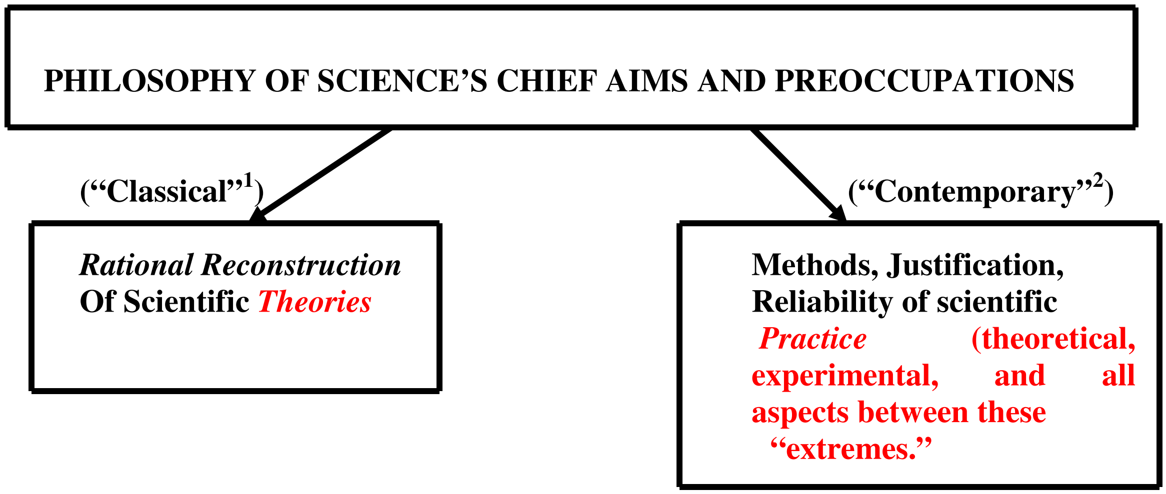
Argument Forms Relevant to Scientific Reasoning: The Role of Logic in the Philosophy of Science



- As the terms **"rational reconstruction"** suggest, "Classical" Philosophy of Science distinguished itself, by and large, as a "***Normative***" enterprise, i.e. preoccupied primarily with questions concerning what **criteria** an *ideal* scientific *theory should conform* to, as well as the **criteria** associated with *scientific reasoning* (suitably idealized). (E.g., Hans Reichenbach (1938[3]): Philosophers of Science deals with science's **context of justification**, not science's **context of discovery.**)

- Moreover, in its attempt to focus on "rational reconstructions" of domains of science, "classical" philosophers of science tended to strictly demarcate the **process** versus the **products** of science. The processes were relegated as part of the ("uninteresting") **context of discovery**, which included ***all*** steps of scientific procedure prior to the completion of a "textbook-ready" fully developed **scientific theory.** Conversely, the **final products** of worthy of study for philosophers of science were the fully-developed ("textbook-ready") **scientific theories.**

