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GRACEFUL17. A Knowledge Graph for Papal Documents of Apostolic Provisions

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GRACEFUL17. A Knowledge Graph for Papal Documents of Apostolic Provisions

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1. Introduction

Until the 19th Century, papal administration regularly sidelined local channels of recruitment for the clergy and intervened massively in local clerical job markets across Catholic Europe. The data collected by the GRACEFUL17[1] project concerns the granting (›provision‹) of lower and middle church offices (›benefices‹) by the papacy in the 17th century.[2] A parameter of papal theocracy for medievalists, the system of papal provisions was widely held to be in decline by scholarship on the early modern papacy.[3] The sheer [1]

[1] *GRACEFUL17: Global Governance, Local Dynamics. Transnational Regimes of Grace in the Roman Dataria Apostolica (17th Century)* is a transnational, Franco-German research project funded by the Deutsche Forschungsgemeinschaft and the Agence Nationale de la Recherche, and directed by Birgit Emich (Goethe-Universität Frankfurt a. M.) and Olivier Poncet (École nationale des chartes in Paris). Other partner institutions include the Deutsches Historisches Institut in Rom, the École française de Rome, and the Université de Reims-Champagne-Ardenne. The project's Digital Humanities component is based at the German Historical Institute in Rome.

[2] Roughly, it concerns rectorships and vicarages in the parishes charged with the care of souls, canonships at collegial and cathedral churches, and a plethora of chaplaincies and administrative functions. A benefice is the right to permanent income attached to a church office. Although *beneficium* (income) and *officium* (office) are clearly distinguished in canon law, the *beneficium* was awarded together with and because of the office (*beneficium datur propter officium*) and often was mentioned as a synonym of the office it remunerated. Benefices, themselves the immaterial object of legal and administrative practices, by consequence merge legal, sacral, hierarchical, as well as material dimensions. For a short introduction, cf. Landau 1980, as well as Viana 2018, p. 711; for a social history approach cf. Balavoine 2011.

[3] For the vast medieval research we want to highlight Tewes 2001 and Smith 2015. With respect to the alleged ›italianisation‹ of the curia and curial affairs, see Menniti Ippolito 2011.

dimensions of our data highlight instead the ongoing vitality and centrality of Roman governance in the field even outside Italy. In sharp contrast with the widespread scholarly view that absolutist princes and ›national‹ churches reduced Roman primacy to mere symbolism, papal regimes of grace continued to thrive in the confessional age. However, papal graces were routinely granted upon the request of petitioners: this entails that the papacy's global governance in the field was enacted and conditioned by circumstances, interests and strategies on the ground. By consequence, papal registers contain information about the intentions of individual petitioners and about local dynamics of conflict or negotiation rather than about anachronistic, grand nomination policies unfolded by the papacy. This assessment warrants the bottom-up, glocalist approach to the circulation of apostolic authority adopted by GRACEFUL17.[4] The data that are discussed here function as a global sample for comparison with data assembled in three local case studies analysing these dynamics in the Iberian Peninsula, France, and the Holy Roman Empire respectively.

[2] The Apostolic Datary was the main administration of the Roman Curia charged with the vetting of thousands of petitions for a wide range of papal graces, including papal provisions for benefices.[5] The source material in the Vatican Archives consists of serial and highly standardised register entries that reflect the continental scope of the allocation of benefices. They shed light on the identities, practices, social relations and kin of a broad spectrum of clerics seeking office; on the disparate localities and regions that involved Roman bureaucracy (and those that did not), on the diverging constellations and conjunctures governing local church life across Europe. A quantitative and computational approach assisted by AI offers, firstly, the possibility to collect and model similarly massive amounts of data and, secondly, the tools to examine systematically the involvement of transnational governance *avant la lettre* in the allocation of ecclesiastical offices.

2. From Piles of Paper to a Knowledge Graph

2.1 Availability and Scope of Sources – the Vatican Apostolic Archive

[3] Due to a lack of scholarly attention, the Datary lists in the Vatican Archive are in need of inventorisation. Given these archival conditions, we chose to shun the registers of (granted) petitions (supplications) and turned to the few remaining *Expeditiones* volumes for the 17th century which contain, amongst others, standardised summaries of requests for lower and middle ecclesiastical offices being ›expedited‹ (or processed) by the Datary.[6] Ideally, these enormous volumes each list the registrations of one single pontificate year starting with the anniversary of the reigning Pontiff's enthronement and ending with the eve of its next anniversary (or with the date of the Pontiff's death). For our first samples, we chose to collect the apostolic provisions from two *Expeditiones* volumes concerning the second year of the pontificates of Gregory XV (14 February 1622 – 13 February 1623) and Innocent XI (21 September 1677 – 20 September 1678) respectively.[7]

[4] In this context, Hirschmann 2001 points out that the fundamental concept of a ›privilege policy‹ on the part of the popes must be rejected and that the recipients should instead take centre stage in the investigation.

[5] Articles on the Roman Curia and the medieval papacy can be found in Larson / Sisson (eds.) 2016; Prudlo (ed.) 2025. Scattered information on the Apostolic Datary can be retrieved from Celier 1910; Fink 1951; Pásztor 1970; Storti 1969. However, as the Datary has not yet been well researched, our project is planning a publication on the Apostolic Datary, on working with its sources and on its relationship to other Roman institutions, which is expected to be published in 2026.

[6] Alongside papal provisions related to office-holding and benefice matters, these measures also concerned marital and other dispensations (ad hoc concessions to act against specific regulations in canon law), indults (as opposed to dispensations, more permanent but not necessarily perpetual concessions or delegations of certain rights to do so), indulgences, legal absolutions from excommunication, commissions of judges with apostolic authority, and other tools of papal government ›by exception‹ that were only marginally included in our dataset.

[7] Archivio Apostolico Vaticano (AAV) Dataria Ap. (Dataria Apostolica) Expeditiones 2 and 9.

