

The Search for HMAS Sydney II: Analysis and Integration of Survivor Reports

JOHN C. DUNN^{1*} and KIM KIRSNER²

¹University of Adelaide, Australia

²University of Western Australia, Australia

Summary: We describe a novel application of cognitive psychology to the search for HMAS Sydney II and HSK Kormoran. Both ships sank off the west coast of Australia following an engagement during World War II. Tragically and mysteriously, there were no survivors from Sydney and, despite considerable interest in locating both ships, their positions remained unknown until their discovery in March 2008. The main evidence regarding the location of both ships consisted of reports by the German survivors from Kormoran. Working with the Finding Sydney Foundation, the group that ultimately found the ships, we developed a method to extract relevant information from these reports and to integrate it with other physical information and used this method to correctly identify the location of Kormoran to within 5 km. We describe this method and discuss the unique role played by cognitive psychology in solving a previously intractable problem. Copyright © 2010 John Wiley & Sons, Ltd.

On 16 March 2008, following a multi-million dollar search conducted by the Finding Sydney Foundation (FSF)¹, the wreck of the Australian light cruiser HMAS Sydney II was discovered in deep water off the west coast of Australia, approximately 300 km south-west of Carnarvon. This event brought to a close an enduring mystery from the Second World War that began early on the evening of 19 November 1941 when Sydney engaged in a firefight with a German raider, HSK Kormoran. In the aftermath of this battle, both ships were lost. Kormoran was scuttled by its crew, of whom 317 survived. Sydney, last seen drifting to the south, sank without trace and, tragically, there were no survivors—all 645 officers and men perished². The events surrounding the battle and the reasons why Sydney was lost with all hands had never been satisfactorily resolved and, following the discovery of both ships, was the subject of a recently completed Australian Government Inquiry³. Until March 2008, the locations of the two ships had also remained a mystery despite numerous attempts to locate them based on the relatively scant information that was available. The successful discovery of Sydney was announced by the Prime Minister of Australia within hours of being notified and became front-page news throughout Australia. Although the loss of Sydney had occurred over 60 years before, the event had left a deep scar in many Australian's lives. Following its discovery, there was an outpouring of relief from wives, relatives and descendents of the men who had disappeared suddenly and without trace.

The search for Sydney consisted of two phases. The first phase consisted of finding Kormoran. Since Sydney had left almost no physical trace and there was at least some

information concerning the location of Kormoran, it was generally agreed that, in order to find Sydney, Kormoran would have to be found first. If and when Kormoran was found, the second phase—the search for Sydney itself—could be initiated as there was good evidence of the relative bearing and distance of Sydney with respect to Kormoran⁴. Figure 1 shows the positions of both ships as revealed by the successful 2008 search.

Our involvement in the search for Sydney began in 1991 when one of us, Kim Kirsner, organized a workshop of relevant scientists to discuss the feasibility of a search for Kormoran and thence Sydney (McCarthy & Kirsner, 1991). It emerged from this workshop that locating Kormoran would depend critically upon the testimony of the German survivors who had been interrogated by Australian Army Intelligence officers in the weeks following the battle. However, the analysis of these reports was unlikely to be straightforward as much of this testimony was uncertain, fragmentary and open to alternative and often contradictory interpretations. The aim of the present paper is to outline how we approached this problem using the perspectives offered by cognitive psychology and how we used the results of our analysis to identify a feasible search area and, within that area, the most likely location of this ship. As it transpired, these results proved remarkably accurate. Working with FSF over the period 2003–2005, we proposed that Kormoran lay on or about 26°07'S 111°02'E. Nearly 4 years later, FSF had raised sufficient funds to undertake a search and Kormoran was quickly discovered at 26°05'49"S 111°04'27"E⁵, approximately 5 km from the point we had specified.

BACKGROUND

In the days following the battle, all of the Kormoran survivors were captured either while still at sea in life rafts or on land after having successfully reached the coast of Western Australia. Over the weeks that followed, the

*Correspondence to: John C. Dunn, School of Psychology, University of Adelaide, SA 5005, Australia. E-mail: john.c.dunn@adelaide.edu.au

¹FSF is a not-for-profit organization established in 2003 with the aim of identifying a feasible search area for both *Kormoran* and *Sydney*, raising sufficient funds to mount such a search, and then organizing and conducting the search for both ships. It evolved from the previously established HMAS Sydney Search Pty Ltd (HMA3S) that was incorporated in 2001 and appointed Trustee for FSF in 2003.

²This figure also includes six persons from the Royal Australian Air Force.

³Australian Government Department of Defence, HMAS Sydney II Commission of Inquiry (2008; <http://www.defence.gov.au/Sydneyii/index.htm>).

⁴When interrogated a few days after the battle, *Kormoran*'s captain Theodor Detmers is quoted as saying that 'HMAS Sydney last seen turning behind smoke screen bearing 153°, 5 miles from raider and steering South 5 knots' [National Archives of Australia (WA): K997, 1/15/2].

⁵See the Finding Sydney Foundation website:

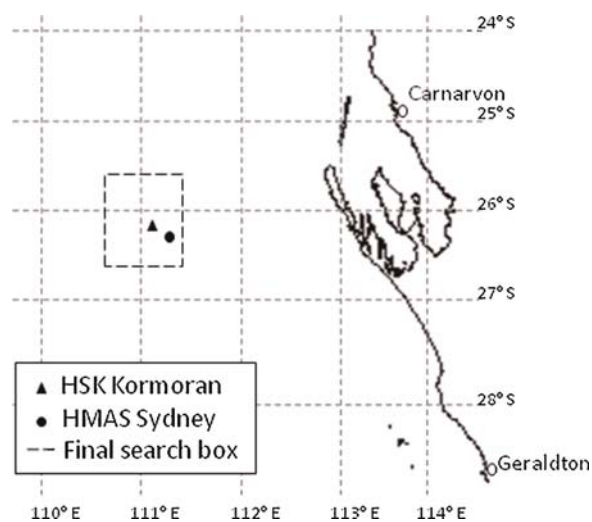


Figure 1. The locations of HSK Kormoran and HMAS Sydney II in relation to the coast of Western Australia. The filled black triangle indicates the true location of Kormoran and the filled black circle indicates the true location of Sydney. Dashed rectangle shows search box used by FSF in the successful 2008 search

survivors were interrogated by members of the Australian Armed Forces. Records of these interviews are held in the National Archive of Australia and contain over 70 references to the location of Kormoran. However, many of these references are cursory since the interrogators at the time were more interested in the events surrounding the battle itself rather than the question of location since, by the time that most of the interrogations were conducted, there was no longer any hope of rescuing survivors from Sydney.

Over the period of more than the 60 years since the battle, numerous attempts had been made to locate Kormoran based on the survivor reports and other known facts (e.g. Frame, 1993; Montgomery, 1981; Olson, 2000; Olsen & Hore, 2001; Winter, 1991). In these attempts, most attention had been paid to the Kormoran Captain, Theodor Detmers and to the position he offered during his interrogation and subsequently reiterated by him in a book he wrote after the war (Detmers, 1959). This position, subsequently referred to as the 'Detmers position' was 26°32'S 111°E which, while in the vicinity of the action, subsequently proved to be nearly 50 km south of the actual location. Although this error was obviously not known at the time, the veracity of this one piece of evidence was open to question. Three possibilities were discussed. The first was the suggestion that this position may only be approximately correct since it is based on the imperfect recall of a single individual (Winter, 1991). The second was that, due to faulty recall, it may represent a misattribution of another position entirely (Olsen & Hore, 2001). The third view was that it may represent an exercise in deliberate disinformation (Frame, 1993).

A further reason for questioning the Detmers position is that it was only broadly consistent with the testimony of other survivors, many of whom placed either the action, or the initial sighting of Sydney, at 26°S 111°E. While this could be considered a rounding error, the distance between these two points is nearly 60 km and demonstrates the level of uncertainty attached to all of the reports. Other survivors

described the location of the action in terms of its distance to the coast or to specific landmarks. Yet, since these reports varied widely, there appeared no obvious way of making much sense of them. The level of disparity and contradiction also fuelled suspicion that some or all of the survivors, including the captain, may have been spreading deliberate misinformation. Such suspicion was further complicated by later speculation of the involvement of a hostile submarine, possibly Japanese⁶ (Montgomery, 1981).

Despite the suspicion and uncertainty that surrounded the testimony of the Kormoran survivors, we believed that it was one of the few sources of information concerning the likely location of both Kormoran and Sydney. For this reason, we undertook a detailed analysis of these records in order to define a feasible search area.

