Imperial College London

IMPERIAL COLLEGE LONDON

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Visualising Financial Systems

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Submitted in partial fulfillment of the requirements for the MSc degree in Computing of Imperial College London

September 2018

Abstract

The Great Financial Crisis of 2008/09 did not only cause the biggest loss in output post World War Two [15], it also led policy makers to push the reset button for much of macroeconomic research, placing the analysis of financial systems and the development of empirical approaches at the top of the agenda.

This dissertation contributes to the empirical analysis of financial systems through the development of interactive data visualisations. It is informed by expert interviews with central bankers, regulators, academics and commercial providers of visualisation software.

In the following, I review the state of financial systems visualisation, identify gaps, set out design principles for such visualisations and introduce three applications:

(1) the Interbank Network Visualiser, developed in collaboration with the Financial Stability Department of the Deutsche Bundesbank. The tool allows analysts to produce custom visualisations of the German banking system based on their own input data without writing a single line of code. Developed as a Flask app which runs in Google Chrome, the Visualiser has minimal system requirements, allowing for its use even in very restricted software environments as present at many central banks and regulators. The network visualisation is based on Vis.js. I illustrate the use of the Visualiser with publicly available data from the Bank of International Settlements (BIS) on global exposures of banks to non-banks, and show how the software can be used to identify the increasing interconnectedness between the financial systems of the United States and the United Kingdom.

(2) A novel visual encoding of balance sheets in the form of Sankey charts, which can be used to represent entities part of a financial system. I develop an example application visualising the consolidated balance sheet of the European banking sector. Data input is generated using R and Python. The visualisation builds on D3-sankey.js and is deployed at `http://philippasigl.com/MFIsEuroArea`. I use the visualisation for an analysis of the European Central Bank's (ECB) unconventional monetary policy and show that the representation can be helpful in tracing how bank balance sheets have reacted to long term financing operations and quantitative easing (QE).

(3) An interactive visualisation of the Euro Area financial system, which also allows for the visualisation of individual countries and asset classes. Data input is generated using R and Python, the visualisation builds on Vis.js and is deployed at `http://philippasigl.com/WhomToWhom`. The application aims to provide recognisable topologies of financial systems and facilitate the analysis of change. I test its effectiveness through a user survey and show how its visualisations can generate useful descriptive insights in the context of analysing the secular rise of non-bank finance.

Acknowledgments

I would like to thank the following people, without whom this MSc dissertation would not have been possible:

- My supervisors, Prof. William J. Knottenbelt and Dr. Co-Pierre Georg for their support in this slightly unusual project
- The Research Centre of the Deutsche Bundesbank, which hosted me from January to March 2018 to develop visualisations
- Sören Friedrich of the Financial Stability Department at the Deutsche Bundesbank and all other experts who volunteered to be interviewed for this dissertation
- Robert Gühne who is responsible for my education in data visualisation
- Alex Hofmann who showed me the way to Monetary Economics
- My family, colleagues at Dezernat Zukunft, Melanie Walker and Steve Sinofsky, all of whom had to endure endless discussions about the economy, money and D3

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Introduction

1.1 Motivation

> *"This is a terribly exciting time to study macroeconomics. [...] As of now I can tell you we know nothing"*

–Sir John Vickers, Professor of Economics All Souls College, *Introduction to Macroeconomics Lecture 2009, University of Oxford*

Prior to the Great Financial Crisis in 2008/09, there was a wide spread conviction that macroeconomics had become a natural science. A set of immutable laws, the profession agreed upon, was seen as determining the workings of the economy. Some economists even believed we had tamed the business cycle[1] [68] with monetary policy stabilising output. There was widespread agreement on "'frictionless finance' [which] had the deep implication that finance had no causal role to play" [88]. Financial systems were viewed as largely irrelevant to the real economy. This fundamentally changed with the Great Financial Crisis. Blanchard and Summers identify three main lessons from the crisis, with the first one being 'the centrality of finance' [7, pp. 5]. In the aftermath of the crisis, public institutions dedicated to the financial system such as the Financial Stability Board (FSB) were strengthened [43] or even founded anew such as the European Systemic Risk Board (ESRB) [40]. Financial systems had arrived at the centre of the academic and policy debate.

The financial crisis also threw into question whether macroeconomic models were rich enough to capture the mechanisms at work in our economies. Jean-Claude Trichet, President of the European Central Bank (ECB) during the financial crisis even went as far as stating:

> *"Macro models failed to predict the crisis and seemed incapable of explaining what was happening to the economy in a convincing manner. [...] in the face of the crisis, we felt abandoned by conventional tools."*

[1] The periodic rise and fall in economic output over time

‘

> *"An important perspective that researchers in other fields bring to economics is a focus on identifying the features that explain economic systems as we know them. [A] determinedly empirical approach which places a premium on inductive reasoning based on the data, rather than deductive reasoning grounded in abstract premises or assumptions - lies at the heart of these methods." [84]*

‘

To which William Playfair, political economist and a pioneer of statistical graphics, had to say in 1801:

> *"The amount of mercantile transactions in money [...] are capable of being as easily represented in drawing, as any part of space, or as the face of a country." [76, pp. 11]*

‘

which are particularly suited to ‘men of high rank' as they allow for an understanding of the whole [76, pp. 11].

Thus, this dissertation aims to answer Trichet's call to action by presenting financial systems and components thereof in visual form in a way that helps policy makers and economists understand the economy as a whole.

1.2 Aims and objectives

The aims and objectives of this dissertation are to

- Provide a notion of effective data visualisation
- Review the current state of financial systems visualisation[2] and identify gaps
- Set out design principles for financial systems visualisation
- Develop a network visualisation tool drawing on user provided data
- Develop a novel visual encoding for balance sheets, which is able to reflect both, their multidimensional nature as well as changes over time
- Develop an interactive visualisation of the Euro Area financial system, allowing one to identify topologies and changes over time

[2] This dissertation uses financial systems visualisation as shorthand for data visualisations of financial systems or components thereof

1.3 Contributions

This dissertation describes and illustrates the rationale for data visualisation in the context of analysing financial systems.

Its specific contributions are:

1.3.1 A notion of effective data visualisation

The effectiveness of a visualisation is defined based Contessa's concept of faithful epistemic representation [18], which states that a user must be able to draw valid and sound conclusions from a visualisation. This makes effectiveness dependent on the input data, the user and the aim of the visual. The implications of this definition in the context of human cognition are laid out, especially with respect to cognitive load.

1.3.2 A review of financial systems visualisation and identification of gaps

A two-dimensional framework is defined, distinguishing visualisations with respect to their unit of analysis as well as their mode of interaction with the user. I draw on this review and expert interviews conducted for this dissertation (for details see appendix B) to identify gaps in the visualisation of financial systems in the following areas: (1) Interactive tools consuming user provided data for the visualisation of markets, (2) a visual encoding of balance sheets, which reflects their multidimensional nature and is able to show change over time, and (3) an interactive visualisation of a financial system, which allows for the identification of topologies and changes over time.

1.3.3 A set of design principles for financial systems visualisation

Based on the review of financial systems visualisation, expert interviews and own prior work, I identify core design principles. The creation of an effective visualisation relies on appropriate filtering and highlighting, a highly controlled layout, the deployment of analytics, the utilisation of economic context, appropriate use of scaling and labeling, a special focus on how to show change and facilitating pattern recognition. For software architecture, ensuring compatibility with institutional requirements (where relevant), security, separation of concerns, simplicity of architecture, ease of error spotting and tracing as well as the deployment of the right tools for the right use case are singled out as key.

1.3.4 The Interbank Network Visualiser

The Interbank Network Visualiser (figure 1.1) is an interactive tool drawing on user provided data. It is built using Python's Flask micro-framework [77] and Javascript and runs on a local server displayed in Google Chrome. The user can upload data to generate a default visualisation, manipulate the former using a graphical user interface (GUI) and save the result as a static image.

1.3.5 A novel balance sheet visualisation of the Euro Area banking sector

The interactive visualisation deploys a Sankey chart to capture the multiple levels of aggregation present in a balance sheet. Interactive analytics complement the visualisation. The visual shows the consolidated balance of the Euro Area banking sector[3] from 2013 to 2017, drawing on the ECB's who to whom data. It is developed in Javascript and draws on the library D3-sankey.js [10]. The visualisation is deployed at `http://philippasigl.com/MFIsEuroArea`. A screen-shot is shown in figure 1.2.

> *"These graphs are very informative and aesthetically pleasing. Balance sheets are not always amenable to pictorial representation on the page, but you've captured the features very nicely."*

–Hyun Song Shin, Economic Advisor and Head of Research Bank of International Settlements, *personal correspondence, 6. July 2018*

1.3.6 A visualisation of the Euro Area financial system

The interactive visualisation depicts sectoral exposures[4] in a network diagram. Data can be shown for the entire Euro Area or individual countries, for all asset classes or individual balance sheet items and for any quarter between 2013 and 2017, drawing on the ECB's who to whom data. Interactive analytics support the identification of certain topologies and dynamics over time. The visualisation is developed in Javascript, draws on the library Vis.js [3] and is deployed at `http://philippasigl.com/WhomToWhom`. A screen-shot is shown in figure 1.3.

[3] this dissertation uses the ESA 2010 sectoral definitions

[4] In the context of this dissertation, exposure of party A to party B is defined as total financing provided by party A to party B