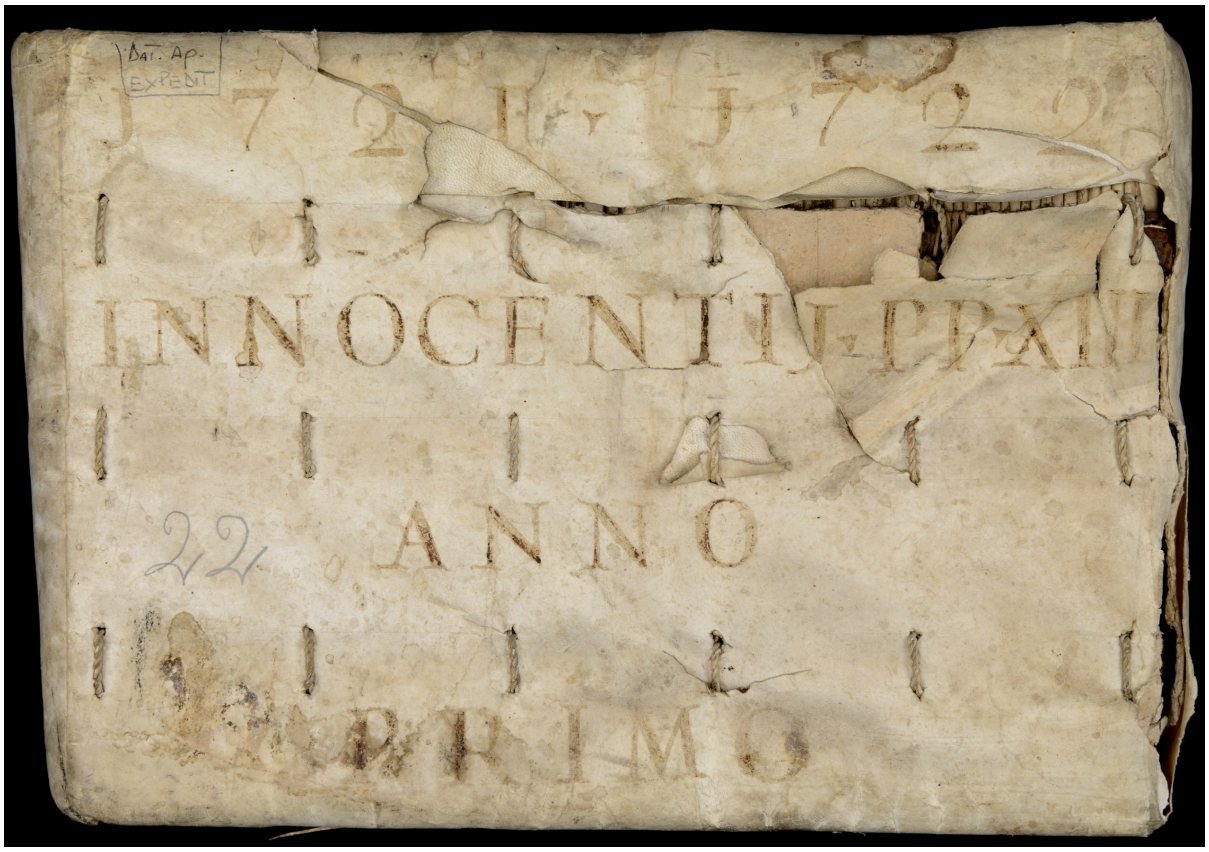


Figure 1: A single year's piles of paper: AAV Dataria Ap. Expeditiones 22 (first year of the pontificate of Innocent XIII, 18 May 1721 – 17 May 1722). [Image: Archivio Apostolico Vaticano]

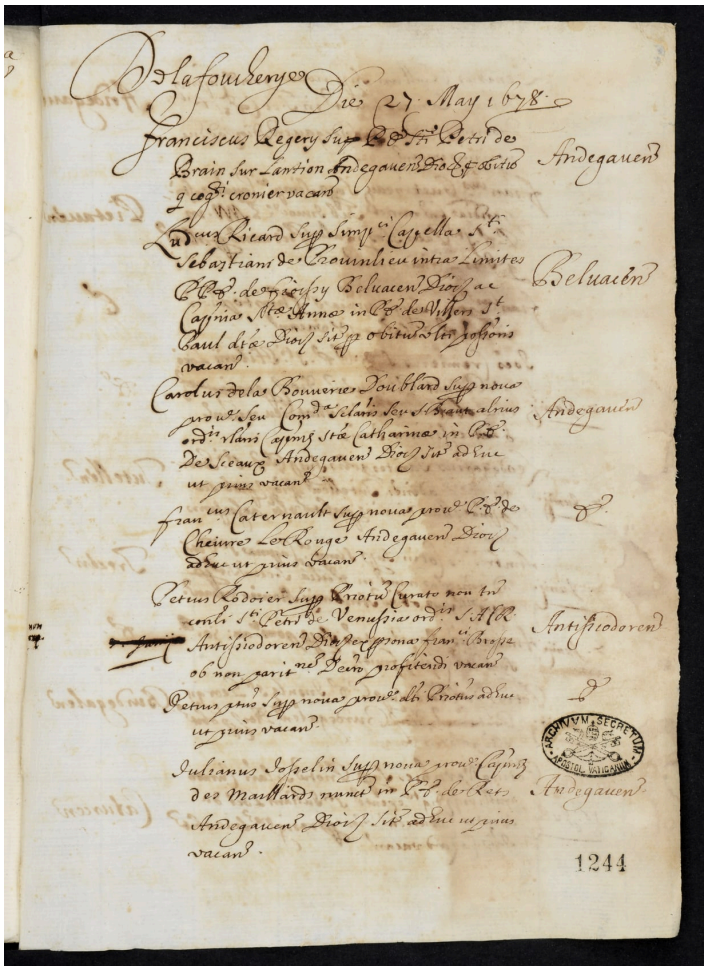


Figure 2: A page from the *Ordinarius Galliarum* subregister (in AAV Dataria Ap. Expeditiones 9, 1244r) dedicated to the provisions of French benefices. In the right margins a Roman curialist inserted the names of the dioceses where the benefices where situated; above we find the date of entry and / or the granting of the supplication. [Image: Archivio Apostolico Vaticano]

These volumes contain, alongside the for our purposes less relevant *Commissiones*, five subregisters that interest us here: (1) *Per Obitum* (containing provisions for benefices that had become vacant because of the death of their previous holders), (2) *Ordinarius* and (3) *Extraordinarius Sanctissimi* (for other vacancies, e.g. resignations or irregularities), for benefices in Italy, the Iberian Peninsula, the Holy Roman Empire and Central-Eastern Europe, as well as two vast subregisters that were exclusively dedicated to French benefices: (4) the *Codex or Ordinarius Galliarum* and (5) the *Extraordinarius Galliarum*. Within these subregisters, dense records of usually two or three lines are listed in a chronological order, i.e. according to the Roman calendar dates which represent the date a supplication was registered and dated (hence: *Dataria*), the formal act before the requested papal graces accordingly gained force of law. [4]

2.2 Recording Structured Data

Modeling of data in the knowledge graph (see section below) starts with a manual transcription of an individual register entry from the archive. At this stage, alongside entries from the individual research projects (cf. above), our collective samples from *Expeditiones* 2 and 9 contain 16,526 transcribed entries, stored in the project database and published as ground truth data (see example below). Each entry is assigned to a source, corresponding to its respective archival volume, which in turn is linked to the holding archive itself. While the transcriptions themselves are not directly relevant for data analysis, they serve as ground truths for subsequent semantic data modeling. In this process, the semantic data is abstracted from [5]

the raw transcriptions in favor of semantic taxonomies and a comprehensive knowledge base. Since the transcriptions are also part of the knowledge graph, the structured data can always be traced back to them. It should also be noted that the structure (elements) of an entry consists of the Latin transcription and added metadata. This applies to the subregister, the place of event, the event date and the diocese. These elements are information from the margin or from headings that has been added to each individual entry. An example of an entry:

> »Per obitum Rome apud Smm Pridie Id Septembri a ii Senen Mattheus Cittadinus super Canonicatu et praebenda ecclesiae Senen per obitum q Marci Antonii Amaroni extra augusti prox pret defuncti vacan fructus 24 duc«[8] [6]

Translation: *[In the subregister] Per Obitum[:] Rome at Santa Maria Maggiore on the eve of the Ides of September of the second year [of the pontificate of Gregory XV] [in the Diocese of] Siena Matteo Cittadino [is granted a provision for] a canonship in the church of Siena [i.e. Siena cathedral] vacant because of the death of Marcantonio Amaroni outside [the Roman curia] [with a tax value of] 24 ducats [of the Apostolic Chamber]* [7]

Each entry is segmented into individual labeled elements in order to atomise its relevant ›information‹. This data capture process is facilitated by machine learning technology, such as *Named Entity Recognition (NER)*, which is described below. Individual elements – as seen from our example below – represent relevant information, such as details about institutions (e.g., dioceses), specific locations, individual persons in different roles, categorical classifications, dates, and so on and so forth. The entities assigned to individual elements are, in turn, independent records. Each of these entity records has additional metadata, such as geographical coordinates, names and description text, relationships between these entities themselves, and links to authority data, e.g., Wikidata. An exemplary and validated segmentation comprises the following elements and their respective labels: [8]

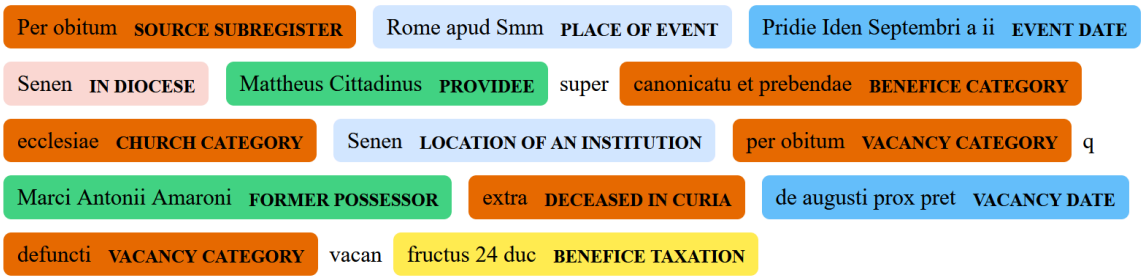


Figure 3: Rendering the Named Entity Recognition spans with displaCy.js (cf. Explosion 2025) as HTML. [Screenshot: Christoph Sander 2025]

Each element stores its label as relational information (set in bold),[9] has its own metadata, and is member of a specific class (coloured):[10] [9]

- **Persons**: Identified or unidentified single persons with different name properties.
  - **Providee**: The name of the individual being appointed, here »Mattheus Cittadinus«, encoded as ›Cittadinus‹ (family name), ›Mattheus‹ (given name).

[8] AAV Dataria Ap. Expeditiones 2 (no pagination). The entry's persistent IRI in our RDF is https://g17.dhi-roma.it/resources/entry_7704.
[9] Labels ultimately encode the relationship or the contextual meaning of an element with regard to its semantic role in the entry. E.g. a person may act in different roles, corresponding to different labels, but the same record in the database, as it is the same person. Hence the element remains related to the label while it links to a member of the class ›persons‹ that entails further metadata.
[10] This example does not include all entities, labels, and classes that are in use.

    - **Former Possessor**: The name of the former possessor of the office, here »Marci Antonii Amaroni«, as ›Amaronus‹ (family name), ›Marcus Antonius‹ (given name).
- **Dates**: Decoded and normalised as relative and absolute time periods.
    - **Event Date**: The date of the decision (i.e., the granting of the provision), here »Pridie Id Septembri a ii«, i.e., the 12th of September; »a ii«, i.e. the second year (14 February 1622 – 13 February 1623) of the pontificate of Gregory XV; the calendar year is hence 1622.
    - **Vacancy Date**: The date of the vacancy, »de augusti prox pret«, and thus in the past month of August, i.e. here between August 1 and August 31, 1622. Depending on the type of vacancy (see below) and the region, Roman bureaucracy only intervened following vacancies occurring in specific ›apostolic‹, months. The specific day within this timespan was hence irrelevant.
- **Places**: Identified or unidentified geographical points or areas with coordinates, name properties, hierarchical information, and relation to types.
    - **Place of Event**: The administrative location of the dating (and hence the granting) of the papal grace, here »Rome apud SMM«, i.e., one of the four major basilicas in Rome, Santa Maria Maggiore.
    - **Location of an Institution**: The precise location of the church here ›Senen‹ and thus the city in which the benefice is located, here Siena.
- **Institution**: Identified (ecclesiastical) institutions with name property and relations to places and types.
    - **In Diocese**: The diocese location, here ›Senen‹ and thus the diocese of Siena.
- **Types**: Categorical information with name property and hierarchical information.
    - **Benefice Category**: The awarded benefice, here: »Canonicatu et praebenda« and thus a canonship.
    - **Church Category**: The ecclesiastical institution to which the office is attached. Here: »ecclesiae« and thus an unspecified church, in this case the city's cathedral.[11]
    - **Vacancy Category**: The reason for the occurrence of the vacancy and thus the reassignment of the office, here: both »per obitum« and »defuncti« mean the death of the predecessor.
    - **Deceased at the Papal Court (Curia)**: Whether a death occurred inside the curia or outside of it, which conditioned the legal grounds of Roman bureaucratic interventions. Here »extra« indicates a death outside the curia.
    - **Source Subregister**: The subregister from which the data originates. Here »per obitum« and thus the subchapter that records allocations following the predecessor's death.
- **Monetary Values**: Decoded and normalised absolute values and type relations.
    - **Benefice Taxation**: The tax valuation of the office, here: »24 duc« and thus 24 ducats, the Apostolic Chamber's currency unit.

These elements are subsequently linked in a many-to-many relationship to specific events or objects documented or referenced by each entry. ›Events‹ and ›Objects‹ thereby constitute the core of our *Resource Description Framework (RDF)* ontology (see the following section). Notably, the act of granting a provision for a benefice is classified as an event (›apostolic provision‹), whereas the benefice itself constitutes an object. Each element is assigned either to the relevant event or to the object it describes. Furthermore, individual elements may be connected to multiple events or objects spanning several entries. Events are themselves linked to corresponding objects, and objects may further reference additional objects.[12] We anticipate also [10]

[11] It can be inferred from the absence of further information concerning the specific church in combination with the mention of Siena, a diocesan capital, as a location, that *the* church of Siena was meant, i.e. the cathedral of Siena.

