CAN ALGORITHMS CALCULATE THE "REAL" SHAREDNESS IN DESIGN TEAMS?

Yamada, Kaori (1); Badke-Schaub, Petra (2); Eris, Ozgur (2)
1: Kobe University, Japan; 2: Delft University of Technology, The Netherlands

Abstract

Mental models have gained recognition as critical cognitive elements in design research. The members of a design team need to develop a shared mental model if their individual knowledge is to be used effectively. In this research, we investigate the development of shared mental models during team-based design collaboration by analyzing the words that are spoken by team members and focusing on the abstraction level of the discussion content.

First, we apply the KeyGraph algorithm to differentiate spoken words according to their abstraction level. KeyGraph can extract words that represent the discussion based on their co-occurrence. We treat the extracted words as abstract level concepts. Next, we propose a method to analyse sharedness by identifying overlaps of the extracted words between team members.

Then, we analyse a case by using the proposed method and compare the sharedness between abstraction levels. The results show that the general level sharedness is higher than the abstract level sharedness. They also show that a lack of sharedness among all of the members of a team does not imply lack of sharedness among subsets of the team members.

Keywords: Design cognition, Collaborative design, Shared Mental Models, Abstraction Level

Contact:
Dr.-Ing. Kaori Yamada
Kobe University
Organization of Advanced Science and Technology
Japan
kyamada@mech.kobe-u.ac.jp

Please cite this paper as:
Surnames, Initials: *Title of paper*. In: Proceedings of the 20th International Conference on Engineering Design (ICED15), Vol. nn: Title of Volume, Milan, Italy, 27.-30.07.2015

1 INTRODUCTION

During the last decade, the importance of mental models in teams has been discussed in various domains (Badke-Schaub et al., 2007). Design activities are often carried out in teams. In order to use the team members' individual knowledge and skills efficiently, it is beneficial for team members to develop shared mental models (SMMs). SMM refers to members of a team sharing their individual mental models (Bierhals et al., 2007).

Our aim is to investigate the development of SMMs during team-based design activity. Previous studies on SMM development were focused on team performance (e.g., Neumann 2012), sketch-based and gestural communication (e.g. Eris et al., 2014), co-design interactions (e.g., Kleinsmann and Valkenburg, 2008), and linguistic analysis (e.g., Dong, 2005). In this study, we are focusing on words and abstraction level in language.

When developing an idea for a new product, team members interpret the given task, identify requirements, generate ideas and discuss them based on their individual knowledge. The extent of overlap between the individual mental models is called 'sharedness'.

In this research, we focus on the words that were uttered by team members in verbal communication in order to measure sharedness in design collaboration. We pay specific attention to the abstraction level of the discussion content.

More specifically, we propose a method for analysing sharedness in design discourse. First, we introduce a method to differentiate spoken words according to their abstraction level. Next, we propose a method to analyse their sharedness. Then, we analyse a case using the method.

2 THEORY

2.1 Abstraction level of Shared Mental Model

People have their individual knowledge and understandings. Depending on context and their background (i.e., culture, age, experience and training), some knowledge is common among them. Moreover, team members often do not make what they assume to be common explicit in teamwork. This assumption might cause misunderstandings in teamwork.

However, misunderstandings might inspire innovation and novel product ideas. In order to further consider misunderstandings in teamwork, we would like to consider the abstraction level of SMMs. Table 1 shows the postulated relationships between shared understandings and abstraction levels. When both the abstract and detail level understandings are shared, the team members refer to the same theme and content. Common knowledge implies that the team members have completely shared understanding at both levels.

Table 1. Classification of abstractions levels and shared understanding

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="2">Abstract level</td></tr>
<tr><td>Shared</td><td>Not Shared</td></tr>
<tr><td rowspan="2">Detail level</td><td>Shared</td><td>Completely shared mental model
or common knowledge</td><td>Misunderstanding
(might inspire novel idea)</td></tr>
<tr><td>Not shared</td><td>Partial agreement
or partially effective discussion</td><td>No distribution of work and
responsibilities</td></tr>
</table>

2.2 KeyGraph

In order to find words that are used at a more abstract level in design discourse, we used KeyGraph (Ohsawa et al., 1998). KeyGraph is a data-mining algorithm for extracting keywords representing the asserted main point in a document. The algorithm is based on the segmentation of a graph, representing the co-occurrence between terms, into clusters. The co-occurrence is term-pairs which frequently occur in the same sentence throughout a document. The link strength of connected pairs is defined according to collocation measuring. Each cluster corresponds to a concept that is based on an idea, and top ranked terms by a statistic based on each term's relationship to these clusters are selected as keywords. The extracted keywords are seen to focus on themes that are more abstract than others. The algorithm was developed to extract keywords with content most accurately matching a user's specific and unique interest from a given document. Thus, we use KeyGraph to find discussion themes in conversations that take place during design teamwork.

