

# Knowledge Graphs and Data Services for Studying Historical Epistolary Data in Network Science on the Semantic Web

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**Abstract.** Communication data between people is a rich source for insights into societies and organizations in areas ranging from research on history to investigations on fraudulent behavior. These data are typically heterogeneous datasets where communication networks between people and the times and geographical locations they take place are important aspects. We argue that these features make the area of temporal communications a promising application case for Linked Data (LD) -based methods combined with temporal network analyses. A key result of this paper is to show how to create and publish a global Linked Open dataset and data service about historical epistolary data, based on distributed data from several international heterogeneous data sources, that can be enriched by data linking and reasoning, and that can be served back for the research community as an open infrastructure, a data service, and a semantic portal for further study in Digital Humanities (DH). A framework for this purpose is presented for publishing and analyzing communication network data, based on recent advances in analysis of temporal communication networks and the behavioral patterns commonly found in them. The framework was applied to two created and published open LD services (CC BY 4.0): (1) the data schema, dataset, and data service of the Dutch CKCC corpus (of ca. 20 000 letters) and (2) the pan-European correspSearch corpus (of ca. 135 000 letters) related to the Republic of Letters (1500–1800). To evaluate and demonstrate the usability of the new data services in DH research, a semantic portal was implemented on top of their SPARQL endpoint demonstrating re-usability, flexibility, and feasibility of the Linked Data approach from a DH research perspective.

**Keywords:** Semantic Web, Linked Open Data, Digital Humanities, Network Science, Early Modern

## 1. Introduction

Since the revolution in network science around 20 years ago [33, 39, 40], this field of research has been extremely successful explaining various phenomena and fundamental concepts in a wide array of systems from societies to brain and cellular biology. The tools and ideas developed for network analysis allow for different levels of granularity ranging from the whole network to diagnostics computed for individual nodes in the network, such as centrality measures, node roles, and local clustering coefficients. However, these tools are often mainly used by the network

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1 scientists as they are difficult to use for the domain experts: accessing them requires programming skills or at 1  
 2 least specialised software that relates the often heterogeneous network data and metadata to the questions that are 2  
 3 important for the domain experts. On the other hand, there is a need to make the rich datasets created by historians 3  
 4 in Digital Humanities (DH) and the Linked Data community available for the network scientists. 4

5 This paper builds on the idea that Semantic Web technologies<sup>1</sup> [11] and Linked Data [8, 15] can be a solution to 5  
 6 these problems. The graph-based RDF data model underlying the Semantic Web is a perfect match for representing 6  
 7 network data, and Linked Data publishing [8] can be used for making the data available for researchers in humanities 7  
 8 with some skills on using SPARQL<sup>2</sup> queries or on programming with SPARQL endpoints. Furthermore, ready-to- 8  
 9 use portal solutions for data analysis can be implemented for DH based on such data services [18]. The idea is 9  
 10 that by combining the flexibility of publishing and using LD with the tools of network science can help domain 10  
 11 experts to tackle massive network data in fruitful manner with little or no expertise in programming. Furthermore, 11  
 12 the LD created can be served back to the research community for further research and application development 12  
 13 in a disciplined and well-defined way by using the Semantic Web methodology [12] the practical LD publishing 13  
 14 principles including SPARQL endpoints. 14

15  
 16 Table 1  
 17 Datasets analyzed and compared in this paper 17

18 Dataset	18 Content
19 CKCC	19 Epistolary data of the CKCC corpus of the Huygens Institute in the Netherlands, an aggregated collection of ca 20 20 000 Dutch correspondences [9, 26] related to the Republic of Letters [14, 26] 20
21 correspSearch	21 Epistolary data 1510–1991 of 135 000 letters aggregated by the correspSearch project at the Berlin Brandenburg 22 Academy of Sciences and Humanities [3] 22

23  
 24 To test and demonstrate this approach in practise, this paper focuses on communication networks that are repre- 24  
 25 sented as temporal networks, a rapidly developing subfield of network science [13, 33]. Two datasets of historical 25  
 26 epistolary data listed in Table 1 are used as case study examples. Temporal networks are a specific type of networks 26  
 27 that carry information on the activation times of the links in addition to the topological structure of the networks. In 27  
 28 communication networks this means that we do not only consider who has been in contact with whom, but also the 28  
 29 exact time instances at which the communication has taken place. This not only adds complications related to how 29  
 30 the various methods and measures are generalised for temporal networks, but also creates possibilities of new types 30  
 31 of network analysis. For example, in communication networks it has been found that the individuals are in contact 31  
 32 in a bursty manner [5, 21] and they distribute their communication efforts via patterns, known as social signatures, 32  
 33 that are specific to each individual [10, 32]. These phenomena are understood in terms of statistical laws found in 33  
 34 anonymized data, but much less attention has been given on how such features translate to interpretations of indi- 34  
 35 vidual relationships or people. Here we introduce a method for giving access to these state-of-the-art network anal- 35  
 36 ysis methods to domain experts, who work through the massive databases of communications using theoretically 36  
 37 grounded analysis tools. 37

38 The paper extends our earlier papers related to publishing and analyzing historical epistolary data and Letter- 38  
 39 Sampo [16, 36] by the network science perspective outlined above and by a tools and systems perspective: new 39  
 40 linked open data resources available online are described in more detail as well as tools for their practical application 40  
 41 to Digital Humanities research by SPARQL querying and by using the LetterSampo semantic portal system. 41

42 It should be noted that this paper focuses on presenting a technical framework and approach for applying network 42  
 43 analysis and LD technology to publishing and using historical epistolary data in research, not on particular domain 43  
 44 specific analyses of the datasets from a humanities point of view. This remains a proposed topic of further research 44  
 45 using the approach and tooling presented. 45

46 The paper is organized as follows. First, related work in epistolary historical network studies and temporal net- 46  
 47 work analysis and systems are discussed to contextualize the work of this paper. Next a new data model and Linked 47  
 48 Data sets conforming to it are presented as well as a LD service platform for publishing them, based on extending 48  
 49 49

50 <sup>1</sup><https://www.w3.org/standards/semanticweb/> 50

51 <sup>2</sup><https://www.w3.org/TR/sparql11-query/> 51

the traditional 5-star model to a 7-star model. After this, examples of network analyses using the Linked Data and SPARQL endpoint are presented. To test and demonstrate usability of the new data resource and data service even further, a semantic portal on top of the data service is presented with examples of data analyses. In conclusion, contributions of the paper and challenges of the proposed approach are summarized and discussed.

