BCS 206: Research Lab Course

Introduction & Scientific Method

Course outline

- Goals:
  - Teach how to perform scientific research
  - Replication & critical evaluation of existing study
  - Generate original research results
- Course structure:
  - In-class: general lectures + progress reports
  - In-group: research + meetings with external advisor
- General: interactive, discussion-based, learning-by-doing
- Course in development, your feedback is needed!

Schedule

Week		Mon: student presentations		Wed: support lectures/discussions
1	8/31	R: Introduction: What is science? Hypothesis Testing	9/2	R: Replication crisis Project Options Students Choose Projects J: IRB approval
2	9/7	LABOR DAY	9/9	E: Background Research & Hypothesis demo: cited reference search, journal impact search *Judi Biden Guest Lecturer*
3	9/14	Present Brief Background of Target Study Hypothesis (3-5 Articles)	9/16	J: Experimental Design discussion: paper assigned, identify design parts
4	9/21	Present Experimental Design of Target Study Conditions, timing, num trials, subjects	9/23	J: Preregistration of Design discussion: what parts to preregister, studies that can/can't be preregistered easily
5	9/28	Present Preregistration https://osf.io/ Hypothesis, Task, Measures, Analyses	9/30	J: Measurement (common paradigms, tools) demo: stimulus programming *Alyssa Kersey Guest Lecturer*
6	10/5	FALL BREAK	10/7*	R: Organization (notes, files, code, workflow) demo: real life project folder, git
7	10/12	Present Study Checklist Work flow plan, Skills needed, IRB	10/14*	R: Understanding Results (graphs & stats) discussion: paper assigned
8	10/19	Progress update: stimuli and task	10/21	J: Working with Data Output demo: data spreadsheets, Excel, Matlab, SPSS, R *Alyssa Kersey Guest Lecturer*
9	10/26	Progress update: behavior recording, example data file	10/28	R: Visualization: Choosing the right graph demo: making clear graphs
10	11/2	Progress update: pilot subjects run, implementation problems	11/4	R: Statistics
11	11/9	Progress update: preliminary analyses and graphs	11/11	J: Presentation Skills discussion: assign some blog post tips, eg. Scholl
12	11/16*	Preliminary Presentation	11/18*	E: Scientific Writing & Dissemination demo: replication journals *Whitney Gegg-Harrison Guest Lecturer*
13	11/23*	THANKSGIVING	11/25	THANKSGIVING
14	11/30	R: Peer Review Process (& flaws) discussion: critique others' target studies	12/2	Present Conference Paper
15	12/7	Final Project Presentation Submit all stimuli, code, data, slides	12/9	FINAL ESSAY