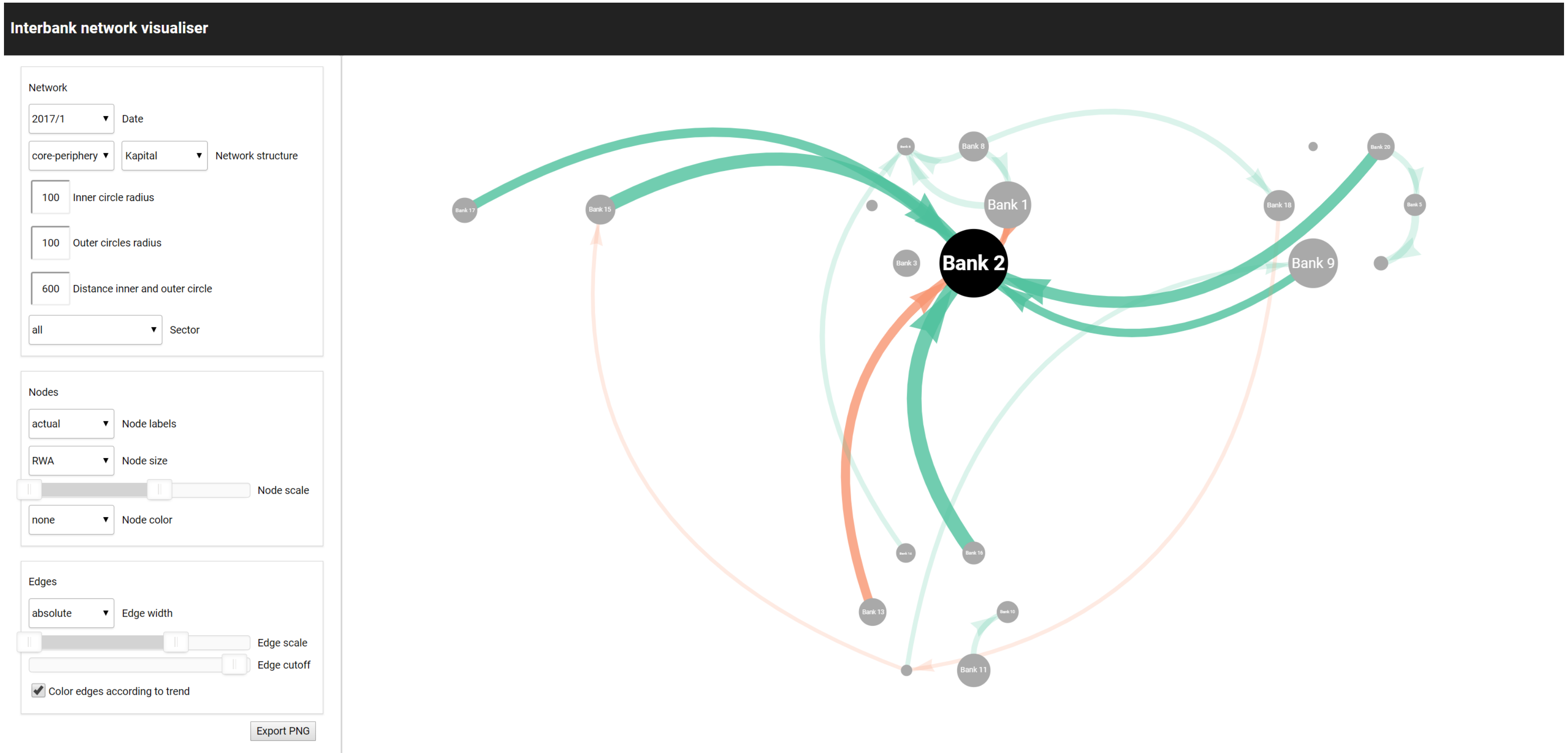


Figure 1.1: Interbank Network Visualiser with test data, banks arranged according to a core-periphery structure with the sector with the largest average risk weighted assets (RWAs) at the centre. Nodes reflect the size of RWAs, edges exposure size and edge colours the direction of change since the last period. Edges are filtered to show only the largest ones. Bank 2 and all edges connected to it are highlighted.

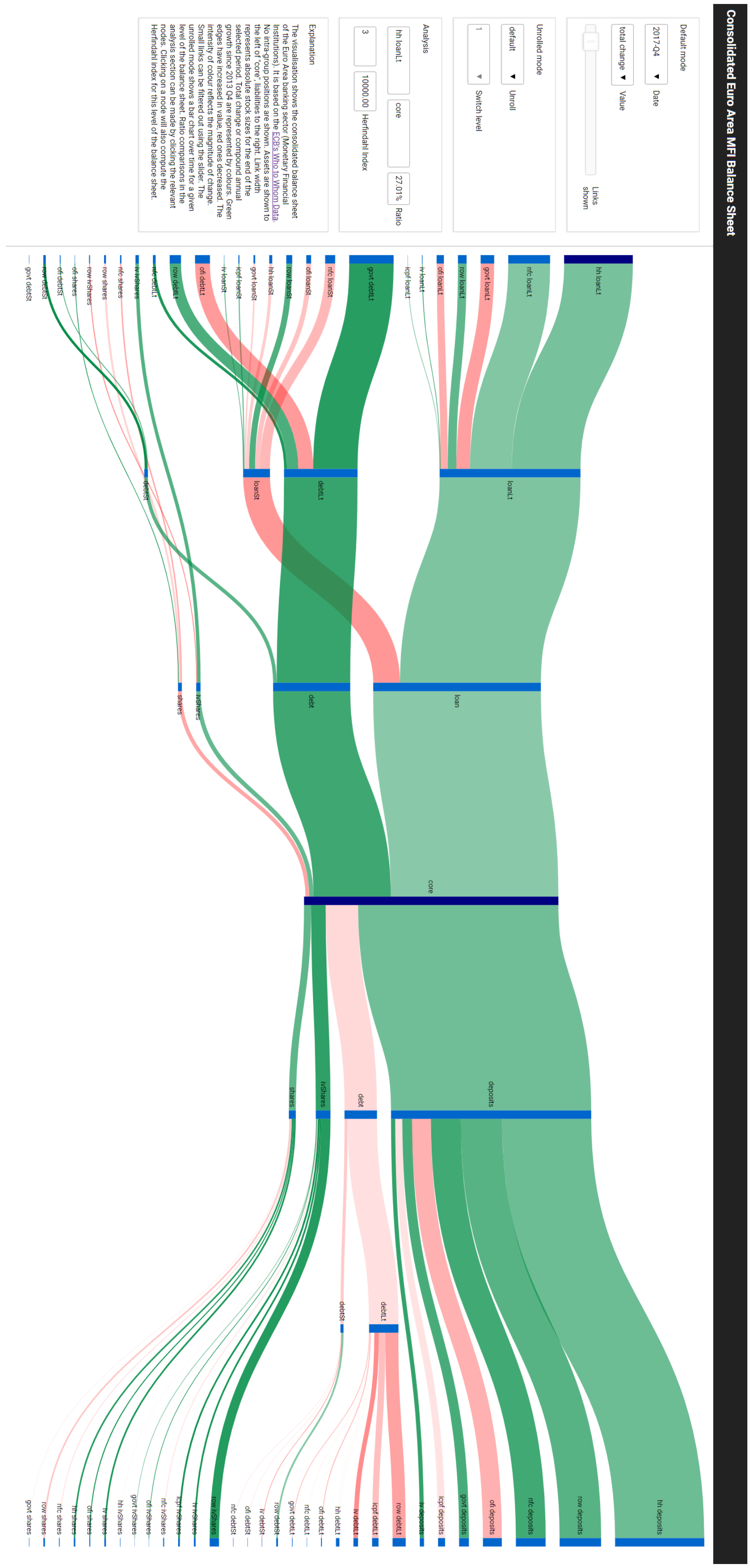


Figure 1.2: Balance sheet visualisation for the European banking sector. Link width shows size of balance sheet position for end of 2017, colour absolute change since 2013. Smallest links are filtered out. The analysis section shows long term loans to households as a proportion of the total balance sheet.

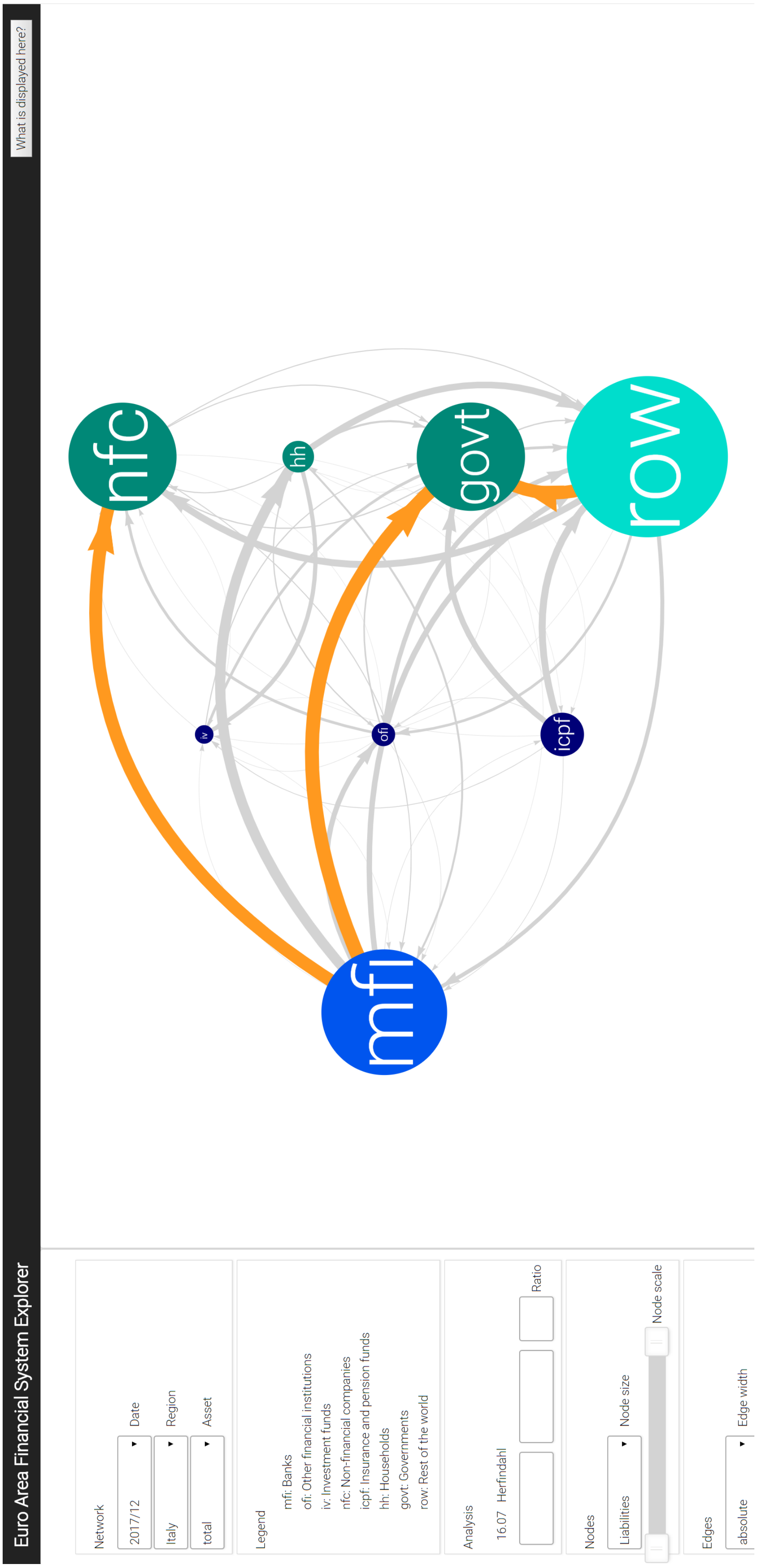


Figure 1.3: Visualisation of the European financial system. This view shows total exposures for Italy for the end of 2017, node size reflects the size of sectoral liabilities, edge width exposure size. The largest three exposures are highlighted.

1.4 Outline

The remainder of this dissertation is organised as follows:

Chapter 2 discusses data visualisation in the context of financial systems. It states the purpose of analysing financial systems, the rationale and use cases for data visualisation in this specific domain, lays out a definition of effective data visualisation and discusses this in the context of human cognition.

Chapter 3 develops a taxonomy for categorising visualisations of financial systems and reviews the current landscape. It concludes with an assessment of gaps.

Chapter 4 lays out design principles for the interface and architecture of applications visualising financial systems.

Chapter 5 describes and discusses the Interbank Network Visualiser and its implementation. It provides an example use case based on data from the BIS on the exposure of banks to non-banks.

