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Quantitative Methods for the Analysis of Medieval Calendars

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1. Introduction: Calendars as Carriers of Ideas

Until the Late Middle Ages, the writing of books was mostly in the hands of the clergymen, and the vast majority of medieval *codices* were thus of ecclesiastical contents. The by far largest genre of medieval books was liturgy. Whatever the exact contents of a liturgical book, it was bound to include an ecclesiastical calendar, since the liturgy varied significantly from one day to another, and calendars were one of the keys to performing the liturgy.

Calendars contained a multitude of important information and were thus very complicated texts. (See, e.g. Hughes 1982, 275-277.) An ecclesiastical calendar was a prerequisite for the Church to function, and every church needed to have its own version that corresponded with the local liturgical practices – and there were tens of thousands of parishes only in Western Europe in the Middle Ages. Consequently, there is still a plethora of extant medieval European calendars in stacks of libraries and archives worldwide.

The calendars were not only ubiquitous and necessary for the liturgy, but also important in both building and manifesting the self-understanding of the community to which it belonged. Although all Christian calendars of Western Europe – i.e., those within the Latin Church – shared a common basis and a number of important feasts like Christmas, Easter and the days of the most important saints, the majority of feasts was chosen locally and to fulfil the needs, wishes and taste of the faithful of a certain geographical area or a parish. Unlike modern “national” calendars, the medieval ones did not follow an entirely uniform model but rather showed a great deal of variation within certain limits.

A medieval ecclesiastical calendar consisted of several layers. It revolved around two overlapping cycles of seasons: the Proper of the Time (*temporale*) with fixed (e.g., Christmas) and semi-fixed (e.g., Easter) pan-Christian feasts, and the Proper of the Saints (*sanctorale*) with saints' days fixed by the date. (On the structure of a medieval calendar, see, e.g. Harper, 1991, 49-57; Hughes, 1982, 3-14.) Whereas the *temporale* was virtually unchanged from one calendar to its contemporaries but showed changes over time, the *sanctorale* varied significantly both over time and geographically to meet the prevailing needs.

Basically, most Western calendars of the High and Late Middle Ages based their *sanctorale* on the Gelasian calendar of saints, a Frankish compilation of the 8th century, and the so-called Gregorian calendar of saints of 791. On the top of this basis, other important entries were added. They might be, e.g., days of saints venerated within the local parish, diocese or realm, or they had to do with, e.g., the dedication of the local church or with important relics. In the end, a calendar gave a detailed picture of all the important saints who were officially venerated and all the feasts that were celebrated within a certain geographic area, be it a diocese or a parish. Thus, there was a huge geographical variation among the contents of the thousands of medieval calendars.

For the communities that created them, calendars were not just chronological aids or lists of days with names, nor they fulfilled just a liturgical function for its own sake. The real significance of calendars for both the contemporary community and a much later historian lies within the fact that they reveal us a carefully composed list of values, ideas and historical or quasi-historical personalities that the community considered important to remember.

As it was vital to keep such lists up-to-date, the contents of a calendar were continuously updated, revised and corrected: New saints and feasts were added, others were removed. In other words, a calendar was never ready, and the procedure of updating and revising its contents resulted in considerable differences that were not only geographically- but also time-oriented. As a trend that can be followed throughout the Middle Ages, the days of an ecclesiastical calendar became more and more populated from one century to another, so that by the Late Middle Ages most calendars contained one or several entries per day. For instance, the calendar of the Roman Missal of 1474 had

only six days without a festal observance in the whole year. (Missale Romanum 1474, fol. 2r-7v.) Moreover, the feasts were ranked according to their liturgical importance towards the later Middle Ages.

While one compares medieval calendars with each other, it is easy to see notable divergence in their contents. However, the big differences were results of a number of small differences piling up. As a calendar mirrored local ideas and values, and these were often shared with the closest neighbouring communities, the contemporary calendars of neighbouring areas were bound to be more similar with each other than those of two places that were very far away from each other in terms of geography or time.

To elucidate this mechanics, let us take some examples from the source material of this article. If one compares two randomly-chosen calendars – P1-07 and P1-08 – both originating from the cathedral of Paris in the 14th century, there are just very small differences: the entries of only five days of the entire year differ from each other. When we compare P1-07 with another Parisian calendar from the 15th century (P1-12), there are more, nine differing entries. A comparison of P1-07 with a later German calendar – GE-02 originating from Mainz in the 15th century – yields well over a hundred differences.

The mechanics of mutating the contents of calendars has an obvious analogy to the development of textual traditions through copying by hand. Just like the contents of a calendar changed to represent the feasts and saints of a certain geographic area in a certain time, the individual scribes copying an exemplar of a text made their own intentional and unintentional changes in their copy. Hence, this article aims to explore the uses of stemmatological and phylomemetical approaches used in textual scholarship in studying large numbers of medieval hand-written calendars.

2. Why Medieval Calendars?

The study and comparison of ecclesiastical calendars can shed new light on a multitude of questions related to several fields of medieval life. As pointed out above, calendars were nearly ubiquitous

sources that had an effect on everyone's life. Not only religious sources, they had important functions in laymen's everyday life, too, as they were organizing principles of social life and dictated the rhythm of work and rest. As a whole, the composition of a calendar offers an interesting insight into the community's values and hopes. On the other hand, if compared meticulously with other calendars, a calendar can demonstrate various of influences received by the local community. Thus, it can show cultural, ecclesiastical, political or economic ties, contacts and varying loyalties.

Another interesting way to look at the calendars is to pay attention to the relationships between centres and peripheries. According to the Church's regulations and customs, the bishops were officially responsible for going through and approving all the liturgical books – including their calendars – used in the parishes of their dioceses. Previous scholarship has brought to light numerous cases, in which such regulations seem to have been completely forgotten. But how does the big picture look like when we have a look at several hundred calendars? Centres and peripheries are also involved when we study the changes that took place in the whole set of calendars over a longer period of time: Why did the changes in some areas take place sooner and faster than in others?

The study of the individual saints' days, in turn, gives valuable information on the pace and directions of the transmission of new cults. For instance, the knowledge of where and how fast the feast of a newly canonized saint was integrated to the local calendars may reveal cultural patterns that no other historical sources can tell us about. By following trails of new cults or other changes in the calendars, one can shape the highways of knowledge in medieval Western Europe.

Taking into account the importance of calendars for many aspects of medieval life, it is astonishing that this significant source group is not being scrutinized by innumerable scholars. In fact, the heyday of the study of medieval calendars was already a century ago, when the current basis of calendar studies was laid. (E.g. Grotefend, 1872; Grotefend, 1898; Zilliken, 1910; Miesges, 1915; Malin, 1925.) In many countries, this was done hand in hand with the local history and the national edition projects of medieval charters. The scholars of the late 19th and early 20th centuries did a marvellous job, and most of their theses and hypotheses still stand. Naturally, there have been and are being done excellent studies on individual calendars, but for a long time it was not *en vogue* to study

103 big corpora of calendar material. This *status quo* seems to be changing. Lately, there are some great
104 scholarly projects, like Giacomo Baroffio's *Iter liturgicum Italicum* (liturgicum.irht.cnrs.fr//fr/;
105 Baroffio, 2003), or Denis Muzerelle's and Erik Drigsdahl's databases of calendars (see below). One
106 should also mention Saskia van Bergen's methodological pioneering work when she used hierarchical
107 cluster analysis using SPSS software package in 2007. (van Bergen, 2007, 510-521; cf. Plummer,
108 1988.)

109 As a whole, our knowledge of large-scale calendrical patterns and how they reflect medieval
110 cultural contacts is not essentially broader than it was a century ago – in spite of the fact that the
111 access to the actual sources if much easier than before. The same can be said about the methods: the
112 sources are often being studied by mostly the very same methods as a century ago. In most cases,
113 attention seems to be paid on individual feasts rather than the whole text and contents of a calendar.

114 The historians of today have access to a far greater amount of medieval calendars than their
115 predecessors. To be able to draw new conclusions based on this multitude new tools are called for. In
116 this article, we propose three computerized approaches that can both facilitate the study of big
117 amounts of calendar data and intensify the scrutiny of individual calendars in the future. First, we
118 explore the uses of a "quick and dirty" method of applying previously successful methods of
119 computer-aided stemmatology to a vast collection of calendars to get quickly an overview of a corpus
120 of calendars and to categorize it. Secondly, we propose a method that compares the contents of a
121 calendar to others in relation to the geographical distance of the places of their origin to see anomalies
122 within the calendar corpus. Our third approach aims to test and develop the traditional method of
123 identifying saints or feasts that indicate a certain origin of a calendar.

124 The first one concentrates on a sizeable group of calendars, the second approach on one
125 calendar in relation to others, and the third approach explores the details of one calendar at a time.
126 Each of the methods also involves a visualization which makes the results more accessible.

3. Methodological Challenges

The first of the methods of studying a high number of medieval calendars proposed in this article owes a great deal to computerized methods developed in the field of stemmatology, the study of textual traditions, during the past decades. Stemmatology, in turn, has taken advantage of phylogenetics of evolutionary biology. Already for some time, many of the methods and algorithms of both phylogenetics and computer-aided stemmatology have been used to explore the development of not only texts, but also languages and cultural artefacts. The approach has been dubbed to "phylomemetics" (Howe and Windram, 2011). Whereas computer-assisted stemmatology of texts has already found a relatively broad and ever widening group of scholarly users and its different approaches are able to give useful hypotheses on history of textual traditions, the computerized methods of phylomemetics are still in their infancy and need to be developed further.

The calendars are an ideal test ground for developing phylomemetical methods. On one hand, calendars are texts and it is partly possible to build on the basis of stemmatology. Just like in ancient and medieval textual traditions studied by stemmatology, the clanedars shared similarities, but there was also an endless heterogeneity among the calendars. Maybe the most significant difference between a tradition of a literary work and a set of medieval calendars lies within the way individual witnesses of the tradition were composed. A textual tradition can usually be described as "stabile", since the single witnesses – or copies or versions of the text – usually tried to imitate the exemplar faithfully and were only seldom changed significantly after they were written down. A group of medieval calendars, in turn, while technically a textual tradition, was much more labile, as the local calendars were being constantly revised and rewritten – i.e., it was a living tradition. Moreover, a calendar extremely seldom had just one single exemplar from which it was copied – the normal case in literary textual traditions – but influences were being taken from several different directions. Thus, the tradition is thoroughly contaminated, i.e. most of the witnesses have several exemplars from which their contents were taken. As a consequence, the graph describing the development and history of calendars and the relationships between the individual witnesses of the tradition is probably more like a complicated network than a tree as in classical textual criticism and computer-assisted

stemmatology. This is a methodological challenge, since contamination has proved out to be the single most difficult obstacle for the previous methods of computer-assisted stemmatology. (See Roos & Heikkilä, 2009.)

It can also be asked if a calendar tradition ever had a real original and correct version in the sense a textual tradition of a literary work had its archetype. In a sense, every calendar was original and correct for the community that used it. A graph hypothesizing the relationships between different calendars can be rooted to show the direction of the development taking place within the tradition, but the advantages of such a procedure are not as obvious as in textual criticism and computerized stemmatology.