## 2. Related Work

### 2.1. Epistolary Historical Networks

During the Age of Enlightenment it became suddenly possible for people to send and receive letters across Europe and beyond, based on a revolution in postal services. This opportunity resulted into what the contemporaries called the *Respublica litteraria*, Republic of Letters (RofL), a cross-national collaborative communication network that formed a basis for modern European scientific thinking, values, and institutions in Early Modern times 1400–1800. Data sources of early Early Modern learned correspondences are proliferating rapidly, including, e.g., *Europeana*<sup>3</sup> [2], *Kalliope Catalogue*<sup>4</sup>, *The Catalogus Epistularum Neerlandicarum*<sup>5</sup>, *Electronic Enlightenment*<sup>6</sup>, *ePistolarium*<sup>7</sup> [30], *SKILLNET*<sup>8</sup>, *correspSearch*<sup>9</sup>, the *Mapping the Republic of Letters* project<sup>10</sup>, and *Early Modern Letters Online (EMLO)*<sup>11</sup> [9, 14, 26]. Visualizing the correspondences has been studied in the *Mapping the Republic of Letters* project<sup>12</sup> and in *Tudor Networks of Power*<sup>13</sup>.

The idea of representing epistolary data as a LD service was introduced in [35] and its application to DH research is discussed in [16] pointing out the analogy between RofL and Linked Open Data movement with some tooling, data analyses, and visualizations as examples. In this paper, the idea of using the Linked Data Service is developed and discussed further from a network analytic perspective, in relation to the correspondences of the Republic of Letters 1500–1800 [14] in the Netherlands and Germany. We demonstrate flexibility and scientific potential of using an epistolary Linked Data Service for research in the following ways: (1) Firstly, by transforming and downloading the data into a suitable form, network analytic tools developed originally for different purposes, in our case for contemporary communication data, can be re-used, making it possible to apply them to historical epistolary networks, too. (2) Secondly, based on the Sampo model [18] and Sampo-UI framework [20], the data service can be integrated seamlessly with tooling for DH research making network analyses possible for researchers who often lack programming experience. (3) Thirdly, it is shown how the LD data service resource can be used for solving DH problems with little programming experience using online programming services, such as *Google CoLab*<sup>14</sup> and *Jupyter*<sup>15</sup>.

### 2.2. Temporal Network Analysis

In the past few decades, communication data has become a relevant resource to understand the underlying social networks [28, 33]. In such cases, auto-recorded logs of pairwise interactions are modelled to construct a communication network, thus allowing the analysis of large-scale societal interactions and behavioural patterns. Here we focus on using epistolary Linked Data about communications to analyse historical correspondence networks of epistolary data but the methodology can equally well be used for modern communication networks, such as those from

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<sup>3</sup><http://www.europeana.eu>

<sup>4</sup><http://kalliope.staatsbibliothek-berlin.de>

<sup>5</sup><http://picarta.pica.nl/DB=3.23/>

<sup>6</sup><http://www.e-enlightenment.com>

<sup>7</sup><http://ckcc.huygens.knaw.nl/epistolarium/>

<sup>8</sup><https://skillnet.nl>

<sup>9</sup><https://correspsearch.net>

<sup>10</sup><http://republicofletters.stanford.edu>

<sup>11</sup><http://emlo.bodleian.ox.ac.uk>

<sup>12</sup><http://republicofletters.stanford.edu/>

<sup>13</sup><http://tudornetworks.net/>

<sup>14</sup><https://colab.research.google.com>

<sup>15</sup><https://jupyter.org>

mobile phone logs, emails and social media platforms [36]. We identify two main approaches to analyzing such communication datasets according to the handling of temporality of the data [33, 36]. In a static approach a link is established between two people if there have been epistolary contacts between them, and in a temporal approach, the focus is on the distribution of dyadic interactions and behavioural features that characterize the way that people communicate. However, while most modern datasets attempt capture all auto-recorded communication within a communication channel (e.g., all emails or other communications within an organization [1, 4, 41]), this may not be true for historical data, since its collection is not automated, but implies broad manual compilation efforts by researchers.

For the static approach, a network is aggregated from dyadic interactions within a certain period or region. A link is created between two people if there has been some contact, and a proxy may be assigned for the strength of a tie based on, e.g., the total number of contacts [28]. From such static perspective it is possible to analyze large-scale properties of the resulting networks, including the degree distribution (i.e., the number of contacts of each node), different centrality measures (i.e., metrics to capture the relative importance of nodes within the network), or measures of the existence of communities or other types of structures.

For the temporal approach, a myriad of models have been proposed to analyzing network evolution [33]; we focus on the distribution of time-sequences of dyadic interactions, along with behavioural characteristics of how individual people communicate with their neighbours. From a sociological standpoint, the *Granovetter Effect* relates the notion of tie strength to network topology, noting that *strong ties* tend to be buried in overlapping circles of friends, akin to small communities where *weak ties* serve more as bridges between such communities [6, 28]. Since it is not possible to directly observe the strength of a tie, it is possible to use different temporal features as proxies [37]. Regarding the relationship of particular nodes to their neighbors, previous research [10, 32] has shown that individuals divide their contacting behaviour across their different neighbors in a persistent manner, known as a node's *social signature*, which is more stable in time than the neighbors themselves.