Chapter 6 discusses the visual encoding of balance sheets in Sankey charts and describes the implementation of such a visualisation for the consolidated balance sheet of the Euro Area banking sector.

Chapter 7 argues for the importance of an interactive visualisation of the Euro Area financial system which is able to show topologies and dynamics, details the implementation of such a visualisation, describes user survey results on financial systems recognition with different settings and illustrates a use case of the Euro Area financial system visualisation by way of analysing the secular rise of non-bank finance.

Chapter 8 concludes by summarising and evaluating the achievements of this dissertation and highlighting opportunities for future work.

1.5 Statement of originality

I declare that this thesis was composed by myself, and that the work it presents is my own except otherwise stated.

2

Visualising financial systems

2.1 The rationale for analysing financial systems

Understanding financial systems is relevant for at least three reasons: (1) Identifying risks to financial stability, (2) understanding the transmission mechanisms of monetary policy to the real economy, a point frequently made by Vítor Constâncio, Vice-President of the ECB [17], and (3) getting a broader understanding of the link between the structure of financial systems, the real economy and growth. Given Euro Area macroeconomic policy is currently an un-hedged bet on quantitative easing (QE) resuscitating growth, (2) is arguably more important than ever.

Yet, the analysis of financial systems faces its own set of challenges due to its multi-dimensional and dynamic nature: Participants interact in different asset classes as well as geographies. And even within asset classes and geographies, there are often several separate sub-markets for the same asset class. Stocks for instance, are traded on exchanges as well as over the counter (i.e. bilaterally without being cleared in a regulated market). Further, the shape of financial systems is constantly in flux, being influenced by market forces, economic developments, and regulation. One example from recent years is the rise of shadow banks in the Euro Area [36].

Both, the multi-dimensionality as well as the dynamic nature of financial systems makes statistical analysis very difficult, since many of its concepts rely on representative datasets, known distributions and a limited number of dimensions. The problem of representative datasets has become even more pronounced as policy makers increasingly require real time data analysis for decision making. Representative time series for the current state of the financial system are often not available.

As argued by Flood et al., data visualisation is well positioned to address these analytical challenges: Instead of relying on static distributions, it leverages the visual and spatial skills of our cognitive system to detect patterns, discontinuities, and outliers. Visualisations act as a form of "externalised memory [...] which can enlarge an analyst's problem-solving capabilities by enabling the processing of more data without overload" [44].

2.2 Use cases

Based on expert interviews conducted for this dissertation and a review of existing data visualisations in the financial systems domain, four purposes have been identified, three of which will be covered here: Analysis, policy making, communication and data cleaning/validation. Data cleaning and validation is likely to significantly benefit from data visualisation enhancing our ability to spot outliers and anomalies in initial datasets. Yet, this purpose requires very different visual approaches from analytical, policy making and communication use cases and is hence not covered in this dissertation. The other three purposes are closely linked and tend to overlap. The difference between analytical and policy making uses cases is normally a stronger focus on reproducibility of visualisations as new data becomes available in the context of policy making. Visualisations used for communication purposes are often the final output of analytical or policy making processes. If sensitive data is involved, an important feature for the adaptation of visualisations for communications purposes is the possibility to anonymise elements of a graph.

2.3 Effective data visualisation

Before reviewing the current state of data visualisation related to financial systems, I propose parameters for a 'good' visualisation. Two questions are covered: (1) What is a good representation and (2) given the former, what properties should a visualisation have to match the cognitive abilities of humans and become effective?

2.3.1 Defining a 'good' representation

The intuitive answer might be: An accurate one, i.e. where the underlying algorithm uses a consistent scheme to translate the data into a visual representation. Using such a definition of 'good' in the given context is problematic for three reasons:

First, 'accuracy' in the area of financial systems representation is highly context specific: Entities constituting a financial system are (constantly changing) constructions of our legal and accounting systems and interpretations of the former[1], so there is not one accurate account but only one that is valid, given the context in and purpose for which the visualisation is used.

Secondly, there are several accurate ways of translating any given dataset into a visualisation, as for instance illustrated in [11] by Bostock. Given cognitive biases humans exhibit [66], different representations most likely give rise to different interpretations. In this case, the accuracy parameter fails to provide a conclusive guide as to which representation should be selected.

[1]The classification of actors is a significant issue for national accounting statistics as outlined by Van De Ven [87]

Third, individual differences in knowledge influence how users interpret a visualisation. Knowledge includes familiarity with the specific form of visualisation the user is presented with and knowledge relevant for the interpretation of the shown data. As Shah finds, this is particularly important since users, who are less familiar with a certain representation, are more likely to draw on existing knowledge, even if inconsistent with the data [80]. Thus, how helpful a visualisation is in generating insights does not only depend on the representation itself but on how well it is tailored towards the intended audience.

Contessa's concept of faithful epistemic representation provides an alternative to the 'accuracy' parameter, which addresses the mentioned issues:

> *"A vehicle [visualisation] is an epistemic representation of a certain target for a certain user if and only if the user is able to perform valid (though not necessarily sound) surrogative inferences from the vehicle to the target. [It] is a completely faithful representation of a target if and only if the vehicle [visualisation] is an epistemic representation of the target and all of the valid inferences from the vehicle to the target are sound." [18, p. 54]*
>
> ‘

Thus, an *epistemic* representation requires a visualisation tailored to its purpose. A counterexample would be a network diagram showing net exposures between sectors of the economy in the context of trying to assess possible contagion and spillover effects. In the context of contagion, it is key to understand how tightly coupled balance sheets are and hence showing gross exposures is required.
The visualisation also needs to be adequate for the given dataset: If there is a wide range in values, for instance, the user won't be able to make valid inferences about changing patterns in smaller values.
To be a *faithful epistemic* representation, the user needs to have the required background knowledge so that his inferences are not only valid but also sound. Hence this dissertation argues that visualisations must be evaluated with reference to their input data, purpose and users.

2.3.2 Data visualisation aiding human cognition

It is sometimes assumed that data visualisation is always supportive of human cognition in understanding complex datasets such as those representing financial systems. While this *may* be the case, it is not necessarily so. According to Lohse, who studied the role of working memory on graphical information processing, "graphs cannot automatically improve performance for complex tasks. Improved performance depends on graphical perception and cognition" [65, p. 306]. More specifically, visualisation improves information processing, if (1) the former is constrained by limitations in working memory and (2) the visualisation reduces processing burden on working memory, freeing up resources for other problem-solving tasks. This happens when mental operations in working memory are replaced with perceptual operations, which "are carried out more or less automatically" and the introduction of visualisation does not place additional demands on working memory, e.g. for storing intermediate results [65].

Huang, Eades and Hong test how complexity affects cognition in the context of network visualisations. They find that increasing the size of the dataset displayed strongly increases the time required to complete tasks as well as reducing accuracy. As the number of nodes increases from 16 to 25 and the number of edges from 36 to 98, processing time more than triples. Using a filtered version of the network, where all relations not relevant to the task are faded out, reduces time by 35% and increases accuracy by nearly 5% [57].

A common solution to representing complex datasets is using several visualisations. In the case of financial systems for instance, network data is often very dense, making intuitive node-link representations difficult to dissect. Adding a matrix representation of the data can help overcome this issue. However, this does not come without cost. Chang et al. study the effects of using complementary node-link and matrix representations for visualising network data and find that accuracy improves on some tasks, but completion time is generally longer than if just one representation was shown. Trained users even tend to stick to the view of their preference [13].

Hence this dissertation argues that it is key to shift focus from arguments about the global usefulness of data visualisation to debating how to develop context specific faithful epistemic representations tailored to human cognition[2]. It proposes initial principles for creating such visualisations in the context of financial systems and applies them in three case studies.

[2] This is by no means a new argument, see for instance [85], but can get lost in the macroeconomic debate, which tends to focus on which methodology to adopt

3

The current landscape

Visual representations of financial systems or its subcomponents have by now become an integral part of policy and research publications. The following provides a taxonomy for categorising visualisations of financial systems as well as a survey of examples.

3.1 Taxonomy

I group visualisations in figure 3.1 by unit of analysis and type of interaction with the user[1].

Units of analysis are:

- 'Entities': Entities participating in the financial system. There are several possible approaches for defining entities, with the most common ones being legal, economic or spatial classifications at various levels of aggregation.
- 'Markets': The interaction of agents exchanging financial assets. In most cases, visualisations of markets depict the exchange of one specific type of asset.
- 'Systems': Interactions of institutional units and markets to place capital and mobilise funds for commercial activities [72]. Such visualisations usually involve a high level of aggregation and selectivity. Further, they frequently adopt a highly stylised representation aiding the perception of structures and changes thereof.

[1] Alternative taxonomies are certainly possible, such as proposed by Flood et al., who group financial systems on two levels: Firstly, in a matrix scheme, differentiating between static/non-static and interactive/non-interactive. Secondly, by system level phenomena the visualisations are supposed to reflect, e.g. liquidity, exposure concentration etc. Given the limited role noninteractive dynamic and interactive static visualisations can and do play in financial analysis, Flood's matrix dimensions have been collapsed into one in this dissertation. Further, visualisations are not grouped by system level phenomena as one argument of this dissertation is that data visualisations excel at making the invisible visible, i.e. reflect system level phenomena we were unaware of. Hence grouping visuals by intended result seems to some extent contradictory.

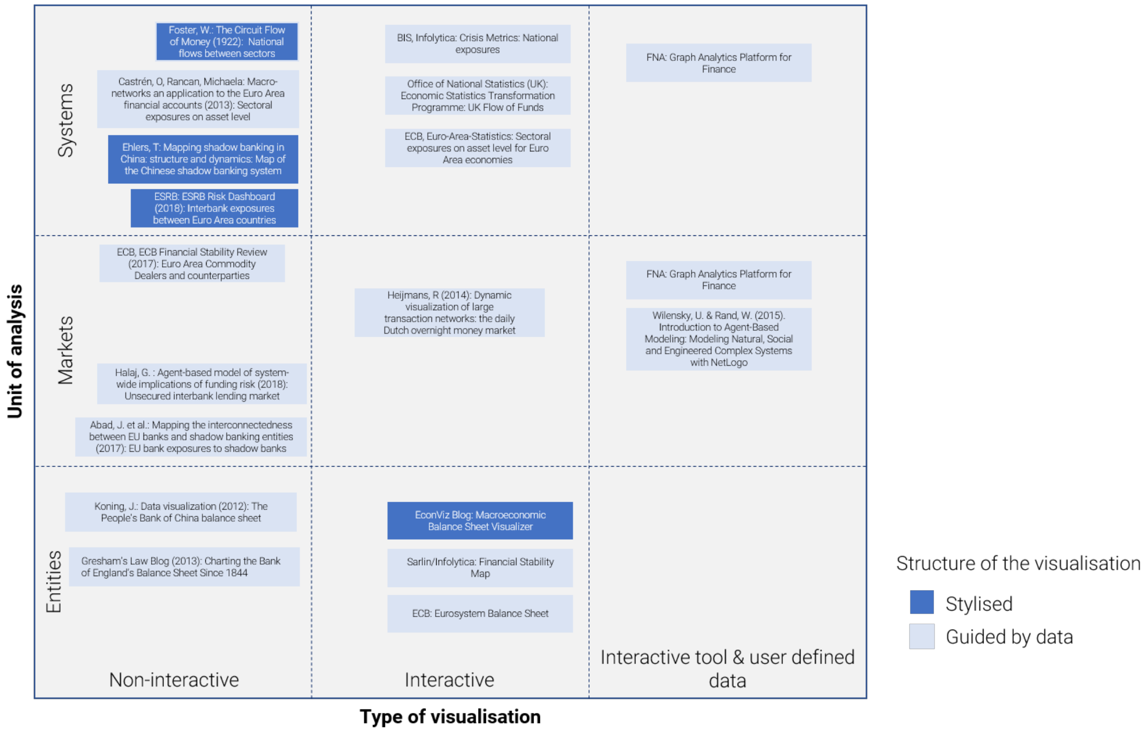


Figure 3.1: Examples of visualisations in the financial systems domain [45], [12], [32], [39], [38], [53], [2], [62], [52], [59], [71], [34], [55], [31], [78], [35], [42], [89]

Markets are the most common object of analysis in the domain of financial systems today, possibly due to the focus on micro-founded macroeconomics in recent years.

