

## Models and Theory

## Overview

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- What do models and theory have to do with science?
- What do models and theory have to do with software research?
- Scientific method
- Model
- Theory
- Goodness criteria for theory
  
- Most radical topic in the course.

## Some Initial Definitions

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- A model is an abstract representation of a phenomenon or set of related phenomena
  - Some details included, others excluded
- A theory is a set of statements that provides an explanation of a set of phenomena
- A hypothesis is a testable statement that is derived from a theory

## Science and Theory

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- Science seeks to improve our understanding of the world.
- Theories lie at the heart of what it means to do science.
  - Production of generalizable knowledge
  - Scientific method <-> Research Methodology <-> Proper Contributions for a Discipline
    - What this course is about

## Software and Theory

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- Software needs to start articulating its theories.
- Every tool and method has a theory embedded within it.
  - World view, assumptions, expectations
  - Helpfulness of an intervention
- These theories need to be stated explicitly and tested.
  - Tools and methods are the means for doing so, they are not generalizable knowledge in themselves.

## Software and Theory

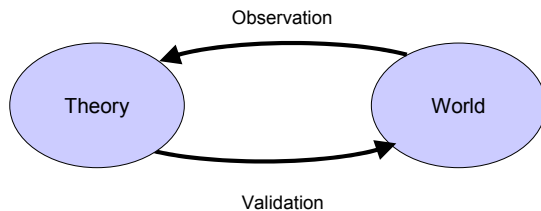
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- Otherwise our results are:
  - Too specific to a tool or setting
  - Don't stand the test of time (when technology changes)
  - Not worthy of empirical validation
    - Finding settings for stereo knobs vs. underlying principles

## Scientific Method

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- No single “official” scientific method  
<http://www.sit.wisc.edu/~crusbult/methods/science.htm>
- However, there are commonalities



## High School Science Version

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1. Observe some aspect of the universe.
2. Invent a tentative description, called a *hypothesis*, that is consistent with what you have observed.
3. Use the hypothesis to make predictions.
4. Test those predictions by experiments or further observations and modify the hypothesis in the light of your results.
5. Repeat steps 3 and 4 until there are no discrepancies between theory and experiment and/or observation.

## Section Titles

- High School Science Fair
- University Laboratory Notebook
- Abstract
- Title
- Table of contents
- Abstract
- Purpose
- Objectives
- Hypothesis
- Equipment
- Experimental design
- Safety Rules
- Materials used
- Procedure
- Procedures
- Data
- Research report
- Calculations
- Results
- Results
- Conclusion
- Conclusions
- Acknowledgements
- Discussion
- Bibliography

## Research Strategy

### Research Methodology

Question  
Formulation

Solution  
Creation

Validation

## One Research Strategy

### Research Methodology

What tools are  
needed?

Tool  
Construction

Do the tools  
help?

## Models

- **Models are abstract representations**
  - Contain essential characteristics and omit non-essential details
    - "Essential" depends on the problem domain
  - There are no perfect representations
- **Models can be representations of the world**
  - Domain models
  - Requirements
- **Models can be representations of software**
  - Specifications
  - Design
  - Systems

## What constitutes a good model?

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- A model should
  - provide abstraction
  - render the problem in a format amenable to reasoning
- There will always be:
  - phenomena in the application domain that are not in the model
  - phenomena in the application domain that are not in the model
- A model is never perfect
  - “If the map and the terrain disagree, believe the terrain”
  - Perfecting the model is not always a good use of your time...