### 2.3. Using Linked Data for Network Analysis

The idea of using Linked Data graphs in network science is intuitive, natural, and not new. For example, in [7] linked data is transformed for network analysis for the LinkedDataLens system. In [29] RDF data is used for Social Network Analysis. Data from different sources can be aggregated into larger networks and enriched by each other and by reasoning new triples, i.e., connections in the network. SPARQL queries and SPARQL CONSTRUCT can be used in flexible ways for network data transformations and creating tabular formats widely used. To facilitate network analysis and visualizations of RDF data there are tools available, such as the Semantic Web Import Plugin<sup>16</sup> available for Gephi<sup>17</sup>, arguably the leading visualization and exploration software for all kinds of graphs and networks. Applications of Gephi include, for example, Exploratory Data Analysis, Link Analysis, Social Network Analysis, and Biological Network analysis. A major contribution of our paper is to apply network analysis in a novel application domain for analysing historical epistolary communication networks, and especially by using temporal network analysis. For this purpose, a new LOD resource is presented and used.

## 3. A Linked Data Model and Service for Epistolary Data

This paper makes use of the epistolary datasets listed in Table 1. In our work these datasets were transformed into Linked Data and published according to the Linked Data publishing principles and other best practices of W3C [8], including, e.g., content negotiation and provision of a SPARQL endpoint. The CKCC corpus is to the best of our knowledge the first public linked open dataset on the Web on historical epistolary data; opening the publication of the correspSearch data in a similar way is done after getting a confirmation of the open license from the data owner.

<sup>16</sup><https://www.w3.org/2001/sw/wiki/GephiSemanticWebImportPlugin>

<sup>17</sup><https://gephi.org/>

### 3.1. Data Model for Linked Epistolary Data

By transforming the epistolary data into RDF we aimed to create knowledge graphs that include not only communication networks but also prosopographical data about the people and organizations involved. For this purpose a customised RDF-based metadata schema was created. The schema contains four different, interlinked classes: *Letter*, *Actor*, *Tie*, and *Place* as described in Table 2. Here the default namespace is the dataset-specific (*ckcc-schema*), *rdfs* refers to the RDF Schema<sup>18</sup>, *crm* to the CIDOC CRM Schema<sup>19</sup>, *geo* to WGS84 Geo Positioning vocabulary<sup>20</sup>, *skos* to SKOS Simple Knowledge Organization System namespace<sup>21</sup>, and *xsd* to the XML Schema of W3C<sup>22</sup>.

The design choices are based on the principles developed in the EMLO project [35]. In the epistolary dataset, instances of the class *Actor* can be either people or groups. The sent letters by each actor are announced using the property *:created*. Each letter is modeled as an instance of the class *Letter* that has seven properties describing the letter. A letter is linked with its recipients using the property *:was\_addressed\_to*, to places of sending and receiving using the properties *:was\_sent\_from* and *:was\_sent\_to*, and to related timespan with *crm:P4\_has\_time-span*. Furthermore, a letter instance is enriched with information about the data source and a human-readable description. The correspondences between two actors are modeled as instances of the class *Tie*. Each of these instances is linked to the two actors and likewise each letter is linked to the corresponding tie. Using the *Tie* instance simplifies the database queries e.g. in cases of querying all the letters between the two actors. In addition, this model facilitates to adding precalculated network metrics such as node degrees and centrality measures to the data model. In addition, the data set also contains precalculated values for the time of flourishing for each actor, e.g. the time period when the actor has been active in letters correspondences. The resources in the domain ontology of the places consist of place labels, the coordinate information, and the hierarchy built with the property *skos:broader*. Finally, the timespans follow the four point model, e.g. with *xsd:dateTime* values indicating the earliest and latest moments for the beginning and the end.

The two datasets, CKCC and correspSearch, were converted from different source formats. CKCC is an extract from an existing RDF dataset, while the correspSearch data was converted from a source in JSON format. In these datasets both the actor and place resources had linkage to external LOD cloud databases, e.g., Wikidata, VIAF, Early Modern Letters Online project (EMLO), or database of Deutsche Nationalbibliothek<sup>23</sup> (GND). This existing linkage was used for two main purposes. First, in the current data publication, the resources in the datasets were reconciled based on the links, e.g. the actors or places refer to the same entity, if they point to the same external link. Secondly, the external databases were used to enrich our data e.g. with images of actors and coordinates of the places. In our work, the “FAIR guiding principles for scientific data management and stewardship” of publishing Findable, Accessible, Interoperable, and Re-usable data are used<sup>24</sup>.

### 3.2. Using the Linked Data and Data Service

The data can be used for research via (1) ready-to-use tools available on a semantic portal or (2) by using the underlying SPARQL endpoint with external tools, based on a framework called *LetterSampo* [16]. The SPARQL endpoint can be used directly in DH research using, e.g., YASGUI<sup>25</sup> [31] and Python scripting in Google Colab or Jupyter notebooks. The endpoint can also be used for filtering and downloading the data in different forms, such as in tabular CSV format, for external data-analysis tools, in our case for network analyses.

This framework is used for creating data services and semantic portals<sup>26</sup> based on the Sampo model [18] for sharing collaboratively enriched linked open data using a shared ontology infrastructure. The portals host ready-to-

<sup>18</sup><https://www.w3.org/TR/rdf-schema/>

<sup>19</sup><http://www.cidoc-crm.org>

<sup>20</sup>[http://www.w3.org/2003/01/geo/wgs84\\_pos#>](http://www.w3.org/2003/01/geo/wgs84_pos#>)

<sup>21</sup><http://www.w3.org/2004/02/skos/core#>

<sup>22</sup><https://www.w3.org/XML/Schema>

<sup>23</sup>[https://www.dnb.de/EN/Home/home\\_node.html](https://www.dnb.de/EN/Home/home_node.html)

<sup>24</sup><https://www.go-fair.org/fair-principles/>

<sup>25</sup><https://yasgui.triply.cc>

<sup>26</sup><https://seco.cs.aalto.fi/applications/sampo/>

Table 2

RDF schema for Letter, Actor, Tie, and Place. Column *C* marks the cardinality of the element. Fields inferred from the data are marked with *curstive* text.

