

I thank my examiners for their thorough and constructive comments. The point by point description of changes are below: the examiners' comments are in red and my response is in black.

## 1 Professor Catherine Hurley

I appreciate all the comments and suggestions, and will incorporate them into future work. Specific comments are addressed as follows:

### 1.1 Chapter 1

Perhaps though, this would be a good place to detail the co-authorship arrangements for the succeeding chapters, and for the student's contribution to be stated clearly.

Done. A table outlining the main chapters' co-authorship arrangements included in Introduction.

### 1.2 Chapter 2

Q1. In Figure 2.1 on the right hand side it should be  $t/24$ ,  $t/(24 \times 7)$

Not change. Figure is already published.

Q2. Last sentence of Section 2.3.4: fix the table reference

Done.

Q3. In Figure 2.4, the outlier glyphs are in my opinion too big and dark and attract too much attention. The log scale for the y-axis should be mentioned in the caption.

Done. The outliers are made smaller and transparent and caption changed.

Q4. The violin plot in Figure 2.5c is barely recognisable, and comparison of the distributions is challenging. The plot deserves a bit more space.

Not change. Figure is already published

### 1.3 Chapter 3

Q1. On page 33 there is a mention of the hakear package, without a reference.

No change. It appears in the abstract of the paper. For the thesis, I have added it since the abstract acts as a summary to the chapter. The package reference is mentioned in the Supplementary section of the paper. Moreover, the plan is to bring all the functions from *gravi tas* to *hakear* when we publish it.

Q2. In the Introduction state the methods are for continuous variables.

Done. Added "for a continuous univariate dependent variable" in the last paragraph of Introduction.

Q3. In Figure 3.1, the points are a bit hard to see, so it looks like whiskers extend beyond the data.

Done. Changed to `theme_bw()` instead of default and `outlier.alpha (0.5 -> 0.2)` and `geom_jitter(alpha = 0.04 -> 0.03)`. Also jitter-width decreased to 0.2.

Q4. On page 35, refer to months consistently using short or long names.

No change. Refer as months or month\_year depending on the context.

Q5. On page 35  $v$  refers to the number of variables, in Section 3.3.3 it refers to the variable.

Done. On p35,  $v$  changed to  $p$ , where  $p$  represents the number of variables. This is analogous to many time granularities and their pairwise combinations and  $v$  represents the univariate measured variable for which distributions are constructed for different time granularities and their pairs.

Q6. In the Figure 3.2 caption, I do not understand the comment beginning “Difference between the 90th. . .”. Also for the sentence “Energy consumption for (a).”, it would clarify to insert the word “median”.

Done. Changed to “distribution of energy usage”

Q7. On the top of page 38, it should say “the distribution means are three standard deviations apart”.

Done.

Q8. Maybe include a reference for gestalt theory.

Added. **wertheimer1938gestalt**

Q9. In Section 3.2.2, I find the references to the null distribution confusing. Surely that is the design in Figure 3.3(a) only?

. DISCUSS No change. Data in Fig 3.3 (a) is consistent with the null distribution. Null distributions refer to the case when there is no significant distributional differences between categories of one or more granularities.

Q10. In table 3.1  $N_c$  is the number of cyclic granularities, whereas in the text (first sentence of 3.3.2 and 3.3.3) it is  $m$ .

Done.

Add  $m$  to table 3.1  $m$  = number of cyclic granularities to display together

$N_c$  refers to the total number of contextual cyclic granularities.  $m$  refers to the number of cyclic granularities we are considering together in the display. For example, contextual cyclic granularities could be  $hour_{day}$ ,  $day_{week}$  and  $month_{year}$  and we want to visualize any one granularity at a time. So  $N_c = 3$  and  $m = 1$ .

Q11. Add  $v$  to table 3.1.

Done. Added  $v$ :continuous univariate measured variable

Q12. In the first sentence on the top of page 42, ordered and unordered are mixed up. Have you considered the setting where the facet variable levels are ordered? For the within-facet ordered distances, you could consider a distance measure that respects circular order, or choose the start level appropriate to the display.

first part: Done. second part: This is a good suggestion. We will include that into future work.

