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The Logicality of Abduction, Deduction and Induction

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1. Reasoning and logic

One of the most crucial and intriguing questions in the cognitive sciences is what thought in general has to do with logic in particular. In order to answer it, of course, we have to enquire into the very notion of "logic", at first. On the one hand, logic is often equated with rules of deduction, so that logic essentially means deductive logic. Consider, e.g., Suppes' notion of a theory of logical inference, which he understands as the theory of correct reasoning, that is "…the theory of proof or the theory of deduction" (1957, p. xi). The very basis of logic, or logical inference, thus seems to be "correct reasoning", which translates directly into principles of deduction. On the other hand, it may, of course, be asked whether deduction is the only way of reasoning correctly and whether, consequently, induction and – perhaps even more so – abduction would have to be regarded as kinds of "incorrect" reasoning, or (differently put) whether they are inferences at all. Indeed, reproaches of this sort have been levelled against advocates of non-deductive inferences. For instance, T. Kapitan argued that hypotheses are not inferred by way of abduction (see 1992, pp. 6-7) and B. van Fraassen claimed that "inference to the best explanation" was "no inference at all" (1989, p. 161). Peirce's notion of abduction in particular has been subject to this criticism, mainly because of his notorious association of abduction with "guessing" (CP 7.219 [1901]; 5.172 [1903]) and "instinct" (CP 7.220 [1901]; 6.476 [1908]; see also Paavola, 2005). The logicality of abduction thus appears to be begging the question.

It should, however, be noted that also for Peirce "logic is, in the main, criticism of reasoning as good or bad" (CP 2.144 [1902]) – a view that is taken to be valid also today (see Copi & Cohen, 2004, p. 4). Therefore, if abduction and induction are to be logical inferences, they have to follow their own specific principles on which their validity in terms of correctness of reasoning depends. In other words, there has to be specific and precise criteria that make specific types of inferences correct or incorrect.

The present paper aims at revealing those principles and thus the specific logicality of each type of inference. This is done by a formal analysis of the inferential process, which incorporates Peirce's distinction of three subprocesses of inferences in general, i.e. colligation, observation and judgement (MS 595:35; CP 2.444). As a consequence of this analysis, a system of the three inferences that encompasses the overall process and dynamic of the discovery of new ideas and the acquisition of knowledge emerges. The inferential approach allows us to pinpoint all crucial steps and the various logical aspects of this overall process.

2. The inferential triad

Before analysing the central question of logicality, we have to be clear about the content of and the relations between the three inferential types. This is important for at least two reasons: Firstly, Peirce changed his inferential theory significantly during the last decade of the 19th century. This is well known, but none the less there seems to be a good deal of confusion prevalent even today (see e.g. Hintikka, 1998; Minnameier, 2004; Paavola, 2006). Secondly, I would like to reveal the core of the three inferences, especially of abduction and induction, which is the necessary basis for the subsequent analyses.

The mature Peirce understands abduction as "the process of forming an explanatory hypothesis. It is the only logical operation which introduces any new idea" (CP 5.171 [1903]). "Explanation" in this context means to develop a theory to accommodate explanation seeking facts in a very broad sense. It can be a narrative account of certain puzzling facts like in a criminal case or a scientific theory or merely a simple disposition like the "dormitive power" of opium, to quote a famous example of Peirce (see CP 5.534 [c. 1905]).

Now Peirce himself has contributed to the controversy about abduction being an inference with his notorious claim that our capacity of abduction is grounded in an obscure guessing instinct (see e.g. CP 5.172 [1903];

CP 7.219–220 [1901]). If abducing meant just guessing, one could well rely on Popper and Hempel who have argued that the invention of theories is a matter of "happy guesses" and that "(s)cientific hypotheses and theories are not *derived* from observed facts" (Hempel, 1966, p. 15). As opposed to this view, however, Peirce maintains "that abduction [...] is logical inference, asserting its conclusion only problematically or conjecturally, it is true, but nevertheless having a perfectly definite logical form" (CP 5.188 [1903]). And he is certainly right, for *new* theories cannot be generated by way of guessing, not only because "the possible theories, if not strictly innumerable, at any rate exceed a trillion" (CP 5.591 [1898]; see also CP 7.220 [1901]), but also because guessing implies a certain given frame of reference from which we pick out any piece of information by chance. In the case of new theories, or abduction in general, however, we have to come up with an entirely new concept (relative to where the reasoning starts from).