[12] Objects such as pensions were levied on a benefice and to be paid by a benefice holder to a third party. Coadjutors gave their holders the right to assist and succeed, somewhere in the future, the current benefice holder in his functions without immediate transfer of the possession of the benefice itself between parties. In both cases the benefice was not immediately affected by the apostolic provision, but only via other ›objects‹, i.e. the pension or a coadjutory affecting the benefice. A third, analogous type occurring in our sources is the commenda (transfer of income from a monastery office to a third party, usually a secular cleric or even a lay person, with exemption from official duties) installed on abbeys or priories (and hence constitute, when occurring, the immediate objects of events subsequently to be linked to other objects, the abbatial or priory benefices), cf. Marceau 2017.

the possibility to link events with each other (e.g., for those events linked to ›double entries‹), but the need to do so has not occurred just yet at this stage of research. The association of elements with events and objects explicitly conveys their semantic relationships through descriptive labeling.

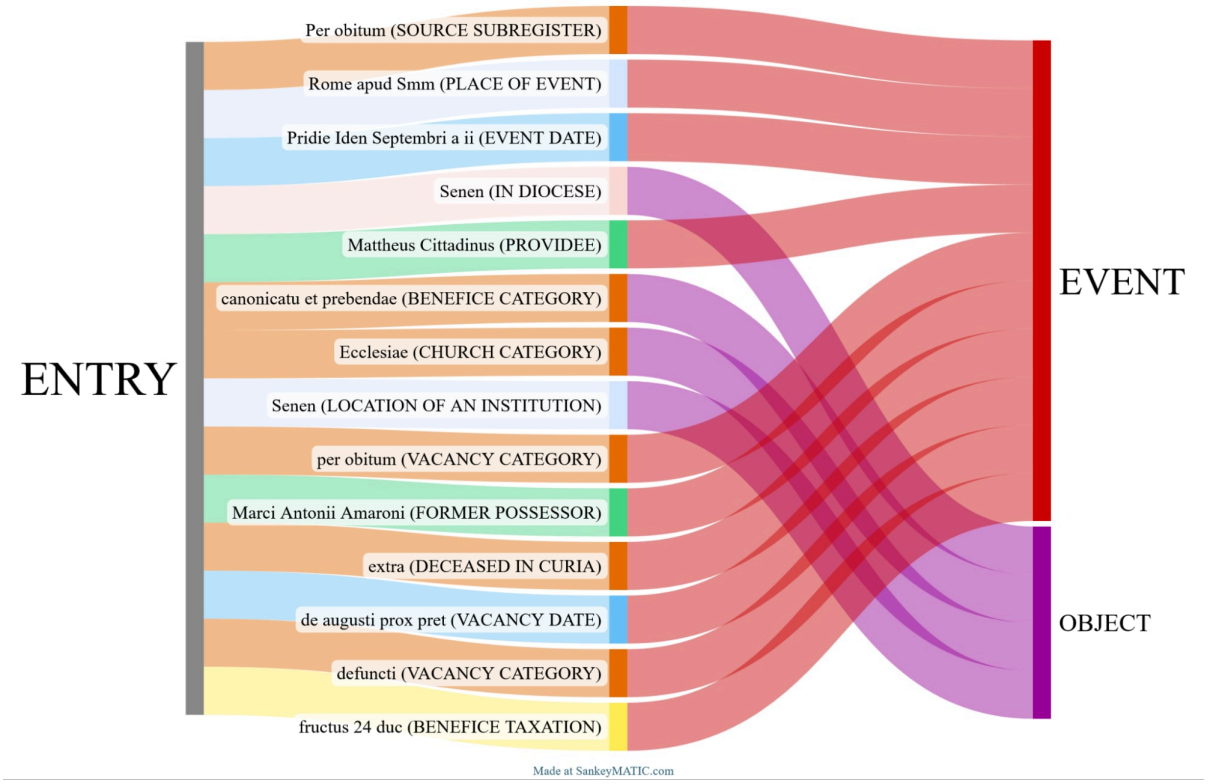


Figure 4: Assignment of elements to events / objects in the underlying conceptual framework. Sankey diagram created with SankeyMATIC (cf. Bogart 2014). [Diagram: Christoph Sander 2025]

2.3 Encoding Data in a Knowledge Graph

[11] Within the semantic Resource Description Framework, we conceptualise the data structure outlined above as a knowledge graph.[13] This approach relies primarily on our domain-specific *Web Ontology Language (OWL)*-compliant[14] ›GRACE‹ ontology that has been created by the entire project team of researchers and developers.[15] The core of our approach involves transforming textual segments, i.e. the elements, into unique entities – individuals of OWL classes – such as persons, dates, places, institutions, and more. The labels of these elements are primarily modelled as direct OWL object properties, although more complex relationships are also considered. For instance, for some element with some label, as previously described, we express the label's meaning through a specific property (*grace:providee* for the label ›Providee‹) and create an entity for the element (e.g. a person for the element ›Mattheus Cittadinus‹). By employing this direct use of labels as properties, we establish meaningful relationships between specific entities in appropriate roles or aspects using distinct predicates for specific phenomena described by the sources. This method offers a streamlined alternative to more cumbersome approaches that rely on reified properties to model specific aspects or roles of generic relationships.[16]

[13] RDF Core Working Group 2014.
[14] OWL Working Group 2012.
[15] Sander / Boute 2025. The GRACE ontology is served from https://w3id.org/grace/ontology. As stated below, we also expose our data to upper-level ontologies for re-use.
[16] Cf. van Hage et al. 2011.

OWL datatype properties are mainly used to encode metadata for individual entities, particularly normalised and enriched literals, such as appellations or numerical values. The complete ontology, encompassing almost 2,000 triples, almost 200 (sub)properties, and around 100 (sub)classes, is too extensive to be fully explained here. However, its simplified structure is illustrated in the following manually crafted diagram. [12]