ANALYSIS

We approached the analysis of the survivor reports as a problem of how information is stored and transmitted by people and how it might, through that process, become distorted or degraded. Because of the technical nature of location information, it is likely that the original source material was known to relatively few people such as the captain, the navigator and the signals operator, and that this material, or versions of it, was communicated to other survivors either directly and indirectly through a network of individuals over the period of time leading up to individual interrogations. We proposed therefore that the set of survivor reports may be viewed as variants of a relatively small number of original location statements that we called source statements. Our analysis of the reports consisted of three stages. First, given the controversial nature of the survivor reports, we needed to show that the observed variation could be attributed to the distortion of relatively few source statements due to inter-individual communication and intra-individual memory. Second, we attempted to identify these source statements and, third, to use them to define a feasible search area for Kormoran.

The effect of memory on information transmission

The manner in which information changes during its transmission within and between individuals was first studied by Bartlett (1932) and has undergone a recent revival of interest across a range of different fields including cultural evolution (Mesoudi & Whiten, 2008), the evolution of language (Smith & Kirby, 2008), iterated learning (Kalish, Griffiths, & Lewandowsky, 2007), and reconstruction from memory (Hemmer & Steyvers, 2009). In Bartlett's original research, information transmission was investigated both between individuals, using the serial reproduction task, and within individuals, using the repeated reproduction task. In serial reproduction, a picture or text is shown to an individual who then attempts to reproduce it from memory. The product of this attempt is then shown to a second individual who subsequently attempts to reproduce it from memory, the

⁶The sinking of *Sydney* on 19 November 1941 occurred approximately two weeks before the Japanese attack on Pearl Harbour on 5 December 1941.

product of which is shown to a third individual and so on. Bartlett's investigations revealed that the original material may undergo substantial alteration through this procedure which he interpreted as reflecting the imposition of a higher-order schema that guides encoding and storage of the material. On this view, the product of memory retrieval is a combination of the data that are presented and a theory of what the data could represent.

More recently, Kalish et al. (2007) have proposed a precise mathematical description of how data and theory may be integrated to affect performance in the serial reproduction task. They suggested that humans can be modelled as ideal Bayesian learners. On this view, the information present in a target episode is regarded as a set of noisy data that is consistent, to varying degrees, with several different hypotheses. For example, in one of Bartlett's studies, a schematic picture of an owl gradually changed into a picture of a seated cat through a sequence of serial reproductions. It follows that at one point in this sequence, the transmitted drawing would have been equally consistent with the hypotheses that it portrays an owl or a cat, as well as perhaps many others. Kalish et al. proposed that given noisy data, an optimal Bayesian learner should integrate this information with their theory or prior expectation of which hypothesis is most likely to have generated the data (see also Huttenlocher, Hedges, & Vevea, 2000). Furthermore, as the serial reproduction task continues, the original information plays a progressively smaller role in determining the data transmitted on each trial which, in turn, becomes increasingly dominated by each individual's theory. If this theory is essentially equivalent across individuals, Kalish et al. showed that the transmitted information must necessarily converge upon the most likely prior expectation. They tested this implication in a serial reproduction task using function learning in which participants learned a functional relationship between two continuous variables. They found that irrespective of the initial form of this relationship, serial reproduction almost always converged upon a positive linear relationship reflecting participants' prior expectation of the most likely such relationship.

The principles underlying serial reproduction also apply to Bartlett's repeated reproduction task in which the same individual makes multiple attempts to recall an initial set of information over a period of time. As in serial reproduction, each recall attempt serves as an additional opportunity to learn and has a similar effect of progressively undermining the influence of the original veridical information and integrating it with prior expectations. Bartlett (1932) investigated repeated reproduction in the well-known War of Ghosts experiment in which five individuals were presented with the same version of an Amerindian folk tale and required to recall it multiple times at intervals ranging from several minutes to several years. As well as observing a progressive loss of information over time, Bartlett also observed that the content of the story tended to become progressively assimilated to the norms of traditional story telling in Western culture. Although impossible to quantify, this observation is consistent with the integration of data and prior knowledge reported by Kalish et al. and also recently been confirmed by Hemmer and Steyvers (2009) in their

study of reconstruction from memory. In this study, participants were shown pictures of common fruits and vegetables. Some of these pictures were physically larger than the objects they portrayed and some were smaller. Later, participants were asked to recall the sizes of the pictures they were able to recognize as having been studied. Hemmer and Steyvers found that recalled size was biased upward for large fruits and vegetables and biased downward for small fruits and vegetables. No biases were found for random shapes. Consistent with Bartlett's original hypothesis, these results suggested that participants were integrating noisy data, or poorly remembered knowledge of the size of the pictures, with their theory, or prior expectation of the actual sizes of the corresponding items.

The results found by Bartlett (1932) and confirmed in more recent studies suggest that the contents of memory may be viewed as consisting of two kinds of information—data, consisting either of the initial to-be-remembered material or the products of subsequent recall attempts, and a theory consisting of prior expectations concerning the likely nature of these data. This distinction is also captured in some formal models of memory. For example, in the REM (Retrieving Effectively from Memory) model of memory (Shiffrin & Steyvers, 1997), to-be-remembered items are represented as vectors of features. When an item is encoded, depending upon the nature of this encoding, a subset of these features is copied into memory. Of this subset, a further subset of features is copied correctly while the remainder is copied incorrectly. Importantly, if a feature is copied incorrectly, its value is replaced by a random sample from the prior distribution of the values of that feature in the environment. As a result, poor encoding leads to the retention of both less information as well as of information that increases the similarity of the particular item to competitors in the environment, one of which may subsequently be retrieved in place of the item itself.

Figure 2 illustrates a simplified version of the REM model applied to serial and repeated reproduction tasks. Information is represented as a vector of feature values which, in the REM model, are positive integers drawn from a geometric distribution. The first set of feature values, labelled 1*, corresponds to an item of information that is to be learned. The second set of feature values corresponds to the product of a first recall attempt. In this case, the recall is veridical and the recovered feature values match exactly those of the original data. On subsequent recall attempts, either between individuals or within the same individual, feature values are either lost and replaced by zeros or misrepresented and replaced by values randomly drawn from the environmental distribution of values for that feature. After several successful recall attempts, mis-recall occurs for the attempt labelled 2, and again at the attempt labelled 3 and so on. As a result, the set of recall attempts will consist of sub-sequences of equivalent information and these subsequences will have a characteristic frequency distribution. For example, one particular chain may generate the sequence, 11122345556. In this sequence, the first three attempts, labelled 1, are equivalent. At the fourth attempt, labelled 2, there is a change in the retrieved information, and so on. Thus, for a given item of information, the products of successive recall attempts can

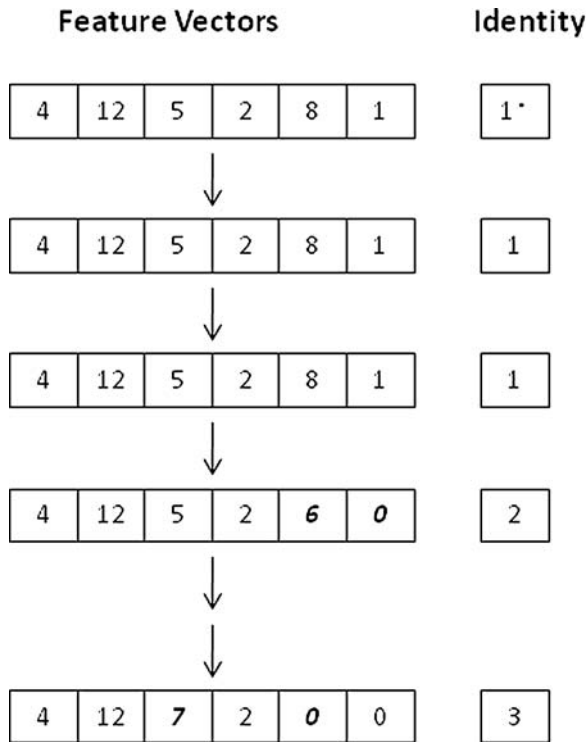


Figure 2. Successive transformation of feature vectors in a simplified REM model

be grouped into a smaller set of types and the frequency of each type calculated. In the above example, two types (1 and 5) occur three times, one type (2) occurs twice and three types (3, 4, 6) occur once. Such sequences generate a characteristic frequency distribution and the first step in our analysis was to determine the general form of the distribution generated in repeated reproduction tasks and to examine

whether the same distributions applies to the set of survivor reports.

Abundance distributions

The frequency distributions of types generated by a process of imperfect transmission have been studied by biologists who refer to them as abundance distributions (for a discussion see Luscombe, Qian, Zhang, Johnson, & Gerstein, 2002; McGill et al., 2007). In this section, we identify this signature, show that it can be generated by a known example of human transmission involving memory, and show that it also applies to the testimony of the Kormoran survivors.