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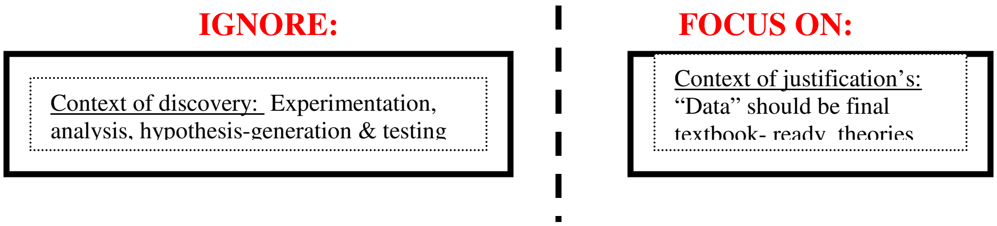
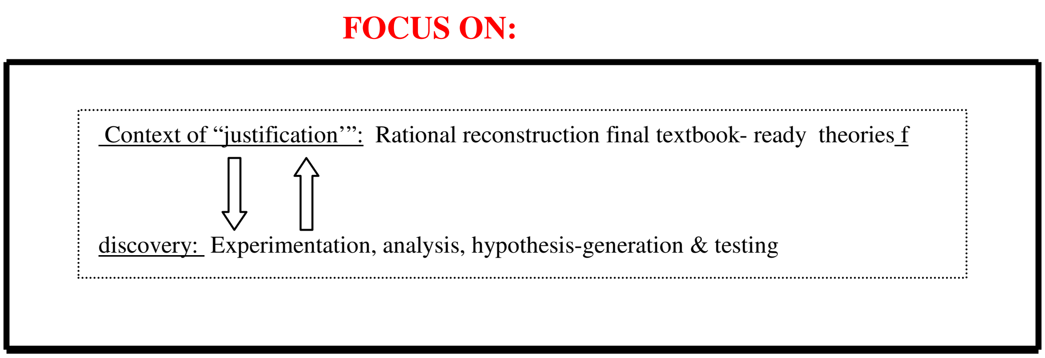
[1] Ca. before the 1980s
[2] Ca. 1980 to present
[3] *Experience and Prediction* (Chicago: University of Chicago Press, 1938)



The "Classical" Conception

- Conversely, contemporary Philosophy of Science distinguishes itself (from "Classical") as being more of a ***descriptive*** enterprise, focusing, for instance, on questions concerning the **methods, reliability, justification** of ***actual* procedures** employed by *practicing scientists.*

- This naturally leads contemporary philosophers of science to blur the distinctions between **process and product,** and resist the division of the philosophical study of science into contexts of discovery versus contexts of justification. This lends itself to a more inclusive picture: contemporary philosophers of science see their field as *both* a *"normative"* as well as a "descriptive" enterprise.



The "Contemporary" Conception

LOGIC plays an essential role in the Philosophy of Science (both Classical and Contemporary)

"Logic is the science of pure idea, i.e. the idea in the abstract element of reasoning."

-G. W. F. Hegel[4] (1930: p20)

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[4] *Encyclop die d. philosophische Wissenschaften im Grundrisse. Zum Gebrauch seiner Vorlesungen* (Dritte Ausgabe Oss wald'scher Verlag: Heidelberg, 1830), p.20

"[W]e can safely admit the definition that is…presupposed by *whatever* 'theory of truth'…consists of saying that a proposition[5] is **true** if and only if that aspect or item of reality to which thought intends to *refer* is actually such as the proposition says. Now there are cases in which this aspect or item of reality is *immediately* present to our thought…[however] humans… [are also] endowed with the marvelous capacity of attaining truth even in these cases in which this is not immediately present…they are able to capture this **truth** by their *reasoning*. This reasoning is able to establish certain *links* between propositions that are 'truth-preserving'…**[A]n acceptable characterization of logic [therefore] is a theory of…correct reasoning…[which] cannot be understood simply as a *descriptive* enterprise.** Sure, in order to concretely construct logic, we must take into consideration human reasoning or 'thinking'…but…**we still need a meta-reflection[6] in which the necessary truth preserving forms could be…explicitly codified.** This is the *normative* aspect of logic, that entitles its being called the investigation of the 'laws of thought.'"

Evandro Agazzi[7] (2003: pp 6-7)

- Logic **can't be fully reduced to some purely *formal* construction**, "**logic** cannot help subjected to the **'variable' conditions of thinking**…even if we maintain that **the most fundamental part of logic is that which makes explicit the truth-preserving linkage among propositions**, we might be in difficulty in applying this fundamental part of logic in a certain cases, owing to **the *particular* content of the propositions.**"

