Andrea Censi, Jonathan Lorand, Gioele Zardini
ETH Zurich
Department of Mechanical and Process Engineering
Institute for Dynamic Systems and Control
Sonneggstrasse 3, ML K42.2,
8092 Zurich, Switzerland

MIT Press
One Broadway
12th Floor
Cambridge, MA 02142

Fill cover letter

Yours sincerely,

Andrea Censi, Jonathan Lorand, Gioele Zardini

1 The prospectus

Title: Applied Category Theory for Engineering

1.1 Brief description

In many domains of engineering and applied sciences, it is advantageous to think explicitly about abstraction and compositionality, to improve both the understanding of problems, and the design of solutions. However, the type of math which could be useful to applications is not traditionally taught. Applied Category Theory is a recent field of mathematics which could help a lot, but it is quite unreachable by non-mathematicians. While several valuable resources for learning applied category theory have emerged recently, they fail to meet the two essential criteria of a) being approachable from an engineering background and b) highlighting how applied category theory can be used to formalize and solve concrete problems.

This book will fill this gap, by illustrating how applied category theory can be effectively leveraged to address the design and analysis of complex systems, through the "compositionality way of thinking". The book adopts a computational and constructive approach: each concept is accompanied by pen-and-paper exercises, as well as computer-based (Python-based) ones. Furthermore, each section provides exhaustive video content (in the style of MOOCs), explaining concepts and providing further examples.

1.2 Outstanding features

The book is unique in at least five aspects.

- It is specifically written **for engineers and practitioners** (unlike existing efforts, as described in), and applied category theory is just the means toward practical tools for complex system analysis and design. This implies that the presentation of materials sometimes diverges from the usual way category theory is taught, and some common concepts will be de-emphasized in favor of more obscure concepts that find extensive use in applications. Furthermore, the book is **self-contained** for readers with a basic background in engineering. The book culminates presenting a success story of the aforementioned "compositionality way of thinking", presenting a monotone theory of co-design and its application to engineering design optimization problems.

add ref

- It uses an **inductive exposition** style, rather than a deductive explanation style. Indeed, in a typical mathematical exposition of category theory, one usually defines a general mathematical structure, and then gives several specific examples. Instead, in this book, we first build up the examples as something that is interesting per se, and then we show how they can all be instances of the same general concept. This way, the general concept is well motivated. The path laid by the book is one of *spiral learning*.

- The book follows a **computational approach**: in addition to classic pen-and-paper exercises, the reader can implement various constructions in Python, and leverage an auto-grading system to get feedback. Once more, this allows one to fully grasp the practical advantages promoted by the presented "compositionality way of thinking".

- The book uses a **new pedagogy of colors** to aid in the parsing of formulas and diagrams (see attached example). We also color the various composition operations. Typically, applied category theory features many different quantities, which are used in different contexts: our approach, which is colorblind-friendly (one of the authors is colorblind), helps the reader understanding the various concepts introduced.

add use of colors table

- Every section of the book features **dedicated video content** (e.g., explanations of concepts and step-by-step solutions of exercises) in the style of MOOCs. We are in the process of creating exhaustive content for a MOOC.

1.3 Competition

Re-elaborate the full section

Our book stands in competition with books which are general introductions to category theory or to applied category theory. Below we discuss the main titles of this kind which exist today, in order to compare and contrast them to our book. Our book is unique among these existing books because it has the following two qualities simultaneously:

1. it is slow-paced, nearly self-contained, and written in an accessible style oriented toward people who do not have a formal training in pure mathematics, including in particular engineering students and practitioners;

2. it's contents and style are oriented expressly towards applying category theory for engineering.

Categories for the Working Mathematician, ***S. MacLane, Graduate Texts in Mathematics, Springer, 1978***
This was the early major expository monograph on category theory and for a very long time the go-to book for mathematicians to learn category theory. Written in a terse and dense style, it is comprehensive, insightful, and a slow and challenging read, even for mathematicians. As far as introductory category theory texts go, this is probably the least accessible one. It focused on only on pure mathematics, and assumes a good deal of prior mathematical experience.

Conceptual Mathematics, 2nd Ed., ***S. H. Schanuel, F. W. Lawvere, Cambridge University Press, 2009***

Category Theory, ***S. Awodey, Oxford University Press, 2010***

Category Theory in Context, ***E. Riehl, Aurora: Dover Modern Math Originals, 2016***

The Joy of Abstraction: An Exploration of Math, Category Theory, and Life, ***E. Cheng, Cambridge University Press, 2022***

Category Theory for the Sciences, ***D. I. Spivak, MIT Press, 2014***

An Invitation to Applied Category Theory: Seven Sketches in Compositionality, ***B. Fong, D. I. Spivak, Cambridge University Press, 2019***

Picturing Quantum Processes: A First Course in Quantum Theory and Diagrammatic Reasoning, ***Coecke and Kissinger, Cambridge University Press, 2017***

While definitely offering a more approachable alternative, such books are still (intentionally or not) inherently targeted to mathematicians, lacking practical applications, and, most importantly, an application-driven selection of topics.