A species abundance distribution (SAD) is a plot of the number of instances of each species observed in a given ecosystem. Figure 3(a) shows an example of a typical SAD used by McGill et al. (2007) to demonstrate the classic form of a hyperbolic or ‘lazy J-curve’ distribution in which most species have relatively few members while one or two species have many members and tend to dominate the ecosystem. Importantly, McGill et al. stated that ‘in this form, the law appears to be universal; we know of no multi-species community, ranging from the marine benthos to the Amazonian rainforest, that violates it’ (p. 996). Similar functions have also been obtained by Luscombe et al. (2002) in their analysis of genome sequences while Speelman and Kirsner (2005) proposed that this may also be a characteristic signature of cognitive systems in which components (such as lexical entries) are acquired and used over time.

Given the ubiquity of this form of SAD, we were interested to determine whether the same or a similar form applies to information transmission in repeated reproduction tasks. On the surface, there would be little reason to suspect that this might be the case. SADs in ecological systems are driven by

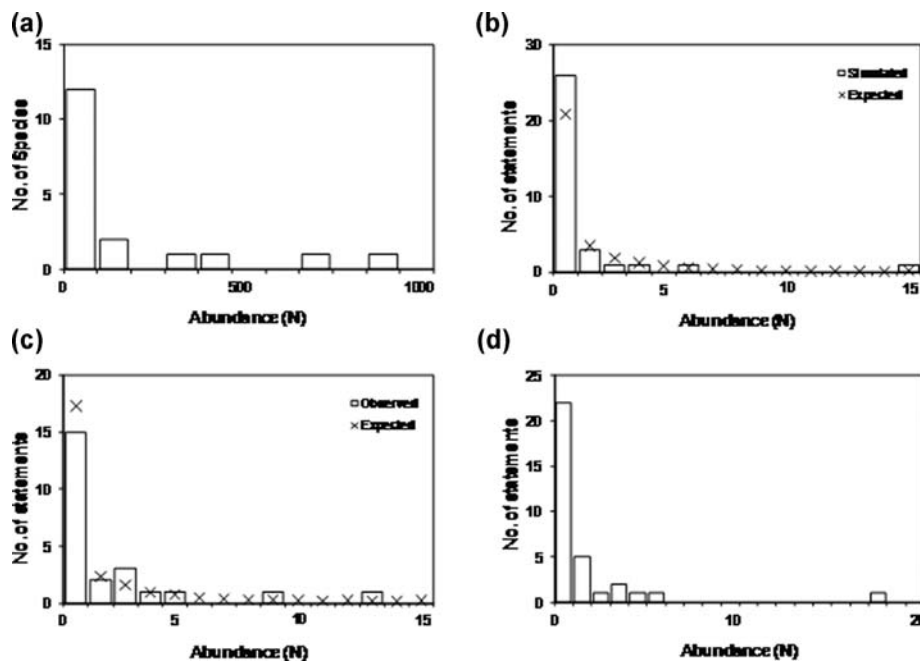


Figure 3. (a) Illustrative species abundance distribution (from McGill et al., 2007). (b) Observed and expected statement abundance distribution derived from a mixture of transmission probabilities for a simplified REM model. (c) Observed and expected statement abundance distribution based on initial story elements of recall attempts from Bartlett’s War of Ghosts study. (d) Statement abundance distribution obtained from location statements from the testimony of Kormoran survivors

many factors such as natural selection, mutation rates and environmental change over what may be very long time spans. Systems dominated by inter-individual communication and intra-individual memory retrieval may have very different dynamics which may lead to different abundance distributions of statement types. At the same time, because empirical SADs appear almost always to have the same form, this form may be largely unaffected by the specifics of the underlying generating process. In order to investigate this issue, we used the simplified REM model shown in Figure 2 to derive an expected statement abundance distribution. As noted above, this model describes a simple chain where, at each link, there is some probability that information is correctly transmitted. If there is a high correct transmission probability, information change will be rare and there would be relatively few variants. On the other hand, if there is a low correct transmission probability, information change will be common and there should be a large number of variants each of which, in the limit, may appear only once.

Although it is unlikely that the Kormoran reports conform to a single chain, this model may be sufficient to generate the appropriate statistics. Since we supposed that these reports consisted of variants derived from a small set of source statements, we simulated a mixture of four transmission probabilities for a convenient chain length of 15. That is, we notionally passed four statements down four chains each of length 15. Each chain had a different probability of correct transmission arbitrarily set to 0.01, 0.5, 0.75 and 0.875. Within each chain, we counted the number of statement types that appeared with different frequencies to obtain the corresponding abundance distribution. The results are shown in Figure 3(b). The bars correspond to one such distribution while the crosses correspond to the expected abundance distribution averaged over 1000 samples. It is clear that

despite considerable differences in the generative mechanism underlying the distributions in Figure 3(a) and (b), they have a largely similar form. We next examined the abundance distribution derived from Bartlett's study of the War of Ghosts (Bartlett, 1932).

In Bartlett's study, the War of Ghosts story was separately presented to five individuals, labelled H, L, N, P and R, who subsequently attempted to recall the story on between two and five separate occasions. We were interested in the statistical structure of a single story element—the phrase, 'two young men from Egulac', that appears in the first line of the story. We chose this as it seemed to provide a model of the kind of location information provided by Kormoran survivors which also corresponded to a single phrase (e.g. 'one hundred miles to the coast'). However, because we hypothesized that the survivor testimony was likely to contain variants of several source statement, we also analysed different components of the target phrase (e.g. 'two young men') treating these as surrogates for different source statements each with its own probability of correct transmission. We then counted the number of different forms of each target statement across the set of reproductions of the War of Ghosts story, including the original. Table 1 presents the outcome of this procedure. The first column identifies each participant and recall attempt. Thus, report P1 refers to the first recall attempt from participant, P. The second column gives a verbatim transcription of the relevant part of the corresponding recall attempt. These are, in effect, different versions of the first sentence of the original story, given in the first line of the table. The final four columns of Table 1 offer a categorization of each recall attempt according to each of the four different target texts varying from low to high specificity. Thus, the first target text, 'two' has low specificity and admits to relatively few variants. There is

Table 1. Frequency of distinct statements from War of Ghosts recall attempts according to four different target texts

Report code	Statement	Target text			
		Two	Two men	Two young men	Two young men Egulac
Original	One night two young men from Egulac went down to the river to hunt seals	1	1	1	1
H1	Two men from Edulac went fishing	1	1	2	2
H2	Two young men from Edulac went fishing	1	1	1	3
L1	Two young men from Egulac went out to hunt seals	1	1	1	1
L2	There were two men in a boat, sailing towards an island	1	1	2	4
N1	There were two men on the banks of the river near Egulac	1	1	2	5
N2	There were two men on the banks of a river near the village of Etishu	1	1	2	6
P1	Two youths were standing by a river about to start seal-catching	1	2	3	7
P2	There were two young men who once went out in the afternoon to catch seals	1	1	1	8
P3	Two youths went down to the river to fish for seals	1	2	3	7
P4	Two youths went down to the river to hunt for seals	1	2	3	7
P5	Some warriors went to wage war against the ghosts	2	3	4	9
R1	There were two young men, and they went on the river side	1	1	1	8
R2	There were two ghosts. They went on a river.	1	4	5	10
R3	There were ghosts		5	6	11

Report code identifies participant (by letter) and recall attempt (by digit).

in fact only one variant in the database where it is replaced by 'some' in report P5. Report R3 also offers what could be counted as a variant—in this case a deletion. We chose to treat this as missing since in the Kormoran database, if a survivor fails to report any location information, it is impossible to know what they would have said had they done so. Similar principles apply to the remaining target texts. In the case of the target text, 'two men', there are five different variants—'two men', 'two youths', 'some warriors', 'two ghosts' and 'ghosts'. The procedure we adopted to identify these variants depended upon an analysis of the internal structure of these statements. For example, we analysed 'two men' as consisting of a quantifier and a noun that referred to the protagonists of the narrative—men, youths, warriors, or ghosts etc. Similarly, the most specific target text, 'two young men from Egulac', can be analysed as a quantifier, an age descriptor, an agent, and a place name or location. The different variants transform or delete one or more of these elements. For example, in variant 7—'two youths', the quantifier /two/ is preserved, the descriptor /young/ and the agent /men/ are blended to form 'youths' and the location is omitted entirely.