Figure 1 shows an output of KeyGraph on Polaris (Okazaki and Ohsawa, 2003; Okazaki, 2007). Polaris is an application that implements the KeyGraph method. Polaris outputs graph representation and word lists including the frequency of an inputted target document. Black nodes show high frequency words and red nodes show words that strongly affect the connected clusters. Solid links shows strong connection and dotted links show weak connection between pair of words.

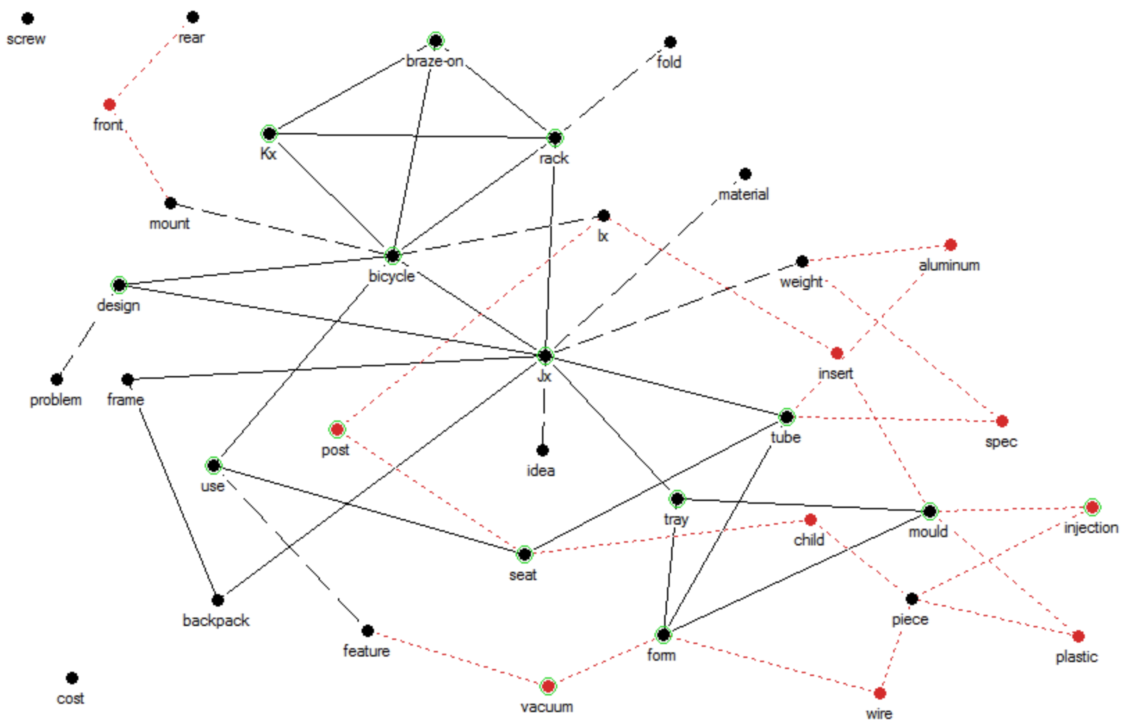
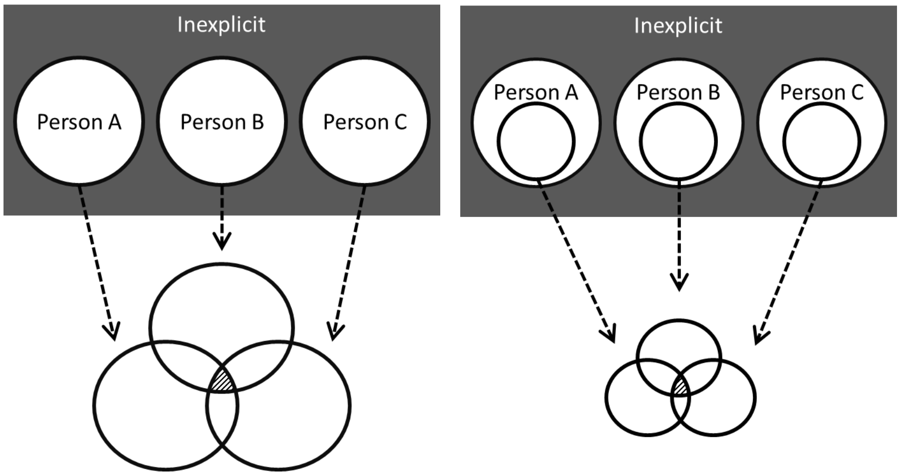