Analysis at the systemic level, describing individual units engaging in the financial system or their interactions, is at a very different stage of development. There are no generally agreed upon definitions as to what those units of the financial system are and how we should describe them[2]. Hence any development of visualisations at this level requires engaging with economic theory to define the what, the how and the why of a certain representation. This dissertation builds on the economic tradition of Godley and Lavoie, which analyses entities in terms of their balance sheets, adopts economic sectors as unit of analysis, views interactions through the prism of transaction matrices, and integrates the monetary and the real dimension [50].

Types of interaction for the taxonomy of visualisations are:

- 'Non-interactive': Both, underlying data and its representation are fixed and cannot be modified by the user

[2]Fundamental questions without consensus are for instance: 'How do we define an actor at the systemic level?', 'Is the internal state of an actor relevant for how he behaves in the financial system as in [63], and if so, 'How do we describe the internal state of an actor?', 'What role does each actor take?'. The fact that the role of banks as creators of money was only established in recent years illustrates this. Papers describing the creation of money through private banks were published by the Bank of England in 2014 [67], and by the Bundesbank in 2017 [28].

- 'Interactive': The user can modify the representation but not the underlying data
- 'Interactive tool and user defined data': The user can modify the representation as well as the underlying dataset (the user can input data of his choice as long as it fits the requirements of the tool). Only domain specific tools are considered

In addition, a distinction is made between visualisations which feature heavily stylised structures and those which are guided primarily by data (figure 3.1 reflects this in differentiated colouring). It might be more helpful to think about this second distinction on a continuous scale rather than being binary, since most visualisations whose representation is guided by input data will also include stylised structures (as, for instance, the layout of a network is always co-determined by the data and the chosen algorithm for organising nodes and edges). Further, visualisations with heavily stylised structures will still contain elements determined by the underlying data to convey information to the user. The use of stylised features introduces the question of what still qualifies as an accurate representation of the data, an issue which will be further discussed below.

3.2 Examples

The following overview is not aimed at completeness but rather at providing a representative sample of the current state of data visualisation as related to financial systems. More detail is provided on examples of particular importance for this dissertation. Figure 3.1 categorises the reviewed examples according to the taxonomy introduced above.

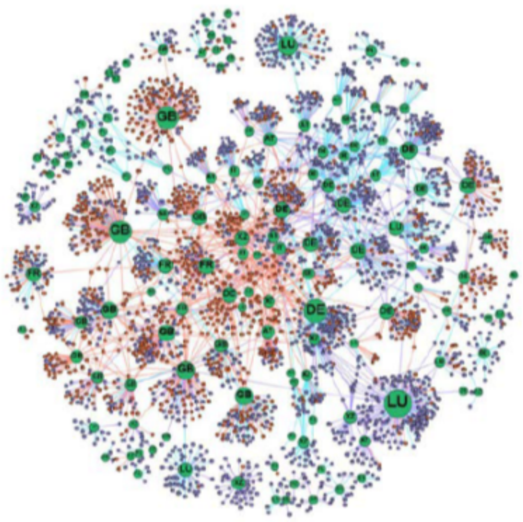
3.2.1 Non-interactive visualisations

Entities

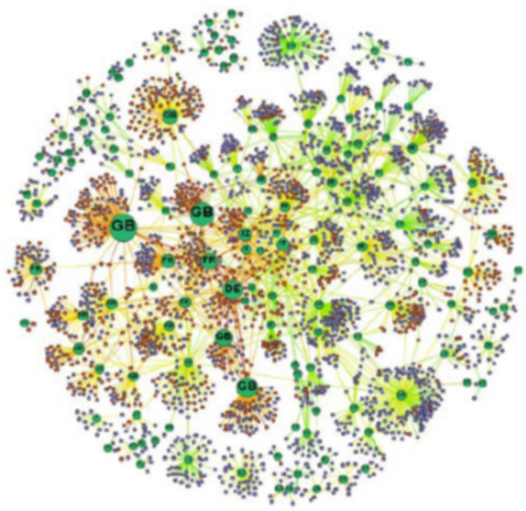
Visualisations of entities are mostly stacked area charts representing balance sheets, such as [35] and [52] or schematics such as [67].

Markets

The vast majority of visualisations are representations of interactions between individual entities such as banks participating in the interbank market. These visualisations are usually large scale static networks constructed with Gephi [5] or R, embedded in academic papers and targeted at an expert audience. Their purpose is to support the analysis given in the text. Abad et al., for instance argue in [2] that understanding the exposures of EU banks to shadow banks is key. Hence they show two networks of the same data in figure 3.2, varying the colouring of nodes and edges to highlight that EU banks have a lot of exposure to shadow banks (a) and that these exposures tend to be large (b). Keeping nodes in fixed positions across both visualisations and only varying certain layout elements, their representation facilitates pattern recognition. The networks are large and complex, but their design is aligned with the expected background knowledge of users, their purpose and the input data, thus fulfilling the criteria for a faithful epistemic representation.



(a) Green nodes: Reporting banks, Purple and orange nodes: EU and non-EU domiciled shadow banking entities. Node size is proportional to degree centrality (the number of counterparties). Blue links represent domestic exposures (EU institution to a domestic shadow banking entity); purple links represent EU exposures (EU institution to EU-domiciled shadow banking entity) and orange links represent non-EU exposures



(b) Green nodes: Reporting banks, purple and orange nodes: EU and non-EU domiciled shadow banking entities. Node size is proportional to total exposures (sum of all individual exposures). Colour of link ranges from green to orange depending on the size of the individual exposure (green links: smaller exposures, orange links: larger individual exposures)

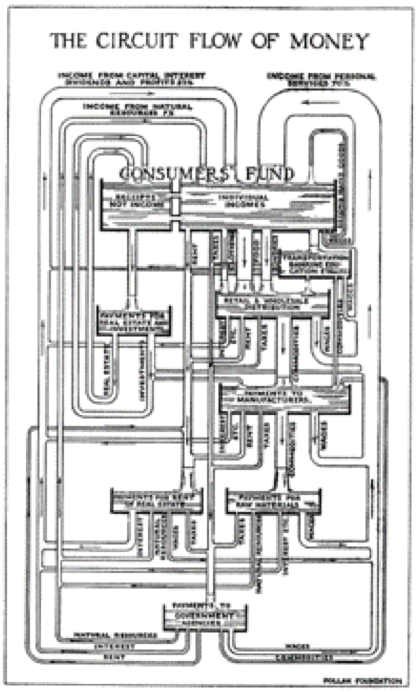
Figure 3.2: Network of EU banks exposures to shadow banking entities adapted from [2]

Reusability of code used to produce such visualisations is normally limited due to the chosen tools as well as the tailored design required for research publications.

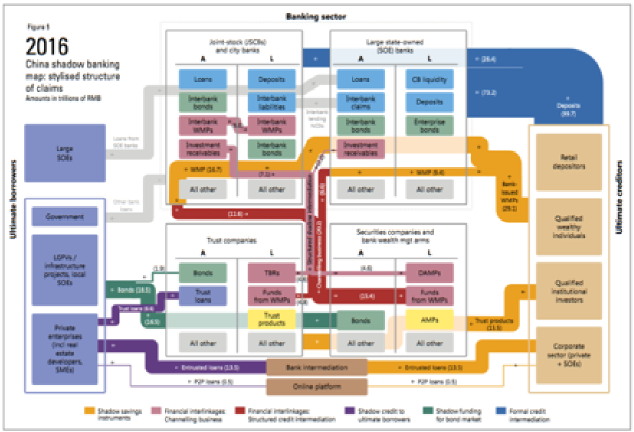
Systems

Visualisations describing interactions between actors on the systemic level often exhibit stylised structures to facilitate pattern recognition. Figure 3.3 shows three different examples of this.

Foster provides an account of expenditure/income flows between consumers, various categories of businesses and the government (figure 3.3 (a)). The chart is highly



(a) Circuit flow of money adapted from [45]



(b) China's shadow banking sector adapted from [32]

(c) Euro Area cross-border claims of banks adapted from [39]

Figure 3.3: Non-interactive visualisations of financial systems

stylised and only draws on data to a limited extent but provides insights into the topography of the economy at the time, for instance by showing the dominance of wages in income generation relative to returns on capital [45].

Ehlers, Kong and Zhu draw a sequence of stylised maps for the Chinese shadow banking sector, showing the evolution of claims from 2013 to 2016, the last one of which is shown in (figure 3.3 (b). While the size of nodes is kept constant, the size of edges varies with the size of flows represented [32]. Hence changes such as the fast growth of wealth management products emerge very clearly, supporting the argument of the paper.

Figures 3.3 (a) and (b) are embedded in academic papers whose audience allows for novel and complex representations and is likely to derive a sound interpretation drawing on the required background knowledge.

Figure 3.3 (c), which is part of the ESRB risk dashboard, published on a quarterly basis to inform policy makers, shows the share of cross border to domestic claims of banks in the Euro Area projected onto a map of Europe [39]. The visualisation is presented in every update of the dashboard, hence ensuring familiarity of users with the topography of interbank exposures across the geography. For now, there is no explicit visual aid or measure showing change vis-à-vis the last quarter, which may facilitate identification of changes over time. Given the high level of the visualisation, it seems to be mainly aimed at communication. The dashboard is produced in a semi-automated process in the FAME database environment based on a script written in FAME's own language 4GL [1].

3.2.2 Interactive visualisations

Entities

Interactive visualisations of entities are rare. An exception is the macroeconomic balance sheet visualiser produced by the EconViz blog in figure 3.4, which shows the structure of the balance sheet of an economy.

