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DRAFT

Mutually Supporting Evidence in Radiocarbon Dating

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Chapter for a book provisionally titled
The Large-Scale Structure of Inductive Inference

1. Introduction

Consider two ways that we may date artifacts and samples. First, traditional methods of historical analysis and archaeology enable us to date artifacts; and the counting of tree rings enables us to date wood from ancient trees. Second, radiocarbon dating provides another means of dating these samples. What results are two sets of propositions concerning the age of specific artifacts. The first are called “H” (historical) below in Section 4; and the second are called “R” (radiocarbon).

Each type of dating can provide evidence for the other type. That is, relations of support among these two sets of propositions proceed in both directions, analogously to the relations of support among the stones on either side of an arch.

The second type R can support the first type H: If we are interested in checking the historical dating of some artifact, we can send a sample to a radiocarbon laboratory for dating.

The first type H can support the second type R: Radiocarbon dating itself requires empirical calibration to correct for many confounding variables, such as changes in levels of atmospheric carbon 14. Historically dated artifacts and wood dated by tree ring counting can be used in this calibration process. In it, the evidence of these other methods of dating provides evidential support for the recalibrated radiocarbon dating of the samples.

When the two methods agree for some sample, we have support relations passing in both directions. However, the circumstances of the sample may incline us to emphasize only one direction.

Section 2 below will review briefly how radiocarbon dating works; and Section 3 will describe the need for and methods of independent calibration of radiocarbon dating. Finally Section 4 will review how relations of evidential support cross over among the H and R type propositions, using the example of the dating of the shroud of Turing and associated control samples.

To speak just of two mutually supporting methods oversimplifies greatly in the interests of brevity. An appreciation of the richness of the interactions of many lines of evidence employed in radiocarbon dating has been provided by Alison Wylie in several works, including Wylie (2016). For a related analysis of radiometric dating in geology, see Alisa Bokulich (2020).

2. How Radiocarbon Dating Works

Consider some ancient artifact such as a scrap of linen from an Egyptian mummy's wrapping or a thread from a medieval cloak. How are we to know its age? In the 1940s, William Libby hit upon a method so ingenious and important that it earned him the 1960 Nobel Prize in chemistry.[1] These artifacts are all derived from carbon-based plants. These plants derived their carbon from the CO_2 in the atmosphere. Virtually all the atmospheric carbon is the stable isotope ^{12}C, "carbon 12." However, a tiny portion is a radioactively unstable ^{14}C. This tiny portion is decaying exponentially, with clocklike regularity, with a half-life of about 5730 years. That means that after 5730 years, only half the original amount of ^{14}C remains; and after 2x5730 = 11460 years, only a quarter remains; and so on. Wait long enough and near to none remains. Coal, formed from living plants several hundred million years ago, contains virtually no ^{14}C. By these simple calculations, we can determine the age of an artifact from two numbers: the amount of ^{14}C in the artifact at its formation and the amount of ^{14}C in the artifact now.

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[1] An early mention of the method in the journal literature appears in brief closing remarks Anderson, Libby et al. (1947).

The second of these numbers can be determined by laboratory analysis. The first, however, presents a greater challenge. The amount of ^{14}C in the artifact at the time of its formation is fixed by the level of ^{14}C in the atmosphere at that time. The isotope ^{14}C occurs in atmospheric carbon in roughly the ratio of 1 atom of ^{14}C to 10^{12} atoms of ^{12}C.[2] While atmospheric ^{14}C is decaying with the half life of 5730 years, the atmospheric levels are maintained at roughly constant levels through a process that creates new ^{14}C atoms. Cosmic rays strike nitrogen atoms in the atmosphere and convert them to ^{14}C atoms. Since the rate of replenishment rises and falls with the intensity of the cosmic rays impinging on the atmosphere, there is a corresponding movement in the levels of ^{14}C. The ratio of 1 to 10^{12} is a rough estimate of a ratio that varies in time. Many other processes affect this ratio. Some have a large effect. The ratio dropped significantly after 1880 due to the large amounts of carbon-based fossil fuels burnt in the industrial revolution. The ^{14}C in the atmosphere was diluted by essentially ^{14}C free carbon from the fossil fuels. This and other factors have sufficiently disrupted the rate of replenishment that radiocarbon dating of artifacts is practicable only to artifacts older than 300 years.[3]

3. The Need for Calibration

For artifacts older than 300 years, the variability in the atmospheric ^{14}C levels and other factors leads to incorrect dating, commonly an underestimate of the age of the artifact. In the early years of radiocarbon dating, when there were fewer means available to check radiocarbon dating, a thorough analysis of the errors was not possible. Anderson and Libby (1951) collected eighteen months of radiocarbon dating in a report presented as “an overall-check of the method…the main purpose of the research.” As a part of these efforts, they presented the historically known and radiocarbon ages of samples from ancient Egypt (wooden beams from tombs, wood from a funery ship, wood from a mummiform coffin, ancient wheat and barley

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[2] As cited by Key (2001, p. 2338).

