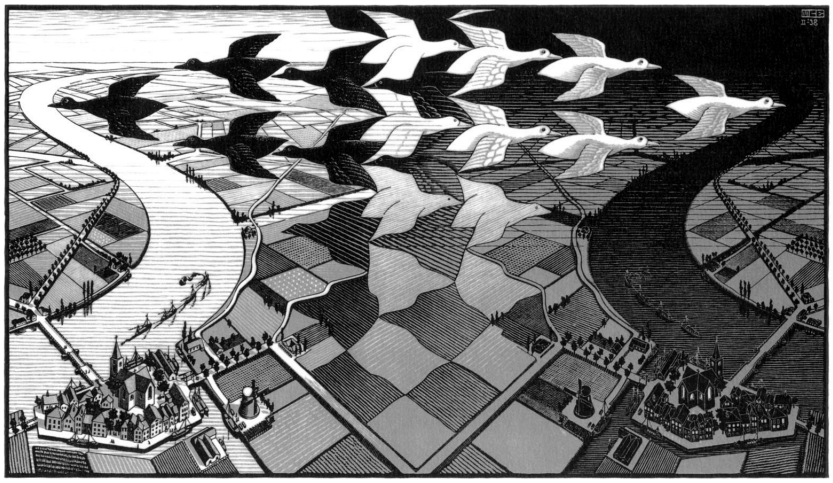
CS 491/691 Foundations of Autonomous Systems: Math, Machines, and Minds

Richard Kelley

Fall 2016



Day and Night by *M.C. Escher* 1938 Woodcut in black and grey, printed from 2 blocks. 677mm x 391mm.

Instructor information

- **Richard Kelley** will be the head instructor, **Banafsheh Rekabdar** will be the lead teaching assistant, and the head teaching fellow will be **Duncan Wilson**.
- Their email addresses are `rkelley@unr.edu`, `rekabdar.b@gmail.com`, and `duncanw@nevada.unr.edu` respectively.
- Office hours with Duncan will be weekly and by appointment with Richard.

Course description and prerequisites

Official Course Description: This course will be an overview of formal systems, discrete math, theoretical computer science, and what the limits of knowledge are for both humans and the machines we build. It will be a quick and challenging ride as we read both *Gödel, Escher, Bach* by Douglas Hofstadter and *Meta Math!* by Gregory Chaitin. Interwoven through these two texts will be a good deal of external readings.

As a student in this class, doing the weekly reading will not be optional. You'll be expected to participate in weekly discussion and write six responses to the readings throughout the course of the semester. You'll also solve problems and code cool projects. There will be three problem sets throughout the semester and they will involve both interesting coding (Cellular automata, simple AIs, etc..) and elegant proofs. The final project will be a paper or coding project regarding the topics covered.

This course will be very work intensive and should only be taken on by students who trust they can and will be invested.

Prerequisite(s): CS 365 or MATH 301 will be required as all problem sets will contain proofs. CS 456 will be highly recommended but not required.

List of required course materials

Required Textbooks:
Gödel, Escher, Bach (GEB) by Douglas Hofstadter. Winner of the Pulitzer Prize, this book applies Gödel's seminal contribution to modern mathematics to the study of the human mind and the development of artificial intelligence. Students will be reading selected chapters paired with external readings to fully integrate the material.
Meta Math! by Gregory Chaitin. Chaitin, father of algorithmic information theory and co-discoverer of program size complexity, outlines in *Meta Math!* his journey through understanding incompleteness, LISP, primes, and maximally unknowable truths. Students will read the entire text, which is quite short and riveting which will be interwoven with *Gödel, Escher, Bach* as well as external readings.

Topics outline

- **Week 1 & 2 Formal Systems, Thought, Proof, and Meaning**:
  (Reading : Chapter 1 & 2 of GEB)
  - Formal Systems:
    - MU Formal System
    - Peano Arithmetic
  - Euclid's Proof of Infinitude of Primes (*Proofs From the Book* reading for graduate students)
  - Isomorphisms and Meaning:
    - Analogy as the Fuel and Fire of Cognition (Hofstadter Lecture)
    - Partial Isomorphisms

  Week 2 the first writing assignment is due.

- **Week 3 Primes, Paradox, and Gödel:**
  (Reading Chapter 3 & 4 and Chapter 1 & 2 of Meta Math!)
  - Revisit the primes in Meta Math!
  - Paradox and self reference in formal systems
  - Gödels Incompleteness Theorems:
    - Completeness
    - Correctness

  Week 3 the second writing assignment is due.

