Dynamics of Complex Systems

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Chapter 1

Course guide

This course discusses research methods and analysis techniques that allow for the study of human behaviour from a complex systems perspective. Complexity research transcends the boundaries the classical scientific disciplines in terms of explanatory goals (e.g. causal-mechanistic) and is a hot topic in physics, mathematics, biology, economy and psychology.

The main focus in the cognitive behavioural sciences is a description and explanation of behaviour based on interaction dominant dynamics: Many processes interact on many different (temporal and spatial) scales and observable behaviour emerges out of those interactions through a process of self-organization or soft-assembly. Contrary to what the term might suggest, complexity research is often about finding simple models that are able to simulate a wide range of complex behaviour.

This approach differs fundamentally from the more classical approaches where behaviour is caused by a system of many hidden (cognitive) components which interact in sequence as in a machine (component dominant dynamics). The most important difference is how 'change', and hence the time-evolution of a system, is studied.

The main focus of the course will be 'hands-on' data-analysis in `R`, or, in `Matlab` if student is already familiar with the scritping language.

Topics include: Analysis of fractal geometry (i.e. pink noise) in time series (Standardized Dispersion Analysis, Power Spectral Density Analysis, Detrended Fluctuation Analysis); Nonlinear and chaotic time series analysis (Phase Space Reconstruction, (Cross) Recurrence Quantification Analysis, Entropy Estimation); Growth Curve models; Potential Theory; and Catastrophe Theory (Cusp model), Complex Network Analysis.

1.1 Learning objectives

Students who followed this course will be able to critically evaluate whether their scientific inquiries can benefit from adopting theories, models, methods and analyses that were developed to study the dynamics of complex systems. The student will be able to understand in more detail the basics of formal theory evaluation, and be able to recognize, interpret and deduce theoretical accounts of human behaviour that are based on component-dominant versus interaction-dominant ontology.

Students will be able to use the basic mathematical models and analyses that allow study of complex interaction-dominant behaviour. Students who finish the course will be able to conduct analyses in `Excel`, `SPSS`, and `R` or `Matlab` and interpret the results from basic (non-)linear time series methods. At the end of this course, students have reached a level of understanding that allows them to find relevant scientific sources and understand and follow up on new developments in the complex systems approach to behavioural science.

Goals Summary

- Read and understand papers that use a complex systems approach to study human behaviour.
- Simulate the basic dynamical models.
- Perform the basic analyses.

1.2 Teaching methods

Each meeting starts with a *lecture session* addressing the mathematical background and practical application of a particular aspect of a model, or analysis technique. During the *assignment session*, students will get hands-on experience with applying the models or analysis techniques discussed during the lecture session by completing assignments provided on blackboard for each session.

Preparation

To prepare for each lecture students read a contemporary research paper or watch a videolecture (e.g., TED) featuring complexity theory and its application on a topic in behavioural science that will be discussed in the subsequent lecture. Students are required to formulate questions about each paper, and to initiate a discussion with their fellow-students on Blackboard.

Before each lecture, students should:

- Read (parts of) a scientific article, or watch a videolecture featuring a complex systems perspective and/or methodology.
- Ask (or answer) a question about what they have read / seen in the appropriate discussion forum on Blackboard.
    - The answers students provide will be discussed during the lecture.

1.3 Literature

The following is part of the literature for this course:

- Lecture slides.
- Articles and book chapters listed in the `Literature` folder on Blackboard for each session.
- In addition, at the secretariat of PWO (5th floor, Spinoza building) selected chapters from the book "Dynamical Psychology" by Jay Friedenberg are available. It is not necessary to own the book to complete this course, but if you can find a copy, it may help to structure all the information provided during the course.

Note: The literature for each session on Blackboard is provided for reference, to fascilitate looking up a topic when it is needed to complete the weekly assignments or the take-home exam.