4. Material

There is a high number of edited and an almost endless amount of unedited medieval calendars. In our experiment, we did not transcribe unedited calendars from manuscript sources but use a set of 339 previously transcribed calendars already in electronic form. All the calendars of our primary data set are housed in the Bibliothèque nationale in Paris, France. They were examined, transcribed and published by a group of Bollandist scholars in the 19th century (Catalogus, 1893, 579 ff.), and put on the Internet as a part of the *Calendoscope* tool (calendriers.irht.cnrs.fr/calscope.htm; a slightly updated version: calendoscope.irht.cnrs.fr) by Denis Muzerelle in the late 20th century.

The 339 calendars are part of as many liturgical books. 152 of the books are Missals, 134 Breviaries, 23 Diurnals, 15 Psalters, six Sacramentaries, four Antiphonaries, two Pontificals, and three uncategorized liturgical books. For reasons of logic and easy operability we use the same sigla (letter code indicating a diocese or ecclesiastical order + a running number) for calendars in individual manuscripts and manuscript groups as Denis Muzerelle, who in turn took them from the Bollandists. The shelf marks behind the sigla can easily be found at calendoscope.irht.cnrs.fr/codicum. In order to facilitate the work of manuscript scholars, the shelf marks of the calendars used in our examples are given in the endnotes.

The data is available in a format where each calendar comprises of 365 entries indicating for each day of the year the feast, many of them dedicated to a particular saint, that was celebrated on that day, if any. In many cases, the calendars give more than one feast for the same day. Some further information about the liturgical importance (i.e., the liturgical grade) of the feast or about the saint (e.g., a bishop, martyr, virgin etc.) celebrated on the day in question was also recorded.

The Parisian calendars published by the Bollandists are mainly of French origin – with some calendars from Spain, Italy, Hungary, England and Germany – and most of them can be dated to the 12^{th}-15^{th} centuries. However, very many of the datings and provenances are vague and preliminary and should be verified if used in traditional historical research. In spite of the effort of Denis Muzerelle to compare many of the descriptions of individual calendars to more recent catalogues of the Parisian manuscripts than that of the Bollandists (Leroquais, 1924, 1927, 1934, 1937, 1940-41.), the material probably still contains errors made during the original transcription of the material. (See the *Calendoscope* website for Muzerelle's caveats.)

As another caveat, it should be emphasized that the collection does not allow watertight conclusions of historical nature that could be applied to whole France. To get a real overview of at least French calendars of the Late Middle Ages, one should use the manuscript collections of several libraries and archives to rule out the chance that the conservation of calendars of just one, however important, library distorts the results. There may be features in the history of the manuscript collections of the Bibliothèque nationale that may have led to surviving of calendar manuscripts from certain period or geographic location. Thus, we make no effort to draw far-reaching historical conclusions based on only this material. Our data set serves to show the possibilities of the computerized approaches and, in the best case, to isolate some promising detailed research questions that need to be examined more closely in due course.

Despite the above-mentioned limitations, the calendars of the Bibliothèque nationale are a very suitable data set for our purposes. An important point for the use of computerized methods is that the calendars were transcribed according to a consequent set of rules; e.g. the names were normalised similarly. The collection of calendars is sizeable – it could not be studied without computers –, and

206 has both geographical dispersion and material from different centuries. The fact that the material dates
207 from the last centuries of the Middle Ages is advantageous, since the calendars of that period contain
208 more feasts than the previous ones.

209 ## 5. Exploratory Analysis – Phylogenetic Analysis by Neighbor-Joining

210 Since the calendar material is too large and diverse for manual exploration – summing together the
211 number of feasts in each of the more than 300 calendars amounts to over 62 000 individual calendar
212 entries – we first approach the material using exploratory techniques. In particular, we apply
213 Neighbor-Joining (NJ) (Saitou and Nei, 1997) to obtain a phylogenetic tree representing the
214 relationships between the calendars. This approach is now widely used in stemmatology, wherein the
215 aim is to discover the copying relationships between a number of extant manuscripts containing
216 versions of the same literary work. However, as discussed above, this aim is unlikely to be achievable
217 in the case of calendars as their evolution is much more convolved than that of typical literary works.

218 Rather than interpreting the phylogenetic tree as a hypothesis about direct copying
219 relationships, we use it to quickly summarize groups of calendars that are more closely related to each
220 other than calendars in distant branches in the tree. Thus, for a single calendar, one can quickly
221 identify which other calendars are most similar to it by looking at the neighbouring nodes in the tree.
222 One has to keep in mind, of course, that the tree can only represent some of the similarities among the
223 calendars and some information in the data is lost. The amount of lost information can be assessed by
224 computing the coefficient of determination[1], R^2, commonly used to measure the fit in regression
225 models and other statistical fitting procedures, see e.g. (Draper and Smith, 1998).

226 The NJ method belongs to the class of distance-based methods and takes as input a distance
227 matrix. We let the distances be defined simply by measuring how many feasts occur in only one of the
228 calendars. This number was divided by a maximum, which we to chose somewhat cautiously as n =
229 500. Note in particular that we ignore the day on which each feast is celebrated.[2] Furthermore,
230 following Spencer and Howe (2001), we applied a Jukes-Cantor correction (for binary states) which

should improve phylogenetic tree inference based on distance-based methods. The coefficient of determination of the resulting tree was $R^2 = 0.946$. This can be considered to be a moderately high score, suggesting that there is a relatively strong tree-like signal but that there is also a residual (0.054 units) of more complex structure in the data.

The results of the NJ on the full calendar data is shown in Fig. 1. As can be seen from it, the groups are not very well separated; the branches rather blend together so that between each of the major branches, if there can be even said to be any, there are a number of intermediate nodes representing calendars that don't really fit to either of the neighbouring branches. This was to be expected, since many of the feasts of a calendar did not always follow the boundaries of an ecclesiastical province, and there were bound to be many similarities between calendars of locations geographically close to each other.

***** Fig. 1 about here *****

The easiest and quickest way to evaluate the results of the stemmatological method giving us an overview of a number of calendars is to compare the results with geography. As calendars written to be used in the same area at the same time were probably rather similar with each other due to practical reasons – e.g. same saints were venerated, same liturgical practices applied etc. – the calendars used within the same diocesis, for instance, should be found close to each other in the stemma, as well. In our results of the NJ, most – although not all – calendars can be grouped roughly according to the ecclesiastical province, i.e. an area consisting of several dioceses but nominally under a Metropolitan bishop, in which they were written and (or) used. The monastic calendars and those of the mendicant orders are an exception, since they did not normally follow the local liturgy but had their own liturgical regulations that, in turn, often influenced the practices of the local parishes. However, the calendars of the different monastic and mendicant orders shared many features typical for just that order and one would therefore expect to find them as their own groups in the correct stemma.

In our NJ tree, all the calendars of ecclesiastical provinces of Albi (AL), Aix (AQ), Bordeaux (BU), Tarentaise (TA) and the calendars of the dioceses of Northern Italy (IT) are bound nicely

together. Moreover, the results of the provinces of Bourges (BI), Paris (both non-monastic, P1-P2, and monastic P3[3]), Tours (TU), Cambrai (CA), as well as the Roman (RM), German (GE) and Spanish (HI) calendars are rather similar. In the provinces of Sens (SE), Rouen (RO), Arles (AR), Lyon (LU), Reims (RE) and Trier (TR) the outcome is more dispersed, although the majority of calendars are still found together. When we look at the calendars of the monastic and mendicant orders, the results are similar. The stemmatological method represents the calendars of the Augustinians (AG), Carmelites (CM), Carthusians (CT), Dominicans (DO) and Franciscans (FR) as their own groups – just as expected since each of the orders had their own distinctive feasts. The finding is not surprising, and corresponds largely to the localization of the calendars in previous scholarship that used mainly calendars to hypothesize the origins of the liturgical manuscripts. However, this is not a case of circular reasoning, since the logic of finding the groups is profoundly different: whereas previous scholars have used individual feasts to localize the manuscript, our method uses the whole contents of the calendar for comparison. Thus, the computerized analysis corroborates the previous findings in many cases.

When looking at the more general geographic picture of the dioceses and ecclesiastical provinces, the outcome is somewhat confusing. Many of the groups representing calendars from certain ecclesiastical province are close to their geographic neighbours: e.g. the calendars from Paris, Reims, Rouen, and Tours are located very close to each other. Calendars of the middle and south-western France, like Bordeaux, Bourges, and Auch show clear similarities; just like most calendars from the southern Arles, Aix and Albi; and those of Lyon, Vienne and Besançon. Those of Trier province are together with other calendars from the German world, as one would expect. Still, there are some peculiarities, as well, like the group of Albi calendars that share the most similarities with Roman, Franciscan and Augustinian calendars. Possibly the closeness with those calendars may be explained by the strict ecclesiastical reform of the area after the crushing of Albigensian heretics in the 13th century, but one would expect the Dominican calendar to have affected the local calendar more, since it was the Dominican order that played the central role in reforming the Albigensians.

In all, the results of the phylogenetic method appear to draw a picture of cultural contacts and influences rather similar to what is known from elsewhere. One can see a very rough division between south-western (Auch, Bordeaux, including Bourges in the middle of France), south-eastern (Albi, Aix), eastern (Sens, Lyon, Tarentaise), and northern (Paris, Reims, Tours, Rouen) group of calendars, and it seems that many calendar influences moved more between the north and the south of France than in eastern-western direction. The most important trade routes, ways of pilgrimage, and the spread of the Black Death shaped a very similar pattern in the mid-14th century and earlier. E.g. the river valleys of Rhône, Seine and Loire as well as the eastern-western trade route in the South of France seem to have been just as natural routes of cultural and calendrical transmission as they were important for trade. (Gauvard, 2010, 259; Benedictow, 2004, 96-109, Map 1; Dubois, 1988, 315.) Consequently, the big pattern of cultural influences shaped by the analysis of a number of different calendars is corroborated, albeit the detailed results of our approach would need much further analysis and work.

As a whole, our results corroborate to a large extent the localizations of the individual calendars made in previous scholarship. This finding is far from trivial, banal or self-evident, nor is this a case of circular reasoning, since previous scholars and the method proposed here have profoundly different approaches to the material. Whereas the traditional localizations were made based on the presence / absence of a small amount of individual feasts, other contentual as well as palaeographical and codicological criteria, our approach yields its results by comparing the whole contents of all the calendars.

In other words, already the very simple approach of taking previously existing computerised tools developed for the study of textual traditions and running the calendar data on them proves out to be useful in quickly categorizing the vast calendar material, the study of which would take years when working with classical methods of pen and paper. Even if one has to keep in mind that a tree graph probably does not represent the relationships between individual calendars in an optimal way, the result is encouraging.

In our computerised approach, the basic mechanics of creating the hypothesis on the liturgical context of a calendar is similar to the classical approach of the scholars: The contents of calendars are compared with each other. But whereas the comparison by a scholar traditionally tends to rely on finding individual typical feasts of a region and only can take into account a small part of the whole number of calendars thus distorting the overall picture, our method quickly compares the whole contents and an almost unlimited number of calendars. Consequently, the resulting hypothesis on a calendar's relationships to others is both better justified and immediately set into bigger context. In addition to quickly giving an overview of the material, all this makes the method a useful tool to get fast, mathematically well-grounded hypotheses about the time and place in which and for which a single calendar or a whole liturgical manuscript was written. This, in turn, is important *per se,* since liturgy was the single most numerous genre of medieval books and a very big part of them has not been dated or localized at all or only poorly.