## Definition of Theory

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- A set of statements that provide a causal explanation of a set of phenomena
  - Logically complete
  - Internally consistent
  - Falsifiable
- Components: concepts, relations, causal inferences
- More than straight description

## Criteria for Evaluating Theory

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- Software does not have a well-understood, well-founded research method
  - No standard methods textbooks or courses
- Discussions about methods always go back to first principles
  - Definitions of software engineering
  - Philosophy of science
  - Look at other disciplines for examples
- Goodness criteria exemplify these difficulties

## Finding Goodness Criteria

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- Wading through the material is not for the faint of heart
  - Goodness criteria are closely bound with the paradigm for a discipline, and rarely explicitly articulated.
- Extensive treatment in philosophy of science, more broadly, philosophy of knowledge
  - Difficult material, lots of hair splitting, practical advice hard to come by
  - Popper figures prominently
  - Example: Implications for post-empiricists, constructivist, and critical theory viewpoints on the nature of theory

## Finding Goodness Criteria

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- Gleaned material from texts on research methodology in the social sciences
- Most useful source was essay by Will Moore, political scientist at Florida State University
  - Written for his students, published only on the web
  - <http://garnet.acns.fsu.edu/~whmoore/theoryeval.pdf>
- Drew on my own experience with empirical evaluation, statistics, and computer science

## Three Types of Criteria

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- Empirical
- Analytical
- Pragmatic

## Some Criteria

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### Empirical

- Postdictive Power (Moore)
- Predictive Power
- Testable (psych)
  - Falsifiable, operationalizable

### Analytic

- Logical Soundness (Moore)
  - Consistent, complete, falsifiable
- Generality of Explanans (Moore)
- Hypothetical Yield (Moore)
- Progressive Research Program (Moore)
- Breadth of Policy Implications (Moore)
- Parsimony (Moore, Popper)

## Empirical Criteria

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- Postdictive Power
  - Does the theory fit the data used to create it?
    - Assessed using a point for point comparison
  - Use much fewer variables than data points
    - Analogous to fitting points to an equation
- Predictive Power
  - Does the theory fit existing novel cases?
  - Does the theory fit future cases?
    - Not immediately testable after the fact
- Borrowed ideas from machine learning
  - Training data vs. test data
- Problems: inductive bias, selection of cases

## Empirical Criteria

- Testable
  - a.k.a. operationalizable, falsifiable
  - Makes claims that are specific enough to be testable
  - Concepts can be tied to variables and values

## Moore's Criteria

- Assess logical soundness of theory
- Identify a rival theory
- Use a hierarchy of criteria to determine superiority
  - When comparison is decided, stop (don't continue with remainder of hierarchy)

## Logical Soundness

- Complete
  - Hypotheses deduced flow logically from assumptions
- Internally Consistent
  - Theory does not contradict itself
- Falsifiable
  - Not tautological, makes specific claims about empirical world
- Problem: How to show this?
  - Rhetoric- corrects vs. persuasiveness
  - Formal logic- loss of richness, mapping problem

