versification among many interacting components [12]. Recent experimental evolution studies show that rapid trait changes with new information processing capabilities are far more complex because adaptation and speciation occur forming new species and phenotypes [13]. For example, eco-evolutionary dynamics strongly affect feedbacks between ecological and evolutionary processes, which in turn influences trait changes to open new properties with new information capabilities [14]. Furthermore, recent studies suggest that the interplay between trait dimensionality and adaptation is key to understand the emergence of new traits and information processing abilities to elaborate novel discovery computation strategies in ecosystems [15].

Going beyond ROBHOOT will, for the first time, employ EEDA to represent spatiotemporal causal inference in systems containing large heterogeneity and dimensionality (Figure 2). EEDA will be extended to deep process-based learning networks including traits and interactions driven by evolutionary changes to understand patterns in these systems. The search for causal knowledge discovery will be applied to the data knowledge discovery generated in WP1 for the sustainability of the Oceans, the largest ecosystem on Earth and key actor of climate change affecting biogeochemical and physical processes. Our approach will explore broad classes of evolving functions combining them to automated Bayesian machines ensuring the search, the evaluation of models, trading-off complexity, fitting to the data and quantify resource usage [16, 17].

Discovery in federated networks (WP3)

Evolutionary neural diversification-inspired federated networks (ENDI): Technologies in digital ecosystems around federated networks are rapidly increasing and mostly focus on decentralization, scalability and security fronts [18–20]. Yet, the implementation of ENDI type algorithms and their application to forecasting in global sustainability problems is still lacking. Recent studies have shown the importance of evolutionary search of mathematical and symbolic operations as building blocks to discover ML algorithms [4, 16]. ENDI will help to decipher how interactions among heterogeneous groups evolve and learn to solve complex sustainability problems. Evolutionary dynamics explore open-ended language of models with varying trait evolution functions to discover biologically inspired solutions in multidimensional systems [4]. ENDI accounts for heterogeneous agents to discover novel biology-inspired solutions for the sustainability of the Oceans federated network.

Going beyond: Our understanding of the outcomes from diversified information processing systems formed by highly heterogeneous groups, a kind of large-scale meta-learning in the federated setting [21], is currently quite limited. Therefore, new science-enabled approaches accounting for diversifying information processing in heterogeneous and highly dimensional systems are required. This allows the development of science-enabled technologies where heterogeneous agents with different interests find (non-optimal) solutions for the sustainable exploitation of ecosystems. Federated objects can be seen as "neural networks" containing many types of heterogeneous nodes with varying degrees of learning, connectivity and firing probabilities [22, 23]. ROBHOOT v.3.0 connects knowledge discovery to ENDI to study the properties of cooperative forecasting in the face of global sustainability challenges.

1.3 Interdisciplinarity and non-incrementality of the research proposed

The success of ROBHOOT relies on a multidisciplinary team: evolutionary biology, ecology, computational neuroscience, data science, complex systems and experts in communication and field studies in biodiversity. Data knowledge discovery will be developed by evolutionary biology, computer science and complex system members of the consortium (EBD-CSIC, IFISC-CSIC, and SDSC). Data discovery will be transferred to the causal domain by the other part of the consortium with expertise in ecology, evolutionary biology, data science and causal inference (EAWAG and TARTUR). The whole process will be enriched with full automation, reproducibility and visualization by ICREA, SDSC, and our company-partner SCITE, respectively. Conversely, scientists working on neurobiology and eco-evolutionary dynamics in ecosystems will feed information back on fundamental discovery computational challenges in federated networks (i.e., role of heterogeneity, expanding EEDA and ENDI and adding cooperation and dimensionality). They will explore novel paths to improve existing theories using EEDA and ENDI algorithms. This cross-fertilizing back-and-forth interaction will allow the project to keep high modularity within the WPs while keeping cross-interactions among the groups to run efficiently the project. Bringing together ESA, EEDA and ENDI algorithms require a long stride and this has not been attempted so far. This way, we expect to realize a truly novel, sustainability-driven knowledge-based society technology for which there are no predecessors. Thus, ROBHOOT will not be incremental, but a jump to a new