In addition to the shaping of the big picture, let us take three examples highlighting emerging hypotheses about individual calendars on the basis of the stemmatological analysis. The *Calendoscope* of Muzerelle labels calendar AR-02 as a 13th-century *pontificale* from Montmajour Abbey, close to Arles.[4] When analysing the contents of AR-02, however, they do not follow the Arles tradition but share exceptionally many traits with the later tradition of Albi; also the Roman and Augustinian calendars are very close to AR-02. By a closer look at the manuscript, the latter connection becomes clear, since it turns out to be a calendar of the Papal chapel between 1255 and 1279. (Leroquais, 1934, 979.) Another example is calendar IN-03 that has previously been vaguely characterized as a calendar of a *Missale Romanum* with no localization.[5] (Catalogue général, 1939, p. 300, nr. 853.) The analysis of its whole contents suggests that it might be useful to search its origin in the middle part of the province of Bourges, maybe within the area of Clermont, since the contents is very close to a later calendar (BI-03[6]) with provenance there.

Calendar DO-05,[7] in turn, was believed to be Franciscan by Leroquais and Muzerelle (although labelled as a part of the Dominican group by both scholars). Our analysis shows it to share more contents with several Augustinian and Roman calendars; in fact, already the missing of the feast

of the stigmata of St Francis on September 17 makes the Franciscan provenance doubtful – although Leroquais and Muzerelle are right in pointing out the close relationship of DO-05 with several Franciscan calendars. As to Dominicans, there has been an intense discussion in previous scholarship about the relationship of the Dominican and Parisian liturgy: According to some scholars, the liturgy of Notre Dame exercised a strong influence on that of the Dominicans in the 13th century, while others have opposed this view vehemently. (Wright, 1989, 80-81; Deladande, 1949, 13-77; Bonniwell, 1944, 171-193.) The calendars allow only a small glimpse to the rich tapestry of the medieval liturgical life, but as an *excursus* we can state that our analysis of the Dominican and Parisian calendars does not support the idea of a very close connection, as the whole contents of the calendars of Notre Dame on one hand and those of the Dominican order on the other are located far away from each other in the stemma.

An interesting question, which is beyond the scope of this article, is how much more information could be extracted from the material by comparing the calendards not only in terms of whether a given feast occurs in the calendar at all but also in terms of when, i.e., on which date, the feasts may occur, and the liturgical ranks of the feasts. Both these pieces of information are readily available in the data. In fact, traditionally, most scholars studying individual saints and their cults have considered the varying liturgical grades to be important in shaping the dissemination of the cult. It is true that they often changed over time and from one place to another, and that the diverse liturgical ranks reflect the intensity and importance of a feast and thus facilitate to see its development (e.g. Wright, 1989, 76-78 with a Parisian example; but cf. Long, 2008, 43-53). Addressing this issue would require that some weights of evidence be attached to the existence, date, and rank of each feast. Choosing an appropriate set of weights is a non-trivial matter, as it may affect the results significantly (see, e.g. Spencer at al., 2004).

6. So Near and Yet So Far – Geographic Distance vs Similarity

Getting an overall picture of a big set of calendars has its uses, but many if not most scholars are interested in studying the contents of individual calendars of certain diocese, monastery or parish, and their relationships to calendars from elsewhere. Therefore, the simple approach of applying phylogenetic algorithms developed for the study of evolutionary relationships is not enough, but a more sophisticated method to visualise the relationships of individual calendars can complement the picture.

Even in the method proposed here, the starting point is the idea that the big differences between two calendars are results of small differences piling up. As the calendars of neighbouring parishes or dioceses shared many of the same (often local) feasts, the contents of two calendars geographically close to each other are probably more similar than those of two calendars geographically far from each other. Thus, it is meaningful to study the differences of the contents of a pair of calendars in relation to their geographical distance. If the similarity is more significant than the geographical distance would suggest, one of the two calendars may have influenced the other more than expected. The only way to properly define what degree of similarity expected based on a given distance is to analyze a large set of calendars across a wide range of geographic distances.

To combine the calendar data with geographic information, we consider in this section only those calendars for which a specific location such as a city, episcopal see, monastery or parish, is given in previous scholarship. In addition, we exclude two calendars which are located far away from all the other calendars (GE-01 in Esztergom in Northern Hungary and HI-02 in Sevilla in Southern Spain): we have insufficient data to extrapolate the expected degree of similarity for such long distances. This leaves 297 calendars.

In order to exclude the effect of the fact that the calendars were from different centuries, we analyse the calendars from each century separately. Thus we first fit the above model to calendars from the 13th (n = 66), 14th (n = 79), and 15th (n = 152) centuries.[8]

First, we construct a measure of the similarity between two calendars. To do so, we let each calendar be represented simply as a set of feasts that occur in the calendar. Thus, again we ignore the particular days of the year on which the feasts are celebrated. Like in the phylogenetic tree analysis above, given two calendars, A and B, we evaluate the number of feasts that occur in calendar A, denoting it by k_A, and likewise the number of feasts that occur calendar B, denoting it by k_B. Finally, we evaluate the number of feasts that occur in both calendars, and denote it by k. Additionally, we need to fix the supposed maximum number of feasts in both calendars, which we denote by n. The choice of n has mainly a scaling effect. We let $n = 500$ which ensures that the highest similarity values are close to 1.0.

Given the above quantities, we let the similarity be defined by the *mutual information* between two random variables, each of which indicates whether a given feast appears in one of two calendars. The mutual information is a general measure of dependency and takes value zero for two independent random variable; see (Cover and Thomas, 2006). The expression for the mutual information metric is given by

$$\begin{aligned} MI_{AB} = \{\, & n \log n - k_A \log k_A - (n-k_A) \log (n-k_A) + (k_A-k) \log (k_A-k) \\ & - k_B \log k_B - (n-k_B) \log (n-k_B) + (k_B-k) \log (k_B-k) \\ & + k \log k + (n-k_A-k_B+k) \log (n-k_A-k_B+k) \,\} \,/\, \mathrm{n}, \end{aligned}$$

where we follow the convention that $0 \log 0 = 0$. For example, if $n = 500$, $k_A = 250$, $k_B = 250$, then the mutual information metric takes value zero, $MI = 0.0$, if the number of feasts occurring in both calendars equals $k = 125$, the number expected by chance when the occurrences are independent. On the other hand, in the case where the calendars are equivalent, i.e., $k = 250$, it is easy to check that the obtain $MI = 1.0$. Note that the maximum 1.0 is possible only for calendars that include exactly half of the maximum number of feasts (which we assumed to be $n = 500$); otherwise the maximum is lower indicating that a calendar that includes very few feasts or almost all the feasts carries little information about any other calendar. A histogram showing the distribution of the MI values between every pair of calendars is shown in Fig. 2. The values range between the minimum 0.015 (calendars AG-01 and P2-

410 15[9]) and maximum 0.9999 (calendars P1-26 and P1-27[10] which include the exact same set of feasts).
411 Note that AG-01 and P2-15 are also very distant in the tree of Fig. 1, whereas the second pair appear
412 next to each other in the tree.

413 ***** Fig. 2 about here *****

414 Generally speaking, as expected the *MI* value tends to decrease with the geographic distance, d_{AB},
415 between the two calendars: the further apart two calendars were located, the more independent they
416 tend to be. We model the dependency of *MI* on the distance using a linear regression model

417 $$MI_{AB} = \alpha\, d_{AB} + \beta \log (d_{AB} + 0.001) + residual,$$

418 where α and β are parameters to be determined by the least squares technique. The constant 0.001
419 ensures that the logarithmic term is bounded even when the calendars are located in the same place
420 but allows for a sharp decrease in *MI* as soon as the geographic distance becomes greater than zero.
421 We chose this particular functional form by trying a number of similar simple models, including for
422 instance only the linear term $\alpha\, d_{AB}$ or replacing the logarithmic term by a quadratic one, but the model
423 above turned out to give the best fit to the data. The coefficient of determination (see Sec. 5)
424 characterizing the explanatory power of the above model is $R^2 = 0.272$ for the 13th century calendars,
425 $R^2 = 0.279$ for the 14th century calendars, and $R^2 = 0.350$ for the 15th century calendars. Note that
426 these values are not comparable to those from the phylogenetic analysis as the phylogenetic tree is
427 optimized to fit the data and includes as many edge length parameters as there are taxa (calendars)
428 while the above geography-based model includes only two parameters (α and β).[11] In accordance with
429 the relatively low R^2 values, the residual variation between individual (pairs of) calendars after the
430 model is fitted to the data is quite high. In other words, there remains a lot to be explained by other
431 factors than geography, which is exactly our aim. In what follows, we apply two visualization
432 methods that enable us to investigate in more detail the variation unexplained by geography.

433 Having fitted the above model to the data, which captures the overall dependency of the *MI*
434 value on the geographic distance, we can compare individual calendars to discover pairs of calendars
435 whose contents are either unusually dependent (high *MI* value) or unusually independent of each other

436 (low *MI* value) compared to other calendars at similar geographic distance. We claim that such
437 deviations from the general trend are interesting and need to be explained by investigating the
438 possible historical reasons that might have caused them.

439 We focus our attention to the group of calendars with medieval Parisian origin. This is
440 because Paris is the most common location of the calendars in our data. Furthermore, Paris was a
441 centre *non plus ultra* in medieval France as the preferred seat of the French king, with an episcopal
442 see of significance, and with the most important university of the Christendom. Therefore, even
443 preliminary new results on the local calendars may be of interest to a number of modern scholars. On
444 the one hand, we try to trace changes that took place from the early 13th to the late 15th century with
445 regard to the relationship of the Paris calendars to other contemporary calendars. On the other hand,
446 we shall compare the calendar traditions of the cathedral of Paris with those of the other local
447 churches and monasteries, especially those of Saint-Victor and Saint-Germain des Prés. Both
448 approaches aim to find similarities in the contents of calendars – similarities that are more obvious
449 than one would expect based on the geographical distance between the ecclesiastical institutions.
450 Those, in turn, can reveal a pattern of cultural influences of which there may not be any direct
451 historical sources and have thus been overlooked in scholarship.

452 As a general observation rising from our Parisian material, it can be concluded that several
453 groups can be found within the calendars of Parisian provenance or contents. Most of them are secular
454 and belong to the tradition of the local cathedral (Notre Dame de Paris, groups P1 and P2). Two other
455 groups testify to slightly different monastic traditions: those of Saint-Victor and Saint-Germain des
456 Prés (both for a part of group P3).