## Logically Complete, Internally Consistent, and Falsifiable

|   |   |                          |              |               |              |                          |              |                          |                          |     |            |                |                            |     |                            |                |   |          |                            |               |                             |  |                                     |                  |                |            |                                     |            |                                     |            |          |     |          |                          |                    |                          |                          |   |                    |   |          |   |                |                            |  |                         |                            |     |                       |     |                       |     |                            |   |   |   |   |
|---|---|--------------------------|--------------|---------------|--------------|--------------------------|--------------|--------------------------|--------------------------|-----|------------|----------------|----------------------------|-----|----------------------------|----------------|---|----------|----------------------------|---------------|-----------------------------|--|-------------------------------------|------------------|----------------|------------|-------------------------------------|------------|-------------------------------------|------------|----------|-----|----------|--------------------------|--------------------|--------------------------|--------------------------|---|--------------------|---|----------|---|----------------|----------------------------|--|-------------------------|----------------------------|-----|-----------------------|-----|-----------------------|-----|----------------------------|---|---|---|---|
| 1<br>2<br>3<br>4<br>5<br>6<br>7<br>8<br>9<br>10 | <table border="0" style="width: 100%;"> <tr><td style="border-right: 1px solid black; padding-right: 5px;"><math>B \supset (C \ \&amp; \ Q)</math></td><td>Assumption 1</td></tr> <tr><td style="border-right: 1px solid black; padding-right: 5px;"><math>S</math></td><td>Assumption 2</td></tr> <tr><td style="border-right: 1px solid black; padding-right: 5px;"><math>(S \ \&amp; \ I) \supset P</math></td><td>Assumption 3</td></tr> <tr><td style="border-right: 1px solid black; padding-right: 5px;"><math>(C \ \&amp; \ Q) \supset I</math></td><td>Assumption 4</td></tr> <tr><td style="border-right: 1px solid black; padding-right: 5px;"><math>B</math></td><td>Assumption</td></tr> <tr><td style="border-right: 1px solid black; padding-right: 5px;"><math>(C \ \&amp; \ Q)</math></td><td>1,5 <math>\supset</math> Introduction</td></tr> <tr><td style="border-right: 1px solid black; padding-right: 5px;"><math>I</math></td><td>4,6, <math>\supset</math> Elimination</td></tr> <tr><td style="border-right: 1px solid black; padding-right: 5px;"><math>(S \ \&amp; \ I)</math></td><td>2,7, <math>\&amp;</math> Introduction</td></tr> <tr><td style="border-right: 1px solid black; padding-right: 5px;"><math>P</math></td><td>3,8, <math>\supset</math> Elimination</td></tr> <tr><td style="border-right: 1px solid black; padding-right: 5px;"><math>B \supset P</math></td><td>5-9, <math>\supset</math> Introduction</td></tr> </table> | $B \supset (C \ \& \ Q)$ | Assumption 1 | $S$           | Assumption 2 | $(S \ \& \ I) \supset P$ | Assumption 3 | $(C \ \& \ Q) \supset I$ | Assumption 4             | $B$ | Assumption | $(C \ \& \ Q)$ | 1,5 $\supset$ Introduction | $I$ | 4,6, $\supset$ Elimination | $(S \ \& \ I)$ | 2,7, $\&$ Introduction  | $P$      | 3,8, $\supset$ Elimination | $B \supset P$ | 5-9, $\supset$ Introduction | <table border="0" style="width: 100%;"> <tr><td style="text-align: center;"><math>B \supset (C \ \&amp; \ Q) \checkmark</math></td><td style="text-align: right;">Set Member</td></tr> <tr><td style="text-align: center;"><math>S \checkmark</math></td><td style="text-align: right;">Set Member</td></tr> <tr><td style="text-align: center;"><math>(S \ \&amp; \ I) \supset P \checkmark</math></td><td style="text-align: right;">Set Member</td></tr> <tr><td style="text-align: center;"><math>(C \ \&amp; \ Q) \supset I \checkmark</math></td><td style="text-align: right;">Set Member</td></tr> <tr><td style="text-align: center;"><math>\sim B</math></td><td></td></tr> <tr><td style="text-align: center;"><math>\vdots</math></td><td></td></tr> <tr><td style="text-align: center;"><math>\sim(S \ \&amp; \ I)</math></td><td></td></tr> <tr><td style="text-align: center;"><math>\vdots</math></td><td></td></tr> <tr><td style="text-align: center;"><math>\sim(C \ \&amp; \ Q)</math></td><td></td></tr> <tr><td style="text-align: center;"><math>\vdots</math></td><td></td></tr> <tr><td style="text-align: center;"><math>I \checkmark</math></td><td style="text-align: right;">5, <math>\supset</math> Decomposition</td></tr> </table> | $B \supset (C \ \& \ Q) \checkmark$ | Set Member       | $S \checkmark$ | Set Member | $(S \ \& \ I) \supset P \checkmark$ | Set Member | $(C \ \& \ Q) \supset I \checkmark$ | Set Member | $\sim B$ |     | $\vdots$ |                          | $\sim(S \ \& \ I)$ |                          | $\vdots$                 |   | $\sim(C \ \& \ Q)$ |   | $\vdots$ |   | $I \checkmark$ | 5, $\supset$ Decomposition | <table border="0" style="width: 100%;"> <tr><td style="text-align: center;"><math>C \ \&amp; \ Q \checkmark</math></td><td style="text-align: right;">1, <math>\supset</math> Decomposition</td></tr> <tr><td style="text-align: center;"><math>C</math></td><td style="text-align: right;">5, <math>\&amp;</math> Decomposition</td></tr> <tr><td style="text-align: center;"><math>Q</math></td><td style="text-align: right;">5, <math>\&amp;</math> Decomposition</td></tr> <tr><td style="text-align: center;"><math>P</math></td><td style="text-align: right;">3, <math>\supset</math> Decomposition</td></tr> </table> | $C \ \& \ Q \checkmark$ | 1, $\supset$ Decomposition | $C$ | 5, $\&$ Decomposition | $Q$ | 5, $\&$ Decomposition | $P$ | 3, $\supset$ Decomposition |   |   |   |   |
| $B \supset (C \ \& \ Q)$                        | Assumption 1  |                          |              |               |              |                          |              |                          |                          |     |            |                |                            |     |                            |                |   |          |                            |               |                             |  |                                     |                  |                |            |                                     |            |                                     |            |          |     |          |                          |                    |                          |                          |   |                    |   |          |   |                |                            |  |                         |                            |     |                       |     |                       |     |                            |   |   |   |   |