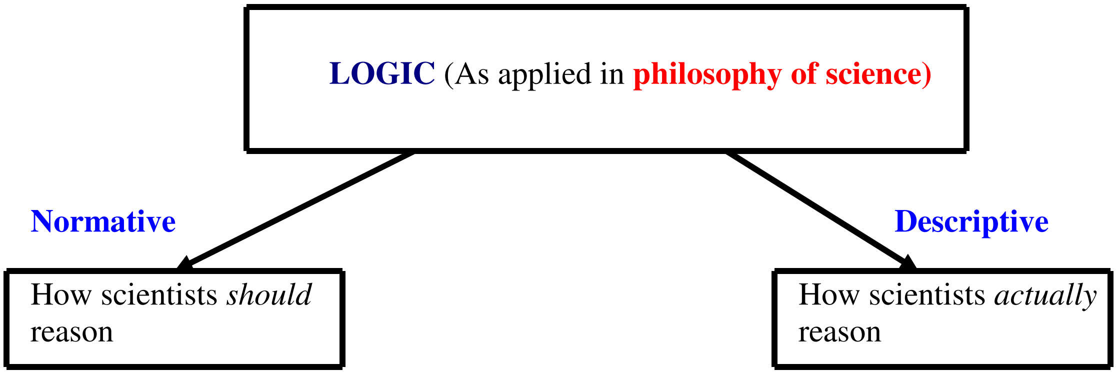
  Ibid (p. 21)

(**Example**: The *de futuris contigentibus*, or propositions expressing singular future contingent events was already discussed by Aristotle. For example, is the proposition: "There will be a sea-battle tomorrow" true or false?)

[5] Though definitions of 'propositions' can vary, here we can assume them to be any kind of thought that can be expressed in terms of a declarative state of affairs that is capable of being *judged* as true or false. For instance, the thought described by the sentence: "The cat is no the mat" *can* be an example of a proposition. For in order for that sentence to be capable of being judged true or false, enough contextual conditions must be supplied to make it unambiguous. For instance, if I were sitting on a bus, and there were no cats or mats around, and I just uttered that previous sentence, I didn't explicitly specify enough information. ("*What* cat is he talking about?" someone would naturally wonder.) On the other hand, if I pointed to a *particular* cat who may (or may not) be sitting on a particular mat, then the sentence is propositional. On the other hand, thoughts described by the phrases or sentence like: "Wow! That's cool!" or "Get out of my way!" aren't propositions. The latter two sentences don't declare states of affairs, but instead *express* a *preference* (in the first case) or *express* a *command* in the second case.

[6] RecallThursday's lecture (August 30). "Meta" means simply "above and/or beyond." By "meta-reflection" it is meant that one must reflect upon human reasoning as an object of study. (Recall Aug. 30 notes: philosophy of science is similarly a 'meta-language' in the sense that it is "talk about" another launguage (the object-language), namely, that of science. Science, of course, is 'talk about' the 'world' (of observable phenomena, processes, etc.)

[7] "Why Is it Logical to Admit Several Logics?" in Paul Weingartner, ed. *Alternative Logics: Do Sciences Need Them?* Berlin: Springer, 3-26.



CLASSICAL ("ALETHEIC[8]") LOGIC

…Expressed in first-order predicate form[9] (abbreviated as F.O. P. L.)

Connective	Symbol	Example(s)
Negation	¬	P : "It's raining now" ¬P: "It's **not** raining now."
Conjunction	∧	P : "It's raining now" Q: "It's cold now" $P∧Q$:"It's cold **and** rainy now"
Disjunction	∨	P∨Q :"It's cold **or** rainy now" Important: Disjunction is always *inclusive*[10]
Implication	→	$P→Q$: a) "It's raining now **implies** it's cold now: b) "**If** it's raining now, **then** it's cold now." c) "It's cold now **if** it's raining now." d) "It's raining now **is a sufficient condition** for it's cold now." e) "It's cold now **is a necessary condition** for it's raining now."