- **Week 4 Recursion, Language, and Software:**
  (Reading Chapter 5 of GEB and Chapter 3 of Meta Math!):
  - Recursion
  - Discussion of recurrences and recursively enumerable sets

  - Fractals
  - Syntax and semantics
  - Perception:
    * Introduction to direct vs. indirect realism
  - DNA and software
  - Biological information and complexity

  Problem Set 1 assigned.
  Week 4 the third writing assignment is due.

- **Week 5 Getting Inside and Out of Formal Systems:**
  (Reading Chapter 7 & 8 of GEB)
  - Propositional Calculus
  - Typographical Number Theory **(Dense and hard material)**

  Short Homework assignment on TNT assigned and due.

- **Week 6 Zen and Chill:**
  (Reading Chapter 9 of GEB and selected koans from The Gateless Gate)
  - Mumon and Gödel
  - What escapes formal systems?
  - Koans and what they say about language
  - Qualia and phenomenal consciousness

  Problem Set 1 is due.

- **Week 7 The $\mathbb{R}$eals, or are they? & is the World One Big Computer?:**
  (Reading Chapter 4 and 5 of Meta Math! and graduate reading: Real Analysis is a Degenerate Case of Discrete Analysis by Doron Zeilberger)
  - Borels know-it-all number
  - Computable functions and Turing
  - Should we believe in a continuous world?
  - Hyper-Reals?

  Midterm this week, Problem Set 2 assigned.

- **Week 8 Complexity, Randomness, and Incompleteness Shows Up Again:**
  (Reading Chapter 6 & 7 of Meta Math and an external reading for grad students)
  - Algorithmic information theory
  - Decidability, halting, and Ω
  - Cantor and Transcendentals

  Week 8 fourth writing assignment is due.

- **Week 9 Minds, Machines, and Ants:**
  (Reading Chapter 10, Ant Fugue, & 11 from GEB)

- Aunt Hilary and Emergent Theories of Minds
- Reductionism and Holism
- Concept and Semantic Space

Problem Set 2 due.

- **Week 10 Who Pushes Who Around in the Careenium:**
(Reading this by Hofstadter and an section from I Am a Strange Loop)
  - Epiphenomenalism and fully exploring emergent theories of mind
  - Basic intro to philosophy of mind

  Week 10 fifth writing assignment due.

- **Week 11 Back to Computer Science; Complexity (Time and Space):**
(Readings from Scott Aaronson and Sipser's Theory of Computation Chapter 7 & 8)
  - Review of Time and Space Complexity
  - Explore the complexity zoo and show elegant reductions

  Problem Set 3 assigned

- **Week 12 P $\stackrel{?}{=}$ NP and Other Million Dollar Questions:**
(Readings from Scott Aaronson, Bill Gasarch, and Sipser)
  - History of the problem
  - Significance and impact

  Guest lecture from Ben Eggers.
  Writing assignment on P $\stackrel{?}{=}$ NP paper assigned.

- **Week 13 Machine Minds: Turing Tests and other bad proxies:**
(Reading Chapter 18 and 19 of GEB and a graduate reading to be decided)
  - What is intelligence? How do we learn?
  - How can we measure other minds?
  - Can we build machines that are intelligent?

  Work on Problem Set 3!

- **Week 14 The Binding Problem and Indirect Realism:**
(Reading on of these two papers and Steven Lehar's website)
  - Do we know anything more than the inside of our skulls?
  - Overview of both local and global binding

  Guest Lecture by David Pearce.
  Problem Set 3 due.

- **Week 15 Consciousness, Binding and its role (or lack thereof) in AI:**
  (Reading physicalism.com and Andrès' website)
  - Proposed and falsifiable solutions to the binding problem
  - Critique of Functionalism and emergent theories of mind

  Guest Lecture by Andrès Emilsson.
  Writing assignment on P $\stackrel{?}{=}$ NP paper due.