Given this function of abduction, the dynamic interaction of abduction, deduction, and induction can be reconstructed as follows and as depicted in Figure 1. Abduction leads to a new concept or theory that explains surprising facts at t0, where facts can be anything that the epistemic subject takes for granted. Thus, a factual constellation could also consist in the firm conviction that a certain theory has been disproved by certain observations – which establishes a need for abductive reflection. According to Peirce, "Abduction merely suggests that something *may be*. Its only justification is that from its suggestion deduction can draw a prediction which can be tested by induction" (CP 5.171 [1903]).

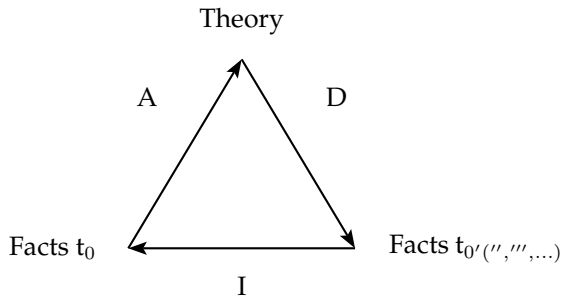

Figure 1: The dynamical interaction of abduction, deduction, and induction

As Figure 1 shows, deduction results in new facts $t_{0'}$, $t_{0''}$ and so on (as forecasts or general consequences) that are the subject of empirical inves-

tigation and inductive reasoning. If induction leads to the conclusion that the theory in question is true, then it (the theory) is projected onto all cases to which it applies, i.e. the original surprising facts (t_0), the tested cases ($t_{0'}$, $t_{0''}$, ...), and all future cases to be encountered (at t_1, t_2, ...) as well as all the relevant cases from the past. This also implies that when the theory is subsequently applied to any suitable case is not only being applied, but also being reassessed over and over again (see also Minnameier, 2004; 2005).

In this sense, induction can only establish truth relative to the current state of affairs. It can never be excluded that future evidence may challenge a currently well established theory. However, it is not necessary to invoke a notion of approximate truth, but as said, truth relative to evidence at hand and the current state of knowledge. Therefore, the extrapolation to future or unobserved instances of the theory in question is only valid based on current evidence, and does not imply prognostic certainty.

3. Logical analysis of abduction, deduction and induction

3.1 The inferential process

All inferences are mental acts of reasoning, and as such describe a process with a definite beginning and a definite end. Any inference begins with an explicit or implicit question that demands an answer in the form of the respective conclusion. Abduction asks for possible explanations in the sense described above, deduction asks for what follows from certain facts or assumptions, and induction asks for the justification for taking on a certain belief or following a certain course of action. According to Peirce, the process of answering these questions, however, can – and supposedly has to – be subdivided into three distinct steps.

Several versions of these three steps can be found in Peirce's work, the most appropriate of which I consider the differentiation between "colligation", "observation", and "judgment".

> The first step of inference usually consists in bringing together certain propositions which we believe to be true, but which, supposing the inference to be a new one, we have hitherto not considered together, or not as united in the same way. This step is called *colligation*.
>
> CP 2.442 [c. 1893]

> The next step of inference to be considered consists in the contemplation of that complex icon [...] so as to produce a new icon. [...] It thus appears that all knowledge comes to us by observation. A part is

> forced upon us from without and seems to result from Nature's mind; a part comes from the depths of the mind as seen from within
>
> CP 2.443–4