The categorization of story elements presented in Table 1 yields the statement abundance distribution shown by the bars in Figure 3(c). Of all the variants listed in Table 1, 15 appear only once, two appear twice, three appear three times, one appears four times, one five times, one nine times and one 13 times. As can be seen, this distribution is broadly similar to the 'lazy J' shape of the typical SAD shown in Figure 3(a) and the simulated statement abundance distribution shown in Figure 3(b). For comparison, Figure 3(c) shows an expected abundance distribution (indicated by crosses) derived from the known structure of the War of Ghosts study. That is, rather than conforming to a simple chain, as in Figure 2, the structure of Bartlett's experiment corresponded to a radial transmission to five individuals followed by chains of varying length within each of these. Because this structure is known, it is possible to generate an expected abundance distribution based on estimates of the transmission probabilities for the four statement types. We did not conduct a systematic search but found that probabilities of correct transmission of 0.9 (for 'two'), 0.75 (for 'two men'), 0.5 (for 'two young men') and 0.01 (for 'two young men Egulac') provided a reasonable fit to the data. The expected distribution derived from these values and shown in Figure 3(c) is based on a 1000 random samples. This again reinforces the view that the general form of the abundance distribution does not depend upon the specific details of the underlying generating process.

There are two caveats that need to be made with respect to the distributions shown in Figure 3(b) and (c). First, the exact forms of these distributions will depend upon the level of granularity that is selected. It is clear that it is possible to generate target texts of arbitrary specificity in which case the chance of observing variants with an abundance count greater than one would be close to zero. In biological applications, the same issue arises when a decision is made concerning when two organisms are to be counted as belonging to the same or different species. In this case, the problem is solved by having a well-defined concept of

species that is independent of the classificatory process. We applied a similar, although less formal, solution to the testimony of the Kormoran survivors. In this case, an appropriate level of granularity was achieved by including within statements those text elements that refer only to location and by excluding other unrelated information. The second caveat concerns the size of the database or corpus of statements. Clearly, larger databases are capable of yielding statements with larger abundances and of identifying rare statements that may otherwise be missed entirely. This is a feature of all finite corpora and applies equally to counts of species diversity as well as to statement diversity. In biology, this necessary limit is referred to as the *veil* (Preston, 1948; Nee, Harvey, & May, 1991).

Data from the War of Ghosts study produced a statement abundance distribution of the same form as that which is commonly observed in biological systems (Figure 3a) and in simulated chains (Figure 3b). Despite differences in the underlying generative processes, a similar statistical signature is observed in each case. If the same signature occurs in the Kormoran survivor database, this would support the view that the contents of this database can also be considered as the product of stochastic processes acting upon a small set of source statements. For this reason, we examined the abundance distribution of location statements in Kormoran survivor database.

The testimony of the Kormoran survivors contains 72 references to location. These, in turn, can be grouped into 33 distinct types. Approximately half of these refer to location in terms of latitude and longitude while the remaining types refer to location in terms of distance to a landmark. Table 2 lists each statement type and its associated frequency of occurrence. Figure 3(d) is a plot of the resulting statement abundance distribution and it is apparent that this also conforms to the same 'lazy J' form as observed previously. Although it is beyond the scope of this article to offer a precise mathematical account of this distribution in terms of an underlying structure, its form suggests that the variability of the survivor testimony is consistent with a stochastic transformation process arising from a pattern of inter-individual communication and intra-individual retrieval from memory.

Identification of source statements

The observed statistical structure of the survivor reports is consistent with the proposition that they represented variants of a relatively few primary source statements that had been transmitted to other survivors by a small number of officers and crew who were in a position to make a determination of location. In this section, we propose a set of seven source statements based on a consideration of their internal characteristics, origin and timing, and support this identification by applying a formal cladistic analysis to the data.

We categorized each survivor location statement in the database into a relatively small number of source statements based on consideration of their internal structure, the status of the originator of the report (e.g. captain, navigator) and the proximity of the date of the report to the time of the action.

Table 2. Frequency of distinct location statements from the Kormoran survivor database

Latitude/longitude statements	Frequency	Distance statements	Frequency
27S 111E	5	60 miles from land	1
26S 11E	1	150 miles from the coast	1
26S 115E	1	120 miles from the coast	3
26S 111E	18	120 miles from land	1
26S 110E	2	100 miles off Fremantle	1
26S 108E	1	SW of Shark's Bay	2
26S	1	20 miles SW of Fremantle	1
25S 111E	1	160 miles SW of NW Cape	1
24S 111E	1	130 nautical miles W of Shark Bight	1
26.34S 111E	6	130 nautical miles W of Shark Bay	1
26.32S 111E	4	130 nautical miles SW of Shark Bay	1
26.32S 111.00E	2	130 miles W of Perth	1
26.30S 111E	1	130 miles SW of Shark's Bay	1
25.34S 111E	2	125 degrees SW of Fremantle	1
24.32S 111.25E	2	120 miles SW of Fremantle	4
		153 miles to landfall	1
		150 miles north easterly to land	2

Although an element of subjectivity necessarily enters into this process, we ultimately identified seven different source statements. These statements and the basis for their inclusion are listed below:

- (1) *26°S 111°E*: This source statement accounts for 43% of location reports and variants include '26°S 110°E' and '27°S 111°E'. It was first recorded from the wireless telegraphy operator (WTO), Hans Linke, on 26 November 1941 and possibly originated from him. Apart from Linke, versions of this source statement were also recorded from eight other survivors including Detmers, Meyer, signalmen Ahlback and Pachmann, and other officers including Herbert Bretschneider, Johannes Diebitsch and Wilhelm Bunjes, the prize captain⁷. The defining characteristic of this statement is a reference to a latitude and longitude expressed in degrees only. A possible basis for this statement was a radio signal transmitted immediately prior to the action.
- (2) *26°32'S 111°E*: This source statement, also recorded as '26°34'S 111°E' and '26°30'S 111°E' as well as other variants accounts for 24% of location statements. It appears to have originated from the Kormoran captain Theodor Detmers, and was first recorded from him on 27 November 1941, 8 days after the action. Variants of this source statement were recorded on subsequent occasions principally from Detmers but also, on one occasion, from the navigator, Henry Meyer. The defining characteristic of this statement that distinguishes it from source statement 1 is a reference to a latitude value expressed in both degrees and minutes.
- (3) *130 miles SW of Shark Bay*: This source statement, also recorded as '130 nautical miles W of Shark Bight', '120 miles SW of Fremantle' and other variants accounts for 17% of survivor reports. The original version of this statement would appear to have originated from Detmers

⁷Bunjes, a merchant marine captain, was present on *Kormoran* in the position of prize captain. That is, he would take command of any ship that *Kormoran* managed to capture and, with a skeleton crew, attempt to take it back to Germany. Bunjes is also noteworthy for expressing anti-Nazi sympathies.

- and perhaps communicated orally by him to members of the crew. That the original version corresponded to this source statement is supported by a report that appeared in December 1943, in Volume 10 of the German Navy's *Operationen und Taktik*. The information contained in this report had been relayed by *Kormoran*'s senior surgeon, Dr Siebelt Habben, prior to his repatriation to Germany following a POW exchange earlier that year.
- (4) *120 miles to the coast*: This source statement, also recorded as '150 miles from the coast', and '100 miles to land', as well as other variants, accounts for 10% of the survivor reports and may have originated from the prize captain, Bunjes. It was first recorded during formal interrogation of *Kormoran* survivors over a 10-day period from 1 December to 10 December 1941. Apart from Bunjes, versions of this source statement were recorded from four other survivors, including the ship's meteorologist, Hermann Wagner. The characteristic feature of this source statement is identification of a distance of approximately 120 miles to land without an accompanying indication of direction.
- (5) *150 miles north easterly to land*: This source statement appears to have originated from the Kormoran navigator, Henry Meyer and was first recorded on 30 November 1941. It accounts for 4% of the survivor reports. A similar variant, '153 miles to landfall', was also recorded from von Malapert who, with Meyer, came ashore north of Carnarvon in one of the three Kormoran lifeboats to reach land. The defining characteristic of this statement is that direction information is given in relation to the ship rather to the land. This is consistent with the requirements of navigating a lifeboat to landfall.
- (6) *160 miles SW of North-West Cape*: This single statement was first recorded from Bunjes on 28 November 1941. While similar to source statement 3, both the quoted distance and the landfall location are different, suggesting an independent assessment of location by Bunjes.
- (7) *West of Shark Bay at 2000 hours*: The last source statement is the only one which does not form part of the interrogation reports of the *Kormoran* survivors but,

Table 3. Feature description of latitude–longitude location statements from the Kormoran survivor reports

Location statement	Feature									
	10s	1s	0.1s	0.01s	100s	10s	1s	0.1s	0.01s	
27 111	2	7			1	1	1			
26 11	2	6				1	1			
26 115	2	6			1	1	5			
26 111	2	6			1	1	1			
26 110	2	6			1	1	0			
26 108	2	6			1	0	8			
26	2	6								
25 111	2	5			1	1	1			
24 111	2	4			1	1	1			
26.34 111	2	6	3	4	1	1	1			
26.32 111.00	2	6	3	2	1	1	1	0	0	
26.31 111	2	6	3	1	1	1	1			
26.30 111	2	6	3	0	1	1	1			
25.34 111	2	5	3	4	1	1	1			
24.32 111.25	2	4	3	2	1	1	1	2	5	
26.32 111	2	6	3	2	1	1	1			

instead, appeared in Detmers' book published in 1959. Here, Detmers elaborates source statement 3 stating that if *Kormoran* had not encountered *Sydney*, its projected course would have led it to be due west of Shark Bay at 2000 hours on the day in question.

