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Computational thinking: a case study of Buddhist terminology using new software

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With the advent of digital technology, there are radical changes sweeping through disciplines that cannot be resisted. It is part of this shift that is described by the term "Computational Thinking". It is defined as the scholarly strategy of thinking at multiple levels of abstraction with the added use of the capacity of the computer to count and analyze complexity. As an example of "Computational Thinking", I have used the digitized Korean version of the Chinese Buddhist canon, to explore an important term 本覺. The expression is usually translated as "Original Enlightenment" and is a major doctrinal teaching in East Asia. The analytic computation of the canon is further enhanced by the metadata tag of time, the purported date of translation. Providing temporal aspects to the computation gives us invaluable ways of analysis that would not be possible without the dating. The computation provides a glimpse of the history of the occurrences.

Keywords: computational thinking; Buddhist canon; digital technology

A new term has come into vogue among scholars – "Computational Thinking".[1] It is defined as the scholarly strategy of thinking at multiple levels of abstraction with the added use of the capacity of the computer to count and analyze complexity. In the Humanities, there is resistance to quantitative methods since the historic role of the field has been to work only with qualitative strategies. "Computational Thinking" might be described as one way to have an interactive continuum that uses both quantitative and qualitative approaches. There are weighty issues at stake here and scholarship is an ever shifting array of constructs that require long and detailed examination. For very good reasons, much of this discourse will be missing in the following remarks that describe the exploration of one grounded theory.

In order to set the context for the approach presented here, it is important to provide a biographical narrative of the process. In 2010, three members at the University of California, Berkeley, were given a "challenge" grant by Coleman Fung,[2] who had already been involved in research support through the establishment of centers of research on the campus.[3] For his challenge, he selected three faculty members representing different fields of research that are usually quite removed from one another. Professor Michael Buckland from the School of Information has a long career in the library world and issues of reference development and use.[4] The second member was Professor Michael Frenklach of the College of Engineering with a specialization in combustion research.[5] My own area is in textual study of the Buddhist canons, especially the Chinese language versions.[6] We were challenged to find out if there was a single software solution that could apply effectively to the research of all three of us. In essence, Coleman Fung asked if it was possible to have a synthesis of qualitative and quantitative studies that could be translated

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into a single computerized program. As we began our deliberations, it soon became apparent that we faced a massive task, intricate and complicated. As we pondered on our various approaches and tried to consider them from all angles so that nothing of importance would escape us, the hoped-for solution remained elusive and the months turned into several years. We almost despaired and began to wonder if the goal could ever be achieved by the means at hand. However, by this time, we recognized the importance of the task and persevered. A major milestone was reached when we decided that the goal was highly possible and practicable. We still had to develop the concrete ways and means. That process continues and we have sought for corporate help[7] as we create the final "platform" that can provide new ways of dealing with the needs of all three as well as to a wide range of disciplinary fields.

In the work reported below, there is a description of my attempt to bring one aspect of current research in textual study to a point that would profit from the analytic software of Professor Frenklach, dealing with combustion laboratory results.[8] His software is based on the relationship between variables. It is able to make a "prediction" of the results of changing variables without having to resort to long and expensive laboratory procedures. The "prediction" is based, in part, on being able to search reports found in the published works of the field and use that data to determine what might be expected from changing a variable in a combustion experiment, such as heat, pressure, or chemical. In one sense, this is a prediction of the "future", "...if I make a different arrangement of variables what will result?". At first glance, this function would seem to be of little use in my case because the textual data that I use is complete and has been so for nearly 800 years. It all happened in the past and my research is not predicated on the "future" of canonic material. Eventually, I came upon the idea of reversing the software function and using it to predict the "past" rather than the "future". Can we look back in time across a textual corpus with variables that can be used in the same fashion as PrIMe now does with combustion for the future? If so, what would constitute "predictions" of the past? To answer this, I began to experiment with simple searches for word occurrence. Are there examples of occurrence that are not logical? Finding instances of anomalies would constitute one illustration of "predicting" the past, i.e. "... this pattern of word occurrence would not have been possible...".