> A few mental experiments – or even a single one [...] – satisfy the mind that the one icon would at all times involve the other, that is, suggest it in a special way [...] Hence the mind is not only led from believing the premiss to judge the conclusion true,[1] but it further attaches to this judgment another – that *every* proposition *like* the premiss, that is having an icon like it, *would* involve, and compel acceptance of, a proposition related to it as the conclusion then drawn is related to that premiss. [This is the third step of inference.] CP 2.444

He concludes that "[t]he three steps of inference are, then, colligation, observation, and the judgment that what we observe in the colligated data follows a rule" (CP 2.444). The step of colligation is consistently used and explained and thus seems to be rather clear (cf. e.g. CP 5.163; 5.569). However, Peirce is less precise about the other two – or about the distinction between the other two – sub-processes. In particular, his differentiation between a "plan" and "steps" of reasoning may cause some confusion (see CP 5.158–66). As for the "plan", he says that "we construct an icon of our hypothetical state of things and proceed to observe it. This observation leads us to suspect that something is true, which we may or may not be able to formulate with precision, and we proceed to inquire whether it is true or not" (CP 5.162).

This account matches perfectly with the above description. However, Peirce then proceeds "to the reasoning itself" (CP 5.163) and distinguishes "three kinds of steps" (ibid.). "The first consists in copulating separate propositions into one compound proposition. The second consists in omitting something from a proposition without possibility of introducing error. The third consists in inserting something into a proposition without introducing error" (ibid.). Apparently, those three steps are all to be subsumed to the process of "judgement", i.e. the inquiry into whether an inference is valid or not. At least this would explain why Peirce emphasises the exclusion of error in the last passage. And it is also supported by a similar description that he gives elsewhere:

> [We] begin a Deduction by writing down all the premises. Those different premisses are then brought into one field of assertion, that is, are *colligated* ... Thereupon, we proceed attentively to observe the graph.

[1] The talk of "truth" here is certainly misleading, since the passage should apply to all three inferences. It would be more appropriate to speak of a "valid" inference.

> It is just as much an operation of *Observation* as is the observation of bees. This observation leads us to make an *experiment* upon the Graph. Namely, we first duplicate portions of it; and then we erase portions of it, that is, we put out of sight part of the assertion to see what the rest of it is. We observe the result of this experiment, and that is our deductive conclusion. Precisely those three things are all that enter into the experiment of any Deduction – Colligation, Iteration, Erasure.
>
> CP 5.579 [1898]

It is obvious that "experiment" here is equivalent to the process of "judgement" in the statement further above, and it should be noted that in this statement judgement is also explained in terms of one or more experiments carried out. Furthermore, the last passage reveals that the trivium of "colligation", "iteration" and "erasure" denotes indeed sub-processes of "experiment" (or "judgement" for that matter). I therefore take it that the overall phases of inference are colligation, observation and judgement, whilst the other three refer to the details of proving that the respective inference is valid.

The inferential process may thus be described as follows: It starts with the colligation of relevant facts which constitute the respective logical problem (abductive, deductive, or inductive). Then these facts are observed in order to find a solution to the problem, but although a deliberate act, observation only results in spontaneous ideas that spring to our minds as we contemplate the premises (see CP 5.581 [1898]; CP 7.330–1 [1873]; CP 2.443–4, see above). The very notion of inference, however, requires the result to be controlled by the mind (see CP 5.181 [1903]), and this concerns the process of judgement (see also CP 7.330–4 [1873]). The difference between mere observation and judgement could also be described in terms of secondness and thirdness. In this respect Peirce argues that "if the force of experience were mere blind compulsion, ... we then never could make our thoughts conform to that mere Secondness" (CP 5.160 [1903]), and he goes on: "But the saving truth is that there is a Thirdness in experience, an element of Reasonableness to which we can train our own reason to conform more and more" (ibid.). And it should be noted that all "arguments" are essentially characterised as thirds (see CP 2.252 [c. 1897]).