Finally, our book is specifically written **for engineers and practitioners**, and applied category theory is just the means toward practical tools for complex system analysis and design. Motivated by practical engineering examples, the presentation of materials sometimes diverges from the usual way category theory is taught, and some common concepts are de-emphasized in favor of more obscure concepts that find

extensive use in applications. Furthermore, the book is self-contained for readers with a basic background in engineering.

1.4 Apparatus

The book will include examples, pen-and-paper exercises, and computational (Python-based) exercises. Solutions to pen-and-paper exercises will be provided, and the computational exercises will be automatically graded through a system we have developed during dedicated classes at ETH Zurich. The book will include glossaries, bibliography, and appendices. Furthermore, we have created a "developer" version of the book, for instructors to use in their classes.

1.5 Audience

The book is intended for engineers, and we assume basic knowledge of algebra at the level of a bachelor's degree in engineering/computer science and is self-contained. In the past, we have organized both ETH Zurich lectures, as well as international, online ones. From our records, we highlight that professionals were particularly interested in the subject presented in this book. The book has a rigorous character, and provides both descriptive and quantitative explanations of various ideas.

1.6 Authors

See if we need more exhaustive bios

Dr. Andrea Censi, Senior Research Scientist
Institute for Dynamic Systems and Control, ETH Zurich
E-mail: acensi@ethz.ch
Website: censi.science
Bio: Andrea Censi is deputy director of the Dynamic Systems and Control chair at ETH Zurich. He obtained a Ph.D. from Caltech. Previously, he has been a research scientist at MIT and Director of Research at Aptiv Mobility (now Motional). He is president of the Duckietown Foundation.

Dr. Jonathan Lorand, Postdoctoral researcher
Institute for Dynamic Systems and Control, ETH Zurich
E-mail: jlorand@ethz.ch.
Website: lorand.earth/math/
Bio: Jonathan is a postdoctoral researcher working as a mathematician at the Institute for Dynamic Systems and Control at ETH Zurich. He obtained his PhD in mathematics from the University of Zurich in 2020, working in symplectic geometry and category theory. Since then he is focused on applied category theory, as well on the topic of transdisciplinarity, in which he will obtain an MA in 2024 from the Zurich University of the Arts.

Gioele Zardini, Ph. D. Candidate
Institute for Dynamic Systems and Control, ETH Zurich
E-mail: gzardini@ethz.ch.
Website: gioele.science
Bio: Gioele is a Ph.D. candidate at ETH Zurich, and incoming faculty at Massachusetts Institute of Technology. He received his BSc. and MSc. in Mechanical Engineering with focus in Robotics, Systems and Control from ETH Zurich in 2017 and 2019, respectively. He spent time in Singapore as a researcher at nuTonomy (now Motional), at Stanford University and at MIT.

All three authors have experience in teaching various courses (both at the undergraduate and graduate level) at ETH Zurich and University of Zurich.

1.7 Market considerations

One of the great engineering challenges of this century is dealing with the design of complex systems, and, as explained above, the math traditionally thought is not practical, and does not help reasoning about them. The interest for applied category theory has been growing dramatically over the past few years, taking a small community of mathematicians and bringing it to a worldwide movement, with representatives in academia and in industry.

We believe that the course presented by this book will be taught in at least 50% of the major universities in the next 7 years, as part of every engineering program.

Over the past few years, we organized online classes, as well as dissemination workshops at large international conferences (e.g., in robotics, systems and control, and intelligent transportation systems), and we have created a large, diverse network of interested people. We are curating a dedicated mailing list, with people following our steps in this journey.

1.8 Status of the book

The first version of the book is complete, and needs most probably adaptation to a common format from the publisher. We expect the complete manuscript to be completed within the next six months or less. The manuscript will reach around 200'000 words.

The book features at least two figures on each page (vector figures, typically mathematical diagrams), and one full color photograph per chapter.

You can find the current version of the book at https://z7-stage-act4e-book.zuper.ai/sync/ACT4E/ACT4E/alphubel-prod/build/last/build-public/ACT4E-public.pdf.

1.9 Reviewers

choose order wisely

We suggest the following list of reviewers:

- Prof. Michael Johnson, Macquarie University, Michael.Johnson@mq.edu.au;
- Prof. John Baez, University of California, Riverside and Topos Institute, john.baez@ucr.edu;
- Prof. Daniel Koditschek, University of Pennsylvania, kod@seas.upenn.edu;
- Prof. Aaron Ames, California Institute of Technology, ames@cds.caltech.edu;
- Prof. Paulo Tabuada, University of California, Los Angeles, tabuada@ee.ucla.edu;
- Prof. Hadas Kress-Gazit, Cornell University, hadaskg@cornell.edu;
- Prof. Gregory Chirikjian, National University of Singapore, mpegre@nus.edu.sg;
- Dr. Paolo Perrone, University of Oxford, paolo.perrone@cs.ox.ac.uk;
- Dr. David Spivak, Topos Institute, dspivak@gmail.com;
- Dr. Brendan Fond, Topos Institute, brendan@topos.institute;
- _____ others?

2 Table of contents

Attached, you find the current table of contents.

3 Sample chapters

Attached, you find sample chapters.