| $S$   | Assumption 2  |                          |              |               |              |                          |              |                          |                          |     |            |                |                            |     |                            |                |   |          |                            |               |                             |  |                                     |                  |                |            |                                     |            |                                     |            |          |     |          |                          |                    |                          |                          |   |                    |   |          |   |                |                            |  |                         |                            |     |                       |     |                       |     |                            |   |   |   |   |
| $(S \ \& \ I) \supset P$                        | Assumption 3  |                          |              |               |              |                          |              |                          |                          |     |            |                |                            |     |                            |                |   |          |                            |               |                             |  |                                     |                  |                |            |                                     |            |                                     |            |          |     |          |                          |                    |                          |                          |   |                    |   |          |   |                |                            |  |                         |                            |     |                       |     |                       |     |                            |   |   |   |   |
| $(C \ \& \ Q) \supset I$                        | Assumption 4  |                          |              |               |              |                          |              |                          |                          |     |            |                |                            |     |                            |                |   |          |                            |               |                             |  |                                     |                  |                |            |                                     |            |                                     |            |          |     |          |                          |                    |                          |                          |   |                    |   |          |   |                |                            |  |                         |                            |     |                       |     |                       |     |                            |   |   |   |   |
| $B$   | Assumption  |                          |              |               |              |                          |              |                          |                          |     |            |                |                            |     |                            |                |   |          |                            |               |                             |  |                                     |                  |                |            |                                     |            |                                     |            |          |     |          |                          |                    |                          |                          |   |                    |   |          |   |                |                            |  |                         |                            |     |                       |     |                       |     |                            |   |   |   |   |
| $(C \ \& \ Q)$                                  | 1,5 $\supset$ Introduction  |                          |              |               |              |                          |              |                          |                          |     |            |                |                            |     |                            |                |   |          |                            |               |                             |  |                                     |                  |                |            |                                     |            |                                     |            |          |     |          |                          |                    |                          |                          |   |                    |   |          |   |                |                            |  |                         |                            |     |                       |     |                       |     |                            |   |   |   |   |
| $I$   | 4,6, $\supset$ Elimination  |                          |              |               |              |                          |              |                          |                          |     |            |                |                            |     |                            |                |   |          |                            |               |                             |  |                                     |                  |                |            |                                     |            |                                     |            |          |     |          |                          |                    |                          |                          |   |                    |   |          |   |                |                            |  |                         |                            |     |                       |     |                       |     |                            |   |   |   |   |
| $(S \ \& \ I)$                                  | 2,7, $\&$ Introduction  |                          |              |               |              |                          |              |                          |                          |     |            |                |                            |     |                            |                |   |          |                            |               |                             |  |                                     |                  |                |            |                                     |            |                                     |            |          |     |          |                          |                    |                          |                          |   |                    |   |          |   |                |                            |  |                         |                            |     |                       |     |                       |     |                            |   |   |   |   |
| $P$   | 3,8, $\supset$ Elimination  |                          |              |               |              |                          |              |                          |                          |     |            |                |                            |     |                            |                |   |          |                            |               |                             |  |                                     |                  |                |            |                                     |            |                                     |            |          |     |          |                          |                    |                          |                          |   |                    |   |          |   |                |                            |  |                         |                            |     |                       |     |                       |     |                            |   |   |   |   |
