Abduction

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- *Abduction*, or “inference to the best explanation.”
- This form of inference has roots in the 17th century (Hobbs 2006).
- Explicitly formalized by Charles Sanders Pierce in the 1870s and further developed by him (Pierce 1955).
- **Abduction** represents the reasoning that goes on in much of science—physical, biological, and social—and in everyday life, although it is rarely identified as the mode of inference that is actually being used.

- What exactly is abduction, and how does it differ from deduction and induction?

- The central idea is that a body of data provides evidence for a hypothesis that satisfactorily explains or accounts for that data, or at least provides evidence if the hypothesis is better than explanatory alternatives.

- In Pierce’s original formulation of abductive reasoning:

The surprising fact, Q, is observed:
But if P were true, Q would be a matter of course,
Hence, there is reason to suspect that P is true.

- Pierce: “*in pure abduction, it can never be justifiable to accept the hypothesis otherwise than as an interrogation*.”

- There must be an evaluation scheme for choosing among possible abductive inferences.

- In *deduction* we start with a proposition, P, and if P implies Q, then we conclude Q.

- In *induction*, we start with a number of instances of P and Q together with other considerations and conclude that P implies Q.

Deduction

Rule: All the beans from a bag are white.

Case: These beans are from that bag.

Therefore, Result: These beans are white.

Induction

Case: These beans are from this bag

Result: These beans are white.

Therefore, Rule: All the beans from this bag are white.

Abduction

Rule: All the beans from a bag are white.

Result: These beans are white.

Therefore, Case: These beans are from that bag.

Expert Systems

- The first expert system, DENDRAL, developed by Joshua Lederberg, Edward Feigenbaum, Bruce Buchanan, Carl Djerassi, and others (Lindsay et al. 1993) was designed to automatically carry out inferences (using mass spectrometry data) to the best explanation (specifying organic molecules consistent with the mass spectrometry measurements).

- The task of writing computer programs to do the inferential process forced a precision of thought about abduction that had been absent from prior literature.

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- Missing from the above brief summary is any discussion of assessment of quality of evidence of different types, and its formal incorporation in the inference process *per se*.
- For this, a useful starting point is John Venn’s *The Logic of Chance* (Venn 1888), and more recent literature (Good 1950; Kane 1992; Hobbs et al. 1993; Gaizauskas and Wilks 1998; Katz and Singer 2007), which leads naturally to the notion of *veritas* rankings (scoring) to indicate an investigator’s subjective appraisal of the trustworthiness of a given piece of evidence.
- Indeed, all evidence to be weighed in an inferential process should be accompanied by *veritas* scores and the publication/posting online of the data/evidence being rated so that there is full transparency about this critical step in the inference process.

Example from Katz & Singer

- Long-standing controversy about the possible use of chemical and/or biological weapons (CBW) in Laos, Cambodia, and Afghanistan in the 1970s.
- Katz and Singer (2007) introduced a seven-step abductive strategy for integrating a complex mixture of qualitative and quantitative data.
- The objective was to establish, in a transparent fashion, that one among a range of plausible hypotheses was best supported by available evidence.
- Although their detailed analysis focuses on a CBW investigation, the basic strategy is relevant to Implication Analysis.
- The basic strategy proceeds as follows.

1. Divide the evidence into categories of distinct types of information. In the CBW investigation mentioned above, there were 12 categories of evidence:

   (a) toxicological analysis,
   (b) intelligence reports,
   (c) Hmong interviews, (d) medical records,
   (e) Soviet-link evidence,
   (f) investigator interviews,
   (g) attack data,
   (h) coincidence analysis,
   (i) methodology of conduct of the CBW investigation,
   (j) autopsy results,
   (k) open-source documents, and
   (l) sampling methods.

- The pieces of evidence in these categories ranged across laboratory microbiology, military messages and cables, interview accounts of airplane attacks, etc.

- The key point here is that the evidence is of diverse character and requires an integrated analysis as a process of inference to the best explanation.

2. Assign a *veritas* ranking to each category of evidence, based on a combination of dubiousness and degree of fallacy.

- The distinction between these two notions is that assessment of dubiousness requires an appraisal of ambiguity or likelihood, while degree of fallacy requires an appraisal of possible deception, or purposeful introduction of falsity.
- Quantifying dubiousness has a considerable history (Venn 1888; Kane 1992), including the measurement of "dubiety" (degree of dubiousness) in measurements of the velocity of light (Dorsey 1944).
- In the context of a CBW investigation, making fine distinctions in degree of belief and assigning numerical weights or probabilities to categories of evidence when determination of error and level of ambiguity is fluid is not feasible.