[8] I.e., 'truth-preserving,' in the sense of being primarily the activity of securing the truth of linkages between propositions

[9] This is a bit of a technical notion. A first-order logic is one that *quantifies* (i.e. applies modifiers like 'all' or 'some' to classes of *objects*, but cannot apply quantifiers to *predicates* which modify those objects or describe the classes the objects fall under. For example, the proposition: "Some apples are golden" is first-order, since the modifier "some" pertains to the object (apples) and not to the predicate (golden) which modifies the object. On the other hand, the proposition "All birds possess **some** of these characteristics: having feathers, having wings, being able to fly, egg-laying,…" is second-order, since the modifier "some" pertains to the *predicates* "having wings," " having feathers," etc. Second-order and higher-order propositions lie outside the domain of 'ordinary' ('classical' first-order) logic.

[10] Meaning "either/or, and maybe both." In other words, if I were to say: "I can name the new baby Sue **or** I can name her **Anne**" I am using *inclusive* disjunction. (For three cases can hold: a) I decide to name her "Sue." b) I decide to name her "Anne". c) I decide to name her "Sue-Anne." a) and b) are the 'either/or' cases, whereas c) is the 'both-and' case.

- **Note1:** *Conditional* statements ($P \rightarrow Q$) play a central role in **deductive reasoning.** (Note all the different ways a)-e) used to express the same thing…that should tell you its importance!) P (what lies to the left of $\rightarrow$) is the antecedent. Q(what lies to the right of $\rightarrow$) is the consequent.

- **Note 2:** One speaks of two (or more) propositions as *logically equivalent* (denoted by the biconditional $\leftrightarrow$ or by $\equiv$ in the case of a definition, and expressed as **"if and only if"**) when the two (or more) statements are true and false in exactly the same set of conditions. Logical equivalence is constructed from implication and conjunction:

$$P \leftrightarrow Q \equiv (P \rightarrow Q) \wedge (Q \rightarrow P)$$

- **Note 3:** It's wrong to assume logical connectives mean exactly the same thing as their associated ordinary language counterparts "not, or, and,…" (For instance, recall the note above regarding disjunction being inclusive). Another counter-example: In ordinary language we often specify "and" in terms of a *specific* order, i.e. "Put on your shirt **and** your sweater" whereas disjunction is *commutative* (independent of order, i.e. $P \wedge Q \leftrightarrow Q \wedge P$.)

Quantifier	Symbol	Example
Existential	$\exists$	$x \in$ {cats} M : "meows" $\exists x{:}Mx$: a) "**Some** cats meow" b) "**There exists**[11] a cat that meows" c) " **A** cat meows" d) "**There is**[12] a cat that meows"
Universal	$\forall$	$\forall x{:}Mx$: a) "**All** cats meow" e) "**Any** cat meows" c) " **Every** cat meows"

- **Note 4:** In the above table, the examples can be expressed more formally by not restricting the (logical) variable x initially to the set of cats, but rather define the predicate C as "being a cat". Then the first example ("some cats meow," etc) can be re-written as: $\exists x{:}Cx \wedge Mx$, ("**There exists** an x **such that** x is a cat and x meows"). The second example can be re-written as a universal conditional: $\forall x{:}(Cx \rightarrow Mx)$. In other words, "all cats meow" is logically equivalent to the universal conditional: "For **all** x, **if** x is a cat, **then** x meows."

[11] "There exists" doesn't imply *unique* existence (i.e., it doesn't imply there's *only one cat that meows*)
[12] See note 11. Again, the discrepancy with ordinary language (recall **Note 3**) appears here as well. "*There's* a" is often used *ostensively* in ordinary language, i.e. when *indicating a particular cat*. While "there is a" here is purely *descriptive*, i.e. meowing pertain to one or more cats.

- **Definition:** A proposition that is <u>always true</u> is a tautology (denoted by $\top$). A proposition that is <u>always false</u> is a contradiction (denoted by $\bot$).