Element URL	C	Range	Meaning of the value
<b>ACTOR</b>			
skos:prefLabel	1	xsd:string	Preferable label
:created	0..n	:Letter	Created letter
:birthDate	0..1	crm:E52_Time-Span	Time of birth
:birthPlace	0..1	crm:E53_Place	Place of birth
: <i>flourished</i>	0..1	crm:E52_Time-Span	<i>Time of flourishing</i>
:deathDate	0..1	crm:E52_Time-Span	Time of death
:deathPlace	0..1	crm:E53_Place	Place of death
: <i>has_statistic</i>	1..n	:NetworkStatistic	<i>Precalculated network statistics, e.g., centrality measures</i>
:source	1..n	rdfs:Resource	Used data source
<b>LETTER</b>			
skos:prefLabel	1	xsd:string	Preferable label
:was_addressed_to	0..1	crm:E39_Actor	Recipient of the letter
:was_sent_from	0..1	crm:E53_Place	Place of sending
:was_sent_to	0..1	crm:E53_Place	Place of receiving
crm:P4_has_time-span	0..1	crm:E52_Time-Span	Time of sending
:source	1..n	rdfs:Resource	Used data source
: <i>in_tie</i>	1	:Tie	<i>Correspondence in which this letter belongs to</i>
<b>TIE</b>			
:actor1	1	crm:E39_Actor	First correspondent
:actor2	1	crm:E39_Actor	Second correspondent
: <i>num_letters</i>	1	xsd:integer	<i>Number of letters in this correspondence</i>
skos:prefLabel	1	xsd:string	Preferable label
<b>PLACE</b>			
crm:P89_falls_within	0..1	crm:E53_Place	Place higher in hierarchy
skos:prefLabel	1	xsd:string	Preferable label
geo:lat	0..1	xsd:decimal	Latitude of the coordinates
geo:long	0..1	xsd:decimal	Longitude of the coordinates
<b>TIMESPAN</b>			
crm:P82a_begin_of_the_begin	0..1	xsd:dateTime	Earliest time for the beginning
crm:P81a_end_of_the_begin	0..1	xsd:dateTime	Latest time for the beginning
crm:P81b_begin_of_the_end	0..1	xsd:dateTime	Earliest time for the end
crm:P82b_end_of_the_end	0..1	xsd:dateTime	Latest time for the end
skos:prefLabel	1	xsd:string	Preferable label

use data-analytic tools for DH research, as suggested in [17]. The Sampo-UI framework [20] is used as the interface model and as the full stack JavaScript tool was used for implementing the user interface. Sampo portals are based— from a data perspective—on querying the SPARQL endpoint from the client side using JavaScript. The networks in the portal pages are constructed using a customizable back-end service [24] which builds Sampo-UI compatible network based on related SPARQL queries. The portals in the Sampo series demonstrate the idea that versatile web applications can be implemented by separating the application logic and data services via SPARQL API, which arguably facilitates developing new applications efficiently by re-using the same data.

### 3.3. New Resources on the Web

The CKCC knowledge graph<sup>27</sup> as well as the correspSearch knowledge graph<sup>28</sup> have been published on the Linked Data Finland platform LDF.fi [19]. Both dataset are also available at Zenodo<sup>29</sup>. LDF.fi uses the 7-star model for LD deployment [19] that extends the 5-star model<sup>30</sup> coined by Tim Berners-Lee: to enhance re-usability of

<sup>27</sup>The data, schema, and service are openly available (CC BY-NC 4.0) at the homepage <https://www.ldf.fi/dataset/ckcc>.

<sup>28</sup>The data, schema, and service available (CC BY-NC 4.0) at <https://www.ldf.fi/dataset/resp>.

<sup>29</sup>CKCC: <https://zenodo.org/record/6631385>, correspSearch: <https://zenodo.org/record/5972316>

<sup>30</sup><https://5stardata.info/en/>

LD, the *sixth star* is given if the data is published with its schema and the *seventh star* if validation results of the data using the schema are provided. LDF.fi is powered by the Fuseki SPARQL server<sup>31</sup> and Varnish Cache web application accelerator<sup>32</sup> for routing URIs, content negotiation, and caching. The portal user interface was implemented by the Sampo-UI framework [20]. The system uses Docker microservice architecture containers<sup>33</sup>. By using containers, the services can be migrated to another computing environment easily, and third parties can re-use and run the services on their own. The architecture also allows for horizontal scaling for high availability, by starting new container replicas on demand.

#### 4. Network Analyses Using the Linked Data Service

In this section we first show some general network analyses results of the epistolary datasets of Table 1. After this, it is shown how the SPARQL endpoint can be used for research using querying and by programming. For these purposes, examples using the data with custom network analytic tools, Yagui and Google Colab are presented, respectively. Finally, analyzing the data with ready-to-use tools and the two-step analysis model of the LetterSampo portal is discussed with examples.

##### 4.1. Exporting Data for Data Analyses

A simple way of reusing the data resources is to download and transfer them for the analysis tool of choice. For this purpose either data dumps from Zenodo or the SPARQL endpoint can be used. A benefit of using the endpoint is that the data can be filtered and even transformed during the download to fit better for the aimed purpose. An example of using the data resource in external network analytic tools is presented in [38]. In this case study, the Linked Data of CKCC and correspSearch were analyzed in terms of network metrics and compared with four modern datasets of mobile phone call networks, emails, community boards, and wall-postings on a social media platform. It turned out that contemporary and historical epistolary communication networks resemble each other strikingly even if the media were quite different.

##### 4.2. General Analyses on Epistolary Networks

The network portal also shows the precalculated centrality measures for each actor. First, a correspondence network was created from the RDF data and thereafter the measures were calculated using the Python library NetworkX<sup>34</sup>. These measures are based on a network containing both the CKCC and the correspSearch datasets.