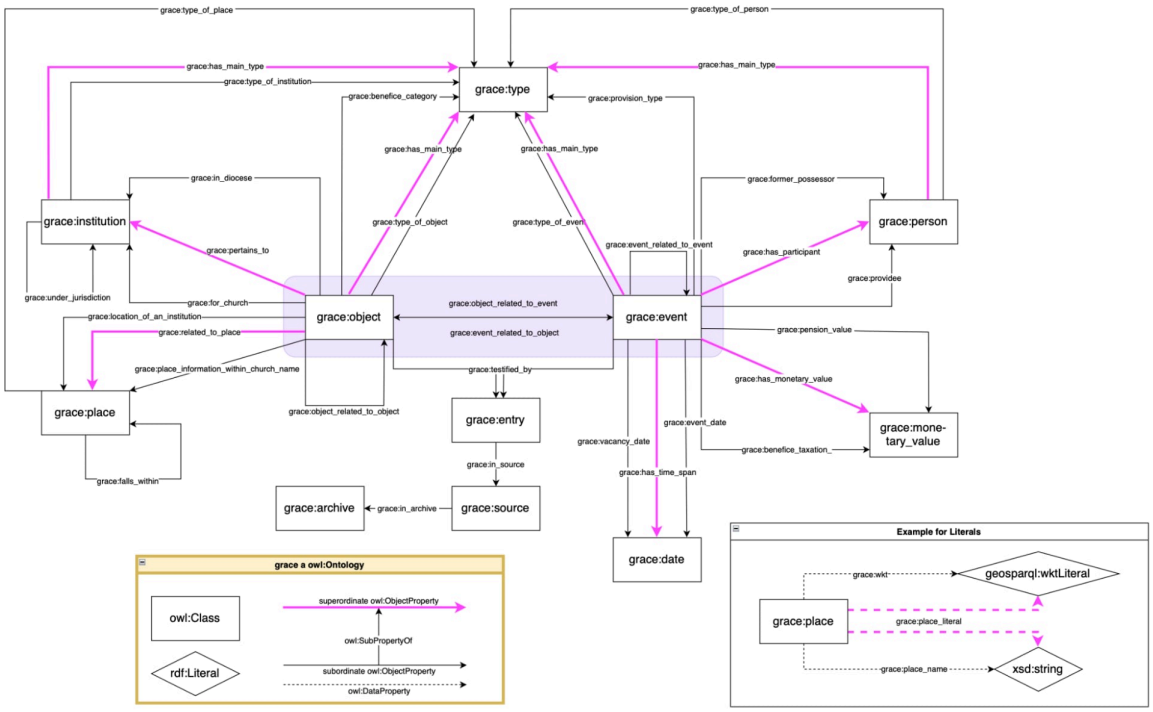


Figure 5: The ontology diagram visualises the encoding of historical data as a knowledge graph. This ontology is specifically designed to model relationships between various entities centered around the granting of ecclesiastical offices in the 17th century through the Apostolic Datary. It is fully compliant with the Web Ontology Language (OWL). [Diagram: Christoph Sander et al. 2025]

The core of our knowledge graph consists of two primary classes: *grace:event* and *grace:object*.[17] At this stage, events are mainly papal graces, specifically apostolic provisions for benefices, while objects primarily include benefices, pensions, commendas and other codified immaterial objects of church administration. This central connection between object and event is reflected in our ontology through the relationship between these two classes using the symmetrical properties *grace:object_related_to_event* and *grace:event_related_to_object*. Besides these core classes around which the ontology is structured, the diagram displays our primary classes as well as their relationships, expressed through properties that define how a particular entity is related to an event or object. The main (super-)classes are *grace:place*, *grace:institution*, *grace:person*, *grace:event*, *grace:entry*, *grace:type*, *grace:monetary_value*, *grace:source*, and *grace:archive*. Some classes are structured as superordinate classes that can be further subdivided into subclasses: for example, the class *grace:apostolic_provision* is a subclass of *grace:event*, just as *grace:benefice* is a subclass of *grace:object*. [13]

[17] Events comply with their counterparts in common upper ontologies and require a spacetime volume, while objects are taken to be persistent over a period of time, be they material or immaterial, and can feature as an object in or of an event.

[14] Each church office or benefice, i.e., all objects,[18] are described by properties in their domain, including, e.g., the office's institutional affiliation, most importantly the diocese (e.g., *grace:pertains_to* or *grace:in_diocese* with *grace:institution* in its range) as well as multiple categorical information (*grace:type*). In contrast, particularly date-related (with *grace:date* in their range), person-related (*grace:person*), and monetary value-related (*grace:monetary_value*) properties are used to describe an event.[19] Whether a property has *grace:event* or *grace:objects* (or both) as its domain depends on semantic reflection on the phenomenon or thing being modeled: while, e.g., the location, church institution, and characteristics of the benefice object generally remain stable,[20] event-related properties (including taxing yearly revenue in *that* specific context by *this* Roman bureaucracy) describe the contingency of ›what happened‹ to the object at some point, entailing, most importantly, to person stakeholders and an event date. As a corollary, objects logically are presupposed for events to relate to these objects.

[15] Any information, or property assignment, about events and objects is testified (*grace:testified_by*) by one or many entries further linked to sources and archives (as instances of *grace:entry*, *grace:source*, and *grace:archive*, from which metadata can be retrieved via *grace:in_source*, and *grace:in_archive*). Additionally, each instance of any class has a specific *grace:type* instance, rendering its super-property *grace:has_main_type* a functional property. Just as classes are divided into superordinate and subordinate classes, the properties defining relationships between classes are hierarchical, too, using *rdfs:SubPropertyOf*. Some properties are more general than others, connecting many (or even all) classes: for example, *grace:has_participant* has all *grace:person* instances in its range (thus, in all roles, instantiated as subproperties),[21] while *grace:refers_to* is fully agnostic to range restrictions and will return entities of any class. The more specific properties are, the more constrained is their range of classes and the smaller their extension. Properties with a large extension facilitate queries and make these much more performant.[22]

[16] Datatype properties for literals encode names, dates, monetary values, geographical coordinates (represented here as WKT[23] and GeoJSON[24]), etc. Having hierarchical datatype properties allows for direct literal searching in SPARQL queries, retrieving literals of any datatype property of some node, e.g., using *grace:appellation_literal*.

2.4 Linked Open Data

[17] In alignment with the principles of *Linked Open Data*, the GRACEFUL17 project models its data to support structured interlinking, semantic querying, and interoperability across platforms. This ensures that the dataset can be reused, referenced, and integrated within the wider knowledge graph ecosystem. In GRACEFUL17, we primarily use Wikidata as a hub for Linked Open Data. Where possible, our data links directly to entities in Wikidata, particularly institutions such as individual dioceses and specific locations. When no corresponding entity exists in Wikidata, we plan to create the necessary Wikidata items and link them to our dataset. For this purpose, the property P13367 ›Graceful17 ID‹ is used to connect Wikidata items

[18] Of particular importance is the relationship between objects via the property *grace:object_related_to_object* (cf. Fig. 5). This property links benefice-related grants such as pensions, commendas, and coadjutories to a benefice and thus to another object, as these grants cannot exist independently of a benefice. Other classes can also refer to themselves for hierarchical structuring, as shown here for *grace:place* (via the property *grace:falls_within*): a location falls into a subregion, into a region, into a continent, etc.

[19] The absence of information or relationships maps into the absence of respective instantiated properties: If no monetary value is specified for a given event, no property would link to any *grace:monetary_value* instance.

[20] Philosophically speaking, once an object changes with regard to a property, it is no longer considered identical and brings a novel object into existence.

[21] For example, some *grace:event* instance may relate to a *grace:person* via properties such as *grace:providee* and *grace:former_possessor*.

[22] In SPARQL, e.g., it is often unnecessary to define the range of the query object, as the object is defined by a property already, rendering additional FILTER statements rarely necessary. Moreover, UNION statements can be replaced by more extensive property paths directly, boosting the performance considerably.