In order to have some verification of using computation to "predict" the past, I began to explore the limits of what can be discovered by using this approach with ancient texts. In the work reported below, two Chinese characters (glyphs) 本 and 覺 are studied using computation limited to one data set. The research attempts to find out how much we can know about these two glyphs through such a method and later compare the results with the more traditional approaches reported in the published literature of the field. The data is contained in a digital version of the Chinese Buddhist canon preserved on thirteenth century printing blocks in Korea.[9] There are over 83,000 of these blocks, most carved on both sides so that we have the equivalent of 166,000 printed pages when impressions are made. The whole of the written material is comprised of 52 million Chinese characters found in 1514 texts. The digital version of this version was an early attempt to produce large sets of data in the new technology. It took nearly 10 years (1988–1998) to plan, execute, proof, and finally place the information on a CD ROM and eventually on the internet.

In the past, scholars have approached a corpus such as the Korean canon through references in the form of catalogs, dictionaries, glossaries, concordances, and bibliographies. Academic training focuses on learning how to follow certain procedural steps. For the Humanities, a crucial task of research is contingent on codex collections of data. The

use of these data is often directed by library reference assistance. However, in the digital age where thousands or even millions of data are available, these former methods have begun to falter. Today we can go directly to the data without the intermediate step of consulting collateral documents. There are inherent dangers in this unmediated connection to the material. Without the considered judgment of the compilers of reference works, how are we to verify the accuracy of retrieved information? One possible solution to this query is to determine if we can use computation of the data itself to determine its accuracy.

In many ways, the notations given in most scholarly articles and translations are anecdotal in nature rather than complete inventories of occurrences and statements. That is, such notations in essence, "say" to the reader:

> . . .during the event of my search for examples, I came across the following ones. It is impossible to find all of the examples but I judge that mine are sufficient to make a valid statement about the nature of the material. . .

Unfortunately, an anecdotal report of our process, often leaves us without a clear picture of how our "found" examples may be understood in relationship to the entire corpus. In the past, this was often the best a scholar could achieve, since the task of going through thousands of pages finding every occurrence of a term had diminishing value given the time that would be required to accomplish such a feat. Today, a researcher is faced with the fact that in many cases, the computer can provide an immediate full report of every occurrence of a word, even though the count reaches into the thousands. While the completeness of the search is welcomed, the size of the resulting report creates new and non-trivial challenges.

This type of research, currently being opened to the digital technology, has been little changed in the field of Buddhist Studies since the nineteenth century. Even though scholars have a new digital format available, the use of "Computational Thinking" has been slow in coming. As one of the organizers of the input project for the Buddhist texts, I believe that there is a need to provide examples of "Computational Thinking" in order to encourage scholars to use the new technology to its fullest potential. With this in mind, I have been publishing reports, giving lectures, and exploring further developments of how these data can be used effectively and efficiently. This article is one way of sharing some of the findings outside the field of Buddhist studies.

As an example of "Computational Thinking", I have used the digitized Korean version of the Chinese Buddhist canon described above, to explore an important term 本覺.[10] The expression is usually translated as "Original Enlightenment" and is a major doctrinal teaching in East Asia. Previous studies have been used as "ground truth" for the findings based on computation alone.[11] The current work flow approaches this from a very different method. Since the whole of the data is over 160,000 pages, and represents 1514 different texts, it is not surprising that no one has gone manually page by page to make a complete count of occurrences. Of even greater import is that no scholar has even raised the issue about lacking a complete inventory of the places where the term is found. Having a full digital version of the thousands of pages gives us the easy option of "counting" with a full report available in seconds. While such computation is now within our grasp, the report from the computer still leaves us with questions.[12]