Q13. I like Figure 3.4. In (3), the dotted arcs only connect to  $a_1$  which might be misleading.

Done. Caption changed to incorporate that. Within-facet distances are illustrated in Panels 3) (when categories are un-ordered, shown only with respect to  $a_1$ ) and Panel 4) (when categories are ordered)

Q14. In the pairwise distance measure on page 43, is there any adjustment made for varying numbers of observations across the levels of A and B? For example in Figure 3.3(d) if there are few values at  $x_{level}=1$  the comparison shown is less interesting

. DISCUSS No change. We assume we have enough observations for each level or combination of levels to compute distributions. As long as that holds, no adjustment made for varying number of observations.

Add it somewhere, need to have reasonable number of observations, otherwise collapse categories (To do)

Q15. The equations on page 44 could be tidied up. There are extra  $()$  on the definition of  $wpd_{perm}$  and on the residual definition at the bottom of the page. Use  $\times$  for the equations.

Done.

Q16. Is there a practical reason why  $wpd_{glm}$  is not working as expected for lower  $n_x$  and  $n_f$ ?

To do. Need to mention it in the paper. No practical reason but a more theoretical one. For lower  $n_x$  and  $n_f$ , the number of combinations  $n_x n_f$  is low such that the max do not have an asymptotic distribution which can be assumed as Normal by CLT. With higher combinations, the distribution of the each combination could be assumed to be normal.

Q17. In the 3.3.1 algorithm, there is  $m$ , and then  $M$ .

Changed. 1.b) for  $i \in 1, 2, \dots, M$ .

Q18. In Table 3.2, I would suggest separating the  $m = 1$  and  $m = 2$  tables.

Not changed.

Q19. The presentation of the material on the simulation study on page 48 could be improved. Where is the notation  $wpd_{l,s}$  used? Figure 3.5 shows the  $m = 2$  results only. The text alludes to a simulation involving different underlying distributions, but this is not mentioned again.

. DISCUSS first part: How? second part: The results are made available in the supplementary paper (Discuss)

Mention  $m=1$  results are same as  $m=2$ , although important not included in the paper but in the supplements. Make subsections for  $m=1$  and 2. TO DO

Q20. In Figure 3.5 the axis tick labels should be smaller. The blue and orange marks are hard to see. Maybe show fewer panels?

Done.

Q21. In Figure 3.6 the axis tick labels should be smaller. The blue and orange are hard to see. The caption should refer to the rug. Maybe show fewer panels?

Done.

Q22. In Figure 3.7 (a) the heatmaps need id labels. The grey color is missing from the legend. Maybe use a different colour in the heatmap for the significant comparisons. State the threshold for significance in the caption. In Table 3.3 the caption should explain the threshold. (Maybe use colour instead of stars to indicate significance?)

To do. DISCUSS.

Q23. The link in the Acknowledgements <https://github.com/Sayani07/paper-hakear> is not available. Neither are the supplementary materials. I understand this is for the paper version, I mention it for completeness.

Changed. The link works. The repository has now been made public.

## 1.4 Chapter 4

Q1. In Section 4.1, line 5 “method of time series clustering”.

Done.

Q2. Page 59, fourth bullet point. I found these sentences confusing.

Done. Rephrased to make it clear.

Q3. In the material in the bottom of page 59, make it clear from the outset you only have data on energy use, not on property size, location, family size and so on.

Done. Added the statement in page 60.

Q4. End of Chapter 4.1: incorrect reference to Section 2.7.

Done.

Q5. I found Figure 4.1 very useful. In each box, would be helpful to put in “or”, in places where only one of the steps listed is performed, eq Normal quantile transform or Robust scaling. As there are many steps in the algorithm, it would be helpful to the reader to label the pipeline steps and to refer back to them in the text. The text in the Data pre-processing box does not make sense to me.