[23] Open Geospatial Consortium 2023.

[24] Butler et al. 2016.

(e.g., persons, dioceses, places) to their corresponding entities in our dataset via a unique identifier. The base URI of the entities is `https://g17.dhi-roma.it/resources/`, extended by the relevant resource class and a sequential identifier (`person_[0-9]+`, `place_[0-9]+`, `institution_[0-9]+`, etc.). Using this property enables straightforward integration of our data into federated SPARQL queries and facilitates referencing our dataset in other academic or public projects.

[18] The geodata – in particular for boundaries of dioceses and ecclesiastical provinces – are derived from public geospatial sources, primarily the Earthworks project at Stanford University[25] and the dataset *Bistumsgrenzen Altes Reich um 1500* from the Germania Sacra project of the Göttingen Academy of Sciences and Humanities.[26] The goal of our project is not to reconstruct an exact geography of ecclesiastical administration. The (multi)polygons used represent simplified approximations of historical boundaries at around 1650 and thus do not account for any diachronic changes. These data instead are primarily used to draw geographical inferences about the belonging of places to certain regions. This kind of detection – performed via geospatial joins, a method to combine two datasets based on a specific spatial relationship between their geometries – is significantly more efficient than manual case-by-case analysis or relying solely on hierarchical associations, especially when such spatial relationships are already implicit in the data and can be made explicit.

[19] We map the RDF data to higher-level ontologies: CIDOC CRM[27] (for modeling cultural heritage information) and RiC-O[28] (for archival classification and provenance concepts). Thus, the RDF triples in the ABox – the facts about individual things in our knowledge graph – can be queried using these widely adopted standard ontologies. Although the full semantic richness of the data is only accessible through the GRACE ontology, this mapping enhances interoperability and significantly improves the reusability of the data. For easier access, the RDF triples are organised into separate named graphs according to the specific ontology they conform to.

[20] The controlled vocabularies and thesauri developed in the project (categories of benefices, churches, religious orders, ecclesiastical provinces, etc.) are represented by *Simple Knowledge Organization System (SKOS)* objects in the form of hierarchically organised taxonomies.[29] To describe the specific contributions of each author or collaborator to the research project, we use the CRediT taxonomy.[30]

2.5 Data Entry and AI Support

[21] Researchers enter data using a commercial cloud database provided by Ninox and hosted by a private, dedicated server.[31] While Ninox offers its own scripting language and *Application Programming Interface (API)*, the database's functionality is significantly extended through the integration of an external *Representational State Transfer (RESTful)* API application called DATAria.[32] This Python-based application, run in a Docker container and accessible via a public HTML User Interface, enhances data entry through a series of modular components. Although a comprehensive description of all API endpoints is beyond the scope of this paper, one of its key modules significantly facilitates data entry. Semantic segmentation, as outlined earlier, is performed using the spaCy NLP Python package, specifically leveraging the NER and SpanCat pipelines.[33] To accommodate the diverse requirements of individual researchers and varying sources, custom models are frequently trained (active learning) and then called from within the database application to automatically generate the described elements. DATAria also supports fuzzy entity matching to align elements with actual

[25] Dorin et al. 2021.
[26] Germania Sacra 2020. In several instances, new shapes were created using QGIS. This GIS data is published as GeoJSON.
[27] Bekiari et al. 2024.
[28] International Council on Archives Expert Group on Archival Description 2025.
[29] Miles / Bechhofer 2009.
[30] NISO CRediT 2022.
[31] Ninox Software GmbH 2025.
[32] Sander 2025e, also available at https://dataria.org.
[33] Honnibal et al. 2020; cf. Sander 2025f.

entities – such as places, dates, and other named entities – by employing Python's RapidFuzz package and Levenshtein distance.[34] Additionally, the assignment of elements to events or objects is aided by a gradient boost classifier (a machine learning technique aligning multiple models in a sequence so that they can learn from the errors), utilising the CatBoost framework and Python package. These automated assistance tools are carefully supervised, as they are trained on validated data and their predictions are immediately reviewed by researchers in real time. Their primary purpose is to accelerate data entry without excluding researchers from the data validation process. This greatly enhances the feasibility (and future funding prospects) of a humanities research project aiming to collect and publish comparably large amounts of data without jeopardising their complexity and accuracy.

2.6 Serialising RDF and SPARQL

[22] The transformation of relational data into RDF is accomplished through a sophisticated serialisation process based on *JavaScript Object Notation for Linked Data (JSON-LD)*[35] within DATAria. This process involves namespace management / mapping and ontological reasoning to ensure compatibility with RDF standards. The serialisation itself is performed using Python's RDFLib, which is enhanced by customised JSON-LD streaming to facilitate the processing of large files, potentially in the range of gigabytes.[36] The resulting RDF data is converted into *Turtle (Terse RDF Triple Language)* or *N-Triples* files and stored in dedicated named graphs in a Oxigraph triple store.[37] This transformation process is designed to be easily repeatable, enabling regular updates to the graph database while preserving data history. To ensure semantic consistency, Ninox also parses the GRACE ontology as an OWL-compliant encoding. The resulting OWL RDF file is then utilised to dynamically generate ontology documentation through WIDOCO[38] and OntoSpy[39], producing static HTML files that allow users to explore definitions and axioms interactively. Additionally, the graph's structure is specified with the help of *Shapes Constraint Language (SHACL)*,[40] which provides the basis for a dynamically adaptable graphical query builder, Sparnatural.[41] This tool simplifies the construction of SPARQL queries through an intuitive graphical interface.[42] Query results can be visualised as tables, maps, or diagrams using built-in plugins. The use of the integrated dockerised app SHMARQL, a linked data publishing platform, provides immediate and dynamic insights into the RDF data through templates generated on the fly.[43] For each data point, SHMARQL enables users to view all relevant RDF data in tabular views with simple clicks, providing an accessible and efficient interface for examining the knowledge graph.

2.7 Analysis

[23] Data analysis primarily addresses social, geographic, and chronological data, with a strong focus on identifying correlations and clusters that are then examined through temporal and spatial aggregations. This analytical approach offers deeper insights into the dataset at any stage, enhancing the flexibility and iterative use of data during the data entry process. The core analytical features are facilitated by the DATAria API, which provides various methods for complexity reduction, statistical analysis, and decision tree classification.

[34] Bachmann 2025.
[35] Sporny et al. 2020.
[36] Krech et al. 2023. Since Oxigraph v.0.4.0, JSON-LD streaming is supported and RDFLib-based serialising is no longer needed.
[37] Pellissier Tanon 2025. We use pyOxigraph within DATAria to populate the story via a POST API call. Our choice of oxigraph is for various reasons: its being written in Rust and its underlying RocksDB make it a highly performant database. Its Python library allows seamless integration into our workflow. As we create JSON-LD from our internal database and wish to expose a SPARQL endpoint, a triple store is a better choice than any graph database, as data exchange is fully RDF compliant and needs no middleware.
[38] Garijo 2017.
[39] Pasin 2022.
[40] Knublauch / Kontokostas 2017.
[41] Sparna 2025.
[42] Sander 2025d.
[43] Posthumus 2025.