- **Week 16 Final Writing or Coding Projects!**

Grading

- In-Class Participation (10-20%)
- Assignments (40%):
  - Six Writing Assignments (One of which is an extended writing on P vs NP) (10%)
  - Three Problem Sets (30%)
- Tests (40-50%)
  - One Midterm Exam
  - One Final Project or Final Exam

Notes on assignments:

Assignments will be based on problems collected from: *An Introduction to Theory of Computer Science* (Sipser), *Concrete Mathematics* (Knuth, Patashnik, and Graham), problems from Bill Gasarch, Nathan Klein, and Andrès Emilsson as well as created by ourselves to match student needs and skills as the semester progresses.

There will be a mixture of coding and proofs on problems sets. Coding questions (& the final project) may include number theoretic algorithms and problems, studying program size complexity with functional languages, generating and studying cellular automata, looking into the NP abyss (SAT solvers and other really hard problems), language based AI (analogy, word2vec, etc. . .), as well as many other possibilities.

Proofs will span a great deal of topics but the core theorems and styles of thought will be shown in class or in SI sessions. Topics will range from: graph theory, theory of computation, complexity theory, algorithmic information theory, combinatorics, introductory formal languages, number theory, and all types of formal systems.

The writing assignments will be mainly feedback on reading, as they occupy a small amount of the course grade the expectation is that the main expectation is for you to just write your opinion about the recent reading. On the one larger paper the students will be analyzing papers that claim that they have solved the P $\stackrel{?}{=}$ NP problem and find the flaws in the paper.

Additionally, graduate students will be required to complete a small (but nontrivial) amount of external reading and will have a higher expectation of performance on their final projects.

Statement on Academic Dishonesty

Cheating, plagiarism or otherwise obtaining grades under false pretenses constitute academic dishonesty according to the code of this university. Academic dishonesty will not be tolerated and penalties can include canceling a student's enrollment without a grade, giving an F for the course or for the assignment. For more details, see the University of Nevada, Reno General Catalog.

Statement of Disability Services

Any student with a disability needing academic adjustments or accommodations is requested to speak with the Disability Resource Center (Thompson Building, Suite 101) as soon as possible to arrange for appropriate accommodations.

Statement on Audio and Video Recording

Surreptitious or covert video-taping of class or unauthorized audio recording of class is prohibited by law and by Board of Regents policy. This class may be videotaped or audio recorded only with the written permission of the instructor. In order to accommodate students with disabilities, some students may be given permission to record class lectures and discussions. Therefore, students should understand that their comments during class may be recorded.

Statement for Academic Success Services

Your student fees cover usage of the Math Center (775) 784-4422, Tutoring Center (775) 784-6801, and University Writing Center (775) 784-6030. These centers support your classroom learning; it is your responsibility to take advantage of their services. Keep in mind that seeking help outside of class is the sign of a responsible and successful student.

FIND GOLD COIN

The Set Up: There are 2015 coins that all look identical. Some are gold, some are silver, some are bronze, but the majority are gold.

Your Goal: Identify a gold coin.

Operations Allowed: There is a machine that does *equality tests*: given two coins determines if they are the same type (but it does not tell you what type they are).

1. Give an algorithm that will, using the machine, find a gold coin. Try to make the number of tests small.
2. (Coins wear down!) In your last algorithm did you do a test on coin 17 like a million times? You fool! Didn't I tell you that a coin can only be involved in a test a small number of times? (The operation wears them down!) Try to do this problem keeping the number of times a single coin is tested as small as possible.

HAT GAME

The Set Up: n people, working together as a team, must stand in a line. Each person can see the heads of everyone in front of her, but not her own head, or the heads of those in back of her. BEFORE hats are placed (the next step) they can discuss strategy; however, the adversary listens in on that conversation.

The Adversary's Move: The Adversary places either a red hat or a blue hat on top of each contestant's head. The contestants cannot communicate at all except as specified in the next step.

The Contestants Move: After the hats have been placed, each contestant, in turn starting from the back of the line and proceeding one by one to the front of the line, will call out one of the two colors, red or blue. Their goal is to get as many people as possible to correctly call out their own hat color.

Note: The n people may discuss strategy ahead of time. However, the adversary will be listening.

1. Is there a strategy that is guaranteed to get at least $n/2$ hats correct? (YES)
2. Is there a strategy that is guaranteed to get MORE THAN $n/2$ hats correct?
3. What is the best they can do?
4. Ask Bill to tell you about when this problem was a project in another summer program.

Extensions:

1. What if there are 3 colors of hats? c colors of hats?
2. What if there are just 2 colors of hats BUT there are a COUNTABLE number of people? Can you make sure that all but a finite number guess there correct hat color?