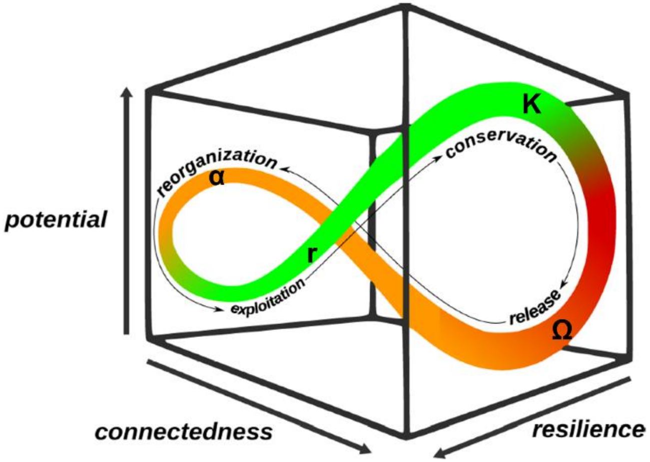
From the Idea to the Software Tool

Dr. Hannah Zoller

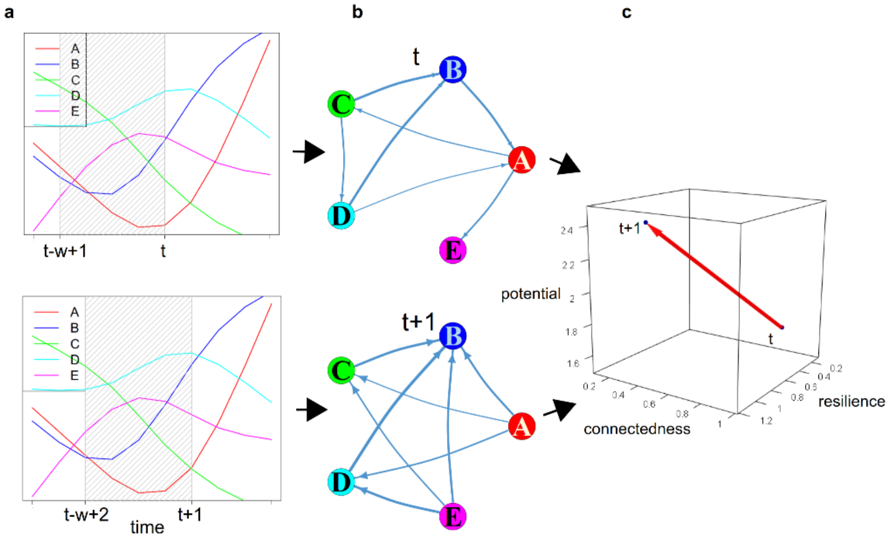
Section 5.4

The Idea



The adaptive cycle metaphor

(Gunderson and Holling, 2002)



Stage-dependent Purposes and Characteristics of the Code

Working Code

produce results

Research Software

www.nature.com/scientificreports

scientific reports

OPEN

Computing the adaptive cycle

Wolfgang zu Castell[1,2] & Hannah Schrenk[1]✉

Gunderson's and Holling's adaptive cycle metaphor provides a qualitative description of the development of a dynamically evolving complex system. According to the metaphor, a complex system alternately passes through phases of stability and predictability and phases of reorganization and stochasticity. So far, there have been no attempts to quantify the underlying notions in a way which is independent of the concrete realization of the system. We propose a method which can be applied in a generic way to estimate a system's position within the adaptive cycle as well as to identify drivers of change. We demonstrate applicability and flexibility of our method by three different case studies: Analyzing data obtained from a simulation of a model of interaction of abstract genotypes, we show that our approach is able to capture the nature of these interactions. We then study European economies as systems of economic state variables to illustrate the ability of system comparison. Finally, we identify drivers of change in a plant ecosystem in the prairie-forest. We hereby confirm the conceptual dynamics of the adaptive cycle and thus underline its usability in understanding system dynamics.

Understanding the dynamics of self-organizing systems is steadily gaining attention with the challenge to deal with increasing complexity and to manage systems on a sustainable basis . Examples range through many areas of high societal relevance, such as coping with climate change, managing economical crises, or adapting to the digital transformation. One of the major challenges in managing complex systems of interacting agents is to close the gap between qualitative theory describing system evolution and quantitative methods accessing the actual state and development of a given system.

Schrenk, H., B. Magnússon, B. D. Sigurdsson, and W. zu Castell. 2022. Systemic analysis of a developing plant community on the island of Surtsey. Ecology and Society 27(1):35. https://doi.org/10.5751/ES-12980-270135

E&S

Research, part of a Special Feature on Panarchy: the Metaphor, the Theory, the Challenges, and the Road Ahead

Systemic analysis of a developing plant community on the island of Surtsey

Hannah Schrenk [1], *Borgþór Magnússon* [2], *Bjarni D. Sigurdsson* [3] and *Wolfgang zu Castell* [4]

ABSTRACT. Based on our recently developed method to quantify Gunderson and Holling's adaptive cycle, we provide a holistic analysis of a vascular plant community on the volcanic island of Surtsey between 2000 and 2018. We identify one complete adaptive cycle during the study period, which reflects the system's transition from a classic pioneer to a grassland community. Our results support the hypothesis that nutrients brought to the island by breeding gulls are the main driver of this development. The study period includes the beginning of a second cycle, which deviates from the pattern described in the metaphor. Indeed, the cycle's exploitation phase is interrupted by a simultaneous decline of all three systemic variables. We can trace this phenomenon back to a severe drought in 2012. Furthermore, the method allows us to establish the systemic role of individual species during the maturation process.