Figure 1. Output of KeyGraph

Implicit common and individual knowledge is often behind explicit concepts that are uttered by team members. By using KeyGraph method, abstract concepts that relate to 'what are they talking about?' can be extracted from explicit concepts. The abstract words might be discussion themes, and the detail words might be specifications and features of a product. The theme of a discussion is much more abstract than its content. In this research, we use KeyGraph to extract the abstract concepts in design discussions.

3 METHOD

Two types of analysis are proposed to investigate both the detail and abstract levels of sharedness. The outlines of the methods are shown in figure 2 (a) and (b). In both figures, speakers A, B and C are participating in design team work. The white circles stand for each person' explicit mental models. In figure 2 (b), the inner small circles represent the abstract levels of the mental models. At the bottom of figures, the overlapping areas are SMMs.



(a) Analysis 1 *(b) Analysis 2*

Figure 2. Outline of the methods to investigate detail and abstract level of sharedness

3.1 Analysis 1

Analysis 1 is a method to find words at a general level of sharedness. The sharedness can be measured using the equation below:

$$\text{Sharedness} = \frac{A \cap B \cap C}{|A| + |B| + |C|} \tag{1}$$

Here, |A| refers to the explicit concepts that were uttered by team member A. |B| was uttered by member B, and |C| was uttered by member C. They are shown as circle in Figure 2. A∩B∩C is the overlap area at bottom of figure 2(a), and depicts the shared understanding between the team members. First, all uttered words by each team member are extracted from the transcript of the conversation. Then, words which have been used by multiple team members are identified. The words that are commonly used by all team members are taken as a part of the shared mental model on a general level. The sharedness can be found as a ratio of overlap between team members to all uttered concepts among the members. In order to find uttered concepts, raw utterances need to be pre-processed. Noise terms, such as interjections (e.g., "huh" and "sigh") and articles (e.g., "(laugh)" and "(reading)") are excluded from the analysis. Moreover, words that cannot be interpreted as a specific concept, such as substantive verbs (e.g., "be" and "are"), conjunctions (e.g., "but" and "further"), "the" and "do" are excluded as well. Uttered words are inflected to base form in order to find instances of the same concept that might have been expressed in a different format. For example, "uttered" and "utters" are changed to "utter," and "mountain-bikes" and "mountain bicycle" are changed to "mountain-bike."

3.2 Analysis 2

Analysis 2 is a method for finding the abstract level sharedness. The extracted abstract level concept is denoted as A_{abst}. Sharedness at the abstract level can be measured as follows:

$$\text{Sharedness} = \frac{A_{abst} \cap B_{abst} \cap C_{abst}}{|A_{abst}| + |B_{abst}| + |C_{abst}|} \tag{2}$$

|Aabst| refers to the abstract level concept extracted from explicit concepts that were uttered by team member A. |Babst| was uttered by member B, and |Cabst| was uttered by member C. They are shown as inner small circle in figure 2(b). Aabst∩Babst∩Cabst is the overlap at the bottom of figure 2(b), and refers to the shared abstract level focusing theme between all of the team members.

Similar to analysis 1, raw transcription needs to be pre-processed. In order to identify words at the abstract level in the conversation, KeyGraph is applied to each member's utterances separately. The words that are commonly used by all team members among the words extracted by KeyGraph are identified, and represent the abstract level shared mental model.

The abstract level sharedness can be calculated as the ratio of the words that are commonly used by team members to all extracted abstract level words.