Now, Peirce's reflections on the present issue mainly refer to deduction, so that it may be asked how these processes relate to abduction and induction. To be sure, Peirce says something in this respect, but is less explicit about the sub-processes (especially judgement) as far as abduction and induction are concerned (see esp. CP 5.579–83). Nonetheless, I

think the revealed principles can be transferred in a fairly straightforward manner.

As for abduction, the colligated premise consists of all the relevant facts that constitute the initial problem, i.e. colligation here is equivalent to the problem statement. Observation refers to the search for a solution and the subsequent spontaneous generation of an explanatory idea that allows us to accommodate the problematic facts (see CP 5.197 [1903]). In this regard, Peirce argues that observation "is the enforced element in the history of our lives ... which we are constrained to be conscious of by an occult force residing in the object which we contemplate" (CP 5.581 [1898]) and to which we ultimately surrender. "Now the surrender which we make in Retroduction, is a surrender to the insistence of an Idea" (ibid.).

This eventual surrender, however, is the result of the third inferential sub-process ("judgement"). The abductive judgement consists in the adoption of the hypothesis as worth of further consideration. In other words, it is to be judged that (or whether) the new idea really does accommodate the facts, i.e. that the hypothesis really solves the problem so that the "surprise" inherent in the initial problem statement vanishes (see also below, where the validity of the three inferences is discussed).

Let us finally turn to induction:

> Induction consists in starting from a theory, deducing from it predictions of phenomena, and observing those phenomena in order to see how nearly they agree with the theory. CP 5.170 [1903]

> (Induction) has three parts. For it must begin with classification...by which general Ideas are attached to objects of Experience; or rather by which the latter are subordinated to the former. Following this will come the testing-argumentations, the Probations; and the whole inquiry will be wound up with the Sentential part of the Third Stage which, by Inductive reasonings, appraises the different Probations singly, then their combinations, then makes self-appraisal of these very appraisals themselves, and passes final judgment on the whole result. CP 6.472 [1908]

In other words, induction begins with deduced observable facts (colligation) which are then being observed. It may either be an experiment to be carried out, or past events that are recollected in order to be observed under the current aspect. The important point is only that premises for induction are items that can be deduced from the hypothesis in question and prior knowledge (where these items might also simply be reiterated).

Thus, the colligated inductive premise contains necessary consequences that can be used to test a hypothesis or evaluate the suggested idea.

In the next step, the experiments or past experiences are observed in order to determine whether the hypothesis can ultimately be accepted or rejected, or whether the matter is still pending. In this way, the epistemic subject perceives aspects that speak for or against the approach that is to be tested.

The eventual inductive judgement accordingly consists in weighing the evidence and deciding

> whether the hypothesis should be regarded as proved, or as well on the way toward being proved, or as unworthy of further attention, or whether it ought to receive a definite modification in the light of the new experiments and be inductively reexamined *ab ovo*, or whether finally, that while not true it probably presents some analogy to the truth, and that the results of the induction may help to suggest a better hypothesis. CP 2.759 [1905]

3.2 The validity of abduction, deduction, and induction

So far we have analysed the three inferential sub-processes with respect to all three inferential types. However, one question deserves still closer attention: What precisely does it mean to say that an inference (i.e. the judgement) is valid, especially with respect to abduction and induction? Peirce propounds a strong notion of logicality for all three inferences:

> [W]hile Abductive and Inductive reasoning are utterly irreducible, either to the other or to Deduction, or Deduction to either of them, yet the only *rationale* of these methods is essentially Deductive or Necessary. If then we can state wherein the validity of Deductive reasoning lies, we shall have defined the foundation of logical goodness of whatever kind. CP 5.146 [1903]

When Peirce says that abduction and induction, i.e. the respective judgements, are "essentially Deductive and Necessary", the stress must be on "essentially", for if they were equivalent to deduction, the argument of irreducibility would be false. The inconsistency on the surface vanishes with Peirce's explanation of what he means by necessary reasoning: A statement is "necessary", if it makes us see that what we perceive is of a general nature. He gives us an example:

> A line abuts upon an ordinary point of another line forming two angles. The sum of these angles is proved by Legendre to be equal to the

> sum of two right angles by erecting a perpendicular to the second line in the plane of the two and through the point of abuttal. This perpendicular must lie in the one angle or the other. The pupil is supposed to see that. He sees it only in a special case, but he is supposed to perceive that it will be so in any case. The more careful logician may demonstrate that it must fall in one angle or the other; but this demonstration will only consist in substituting a different diagram in place of Legendre's figure. But in any case, either in the new diagram or else, and more usually, in passing from one diagram to the other, the interpreter of the argumentation will be supposed to *see* something, which will present this little difficulty for the theory of vision, that it is of a *general nature*. CP 5.148 [1903]

This may remind us of another passage quoted above, where Peirce describes judgement as satisfying the mind "that the one icon would *at all times* involve the other" (emphasis mine) and "that *every* proposition *like* the premises ... *would* involve, and compel acceptance of, a proposition related to it as the conclusion". A valid judgement, then, must basically reveal that it would at all times yield the same result. In fact, this is what distinguishes judgement from observation which is spontaneous, volatile and uncontrolled.

Peirce's notion of the abductive judgement is well known and goes like this:

> The surprising fact, C, is observed;
> But if A were true, C would be a matter of course,
> Hence, there is reason to suspect that A is true. CP 5.189 [1903]

It has been questioned whether this can be rightly called an abduction, it being essentially a deductive argument (Kapitan, 1992). However, Kapitan fails to see that this statement does not describe the entire process of abductive reasoning, but only the abductive judgement (see also Fann, 1970, p. 52; Paavola, 2005, p. 141). Moreover, we have just seen that Peirce requires any judgement to be "deductive" or "necessary" in some sense. Therefore, Kapitan's criticism misses the point. What the judgement tells us is no more and no less than that A explains C, and that this is necessarily so. It is easy to see that necessity of this kind does not imply any statement regarding the truth of A. Nor does it involve any claim of entailment in the deductive sense, for C does not entail A. It is only stated that A entails C, which is just the explanatory relation.[2]

[2] As opposed to this, deduction aims at revealing further necessary consequences (new derivable statements) of the hypothetical statement of A together with premises from back-

As Fann points out, however, the validity of abduction also depends on what is being asserted by the abductive judgement, and he claims that explaining the facts is a weak criterion, since it simply (re)states what abduction *is* rather than providing an independent argument for its validity (1970, pp. 52–53). However, Fann's reservations can be countered in a twofold manner. First, when discussing the logical validity of abduction, we are not concerned with explaining how humans manage to come up with fruitful hypotheses, as he does. Second, what we should be concerned with is the nature of explanation, and here we have to distinguish "explanation" in the deductive nomological sense (which is equivalent to the early Peirce's concept of hypothesis) and theoretical explanation (which is equivalent the mature Peirce's concept of abduction). Earnan McMullin has made this very clear:

> To explain a law, one does not simply have recourse to a higher law from which the original law can be deduced. One calls instead upon a theory, using this term in a specific and restricted sense. Taking the observed regularity as effect, one seeks by abduction a causal hypothesis which will explain the regularity. To explain why a particular sort of thing acts in a particular way, one postulates an underlying structure of entities, processes, relationships, which would account for such a regularity. What is ampliative about this, what enables one to speak of this as a strong form of understanding, is that if successful, it opens up a domain that was previously unknown, or less known.
>
> McMullin, 1992, p. 91

Even Hempel differentiated between explanation in the deductive-nomological sense and theoretical explanation (1965, pp. 5–6). And explanation in this latter sense means that an explanatory concept has to render something possible, i.e. the explanation-seeking facts, which before have been perceived as impossible (not as facts, but from a logical point of view). And therefore, the explanatory concept is accepted as a possibility, too. Hence, a valid abductive judgment establishes the possibility of an explanatory concept. This is why Peirce also claims that "Deduction proves that something *must be*; … Abduction merely suggests that something *may be*" (CP 5.171 [1903]).