The very first information from computation is count of the total number of times that the glyphs 本 and 覺 appear adjacent to one another. Our software reports that this arrangement happens 763 times. In order to deal with the simple word count, our software

also provides the information that the two glyphs are adjacent to one another in 28 of the 1514 texts. This is further refined by showing that this number of texts (28) represents about 2% of the total (1514). While the search is for the places where the two glyphs come together, the count for each one individually is also important. Next the count shows the following information:

本覺 763 hits compared to
本 by itself 71,833
覺 by itself 69,527

The adjacent occurrence (763) is less than half of 1% of the separate individual examples of the glyphs that form the compound (71,833/69,527). At this point, the researcher has more data than has ever been available for consideration. If the adjacent string of the two glyphs appears in only 2% of the texts and the combination of the two is less than half of 1% of the times when the single glyphs appear, we now know that 本覺 is a specialized term that has limited range in the canon.

The analytic computation of the canon is further enhanced by the metadata tag of time, the purported date of translation. Providing temporal aspects to the computation gives us invaluable ways of analysis that would not be possible without the dating. Now the computation provides a glimpse of the history of the occurrences. The software takes the very complex configurations of time and texts and presents the findings in an easy-to-read timeline image (Figure 1).

This is a profile of word occurrence based on number of occurrences at any given period of time. Since every word has such a profile, it is now possible to search for profile as well as occurrence. After doing a pattern search in nearby glyphs, the "software" makes a discovery that changes the workflow. There is a profile match with another term 始覺. The two terms march side by side in a surprising profile match as shown in Figure 2.

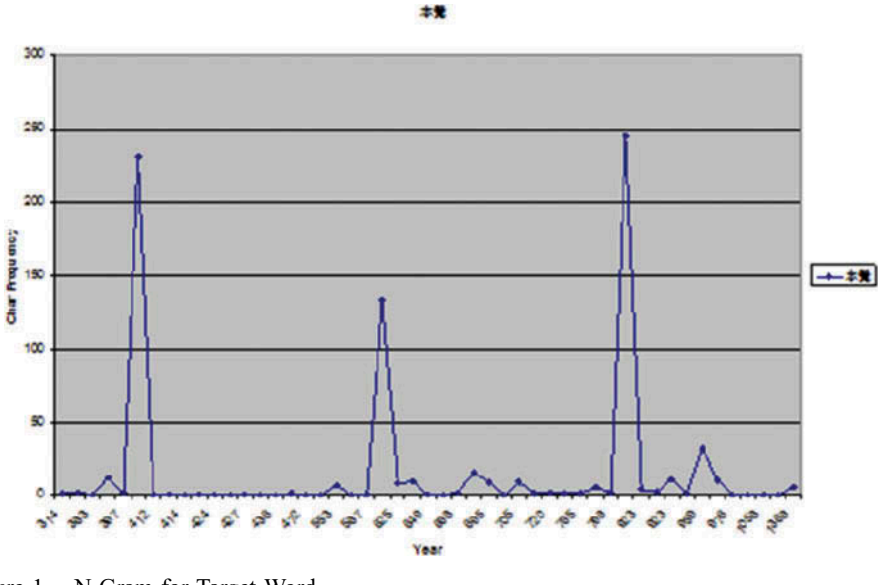

Figure 1. N-Gram for Target Word.

