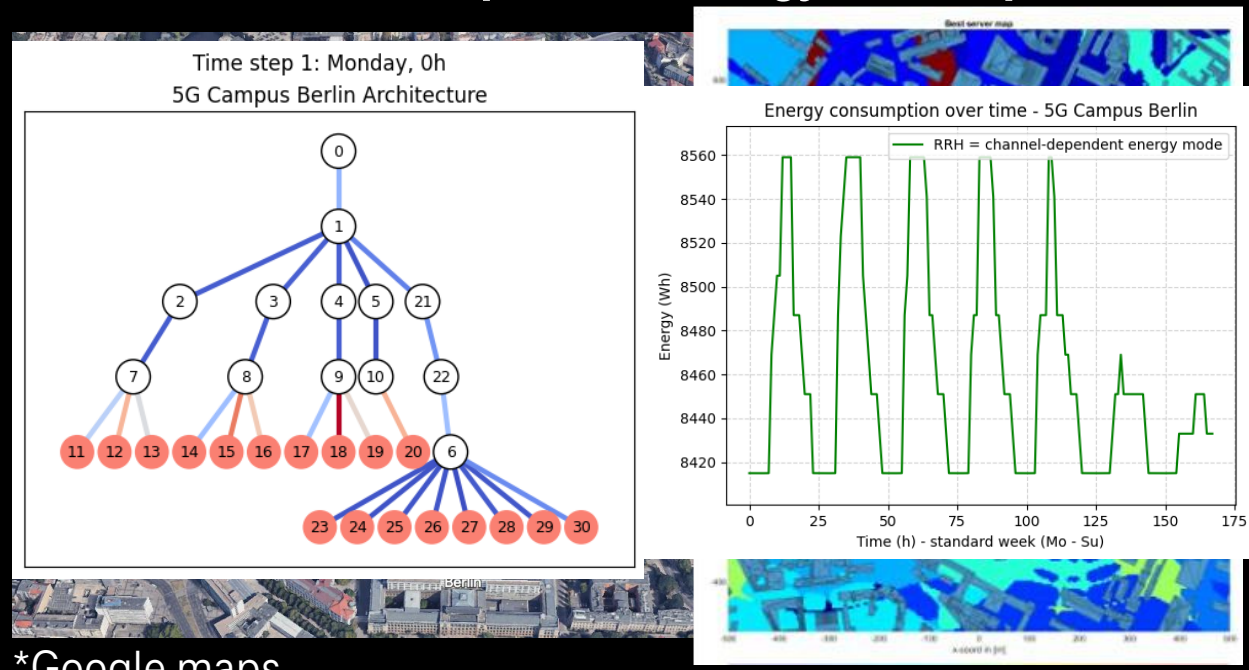
Scales and resolution: space, time, …

→ Data & tools

→ Network Digital Twin

Example

- **Estimate load-dependent energy consumption**



*Google maps

- **Area, norm week**
- **Abstraction → architecture graph**

→ Load distribution

→ Energy consumption

Everything is a network digital twin.

- Emulators
- Simulators
- Planning tools
- Agents g_i
- NOC

Every function interacting with the network contains an expectation of how the network might react.

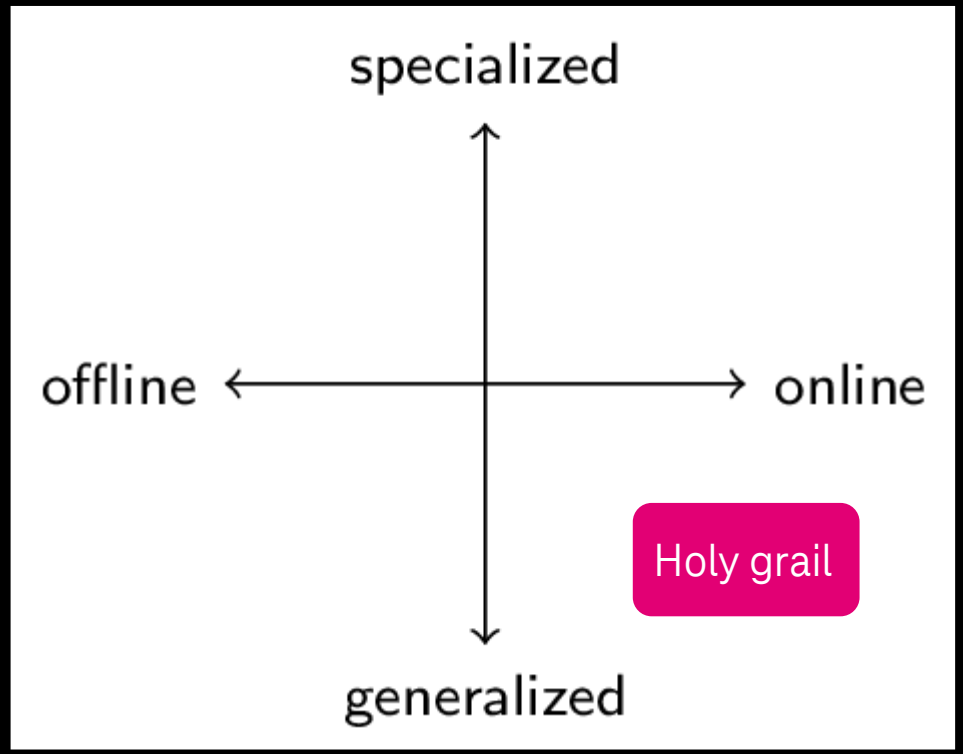
This could be considered a network digital twin.