Marr’s levels of understanding the brain

Computational goal

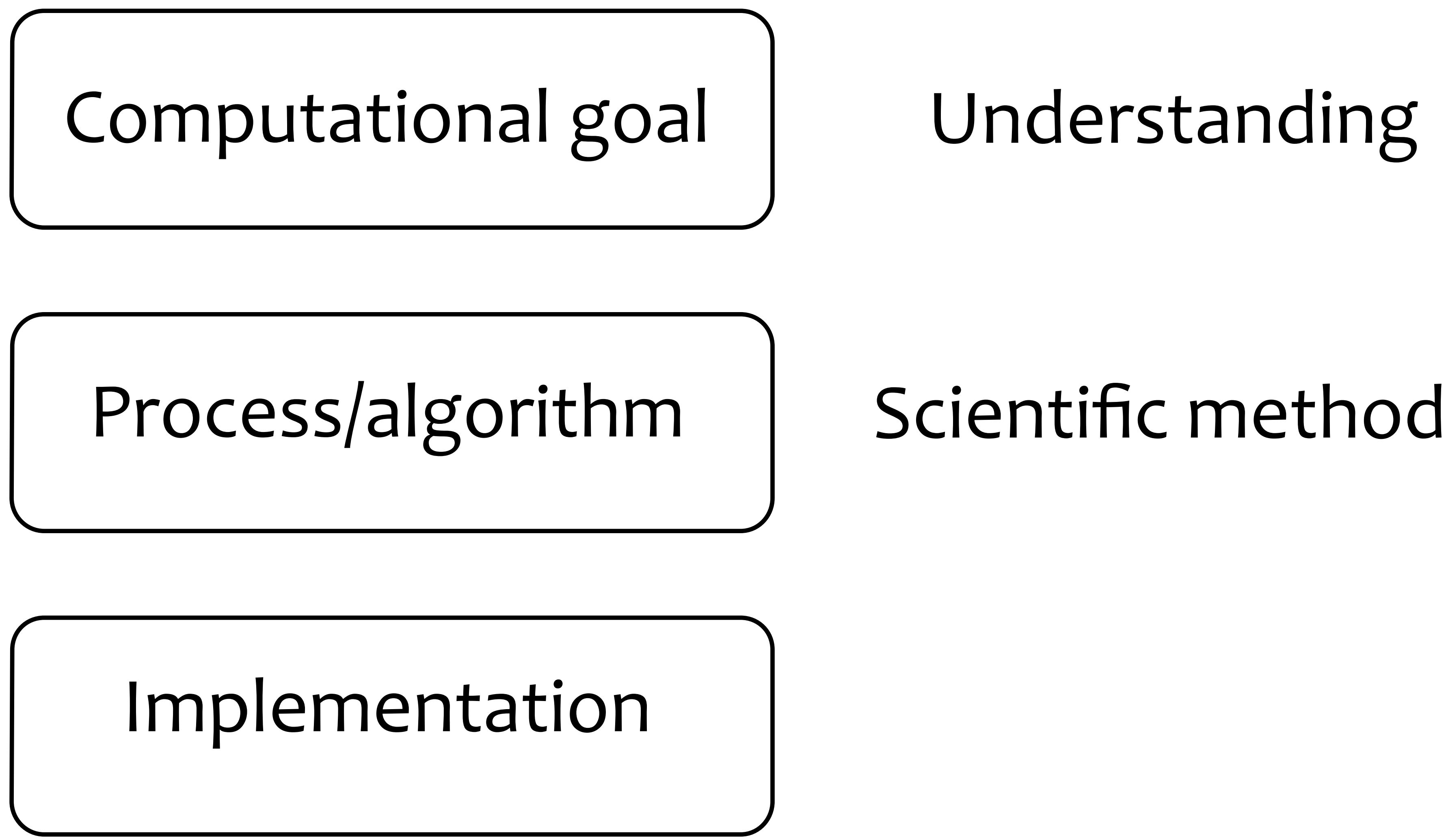
Process/algorithm

Implementation

Goal of science

- Generate knowledge/understanding
  - hypotheses, models, theories
- Allow predictions
  - e.g. weather (physical), behavior (biological)
- Enable interventions
  - e.g. engineering, medicine

Marr’s levels of understanding the brain



Scientific Method: elements

- Data characterization
- Hypotheses generation
- Predictions
- Experimentation/observation

Data characterization

- Summarization of existing data
  - as predictors & to be predicted
- Precise definition/mathematical formalization
- Accounting for uncertainty
  - observed and inferred variables
  - ignorance and stochasticity
- Limited by technology
- Depends on existing understanding ("theory-laden")

Scientific Method: elements

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Hypothesis generation

- Hypothesis: empirically falsifiable conjecture

  (Conjecture: unproven assertion, partially supported)

- Practical considerations
  - Testability (ex. Democrit, string theory)
  - Parsimony (Occam's razor)
  - Scope (ex. sheep)
  - "Fruitfulness" (ex. neural variability)
  - Conservatism (ex. gravity)
- Mathematical formalization, qualitative vs quantitative

Scientific Method: elements

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Prediction

- Deductive reasoning
- Can be probabilistic
- Postdiction vs prediction (see scope)
- Should be unlikely under alternative hypotheses
  - Differential diagnosis in medicine
  - “Crucial experiments”
  - Bayes-factors

Bayesian model comparison

$$\Pr(M|D) = \frac{\Pr(D|M)\Pr(M)}{\Pr(D)}.$$

$$K = \frac{\Pr(D|M_1)}{\Pr(D|M_2)} = \frac{\int \Pr(\theta_1|M_1)\Pr(D|\theta_1, M_1)\,d\theta_1}{\int \Pr(\theta_2|M_2)\Pr(D|\theta_2, M_2)\,d\theta_2}.$$

2 ln *K*	***K***	**Strength of evidence**
0 to 2	1 to 3	not worth more than a bare mention
2 to 6	3 to 20	positive
6 to 10	20 to 150	strong
>10	>150	very strong

Kass and Raftery (1995)

Scientific Method: elements

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Experimentation/observation

- Goal: evaluation of hypotheses
- Aim to:
  - falsify (hypothesis-testing)
  - differentiate (model comparison)
- Types:
  - Controlled experiment (ex. medicine)
  - Natural experiment (ex. Vietnam draft by lottery)
  - Observation (ex. astronomy)
- Confirmation holism (ex. Neptun & Vulcan)