Key Words: *adaptive cycle metaphor; information transfer; nesting density; succession; vascular plants community*

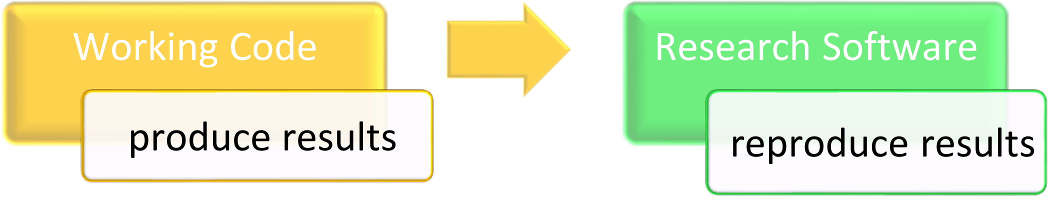
INTRODUCTION

Analyzing the dynamics of change in ecosystems remains a challenging endeavor. Ecosystem characteristics are formed by physical and chemical processes, as well as the interactions of organisms inhabiting the system, their adaptation to the given environment, and the shaping of the latter.

Dynamics of ecosystem development have been extensively studied and several frameworks for qualitative (Bossel 1992, Holling 2001) and quantitative descriptions (Odum 1983, Ulanowicz 1986) have been proposed. One of the qualitative descriptions is given by Gunderson and Holling's adaptive cycle metaphor (Gunderson and Holling 2002), centerpiece of their panarchy theory. According to the metaphor, system development is shaped by three comprehensive systemic properties: (1) the system's potential available for future change, (2) the connectedness among its internal variables and processes, and (3) its resilience in the light of unpredicted perturbations. The are exploited, new components might enter the system, whereas others might get lost. The latter two phases are thus characterized by a high degree of stochasticity, admitting chance for creative change. With a set of components slowly settling in, the system starts into another r-phase. According to the metaphor, this alternation between growth and renewal, consolidation and creativity, allows a complex system to repeatedly adapt to a changing environment.

Due to its high degree of generality, the metaphor serves as a valuable framework for the development of a broad range of complex systems. However, it has its limits as well. Systems living passively with external variability and systems anticipating and manipulating variability may, for example, permanently remain in single phases (Gunderson and Holling 2002). Besides, the interplay of internal and external factors may generally result in the skipping or stretching of single phases. Although being intuitively plausible, the adaptive cycle has so far to a great extent

Stage-dependent Purposes and Characteristics of the Code



Research Tool

QtAC: an R-package for analyzing complex systems development in the framework of the adaptive cycle metaphor

Hannah Schrenk[a,*], Carlos Garcia-Perez[a], Nico Schreiber[a] and Wolfgang zu Castell[a,b]

[a] *Strategy & Digitalization, Helmholtz Zentrum München, Ingolstädter Landstraße 1, D-85764 Neuherberg*
[b] *Department of Mathematics, Technische Universität München, Boltzmannstraße 3, D-85748 Garching bei München*

ARTICLE INFO

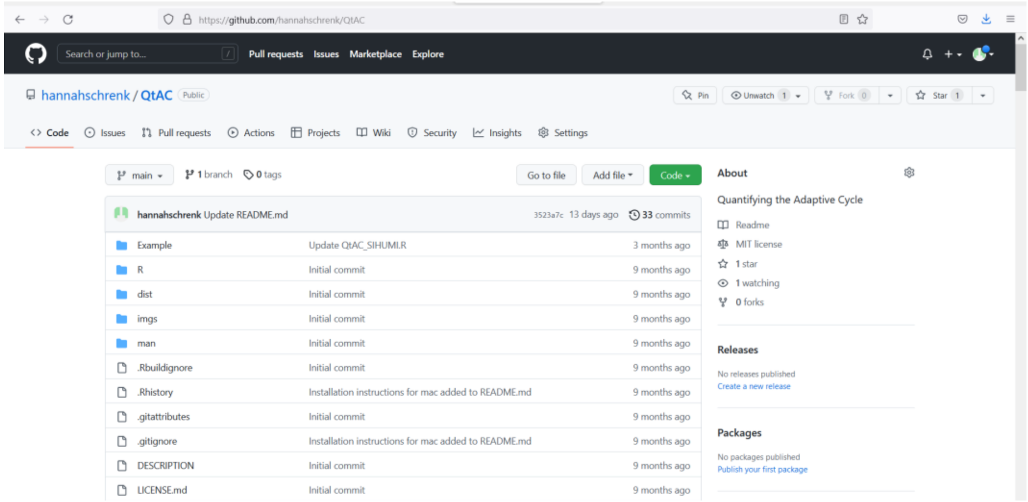
Keywords:
complex systems
adaptive cycle
information networks
R package
biodiversity