Additionally, it integrates geographic functions from widely used Python libraries such as Shapely[44] and Geopandas.[45] This functionality enables robust geographic queries for data aggregation and supports the streamlined adjustment of imported geodata, making it highly relevant for digital humanities projects concerned with spatial analysis. A lightweight Python package named DATAria Utils acts as a wrapper to simplify data access and processing.[46] This package allows researchers to interact with the dataset via SPARQL queries, rendering analyses directly within Jupyter notebooks.[47] The outputs are highly customisable and can be produced in various formats, including static visualisations (e.g., plots, maps, charts), tabular data (e.g., CSV files, pandas.DataFrame), and interactive widgets for in-notebook exploration.

3. Data Publication

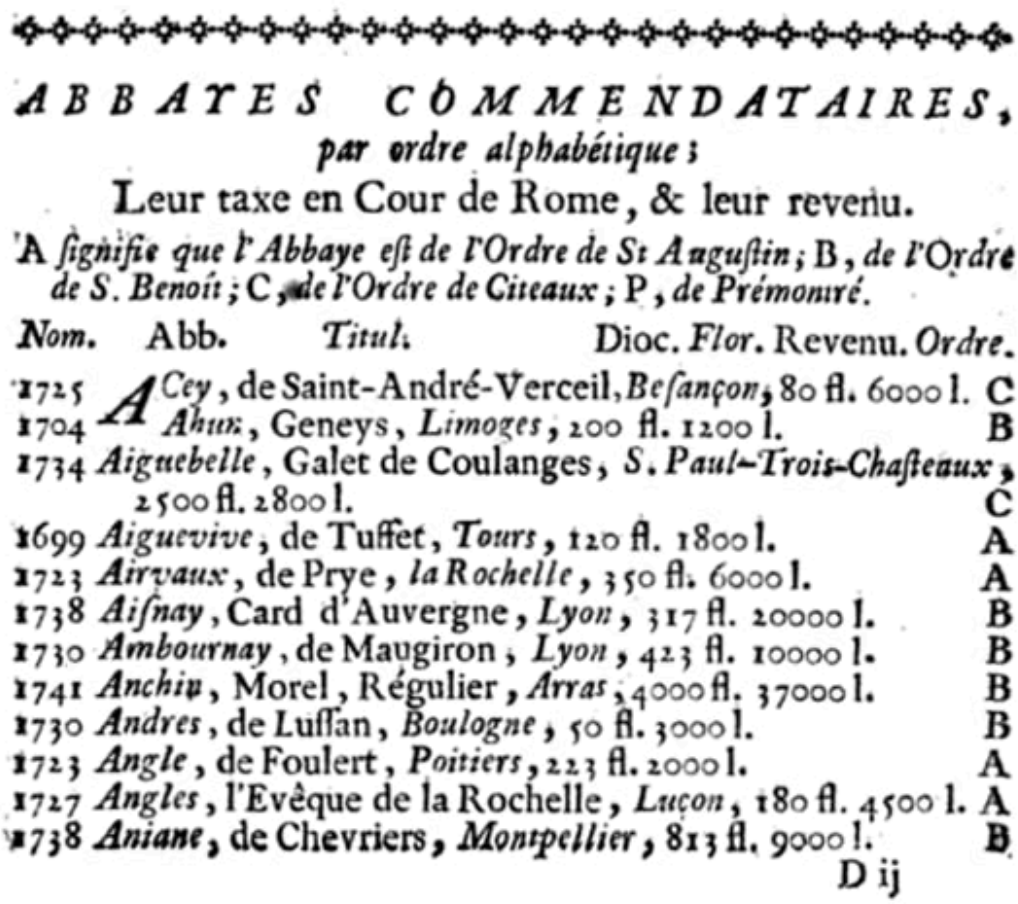
[24] The GRACEFUL17 project publishes its data in accordance with the FAIR Data Principles.[48] As outlined in the paragraph on Linked Open Data, both the project's ontology and the knowledge graph entities are made available via persistent identifiers. All RDF data generated within the project are accessible through a public SPARQL endpoint listening at https://graph.dhi-roma.it/query. To facilitate and ensure long-term preservation, thorough documentation, as well as the reuse and verification of research data and results, all datasets are published in open data and software repositories. These are made available under open licenses (MIT, CC BY) and are regularly updated.

[25] The knowledge graph data are provided through a research data repository[49] as separate static dumps for each named graph, one per ontological mapping (currently GRACE, CIDOC-CRM, RiC-O, SKOS), in N-Triples and JSON-LD formats. The GRACE graph currently entails 14,264,742 triples.[50] The repository also includes the ground truth data from the initial transcriptions (entries), along with metadata describing archival storage conditions and creation dates that are provided in *Tab-Separated Values (TSV)* format. Additionally, it contains both reused and newly created geodata in GeoJSON format, as well as extended project documentation. In a GitHub repository maintained by the DHI Rome, the GRACE ontology is stored in the Turtle (TTL) format. Related repositories also host a fork of the DATAria API and its web application, as well as a dedicated repository containing research-relevant SPARQL query examples embedded in Jupyter notebooks and a repository with explorative web interfaces. The models created and used in the project for spaCy NER and the CatBoost model are published separately on Hugging Face.[51]

4. Using Data from Stockpiles of Paper

[26] The semi-automated workflow supported by Deep Language Learning and monitored by researchers at each stage of entry and data modelling facilitates the management, researchability and curation of amounts of data that are very large by humanities research standards, enhancing thus both the feasibility and fundability of similar projects. Although the ontology was developed in tandem with archival research into two specific volumes preserved in the Vatican Apostolic Archive, the knowledge graph's core structure centering on events and objects allows to integrate a wide variety of sources documenting information that can be modelled likewise (cf. Figure 5), including information unrelated to papal and / or benefice administration.

[44] Gillies / Shapely contributors 2025.
[45] GeoPandas developers 2025.
[46] Sander 2025c.
[47] Sander et al. 2025b.
[48] Wilkinson et al. 2016.
[49] Sander et al. 2025a.
[50] December 12, 2025.
[51] NER: Sander 2025b, CatBoost: Sander 2025a.



ABBAYES CÔMMENDATAIRES,
par ordre alphabétique;
Leur taxe en Cour de Rome, & leur revenu.

A signifie que l'Abbaye eſt de l'Ordre de St Auguſtin; B, de l'Ordre de S. Benoît; C, de l'Ordre de Cîteaux; P, de Prémontré.