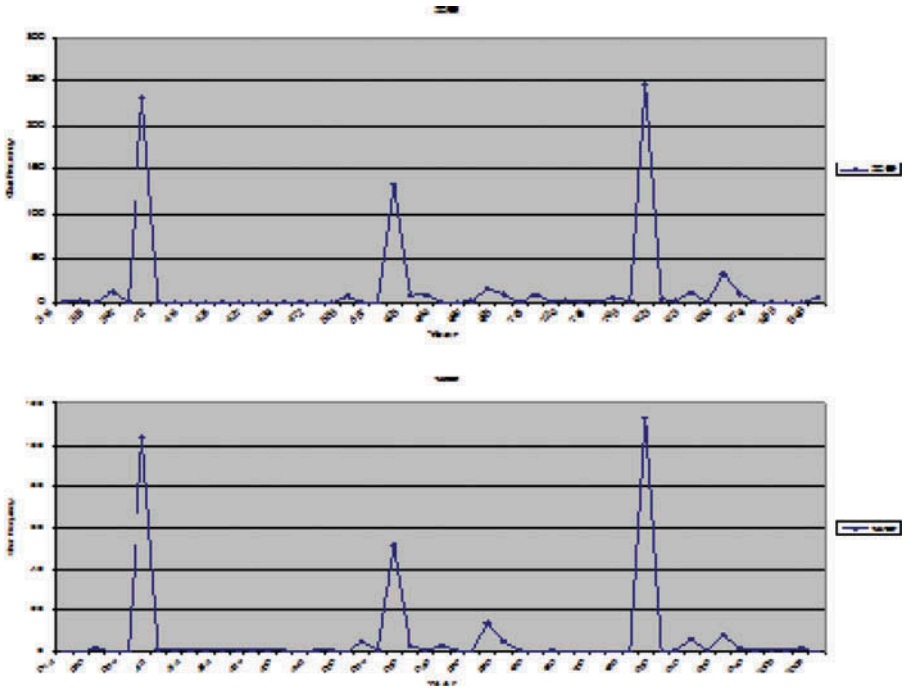

Figure 2. N-Gram for Target Word and Companion Word.

The ability to create a profile for a word gives us a "variable" that can be used to determine connections between the vocabulary in a text or in the whole set of data.

A further issue is raised by the search result. Given the information that the two glyphs appear independently tens of thousands of time, how can we know if the adjacent occurrence is always our target compound. It is very possible that the two are together in a variety of meanings and grammatical use. Can computation be used to solve this problem? Below, we consider several of the earliest examples of the two glyphs beside one another and use "counting" to see what the relationship between them might be.

Our first example comes from K. 186,[13] said to have been translated on 28 January 314 CE. It is a text attributed to the well-known translator Dharmarakṣa. If the compound 本覺 is found this early, it would give substance to the assertion that it is an ancient expression in Buddhism and belongs to an Indic origin, even though no Sanskrit equivalent has yet been found.

The sentence being put through the software is:

如來覺了意則無本覺了

The two glyphs 本 and 覺 are adjacent to one another and the usual word search will note this occurrence and it is part of the report of 763 "hits" for the "word". Without "reading" and without attaching any meaning to the glyphs, can the computer give us a report about the relationship between the two?

One method to solve this question by only using computation is to have the software search for the first character in our target compound 本 along with the glyph that precedes it, in the case of our phrase, 無. Thus a search is made for 無本. The second character is

subject to a separate search combined with the glyph that follows it 覺了. The result of the three searches is as follows:

本覺 = 763
無本 = 707
覺了 = 1039

The computer count indicates that there is a probability that this occurrence of adjacency is not our target word since 覺 and 了 appear twice in the phrase and in addition this combination is more used throughout the data (1039 times) than the two adjacent characters 本 and 覺 (763 times). In order to check on the accuracy of the prediction made by the computer, we can now read the phrase and analyze it from the point of view of meaning and interpretation.

如來覺了意則無本覺了

Here the first use of 覺了 represents a verb with the attendant particle to indicate that the action is completed or in the past tense. A similar example occurs four characters later. It would appear to be a denial of the teaching about 本覺 to take it as a compound since the negative 無 preceding it would read:

The Tathagata has realized that the mind consequently is lacking Original Enlightenment. . ..

If this were the case, there would be no need to discuss 本覺 further. However, based on the prediction of the computer computation, we see that the sentence can be read differently. The alternate translation would be:

The Tathagata has realized that the mind consequently lacks any basis and (he also) realized . . ..

