CSC 595 - Research Skills

On Great Ideas #1: Scientific Revolutions

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*This lecture is from Nick Feamster and Alex Gray with only small modifications: https://noise-lab.net/research-course/

How does research work, as a process?

First thing to realize: It's a *human,* or *sociological* process.

We'll discuss:

- Knowledge and paradigms
- Why/how paradigm shifts arise
- The establishment, and revolutions
- Prediction of the process

Much of this is due to Thomas Kuhn's *The Structure of Scientific Revolutions.*

Knowledge

- Making progress in this process requires a lot of knowledge, to get to the edge of a topic, where the questions are.
- Herbert Simon: takes about 10 years of experience to get to the point of great accomplishment (even for prodigies).
- There is a high barrier to entry in general (though the Internet is reducing it).

Knowledge

- Much of the knowledge critical for research is not written down coherently anywhere
  - What the open questions are
  - What the important questions are
  - What the different alternative solutions to a question are, and were historically
  - What the different alternatives for posing the question are, and are being considered now

Knowledge

- There are actually different levels of acceptance of knowledge: research papers, research lectures, textbooks, courses
- We learn a field through textbooks and courses, in which everything is presented as law, and as if it all developed linearly

Knowledge

- There were intermittent revolutions in the real story, and even current dissenting frameworks, but these are suppressed and invisible; full history and discourse is not preserved in books and courses
- Why?
  - Because it's too inefficient and confusing, especially at the beginning
  - Humans like to tell and hear stories (good stories are not rambling)

Paradigms

- So we tend to operate within a ‘paradigm’, the current framework which acts as a map for researchers in that problem area.
- Paradigms are frameworks for problem formulation which guide/define a field
  - e.g. in machine learning: all data is in the form of a table, where each column is a ‘random variable’
- Paradigms are sets of simplifying assumptions we make to make progress.
  - Sometimes we forget that they are just assumptions, or that these assumptions may not always be true.

Paradigms

- Problem formulation is slow/hard; solution formulation is fast/easier
  - Takes a long time to make a fuzzy problem precise, or formulate it in a way that admits or suggests solutions, e.g.
    - Making models that reduce the world
    - Deciding on how to measure success
  - But we make progress on solutions quickly once we've stated a problem precisely, and extensions to the paradigm come quickly

The power of paradigms

- We make progress by forgetting about the basic assumptions
- We can investigate at a level of detail and depth that would otherwise be impossible
- Allows us to define the boundaries of a discipline, which we need to do – what we can and can't answer

Normal vs. revolutionary science

Two types of science:

- **Normal science:** work within and extend the current paradigm (cumulative)
- **Revolutionary science:** make a new paradigm (non-cumulative; must reinvent everything)

What you learn is normal science

- Our system:
  - Learn a bunch of stuff in courses
  - Demonstrate mastery of the current paradigm
  - Practice research in the paradigm with your advisor
  - Then do research
- Note:
  - An apprenticeship system – learn to work like your advisor to a large extent
  - Learn once, then do
  - You are learning within the existing paradigm

How do new paradigms arise?

1. Begins with the need to explain or treat some facts or situations which the old paradigm didn't handle well ("anomalies").
2. Vying pre-paradigmatic movements appear, then usually one becomes dominant.
3. The dominant one leads to formation of journals, societies, conferences, a discipline.
4. The others become isolated, then fade and die.

How do new paradigms arise?

- Paradigms gain their status when they are more successful than their competitors in solving a few problems that the group of practitioners has come to recognize as acute
  - But more successful does not mean completely successful with a single problem or notably successful with any large number
- Initially, a paradigm offers the *promise* of success.

How do new paradigms arise?

- Normal science consists in the actualization of that promise. This is achieved by:
  - Extending the knowledge of those facts that the paradigm displays as particularly revealing
  - Increasing the extent of the match between those facts and the paradigm's predictions
  - Further articulation of the paradigm itself
    - i.e., a lot of “mopping up” – in fact most of the work researchers do is mopping up – which can prove fascinating work

Limitations of paradigms

- We investigate the kinds of research questions to which our own theories can most easily provide answers. "Normal-scientific research is directed to the articulation of those phenomena and theories that the paradigm already supplies."
- Within the paradigm, find a solution to this problem" - a lot like puzzle-solving - puzzles have predetermined solutions
- We have a notion that certain past problems are already 'solved'.

Limitations of paradigms

- No effort to invent new theory (and no tolerance for those who try)
- No effort made to call forth new sorts of phenomena
- No effort to discover anomalies
  - When anomalies pop up, they are usually discarded or ignore
  - Anomalies usually not even noticed (tunnel vision/one track mind)
  - When recognized, often a hope anomalies will go away when refining current paradigm (doing normal science)

Where do new ideas and paradigms come from?