457 We were also keen to look at a long timescale of calendars of the cathedral of Paris from the
458 early 13th to the end of the 15th century, for which the data is especially well suited. In order to trace a
459 chronological pattern, we arranged the calendars with the provenance of the cathedral of Paris
460 according to their age. Some of the calendars have been dated to a year by their scribes, but as most of
461 the calendars have been dated by previous scholars according to the contents, palaeography and
462 codicology of the manuscripts, the majority of their datings are rather vague, with many calendars

463 dated only to a certain century or a part of it. To achieve a rough chronological order, we calculated
464 an average year for every calendar, based on the previous datings: e.g. a dating to 15th century resulted
465 in average 1450, a dating to the first third of the 13th century an average year of 1217, a dating to the
466 mid- or late 14th century an average of 1363 etc. We are fully aware of the problems of such a
467 procedure,[12] but found it necessary in order to create a time series in which the calendars are situated
468 in a sequence roughly by their date. Although not all the calendars are likely to be dated correctly in
469 relation to the others, the time series gives a truthful big picture of the long development that took
470 place in the Paris calendar during the 13th to 15th centuries.

471 Figure 3 illustrates the similarities between a typical example of a 13th century calendar, P1-
472 03,[13] compared to other 13th century calendars using two visual displays. The graph display shows the
473 general trend within the century estimated using the linear regression model as described above as
474 well as the individual deviations from this trend. The deviations are also shown on the map display as
475 arrows whose lengths are proportional to the deviation. Orange arrows pointing towards the calendar
476 that is chosen as the center point, in this case P1-03 and Paris, correspond to higher than average
477 similarity and blue arrows pointing away correspond to lower than average similarity. For more
478 details, see the figure caption.

479 ***** Fig. 3 here *****

480 Already this first example goes to prove that this kind of analysis may help to pinpoint anomalies on
481 the level of individual manuscripts. A good example of this is the 13th-century P2-04,[14] a missal
482 generally considered to be from Senlis (Leroquais 1924, II, 78 nr. 258; modern catalogues of the
483 *Bibliothèque nationale* agree; see archivesetmanuscrits.bnf.fr). On a closer look, its calendar shows a
484 striking resemblance to the contemporary calendars of the cathedral of Paris.[15] Maybe the provenance
485 of the missal is more complicated than believed by the previous scholarship. In fact, the Parisian
486 provenance was suggested already a hundred years ago (Poëte and Clouzot 1916, II, 227), and the
487 analysis of its calendar gives additional reason to question the origin of the manuscript.

The calendars of the cathedral of Paris had a distinctive own tradition that differed significantly from the vast majority of other calendars during the 13th to 15th centuries. The differences of the contents are much more marked than one would expect on grounds of mere geography. The influence of Paris liturgy to the other dioceses of the North of France – or vice versa – seems not to have been very significant, since the graphs showing similarities with other calendars have a sharp peak that is followed by a very deep descent; already in the calendars of the neighbouring dioceses there are more differences than similarities to Paris to be found. Still, there are more fine-grained patterns to be observed. For example, the calendars from the North of France and West of Paris tend to be more similar with Parisian calendars than the ones from East or South of Paris. The overall difference of the contents of the calendars of our data set grew slightly from one century to another, probably mostly due to the addition of new feasts in most of the calendars. Figure 4 shows a typical example of a 15th century calendar of Parisian origin, P1-25.[16] Interestingly, it suggests that the overall differences of the calendars of Paris cathedral to the others remained more or less on the same level during the 13th to 15th centuries; compare in particular the similarity values in Figs. 3 and 4. A very similar pattern is present in most other Parisian calendars.

***** Fig. 4 here *****

The latter result is in contrast with the findings of Craig Wright, who has scrutinized the liturgy of the cathedral of Notre Dame during the Middle Ages: According to him, the Parisian calendar became more and more distinctive with more local traits during the 13th and 14th centuries. (Wright, 1989, 76-79.) Wright argues that this also meant the decrease of the influence of the Roman ecclesiastical calendar on that of Paris. The idea is logical *per se*, since it is well known that the French dioceses distanced themselves from Rome and the Pope in terms of the Gallicanism during the Great Schism of the late 14th and early 15th centuries. In addition, the growth of the sheer size of the Parisian calendars (and Roman or any other calendars, for that matter, since nearly all local calendars became more and more populated with feasts towards the end of the Middle Ages) was bound to decrease the amount of same feasts contained in any other calendar. However, in the analysis of our calendar material we did not find strong support to Wright's hypotheses.

What about the relationship of the Parisian calendars to those of other places? When looking at the graphs describing the similarity of their contents with calendars from elsewhere, one is struck by a number of further anomalies. One of them implies that there is a group of Paris calendars (RO-16, P1-01, P3-03, P3-06, and P3-20)[17] the contents of which are much closer to another set of calendars not very far away from Paris. An example is shown in Fig. 5. What all the members of the group have in common, is an emphasized similarity with the contents of several calendars from the monasteries of Saint-Maur des Fossés, just south-east of Paris, and Saint-Corneille in Compiègne, some 60 kilometres north of Paris. (Calendars of Saint-Maur: RE-25–RE-28; those of Saint-Corneille: P3-16, P3-18.) A detailed study on the liturgical contacts between Paris and the monasteries nearby is beyond the scope of the present work, but it suffices to say that there seems to be good grounds to hypothesize such a close connection and to investigate it in future work.

***** Fig. 5 here *****

The great Parisian monasteries of Saint-Victor and Saint-Germain des Prés had, like any significant monastery, their own calendar and liturgical traditions. Our material contains only few – six from the first and three from the latter – calendars from those institutions, but it is safe to conclude that their traditions differed greatly both from that of the local cathedral and from each other. As to Saint-Victor, only its first calendar among the material (P1-02, from the 13th century)[18] concurs with those of the cathedral of Paris, but the others show a totally different and rather coherent tradition with apparent links to the calendars from the South of France (esp. P3-04–P3-06, and P3-10).[19] The calendars with a provenance in Saint-Germain des Prés, in turn, do not allow a scrutiny of a longer development, since all three among our material come from the 14th century (P3-01–P3-03).[20] Their contents and relationship to the calendars from elsewhere are very similar from one Saint-Germain calendar to another, and testify to marked differences from the cathedral of Paris. This underlines the well-known fact that although geographical distance can be a good point of comparison in shaping the calendrical differences, there could be very different calendar traditions within a short geographic distance. Therefore, in a detailed study of individual calendars and the tradition of a certain place or

541 community it is always necessary to combine the hypotheses provided by the computerized methods
542 with historical context as testified by the original sources.

543 7. Identifying Locally Common but Globally Uncommon Saints

544 Localizing medieval calendars and (other) liturgical manuscripts has remained a major challenge for
545 medieval studies, as most manuscripts do not tell explicitly where and for whom they were written.
546 Hence, it is useful to identify calendrical features that define a group of calendars from a certain
547 geographic area or period of time.

548 The most common feast that occurs in a group is obviously not a good way to define the
549 group. All calendars in, e.g., Paris or Rome, contain the various celebrations of Saint Mary,
550 Christmas, and other ubiquitous Christian feasts but this applies just as well to most other places as
551 well. In addition to the popularity of a feast in the calendars *within* the group of interest, we should
552 take into account the popularity of the feast *outside* the group, i.e., in other calendars. The less
553 common the feast outside the group, the more defining it is for a group where it is common.

554 We quantify the tradeoff between being common within and uncommon outside the group of
555 interest by the following simple ϕ (phi) metric which is closely related to the familiar χ^2 (chi-squared)
556 test of independence (see e.g. Cramer, 1946) as well as the familiar Pearson correlation coefficient. To
557 begin, we choose a set of calendars, S, that we wish to characterize by locally common but globally
558 uncommon feasts or saints. For a given feast, let k_{in} denote the number of calendars *within* the set S
559 that contain the feast, and let k_{out} denote number of calendars *outside* the set S that contain the feast.
560 The total number of occurrences of the feast in any of the calendars is thus $k = k_{in} + k_{out}$. Also, let n_{in}
561 and n_{out} denote the number of calendars within and outside set S, respectively. In this case, we include
562 all calendars in our data, so $n = n_{in} + n_{out} = 339$. The ϕ value then becomes

563 $$\phi = \frac{k_{in}\,(n_{out} - k_{out}) - k_{out}\,(n_{in} - k_{in})}{\sqrt{n_{in}\,n_{out}\,k\,(n-k)}}.$$

The ϕ values range between –1.0 and 1.0 so that negative values indicate that the feast in question is more common outside the set *S* than within it, and positive values indicate the opposite trend. The higher the absolute value, the clearer the difference in popularity within and outside. Given a set of calendars, we can then rank all the feasts by means of the ϕ value so that we can identify which feasts are most characteristic of the set (have the highest ϕ values).

Our numerical approach can be compared to the traditional approach to locating medieval calendars, where the aim has mostly been the identification of individual feasts and saints' days that could indicate the provenance of a calendar. Maybe the best examples of localizable feasts are the dedication days of churches and local celebrations of relics, since they are calendar entries closely tied to one church only. Such ecclesiastical feasts aside, it is a matter of finding useful indications among a huge amount of different feasts. In most cases, attention has been paid to local patron saints and other important feasts and cults that have been considered locally important due to extra-calendrical information.

To compare the two approaches – the traditional and our numerical one – we take the example of the three patron saints of Paris – Dionysius (Denis), Genovefa (Genevieve) and Nicolaus – and study their presence in our material. Is it possible to find Parisian calendars among our material based on the simultaneous appearance of all three patron saints? It soon becomes clear that the answer is negative. Albeit the three patron saints can be found together in practically all Parisian calendars, it turns out that the trio is far too popular and common in most French calendars to be indicative of a Parisian origin.

After learning that the most important local saints may not always be the best indicators of a calendar's origin or place of use, let us now forget the tradition of building hypotheses on prior expectations for a while and see which feasts really differentiate the calendars from each other. Even such an approach cannot function hermetically *in vitro,* as it were, but we need to have an idea of a group of calendars possibly belonging together. In other words, the higher the score, the more typical the feast is for the calendar in question in relation to the others. I.e. the higher the score, the more

indicative the feast is – but also vice versa, a very low negative score reveals feasts that are very atypical for the calendar and thus help a scholar to rule out saints and provenances.

When applying the method on a group of 47 calendars that have been considered to originate from the cathedral of Notre Dame in Paris (P1 and P2 groups) by previous scholarship,[21] the results are striking. The feasts of the most important local patron saints get very average scores; Dionysius and Nicolaus can be found in all the more than three hundred calendars within our material, and even Genovefa enjoyed immense popularity among the French calendars; see Fig. 6. The most indicative – that is, as most typical of the P1 and P2 groups and simultaneously as most atypical of all the other calendars – feasts for the Parisian group are the days of local, not widely known saints with a limited cult. In the case of P1 and P2 groups, they include fairly forgotten saints like Herblandus, Leonius, Senator, Metrannus, Serenus, Guenailus, Chrodogandus, Leonorius and Fara. All of them appear more within the Notre Dame group than in the bulk of the rest of the calendars, more than six times the size of our Parisian group, and can thus be considered to be very indicative for the cathedral of Paris – in spite of the fact that their cults were far from primary importance for the liturgical life of Notre Dame. The list of such indicative feasts is, in fact, even longer, as there is a number of saints that are almost certainly present in a Notre Dame calendar but appear very rarely elsewhere.