An example of the measures for French philosopher and scientist René Descartes are listed in Table 3. In the table, e.g., the *Clique Number* with a value of 4 indicates that Descartes is a part of complete subgraph where all the nodes have a degree of 4, and the rank of 14 indicates that there are 13 larger cliques in the entire network. The *Weighted Out-* and *In-Degrees* correspond to the total number of sent and received letters while the *Number of Correspondences* equals the unweighted node degree. Also the actor perspective facet page has a socio-centric network visualization where the actors can be filtered e.g. by their gender, years of living, or data sources.

##### 4.3. Querying the SPARQL Endpoint

For the analyses presented in this article, there are basically two practices for using a SPARQL endpoint. Firstly, for showing the data results on the web portal, the tabular results of a relatively simple query are shown on the portal page. An example of such of query is shown in Fig 1. It queries all letters sent by Descartes and shows their recipients, labels, and dates sorted by the date. Secondly, analyzing or visualizing network structures may require several database queries e.g. for separated lists of actors (*nodes*) and letters (*edges*). The actual results are thereafter calculated based on the data of these simple, straight-forward queries with spreadsheet-like results.

<sup>31</sup><https://jena.apache.org/documentation/fuseki2/>

<sup>32</sup><https://varnish-cache.org>

<sup>33</sup><https://www.docker.com>

<sup>34</sup><https://networkx.org>

Table 3  
Precalculated network measures for René Descartes

Measure	Value	Rank
Betweenness Centrality	0.00930	6
Clique Number	4	14
Clustering Coefficient	0.000162	380
Core Number	7	1
Eigenvector Centrality	0.064	5
Number of Correspondences	92	12
Pagerank Centrality	0.00417	23
Weighted In-Degree	164	16
Weighted Out-Degree	585	5

```

PREFIX ckccs: <http://ldf.fi/schema/ckcc/>
PREFIX crm: <http://www.cidoc-crm.org/cidoc-crm/>
PREFIX skos: <http://www.w3.org/2004/02/skos/core#>

SELECT DISTINCT ?source_label ?target_label ?letter_label ?date
WHERE {
  VALUES ?source { <http://ldf.fi/ckcc/actors/p300075> }

  ?source ckccs:created ?letter ;
    skos:prefLabel ?source_label .

  ?letter a ckccs:Letter ;
    ckccs:was_addressed_to ?target ;
    skos:prefLabel ?letter_label ;
    crm:P4_has_time-span/skos:prefLabel ?date .

  ?target skos:prefLabel ?target_label .
} ORDER BY ?date

```

Figure 1. SPARQL example for querying the letters by René Descartes

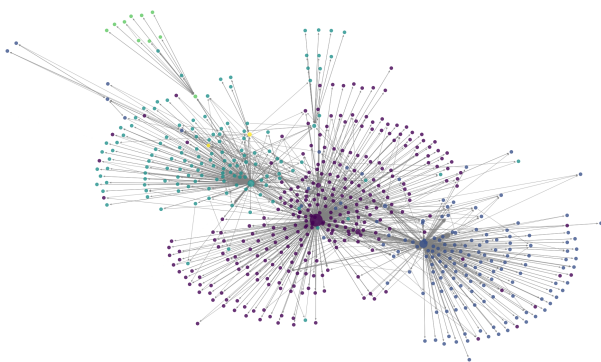


Figure 2. Network of CKCC data



Figure 3. Network of correspSearch data

#### 4.4. Using the LetterSampo Portal

Figure 4 depicts the main entry page of the LetterSampo UI. The entry page contains three faceted search perspectives for the Letters, Actors, and Places. On the facet pages the data can be filtered by e.g. choosing a certain

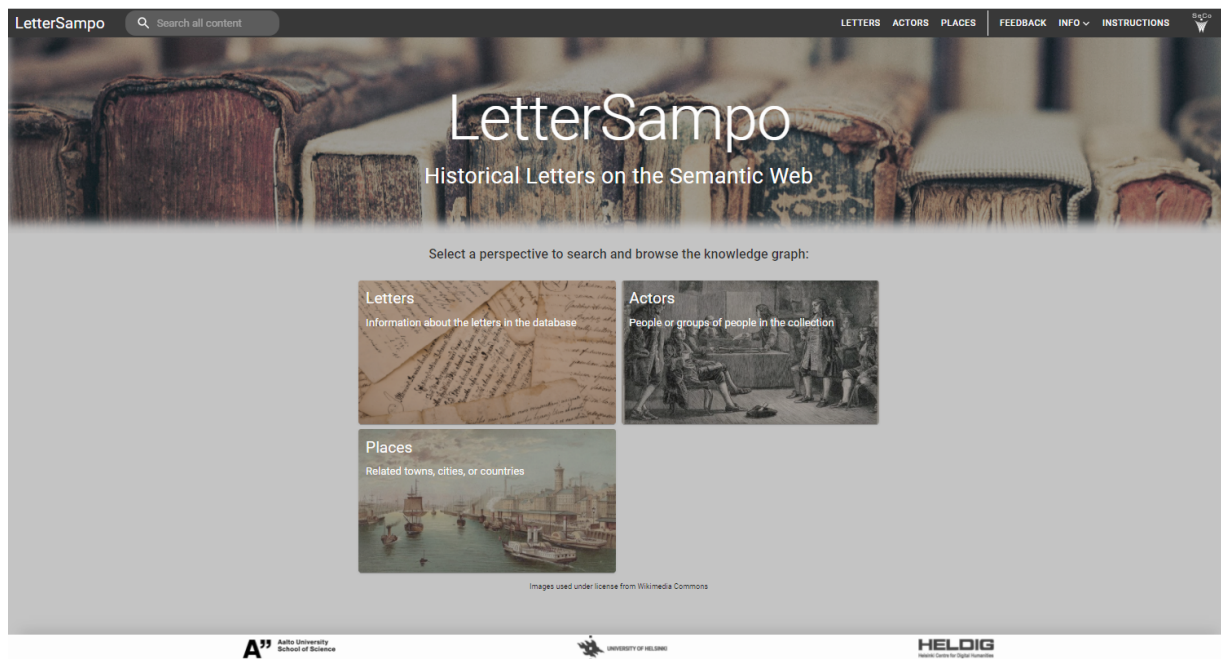


Figure 4. LetterSampo landing page with three application perspectives or searching, browsing, and analyzing letters, actors, and places

period of time. The tabs on the facet pages allow to view the search results, e.g., as lists, map visualizations, time series charts, or networks. [16]