[3] These other effects include 17th century rapid changes in solar magnetic intensity and the artificial production of ^{14}C as a result of atmospheric testing in the 20th century. For more details and more general background, see Taylor (1997, p.69).

grains). They reported the radiocarbon ages of samples from many other locations but generally without historically determined ages.

By the 1960s, discrepancies between the radiocarbon and true dates of historical artifacts were becoming apparent. Stuiver and Suess (1966) reported on the accumulation of evidence of the discrepancies. The relationship between the two ages, they stressed, depends upon so many potentially variable factors that it requires an approach other than the theoretical analysis that then gave radiocarbon ages (p. 534):

> This relationship cannot be determined theoretically, but can be derived empirically by determination of the radiocarbon contents of samples of known age.

They reported the existence of samples of known age from old wood, whose age could be determined by the counting of tree rings. They expressed high hopes for samples that would soon be available of bristlecone pine wood that would be more that 6,000 years old. These bristlecone pine wood samples did meet their expectations and now play a central role in determining the relationship they sought.

The corrections needed came to be summarized in calibration curves that map the radiocarbon age of a sample against the sample's true calendar age. The term "radiocarbon age" is a precisely defined term of art in the radiocarbon dating literature. It designates the age indicated by depletion of ^{14}C in the artifact if we make a series of convenient but false stipulations. They include the assumption of the constancy of reservoir ^{14}C levels; an incorrect but formerly used half life of 5568 years; the counting of time from 1950AD as the zero point; and more.[4] Recent calibration data and curves have been provided by Reimer et al. (2013). Figure 1 is a calibration curve plotted from their data for samples created in the northern hemisphere.

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[4] For more details, see Taylor (1997, pp. 67-68).