Yet, this is an educational tool only suitable for simplified and stylised data, limiting insights into the operation of balance sheets. Thus, there appears to be a gap in effective visualisations of entities, partly resulting from the fact that there is currently no established visual encoding of balance sheets. Given how important we know balance sheets to be following the Great Financial Crisis, this dissertation seeks to address this gap. I develop a new type of visualisation to show the asset and liability allocation of individual and aggregated entities.

Markets

Interactive visualisations of markets are limited in number but this seems to be partly a result of confidentiality concerns. Static visualisations make ensuring anonymity

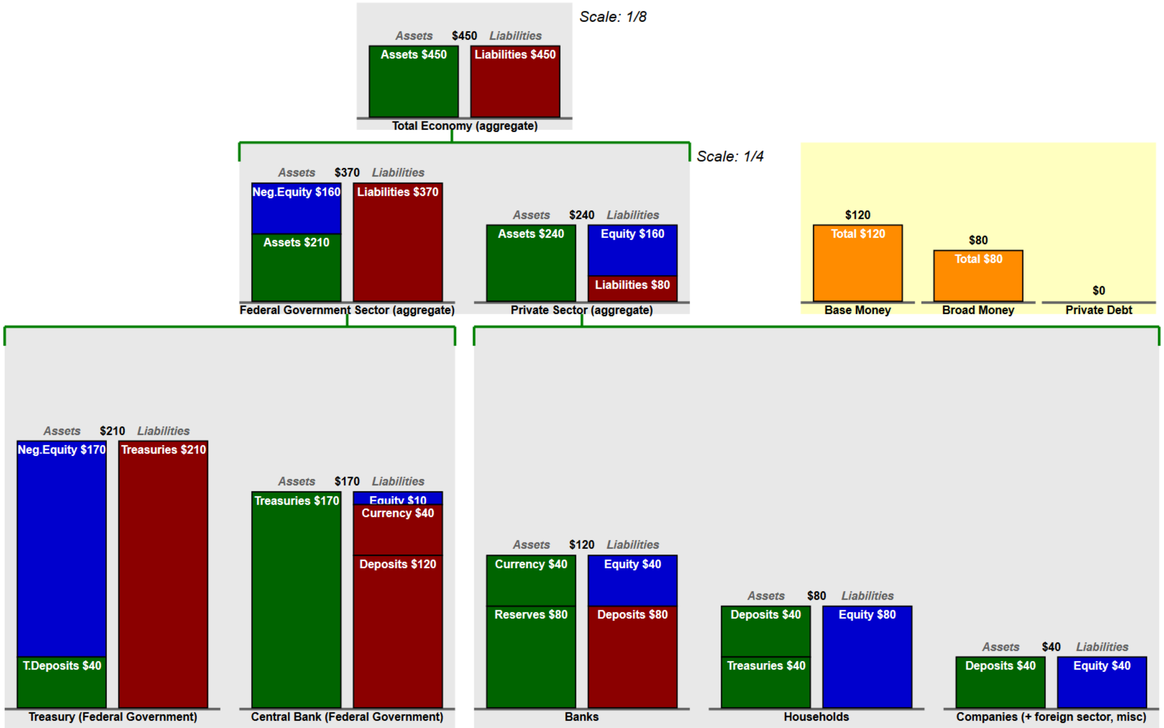


Figure 3.4: Macroeconomic balance sheet visualiser adapted from [31]

of individual entities significantly easier as only one view is available. An exception are the videos of the Dutch money market by Heijmans et al. [55].

Systems

Interactive visualisations of financial systems take several forms including networks, Sankey graphs, and Chord diagrams as shown in figures 3.5, 3.6 and 3.7. The three examples are all published on websites: Crisis Metrics, the Flow of Funds Project of the Office of National Statistics in the UK (ONS) and Euro Area Statistics respectively. They serve a range of use cases including analysis, policy making and communication.

Crisis Metrics (figure 3.5), a collaboration of the BIS and Infolytica, provide various options for displaying foreign claims and exposures between countries as a network, Chord diagram or bar chart. They are based on BIS data. In the network visualisation the trade-off between flexibility/interactivity and a clear visualisation becomes obvious as it is challenging to identify patterns or changes given the density of edges.

The UK flow of funds (figure 3.6) and the ECB who to whom visualisation (figure 3.7) build on the same type of dataset, sectoral who-to-whom statistics, whose compilation is one of the main recommendations of the G 20 Data Gaps Initiative, launched in response to the data gaps revealed by the financial crisis [8]. The former allow us to gain insight into how different sectors of the economy are connected to

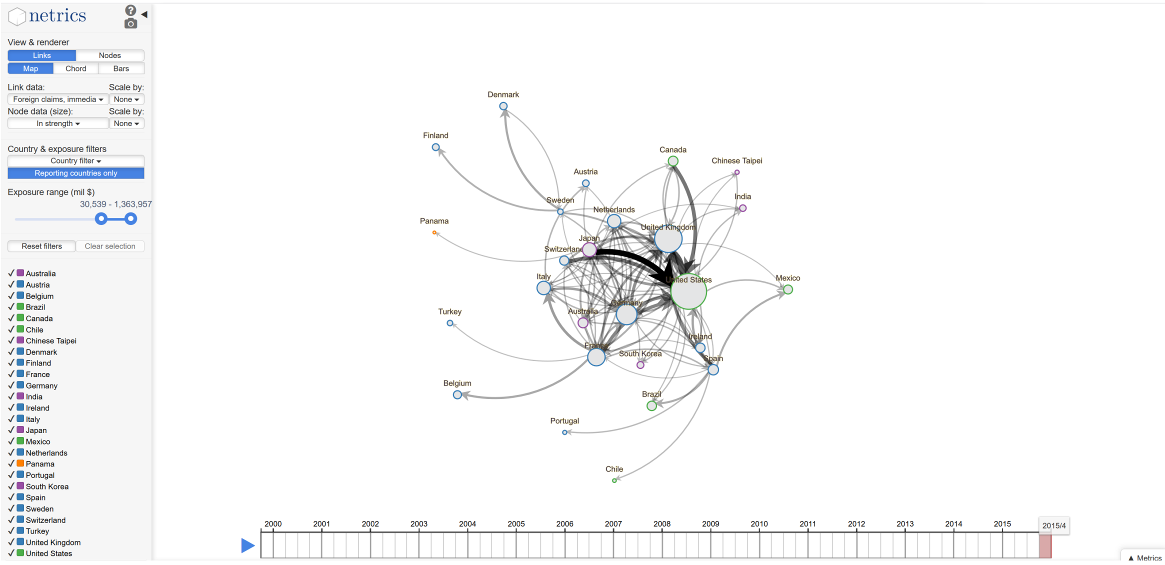


Figure 3.5: Global cross-border bank claims adapted from [59]

each other in financial terms. This is relevant for monetary and macro-prudential policy, financial stability analysis [79] as well as for gaining insights into the link between financial systems and the real economy more broadly.

UK flow of funds The UK flow of funds visualisations are part of a larger project on enhanced financial accounts by the Office of National Statistics (ONS), commenced in 2016 [70], which has already gone through several iterations of development. The visualisations are embedded in a document, which provides context regarding the input data and a guide to interpreting its various representations. According to ONS, the intended audience is not only macroeconomic researchers, but also macro-prudential policy makers concerned with the stability of the financial system [70]. Implementation draws on D3.js [9] and D3-sankey.js. All visualisations can be embedded in other websites.

The central visualisation is a Sankey diagram instead of a network as displayed in figure 3.6. It shows total financing from each sector of the economy going into a specific asset class and the financing provided by each asset class going to each sector of the economy for a selected year between 1997 and 2015. All edges originating with a certain sector have the same colour as the respective sector. Opacity of edges is set to very low. Only the colours of edges linked to a hovered over node or a hovered over edge appear in high opacity. The value of the highlighted edge appears above the diagram. In addition, there is a 'tooltips' option. When toggled to 'on' it shows a bar chart of the evolution of the specific stock value over time from 1997 to 2015.

Sankey graphs have the advantage of reducing visual complexity by following a clear left to right order. However, in their default implementation (e.g. using D3-sankey.js), the vertical ordering of nodes is not fixed, making it difficult to compare

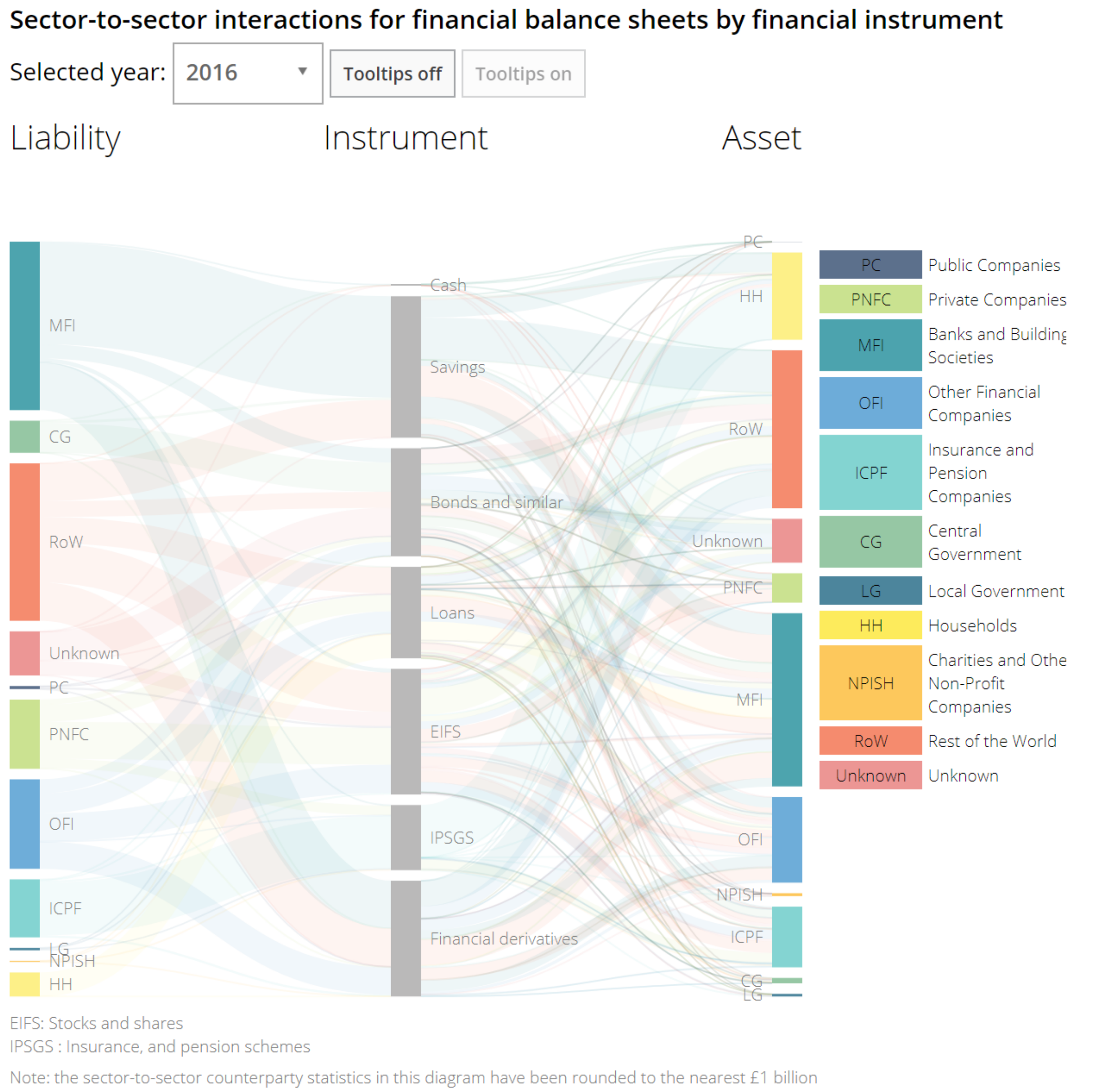


Figure 3.6: UK flow of funds adapted from [71]

topographies across time. Hence it is notable that the latest version of the UK flow of funds Sankey exhibits a fixed ordering, showing the importance of tightly controlled visualisations in the domain of financial systems visualisation. The fixed vertical positions of nodes enable very fast visual comparison across years, for instance allowing one to quickly identify the rise in financial derivatives from 0 trillion Pounds to 8 trillion pounds between 1997 and 2016, an important fact for financial stability monitoring.