The network portal provides components for visualizing the epistolary data using line charts, maps, and networks. Figure 5 depicts an egocentric network around Descartes. In this visualization the widths of the edges are proportional to the number of letters between the two actors while the sizes of the nodes are based on the network distance so that the main actor appears with the largest node and the most distant actors have the smallest nodes. In spite that Descartes is the center actor, Constantijn Huygens has a higher node degree due to the fact that the CKCC dataset contains a larger amount of letters by him.

Figure 6 depicts a visualization of the *social signatures* [10, 32] of Descartes. Social signatures represent how individuals communicate with their neighbours in a given time. This visualization has curves for his entire time of flourishing (blue line) and separated curves during his career, e.g. the red line for time period 1643–1650. For an interval (e.g., 1631–1637, 1637–1643), a social signature is obtained by (1) computing the fraction of outgoing contacts per alter, and (2) ranking the alters. This approach allows characterizing the relative importance of different alters in an ego network. When comparing different individuals, it is found that their social signatures tend to be stable [10, 32, 36].

#### 4.5. Using the Endpoint by Programming

Due to performance issues when attempting to render a larger network of more than, e.g., 1000 nodes on a browser page, data was further visualized in Google Colabs environment using Python. As an example, the largest connected component of the CKCC data is visualized in Figure 2. The network is built around three center actors: Dutch poet and composer Constantijn Huygens, philosopher Hugo de Groot, and mathematician and physicist Christiaan Huygens, who have high node degree values. On the other hand, there is a multitude of actors with low node degree. As a comparison in Figure. 3 the correspSearch data has much more of these hubs.

Figure 7 depicts the correspondences of Descartes on a timeline. The entire timeline is shown on the lower part of the chart. On the upper part of the chart there are separately the ten most active correspondences of Descartes and the lowest line depicts the correspondences with all the other actors. The visualization also reveals biases

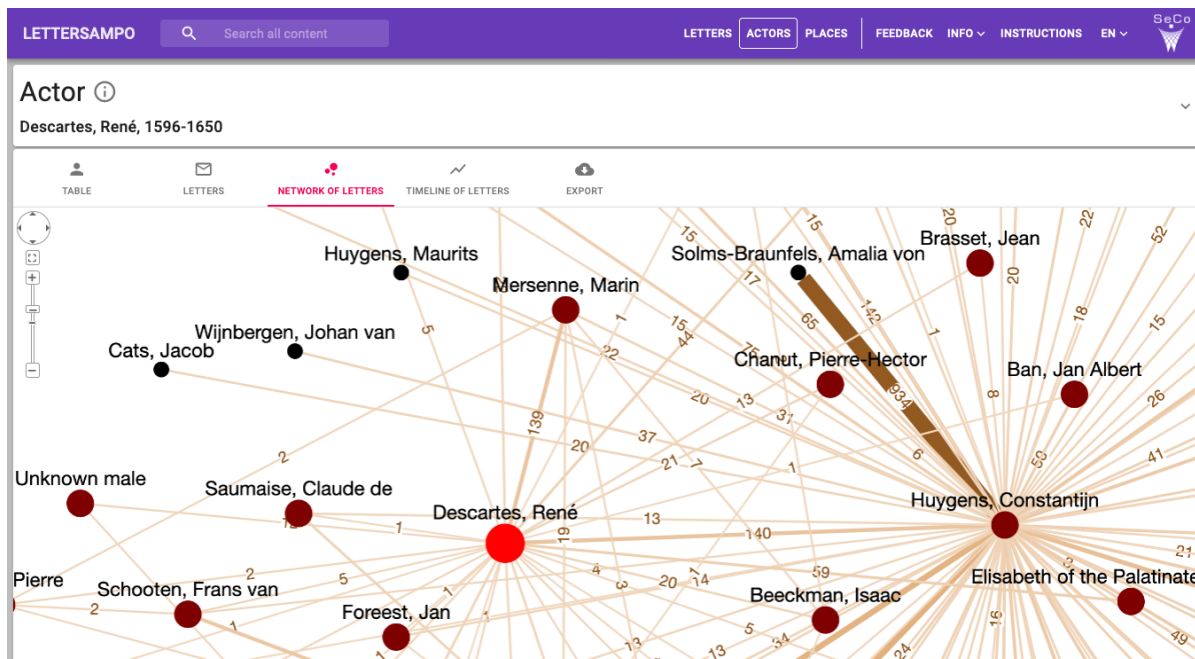


Figure 5. Network of correspondences around René Descartes

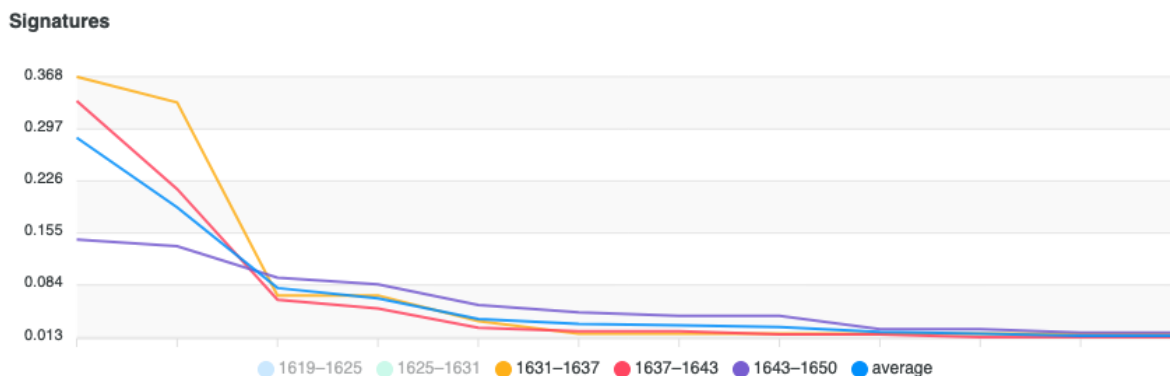


Figure 6. Timeline depicting the social signatures of René Descartes

caused by missing information in the source data. For example, when studying the correspondence with French philosopher and mathematician Marin Mersenne, it can be observed that the source collections contains 134 letters from Descartes to Mersenne, but only of five by Mersenne to Descartes.