To do? (Or not) Partially done. Need to add “or”

Q6. The section describing RS and NQT is confusing. It states RS is applied to each time series separately. Is NQT also applied to each observation separately? How does “it could be useful to standardize it for the selected set of significant granularities prior to computing the distances” relate to the following bullet points?

Done. Clarification: Each observation (time series) is scaled independently in both JS-NQT and JS-RS. For the WPD approach, each observation might be scaled or not scaled, resulting in usable groups in either case.

Q7. Page 64 “D is the Jensen-Shannon distance”.

What is the question? I have mentioned that D stands for Jensen-Shannon distances.

Q8. In Table 4.1, the R column should have 250, not 20.

Done.

Q9. The description of the data generation on page 67 and Table 4.2 is confusing. Maybe state the distribution of each vt.

To do.

Q10. Where is  $\mu$  in Table 4.2?

Done. Clarification:  $\mu$  is the difference between means considered for consecutive categories.

Q11. In Section 4.3.3 what are the values of R and T?

Done. Clarification: All

Q12. Figure 4.5 caption: MDS summary plots of what?

MDS plot summary of the data sets from the validation study.

Q13. Figure 4.7 is missing labels (a), (b) (c).

Done. Added a, b representing 12 customers (rows) in each of them.

Q14. Why do you chose to summarize 4 and 5 clusters from JS-NQT when index suggests 3 clusters?

Done. The caption and description of the figure in the text have been changed to indicate that Fig. 4.9 depicts a visual summary of why three clusters are insufficient for this data set, however it is recommended by index summary plots. In a cluster analysis, it is standard practice to test a few cluster sizes before and after the optimal  $k$  to see if a different number of clusters is useful. In this example, increasing the number of clusters actually unfolds some behavior which was not apparent with  $k = 3$  as suggested by index.

Q15. The reference to the stationarity assumption in the Discussion needs clarification.

Done. Clarification: “we have assumed the time series to be stationary” has been changed to “the conditional distributions are assumed to remain constant for the observation period” in the Discussion section.

Q16. Page 81 “can not” should be “cannot”

Done.

Q17. Again, the computational burden could do with more Discussion. At present, if I were to use this method on my data, what kind of sizes are realistic to work with?

. DISCUSS

## 2 Prof Juergen Symanzik

### 2.1 Chapter 1

Q1. While the author hints at other sources of similar data, I think it would be worthwhile to give the reader some further specific ideas here in the Introduction where similar complex data may occur, e.g., data from traffic sensors, movement data (turnstiles in metro stations or public buildings), and even more traditional measurements such as temperatures or precipitation over time that could benefit from the methods and software described in this thesis.

. DISCUSS

Q2. It may also be helpful to state what is not covered in this thesis: The spatial component of such data where an additional component could be latitude and longitude or some areal code, such as the post code or some administrative units. Extending the work from this thesis with spatial proximity methods for clustering (<https://doi.org/10.1016/j.cageo.2011.12.017>) [assuming that households in certain residential neighborhoods may have similar energy usage patterns] and trying spatial visualization methods (if possible) such as glyph maps (<https://onlinelibrary.wiley.com/doi/abs/10.1002/env.2152>) should be mentioned somewhere as a consideration for future work | but that may become a future new thesis by itself.

. DISCUSS

Q3. Finally, it would be helpful to indicate here (and in each chapter) what the names or abbreviations for the three R packages (gravitas, hakear, and gracs) represent. Even the full R package title of “gravitas: Explore Probability Distributions for Bivariate Temporal Granularities” does not provide a full answer what the “tas” component means (I am assuming that Gravi stands for Granularities Visualization). I am even more lost with hakear.

### 2.2 Chapter 2

Q1. One reference to a table (Table 2.3) does not resolve and appears as `ref{tab:tab-mayan}` in the main text on p. 16.

Done.

