

# A Course in Model Theory I:

## Introduction<sup>1</sup>

Rami Grossberg

DEPARTMENT OF MATHEMATICAL SCIENCES, CARNEGIE MELLON UNIVERSITY, PITTSBURGH, PA 15213

---

<sup>1</sup>This **preliminary draft** is dated from August 27, 2022. The book will be published by Cambridge University Press. The book is approximately 99.908% complete. I expect that the final version will have about 810 pages, many sections of the current version will be revised and few will be added. I hope to have a stable version of this volume soon.

This version is made only for students studying model theory with me and not for distribution outside CMU. If you have a copy not received directly from me, it is an illegal copy and I request that you will not share with others.

Exercise #=785

[www.math.cmu.edu/~rami](http://www.math.cmu.edu/~rami)

©Rami Grossberg



# Contents

Preface	7
1. About this book	7
2. A mathematical introduction to the book	16
Course outlines	23
<b>Part 1. Definability</b>	<b>25</b>
Chapter 1. Fundamentals	27
Introduction	27
1. Structures and languages	31
2. The basic concepts	47
3. On existence of models and elementary submodels	83
4. The Erdős-Rado Theorem	103
5. Applications of the compactness theorem	118
6. Joint embedding and the Amalgamation properties in first-order logic	133
7. Types and the diagram of $T$	140
8. Some extensions of first-order logic	153
9. Countable models and Henkin's omitting types theorem	177
10. Models of weak set theory	194
11. Absoluteness	202
12. Two cardinal theorems, by Vaught, Chang, Keisler and Morley	204
13. Model complete-theories	217
14. Skolemization	226
Chapter 2. Abstract Elementary Classes	233
Introduction	233
1. Abstract Classes	235
2. Abstract Elementary Classes	252
3. Axiomatization of AECs and Kueker's theorem	267
4. The major open questions concerning AEC	269
5. Shelah's presentation Theorem and 2-categories	274
6. Basic Examples	284
7. PC-classes and omitting types	289
8. $I(\aleph_0, \mathcal{K}) = I(\aleph_1, \mathcal{K}) = 1 \implies \mathcal{K}_{\aleph_2} \neq \emptyset$ .	311
9. Categoricity in $\aleph_1$ for AECs is not absolute	318
10. Random power set in higher order	332
11. $\text{Ext}_{\mathbf{Z}}^1(G, \mathbf{Z})$	333
12. Weak amalgamation	334
13. Few models imply the amalgamation property	337
Chapter 3. More Fundamentals	345
Introduction	345
1. The filter of closed unbounded sets	346

2. Ultraproducts	358
3. Ehrenfeucht-Fraissé games	372
4. Two applications to algebra	375
5. Non-standard analysis*	381
6. When does a class have a structure theory? Shelah's thesis	381
<b>Part 2. Galois Theory</b>	383
Chapter 4. Complete types and indiscernibles	385
Introduction	385
1. Saturated models	387
2. The monster model, homogenous and special models	400
3. Indiscernibles and Ehrenfeucht-Mostowski models	425
Chapter 5. Galois types and monster models in Abstract Elementary Classes	447
Introduction	447
1. Types in Abstract Elementary Classes	449
2. Galois saturation and model-homogeneity are the same	453
3. $\alpha$ -limit models a substitute to saturation	456
Chapter 6. More on Types	463
Introduction	463
1. Definability and the Lascar group	465
2. Using models of set theory to establish consistency of a first-order theory	477
3. Game theoretic characterization of elementary embedding and isomorphism	480
4. Saturation of ultraproducts	482
5. Keisler-Shelah's theorem*	482
6. More on model complete theories*	483
7. Shelah's Generalization of Ehrenfeucht-Mostowski models	484
8. $D(T)$ as a topological space*	487
9. The topology of Lascar's groups	494
10. More on existence, omitting types, and the completeness theorem	495
11. The Paris Harrington's theorem*	501
12. More on two cardinal theorems*	502
13. Chang's conjecture and Jónsson algebras*	506
Chapter 7. Morley's Theorem	513
Introduction	513
1. Dimension in model theory	516
2. A rank function	518
3. $\aleph_0$ -stability	526
4. Existence of indiscernibles, non-splitting and cohiers	535
5. Prime, primary and atomic models	547
6. Every model is saturated	556
7. Chang's Conjecture is true for $\aleph_0$ -stable theories	562
8. Quasi-minimal formulas and an omitting types Theorem	564
9. Strongly minimal sets and the Baldwin-Lachlan proof	571
10. Some properties of $ T ^+$ -categorical theories	590
11. The Baldwin Lachlan proof	595
12. Keisler's rank-free proof of Morley's theorem	597
13. Morely's rank and the local rank	603
14. Some properties of $\aleph_0$ -stable theories	605
Chapter 8. Basics of Stability	607

Introduction	607
1. Local Types	608
2. Infinitely many Rank Functions	613
3. Characterizations of stability by rank and $\varphi$ -types	629
4. Definability of types is equivalent to stability	632
5. The order dichotomy	637
6. Sequences and sets of indiscernibles	647
7. Towards Los conjecture for uncountable first-order theories	657
8. The independence and strict-order properties	659
9. Superstable theories	672
10. Simple Theories	673
11. Noetherian topological spaces	674
Chapter 9. Forking calculus	677
Introduction	677
1. Basics of Forking	678
2. Stability spectrum theorem	708
3. Forking in Simple theories is symmetric and transitive	709
4. Applications of forking	713
5. Forking is canonical	714
Chapter 10. Applications	715
Introduction	715
1. Harnik's theorem	715
2. Uniqueness and characterization of prime models	716
3. Uniqueness of prime models	717
4. Stability spectrum	717
Chapter 11. Survey	719
Introduction	719
1. The main gap (Shelah's great theorem)	719
2. Classification theory for non-elementary classes	721
3. Geometric stability (or the fine structure theory)	721
4. Lang-Mordell	721
5. Ax and Kochen	721
6. $o$ -minimal theories	721
7. Abstract model theory	722
8. Finite model theory	723
9. Non standard analysis	723
Chapter 12. A miniguide to the literature	725
Chapter 13. Open Problems	727
Introduction	727
1. Classification theory for non-elementary classes	727
2. Shelah's categoricity conjecture	727
3. Main Gap for uncountable theories	727
4. Other problems	728
Chapter 14. Historical comments	731
<b>APPENDIX</b>	741
Chapter 15. Some set theory	743
Introduction	743

1. Sets, functions and relations	743
2. Cardinal numbers	745
3. The Axiom of Choice, Zorn's Lemma and the well-ordering theorem	751
4. Ordinals	753
5. The commulative hierarchy and the reflection principle	757
6. Martin's Axiom	758
7. On weak diamonds	759
8. The small subsets of $\lambda^+$ is a normal ideal	769
9. Kuratowski's and Hajnal's free subset theorems	772
10. The building-stones of many models	776
Chapter 16. Combinatorial geometry	779
Introduction	779
1. Pregeometries (or Matroids)	779
2. Abstract dependence	789
3. Projective geometries	789
Chapter 17. Plato: The Allegory of the Cave, from book VII The Republic	791
Bibliography	795
Index	807