***** Fig. 6 about here *****

To get a more concrete idea, all the above-named saints appear with a 98 % certainty in our calendars stemming from Notre Dame; on the other hand, there is only a ca 4 % chance to find them in any calendar with an origin other than the cathedral of Paris.[22] Hence, when trying to identify Parisian manuscripts among a number of medieval liturgical books and calendars, it should be more advantageous for a scholar to look for Herblandus, Leonius, Senator, Metrannus, Serenus, Guenailus, Chrodogandus, Leonorius or Fara than to search for the big feasts of Dionysius, Genovefa or Nicolaus. It is of interest for the study of Parisian liturgy that the only calendar lacking the named indicative saints within our 47 calendars of Notre Dame is P1-01,[23] the calendar of an early 13th century liturgical book that has traditionally been considered to be definitely Parisian and one of the two earliest liturgical books for the Office services for the church of Paris. In fact, all our three

617 approaches discover P1-01 not being of typically Parisian contents and suggest a closer likelihood to
618 several calendars from Compiègne and other parts of the diocese of Paris.[24] (See also Fig. 5 above.)

619 Interestingly, the indicative saints of Notre Dame calendars were not indicative of an origin in
620 the significant monasteries of Saint-Victor and Saint-Germain that were located only a couple of
621 hundred metres from the cathedral. In them, Herblandus and the others are practically unknown; only
622 two of the Saint-Victor calendars know St Guenailus. Still, the big picture is *mutatis mutandis* similar
623 to that of the cathedral: it is not the important patron saints Victor and Germanus that indicate a
624 calendar to be of Saint-Victor or Saint-Germain origin, but the small, very local cults. In the case of
625 Saint-Victor such feasts include the days of saints Euphrasia, Magnus, Gendulfus and Maglorius; in
626 Saint-Germain the feasts of Vulfrannus, Ansbertus, Oswaldus and Venantius.

627 As the last example elucidating this approach of computerized study of medieval calendars,
628 we may take a group of calendars of an ecclesiastical order, namely Franciscans (group FR, 28
629 calendars altogether). Within this group, the most important Franciscan saints, like St Francis or St
630 Clara, are naturally found in their respective places, but they were so universally venerated throughout
631 Western Christianity that their feasts are of no use in determining the origin of a calendar, see Fig. 7.
632 On the other hand, the existence of the feasts of Sts Gelasius, Lucius, Zephyrinus, Symphorosa or
633 Anicetus is a strong indication of the calendar being of Franciscan use. In the case of Franciscan
634 calendars, we also find a very strong negative correlation: should one find the feasts of saintly
635 brothers Medardus or Gilardus in a calendar, the liturgical work is most likely not of Franciscan
636 origin, as none of the FR group calendars include those widely venerated saints.

637 ***** Fig. 7 about here *****

638 Naturally, a caveat is in order. As our material was gathered mainly from French dioceses,
639 monasteries and parishes, one should not automatically generalize these lists of saints as certain
640 indicators of calendars from elsewhere. However, we believe to have made an important point here:
641 the traditional approach of relying on important, well known saints' feasts in determining the origin of
642 a liturgical book or a calendar has its dangers, and it is well justified to take the local saints of modest

643 cult into close consideration, too. This has, in fact, been acknowledged by scholars for a long time in
644 principle, but in practice it is not one or two scholars who have tried to take a shortcut by searching
645 for the most obvious feasts to locate a medieval calendar with an unconvincing outcome.

646 ## 8. Conclusions

647 Medieval calendars are so numerous that the help of computational aid is needed to get an overview
648 of the material. The phylomemetic methods proposed in this paper approach the calendars on three
649 different levels. They provide a scholar with well-grounded hypotheses on study of the development
650 and relationships between a large number of calendars, on the broader context of an individual
651 calendar's contents as well as on the single feasts that can be indicative of the origin of one or several
652 calendars.

653 On one hand, a more effective study of the calendars allow us shape underlying cultural
654 contacts, transmission of ideas, values, and cults of saints, for instance. On the other, the approaches
655 contribute to a better understanding of the context and provenance of medieval liturgical manuscripts
656 that are probably the single most numerous genre of medieval books. Unfortunately for scholars of the
657 Middle Ages, liturgical books were normally not dated and it is often hard to pinpoint them to certain
658 geographic location. As the calendar ofte gives the strongest clues about the provenance of a medieval
659 liturgical book, the similarities of a calendar with other calendars from a diocese or a parish may
660 significantly add to the scholarly usability of liturgical manuscripts without a provenance. (See, e.g.
661 Morard, 2012, esp. 341-345; cf. Vezin, 1990, 473-479.)

662 As to the particular observations that were apparent in the geographical analysis, it should be
663 stressed that although the Paris calendar has been a topic of interest for many previous scholars, it has
664 not been easy for historians to get a clear idea of its development in the Middle Ages. (Cf. Wright,
665 1989, 66-81.) Many scholarly works are either very detailed – and are hence not very useful in terms
666 of the big picture – and give the contents of a certain individual calendar or some calendars during a
667 brief period, or are very sketchy in their nature. It has often been the problem with the study of

668 medieval calendars that it is very easy to pay attention to the small details and to leave the whole
669 aside. (See, e.g. Hughes, 1998; Vezin, 1990; Perdrizet, 1937; Perdrizet, 1933.) Thus, there are
670 surprisingly few previous studies by traditional means on the long development of Parisian calendars.
671 It is not the aim of present article to scrutinize the Parisian tradition here but the methods we outlined
672 will hopefully be useful in future work.

673 The many hypotheses arising from the results of the three approaches to broad calendar data
674 elucidate the versatility of possibilities of computerized calendar studies, as they range from broad
675 cultural patterns to details of one single church's liturgical traditions. However, just as in the
676 computerized study of (other) texts, one should keep in mind that the approaches provide a scholar
677 with only hypotheses that need to be tested with the more traditional methods. Still, as the approaches
678 quickly pinpoint and suggest similarities and differences that a human eye might overlook and that
679 would take an eternity for the human brains to notice, they help focus the research. Therefore, they are
680 a powerful addition to a scholar's toolkit, and we consider it definitely worthwhile to use them in
681 studying medieval calendar traditions.

682

683

Notes

[1] The coefficient of determination R^2 is defined as the fraction of the variance explained by the model. For a phylogenetic tree, let p_{ij} denote the path length between taxa *i* and *j* in the tree and let d_{ij} denote the actual distance between the same taxa evaluated from the data. The sum of squared residuals S_{res} is the sum of $(p_{ij}–d_{ij})^2$ over all pairs (*i,j*). The total sum of squares S_{tot} is the sum of $(d_{ij}^2–d_{avg})^2$over all pairs (*i,j*), where d_{avg} is the average distance between each pair of taxa. The coefficient of determination is given by $1– S_{res} / S_{tot}$. The values are between 0.0 and 1.0. Values close to 1.0 indicate that the pairwise distances are well captured by the tree.

[2] An analysis involving the dates and further information about the importance of the feasts gave results that are roughly similar to the ones presented here. In other words, it seems that the information included in the presence of absence of the feasts was sufficiently rich to determine the outcome of the analysis.

[3] In P3 group even the three big Parisian monasteries of Saint-Victor (P3-04 – P3-07, P3-10) Saint-Germain des Prés (P3-01 – P3-03) and Saint-Maur aux Fosses (P3-08, P3-11, P3-15 – P3-19) can be found as their own groups.

[4] Paris, Bibliothèque nationale (= in the following BNF), Ms. Lat. 755.

[5] BNF, Ms. Lat. 853.

[6] BNF, Ms. NAL 116.

[7] BNF, Ms. Lat. 8887.

[8] Although we are well aware of the methodological problems of dating manuscripts somewhat artificially according to centuries, it suits our purpose of roughly categorize the vast amount of our calendar sources.

[9] BNF, Ms. Lat. 1050; BNF, Ms. Lat. 1098.

[10] BNF, Ms. Lat. 13238; BNF, Ms. Lat. 758.

[11] See (Freckleton and Jetz, 2009) for a method that can quantify the relative explanatory power of a phylogenetic signal versus a geographic (spatial) signal. Such an analysis would presuppose a phylogenetic tree hypothesis based on *other* data than that which it is used to explain. In the case of calendars, a reasonalbe hypothesis may perhaps be obtained from an ecclesiastic hierarchy. Carrying out this kind of analysis is an aim for future work.

[12] E.g. the manuscripts can seldom be dated with such accuracy; in addition, the contents of most of the calendars do not actually represent a state of a certain year, since they were updated constantly.

[13] BNF, Ms. Lat. 1023.

[14] BNF, Ms. Lat. 832.

[15] Another trait questioning the Senlis provenance is the absence of St Regulus (St Rieul, March 30th), a patron saint of Senlis, in the calendar.

[16] BNF, Ms. Lat. 1051.

[17] RO-16 (BNF, Ms. Lat. 15616: Paris, adapted to use in Évreux, probably originally from College de Sorbonne; 13th cent.), P1-01 (BNF, Ms. Lat. 749: traditionally connected to Notre Dame; 13th cent.), P3-20 (BNF, Ms. Lat. 12066: diocese of Paris; 13th cent.), P3-03 (BNF, Ms. Lat. 13224: Saint-Germain des Prés; 14th cent.), P3-06 (BNF, Ms. Lat. 14810: Saint-Victor, 15th cent.).

[18] BNF, Ms. Lat. 1022. The calendar originates from the 13th century and was used in Saint-Victor. However, several additions and changes were made – probably elsewhere – during the 15th to 17th centuries. See Leroquais, 1934, nr. 480.

[19] BNF, Ms. Lat. 14811, 14279, 14810, 14448.

[20] BNF, Ms. Lat. 13239, 12043, 13224.

[21] P1-01, P1-03–P1-25, P1-27; P2-01–P2-03, P2-07–P2-11, P2-13–P2-14, P2-16, P2-19, P2-21–P2-30 . P1-02 and P1-26 as well as P2-04–P2-06, P2-12, P2-15, P2-17–P2-18 and P2-20 were eliminated as they do not seem to originate from the cathedral of Paris.

[22] Cf. a “Reconstructed Model Calendar Paris c. 1400-1420” by Erik Drigsdahl from the Center for Håndskriftstudier i Danmark (Danish Centre of Manuscript Studies, a private research centre). It contains only four of the nine mentioned saints: Fara, Chrodogandus, Metrannus and Leonius. Drigsdahl explains the reconstruction to be based on a comparison of 42 “Paris-type” calendars. See http://manuscripts.org.uk/chd.dk/cals/pariscal.html (accessed October 6, 2017).

[23] BNF, Ms. Lat. 749.

[24] Compiègne: calendars RE-25–RE-28 (BNF, Ms. Lat. 259, 296, 339, 340); Saint-Maur des Fossés: P3-16, P3-18 (BNF, Ms. Lat. 12058, 13247; diocese of Paris: P3-20 (BNF, Ms. Lat. 12066). All these are roughly from the same period as P1-01 (BNF, Ms. Lat. 749).

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768 **Figure Legends**

769

770 Fig. 1: NJ results in a phylogenetic tree representing the relationships between all the calendars of our
771 material. Some groups, such as the calendars with labels starting with *P*, all of the Parisian, as well as
772 Franciscan calendars labeled *FR,* are colored to highlight certain features of the tree. (A machine-
773 readable version will be made available in the supplementary material.)