NDTs – Classifications

- **Classification rather arbitrary**
- **Heuristic vs AI**

- **Similarities to foundation model**
- **What to do with all the twins?**

- Specific purpose
- Often implicitly contained

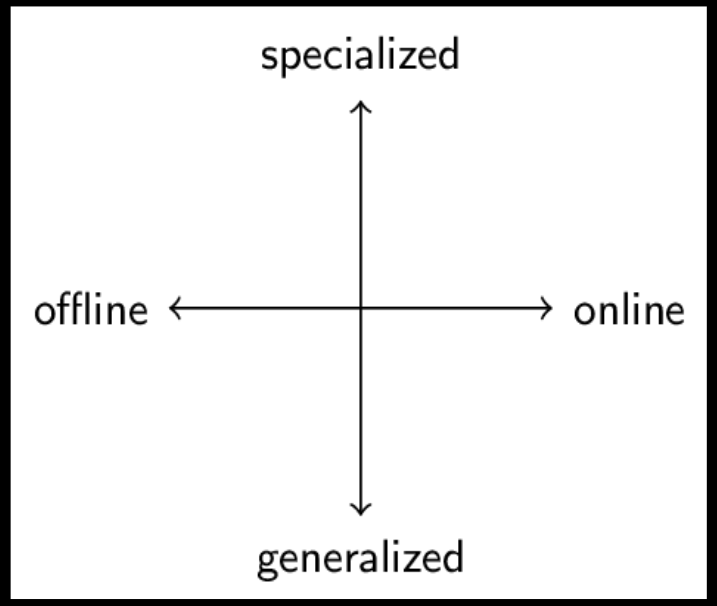


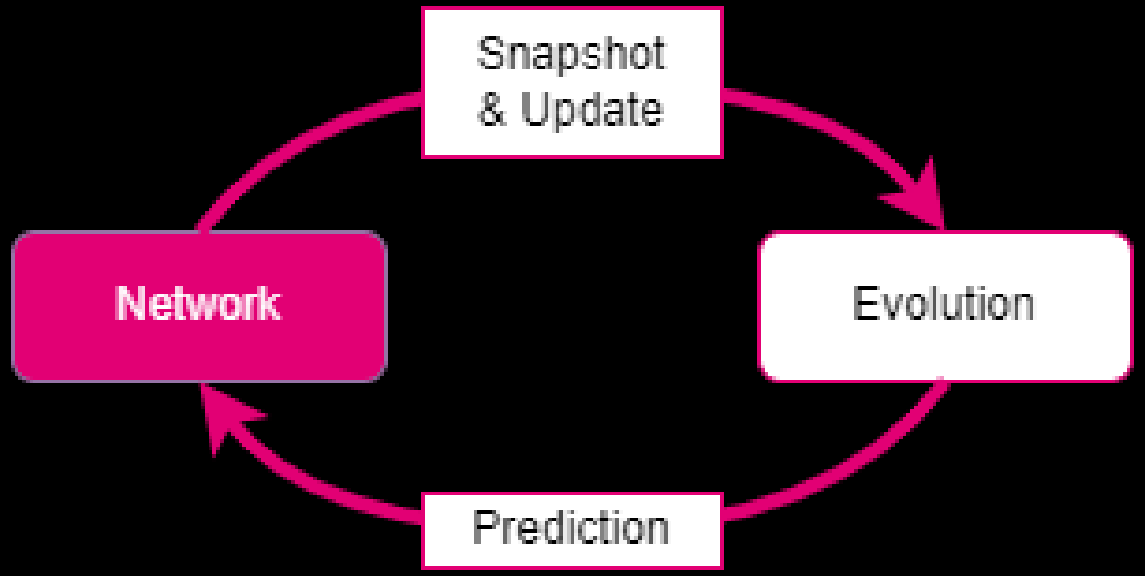
- What-if questions
- Detailed „heavy“ solutions