<u>Arguments in FOPL</u>

- Recall <u>**Note 1**</u> discussed above. **An argument is an extension of a conditional statement (*P*→*Q*) in which the antecedent consists of two or more propositions. To distinguish arguments from ordinary conditionals, one speaks of *premises* in place of *antecedents* and *conclusions* in place of *consequents*. The simplest kind of argument is the *syllogism*, which has just two premises.**

  Example:

  "All integers are real numbers**, *a*** is an integer**, therefore** *a* is a real number."

  ..is an example of a syllogism. Using the abbreviations for predicates *N, R* to denote the integers and real numbers, respectively, the above can be written in FOPL as:

$$\begin{array}{ll} & \forall x{:}(Nx \to Rx) \\ & Na \\ \hline \therefore & Ra \end{array} \qquad \text{or} \qquad (\forall x{:}(Nx \to Rx)) \wedge Na \vdash Ra$$

  ..where the **therefore** is depicted as a **logical consequence** from the premises either by the symbol $\therefore$ (if the argument is represented in column-form, as on the left had side) or by the symbol $\vdash$ (if the argument is represented in row-form, as on the right had side). I will follow the convention used by the authors in the anthology, by depicting arguments in the (more intuitively appealing) column form.

- Recall Agazzi's quotes above. What distinguishes logic from any old rule-based formal system, is that in logic, the rules must be truth-preserving. In the case of FOPL, this translates into (14) rules of inference[13], i.e. rules for forming valid arguments. **A valid argument is one whose truth of its premises *guarantee* the truth of its conclusion. (*If* all its premises are true, then its conclusion is true). A sound argument is a valid argument whose premises all happen to be true.**

- <u>**Note5 :**</u> *Validity* is a *necessary feature* of logical *form*, i.e. it's a property of the machinery of the logic's *rules of inference*. Soundness is a contingent feature of logical *content*. For example, the argument:

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[13] They are subdivided into: 6 **rules of introduction** of the connectives ¬, ∧, ∨, →, and the quantifiers ∀, ∃, and 6 **rules of elimination** of the connectives ¬, ∧, ∨, →, and the quantifiers ∀, ∃, and the additional two rules: EFSQ (i.e., *any* proposition can follow from a premise list containing a **contradiction)** and the Double negation rule: for any sentence φ: $\neg\neg\varphi \vdash \varphi$.

"All dogs are cats, **and all** cats are alligators, **therefore** all dogs are alligators**"**

…is valid! It's an example of the medievals referred to as a "Barbara" (AAA form categorical syllogism) which today we recognize as **transitive reasoning** ("All A are B, and all B are C, therefore all A are C" or more formally:

$$(\forall x{:}(Ax \rightarrow Bx)) \wedge (\forall x{:}(Bx \rightarrow Cx)) \;\; \vdash \; (\forall x{:}(Ax \rightarrow Cx))$$

which can be proven rigorously as valid in FOPL using its 14 rules of inference) The argument, however, is clearly **unsound** (since its two premises are false).

- **Question: Does FOPL adequately characterize scientific reasoning, or arguments typically made by scientists?**
- **Answer: ABSOLUTELY NOT! ☹**

Aside from only acting as some constraint in the most abstract normative discussion of what theories 'should' look like when rationally reconstructed, FOPL fails for that matter to even capture the reasoning found in ordinary arithmetic! (As discussed by Gottlob Frege in the 1880s). Recall note 9 above. FOPL can't quantify over *predicates* (i.e. you're note allowed to say things like: "*some* property *P* holds) but both mathematicians and scientists (as well as ordinary lay-people) do this all the time! (Unbeknownst to us, in fact, we usually quantify over arbitrarily many levels or orders. For example, when one utters: "**Some** tastes for **some** colors for **all** shirts…" this is a *third-order* statement (The first "some" modifies the 3-rd level property "taste", which in turn modifies the 2nd-level property "color," quantified by the second "some", which modifies the objects "shirts" which are quantified by all.)