Q2. how to define and handle pay day (or loan day) which often is defined as the 1st (and/or possibly 15th) work day of a month, resulting in some aperiodic granularity as some of these days across the year could initially fall on a weekend, but even more in a few cases, may coincide with a public holiday (and thus shifting pay day by 2 or 3 days). Similarly, extended weekends that could stretch from Fridays to Sundays or from Saturdays to Mondays (and possibly even over a 4-day period) might be worth some discussion, in particular as a case of variable-length aperiodic granularity. This latter granularity may be of particular interest when working with temporal data with an economic (travel, restaurants, etc.) or entertainment (movie theaters, casinos, etc.) aspect.

Very good point. Paper is already published. We would incorporate this in our future work.

### 2.3 Chapter 3

Q1. In Figure 3.1, it would help the reader to mention in the figure caption that a log-scale has been used for the vertical axis. Moreover, it might be helpful to add a tickmark label at 10 kWh and add tickmarks representing each fraction of 10 on the log-scale and not only the midpoint between two tickmark labels. Also, reminding the reader that summer months are in January and February in Australia would be helpful. When looking at the figure (prior to reading the main text), my first interpretation for the increased energy usage in January and February was because of (electric) heating | and not cooling.

Can do.

Q2. Readers may not be familiar with administrative units in Australia. So, instead of speaking of Victoria on p. 35, simply speak of Melbourne (as this seems to be the source of the data).

Can do.

Q3. In Figure 3.2, two households are being compared. It would be much easier for most readers if the graphs use a common scale, thus following the small multiple principle. Both vertical axes should be extend to 1.5 kWh and a ticmark label should be placed there as well.

Can do.

Q4. In general, I like to see ticmark labels close to the extrema of the shown data points. So, in Figure 3.3a, there should be additional ticmark labels at -3 and +3, in 3.3b at -5 and +10, and so on.

Can do.

Q5. Before introducing a new distance measure in Section 3.2, I would like to see a literature review of existing distance measures | and their limitations. Why is it necessary to introduce a new distance measure here? This is partially addressed on p. 41, but that should be placed earlier in the text. One clarifying question: Which density is represented by  $f$  in the equation? And shouldn't there be a  $dx$  at the end of the integral? Also, the distance measures that are mentioned at the end of that paragraph should be explained in one or two sentences.

DISCUSS (Existing distance measure to obtain differences between categories like in ANOVA, limitation: only capture one measure of central tendency Cite some anova here as lit review?

Q6. For the data transformation steps on p. 40, a small table, say with a sample of 5 values from an exponential distribution, might be helpful to better explain each of the three steps.

Discuss.

Q7. A few editorial corrections are necessary, e.g., Dang and Wilkinson (2014); Wilkinson, Anand, and Grossman (2005) provide misses an \and" between the two references. The same holds for Buja et al. (2009); Majumder, Hofmann, and Cook (2013) present. I would leave it to the author to check for similar omissions. Moreover, these should be past tense: "provided" and "presented".

Done. Made it past tense.

Q8. The term Gestalt theory is mentioned a few times (p. 38 & p. 42), but it is never supported by a reference.

Done.

Q9. It would be helpful to add a specific link to a subsection in a cross-reference such as (See the supplements for more details.) on p. 42. Same on p. 47 and p. 48.

Done. (Adding link in supplementary section enough?)

Q10. On p. 45 and in (3.2), it is not immediately clear whether  $n_x$ ;  $n_f$  simultaneously have to be less than or equal to 5 so that  $wpdperm$  is being used - or whether only one of them has to be less than 5. Just a verbal clarification is needed. A practical scenario where this applies might be months (12) and weekdays/weekend (2).

Done. We have assumed both  $n_x$ ;  $n_f$  simultaneously to be less than or equal to 5

Q11. On p. 47, Again consider 3.1(a) and 3.1(b) seems to miss the word "Figure".

Done.

Q12. In Table 3.2, listing a p-value as 0 never is a good idea. List it as  $< 0.01$  or  $< 0.0001$  or any other meaningful threshold that matches the number of your simulation runs.

Q13. The Results section and Figure 3.5 need some clarifications. The text states: Figure 3.5 shows that both the location and scale of the distributions change across panels. I suppose this figure relates to  $m = 2$ , but this is not stated in the main text. Table 3.2 lists both,  $m = 1$  and  $m = 2$ . Moreover, in Figure 3.5, the y{axis ticmark labels overplot and the nx values are partially cut off.