ABSTRACT

We present the QtAC R-package, which enables the analysis and assessment of general complex systems in terms of the adaptive cycle metaphor. According to the metaphor, complex systems typically develop through alternating phases of consolidation and reorganization, being defined by the systemic properties of potential, connectedness, and resilience. QtAC builds on a recently published universal method of quantifying the adaptive cycle. Based on time series of abundance data, networks of information transfer are estimated, yielding insight into the internal interaction structure of the system and the functional role of its components. Potential, connectedness, and resilience are computed on basis of the information networks, defining the system's course through the cycle. We illustrate the application of QtAC using an example of grassland communities varying in species richness and functional composition.

1. Software and data availability statement

The QtAC R-package is available through the GitHub repository Schrenk and Schreiber (2020) under the MIT License. It was first released in August 2020. The code runs on Windows and Linux operating systems with R version 3.6 or higher. All data used in this article is provided as supplementary material of the paper and through the GitHub repository.

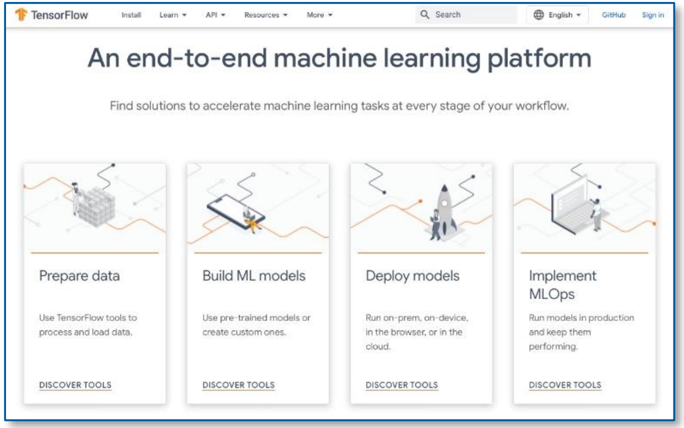


Stage-dependent Purposes and Characteristics of the Code

Data Science and the Machine Learning Interest Group @GFZ

Potential of Professional RSE for Data Science

- data scientists do programming, so obviously they also profit from doing this in a professional manner
- professional RSE fosters findability, reproducibility and reusability of code
  → significantly speeds up your implementation
- stepwise following an implementation is an efficient way of learning a new method/approach
- implementation of ML/AI models is a condensed form of documenting research in data science
- concepts such as transfer learning make explicit use of the information being captured in pre-trained networks



☞ we should agree on sharing our data science models at GFZ

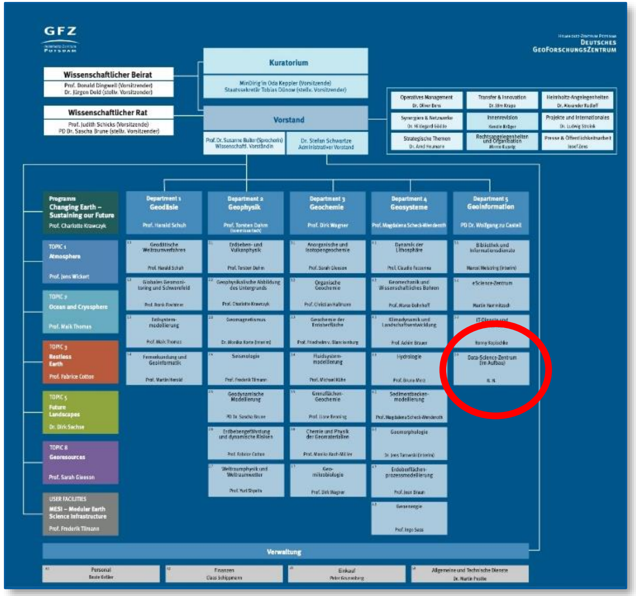
Data Science at GFZ

- we are currently implementing a Data Science Section within Department 5 (Geoinformation)

- there are various Data Scientists working in different sections

- we are coordinating activities in Data Science via
  - ✓ NFDI4Earth Academy
  - ✓ HEIBRiDS
  - ✓ Helmholtz.AI
  - ✓ Helmholtz Imaging
  - ✓ Helmholtz Metadata Collaboration (HMC)
  - ✓ Helmholtz Information & Data Science Academy (HIDA)
  - ✓ HIFIS

- there exists a ML Interest Group at GFZ



Machine Learning Interest Group at GFZ

https://git.gfz-potsdam.de/ml-gfz

- there is a transition with new people coming and others leaving

Christopher Irrgang

Ruggero Vasile

Hannah Zoller

Jonas Kuppler

Thanks to Christopher and all the best for the new job!

Frederik Tilmann, Wolfgang zu Castell (advisors)

- we will (re)start – after the Covid break – with joint events, soon

☞ join the Machine Learning Interest Group at GFZ (mail to jonas.kuppler@gfz-potzsdam.de)