Scientific Method: elements

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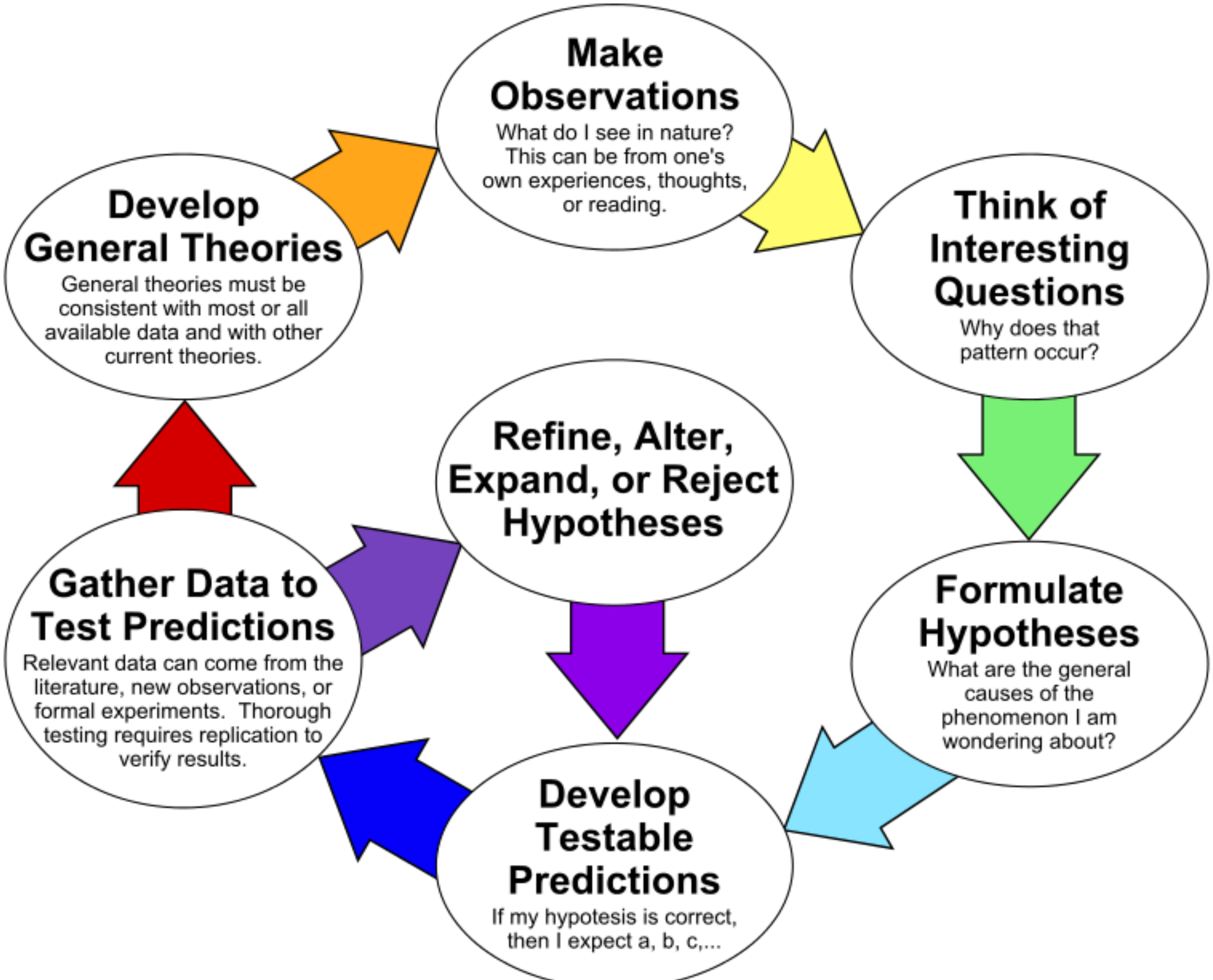
The Scientific Method as an Ongoing Process



Source: wikipedia

Marr's levels of understanding the brain

Computational goal	Understanding
Process/algorithm	Scientific method
Implementation	Scientific community

-> Replication crisis

Project 3

Project: A subconscious association between numbers, hands, and space
Background: Researchers are interested in discovering how culturally-acquired mathematical concepts are structured in the human brain. Current evidence suggests that humans' numerical representations interface with their spatial reasoning and motor structures in surprising ways. The interactions between people's mathematical concepts and other sensory/motor and conceptual systems provide information about the organization of numerical and mathematical information in the human brain. This study tests for implicit associations between spatial representations, motor effectors (hands), and number concepts in humans.
PI: Cantlon
Paper: Dehaene, S., Bossini, S., & Giraux, P. (1993). The mental representation of parity and number magnitude. *Journal of Experimental Psychology: General*, *122*(3), 371-396.

Study: Experiment 1: One digit Arabic numerals (p. 374)
Summary: Subjects are given a task in which they must judge whether a number is even or odd (ie., its parity) using either their right hand or their left hand. Subjects tend to be faster to judge parity with large numbers using their right hand but are faster to judge small numbers with their left hand. The results suggest that subjects automatically activate implicit representations of numbers that are spatially organized from left to right. This result implies that numerical concepts are connected to spatial coordination mechanisms in the human brain.
Impact: This is a classic study in the field with over 1500 citations due to its surprising result. It has sparked several new areas of behavioral, developmental, clinical, and neurobiological research with humans and animals.
Skills Required: Simple stimulus/response programming, ANOVA