The grammar would be:

如來 (subject) 覺了 (verb in perfected tense) 意 (object) 則無 (temporal/verbal) 本 (object) 覺了 (verb with subject understood to be previously stated (如來).
如來覺了意則無本. . .(如來). . ..覺了

If this is a correct interpretation of the use of the adjacent glyphs, then 本覺 is not a compound but the placement of two characters next to one another with each having a separate grammatical function. The "software" has correctly predicted that in this phrase, 如來覺了意則無本覺了, the adjacent glyphs 本覺 are not a compound in themselves but simply members of two other compounds. Computation was able to detect the subtle issue of glyph combinations within a sentence.

Another of the early dated adjacent glyphs is found in K. 951, a translation attributed to Buddhavarman and dated from 437 to 439 CE.[14]

以彼地有言語根本覺觀法故

The search for glyph occurrence provides the following report:

根本 = 7427
覺觀 = 2515
本覺 = 763

It is not a surprise that the software "predicts" that it is unlikely that 本覺 is a word in the phrase. Rather, we can see that the phrase would be better parsed as follows.

以彼地有言語.....根本.....覺觀,,,,,法故

The software has applied the principle of looking at variables. When we apply the variable of shifting the search from our target word to the adjacent compound candidates, the logic of mathematics predicts that 本覺 is not the target word.

We can note in the clustering of text by date of translation given in the catalogs that there are two periods of no recorded use of the adjacent glyphs. That is from 553 to 635 CE and from 798 to 904 CE. It is just as important to note the lack of occurrence as to record examples of them. The first temporal hiatus is made more impressive when we note that except for one text in 553 CE, there was no example found after 439 CE until regular appearance seems to "resume" in 635 CE. This means that with one exception, our target word or adjacent position of the two glyphs disappeared from the corpus for nearly two centuries from 439 CE to 635 CE. It is hard to explain why a word would have been so popular in the fifth century and then fade from the texts only to reoccur in large numbers centuries later. Having found the profile from the purported dating, the software uses the variable of time to identify an apparent anomaly: "... large numbers of instances of use followed by centuries of no mention...". The result of this discovery is the possible suggestion that the texts have been mis-dated and if so, it is crucial to our historical research to take this into account. Context that involves history of appearance, occurrence, and shifts over time is now within the range of the computer capability for the Chinese Buddhist canon.

Next, we have an example where computation fails to spot the nature of the grammar. Here, it is important to have some description of how the texts in the canon came into existence. The translation of Buddhist material originating in India and Central Asia into Chinese started in the second century and continued for over 1000 years.[15] The process of transferring thousands of pages of texts from one language family to another still ranks as one of the outstanding achievements of linguistic, religious, and cultural expression. It was a difficult linguistic exercise because it involved languages that differed from one another in history and formation.[16] On the one hand, we have the highly inflected Indic texts being translated into Chinese where, for example, there was no number, no gender, and placement was a primary method of expressing grammatical syntax. We are still not certain of the details of the Indic texts that were coming into China from the Western regions. While they did represent the so-called Indo-European forms, it is not enough to simply say that the texts were in Sanskrit. Some of them may well have been in Gandhari or other Central Asian languages.[17] The material arrived in East Asia as either oral remembrances of the missionary monks or as written texts on birchbark and palm leaves. This meant that since a number of translations may have been made from recitations rather than written texts, phonology had a role and a complexity that matched the variety of grammatical forms. Many had Prakrit formations of word pronunciation. In a number of examples from the second century texts, one can identify sounds that belong to Middle Indic rather than later Sanskrit. Over time and in different regions, Chinese characters had a variety of shifting sounds. Thus, the work of reviewing the phonological issues of the

Chinese texts that were being produced is as complex as the sound shifts in the Indic languages and dialects. Added to these extremely challenging aspects of the translations was the fact that in the early days of the translation bureaus, there were no dictionaries or even word lists to aid the process. Having consistent equivalents was a major hurdle without reference works and models.