Figure 8 depicts the most active scientists by the decades 1620–1690. The ranking is based on the total amount of sent and received letters and the data is visualized so that the first ranking scientist is on the top of the chart. The figure depicts that from 1620 to 1640 Descartes is on the first rank, but later replaced by Christiaan Huygens.

#### 4.6. Comparing Contemporary and Historical Communication Networks

As a use-case scenario, a comparative analysis of historical and contemporary communication networks was performed, with results formally introduced in [36]. In this study, the goal was to compare aspects of temporal communication networks at different granularity levels, including snapshots of static graphs, the time series of

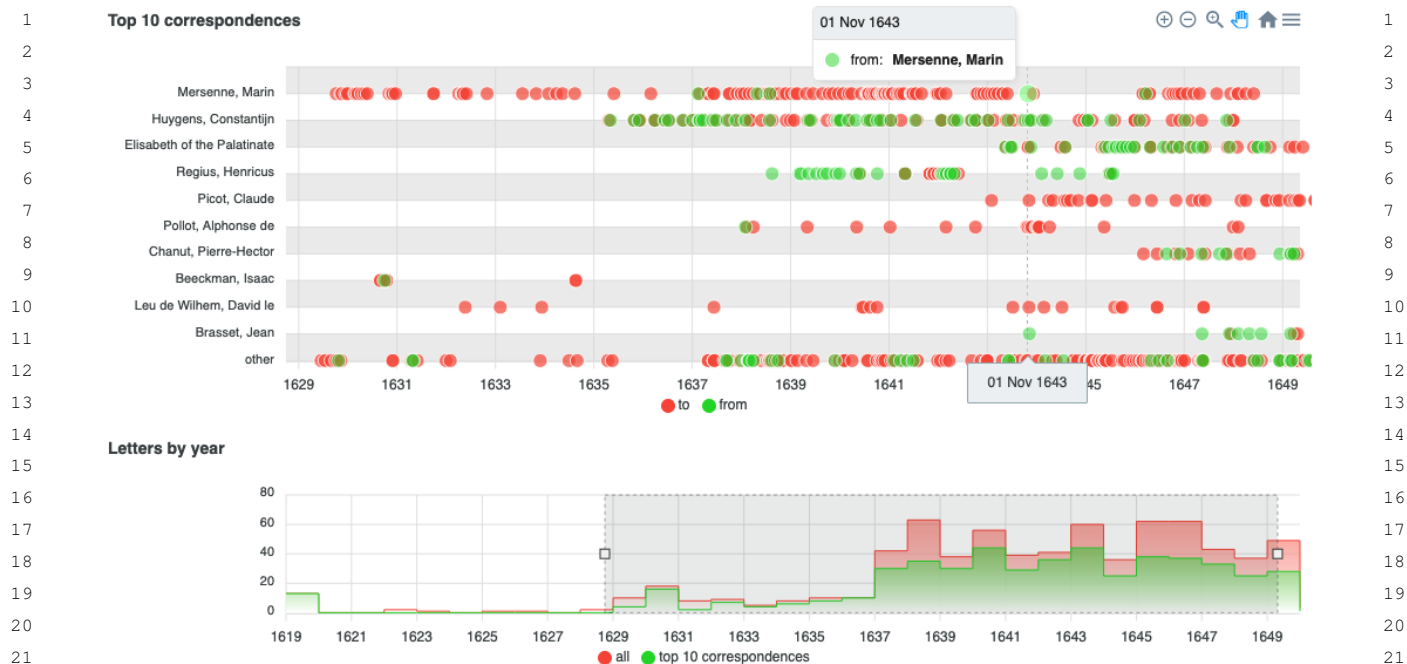


Figure 7. Timeline depicting top 10 letter correspondences of René Descartes

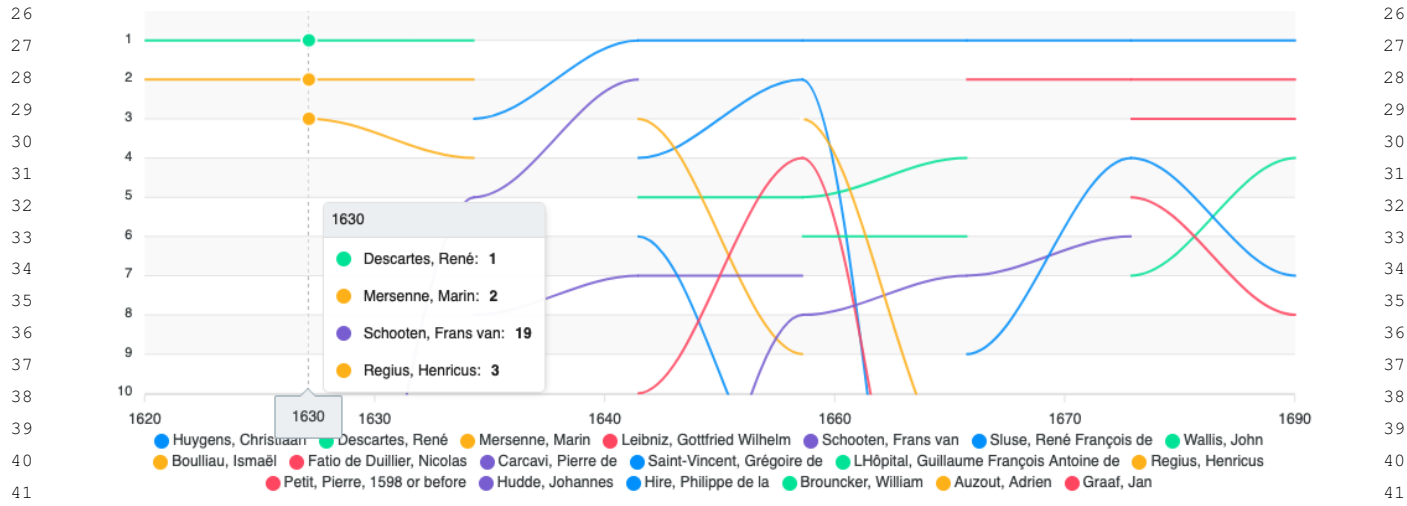


Figure 8. Top scientists in the CKCC data during 1620–1690

dyadic interactions, as well as ego networks. We compare these features with different contemporary communication channels, including emails, social media platforms, forums and mobile phone calls.

In brief, the goal was to analyze to what extent different behavioural features of contemporary communication networks can be found in historical datasets. We find similarities at different degrees of success. Particularly, we find evidence for the persistence of social signatures in historical context, as well as the Granovetter effect for different proxies of tie strength, and important similarities in the distribution of dyadic timings. We found, however,

difficulties in drawing conclusions from global network analyses, particularly given that some individuals are over-represented in historical datasets.

Regarding social signatures, the results suggest that individuals divide their communication similarly across top-ranked alters; in other words, that the social signatures of a given individual are more similar among different periods than to the signatures of different egos. These results were consistent across different filters for the constructions of ego networks. Taken together, they suggest that in practice individuals allocate time and resources systematically when communicating. Regarding the Granovetter effect, it is found that stronger ties are associated with overlapping circles of friends, a feature that persists even when considering different proxies for the strength of ties. While these results have been previously observed in contemporary datasets [10, 28, 32, 37], historical datasets bring an added value on two fronts: (1) They provide evidence for human communication patterns in a distinct context—contemporary examples are usually the result of auto-recorded digital logs, and are thus representative of modern practices. (2) They provide a timeframe that is unachievable in contemporary datasets, where samples of ego networks are examined across different decades, and where aggregate network evolution spans centuries.

## 5. Discussion

This paper presented new data resources and data services for historical epistolary linked open data. The presented CKCC and correspSearch datasets are, to the best of our knowledge, first LOD-based epistolary datasets available on the Semantic Web. Examples of analyzing and visualizing the data were presented and discussed using SPARQL querying and Python scripting as a proof-of-concept of the usability of the data resources. The aggregated data is now openly available for the research community for related analyses. We also demonstrated the idea of developing applications, i.e., semantic portals, on top of the data service that require no programming skills from the end user. More details about the demonstrator can be found in [16] and there is an online video<sup>35</sup> demonstrating how the LetterSampo portal is used in practise on the Web, too.