Although it did not form part of our original identification of the seven source statements listed above, in order to provide additional support for this conceptualization, we later submitted the set of distinct location statements to a cladistic or phylogenetic analysis. This is a procedure for reconstructing the evolutionary history of a set of related organisms or other entities, such as texts, that undergo similar mutation-like processes (for an overview, see Forey, Humphries, Kitching, Scotland, Siebert, & Williams, 1992). Cladistic analysis starts with a matrix of distances calculated from the number of common and distinctive characteristics of a pair of entities. It is assumed that shared features are the product of descent from a common ancestor while the number of distinctive features indicates the degree of evolutionary divergence. From this matrix, the method produces the most parsimonious phylogenetic tree or cladogram that reveals the evolutionary history of the entities by grouping them into hierarchical clusters with entities sharing a common ancestor being grouped within the same cluster or set of clusters. We have suggested that each survivor report may be viewed as a variant of a one of a relatively small number of source statements. If this is so then cladistic analysis should group variants of the same source statement within the same cluster in the cladogram.

As noted earlier, the 72 individual survivor reports of location information correspond to 33 distinct type statements. These type statements can be further divided into 16 statements that express location information in terms of a latitude and longitude, and 17 statements that express location information in terms of distance to land. In order to undertake a cladistic analysis of these data, it is necessary to code each statement in terms of a set of features each of which may undergo modification through inter-personal and

intra-personal transmission. Table 3 shows the feature coding scheme we used for location statements expressed as a latitude and longitude. To do this, we divided each latitude and longitude number into its respective numeric place value. We then defined the overall difference or distance between each pair of statements as the total number of mismatching features. For example, the distance between the statements '27S 111E' and '26S 11E' is 2, corresponding to a mismatch between the '7' and '6' in the second position or the 1s place of the latitude number and a mismatch between the '1' and a missing or zero value in the first position or 100s place of the longitude number. We then submitted the resulting distance matrix to a standard phylogenetic tree building program based on the neighbourhood joining method (Saitou & Nei, 1987)⁸. Figure 4 shows the resulting tree which reveals two main clusters corresponding to source statements 1 and 2. Although this supports the distinction we have drawn between these two source statements, it does not directly yield the form of the original or ancestral statement.

Table 4 shows the feature-coding scheme used for location statements expressed as distances. We adopted a similar approach to that used for latitude and longitude statements and parsed each statement into a set of common descriptors. Figure 5 shows the resulting phylogenetic tree. Although not as clear-cut as the tree based on latitude and longitude statements, it is possible to discern four clusters corresponding to source statements 3–6 (source statement 7 was not included in the analysis). Of these, clusters corresponding to source statements 3 and 6 are the most clearly defined while clusters corresponding to source statements 4 and 5 appear to share several features in common. There are also two outlier statements, '100 miles off Fremantle' and '130 miles W of Perth', which are not clearly associated with any source statement cluster⁹. The similarity of source statements 4 and

⁸The analysis was conducted in Matlab using the function *seqneighjoin*.

⁹Perth is the largest city and capital of Western Australia and Fremantle is the name of its port. Both these places would be well known to the *Kormoran* crew but lie over a thousand kilometres to the south of the action. Any reference to them as being less than 200 km distant is necessarily incorrect.

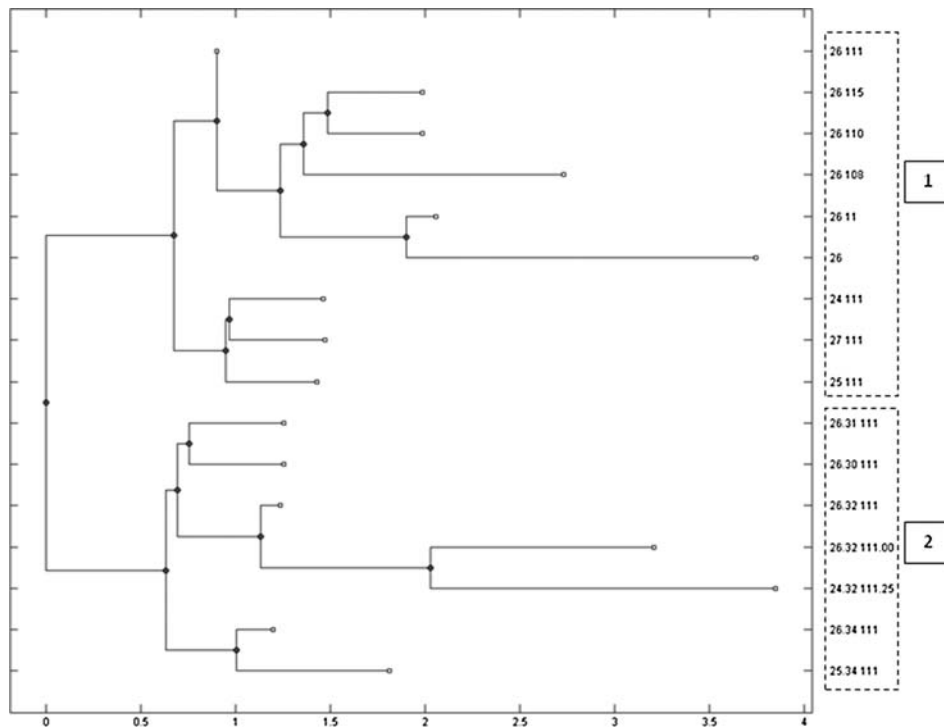


Figure 4. Results of cladistic analysis of latitude–longitude based location statements from Kormoran survivors. Dashed rectangles identify clusters corresponding to source statements 1 and 2 (corresponding numbers given in adjacent filled rectangles)

5 suggests that they may conceivably be variants of a common originating statement, such as ‘150 miles north easterly to land’, that has been successively corrupted to a variant such as ‘120 miles to land’ which we have treated as a distinct source statement. Although this is possible, it turned out that excluding this statement from the analysis did not affect the final outcome.

Integration of location information

In the final stage of our analysis, we used the source statements to define a feasible search area. Although we felt that it was possible to identify and to provide plausible support for each source statement, they nevertheless each contained an unknown margin of error and none were

Table 4. Feature description of descriptive location statements from the Kormoran survivor reports

Location statement	Feature										
	100s	10s	1s	Descriptor	Distance measure	NS	EW	Preposition	Place name	Modifier	Place type
60 miles from land		6	0		Miles			From	Land		
150 miles from the coast	1	5	0		Miles			From	The coast		
120 miles from the coast	1	2	0		Miles			From	The coast		
120 miles from land	1	2	0		Miles			From	Land		
100 miles off Fremantle	1	0	0		Miles			Off	Fremantle		
SW of Shark’s Bay						S	W	Of	Shark	s	Bay
20 miles SW of Fremantle		2	0		Miles	S	W	Of	Fremantle		
160 miles SW of NW Cape	1	6	0		Miles	S	W	Of	NW Cape		
130 nautical miles W of Shark Bight	1	3	0	Nautical	Miles		W	Of	Shark		Bight
130 nautical miles W of Shark Bay	1	3	0	Nautical	Miles		W	Of	Shark		Bay
130 nautical miles SW of Shark Bay	1	3	0	Nautical	Miles	S	W	Of	Shark		Bay
130 miles W of Perth	1	3	0		Miles		W	Of	Perth		
130 miles SW of Shark’s Bay	1	3	0		Miles	S	W	Of	Shark		Bay
125 degrees SW of Fremantle	1	2	5		Degrees	S	W	Of	Fremantle		
120 miles SW of Fremantle	1	2	0		Miles	S	W	Of	Fremantle		
153 miles to landfall	1	5	3		Miles			To	Land		Fall
150 miles north easterly to land	1	5	0			North	Easterly	To	Land		