Discuss for changes. Can do.

Q14. There are similar problems with the labels in Figure 3.6. Moreover, the two overlaid curves are very hard to distinguish. Would it help to change colors and transparency, or draw the boundary of the curves with the specific colors (and not in black)? This may require some experimentation. Finally, using a differently colored background (say light yellow) would be helpful to visually demonstrate where `wpdperm` is being used. For the legend, use the terms as in equation (3.2) and not the full word.

Discuss

Q15. The last paragraph on p. 48 uses  $<$  while equation (3.2) uses  $\leq$ . Which one is correct?

Done.  $\leq$  for both.

Q16. Match the text on p. 50 and introduce the abbreviations from Figure 3.7 and Table 3.3, e.g., “hod” likely is “hour day” and so on. Introducing these abbreviations on p. 53 comes too late.

Can do.

Q17. In Figure 3.7a, it is not clear what the eight heatmaps represent. Do they belong to id 1, ..., id 8? Some explanation in the text or listing the id information on the left would be helpful. Similarly, on p. 53, the text states: id 7 and 8 have the same significant harmonies. I do not know where to look at the heatmaps in Figure 3.7a to find this information (and what is mentioned under items 2. and 3. in the text). Some explanation and labeling is needed here.

discuss.

Q18. How were the harmony pairs selected and sorted in Figure 3.7 and Table 3.3? headmaps show 25 pairs, the parallel coordinate plot shows only 14 (same as Table 3.3). However, the last two are sorted differently, “hod wdwnd” (the first row in the table) is neither the first nor the last row in the parallel coordinate plot.

Can do.

Q19. On p. 53, you use the term inconsequential. This hasn't been introduced. Do you mean “not significant” here?

Done. Changed to “insignificant”

Q20. Apparently, Figure 3.8 uses a logscale again. Adjust similar to my comments for Figure 3.1.

Done.

Q21. Are parts a and b in Figure 3.8 correctly labeled and also matching with the figure caption? The caption reads For id 1, patterns look similar within weekdays and weekends. Visually, this seems to be the case for id 7 (in part b). This also visually matches Figure 3.7b.

Caption rephrased to make it more clear.

For id: 7, there is more distributional difference between consecutive hours of the day compared to id:1. Also all the days of the week are different from each other in id:7. id:1 has similar behavior across all days within both weekdays and weekends. For this reason, the `wpd` for id:7 has a higher value than id:1 as the similar behavior within weekdays and weekends balances out the difference between weekdays and weekends. The display with `hod` vs `wdwnd` would have shown higher values of `wpd` for id:1 (as can be verified from Table 3).

Q22. I didn't ask earlier, but how were the eight households for Section 3.4 being selected? Was this based on a random sample, or manually do obtain rather different energy usage patterns? This should be answered earlier on, but this also should be addressed in the Discussion: What can be expected when working with the full data set of Chapter 2, i.e., about 13,000. You indicate: A future direction of work is to be able to explore and compare many individuals/subjects together for similar patterns across significant granularities. What would be computationally (and visually) feasible as 13,000 is a few orders of magnitude higher than the number of eight households used in this example? Clearly, no full answer is expected here, but rather some speculation of what could possibly be done in the future (or what is done in the next chapter).

Discuss.

Q23. The Supplementary materials section mentions data and scripts and a supplementary paper. For the thesis, it would be helpful to indicate where these can be located on github. There is only a link for the R package.

Done.

## 2.4 Chapter 4

Q1. There seems to be some contradiction on p. 60. One sentence states: Tureczek and Nielsen (2017) conducted a systematic study of over 2100 peer-reviewed papers on smart meter data analytics. Another sentence states: Time series data, such as smart meter data, are not well-suited to any of the techniques mentioned in Tureczek and Nielsen (2017).

Done. Rephrased to make it clear that most techniques mentioned in Tureczek and Nielsen (2017) do not treat smart meter data as a data type with temporal component.