This paper focused on presenting, discussing, and illustrating design principles for publishing and using epistolary data as Linked Data, not on presenting actual analysis results of particular datasets. This remains a topic of further research, but the first experiments presented show in our opinion that the framework and the published resources, the linked open data and data service at LDF.fi, and the LetterSampo portals are promising in filtering our patterns of possibly interesting phenomena in Big Data using distant reading [27]. However, traditional close reading by a human is needed as before in interpreting the results.

A major challenge in creating data analyses like the ones shown in this paper is related to the quality of the data produced. Historical (meta)data is typically incomplete and our knowledge about it is uncertain. Also using more or less automatic means for transforming and linking the data leads to problems of incomplete, skewed, and erroneous data [25]. In historical epistolary data in particular, the data is seldom complete as only part of the letters have survived or are included in the data available. This as well as conceptual difficulties in modeling complex real world ontologies, such as historical geogazetteers, become sometimes embarrassingly visible when using and exposing the knowledge structures to end-users. The same problems exist in traditional systems but are hidden in the non-structured presentations of the data. In general, more data literacy [23] is usually needed from the end-user when using data analytic tools.

The methods of network analysis can be very sensitive to even small errors in the data or biases in the sampling schemes. For example, the values of betweenness centrality can dramatically change by removal of even a single link, or long silences in communication in historical data can be explained by missing data from some historical period rather than inherently bursty communication tendencies. While computing various measures based on network data can be relatively simple with tools that are introduced here, the remaining challenge is to correctly interpret the results. This requires expert knowledge both in the domain to know how the data is biased and the methods to know how this affects the various measures. In the future, sampling schemes and missing data could be encoded in the data framework and the measures could be adopted to handle these situations. However, this work would first need

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<sup>35</sup><https://vimeo.com/461293952>

to be done within the domains (e.g., encoding sampling details of historical correspondence) and network method development (e.g., measures that consider missing data [22]).

Both datasets, CKCC and correspSearch, contained linkage to external LOD cloud databases which facilitated enriching the data by extracting, e.g., information about the lifespans of the actors or geological metadata of places. Communication networks are easily huge, consisting of millions of links, which causes performance issues when, e.g., querying the database or rendering a large network on the web portal.

In spite of the challenges inherent in historical epistolary data, application of network analysis to the data can be useful for the researchers in finding out potentially interesting patterns of knowledge for closer study in datasets that are too big or complex for traditional manual means only. The new LOD resources and applications presented in this paper can now be used for this purpose. The framework will be used in the *Constellations of Correspondence (CoCo)* project<sup>36</sup> on correspondences in the Grand Duchy of Finland in the 19th century [34].

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<sup>37</sup><http://www.republicofletters.net>

<sup>38</sup><http://openscience.fi>

<sup>39</sup><https://intavia.eu/>

<sup>40</sup><https://nexuslinguarum.eu/the-action>

<sup>41</sup><https://www.csc.fi/en/home>

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