4 CASE STUDY

We presented two equations to analyse different kinds of sharedness. In order to illustrate the utility of our approach, we conducted a case study. The data were originally collected for the 1994 Delft DTRS Workshop (Cross et al., 1996).

4.1 Sample

The design exercise involved three professional designers (identified as A, B and C) working in a team, and lasted 120 minutes. The task was to design a 'fastening device' for fastening a backpack on a mountain bike. The design activity was audio-visually recorded.

4.2 Procedure

Data were pre-processed as follows:

1. Transcribe utterance in the video data (provided by the workshop organizers).
   (ID of the speaker is included at start of each sentence.)
2. Inflect words to base form.
   (e.g., plural forms to singular forms, preterit forms to present forms, abbreviations to complete expressions)
3. Delete unnecessary words.
   (e.g., substantive verbs, interjections, conjunctions, articles)
4. Segment the word data by time intervals.
   In this case, the data were divided into 10 consecutive 12 minute intervals.

Then, each analysis was conducted:

- Analysis 1
  Count the number of words in each segment, and check the overlap between team members.
- Analysis 2
  Run Polaris [0.19alpha, English version] (Okazaki and Ohsawa, 2003; Okazaki, 2007) to extract abstract words based on the KeyGraph method. Its output visualizes as a network graph by analysing co-occurrence relations for each participant. To identify the abstract level sharedness, count the number of words extracted by Polaris, and check the overlap between team members.

5 RESULT

The transcript contains 2093 utterances and 22502 words for the 3 designers. Excluding unnecessary words such as "(laugh)", "oh", "are", and "and", 3618 words (1321 baskets) were analyzed.

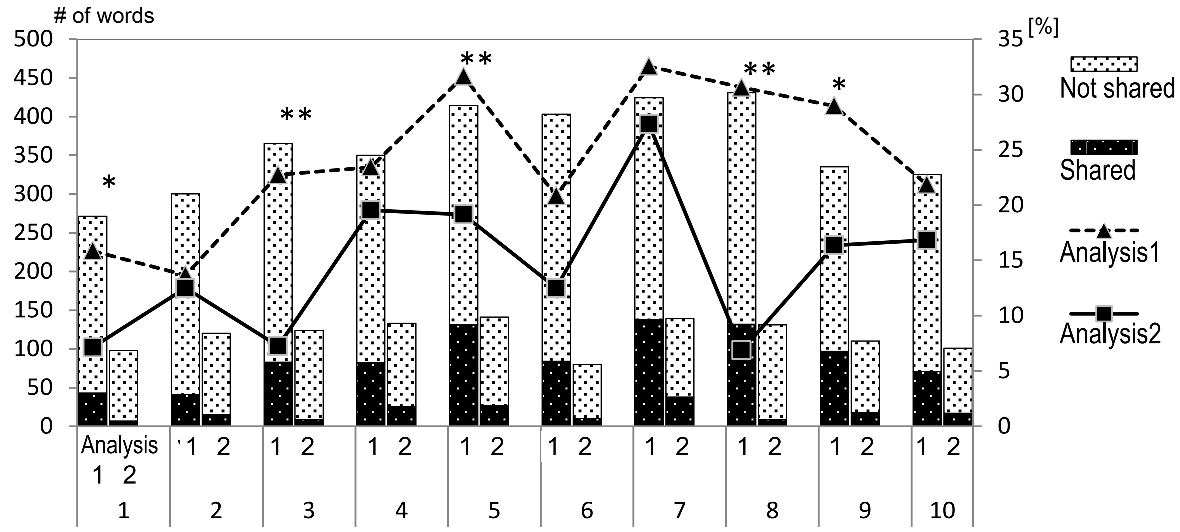


Figure 3. Result of the analyses

Figure 3 shows the comparison of sharedness between Analysis 1 and 2. The horizontal axis shows time segments. The bar chart uses the left vertical axis, and shows the total of the number of words uttered by the three team members. 'Shared' words were common to all team members. The line graph uses the right axis, and shows the percentage of 'shared' word.
Chi-squared test was conducted to compare the sharedness measured by Analysis 1 and 2. There are significant differences in segment1 ($X2(1) = 3.96$, $p < 0.05$), segment 3 ($X2(1) = 13.53$, $p < 0.01$), segment5 ($X2(1) = 7.46$, $p < 0.01$), segment8 ($X2(1) = 28.92$, $p < 0.01$) and segment9 ($X2(1) = 6.21$, $p < 0.05$). In these segments, detail level sharedness is higher than abstract level sharedness.
Both analysis1 and 2 yield the highest score in segment 7. An example of conversations in this segment is as follows:

> A: yeah OK we are gonna be rearward facing er we are going to be horizontal.. we are going to er OK pack to rack or are you ready to do that yet
> C: pack to rack
> A: joining concepts
> B: yeah I think if we
> C: yeah (inaudible)
> B: I think if we do the joining concepts that might help us make some of our materials decisions too sort of
> A: right OK Velcro

In this segment, the team members talked about their common understanding for a considerable amount of time. That is congruent with the classification shown in Table 1.
In segment 8, analysis 1 yields a high score while analysis 2 yields the lowest score.

> B: knobs for quick release
> A: we are gonna need them here too
> C: mm mm four knobbies
> A: but they will all be the same
> C: mm mm because it's the same thread that goes through the braze-ons
> A: and there's plenty of room for it so because we have access to the outside here
> B: yeah maybe I mean I I would not feel horrible if we gave away the er the idea of locking it but um
> A: well we will just throw in an extra set screw so people who want it can do that
> C: mm mm

Since 'sharedness' refers to the overlap of usage between all team members, we first took a closer look at the overlap between each designer, we then compared overlaps between team members.

Figures 4 to 6 show the percentage of the overlap of words for each team members. The line graphs show the overlap between 3 or 2 team members at the abstract level. In comparison with these figures, even though the overlap in all members is low, the overlap in 2 members may not be low. In segment 9, the overlap in all members is low, and the overlap in person B and person C is not low while the overlap in person A and person C is low. It indicates that while person B and C were in discussion, person A might have misunderstood or had another idea.

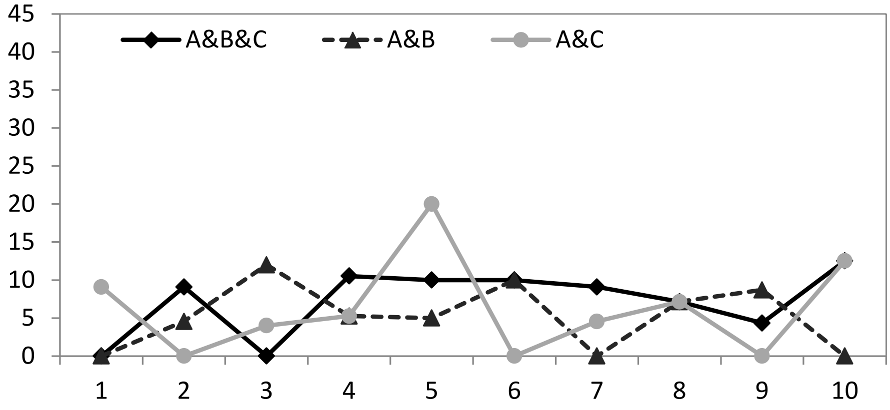


Figure 4. The overlap of words in person A [%]

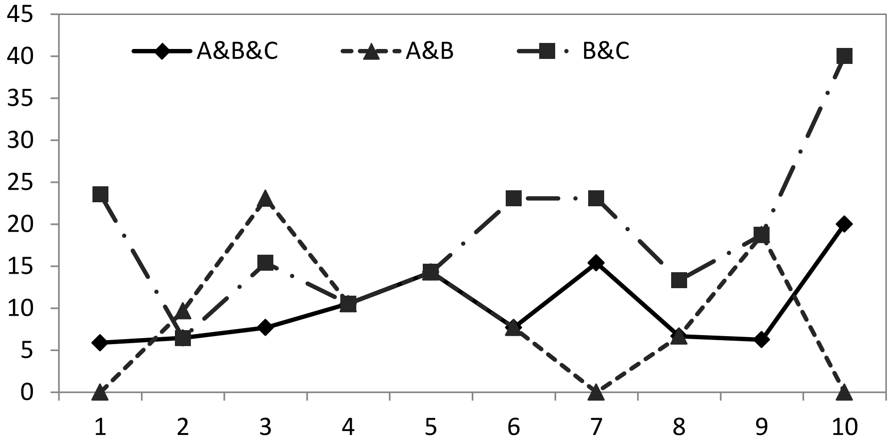


Figure 5. The overlap of words in person B [%]