- Thus, the CBW study relied on a system of ranks.
- Each category of evidence was assigned a “degree of dubiousness” score and a fallacy score.
- The sum of these scores was assigned a rank of low, medium, or high, thereby specifying an overall *veritas* rank.
- Because of the subjective judgment that enters into these scores, we feel that it is imperative to make primary data available in a publicly accessible file so that others may challenge the rationale of the judgments used (Katz and Singer 2007), and introduce alternative appraisals and potentially different conclusions.
- We feel that this kind of transparency is lacking in much social science research where significant judgments are involved.
- From our perspective, transparency and explicitness in subjective judgments needs to be an integral part of the abductive inference process and in any refinements of Implication Analysis.

3. Specify multiple plausible hypotheses.

4. Assess each evidence category for strength of association to each hypothesis, assigning a ranking of strong, medium, or weak to strength of association.

- This is a step that can involve considerable subjective judgment.
- It requires explicit specification of the rationale for strength of association rankings to ensure transparency in the abductive process.

5. Organize the evidence categories by hypothesis into a matrix based on strength of association and *veritas* rank.

- Assign numerical scores to the evidence categories as they pertain to the hypotheses in accordance with a scoring scheme such as indicated in Figure 1.
- This numerical specification represents only one of a myriad of possible scoring schemes.
- What they should all have in common is the order relations among the cells in the table as reflected in the numerical ordering in Figure 1.

Association \ Veritas	High	Medium	Low
Strong	10	8	4
Med.	8	6	2
Weak	4	2	0

FIGURE 1. Scoring scheme for association X *veritas* rankings.

6. With the numerical assignments at hand, we compute six summary statistics:

(a) maximum score over all evidence categories;
(b) minimum score over all evidence categories;
(c) average score;
(d) average score over evidence categories in the "minimally strong– support" cells (white background in Figure 1);
(e) average score over evidence categories in "relatively strong–support" cells (shaded background in Figure 1);
(f) percent of evidence blocks in strong–support cells.

- These statistics are calculated for the evidence categories relevant to individual hypotheses, to pairs of hypotheses, and to multiple hypotheses simultaneously, thereby producing summary scores of strength of support for all candidate hypotheses.
- This kind of scoring scheme was a useful device for showing discrimination among rival hypotheses on the basis of strength of evidence, including *veritas* rankings, in the CBW investigation of Katz and Singer (2007).
- It is by no means restricted to this kind of application.
- Indeed, all of the above steps were tested by Katz and Singer on some of Sir Arthur Conan Doyle's detective stories involving Sherlock Holmes (Doyle 1998), multiple episodes of the television drama series Law & Order, and the evidence base for the Sverdlovsk (Siberia) anthrax attack of 1979 (Guillemin 1999;Wampler and Blanton 2001).

7. The strongest hypothesis identified with our numerical scoring scheme should be further checked for

(a) consistency with the overall state of historical and scientific knowledge about the topic at hand;
(b) satisfying guidelines for causation;
(c) the possibility of satisfying the legal profession criterion "beyond a reasonable doubt."

- The above steps represent one approach to abductive inference that we see as relevant for adding considerable specificity to Implication Analysis.
- The substantial literature on natural language processing covers similar ground and invokes weighted abduction to deal with the *veritas* issues we have discussed above (Hobbs 2006).
- The intelligence investigation setting, and probably many complex sociological inquiries, will not lend themselves quite so readily to the extensive computerization of the expert systems designed for special purposes infields such as molecular biology (Raychaudhuri et al. 2002; Chen and Altman1999).
- However, the exercise of trying to develop computerized systems for abductive inference serves to enforce greater precision of thought about this mode of analysis, and especially to clarify where extensive subjective judgment must inevitably be invoked and where maximal transparency about investigator-based decisions is needed.

Subsequent expert systems focused on medical diagnosis (Shortliffe 1976; Buchanan and Shortliffe 1984; Sager et al. 1994), where we can readily characterize the reasoning of physicians in diagnosing an illness as a process of abduction. The precision of thought in weighing evidence of different types and quality—for example, laboratory assays, narrative patient histories, qualitative appraisal of a patient's physical condition, comparisons with published and archived histories of similar cases—that was forced on computer science people who were developing software as a diagnostic aid served to advance our understanding of abduction. An informative history of the successive stages involved in computerization of abductive inference on a diversity of scientific problems is given in Josephson and Josephson (1994).

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