Yet, the Sankey visualisation still faces limitations: As the data shown is stocks, changes in financing flows will take several periods translate into a visible change in representation. Identifying changed financing dynamics from one period to another becomes difficult, except for very large adjustments. Secondly, density of the network data shown is very high at 81%, resulting in a Sankey graph suffering from visual clutter. ONS' design choice to overcome both issues has been the implementation of three additional visualisations: The pop-up bar charts showing stocks over time, a small multiples representation of transaction flows and a heatmap of the adjacency matrix of the network, better suited to displaying dense data. While these supplementary visualisations indeed alleviate the mentioned issues, they increase mental processing time as described in Chapter 2.

To reduce the impact of visual clutter in the Sankey graph itself, edges have very low opacity unless the user hovers over them. This produces visual filtering and a reduction in complexity along the lines of [58]. The design choice works very well as visual guide but becomes difficult when trying to extract values for edges leading from instruments to asset holders for a specific receiver of financing to compare those across time (this would be a typical question in the analysis of the transmission channels for monetary policy).

While the flow of funds visualisations give a very detailed picture of the change in topology of the UK financial system, the change in overall magnitudes is less in focus. Yet, in macroeconomics both, proportional and absolute changes are important. In the UK case, for instance the financial system nearly quadrupled in size from 1997 to 2016, a fact that is likely to matter for policy makers.

Finally, Sankey graphs are very helpful in reducing the complexity of network visualisations, but they are unable to represent directed graphs required to convey bilateral relationships. This is important if the visualisation is intended to be used for financial stability analysis where understanding mutual exposures is relevant for the propagation of shocks through the system.

Euro Area who to whom financing and investment dynamics The financing and investment dynamics section of Euro Area Statistics uses the ECB's who to whom data and shows sectoral exposures by asset class (again a stock metric) on the Euro Area level as well as for individual countries over time from Q4 2013 to Q3 2017 (see figure 3.7). The visualisation can either display a single country or two countries side by side. The data is presented in a Chord diagram. The user can switch between geographies, time periods and asset classes as well as eliminate sectors from the visual. Nodes are split in two with the dark blue part of each node representing the assets of the respective sector and light blue its liabilities. Arcs are all grey, their width represents total exposure value. The opacity of arcs is set to very low unless hovered over. Upon hovering over an arc, a tooltip shows the absolute value of exposure, names the financier and the receiver, the share of total assets it contributes to the financier's balance sheet and the share of total liabilities of the recipient's balance sheet. In addition, a pop-up box in the top right corner of the visualisation provides all this information in two complete English sentences. There is the option of downloading the data, showing definitions and embedding the visualisation in another website as well as sending it via email. The tool has been developed in collaboration with the OECD and is also embedded in the websites of the national central banks of the Euro Area.

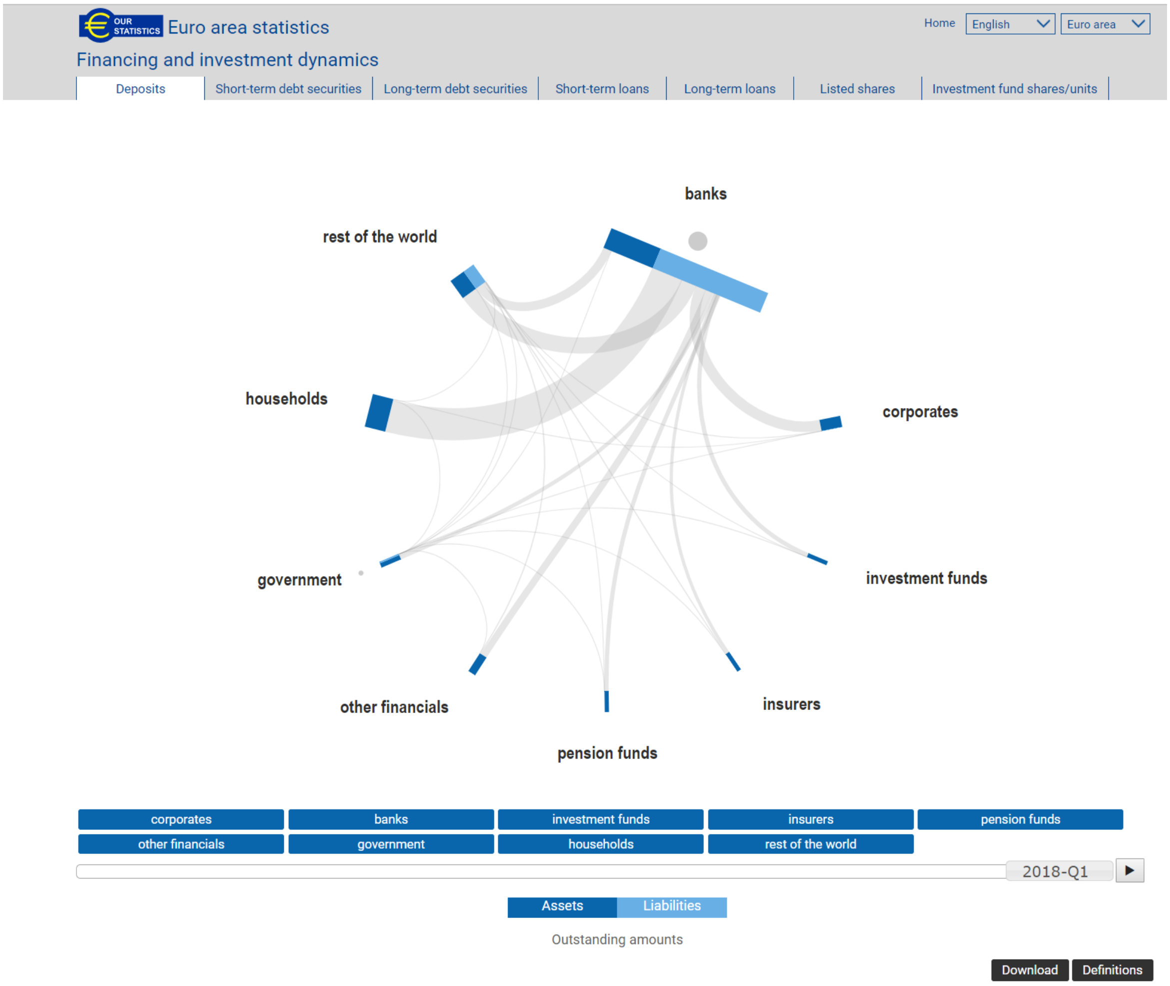


Figure 3.7: Euro Area who to whom financing and investment dynamics [34]

As in the UK flow of funds example, the low opacity of arcs limits visual clutter resulting from high network density. Another filter is provided by the possibility to hide individual sectors. The choice of a Chord diagram further reduces spatial complexity by placing all nodes on a circle with a fixed radius. As in the Sankey diagram for the UK, nodes appear always in the same order, facilitating comparisons. The two-country view is particularly well suited for the identification of different topologies of financial systems.

Contrary to the Sankey used for the UK, the choice of a Chord diagram does not come at the cost of being able to show mutual exposures. The additional complexity resulting from the need to understand which arc represents which exposure is mitigated by the descriptions in plain English (or any other language of the Euro Area) displayed when hovering over the visual. This also makes the visualisation accessible to a broader non-technical audience, less familiar with balance sheets. The usage of a Chord diagram also allows for a splitting of nodes into assets and liabilities in any given asset class, providing insight into the balance sheet structure of each sector of the financial system. Thus, the visualisation shows a novel way of combining sectoral balance sheets with exposure data.

The Euro Area visual is designed to show exposures for one asset class at a time, never presenting exposures or balance sheets in their entirety (there is no option for the Chord diagram to display the sum of all exposures). This could be problematic in times where investors shift from one asset class to another (as happened during quantitative easing (QE) where households, for example, replaced bonds in their portfolio with investment fund shares [61]) or if one wanted to understand the overall size of different parts of the financial system (to differentiate between market and bank-based economies for instance).

Further, one could argue that placing all nodes on a circle does not fully capture the varying roles individual entities play in financial markets: While banks are producers of money, investment funds, insurers, pension funds and other financials are financial intermediaries. Governments, households and corporates spend money in the real economy.

Finally, there is no explicit visualisation of change over time, possibly impinging on the ability of the user to spot emerging trends (especially given how slowly aggregate stocks move over time). As is the case with the ONS flow of funds visualisations, the Chord diagram is also focused on showing changing proportions rather than changes in absolute size over time.

3.2.3 Interactive tools with user defined data

As evident from figure 3.1, there exist a very limited number of domain specific tools which allow for data input by the user. Only FNA's proprietary platform works based on user provided data [42]. It provides highly customisable networks visualisations with extensive analytical support and can be used for any suitable input data. Initial set up requires writing code in FNA's own scripting language. Wilenksy's Netlogo model [89] visualises the output of agent-based models but is not suitable for empirical data as used by policy makers.

Yet, many policy makers across central banks and regulatory institutions have adopted network analysis as part of their regular analysis. The ESRB publishes the map of interbank exposures as shown in figure 3.3 (c), the Bundesbank uses network analysis for monitoring systemic risk in the German banking sector, the Federal Reserve Board looks at networks of financial institutions to identify nodes posing systemic risk, Canada is in the process of setting up a capital markets regulator, which is currently selecting models of systemic risk to implement and the Central Bank of Colombia already monitors the national payments network using a visual interface to name just a few. As soon as regulators and supervisors work with network data on a regular basis, the data will be in a standardised format, which should make updating visualisations straightforward.

However, visualisations of such regularly updated network data seem to still be largely generated in one-off efforts using for instance R scripts. This makes the production of network charts on a recurring basis extremely costly, as is confirmed by the fact that none of the Bundesbank's regular reports contains a network graph as standard element.