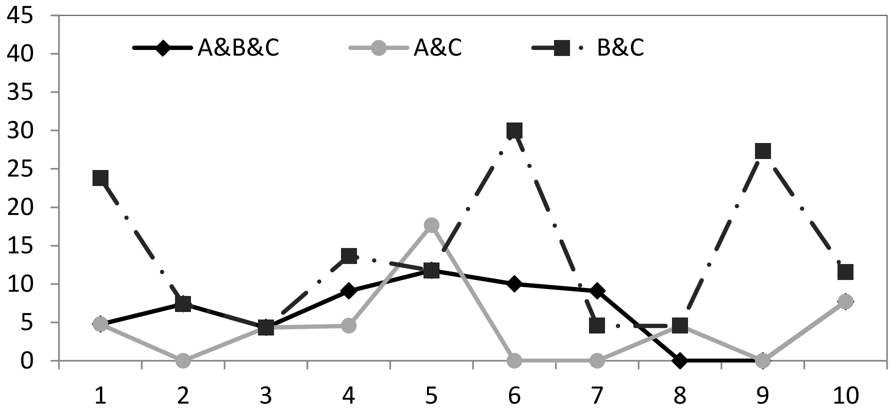


Figure 6. The overlap of words in person C [%]

6 CONCLUSION

In this paper, we proposed a method for analysing sharedness in design teamwork. Then, we applied the proposed method to a case study, and compared the sharedness between abstraction levels. As the results show, sharedness at the general level is higher than sharedness at the abstract level. While this applies to the whole experiment, there are also significant differences in some of the segments. Moreover, while comparing the overlap between each team member, we found that even though sharedness (overlap between all team members) is low, the overlap between any two members can be high. This illustrates the relevance of considering the overlap between a subset of the team members.

The result of the case study suggests that our framework and method has potential for evaluating the development of shared mental models in design teamwork.
However, our approach has limitations. The highest ratio of sharedness was 32.6%, and it is difficult to judge if that is a sufficiently high score. Moreover, abstraction level does not have an absolute standard either; it has relative criterion. When attempting to strictly measure sharedness, it is necessary to correctly weigh sharedness according to the abstraction level and overlap between all or a subset of team members.

REFERENCES

Badke-Schaub, P., Neumann, A., Lauche, K., and Mohammed, S. (2007) Mental models in design teams: a valid approach to performance in design collaboration? CoDesign: International Journal of CoCreation in Design and the Arts, Vol. 3, No. 1, pp. 5–20.

Bierhals, R., Schuster, I., Kohler, P., and Badke-Schaub, P. (2007) Shared mental models—linking team cognition and performance. CoDesign: International Journal of CoCreation in Design and the Arts, Vol. 3, No. 1, pp. 75–94.

Cross, N., Dorst, K., and Christiaans, H. (Eds.) (1996) Analysing design activity. Wiley.

Dong, A. (2005) The latent semantic approach to studying design team communication. Design Studies, 26(5), 445-461.

Eris, O., Martelaro, N., and Badke-Schaub, P. (2014) A comparative analysis of multimodal communication during design sketching in co-located and distributed environments. Design Studies, Vol. 35, No. 6, pp. 559–592.

Kleinsmann, M. and Valkenburg, R. (2008) Barriers and enablers for creating shared understanding in co-design projects. Design Studies, Vol. 29, No. 4, pp. 369-386.

Neumann, A. (2012) Designerly Ways Of Sharing: The Dynamic Development of Shared Mental Models in Design Teams, Delft, Delft University of Technology.

Ohsawa, Y., Benson, N.E., and Yachida, M. (1998) KeyGraph: Automatic Indexing by Co-occurrence Graph based on Building Construction Metaphor, IEEE ADL '98, California, April 22-24, pp. 12–18.

Okazaki, N., and Ohsawa, Y. (2003) Polaris: An Integrated Data Miner for Chance Discovery, Workshop of Chance Discovery and Its Management (in conjunction with International Human Computer Interaction Conference (HCI2003)), Crete, Greece, June 22-27, pp. 27–30.

Okazaki, N. (2007) Polaris - Naoaki Okazaki's website [online], http://www.chokkan.org/software/polaris/#id433544 (5 Dec. 2014 accessed)