We have received Sanskrit texts for some of those appearing in the Chinese canon. These received texts often show late additions and changes. In some cases, it is archaeological discoveries that provide examples of the oldest witnesses in both ancient Indic language manuscripts as well as Chinese versions. From these textual witnesses, it is possible to note the changing readings over the centuries. Looking at a tenth century Sanskrit manuscript in India for a comparison with a fifth century Chinese translation of the same text shows that the late Sanskrit has been significantly altered over the centuries. Thus, it is incorrect to imply that the tenth century Sanskrit manuscript represents the autograph and can be assumed to be an example of the "original" text. Even the Chinese translations were often copied and recopied with inadvertent errors and changes, so that it is difficult to reconstruct the exact readings for the autograph for the translation much less for the older Indic version. The very idea of an autograph for a Buddhist text that can be reconstructed from the available witnesses in multiple languages may be a mistake.[18] These documents were produced over a long period of time and at distant locations. Rather than a stemma that leads back to an autograph, we have a systemic model where multiple streams of discourse have intermingled and determining which is the oldest or best or closest to the original intent is task beyond our present ability (Nattier 2008).

Given the multitude of problematic readings, the task of a contemporary translator is filled with non-trivial issues. Some form of reconstruction of the process of translation is necessary to understand the meaning of passages. Perhaps it is better to say "rendering" into a partial Chinese rather than assuming that we are looking at true translations of meaning. There are many places where the arrangement of the characters cannot be explained by the syntax of classical Chinese.

In order to give a clear example of how complex the "translation" work , one text offers us insight into the puzzling arrangements of characters. In the Sui dynasty, colophons and ancient catalogs identify an Indian monk named Dharmagupta as the "translator" of a rendition of the *Vajracchedikāprajñāpāramitāsūtra*, best known by its English title as the *Diamond Sutra*.[19] It is a peculiar translation that is like no other in the canon. The work is a strange mixture of elements that are sometimes in the familiar Chinese style for Buddhist translations and other parts that are inexplicable by any known grammatical rules. For example we find the phrase[20]:

聞者遊行勝林中

One is tempted to take 聞者 as a subject of the sentence; 遊行 as the verb; and 勝林 as the object of the verb with the final 中 as a difficult element but understood as location.

A literal and awkward translation might be something like "The hearer moves about in the middle of the Victory Grove".

If we ask the software to do computation on the use of the terms, it would verify that there are three well-established "words" in the string. For example, the number of hits for them is sizable:

聞者 (Noun) = 2210
遊行(Verb) = 2655

勝林 (Place) = 164

In this case, a count of the string of characters does not give us the correct meaning. When we compare this phrase with the Sanskrit, we can see that the characters are literal translations of the Sanskrit words placed in the exact order of the Indic text and having no relationship to Chinese grammar. When matched with the Sanskrit, we find the following meanings:

聞者 = Śrāvastī

This is the name of a city where the Buddha spent time during his career as a teacher (Chandra 1977, 17). If one analyses the compound, it is made up of two words:

(1) Śrāva
Coming from the root *śru* "to listen", "to hear".
Hence the character 聞
(2) Astī
Based on the root *as* "to be" "to live"
Hence the character 者

Here the name of *Śrāvastī* has not been translated but the word has been analyzed for its root to stem structure. There is no way that analysis from an algorithm could currently discover this usage since the phrase 聞者 appears 2210 times in the canonic texts and seems in every other case to mean "the one who hears".

The remaining words in the string are more easily understood by normal usage:

遊行 = vihara

Living, dwelling (moving about in)

勝林 = Jetavana[21] Grove (vana) of Prince Jeta[22] (the victorious).

中 = in or at location. In this case, the glyph is used in the final position to equal the suffix marker "e" for the locative case ending in Sanskrit.

The meaning from this comparison is

(the Buddha) was in Śrāvastī staying in Jetavana.

Problems such as this remind us that the qualitative approach is as needed as the quantitative counts. That is why we must seek for some form of an interactive continuum between the two strategies.