…But there is a far more basic shortcoming.

> **Ordinary logic is *deductive*; i.e. *conclusions* (whether general or particular) are derived from *closed sets of premises* (whether general or particular) based on *a finite and closed set of rules of inference.***

Science, however, naively conceived, is an **activity whose aims obviously include increasingly refined knowledge of the world of phenomena.** Essential scientific reasoning, then, **though it may *involve* deduction, is obviously *not essentially* deductive.** (If it were, such a science would presume itself "final" and "omniscient", undercutting its fundamentally *empirical* nature. In other words, it would no longer *be* science!)

Deductive Reasoning	**Inductive Reasoning**	**Abductive Reasoning**
Conclusions **are derived from** ***closed sets of premises*** **based on** ***a finite and closed set of rules of inference.***	A general claim (usually expressed as a **law** or as a **principle**) is *inferred* from particular claims	***Puzzlement*** ⇒ ***Speculation*** ⇒ ***Adaptation*** ⇒ ***Explanation***

As we'll come to see and appreciate, *all three forms* of reasoning are often employed in even the most simplest examples involving scientific theorizing. This has led many philosophers of science (both 'classical' and 'contemporary' to aspire after some general **"logic of discovery"** which would systematically regiment and characterize the essential aspects of scientific reasoning, both as *process* (e.g., the 'logic' of the **context of discovery**) as well as a *final product* (usually conceived to be textbook-ready theories, capable of being 'rationally reconstructed' in some precise formalism involving a specialized logic).

- A toy example

"**Every** crow in a random sample of n crows is black. **Therefore**, this strongly supports the hypothesis that 'all crows are black.'

Inductive logic seeks to extend the principles of deductive reasoning to statements which aren't fully certain. The aim of inductive logic, using tools from **probability theory and statistics** is to derive such rules of inference that would provide an optimal support for a conclusion. Inductive logic essentially **involves** probability and statistics, but is **not merely** probability and statistics.

Regimented according to inductive logic, the above argument could be characterized by the following scheme:

1. S is a **random sample** of C (crows).
2. $|S| = n$ (i.e. S has n members)
3. The **frequency** (or proportion) of members of C having property B (i.e., being black) in sample S is r (= 1). (I.e. $f[B,C \cap S] = r = 1$)

--[p][14]

$\therefore$ [To a **margin of error** q conclude that] The **proportion** of **all** members of C having property B is r (= 1).

[14] Note: the ====[p] notation means: "Conclude with degree of support p."

(Just a) small sample of different kinds of logic, applicable to the study of science as a whole, as well as to its sub-specialties:

- **Inductive Logic:** rules of inference that would provide an optimal support for an inductive conclusion.

- **Epistemic Logic:** Reflecting the actual inferences and beliefs a scientist make "if [s/]he wants to adhere to the actual cognitive and ontological situation of his [or her] discoveries and its referents." (Agazzi (2003), p. 25)

- **Intuitionistic (or Construcitivst) Logic:** A logic reflecting the *constructed nature* of mathematical reasoning and its objects. This logic is 'stricter' than FOPL, as it rejects, for instance, **double-negation** ($\neg\neg p = p$) as well as the **excluded middle** ($\neg p \vee p = \mathrm{T}$).

- **Quantum Logic:** Reflecting the unique conceptual features of operational procedures of quantum theory, based on notions like **superposition, Heisenberg Uncertainty**, the **statistical nature of measurements and predictions.**

- **Temporal Logic**: Logic that accommodates how truth-values depend on time (recall the *de futuris contigentibus* example discussed above).

- **Default Logic**: Related to **Epistemic Logic**, seeks to characterize how *beliefs* (described as 'conditional' defaults) can revise, override, and undercut one another. Such a logic is *paraconsistent* i.e., it's possible to hold conflicting beleifes and still reason in a consistent manner

Etc…