3.2.4 Summary

Three findings emerge from the review of financial system visualisations:

1. There are a lot of 'one off' network visualisations. Many of them are related to academic papers and hence require a very specific design with limited opportunities for reuse. Yet, network analysis has also entered the policy space and is used for supervisory purposes on a regular basis. However, there is currently no finance specific tool beyond FNA's proprietary platform allowing for the recurring production of standardised network visualisations. This dissertation attempts to develop such a visualisation tool, enabling regular low-cost visualisations of German bank networks.

2. There is a gap in visualising entities. However, doing so involves creating a visual encoding for balance sheets. Such a visualisation faces the same challenge as representations of the entire financial system: It should ideally reflect the size of positions as well as changes over time. Only then will one be able to quickly identify significant developments in material exposures. In addition, a balance sheet visualisation should ideally preserve the hierarchical structure of the underlying data. This allows one to identify at which level concentrations start to occur (e.g. in government bonds vs. in German bonds). While Sankey charts might be problematic in the case of who to whom data, they have shown to be useful for the analysis of exposures. Hence this dissertation explores their usage for balance sheet data.

3. As the importance of who to whom data has been recognised following the financial crisis, aggregate visualisations of financial systems have started to receive attention. Ideally, they would allow us to spot patterns of financial systems and changes thereof (something statistics is not well suited to with small datasets). A first challenge for interactive visualisations of such complexity is keeping cognitive load at a level that several visuals can be processed by a human, allowing for comparison and pattern spotting. Examples have shown how this can be achieved by reducing spatial complexity (e.g. through placing all nodes on a circle or fading out all edges not related to the sector currently highlighted). Secondly, all reviewed examples focus on visualising stock metrics, giving us a better understanding of the topography of the financial system but providing limited insight into changes over time. The flow of funds project aims to mitigate this by complementing the Sankey graph with several other visualisations. Yet, as described, this increases cost in terms of processing time. This may explain why, to my knowledge, no who to whom visualisation is included in regular statistical reports to date. Thus, it is an open question whether visualisations of financial systems can provide enough

analytical depth and granularity to show changes over time as well as giving a faithful representation of topographies without overburdening the user. Building on the examples discussed above, I will attempt to build such an interactive visualisation for the Euro Area.

4

Design principles

The design of the three visualisations introduced in this dissertation varies given their different purpose, intended users and data inputs. However, design choices are made based on the same considerations resulting from the review above and expert interviews. These considerations are laid out below.

4.1 Interface

Key for the effectiveness of financial systems visualisations is the following:

- **Filtering and highlighting**: Where datasets represent dense networks, providing options for filtering and highlighting certain data points is crucial to reduce complexity and aid pattern recognition. Yet, design choices have to be made carefully as eliminating or emphasising data points increases the risk of partial or distorted representations. These may prompt invalid conclusions or even increase mental effort required for completing a certain task if applied out of context. Hence options for filtering and highlighting have to be designed with (1) knowledge of the input data and (2) the purpose of the visualisation in mind.
- **Control**: Many data visualisation libraries optimise graph representations according to aesthetic criteria. Most network libraries, for instance, implement some form of force directed graph drawing[1]. This is problematic as positioning of nodes happens according to criteria which have no meaning in the economic context, such as minimisation of edge crossings and variance in edge length. The resulting node positions can very easily be mistaken as representing market structure, giving rise to invalid interpretations of the data. Further, layout optimising algorithms impinge on the possibility of comparing visualisations across a given dimension since elements may not remain in the same place.

[1] This also applies to other forms of visualisation, e.g. D3-Sankey.js uses an iterative relaxation algorithm for node positioning

Thus, making data visualisation useful in the context of financial systems analysis requires creating a controlled environment where (1) layout optimisation according to aesthetics is minimised, (2) layout choices reflect the economic context where possible and (3) change in the representation not reflecting a change in the data is minimised[2].

- **Analytics**: Data visualisation and data analytics are not methods opposed to each other but can be mutually reinforcing. Ideally, the visualisation allows for pattern identification and the generation of hypotheses, which are then quantified through numerical analysis. Yet, this is only possible if layout and analytical measures are aligned. The appropriateness and relevance of a specific analytical measures is highly dependent on input data. Hence designing visualisations without a specific dataset in mind can be challenging.

- **Context**: If one subscribes to the definition of an effective data visualisation as one that produces a faithful epistemic representation, the ability to assign meaning to the former becomes important. Meaning is generated through contextualising information. In financial systems this can be difficult as there are many unsolved questions on the theoretical as well as empirical level. But especially considering that, it seems even more important to include all available context. One example would be the positioning of nodes according to functions in the financial system, another placing similar assets close to each other in a vertical hierarchy. In practice, the need to add context to generate meaning limits the generalisability of visualisations even if they are designed to allow for data input by the user.

- **Scaling**: A key design choice is whether to size elements in interactive visualisations in proportion to the other elements in the given view or on an absolute scale considering all values from the underlying dataset. For the analysis of financial systems, both can be important. Proportions tend to show dependencies while absolute scale is likely to be relevant for judging impact. The choice is further complicated by the fact that ranges for macroeconomic variables can often be very large and don't necessarily follow a normal distribution. Network and Sankey visualisations will in most cases be able to handle the data using bounded scaling functions but the former produce a highly skewed output. Thus, which scale is appropriate depends on (1) the purpose of the visualisation, (2) the range of the input data and (3) its distribution.

- **Change**: If visualisations are to be used as regular input for policy making, they need to be granular enough to clearly show changes from one period to the other (without being so specific that they can no longer contextualise this change). This is extremely challenging in the context of financial systems since stock values tend to be very large compared to changes in flows from period to period. In addition, not all changes in financial flows are created equal: Some are of seasonal nature or the expected results of policy interventions while others signify a changing trend in the market. Hence, it is hardly ever

[2]for a detailed exposition of this principle see [85, chapter 6]

sufficient to look at one metric of change. To get a better understanding of the significance of movement in the data, it needs to be possible to interrogate the visualisation and compare different metrics of change.

- **Pattern recognition**: Financial systems are very complex in nature and even many macroeconomists will not be familiar with their topology. Hence a major challenge is the high cost of processing such visuals. This can be alleviated somewhat by guiding the attention of users through the targeted emphasis of certain patterns. However, directing pattern recognition in this way also entails significant risks of distorting perception, which is particularly dangerous in the context of analysis (as opposed to communication of results). Thus, the implementation of specific aids for pattern recognition should depend on the purpose of the visualisation and the intended user base as well as being an optional (rather than default) feature of the visualisation.
- **Labels**: As for all visualisations, appropriate labeling is key for interpretability. Beyond this, there are two issues specific to the context of financial systems: First, terminology related to financial systems is highly specialised and varies by geography. Thus, there is a trade-off between specificity and how widely understood a visualisation can be. Further, financial data is often highly confidential, especially when it is current and describes individual entities. Hence, the ability to provide anonymised descriptors of data points is key. One solution to both issues can be embedding various options for labeling.

4.2 Software architecture and tools

The development of interactive data visualisation differs from other software in the sense that there are two possible user groups which may overlap (and impact on the scope to be covered by the developer): Those producing visualisations and those viewing the former. The most fundamental decision seems to be defining who the intended users for a visualisation are and which role they should take on, ranging from passive observer to data creator and visualisation designer. Tasks to be covered for generating effective visualisations can be divided up in four steps as shown in figure 4.1. Core tasks any tool has to include are processing the data and generating possible representations. Depending on the purpose, the tool may already include data and tailor the final visualisation or leave this to the user.

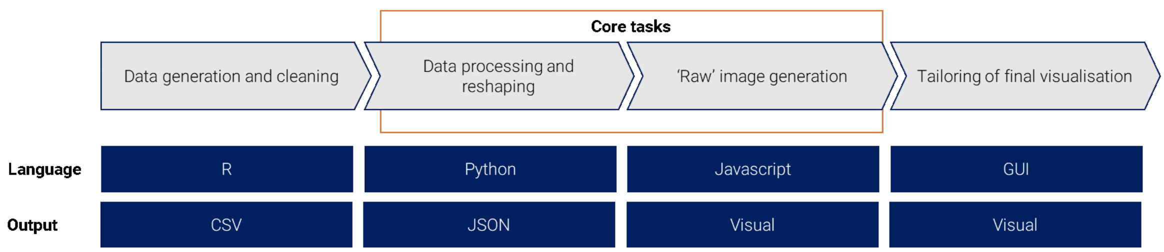


Figure 4.1: Tasks and tool structure for visualising financial systems

Describing users and their roles with sufficient precision requires a clear definition of the purpose of the visualisation and what problem it solves. If the issue is the absence of a conceptualisation of how to generate the data to draw a financial system or to represent one of its components, no tool requiring the user to provide input data and tailor the visual will alleviate the problem. If, on the other hand, the goal is interrogating regularly updated network data of the same input format and structure for possible changes, such a tool would serve the purpose.

With a defined scope in mind and drawing on established principles for software architecture design [69], the following considerations were central to the choice of architecture and tools for the three applications introduced in this dissertation:

- **Compatibility with institutional requirements**: Most users of interactive data visualisations in the financial systems domain will be based in central banks, regulatory agencies, governmental organisations, or academia. For all but the last, there are very tight restrictions on software that can be run using institutional infrastructure. At the Bundesbank for instance, only pre-approved software can be installed without going through a case-by-case approval process, including extensive vetting of the software in question. Similarly strict procedures apply at other central banks and regulators, which has been reported as one of the major reasons why third party visualisation software still has such a limited spread despite there being a clearly identified need. Thus, there is a clear advantage in building on pre-approved infrastructure and tools. This heavily favours browser-based implementations given their universal availability. Further, in the Bundesbank context, the Anaconda distribution of Python has pre-approval, making Python and its micro-framework Flask (included in Anaconda) the obvious choice for server-side development.

- **Security**: Financial data used by central banks, regulators and academics is often highly sensitive. Hence distribution is restricted to individuals who have been granted permission for access. Transmission may be done through encrypted files in csv format. The implications of this are threefold: (1) For any interactive visualisation that consumes sensitive data, there needs to be a clear separation between data and software. (2) The software needs to be able to consume files rather than an application programming interface (API) and (3) it should work entirely offline.

- **Separation of concerns**: One of the key issues of domain specific, specialised data visualisation is high development cost as it requires precise tailoring. Building an architecture where tasks are handled by separate, independent components reduces development cost in the long term as components can be swapped in and out and the application reused in a slightly different context. Further, in many cases not all stages of data processing may be required every time the application is run: Most macroeconomic data for instance, is only updated every quarter. A modularly built application can easily be modified to accommodate this.

- **Simplicity of architecture**: To make modularity effective, the architecture needs to be comprehensible and decomposable for a third party. Hence the aim in all three visualisations presented in this dissertation is to minimise interaction between different components, which results in difficult to debug dependencies.