From the examples given above, we can begin to understand that the way in which we deal with abstractions in our study takes on a new look when we add computation that involves accurate information based on the whole of a data set. That is why this type of "thinking" must be linked to the new technology that can process digital data. Centuries ago, written texts in printed format brought about a new development of Humanities scholarship in Europe with certain patterns of thinking being determined by the codex format. With the advent of digital technology, there are radical changes sweeping through disciplines that cannot be resisted. It is part of this shift that is

described by the term "Computational Thinking". The challenge of Coleman Fung is still unmet, but increments of the solution are being enabled as we determine what is suitable for our purpose and what is appropriate if we are to accomplish our goal. The Buddhist canonic literature provides a rich source of linguistic information which can be now accessed with greater precision and the future promises even more improvements to our digital usage.

Notes

1. The term is attributed to Seymour Papert and used in Seymour Papert (1993, 182). For a detailed discussion of issues, see the report of a meeting held in February 2010 (Committee for the Workshops on Computational Thinking; National Research Council 2011).
2. His profile can be found at: investing.businessweek.com/research/stocks/private/person.asp? (last accessed December, 2013).
3. Coleman Fung Institute of Engineering Leadership, Coleman Fung Risk Management Research Center, and the Fung Center and C.V. Starr East Asian Library.
4. See a listing of his work at http://www.ischool.berkeley.edu/~buckland (last accessed December, 2013).
5. http://www.me.berkeley.edu/faculty/frenklach/ (last accessed December, 2013).
6. See buddhiststudies.berkeley.edu/people/faculty_profiles.html (last accessed December, 2013) for a brief description of my work.
7. Support and strategic planning have been provided by YuniQX corporation operated by Roger Frank and Jonathan Strum.
8. A description of PrIMe (Process Informatics Model) appears at http://www.primekinetics.org (last accessed December, 2013). See also a description in Gorbau and Roose (2010).
9. See http://kb.sutra.re.kr/ritk_eng/index.do (last accessed December, 2013) for a description of the collection and the process of digitization.
10. This follows up on a lecture that I gave more than two decades ago under the title of "The Question of Aprocryphal Words in the Chinese Buddhist Texts" at the Annual Meeting of the American Academy of Religions, November 8, 1986, in Atlanta. I suggested that the term 本覺 should be considered "apocryphal" since no Sanskrit equivalent could be determined.
11. Note that the publication of Stone (1999) contains bibliography and description of the studies of this topic in Japan and elsewhere. See the work of Buswell (2008). A review of the book by Charles Muller is found at: http://www.acmuller.net/reviews/cultivating_original_enlightenment.html (last access January, 2009) originally published in the International Journal of Buddhist Thought and Culture, Vol. 10, February 2008.
12. The information presented here has been gathered through a software interface developed at University of California, Berkeley by team members Lewis Lancaster, Howie Lan and Ping Auyeung. A two-year grant of support (2007–2009) was given by the National Science Foundation for the development of this tool.
13. 佛說大淨法門經 K. 186/T. 817 *Maňjuśrīvikrīditasūtra.*
14. 阿毘曇毘婆沙論 (K. 951/T. 1546-161a:1) *Abhidharmavibhāṣāśastra.*
15. For a discussion of this see Chan (2009).
16. An interesting (and amusing) discussion is found at: languagelog.ldc.upenn.edu/nll/?p=6931 (last accessed December, 2013).
17. See Berkwitz (2010, 50). Also a position taken in Boucher (2008, 102).
18. The development of critical text editing based on the search for an original reading has dominated Biblical scholarship, see Kloppenborg and Newman (2012, 106). This approach seldom works with Buddhist materials.
19. 金剛能斷般若波羅蜜經 T.238. This text does not appear in the Korean version.
20. T. 238:0766c18.
21. See description in Gautam (2007).
22. Information can be found in Buswell and Lopez (2013, 383).

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