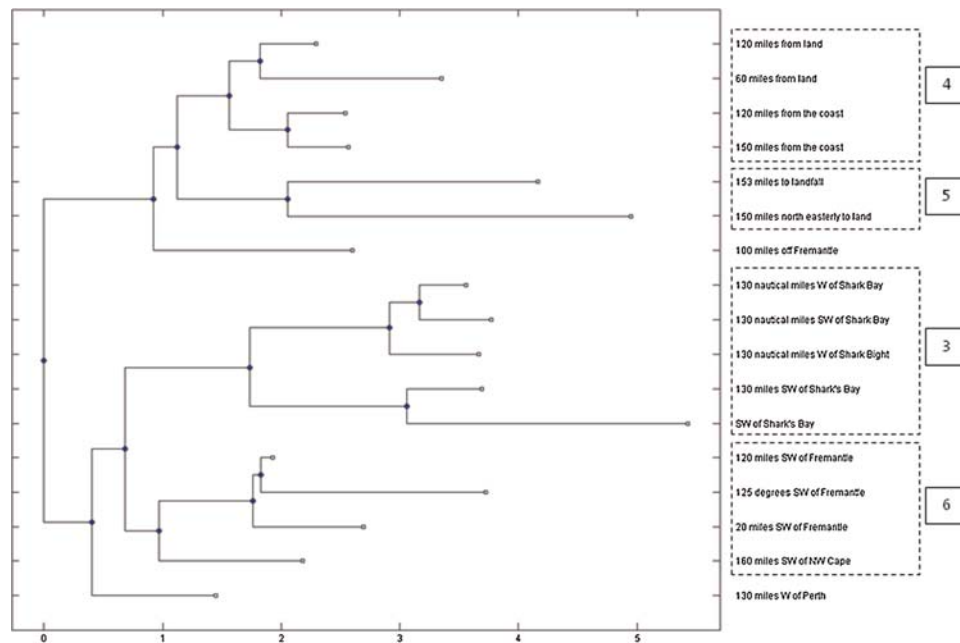


Figure 5. Results of cladistic analysis of distance based location statements from Kormoran survivors. Dashed rectangles identify clusters corresponding to source statements 3–6 (corresponding numbers given in adjacent filled rectangles)

sufficient in themselves to identify a sufficiently precise search area. We therefore chose to integrate all of the available information under the assumption that if each piece of information is broadly consistent with the remainder, the integration of this information should converge on the most likely area and point within that area. In order to do this, we defined each of the seven source statements as a constraint that the true location of Kormoran would have to satisfy, at least approximately. For each candidate location, corresponding to a point in the ocean, and each constraint we calculated the minimum distance that the candidate location would have to be moved in order to satisfy the constraint exactly. This was called the error distance for each location-constraint pair. We then calculated the average error distance for each location by averaging the error distances across the set of constraints. This provided a single ‘goodness of fit’ measure for that location¹⁰. Clearly, a candidate location with a relatively small average error distance satisfies the constraints to a greater extent than a point with a relatively large average error distance. It should be noted that no single candidate location satisfied all the constraints exactly.

The notion of satisfying a constraint needs further elaboration with respect to two issues. The first relates to uncertainty concerning the point of time at which the constraint applies. For example, the statement ‘120 miles to the coast’ may conceivably describe the location of Kormoran at the time at which Sydney was first sighted, the time of the action, or the time at which the ship was abandoned or scuttled. This issue turned out to be particularly relevant

to the interpretation of source statement 2. Although the Kormoran captain consistently described this position as the site of the action, it is not consistent with many of the other location constraints. Based on other considerations, Olsen and Hore (2001) had proposed that the position attributed by the captain to the site of the action was in fact the noon position of Kormoran taken several hours earlier. If this assumption is made, then source statement 2 can be largely reconciled with the remaining constraints. This also illustrates a general strategy that we used. If a constraint was open to more than one interpretation concerning the time at which the constraint applied, we evaluated each possibility and selected the interpretation that yielded the smallest error distance for a candidate location.

We adopted a similar strategy with respect to uncertainty concerning the point in space at which a given constraint applied. For example, the statement ‘120 miles to the coast’ identifies a locus of points lying 120 miles to the nearest point on land. To resolve uncertainty in these and similar cases, we evaluated all possible interpretations of a given constraint and selected the one that yielded the smallest error distance for a candidate location. We did this separately for each candidate location. We also applied this strategy to resolve the identity of ambiguous landmarks. Thus, in the source statement, ‘160 miles SW of North-West Cape’, reference to North-West Cape is most likely in error since this landmark is hundreds of kilometres to the north. It is plausible that the statement referred to another nearby cape or point, the identity of which is unknown. We identified a set of plausible landmarks and, for each candidate location, selected the one for which the error distance was a minimum. More formally, let A be a set of points that satisfy a given constraint exactly, let b be a candidate location of Kormoran and let $d(a, b)$ be the distance between b and a point a in A . Then the error distance of b for this constraint is defined as, $\min_{a \in A} (d(a, b))$.

¹⁰Averaging the error distances treats each constraint as having the same weight or importance. Although we considered other weighting schemes, we did not feel that there was any justifiable basis for treating one constraint as more critical than another. We were also guided by studies of expert decision making in which equally weighted linear models (so-called ‘improper’ linear models) are nearly as efficient as optimally weighted models (Dawes, 1979).

RESULTS

Figure 6 shows the results of our analysis of the seven source statements. The figure includes an area of ocean bounded to the north and south by the lines of latitude, $25^{\circ}30'$ S and $26^{\circ}45'$ S, and to the west and east by the lines of longitude, $110^{\circ}30'$ E and $111^{\circ}30'$ E. Enclosed in this area is the final search box used by the FSF expedition that located Kormoran and Sydney in March 2008. The true locations of these ships are also shown. The set of contour lines correspond to lines of equal mean error distance and the cross marks the point with the lowest mean error distance. This point has a mean error distance of 25.7 km and was subsequently found to be 22 km from Kormoran's true location.

Three main conclusions may be drawn from the results shown in Figure 6. First, the seven survivor reports are all broadly consistent with each other. The minimum mean error distance does not increase dramatically if any one source statement is excluded from the calculation. Overall, the observed range is from 12 to 26 km with a mean of 19.6 km. Second, the survivor reports consistently support a location in the general vicinity of 26° S 111° E which proved to be close to the actual location of Kormoran. Third, although the measure of mean error distance cannot be converted into a probability, the rate of increase in this measure suggested that Kormoran would most likely be found in a relatively small area that falls well within the final search box.

Our analysis of the survivor reports formed a substantial part of our attempt to locate Kormoran. However these data did not exhaust all of the location information that was available to us. Our final analysis therefore included two additional constraints derived from two sources of physical evidence; the location of the drift objects lost from Kormoran and an emergency radio signal transmitted from Kormoran moments before the battle. As with each source statement, both of these constraints were imprecise and insufficient in themselves to identify the location of Kormoran. For example, the drift objects could be used to indicate a set of points lying on the circumference of a circle with a radius of over 100 km. Similarly, the radio signal was garbled and provided little more than an indication of longitude.

Figure 7 shows the results of our analysis of the seven source statements combined with the additional physical evidence. The effect of including this evidence was to increase the overall consistency of the solution and to move the optimal point significantly closer to the true location of Kormoran (although we had no way of knowing this at the time). This is the point that we proposed to the search group as being our best guess for where Kormoran lay (Kirsner & Dunn, 2004). It had a mean error distance of 21.7 km and corresponded to the location, $26^{\circ}07'$ S $111^{\circ}02'$ E, which, 4 years later was found to be less than 5 km from the true location of Kormoran. However, at the time we proposed this solution to the search task, we had no way of knowing how

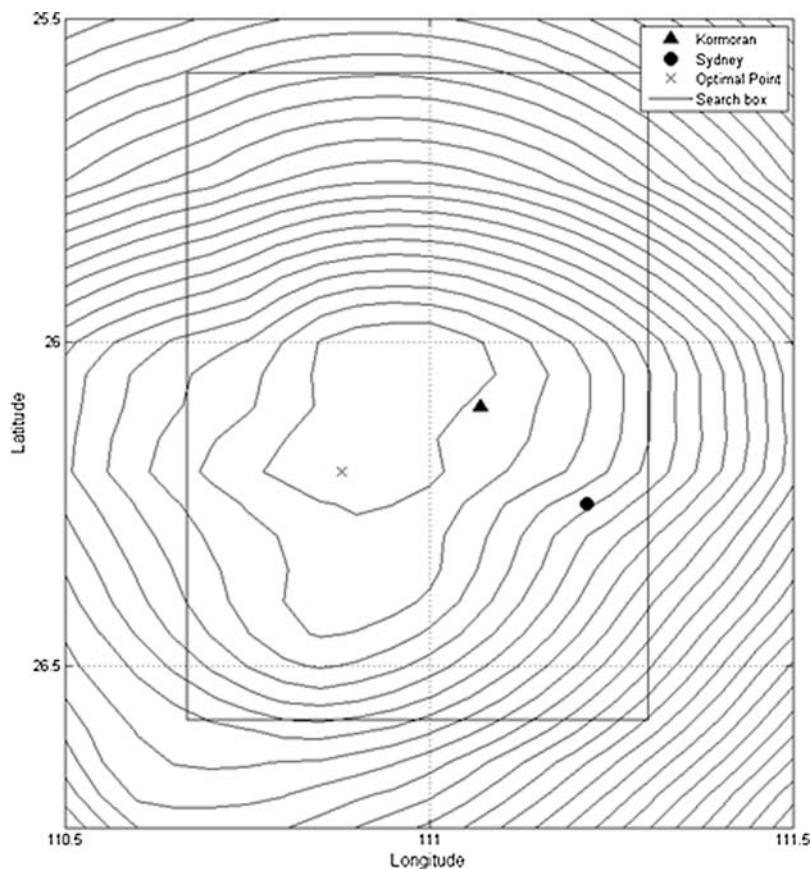


Figure 6. Contour plot of the mean error distance for each point in the vicinity of 26° S 111° E based on the seven source statements obtained from the survivor reports. The cross indicates the best-fitting predicted location of Kormoran; the filled black triangle indicates its true location; and the filled black circle indicates the true location of Sydney. The rectangle shows the approximate search box used in the 2008 search