| $B \supset P$                                   | 5-9, $\supset$ Introduction   |                          |              |               |              |                          |              |                          |                          |     |            |                |                            |     |                            |                |   |          |                            |               |                             |  |                                     |                  |                |            |                                     |            |                                     |            |          |     |          |                          |                    |                          |                          |   |                    |   |          |   |                |                            |  |                         |                            |     |                       |     |                       |     |                            |   |   |   |   |
| $B \supset (C \ \& \ Q) \checkmark$             | Set Member  |                          |              |               |              |                          |              |                          |                          |     |            |                |                            |     |                            |                |   |          |                            |               |                             |  |                                     |                  |                |            |                                     |            |                                     |            |          |     |          |                          |                    |                          |                          |   |                    |   |          |   |                |                            |  |                         |                            |     |                       |     |                       |     |                            |   |   |   |   |
| $S \checkmark$                                  | Set Member  |                          |              |               |              |                          |              |                          |                          |     |            |                |                            |     |                            |                |   |          |                            |               |                             |  |                                     |                  |                |            |                                     |            |                                     |            |          |     |          |                          |                    |                          |                          |   |                    |   |          |   |                |                            |  |                         |                            |     |                       |     |                       |     |                            |   |   |   |   |
| $(S \ \& \ I) \supset P \checkmark$             | Set Member  |                          |              |               |              |                          |              |                          |                          |     |            |                |                            |     |                            |                |   |          |                            |               |                             |  |                                     |                  |                |            |                                     |            |                                     |            |          |     |          |                          |                    |                          |                          |   |                    |   |          |   |                |                            |  |                         |                            |     |                       |     |                       |     |                            |   |   |   |   |
| $(C \ \& \ Q) \supset I \checkmark$             | Set Member  |                          |              |               |              |                          |              |                          |                          |     |            |                |                            |     |                            |                |   |          |                            |               |                             |  |                                     |                  |                |            |                                     |            |                                     |            |          |     |          |                          |                    |                          |                          |   |                    |   |          |   |                |                            |  |                         |                            |     |                       |     |                       |     |                            |   |   |   |   |
| $\sim B$  |   |                          |              |               |              |                          |              |                          |                          |     |            |                |                            |     |                            |                |   |          |                            |               |                             |  |                                     |                  |                |            |                                     |            |                                     |            |          |     |          |                          |                    |                          |                          |   |                    |   |          |   |                |                            |  |                         |                            |     |                       |     |                       |     |                            |   |   |   |   |
| $\vdots$  |   |                          |              |               |              |                          |              |                          |                          |     |            |                |                            |     |                            |                |   |          |                            |               |                             |  |                                     |                  |                |            |                                     |            |                                     |            |          |     |          |                          |                    |                          |                          |   |                    |   |          |   |                |                            |  |                         |                            |     |                       |     |                       |     |                            |   |   |   |   |
| $\sim(S \ \& \ I)$                              |   |                          |              |               |              |                          |              |                          |                          |     |            |                |                            |     |                            |                |   |          |                            |               |                             |  |                                     |                  |                |            |                                     |            |                                     |            |          |     |          |                          |                    |                          |                          |   |                    |   |          |   |                |                            |  |                         |                            |     |                       |     |                       |     |                            |   |   |   |   |