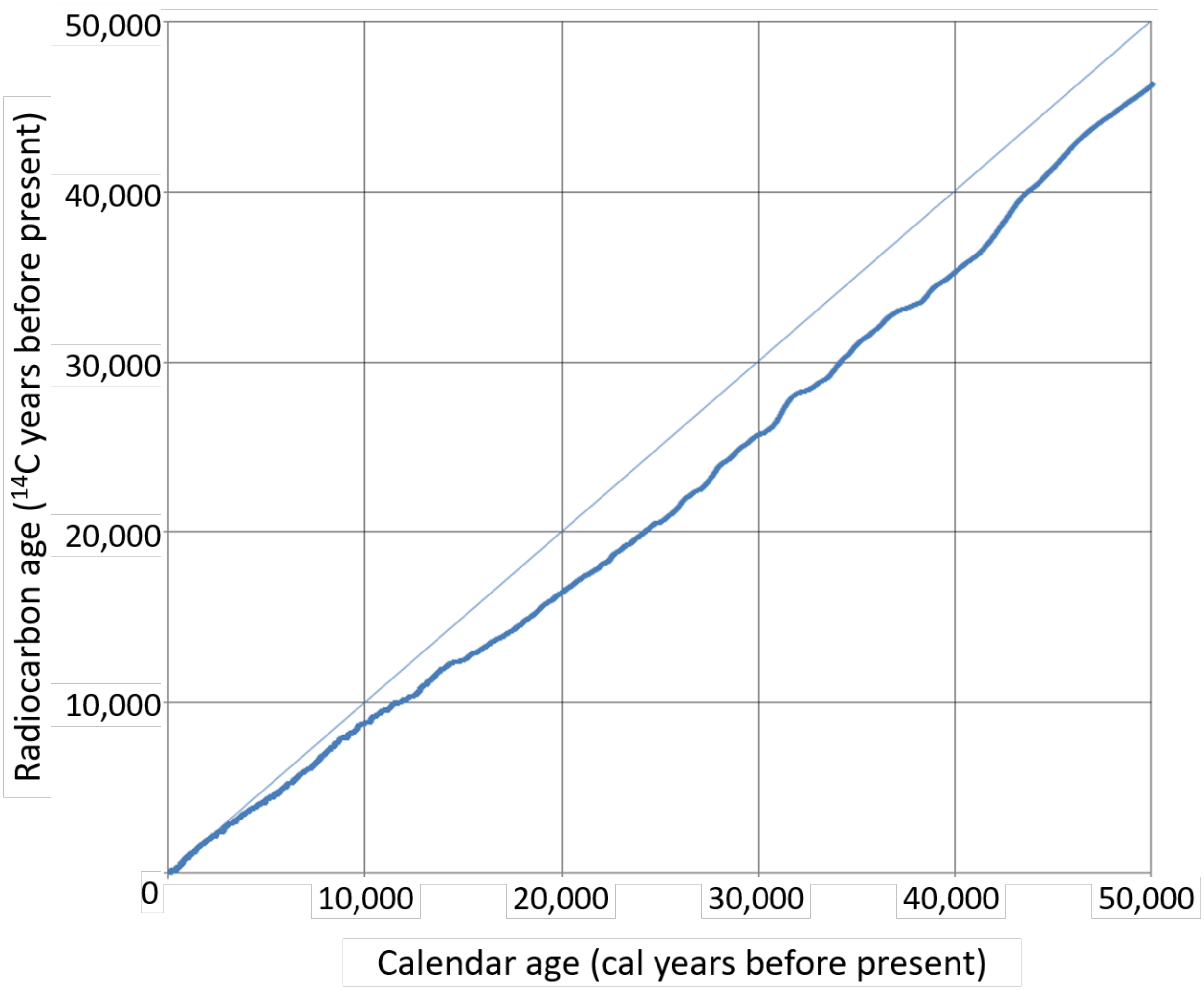

Figure 1. Northern Hemisphere Calibration Curve, IntCal13[5]

The curve shows that radiocarbon age may underestimate the true calendar age by as much as 20%. Once the curve has been used to correct the radiocarbon age, I will call the new age the "recalibrated radiocarbon age."

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[5] This figure is derived from data in Reimer at al. (2013) and is reproduced in conformity with a Creative Commons CC BY-SA 3.0 license granted by the copyright holder at https://en.wikipedia.org/wiki/File:Intcal_13_calibration_curve.png

4. Relations of Evidential Support

The relations of evidential support to be considered here are between two types of propositions:

H: The historically determined age of a designated sample is the true age.

R: The recalibrated radiocarbon age of a designated sample is the true age.

Here "historically determined" indicates that dating was carried out by the traditional methods of history, archaeology and dendrochronology (tree ring dating), excluding radiocarbon methods.

So far, we have seen that propositions of type H are used to give evidential support to propositions of type R. Indeed, propositions of type H are used to construct the calibration curves that recalibrate the propositions of type R. Thus, they provide the evidential support for the correctness of the recalibrated ages.

However, the relations of evidential support can be reversed. Propositions of type R can support those of type H. We may become uncertain over the dating ascribed to some sample in a proposition of type H. Perhaps we become unsure of the archaeological dating of 4650 +/- 75 years of the acacia wood beam from the tomb of Zoser at Sakkara, listed in Arnold and Libby (1951, p. 111). We can use the recalibrated radiocarbon dating of samples from it to reaffirm its archaeological dating.

An interesting, concrete example of the crossing over of relations of support between the two types of propositions is provided by the radiocarbon dating of the shroud of Turin. As most people know, the shroud bears front and rear impressions of someone with injuries compatible with crucifixion. It is purported to be the burial shroud of Jesus. However, it did not appear on public display until the 1350s. In a careful series of tests reported in Damon et al. (1989), samples of the shroud were sent to three laboratories. In a failed effort to blind the tests, three control samples were also sent to each laboratory. The results showed agreement among the three laboratories for dating of all the samples. They concluded with 95% confidence that the linen of the shroud was created from flax grown sometime in 1260-1390 AD.

The crossing over of relations of inductive support arose in the context of the three control samples. They were:

Sample 2. Linen from a tomb excavated at Qasr Ibrîm. Dated by embroidery pattern and Christian ink inscription to the eleventh and twelfth centuries.

Sample 3. Linen from an early second century AD mummy of Cleopatra from Thebes. Radiocarbon dated to 110 BC – 75 AD at 68% confidence.[6]

Sample 4. Threads from the cope of St Louis d'Anjou. Dated by stylistic and historical evidence to 1290 – 1310 AD.

These three samples are dated by H-type propositions and then also by R-type propositions from the three independent laboratories. Since the dating of all samples agree in both types of propositions, we can read the relations of support in each case as passing in both directions.

The intended direction for the calibration of the laboratories is that the H-proposition dating of the samples provides evidential support for the laboratories' R-proposition dating. However, we can equally choose to read the evidential support as proceeding in the opposite direction: if there was any doubt over the dating of the three control samples, the radiocarbon dating of them by the three independent laboratories affirms their correctness. That is, the R-propositions are providing evidential support for the H-proposition.

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[6] Damon et al. (1989) indicate only a radiocarbon dating for the sample. However the description of the artifact at the British Museum also indicates an historical dating. The mummified body is of "Cleopatra, daughter of Candace, a member of the family of Cornelius Pollius, Archon of Thebes in the time of the Emperor Trajan." Trajan's reign 53-98 AD overlaps with the interval provided by radiocarbon dating. http://www.britishmuseum.org/research/collection_online/collection_object_details.aspx?objectId=124280&partId=1&images=true

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