- The power of the outsider/newcomer
  - The logical story of a question may be much simpler than its current telling, due to terminology, history, etc.
  - An outsider/newcomer can see things that insiders may not be able to anymore

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Many great people switch fields every so often.
You cannot buy yourself youth,
but you can get a fresh state of mind

people
^
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Where do new ideas and paradigms come from?

- Ideas flow between people quickly only when represented concisely: “memes”
  - Ideas can flow quickly between fields via memes
  - Good names are like memes: e.g. RAID, RISC, …
  - Importance of aesthetics
- Just one idea or technology from outside your area can change everything
  - James Burkes’ Connections: Random events and chance meetings changed everything
- The current structure is result of series of historical accidents, e.g. names, personalities, events, etc.

The Establishment

- Humans like to form hierarchies
  - Humans like heroes and leaders, and like to follow
  - People are intimidated by leaders, and the large amount of knowledge needed
- Too much to verify, so we just trust certain humans
  - Research is reputation-based, not directly validated by most
  - Leaders have a huge amount of power
  - Reputations and careers are built in the current paradigm

Revolutions

- Whether your work is recorded in the formal record of research is determined by other humans, who are higher in the hierarchy
- Hard to change the written story of a topic significantly
  - Not very easy to oppose views of leaders - everyone follows them
  - If you want to say the existing story is fundamentally wrong, you challenge the reputations of the leaders, which makes a conflict

Revolutions

- Paradigms are surprisingly resilient – a persistent and recognized anomaly does not induce crisis on its own
- Reactions include:
  - ad hoc modifications of the current paradigm
  - feeling that the whole topic is intractable
  - scientists get discredited, before paradigms
- Must be explained clearly how the anomaly is not just another unsolved puzzle, but cannot possibly be treated under the existing paradigm

Revolutions

- Einstein example: very few people realized he was right at first; many famous people fought it; he only became a hero much later
- Like a political revolution:
  - It's a small number of people at first – the smartest people in the field
  - Stages: chaos/void, polarization of camps, attempts at mass persuasion
- There is rarely a clear win – paradigms always have pluses and minuses
  - So much is about persuasion – compelling stories and pictures, allegiances: schools, personalities, nationalities, religions

After the revolution

- The whole field needs to be reconstructed from the bottom
- Concepts and terminologies change
- The definition of the field (core problems, what it doesn’t treat) may change
- Researchers see new things when looking at old objects

After the revolution

- New textbooks are written, and again it looks like it was always that way, without history; that these are always the example problems we considered important, and how we formulate and solve them
- Past heroes work (and problems) may be reinterpreted from the perspective of the *new* paradigm, even if that is incompatible with past heroes' way of viewing the world
- There are new leaders

Research = normal science + revolutionary science

- Research is an oligarchy, but ultimately subject to popular revolution
- Progress is a lot like the process of evolution; the fitness function is the ability to solve more problems (but in particular, those problems that threw the existing paradigm into crisis because it couldn't resolve them well)
- This dual system is useful and necessary:
  - Anomaly appears only against the background provided by the paradigm
  - By resisting change, we ensure correctness

Prediction

- Due to the randomness at the source of new ideas, the exact nature of future technology is hard to predict
- But we do know this: the number of possible connections increases over time – thus the whole process accelerates

Prediction

- Ray Kurzweil: Generalized Moore's Law
- Consequences:
  - May seem like zero progress at first, then suddenly becomes big
  - Things may come sooner than you think – much sooner
  - The rules of entire areas may change qualitatively due to the advent of some technology in another area
  - Singularity: when technology outpaces human capabilities (to understand, compete; e.g. AGI)

So, you should:

- Not just learn once – keep learning
- Be aware that you are operating inside some existing paradigms
- Be aware that your professors probably represent the existing paradigms, or may be revolutionaries
- Know your history - old history matters
- Maintain doubt as you learn things
- (BTW: This should all tell you why courses are not as important as doing research)

Questions

- How do you start a research revolution?
- Why is your reputation as a researcher important?
- What negative reactions and obstacles should you be mentally prepared for?
- How do you adapt your own research to a paradigm shift?
- How do you recognize a research revolution? What should you do when you see it?

So, you should:

- Spend a lot of time on problem selection and formulation - this is where the most fundamental work lies
- Be the outsider
- Consider cross-disciplinary research, which has a higher probability of becoming revolutionary

So, you should:

- Remember that success in research is much about reputation-building and persuasive communication
- Create memes for your research if you can, but try to counter superficiality
- Be prepared for resistance to your change
- Only worry about the most astute people - they may not be the most famous
- Be prepared for change by others and by trends, and be open-minded (though not all proposed paradigm shifts are good)