Concerning the validity of the inductive judgement Peirce points out that it basically consists in projecting a regularity that has been observed

ground knowledge. It should, however, also be noted that things are slightly different with respect to theorematic deduction – an issue which cannot be treated in the present paper (see Minnameier, 2005, pp. 195–218).

and following the suggested hypothesis onto all possible instances. He gives the example of an infinite series of symbols for which a certain pattern is assumed and examined, and for which a judgement as to its overall regularity is made on the basis of finite experience (see CP 5.170). He concludes that "the validity of induction depends upon the necessary relation between the general and the singular" (ibid.).

Induction, thus, is the inference that yields factual knowledge, constituting factual truth (whereas deduction only yields so-called logical truths and abduction merely plausible ideas). Now, what may been seen as problematic in this respect is the relation between knowledge and truth. The classical notion of knowledge as *justified true belief* requires that a proposition be true in order to be known. However, a main theorem from the point of view of pragmatism is that knowledge is logically prior, i.e. knowledge establishes truth rather than requiring it as a condition.

The same line is followed by F. Suppe (1997) when he suggests a non-reliabilistic externalist approach to knowledge. On this view, we know p when it is not causally possible (indicated by a causal possibility operator $\diamondsuit_c$)[3] that we perceive the evidence unless the suggested hypothesis is true. Without being able to spell this out in detail here, this approach meets with the elaborated eliminative inductivism proposed by Earman (1992) and the notion of practical truth suggested by Da Costa and French (e.g. 2003) (see also Minnameier, 2004). According to Suppe's approach truth collapses with knowledge in a conscious act, which is described in condition (iv) below. And "satisfying (iv) entails the satisfaction of condition (iii)" (Suppe, 1997, p. 402), since R and/or K function as decisive indicators for Φ.

S propositionally knows that ϑ *if and only if*

(i) *S* undergoes a cognitive process *R*, or *S* has prior knowledge that *K*;

(ii) *S*, knowing how to use Φ and knowing how to use ϑ with the same propositional intent, as a result of undergoing *R* or having prior knowledge that *K* entertains the proposition Φ with that propositional intent as being factually true or false;

(iii) 'Φ' is factually true;

[3] Causal possibility refers to all logically possible worlds consistent with the natural laws of our world.

(iv) there exists a conjunction C of partial world state descriptions and probability spaces such that C & $\sim\diamondsuit\Phi$(C & R & K & $\sim \Phi$) & $\diamondsuit\Phi$(C & $\sim \Phi$) & $\diamondsuit$R & $\Diamond$(R & $\sim\Phi$);

(v) as a result of undergoing R or K, S believes that Φ. (Suppe, 1997, p. 405.)

4. Conclusion

The results of the above analysis are condensed in the following formal diagram (which is reduced to the essential features).

Inference:	Abduction	Deduction	Induction
Colligation:	C	$H \wedge P$	$\Box((H \wedge P) \rightarrow E) \wedge E$
Observation:	$H \rightarrow \diamondsuit C$	$(H \wedge P) \rightarrow E$	$E \wedge \neg\diamondsuit(E \wedge \neg H)$
Judgement:	$\diamondsuit H$	$\Box((H \wedge P) \rightarrow E)$	$\diamondsuit H$

Figure 2: Formalisation of inferential processes

Abduction starts from the colligated premise C, leads to H as a possible explanation (observation that $H \rightarrow \diamondsuit C$) which is asserted in the conclusion (judgement). H is input into deduction, together with suitable premises from background knowledge or antecedent conditions (P). Deductive analysis (observation) leads to the derivation of E as a consequence which is judged logically necessary in the conclusion. Again, this is input for induction, together with an experimental setting (or prior experience) and the observable results E. These results E are observed in order to reveal aspects of it that speak in favour or against the hypothesis, and eventually – provided the evidence is favourable – it is inductively inferred that H is causally necessary, hence true (or, to be precise, considered true on the basis of all available background knowledge).

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