774

775 Fig. 2: A histogram of the *MI* values for all pairs of calendars.

776

777 Fig. 3. The relationships of the contents of calendar P1-03 (BNF, Ms. Lat. 1023: cathedral of Paris,
778 13th century) with its contemporaries. *Left:* The similarity (mutual information) values between P1-03
779 and all the other 13th century calendars. The horizontal axis gives the geographic distance (in latitude–
780 longitude degree units) and the vertical axis shows the similarity. The black curve is the baseline trend
781 for the 13th century (all pairs) and the orange curve is a non-linear fit to the points shown in the plot
782 with a gray confidence interval for the mean. *Right:* A map display of the same set of calendars,
783 except those located in the same place as P1-03 (Paris). Each calendar is shown as an arrow pointing
784 towards (orange) or away (blue) from the location of P1-03 depending on whether their similarity
785 with P1-03 is higher or lower than expected based on the baseline trend. The length of each arrow is
786 proportional to the deviation from the baseline. Note the striking resemblance of P2-04 (BNF, Ms.
787 Lat. 832: traditionally believed to be from Senlis, about 50 km outside Paris), which shows up
788 particularly well as a long orange arrow that actually passes *through* Paris in the map display on the
789 right. In the graph on the left, the point for P2-04 is highlighted by a red arrow.

790

791 Fig. 4. The relationships of the contents of calendar P1-25 (BNF, Ms. Lat. 1051: cathedral of Paris,
792 late 15th century) with its contemporaries. For an interpretation of the graphical displays see Fig. 3.

793 Notice how the general pattern is quite similar to the one in Fig. 3 (13th century). As is quite typical to
794 most of the Parisian calendars in our data, the similarity with other Parisian calendars is higher than
795 average and the similarity with most calendars in other places is lower than average.

796

797 Fig. 5. The relationships of the contents of calendar P1-01 (BNF, Ms. Lat. 749: traditionally believed
798 to from the cathedral of Paris, mid-13th century) with its contemporaries, zoomed around Paris. For an
799 interpretation of the graphical displays see Fig. 3. The visualization shows concretely how the
800 contents of P1-01 are strikingly close to those of calendars from Saint-Maur des Fossés (BNF, Ms.
801 Lat. 17308, 17318, 17319, 17321: RE-25–RE-28) and Saint-Corneille in Compiègne (BNF, Ms. Lat.
802 12058, 13247: P3-16, P3-18) highlighted with a red circle in the graph on the left. The corresponding
803 arrows in the map display pass through Paris and look somewhat confusingly as arrows pointing away
804 from Paris roughly towards Northwest and Southwest (in which case, however, they should have been
805 blue rather than orange.)

806

807 Fig. 6: A visualization of saints showing their popularity within (y-axis) the group of Parisian
808 calendars versus their popularity outside (x-axis) the same group. Each point corresponds to a saint or
809 another feast. The contours show values of the ϕ metric which measures the difference in the
810 popularity within and outside the group. The highest ϕ value (0.87) is attained by three saints:
811 Herblandus, Leonius, and Senator. Traditional Parisian saints Genovefa (0.55), Nicolaus (0.0), as well
812 as Dionysios (0.0; not shown) attain much lower values owing to their popularity outside the group.

813

814 Fig. 7: A visualization of saints showing their popularity within (y-axis) the group of Franciscan
815 calendars versus their popularity outside (x-axis) the same group. The highest ϕ value (0.88) is
816 attained by St Gelasius, with similar high values attained by St Lucius (0.81), St Zephyrinus (0.80),
817 and St Symphorosa (0.78) (not shown in the figure). The traditional Franciscan saints Francis (0.0)

818 and Clara (0.63) yield significantly lower values due to their popularity also outside the set of
819 Franciscan calendars. At the other extreme, the otherwise popular St Medardus is present in none of
820 the Franciscan calendars and thus, the absence of his feast provides an easy telltale sign of a
821 Franciscan calendar.

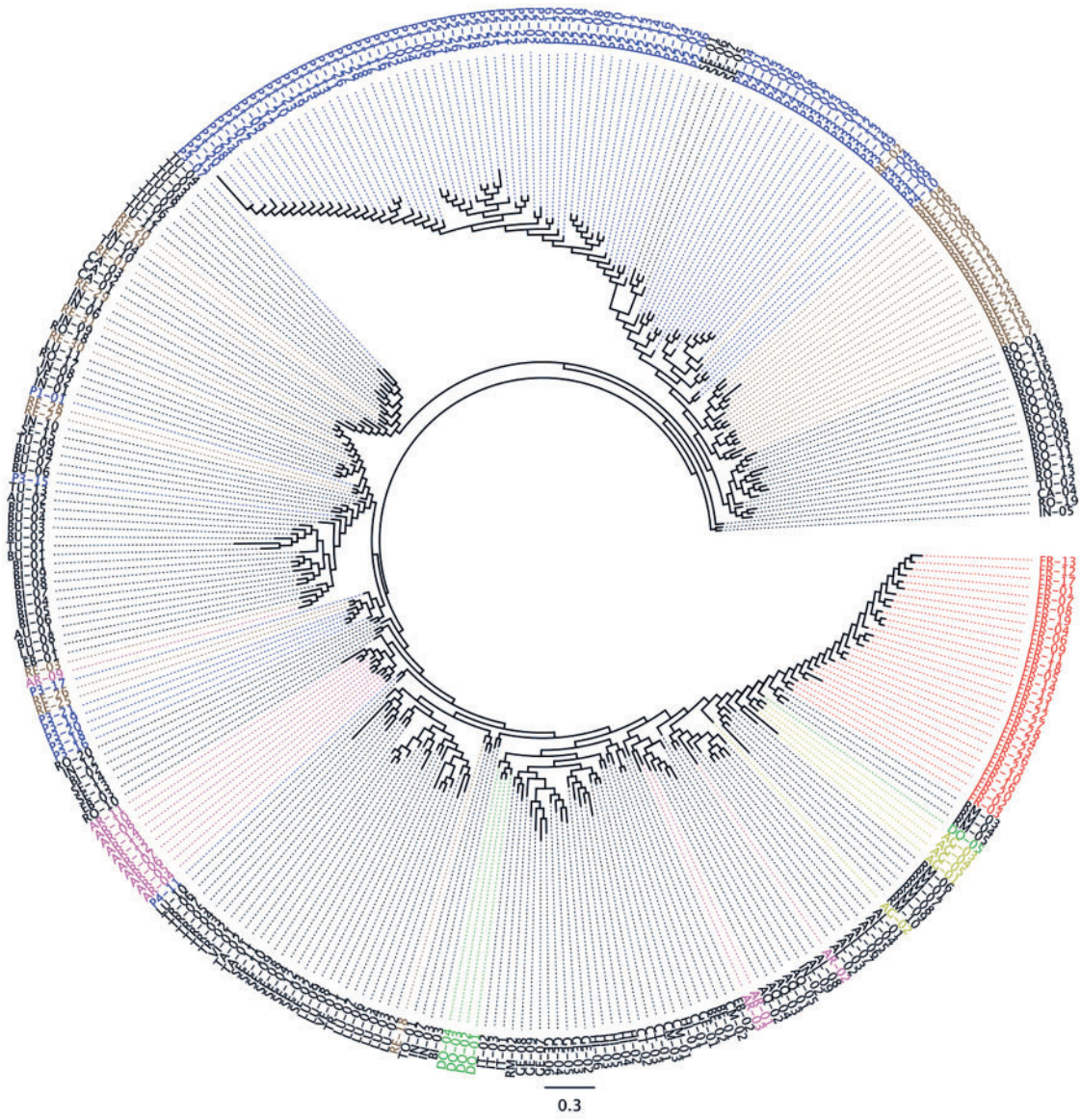

Fig. 1 NJ results in a phylogenetic tree representing the relationships between all the calendars of our material (A machine-readable version indicating some groups with colours will be made available in the Supplementary Material)

and monastic P3),[7] Tours (TU), Cambrai (CA), as well as the Roman (RM), German (GE) and Spanish (HI) calendars are relatively similar. In the provinces of Sens (SE), Rouen (RO), Arles (AR), Lyon (LU), Reims (RE), and Trier (TR), the outcome is more dispersed, although the majority of calendars are still found together. When we look at the calendars of the monastic and mendicant orders, the results are similar. The stemmatological method represents the calendars of the Augustinians (AG), Carmelites (CM), Carthusians (CT), Dominicans (DO), and Franciscans (FR) as their own groups—just as expected, since each of the orders had their own distinctive feasts. This

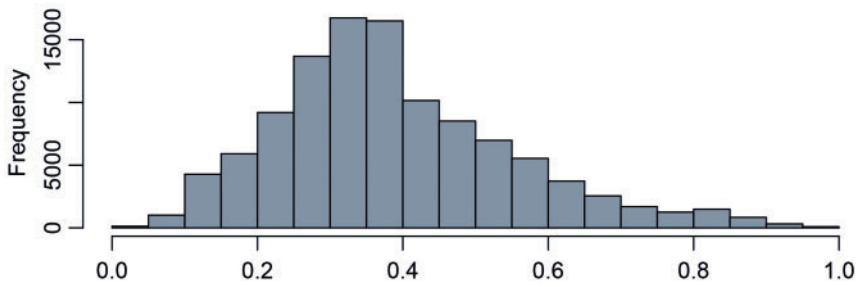

Fig. 2 A histogram of the mutual information (MI) values for all pairs of calendars

A histogram showing the distribution of the MI values between every pair of calendars is shown in Fig. 2. The values range between the minimum of 0.015 (calendars AG-01 and P2-15)[13] and the maximum of 0.9999 (calendars P1-26 and P1-27[14] which include exactly the same set of feasts). Note that AG-01 and P2-15 are also very distant in the tree of Fig. 1, whereas the second pair appears next to each other in the tree.

Generally speaking, as expected, the MI value tends to decrease with the geographical distance, d_{AB}, between the two calendars: the further apart two calendars were the more independent they tended to be. We model the dependency of MI on the distance using a linear regression model:

$$MI_{AB} = \alpha d_{AB} + \beta \log(d_{AB} + 0.001) + \textit{residual},$$

where α and β are parameters to be determined by the least squares technique. The constant 0.001 ensures that the logarithmic term is bounded even when the calendars are located in the same place but allows for a sharp decrease in MI as soon as the geographical distance becomes greater than 0. We chose this particular functional form by trying a number of similar simple models, including for instance only the linear term $\alpha\ d_{AB}$ or replacing the logarithmic term by a quadratic one, but the model above turned out to give the best fit to the data. The coefficient of determination (see Section 5) characterizing the explanatory power of the above model is $R^2 = 0.272$ for the 13th-century calendars, $R^2 = 0.279$ for the 14th-century calendars, and $R^2 = 0.350$ for the 15th-century calendars. Note that these values are not comparable to those from the phylogenetic analysis, as the phylogenetic tree is optimized to fit the data and includes as many edge length parameters as there are taxa (calendars), while the geography-based model includes only two parameters (α and β).[15] In accordance with the relatively low R^2 values, the residual variation between individual (pairs of) calendars after the model is fitted to the data is quite high. In other words, much of the difference remains to be explained by other factors than geographical distance, which is exactly our aim. In what follows, we apply two visualization methods that enable us to investigate the variation unexplained by geography in more detail.