Q2. Use a consistent style and use past tense throughout when you summarize what was previously published.

Done.

Q3. The last cross-reference at the end of the Introduction should be to Section 4.5 (and not Section 2.7).

Done.

Q4. At the end of p. 61, the sentence The flow of the procedures is illustrated in Figure 4.1. should be extended with "and is further described in the following subsections." Also match subsection headings and headers in Figure 4.1, e.g., Selecting granularities vs. Find significant granularities and more.

Done.

Q5. The text on p. 68 speaks of Figure 4.3(b) and Figure 4.3 (right). Either add letters a and b or speak of left and right.

Done.

Q6. Similar to Chapter 3, supplementary material should be specified in more detail, e.g., on p. 68, p. 70, p. 71, and p. 75.

Done. Added links in the supplementary materials section at the end of the chapter.

Q7. In Figure 4.5, it is hard to see which groups are overplotting, in particular for S3. To better reveal this graphically, use different (open) glyphs in addition to different colors. In particular, a + for group 1 and an open circle for group 5 may help to better distinguish the groups (and possibly ×, open triangle, and open box to be used for groups 2 to 4).

Done. Not showing in the plot, check again.

Q8. Apparently, in Figure 4.6, the vertical axis is not standardized to [0; 1] as it is frequently done for parallel coordinate plots. Therefore, it would make sense to display an actual vertical axis in each of the three graphs.



No change. Showing the vertical axis would not give us any more information than it is already giving.

Q9. Figure 4.7 speaks of (a) and (b) in the caption, but those letters do not appear in the figure. Either add them or refer to left and right. Moreover, in previous chapters, you used orange and green for the quartiles and 10th/90th quantile. Why not using the same colors and quantiles here? If this becomes too confusing for a reader, then at least, indicate in the caption which quantiles are covered by the gray areas.

Done.

Q10. Be consistent across chapters. For example, in Table 3.3, you use wdwnd. On p. 72 and in Figure 4.7, you use wnwd. Adjust across all chapters. Check whether other abbreviations need to be standardized as well.

Ok. To do in hakear.

Q11. Similar to Figure 4.9, it would help the reader that cluster P-3 is visually represented via three somewhat similar colors for Q-3, Q-4, and Q-5. Changing from red to blue/purple initially hides this information. Also arrange the legend from P-1 to P-3 and Q-1 to Q-5 to make it more obvious that P-1 & Q-1 and P-2 & Q-2 are identical

Discuss.

Q12. It would help the reader to also mention in the caption of Table 4.3 that P-1 & Q-1 and P-2 & Q-2 are identical. I first looked at Figure 4.9 and then at Table 4.3, but if read in the other order, I likely would have been surprised, to see identical values in some of the table rows (without any further explanation).

Done.

Q13. For the thesis, the work is adequate and meaningful. For a journal paper, I would like to see some of the points outlined in the Discussion being addressed. What happens if this method is applied to the data from the 13,000 customers that were introduced earlier on? As a reader of a journal paper, I would rather like to see limitations of the method proposed here, e.g., if it does not scale up then why it most likely does not scale up. Otherwise, it is hard to assess whether it is worthwhile to try this method for one's own data.

We will include it in the journal paper. Split into a "Limitation" and "Discussion" section separately detailing the drawbacks.

## 2.5 Bibliography

Q1. Capitalize all nouns, e.g., in Time-series clustering - A decade review.

To do. Make it consistent sentence case.

Q2. Use full-length journal names, i.e., do not use abbreviations, e.g., in Inf. Syst.

Done. Fixed all similar problems.

Q5. Make sure that URLs are clickable and lead to the correct web page, e.g., robjhyndman.com/publications/hakear does not resolve correctly.

Done. All URLs checked and they are clickable.

Q6. For Gupta, S, RJ Hyndman, D Cook, and A Unwin (2021), I would suggest to list the DOI as <https://doi.org/10.1080/10618600.2021.1938588> as part of the reference.

Done.

Q7. No need to list the ISBN, e.g., in Xie, Y (2016).

Done.