| $\vdots$  |   |                          |              |               |              |                          |              |                          |                          |     |            |                |                            |     |                            |                |   |          |                            |               |                             |  |                                     |                  |                |            |                                     |            |                                     |            |          |     |          |                          |                    |                          |                          |   |                    |   |          |   |                |                            |  |                         |                            |     |                       |     |                       |     |                            |   |   |   |   |
| $\sim(C \ \& \ Q)$                              |   |                          |              |               |              |                          |              |                          |                          |     |            |                |                            |     |                            |                |   |          |                            |               |                             |  |                                     |                  |                |            |                                     |            |                                     |            |          |     |          |                          |                    |                          |                          |   |                    |   |          |   |                |                            |  |                         |                            |     |                       |     |                       |     |                            |   |   |   |   |
| $\vdots$  |   |                          |              |               |              |                          |              |                          |                          |     |            |                |                            |     |                            |                |   |          |                            |               |                             |  |                                     |                  |                |            |                                     |            |                                     |            |          |     |          |                          |                    |                          |                          |   |                    |   |          |   |                |                            |  |                         |                            |     |                       |     |                       |     |                            |   |   |   |   |
| $I \checkmark$                                  | 5, $\supset$ Decomposition  |                          |              |               |              |                          |              |                          |                          |     |            |                |                            |     |                            |                |   |          |                            |               |                             |  |                                     |                  |                |            |                                     |            |                                     |            |          |     |          |                          |                    |                          |                          |   |                    |   |          |   |                |                            |  |                         |                            |     |                       |     |                       |     |                            |   |   |   |   |
| $C \ \& \ Q \checkmark$                         | 1, $\supset$ Decomposition  |                          |              |               |              |                          |              |                          |                          |     |            |                |                            |     |                            |                |   |          |                            |               |                             |  |                                     |                  |                |            |                                     |            |                                     |            |          |     |          |                          |                    |                          |                          |   |                    |   |          |   |                |                            |  |                         |                            |     |                       |     |                       |     |                            |   |   |   |   |
| $C$   | 5, $\&$ Decomposition   |                          |              |               |              |                          |              |                          |                          |     |            |                |                            |     |                            |                |   |          |                            |               |                             |  |                                     |                  |                |            |                                     |            |                                     |            |          |     |          |                          |                    |                          |                          |   |                    |   |          |   |                |                            |  |                         |                            |     |                       |     |                       |     |                            |   |   |   |   |
| $Q$   | 5, $\&$ Decomposition   |                          |              |               |              |                          |              |                          |                          |     |            |                |                            |     |                            |                |   |          |                            |               |                             |  |                                     |                  |                |            |                                     |            |                                     |            |          |     |          |                          |                    |                          |                          |   |                    |   |          |   |                |                            |  |                         |                            |     |                       |     |                       |     |                            |   |   |   |   |