- Limited resources
- Run-time constraints

- Where to abstract?
- Not use case specific

NDTs – Further aspects & Requirements





- **Modular system**
- **Multilevel simulation**
- **Abstraction**

- **Data:** quality, quantity, scenario generation
- **Calibration**
- **Correction**
- **Error analysis:** uncertainty quantification, error propagation, statistical bounds

Pre-emptive handover

- **Private network**
  - Bosch Hildesheim
  - CampusOS
- **Priority Users**
- **Live data**
- **Enrichment information**
- **Open interfaces**
- **Prediction**
- **Decision**

Location assignment

Determine the optimal location for functionalities

under performance constraints.

$$
\begin{array}{lll}
\min & \text{cost}(L) & \\
\text{s.t.} & \text{resource}(L) & \leq \text{res. bounds} \\
 & \text{latency}(L) & \leq \text{lat. bounds} \\
 & \text{traffic}(L) & \leq \text{capacity} \\
 & \text{more constraints} &
\end{array}
$$

Offline or online

Mathematical modelling

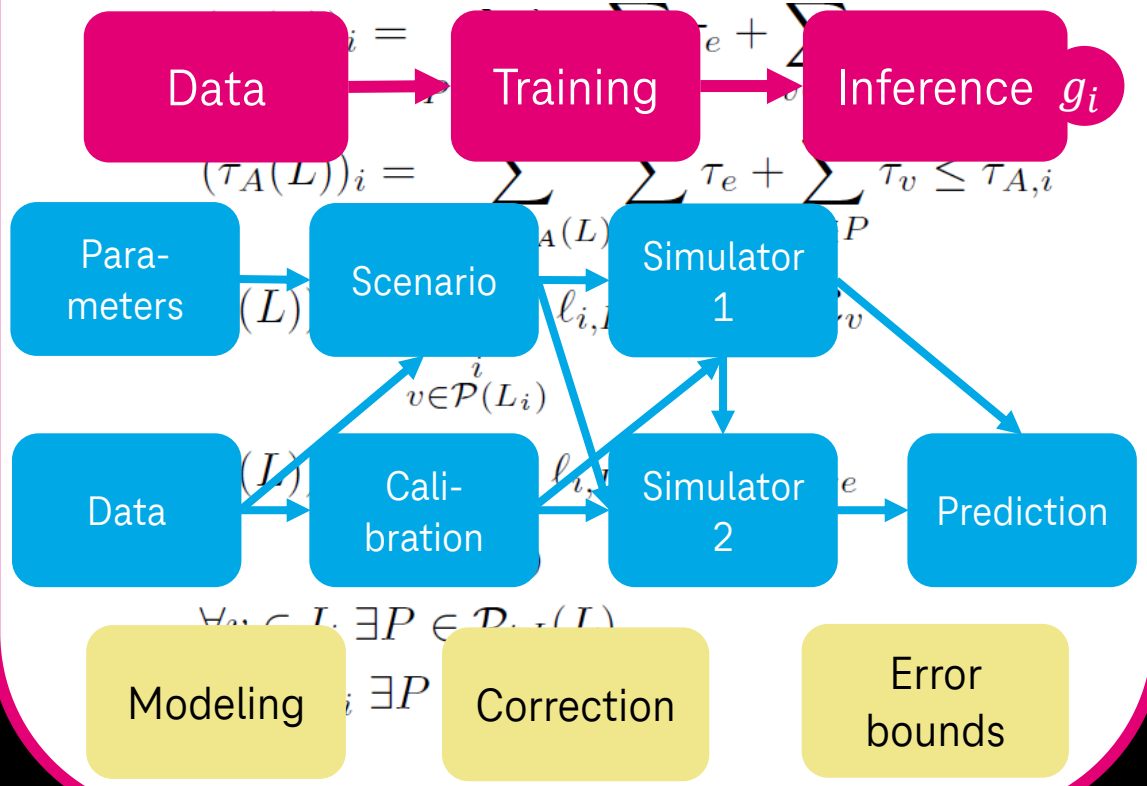
Simulators

AI g_i

Hybrid

$$\min_L \quad \alpha\|\rho(L)\| + \beta\ \text{Sim}(L) + \gamma\ g_i(L)$$

$$\text{s.t.} \quad g_i(L) \leq B_i \quad \text{PI bounds}$$

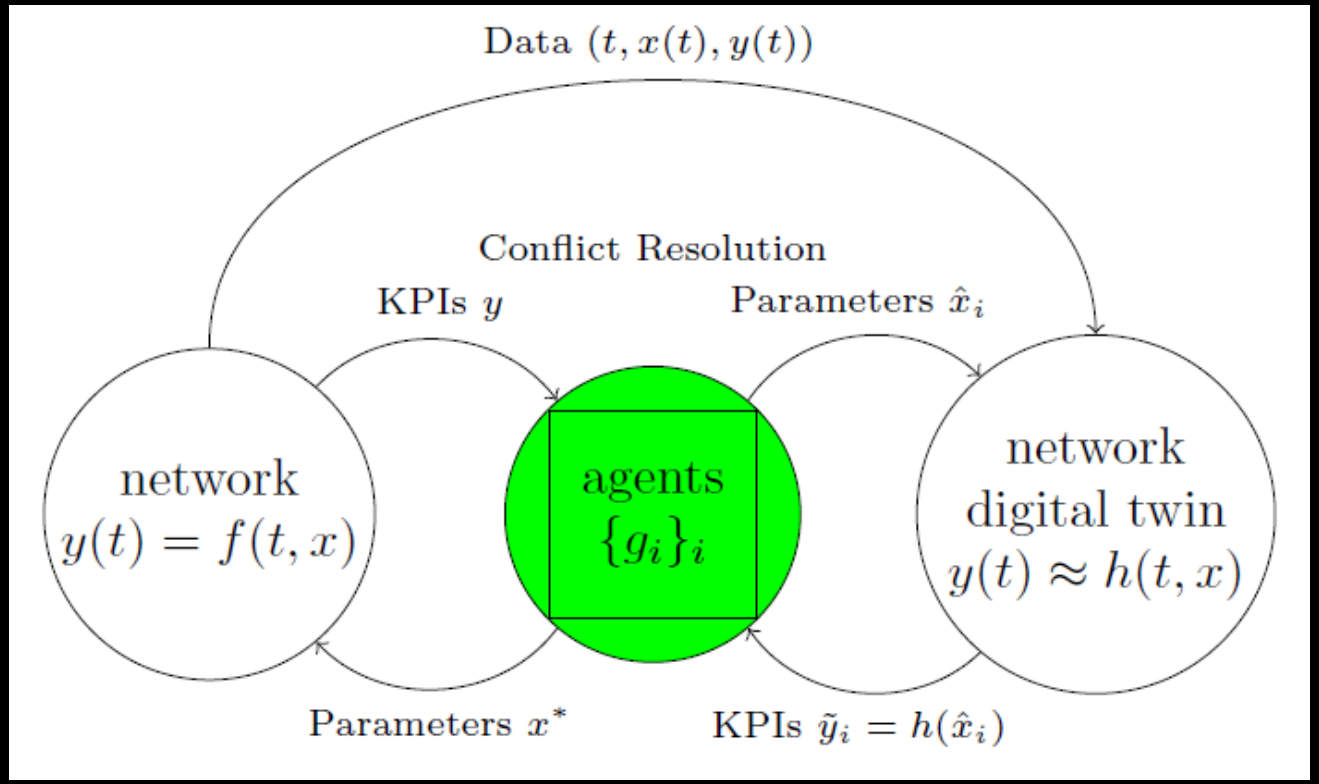


NDTs & Conflict Resolution

Detection and mitigation is not good enough.

Conflict Resolution

- Priority list
- Center of mass
- Mathematical optimization
- Agent consensus



Chaotic dynamical system

Network digital twin enables sophisticated solutions.

Drift to harmony or encouraging extreme behavior?

$$\begin{aligned} \min \quad & \mathrm{dist}(y, \{\mathrm{OP}\}) \\ \text{s.t.} \quad & y = h(x^*) \\ & x^* = \sum_i \lambda_i \hat{x}_i \end{aligned}$$

Thank you
for your attention.