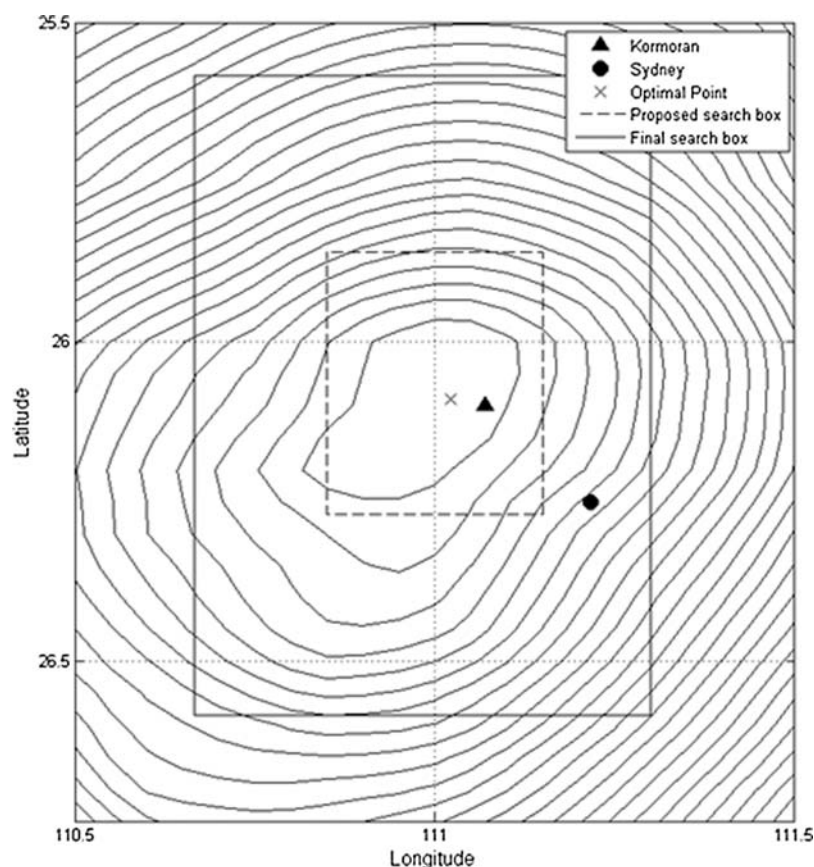


Figure 7. Contour plot of the mean error distance for each point in the vicinity of 26°S 111°E based on the seven sources statements and additional physical evidence. The cross indicates the best-fitting predicted location of Kormoran; the filled black triangle indicates its true location; and the filled black circle indicates the true location of Sydney. The smaller dashed rectangle shows the search box recommended on the basis of the present analysis. The larger continuous rectangle shows the approximate search box used in the 2008 search

precise our prediction would turn out to be. For this reason, we also proposed a search box that incorporated the uncertainty attached to our estimation procedure¹¹. This is also shown in Figure 7.

CONCLUSIONS

The search for Sydney was a major undertaking that was ultimately crowned with success. However, at the time of our initial involvement, the final outcome was highly uncertain despite the efforts of a considerable number of individuals, both professional and amateur. A key element in our approach to the search problem was our view that the survivor reports, although variable, contradictory and fragmentary, could contain a considerable amount of valuable information concerning the likely location of Kormoran. Unique among the contributors to the search, we were able to draw upon the perspectives and knowledge base of cognitive psychology to inform our analysis. This analysis consisted of three phases. In the first phase, we examined the statistical signature of the survivor reports and showed that it was consistent with a general pattern of information diffusion over time similar to that observed in both ecological and memory-based systems. Based on this finding, we proposed that location information in

the reports could be regarded as variants of a relatively small subset of original source statements. In the second phase of our analysis, we attempted to identify these source statements based on the internal structure of the statements themselves and supported by a formal cladistic analysis. In the third phase, we treated each resulting source statement as a constraint on each candidate location and derived a 'goodness of fit' measure for each location. This revealed an area of ocean approximately centred on the point, 26°S 111°E. After adding two additional constraints based on the available physical evidence, this area was further refined and an optimal point identified which subsequently proved to be less than 5 km from the actual location of Kormoran. Although we were able to identify a single point that proved to be highly accurate, the most robust feature of our solution was the identification of an area of high probability, as shown in Figure 7. By considering all of the available evidence, rather than relying solely on one or another contentious piece of evidence such as the 'Detmers position', we were able to show that it was internally consistent and, on this basis, to mount a convincing argument to FSF that this was the area of ocean in which to search¹².

Our involvement in the search for Sydney revealed to us that the domain knowledge and methods of cognitive psychology offered a unique perspective on a problem that

¹¹The definition of the final search box was not based solely on the results of our analysis but on a number of other considerations.

¹²At the time there were other competing views that placed the likely location of *Kormoran* between 50 and 200 km further south.

was not shared by other individuals and groups whose expertise lay in very different fields such as oceanography, engineering, and oral and military history. While historical records and witness reports have proven essential in helping to identify search areas in other successful attempts to locate missing ships (e.g. Ballard, 1988, 1990; Edwards, 1966; Gesner, 2000), and the present approach sits firmly within this tradition, our approach is unique in drawing upon a perspective offered by cognitive psychology informed by the following three aspects:

- (1) *The capacity to account for variability in human data in a systematic manner.* It is noteworthy that other discipline-based approaches were unable to offer a systematic account of human variability. While oceanographic analyses that pre-dated our involvement dealt with variability in physical quantities such as wind speed and direction, none of this domain knowledge could be applied to variability in survivor reports. Similarly, historical reconstruction was also unable to address this issue and resorted either to selecting one or two statements as veridical and ignoring the remainder or to dismissing the entire corpus. The unique perspective offered by cognitive psychology allowed us to generate a principled account of this variability that supported the view that the entire corpus could contain much previously neglected information.
- (2) *A model of information integration as a basis for decision making.* Cognitive psychology offers many different models of information integration and decision making. We employed a linear integration model that is particularly simple and robust and has been shown to yield good results in a variety of contexts (Dawes, 1979). This model, ultimately based on Brunswik's Lens Model (Brunswik, 1957), allowed us to be reasonably confident that an unweighted average of error distances would provide a satisfactory if not optimal prediction of location.
- (3) *Commitment to a quantitative approach.* Cognitive psychology often relies on quantitative models of unseen mental processes. We applied this principle in developing a model of the relational structure of the survivor reports and in evaluating this model against the statistical properties of the data. It also informed our aim of integrating all of the available information quantitatively in the form of a series of constraints that provided a single 'goodness of fit' measure which we used to evaluate each candidate location.

Our analysis revealed a high level of internal consistency among a set of reports that had previously been regarded as being too diverse to be of value. Yet this consistency was not achieved by assigning equal weight to each individual report nor by treating each report as literally true. Rather, consistency was optimized in two ways. First, subsets of reports were treated as imperfect instances of a single source statement which, once identified, was assumed to contain all of the relevant information for that subset. In this, we were guided by considerations of source—who, among the set of informants was in the best position to know, and timing—which was the earliest report. Although these heuristics were

supported by a formal cladistic analysis and the mutual consistency of the final set of source statements, we were never entirely certain that we had correctly identified all of the relevant statements. The second means of extracting consistency was to search for interpretations of the reports that minimized our goodness-of-fit measure. The most striking example of this concerns the report of the Kormoran captain, Theodor Detmers. On several occasions, he unequivocally stated that the site of the action was at 26°32' S 111°E. We now know this was incorrect. However, the effect of this misinformation on our analysis was minimized by considering alternative interpretations. Following the suggestion by Olsen and Hore (2001), we included the possibility that this location referred to the noon position of Kormoran on the day in question rather than the site of the action which occurred 5–6 hours later. Similarly, the statement by the prize captain, Wilhelm Bunjes, that the action took place '160 miles SW of North-West Cape' was also obviously incorrect and so we evaluated several alternative landmarks in our analysis.