Having fitted the above model to the data, which captures the overall dependency of the MI value on the geographical distance, we can compare individual calendars to discover pairs of calendars whose contents are either unusually dependent (high MI value) or unusually independent of each other (low MI value) compared to other calendars with a similar geographical distance. We claim that such deviations from the general trend are potentially interesting and need to be explained by investigating the possible historical reasons that might have caused them.

Let us consider the group of calendars of medieval Parisian origin, since Paris is the most common location of the calendars in our data. Furthermore, Paris was a centre *non plus ultra* in medieval France as the preferred seat of the French king, with an episcopal see of significance, and with the most important university in the Latin West. Even preliminary new results on the local calendars may thus be of interest to a number of modern scholars. On the one hand, we try to trace changes that took place

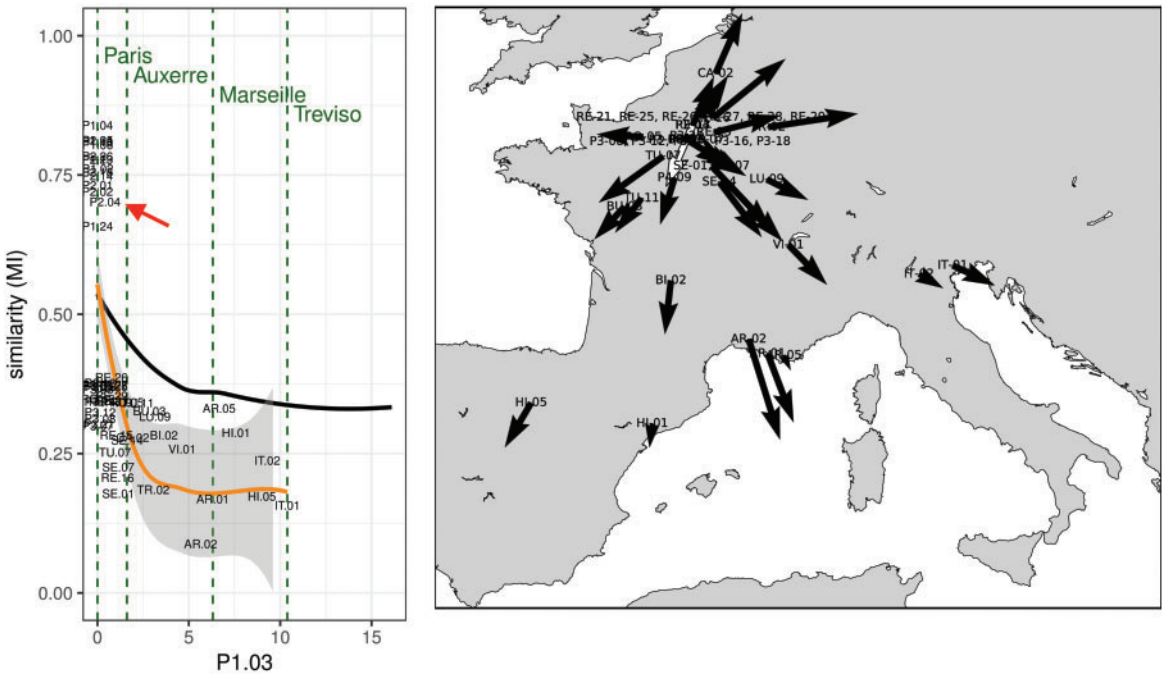

Fig. 3 The relationships between the contents of calendar P1-03 (BNF, Ms. Lat. 1023: cathedral of Paris, 13th century) and its contemporaries. Left: The similarity (mutual information) values between P1-03 and all the other 13th-century calendars. The horizontal axis gives the geographical distance (in latitude–longitude degree units), and the vertical axis shows the similarity. The upper curve is the baseline trend for the 13th century (all pairs), and the lower curve is a non-linear fit to the points shown in the plot with a grey confidence interval for the mean. Right: A map display of the same set of calendars, except those located in the same place as P1-03 (Paris). Each calendar is shown as an arrow pointing towards (white) or away (black) from the location of P1-03 depending on whether their similarity with P1-03 is higher or lower than expected based on the baseline trend. The length of each arrow is proportional to the deviation from the baseline. Note the striking resemblance of P2-04 (BNF, Ms. Lat. 832: traditionally believed to be from Senlis, about 50 km outside Paris), which shows up particularly well as a long white arrow that actually passes through Paris in the map display on the right. In the graph on the left, the point for P2-04 is highlighted by an arrow

from the north of France and west of Paris tend to be more similar to Parisian calendars than those from east or south of Paris. The overall difference in the contents of the calendars of our data set grew slightly from one century to another, probably largely because of the addition of new feasts in most calendars. Figure 4 shows a typical example of a 15th-century calendar of Parisian origin, P1-25.[20] Interestingly, it suggests that the overall differences in the calendars of Paris cathedral from the others remained more or less at the same level during the 13th–15th centuries; compare in particular the similarity values in Figs 3 and 4. A very similar pattern is present in most other Parisian calendars.

The latter result is in contrast with the findings of Craig Wright, who has scrutinized the liturgy of the cathedral of Notre Dame during the Middle Ages: according to him, the Parisian calendar became increasingly distinctive with more local traits during the 13th and 14th centuries (Wright, 1989, pp. 76–9). Wright argues that this also meant a decrease in the influence of the Roman ecclesiastical calendar on that of Paris. The idea is logical *per se*, since it is well known that the French dioceses

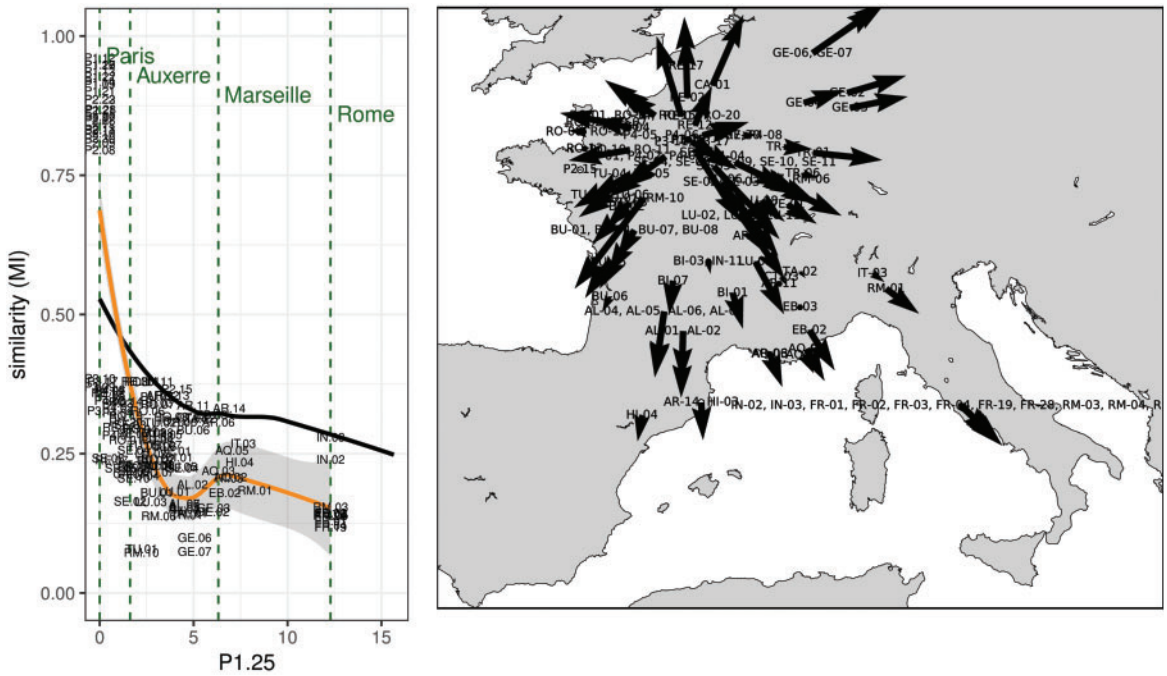

Fig. 4 The relationships between the contents of calendar P1-25 (BNF, Ms. Lat. 1051: cathedral of Paris, late 15th century) and its contemporaries. For an interpretation of the graphical displays, see Fig. 3. Note how the general pattern is quite similar to that in Fig. 3 (13th century). As is quite typical of most of the Parisian calendars in our data, the similarity with other Parisian calendars is greater than average and the similarity with most calendars in other places is less than average

distanced themselves from Rome and the Pope in terms of the Gallicanism apparent during the Great Schism of the late 14th and early 15th centuries. In addition, it is a known phenomenon that the Parisian calendars—and Roman or any other, for that matter—became more and more densely populated with local feasts towards the end of the Middle Ages. Thus, the increasing local variation in liturgical feasts decreased the relative share of feasts that were also contained in other calendars. However, in the analysis of our calendar material we did not find strong support for Wright's hypotheses.

What about the relationship between the Parisian calendars and those of other places? Looking at the graphs describing the similarity of their contents with calendars from elsewhere, one is struck by a number of further anomalies. One of them implies that there is a group of Paris calendars (RO-16, P1-01, P3-03, P3-06, and P3-20)[21] the contents of which are much closer to another set of calendars not very far away from Paris. An example is shown in Fig. 5. What all the members of the group have in common is a marked similarity with several calendars from the monasteries of Saint-Maur des Fossés, just south-east of Paris, and Saint-Corneille in Compiègne, some 60 km north of Paris (Calendars of Saint-Maur: RE-25–RE-28; those of Saint-Corneille: P3-16, P3-18). A detailed study of the liturgical contacts between Paris and the monasteries nearby is beyond the scope of the present work, but it suffices to say that there seems to be good reason to hypothesise such a close connection and to investigate it in future work.