| $P$   | 3, $\supset$ Decomposition  |                          |              |               |              |                          |              |                          |                          |     |            |                |                            |     |                            |                |   |          |                            |               |                             |  |                                     |                  |                |            |                                     |            |                                     |            |          |     |          |                          |                    |                          |                          |   |                    |   |          |   |                |                            |  |                         |                            |     |                       |     |                       |     |                            |   |   |   |   |
|   | <table border="0" style="width: 100%;"> <tr> <td style="border-right: 1px solid black; padding-right: 5px;"><math>B</math></td> <td style="border-right: 1px solid black; padding-right: 5px;"><math>P</math></td> <td style="border-right: 1px solid black; padding-right: 5px;"><math>B \supset P</math></td> </tr> <tr> <td style="border-right: 1px solid black; padding-right: 5px;">T</td> <td style="border-right: 1px solid black; padding-right: 5px;">T</td> <td style="border-right: 1px solid black; padding-right: 5px;">T</td> </tr> <tr> <td style="border-right: 1px solid black; padding-right: 5px;">T</td> <td style="border-right: 1px solid black; padding-right: 5px;">F</td> <td style="border-right: 1px solid black; padding-right: 5px;">F</td> </tr> <tr> <td style="border-right: 1px solid black; padding-right: 5px;">F</td> <td style="border-right: 1px solid black; padding-right: 5px;">T</td> <td style="border-right: 1px solid black; padding-right: 5px;">T</td> </tr> <tr> <td style="border-right: 1px solid black; padding-right: 5px;">F</td> <td style="border-right: 1px solid black; padding-right: 5px;">F</td> <td style="border-right: 1px solid black; padding-right: 5px;">T</td> </tr> </table>  | $B$                      | $P$          | $B \supset P$ | T            | T                        | T            | T                        | F                        | F   | F          | T              | T                          | F   | F                          | T              | <table border="0" style="width: 100%;"> <tr> <td colspan="6" style="text-align: center;">Literals</td> <td colspan="4" style="text-align: center;">Set of Sentences</td> </tr> <tr> <td style="border-right: 1px solid black; padding-right: 5px;"><math>B</math></td> <td style="border-right: 1px solid black; padding-right: 5px;"><math>C</math></td> <td style="border-right: 1px solid black; padding-right: 5px;"><math>Q</math></td> <td style="border-right: 1px solid black; padding-right: 5px;"><math>S</math></td> <td style="border-right: 1px solid black; padding-right: 5px;"><math>I</math></td> <td style="border-right: 1px solid black; padding-right: 5px;"><math>P</math></td> <td style="border-right: 1px solid black; padding-right: 5px;"><math>B \supset (C \ \&amp; \ Q)</math></td> <td style="border-right: 1px solid black; padding-right: 5px;"><math>S</math></td> <td style="border-right: 1px solid black; padding-right: 5px;"><math>(S \ \&amp; \ I) \supset P</math></td> <td style="border-right: 1px solid black; padding-right: 5px;"><math>(C \ \&amp; \ Q) \supset I</math></td> </tr> <tr> <td style="border-right: 1px solid black; padding-right: 5px;">T</td> <td style="border-right: 1px solid black; padding-right: 5px;">T</td> <td style="border-right: 1px solid black; padding-right: 5px;">T</td> <td style="border-right: 1px solid black; padding-right: 5px;">T</td> <td style="border-right: 1px solid black; padding-right: 5px;">T</td> <td style="border-right: 1px solid black; padding-right: 5px;">T</td> <td style="border-right: 1px solid black; padding-right: 5px;">T</td> <td style="border-right: 1px solid black; padding-right: 5px;">T</td> <td style="border-right: 1px solid black; padding-right: 5px;">T</td> <td style="border-right: 1px solid black; padding-right: 5px;">T</td> </tr> <tr> <td style="border-right: 1px solid black; padding-right: 5px;">F</td> <td style="border-right: 1px solid black; padding-right: 5px;">T</td> <td style="border-right: 1px solid black; padding-right: 5px;">T</td> <td style="border-right: 1px solid black; padding-right: 5px;">T</td> <td style="border-right: 1px solid black; padding-right: 5px;">T</td> <td style="border-right: 1px solid black; padding-right: 5px;">T</td> <td style="border-right: 1px solid black; padding-right: 5px;">T</td> <td style="border-right: 1px solid black; padding-right: 5px;">T</td> <td style="border-right: 1px solid black; padding-right: 5px;">T</td> <td style="border-right: 1px solid black; padding-right: 5px;">T</td> </tr> </table> | Literals |                            |               |                             |  |                                     | Set of Sentences |                |            |                                     | $B$        | $C$                                 | $Q$        | $S$      | $I$ | $P$      | $B \supset (C \ \& \ Q)$ | $S$                | $(S \ \& \ I) \supset P$ | $(C \ \& \ Q) \supset I$ | T | T                  | T | T        | T | T              | T                          | T  | T                       | T                          | F   | T                     | T   | T                     | T   | T                          | T | T | T | T |
| $B$   | $P$   | $B \supset P$            |              |               |              |                          |              |                          |                          |     |            |                |                            |     |                            |                |   |          |                            |               |                             |  |                                     |                  |                |            |                                     |            |                                     |            |          |     |          |                          |                    |                          |                          |   |                    |   |          |   |                |                            |  |                         |                            |     |                       |     |                       |     |                            |   |   |   |   |
| T   | T   | T                        |              |               |              |                          |              |                          |                          |     |            |                |                            |     |                            |                |   |          |                            |               |                             |  |                                     |                  |                |            |                                     |            |                                     |            |          |     |          |                          |                    |                          |                          |   |                    |   |          |   |                |                            |  |                         |                            |     |                       |     |                       |     |                            |   |   |   |   |
| T   | F   | F                        |              |               |              |                          |              |                          |                          |     |            |                |                            |     |                            |                |   |          |                            |               |                             |  |                                     |                  |                |            |                                     |            |                                     |            |          |     |          |                          |                    |                          |                          |   |                    |   |          |   |                |                            |  |                         |                            |     |                       |     |                       |     |                            |   |   |   |   |