The errors made by Detmers and Bunjes, among others, raise an interesting question; why did these officers, who were most likely to have been the best informed concerning the correct location of Kormoran, make such glaring mistakes? The answer to this question may lie in the way in which recall depends on the assimilation of theory and data first discussed by Bartlett (1932) and subsequently formally analysed by Kalish et al. (2007). On this view, it is exactly those individuals with the greatest prior knowledge, or strongest prior hypotheses, whose recall of particular data will be most affected by their theory. A similar point has also been made by Freeman, Romney, and Freeman (1987) in their naturalistic study of informant accuracy. In this study, two groups of informants were compared in terms of their memory for attendees at a particular academic colloquium. They found that regular attendees, who would be expected to have higher levels of knowledge of who typically attends, correctly recalled the identities of more of those actually present at the target colloquium than did those who attended less regularly. Freeman et al. suggested that for this group, their well-developed theory of who typically attends the colloquium series facilitated the encoding, storage and retrieval of higher levels of specific information at each colloquium. However, it was also found that the same persons were more likely to falsely recall that typical attendees, who happened to be absent at the target meeting, were nevertheless present. In other words, the same theory that facilitated recall of specific details also generated details which, although typical or likely across the set of all colloquia, were incorrect in the particular target instance. This process may help to explain the errors made by Detmers and Bunjes. Both officers would have had a high level of knowledge concerning the disposition of Kormoran and both recalled detailed information. In the case of Detmers, location information was given precisely in terms of degrees and minutes, while in the case of Bunjes, a precise distance and landmark were offered. In other words, their respective theories helped to organize and hence to retain this information. Yet, the same theories worked to distort their final recall. In the case of Detmers, the habitual experience of

working with the daily noon position may have led him to mistakenly transpose this position to the site of the action. Similarly, in the case of Bunjes, geographical knowledge of the coast of Western Australia relevant to his role as prize captain, may have led him to mistakenly transpose a prominent landmark to a lesser one closer to the action.

The errors made by Detmers and Bunjes reinforce the view that memory consists of an assimilation of specific details, which we have called data, and prior knowledge, which we have called theory. It also indirectly supports our view that the entire corpus of survivor reports needed to be analysed. Although, as Freeman et al. found, individuals with high levels of prior knowledge are able to recall more detail, their recall is also more likely to be distorted by that prior knowledge. If such an intrusion had occurred for a single informant, no matter how knowledgeable, then total reliance on that informant is unlikely to yield a satisfactory outcome.

The method we developed in response to the problem that was placed before us was necessarily tailored to the specific details of that problem. Nevertheless, it may provide a blueprint for potential solutions to other similar problems. Such problems may include, but would not necessarily be restricted to, search problems for missing objects. In our view, the critical feature of a problem that would make it suitable for our methodology would be a set of statements or similar data that can be regarded as a set of constraints on a state of affairs that can be evaluated quantitatively. For example, and to move away from the present spatial domain, a relevant problem may involve the evaluation of eyewitness descriptions of a particular person, e.g. a criminal. In this case, the candidate locations in the present analysis would be replaced by candidate descriptions of real or postulated individuals. The average error distance would be replaced by a measure of similarity between each candidate and the set of key descriptions (perhaps converted into a psychological distance by appropriate scaling techniques). If the descriptions have been obtained from individuals who are part of a social network sharing information over time then a similar analysis that we applied to the Kormoran survivor reports could be applied to these data in order to identify a set of original or source descriptions. Although it is difficult, if not impossible, to specify how the method we developed may be specifically applied to other problems, the apparent success of its application to the search for Kormoran suggests that it possesses a prima facie validity which, in itself, would support its adaptation and application to other problems by other investigators. If we had been in possession of a prior example of the application of our method, we would have had cause for greater confidence in its application.

The search for Sydney has had a long and, at times, controversial history. Fortunately, rather than being consigned to an uncertain fate, its successful location has helped to resolve many of the mysteries that have surrounded its loss. It has also enabled us to discover a new way of using disparate, fragmentary and contradictory information to identify a probable search location. The ultimate success of our approach represents an unexpected positive outcome

arising from a tragic episode that has now finally been laid to rest.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the assistance of the University of Western Australia, the University of Adelaide, the Western Australian Maritime Museum, Fugro Survey Pty Ltd, the Australian Research Council and the Finding Sydney Foundation. They would also like to offer their particular thanks to Mike McCarthy, Ted Graham AM and Bob King OAM for their support and encouragement.

REFERENCES

- Ballard, R. D. (1988). *The discovery of the Titanic*. Toronto: Madison Press.
- Ballard, R. D. (1990). *The discovery of the Bismarck*. London: Hodder & Stoughton.
- Bartlett, F. C. (1932). *Remembering: A study in experimental and social psychology*. Cambridge, UK: Cambridge University Press.
- Brunswik, E. (1956). *Perception and the representative design of psychological experiments*. Berkeley, CA: University of California Press.
- Dawes, R. M. (1979). The robust beauty of improper linear models in decision making. *American Psychologist*, 34, 571–582.
- Detmers, T. (1959). *The raider Kormoran*. London: William Kimber.
- Edwards, H. (1966). *Islands of angry ghosts*. London: Hodder & Stoughton.
- Forey, P. L., Humphries, C. J., Kitching, I. L., Scotland, R. W., Siebert, D. J., & Williams, D. M. (1992). *Cladistics: A practical course in systematics*. Oxford, UK: Clarendon Press.
- Frame, T. (1993). *HMAS Sydney: Loss and controversy*. Sydney: Hodder & Stoughton.
- Freeman, L. C., Romney, A. K., & Freeman, S. C. (1987). Cognitive structure and informant accuracy. *American Anthropologist*, 89, 310–325.
- Gesner, P. (2000). HMS Pandora project—A report on stage 1: Five seasons of excavation. *Memoirs of the Queensland Museum: Cultural Heritage Series*, 2, 1–52.
- Hemmer, P., & Steyvers, M. (2009). A Bayesian account of reconstructive memory. *Topics in Cognitive Sciences*, 1, 189–202.
- Huttenlocher, J., Hedges, L. V., & Vevea, J. L. (2000). Why do categories affect stimulus judgment? *Journal of Experimental Psychology: General*, 129, 220–241.
- Kalish, M. L., Griffiths, T. L., & Lewandowsky, S. (2007). Iterated learning: Intergenerational knowledge transmission reveals inductive biases. *Psychonomic Bulletin and Review*, 14, 288–294.
- Luscombe, N. M., Qian, J., Zhang, Z., Johnson, T., & Gerstein, M. (2002). The dominance of the population by the selected few: Power-law behaviour applies to a wide range of genomic properties. *Genome Biology*, 3, research0040.1–research0040.7.
- McCarthy, M., & Kirsner, K. (Eds.). (1991). HMAS Sydney Forum. *Western Australia Maritime Museum Report No. 52*.
- McGill, B. J., Etienne, R. S., Gray, J. S., Alonso, D., Anderson, M. J., Benecha, H. K., et al. (2007). Species abundance distributions: Moving beyond single prediction theories to integration within an ecological framework. *Ecology Letters*, 10, 995–1015.
- Mesoudi, A., & Whiten, A. (2008). The multiple roles of cultural transmission experiments in understanding human cultural evolution. *Philosophical Transactions of the Royal Society B*, 363, 3489–3501.
- Montgomery, M. (1981). *Who sank Sydney?* Sydney: Cassell.
- Olson, W. J. (2000). *Bitter victory: The death of HMAS Sydney*. Perth: University of Western Australia Press.
- Olsen, W., & Hore, P. (2001). Archival record. *Workshop Report*, HMAS Sydney Wreck Location Seminar, Fremantle, WA.
- Preston, F. W. (1948). The commonness and rarity of species. *Ecology*, 29, 254–283.

- Nee, S., Harvey, P. H., & May, R. M. (1991). Lifting the veil on abundance patterns. *Proceedings: Biological Sciences*, 243, 161–163.
- Saitou, N., & Nei, M. (1987). The neighbor-joining method: A new method for reconstructing phylogenetic trees. *Molecular Biology and Evolution*, 4, 406–425.
- Shiffrin, R. M., & Steyvers, M. (1997). A model for recognition memory: REM—Retrieving effectively from memory. *Psychonomic Bulletin & Review*, 4, 145–166.
- Smith, K., & Kirby, S. (2008). Cultural evolution: Implications for understanding the human language faculty and its evolution. *Philosophical Transactions of the Royal Society B*, 363, 3591–3603.
- Speelman, C., & Kirsner, K. (2005). *Beyond the learning curve: The construction of mind*. Oxford, UK: Oxford University Press.
- Winter, B. (1991). *HMAS Sydney: Fact, fantasy and fraud*. Brisbane: Boolarong Publications.