Nom.	Abb.	Titul.	Dioc. Flor.	Revenu.	Ordre.
1725	A Cey, de Saint-André-Verceil,	Beſançon,	80 fl.	6000 l.	C
1704	Ahux, Geneys,	Limoges,	200 fl.	1200 l.	B
1734	Aiguebelle, Galet de Coulanges,	S. Paul-Trois-Chaſteaux,	2500 fl.	2800 l.	C
1699	Aiguevive, de Tuffet,	Tours,	120 fl.	1800 l.	A
1723	Airvaux, de Prye,	la Rochelle,	350 fl.	6000 l.	A
1738	Aiſnay, Card d'Auvergne,	Lyon,	317 fl.	20000 l.	B
1730	Ambournay, de Maugiron,	Lyon,	423 fl.	10000 l.	B
1741	Anchin, Morel, Régulier,	Arras,	4000 fl.	37000 l.	B
1730	Andres, de Luſſan,	Boulogne,	50 fl.	3000 l.	B
1723	Angle, de Foulert,	Poitiers,	223 fl.	2000 l.	A
1727	Angles, l'Evêque de la Rochelle,	Luçon,	180 fl.	4500 l.	A
1738	Aniane, de Chevriers,	Montpellier,	813 fl.	9000 l.	B

D ij

Figure 6: Alphabetical list of abbeys held ›en commende‹ in France with the date of their provision, their current holders, diocese, taxation value in Roman administration and yearly revenue, in the Almanach Royal of 1742. While this source was not used, to date, in the project, the information it furnishes is compatible with our OWL ontology. [Image: Wikimedia Commons / Google eBooks. Public domain]

The data collected in this project aim to improve our understanding of transnational, global governance by the papacy in the 17th century via its provision of local, lower and middle church offices to thousands of petitioners on a yearly basis. This provides researchers with an excellent vantage point to access, via local church life, a wide range of political, institutional, social, and cultural dynamics. The ›globalist‹, continent-wide samples for the 1620s and the 1670s under discussion in this paper constitute a mirror and point of comparison for the ›localist‹ focus of team members' research into the phenomenon's local dynamics, patterns in the distribution of benefices, and bureaucratic processes in Catalonia, Cologne, and Rouen respectively, shedding light on the diverging constellations fueling Roman bureaucratic interventions on the Iberian Peninsula, in the Holy Roman Empire, and in France. The knowledge graph developed by GRACEFUL17's team in this context functions as a quintessential mediator between 17th century bureaucratic registrations in the sources and modern historians' quantitative research questions. A few examples in the field of social and administrative history suffice to illustrate the point here. [27]

While the ›benefice system‹ had emerged in the High Middle Ages to counter feudalism in the allocation of church offices, it retained a high level of flexibility to support and stabilise families and clientelist networks, an absorption capacity that conversely guaranteed support for and acceptance of church wealth. The data enable the systematic and quantitative study of family ties, social networks, and patterns of patronage within the Church beyond individual case studies and on a much wider social spectrum ranging from humble parish priests in rural areas remote from Rome to papal families consolidating their future influence via [28]

the accumulation of offices and pensions. Office transfers procured by Roman bureaucracies indeed often followed patterns suggesting familial continuity or patronage networks.[52] In cases where family ties are implied, we encode these relationships – where applicable – using the property *grace:kinship*. Additionally, references to close associates of high-ranking church officials in the registrations hint at broader systems of clientelism. These patterns, modelled via the assignment of different roles to stakeholders mentioned in the registrations or of different types of vacancies that were either strongly or weakly correlated with nepotistic behaviour, highlight the extent to which local personal and family strategies were tied to the circulation of Roman authority and allow to differentiate between geographical, synchronic as well as diachronic contexts. These data allow for further research into individuals profiling as (potential) agents of papal primacy and politics versus those activating Roman bureaucratic machinery without notable agency in the field, or who even may have contested papal claims in other circumstances.

[29] The dataset further sheds light on the everyday realities of clerical life. By analysing and comparing vacancy dates (*grace:vacancy_date*) and vacancy categories (*grace:vacancy_category*), for instance, it opens up the possibility of correlating to correlate rhythms and conjunctures in Roman bureaucratic procedure (and, hence, the submission of letters of supplication on behalf of petitioners) with crises and economic conjunctures due to war, (other) excess mortality peaks, or political and dynastic transitions and crises of legality that might inform strategies to obtain clerical office via Rome instead of local recruitment channels. Vacancies occurring because of irregularities are likely to shed light, especially in combination with research in local archives, on local conflict cultures and the diverging levels of ›job security‹ versus acceptance of deviant clerical behaviour.

[30] The data further raise questions about key aspects of the Apostolic Datary's bureaucratic logic: different subregisters in the investigated register volumes handled distinct types of petitions, which we encode using the property *grace:in_subregister*. This functional differentiation points to a rationalised administrative structure within the curial system. In addition, information on the curial taxation of benefices, including different practices of taxation depending on the type of vacancy, provide valuable insight into the financial strategies of the Holy See, shedding light on how spiritual authority was also tied to economic revenue yet needed to take into account local acceptance of proverbial Roman ›greed‹. Temporal data (*grace:date*), including the date of expedition (*grace:event_date*) and the death of previous office holders (*grace:vacancy_date*), allows us to analyse the speed and efficiency of the provision process as well as local incentives urging petitioners and their solicitors in Rome to speed up the process. Spatial and chronological patterns – supported by GIS data – also help assess the intensity of curial involvement ›from below‹, especially in dioceses that frequently petitioned to Rome. Data on revenue (encoded as class *grace:monetary_value*) in combination with differently ›taxed‹ categories of vacancy (*grace:vacancy_category*) allow to compare clerical incomes across Europe and the relative attractiveness of certain offices (*grace:benefice_category*) in specific regions compared to others, enabling us to trace the centrality (or lack thereof) of apostolic authority on the ground within and in between predefined subregions and regions (*grace:region* and *grace:subregion* as subclasses of *grace:place*) or geographical entities tailored by the research question and by the individual researcher. Trends over time could indicate shifting political, institutional, or regional dynamics, including levels of competition on local ›clerical job markets‹ *avant la lettre* warranting costly and time-consuming procedures in Rome. Moreover, the dataset allows for the study of the geographic distribution of graces. Catholic heartlands like France, Spain, and Italy dominate (albeit with different intensity between subregions, dioceses, and localities). However, offices or, to a greater extent, dispensations related to office-holding were also granted in regions far from Rome, including South America and Africa – adding new dimensions to the global transfers of plural Catholicisms and of apostolic authority by a wide range of stakeholders to the four corners of the early modern world.

[52] The method for analysing nepotism on the basis of surnames is described in the article by Stefano Allesina (Allesina 2011). This method was also used by Christoph Sander et al. 2025c in the as yet unpublished article about *Efficiency and Nepotism in Early Modern Ecclesiastical Administration: A New Quantitative Approach*.

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List of Figures