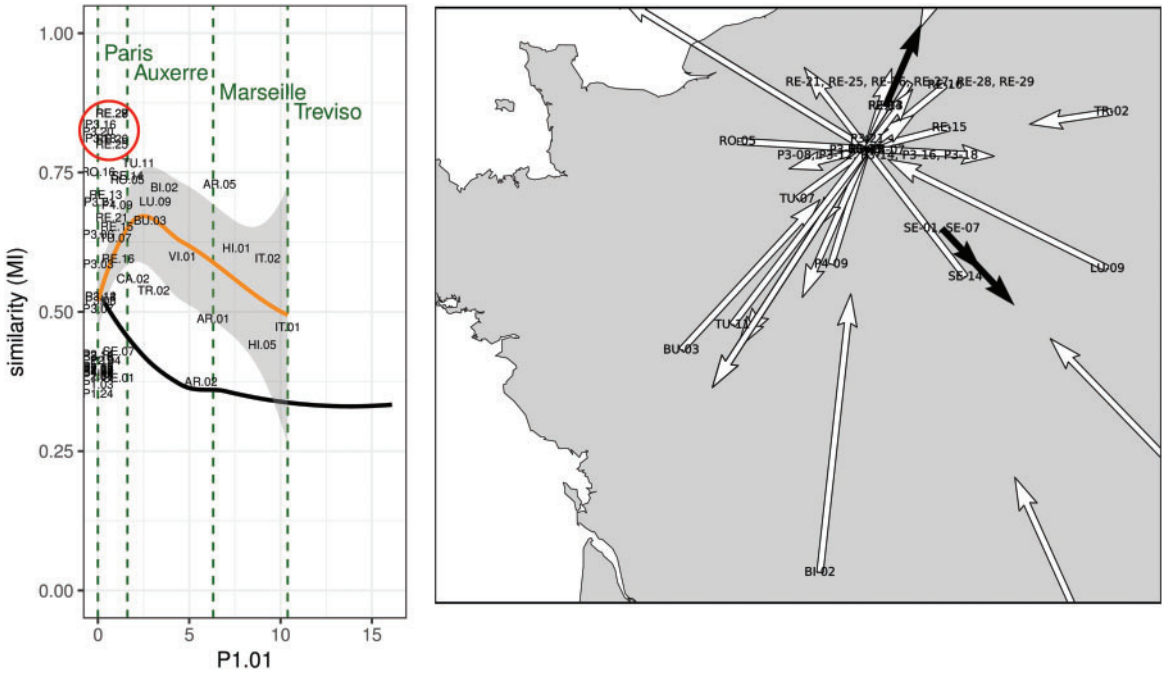

Fig. 5 The relationships between the contents of calendar P1-01 (BNF, Ms. Lat. 749: traditionally believed to from the cathedral of Paris, mid-13th century) and its contemporaries, zoomed around Paris. For an interpretation of the graphical displays, see Fig. 3. The visualization shows how the contents of P1-01 are strikingly close to those of calendars from Saint-Maur des Fossés (BNF, Ms. Lat. 17308, 17318, 17319, 17321: RE-25–RE-28) and Saint-Corneille in Compiègne (BNF, Ms. Lat. 12058, 13247: P3-16, P3-18) highlighted with a circle in the graph on the left. The corresponding arrows on the map display pass through Paris and appear somewhat confusingly as arrows pointing away from Paris roughly towards the north-west and south-west (in which case, however, they should have been black rather than white.)

The great Parisian houses of Saint-Victor and Saint-Germain des Prés had, like any significant monastery, their own calendar and liturgical traditions. Our material contains only a few calendars from those institutions, six from the first and three from the latter, but it is safe to conclude that their traditions differed greatly both from that of the local cathedral and from each other. As to Saint-Victor, only its first calendar among the material (P1-02, from the 13th century)[22] concurs with those of the cathedral of Paris, the others showing a totally different and quite coherent tradition with apparent links with the calendars from the South of France (esp. P3-04–P3-06, and P3-10).[23] The calendars with a provenance in Saint-Germain des Prés, in turn, do not allow scrutiny of a longer development, since all three among our material come from the 14th century (P3-01–P3-03).[24] Their relationship to the calendars from elsewhere is very similar from one Saint-Germain calendar to another, and testifies to marked differences from the cathedral of Paris. This underlines the well-known fact that although geographical distance can be a good point of comparison in shaping the calendrical differences, there may be very different calendar traditions within a short geographical distance. Therefore, in a detailed study of individual calendars and the tradition of a particular place or community, it is always necessary to combine the hypotheses provided by the computerised methods with historical context as testified by the original sources.

score, the more indicative the feast is, while a very low negative score reveals feasts that are very atypical for the calendar and thus help a scholar to rule out saints and provenances.

Applying the method to a group of 47 calendars that have been considered to originate from the cathedral of Notre Dame in Paris (P1 and P2 groups) by previous scholarship[25] produces striking results. The feasts of the most important local patron saints get very average scores; Dionysius and Nicolaus can be found in all the more than 300 calendars within our material, and even Genovefa enjoyed immense popularity among the French calendars; see Fig. 6. The most indicative feasts for the Parisian group, that is, the most typical of the P1 and P2 groups and simultaneously most atypical of all the other calendars, are the days of local saints not widely known with a limited cult. In the case of P1 and P2 groups, they include fairly forgotten saints like Herblandus, Leonius, Senator, Metrannus, Serenus, Guenailus, Chrodogandus, Leonorius, and Fara. All of them appear more within the Notre Dame group than in the bulk of the rest of the calendars, more than six times the size of our Parisian group, and can thus be considered to be very indicative for the cathedral of Paris, in spite of the fact that their cults were by no means of primary importance for the liturgical life of Notre

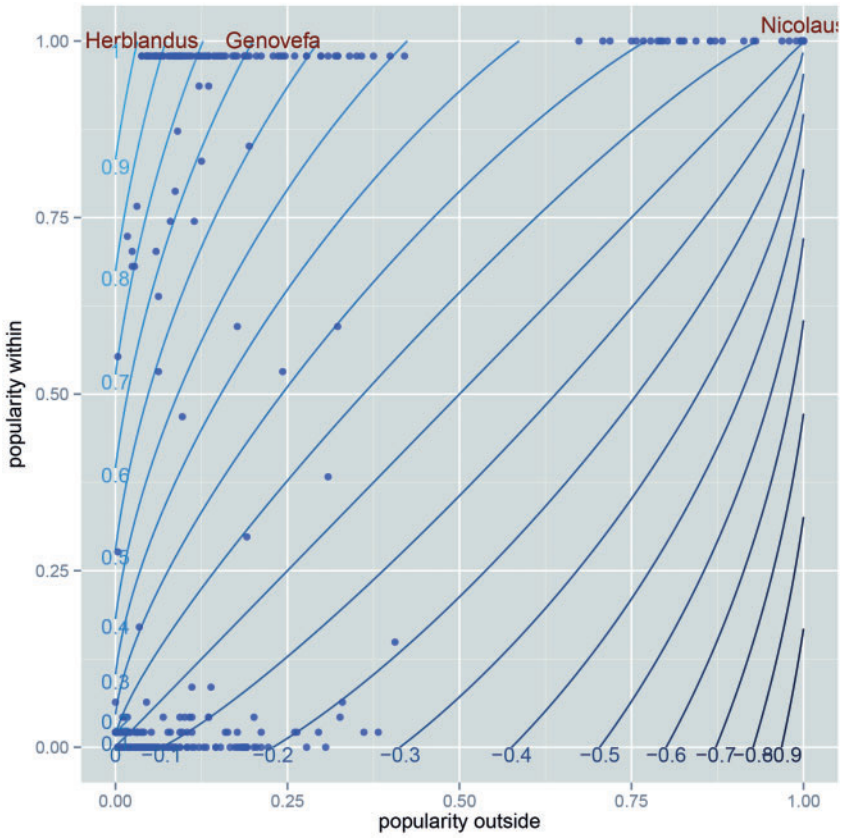

Fig. 6 A visualization of saints showing the popularity within the group of Parisian calendars (y-axis) versus their popularity outside the same group (x-axis). Each point corresponds to a saint or another feast. The contours show the values of the φ metric which measures the difference in popularity within and outside the group. The highest φ value (0.87) is attained by three saints: Herblandus, Leonius, and Senator. The traditional Parisian saints Genovefa (0.55), Nicolaus (0.0), and Dionysios (0.0; not shown) attain much lower values owing to their popularity outside the group

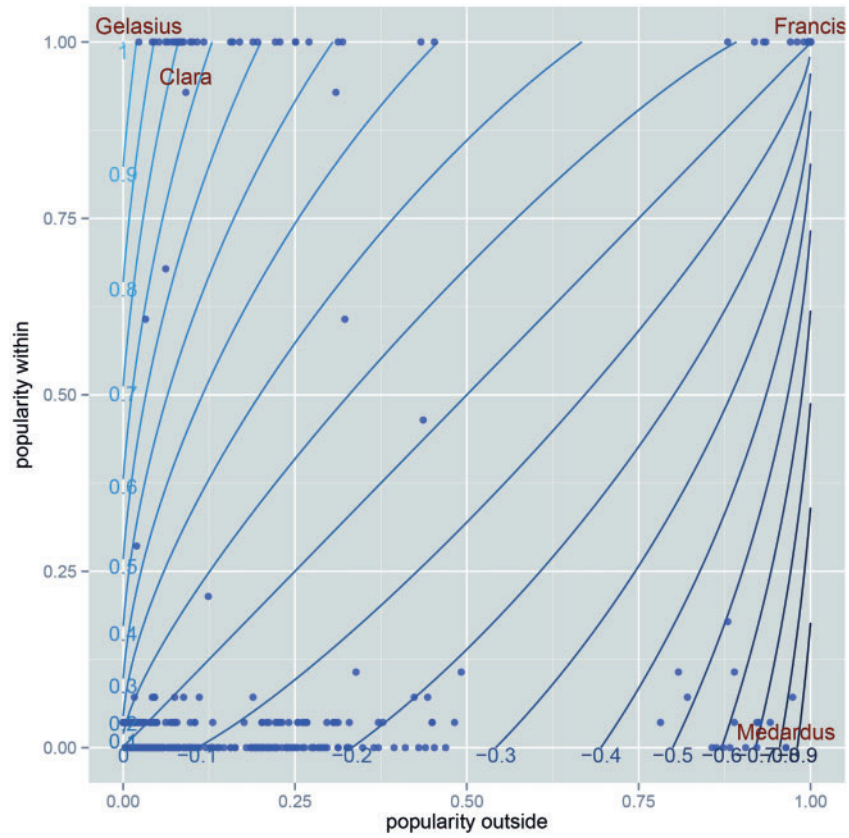

Fig. 7 A visualization of saints showing their popularity within the group of Franciscan calendars (*y*-axis) versus their popularity outside the same group (*x*-axis). The highest φ value (0.88) is attained by St Gelasius, with similar high values attained by St Lucius (0.81), St Zephyrinus (0.80), and St Symphorosa (0.78) (not shown in the figure). The traditional Franciscan saints Francis (0.0) and Clara (0.63) also yield significantly lower values because of their popularity outside the set of Franciscan calendars. At the other extreme, the otherwise popular St Medardus is present in none of the Franciscan calendars, and thus the absence of his feast provides an easy telltale sign of a Franciscan calendar

Dame. The list of such indicative feasts is in fact even longer, as there is a number of saints who are almost certainly present in a Notre Dame calendar but appear very rarely elsewhere.

To get a more definite idea, all the above-named saints appear in 98% of the calendars from Notre Dame, but in only ca 4% of the calendars with an origin other than the cathedral of Paris.[26] Hence, in trying to identify Parisian manuscripts among a number of medieval liturgical books and calendars, it should be more advantageous for a scholar to look for Herblandus, Leonius, Senator, Metrannus, Serenus, Guenailus, Chrodogandus, Leonorius, or Fara than to search for the big feasts of Dionysius, Genovefa, or Nicolaus. It is of interest for the study of the Parisian liturgy that the only calendar lacking the indicative saints within our 47 calendars of Notre Dame is P1-01,[27] the calendar of an early 13th-century liturgical book that has traditionally been considered to be definitely Parisian and one of the two earliest liturgical books for the Office services for the church of Paris. In fact, all our three approaches reveal that P1-01 does not have typically Parisian content and suggest a closer similarity to several calendars from Compiègne and other parts of the diocese of Paris[28] (see also Fig. 5 above).

Interestingly, the indicative saints of Notre Dame calendars did not suggest an origin in the significant