| F   | T   | T                        |              |               |              |                          |              |                          |                          |     |            |                |                            |     |                            |                |   |          |                            |               |                             |  |                                     |                  |                |            |                                     |            |                                     |            |          |     |          |                          |                    |                          |                          |   |                    |   |          |   |                |                            |  |                         |                            |     |                       |     |                       |     |                            |   |   |   |   |
| F   | F   | T                        |              |               |              |                          |              |                          |                          |     |            |                |                            |     |                            |                |   |          |                            |               |                             |  |                                     |                  |                |            |                                     |            |                                     |            |          |     |          |                          |                    |                          |                          |   |                    |   |          |   |                |                            |  |                         |                            |     |                       |     |                       |     |                            |   |   |   |   |
| Literals  |   |                          |              |               |              | Set of Sentences         |              |                          |                          |     |            |                |                            |     |                            |                |   |          |                            |               |                             |  |                                     |                  |                |            |                                     |            |                                     |            |          |     |          |                          |                    |                          |                          |   |                    |   |          |   |                |                            |  |                         |                            |     |                       |     |                       |     |                            |   |   |   |   |
| $B$   | $C$   | $Q$                      | $S$          | $I$           | $P$          | $B \supset (C \ \& \ Q)$ | $S$          | $(S \ \& \ I) \supset P$ | $(C \ \& \ Q) \supset I$ |     |            |                |                            |     |                            |                |   |          |                            |               |                             |  |                                     |                  |                |            |                                     |            |                                     |            |          |     |          |                          |                    |                          |                          |   |                    |   |          |   |                |                            |  |                         |                            |     |                       |     |                       |     |                            |   |   |   |   |
| T   | T   | T                        | T            | T             | T            | T                        | T            | T                        | T                        |     |            |                |                            |     |                            |                |   |          |                            |               |                             |  |                                     |                  |                |            |                                     |            |                                     |            |          |     |          |                          |                    |                          |                          |   |                    |   |          |   |                |                            |  |                         |                            |     |                       |     |                       |     |                            |   |   |   |   |
| F   | T   | T                        | T            | T             | T            | T                        | T            | T                        | T                        |     |            |                |                            |     |                            |                |   |          |                            |               |                             |  |                                     |                  |                |            |                                     |            |                                     |            |          |     |          |                          |                    |                          |                          |   |                    |   |          |   |                |                            |  |                         |                            |     |                       |     |                       |     |                            |   |   |   |   |

## Identify a Rival Theory

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- Find a theory that provides a causal explanation for the same set of phenomena
- In software engineering, easier said than done
  - The null theory is a straw man
  - Biggest problem in using Moore's method in SE

## Hierarchy of Criteria from Moore

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- Postdictive Accuracy
  - Which theory better fits the data?
- Generality of Explanans
  - Which theory explains a larger set of phenomena?
- Hypothetical Yield
  - Which theory generates more hypotheses for testing?
- Progressive Research Program
  - Expanding explanans is better than expanding assumptions
- Breadth of Policy Implications
  - Which theory provides better guidance for action?
- Parsimony
  - Which theory is simpler?

## Pragmatic Criteria

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- A good theory improves our understanding
  - Tells us something about how the world works
  - Narrative
- Convincing to your peers
  - Even mathematical proofs exist for social reasons
  - Format is recognized and accepted
    - Problematic in SE where there is no standard format
- Relevant
  - Address an issue of scientific and societal concern
    - Phenomenon of sufficient size
    - To whom is the theory a contribution?
  - Question: Is it possible to evaluate this in advance of forming the theory?