Table **1.1**
Times and Places 2016-2017

Lecture	Topic	Week	Day	Date	Activity type	Location
1	Introduction to Complexity Science	46	Tue	2016-11-08	Lecture	SP A -1.59
1	Mathematics of Change I	46	Wed	2016-11-09	Lab course	SP A -1.55.A/B
2	Multivariate Systems	47	Tue	2016-11-15	Lecture	SP A -1.59
2	Mathematics of Change II	47	Wed	2016-11-16	Lab course	SP A -1.55.A/B
3	Additive vs. Multiplicative Interactions	48	Tue	2016-11-22	Lecture	SP A -1.59
3	Basic Timeseries Analysis	48	Wed	2016-11-23	Lab course	SP A -1.55.A/B
4	Fractal Geometry in Timeseries	49	Tue	2016-12-29	Lecture	SP A -1.59
4	Fluctuation and Disperion analyses I	49	Wed	2016-12-30	Lab course	SP A -1.55.A/B
5	Multi-Fractal Geometry in Timeseries	50	Tue	2016-12-06	Lecture	SP A -1.59
5	Fluctuation and Disperion analyses II	50	Wed	2016-12-07	Lab course	SP A -1.55.A/B
6	Quantifying Continuous Dynamics	51	Tue	2016-12-13	Lecture	SP A -1.59
6	Recurrence Quantification Analysis (RQA)	51	Wed	2016-12-14	Lab course	SP A -1.55.A/B
7	Quantifying Categorical and Interaction Dynamics	1	Tue	2016-01-20	Lecture	SP A -1.59
7	Categorical and Cross-Recurrence Quantification Analaysis (CRQA)	1	Wed	2016-01-21	Lab course	SP A -1.55.A/B
8	Potential Theory and Catastrophe Theory	2	Tue	2017-01-10	Lecture	SP A -1.59
8	The Cusp Model	2	Wed	2017-01-11	Lab course	SP A -1.55.A/B
9	Complex Networks	3	Tue	2017-01-17	Lecture	SP A -1.59
9	Q&A session	3	Wed	2017-01-21	Lab course	TvA 8.00.14

1.4 Schedule

The dates and locations can be found below. All lectures are on Tuesday from `10.45` to `12.30`. The practical sessions take place on Wednesday from `15.45` to `17.30`.

1.5 Examination

The evaluation of achievement of study goals takes two forms:

- **Participation** - The ability to formulate a question about an advanced topic is a first step towards understanding, answering a question that was posted by a peer is a second step. Questions and answers will not be graded, there will be a check to see if a student participated in all sessions.
- **Final Assignment** - This take-home assignment will be provided at the end of the course. It will consist of a series of practical assignments and at least one essay question to test theoretical knowledge. The submission deadline is two weeks after the last lecture.

Grading

The take home exam will be graded as a regular exam. A student passes the course if the exam grade is higher than 5.5 AND if the student participated in the discussion on Blackboard each session.

Submitting the assignment

The take-home exam must be submitted by sending them by email to both `f.hasselman@pwo.ru.nl` AND `m.wijnants@pwo.ru.nl` no later than **February 1st**.

1.6 We use R!

This text was transformed to HTML, PDF en ePUB using bookdown(**?**) in **RStudio**, the graphical user interface of the statistical language **R** (**?**). bookdown makes use of the R version of markdown called Rmarkdown (**?**), together with knitr (**?**) and pandoc.

We'll use some web applications made in Shiny (**?**)

Other R packages used are: DT (**?**), htmlTable (**?**), plyr (**?**), dplyr (**?**),tidyr (**?**), png (**?**), rio (**?**).

Part I

Assignments

How to …

These assignments were designed to prepare you for "real world" modelling and data analysis problems. That is, after completing the assignments you should be able to decide whether the phenomenon you study could benefit from a complex systems approach and which type of analyses would be a good place to start. The models and techniques discussed here are **not** a definite collection of available techniques, this is really just the tip of the iceberg.

General Guidelines

- Read the instructions carefully.
- Do not skip any of the steps.
- Do not copy-paste from the assignment text into a spreadsheet or syntax editor (except for text in `code blocks`).
- Study the solutions and lecture notes.

Files on GitHub

All the files (data, scripts, the files that generated this document) are in a repository on Github. Github keeps track of all the different versions of the files in a repository.

- If you want to download a file that is basically a text file (e.g. and `R` script), find a button named `raw`, then copy the text in your browser, or save as a text file.
- For non-text files, a `download` button will be present somewhere on the page.

Chapter 2

Mathematics of Change I

In this assignment you will build two (relatively) simple one-dimensional maps. We start with the *Linear Map* and then proceed to the slightly more complicated *Logistic Map* (aka *Quadratic map*). You can use your favourite spreadsheet software (e.g., Excel, Numbers, GoogleSheets).

> If you are experienced in `R` or `Matlab` you can try to code the models using the hints in section **??**.
>
> Besure to check the solutions of the assigment which provide examples of different ways to visualize the time series in `R`