- **Ease of error spotting and tracing**: One major challenge in the domain of financial systems is the evolving nature of available input data. Methodologies for collecting primary data and computing derived metrics as well as definitions are revised on a regular basis[3]. Hence, the ability to closely monitor input data as well as allowing for manual inspection is key. This further motivated Python as language for data processing and reshaping and made R a suitable candidate for the generation of data input.
- **Right tool for the right purpose**: The ease of building input datasets is greatly facilitated by the presence of specific libraries for data manipulation and the handling of APIs of major statistical data warehouses in the financial domain. This privileges R, which has a wide range of packages for APIs of major providers of financial and macroeconomic data, including the ECB statistical data warehouse [74], Eurostat [64], the BIS [73] and the OECD [75] to name just a few. Further data processing is done in Python, which has a very concise and expressive syntax, conducive for maintenance of code as well as being popular with economists, most of which have a background in statistics. Accessibility is particularly important for components relating to data processing as input formats are likely to change over time.

  Javascript with its extensive range of visualisation libraries is well suited for the interface. It can be tempting to use a high level declarative framework like React [41], which allows the developer to focus on what the visualisation should look like rather than specifying how the change is done. Yet, this can be problematic as one tends to have less control over the appearance of the visual. At the other end of the spectrum, working with D3 libraries, gives the developer full control but can be very slow. Hence finding the library with the right trade-off between granular access to manipulate the DOM and high level API allowing efficient development seems key.
- **Open source**: All components should be open source so that any interactive visualisation can be a public good and reused by others.

[3] see for instance [33]

5

The Interbank Network Visualiser

5.1 Context

The Interbank Network Visualiser was developed in collaboration with Sören Friedrich, Financial Stability Department at the Bundesbank, who provided the initial specification and tested the tool. The Financial Stability Department of the Bundesbank is tasked with macroprudential supervision, i.e. it does not focus on individual institutions but the stability of the financial system as a whole. The need for macroprudential supervision became apparent in the financial crisis, when the interconnectedness of the financial system led to the amplification of shocks[1]. Thus, the Visualiser is aimed at enabling analysts to quickly generate and update network visualisations based on German bank data, they collect as part of its supervisory mandate.

The Visualiser including a user guide (found in the annex of this dissertation) has been handed over to the Bundesbank and is available on Github at `https://github.com/philippasigl/BankNetwork`.

Monitoring the structure and interconnectedness of the German banking sector is particularly important, given the ongoing decline in the number of German banks (3.4% in 2017 [29]) and the revision of the Basel III criteria in December 2017. Both factors may have a significant impact on the structure of the banking sector. Even though network analysis forms a key part of macroprudential supervision, the Financial Stability Department of the Bundesbank does not have a tool which allows it to visualise networks. Where network visualisations are required, they are developed in R. Yet, this is very time consuming and has limited the use of visualisations in the past. The network tool developed as part of this dissertation seeks to address this issue, providing a browser-based interface where the user can upload data and tailor the network visualisation according to his or her specific needs.

[1] as for instance the cases of AIG and Lehman Brothers illustrated [22]

5.2 Requirements

5.2.1 Aims

The Interbank Network Visualiser should enable network visualisations of the German banking sector for the purpose of data analysis and communication of results. Visualisations should serve as input for the Report on Other Systemically Important Institutions issued by the Bundesbank, briefings for policy makers and presentations on specific issues related to macroprudential supervision. It should consume user provided csv files, produce a default visualisation which can be interactively modified and allow for saving the generated visualisations as static images.

5.2.2 Specification

The following functionality was agreed for the pilot version of the network tool, developed as part of this dissertation:

- Data upload
  - For a flexible number of node and edge files according to a pre-specified format (and naming convention)
  - Required inputs for nodes are unique IDs, a sectoral classification and at least one numerical attribute with flexibility for further numerical attributes; a custom colour can be provided
- Network layout
  - Default visualisation
    - A default network visualisation for the latest available date optimised for showing ca 15-20 nodes with larger datasets being possible
    - Fixed positioning of nodes for networks with the same number of nodes (allowing for comparison of the same bank network across time periods)
    - Tooltips for nodes and edges
    - Ability to highlight individual nodes and the edges connected to them
  - Network structure
    - Option for changing the date for which the network is displayed (based on the input data provided)
    - Three options for selecting the network structure; per default, nodes are arranged in a circle. Alternatively, there is a core-periphery structure with one sector at the centre and all other sectors spread around and a grouped structure where circles for each sector are spread

around a circle (similar to the core-periphery structure, without a sector at the centre)

  – Option for changing the node attribute by which the central sector is chosen in the core-periphery structure

  – Option for filtering by bank sector

- Nodes
  - Three options for labeling: None, according to the names provided by the input and numerical labeling
  - Sizing according to all numerical attributes provided and option for uniform size (for anonymisation purposes)
  - Option to adjust the range for node sizes
  - Three options for node colouring: Custom colouring provided by the user in the input data, default colouring according to bank sectors and a uniform colour for all nodes
- Edges
  - Option for showing edges according to their absolute value or as change to the preceding period
  - Option to adjust the range for edge sizes
  - Option for setting a cut-off for minimum edge size shown
  - Option for colouring edges according to change to the preceding period
- Other
  - Option to export the network as png with the selected options saved in the filename
  - Ability to highlight nodes and all outgoing/incoming edges

5.3 Implementation

5.3.1 Software architecture and tools

The tool is built using Pythons micro-framework Flask with a browser-based interface tailored to Google Chrome, which is used by the Bundesbank. It consumes user provided csv files and turns them into a default visualisation which can then be modified and saved as images by the user. As outlined above, a key consideration for this set-up was the requirement to use tools already approved for internal usage at the Bundesbank. Flask meets this criterion while this is not the case for Node.js [83]. Secondly, Python is particularly well suited to data processing and facilitates error spotting. The network visualisation is based on the Javascript library Vis.js. The Vis.js API enables very quick set-up based on pre-configured options allowing for faster development than using D3.js. Further Vis.js still allows for any configuration option to be replaced with a custom method, thus making the use of a lower level library like D3.js superfluous.

Figure 5.1 shows the structure of the visualiser, separating out concerns: The Flask app runs in 'app.py' which launches the 'upload.html' interface, where the user can select csv files from his own file system. The data is then processed with 'graph_data.py' and sent to 'index.html' in json format, where values for the control panel, the default network visualisation and the state variables are initialised.

If unsuitable data is uploaded, the upload interface will return an error message indicating why the data could not be processed.

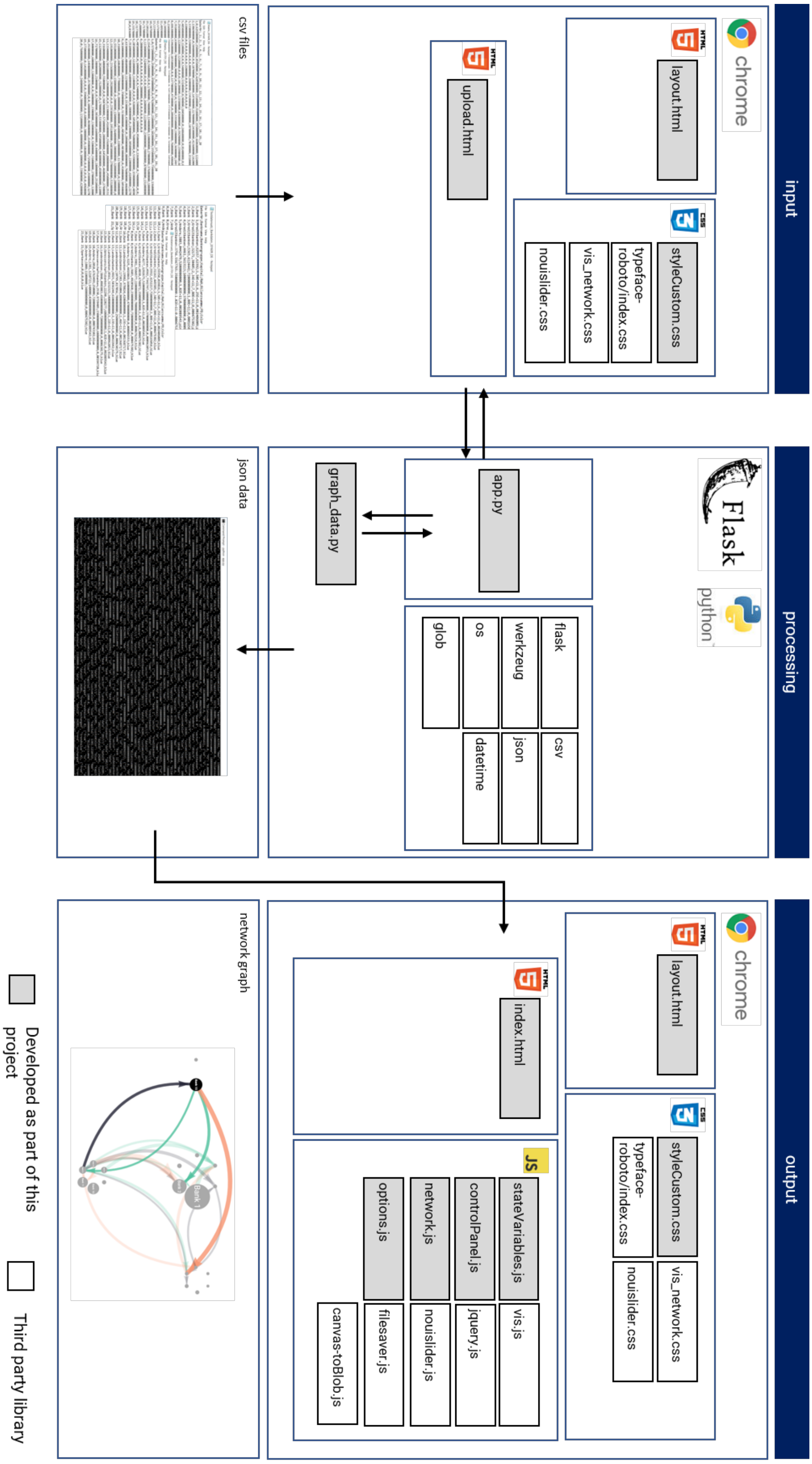


Figure 5.1: Structure of the Interbank Network Visualiser

The input format is currently tailored to files generated with Stata [82]. Should the input format change over time, required changes would be limited to the Python scripts 'graph_data.py' and 'app.py', facilitating maintenance by economists. Further, the structure allows for adaptation to (1) other types of data by replacing 'graph_data.py' and the network visual or (2) other use cases such as a website, replacing the Flask application with json files (examples are provided by the two further visualisations introduced in this dissertation).

The tool is built mimicking the React concept of state through global variables, which keep track of all current settings of the visualisation. User actions trigger an update of the relevant global variable, upon which the network is redrawn with options set according to the values of the state variables.

5.3.2 Interface

The interface is divided up in a control panel and the network visualisation, as shown in figure 5.2. The control panel includes three sections for specifying options regarding the network, nodes and edges as well as providing a button for exporting a png image. The visualisation defaults to displaying the most recent data found in the user provided input. Dropdown options for date, sectoral selection, node size and colour are generated based on the input data.

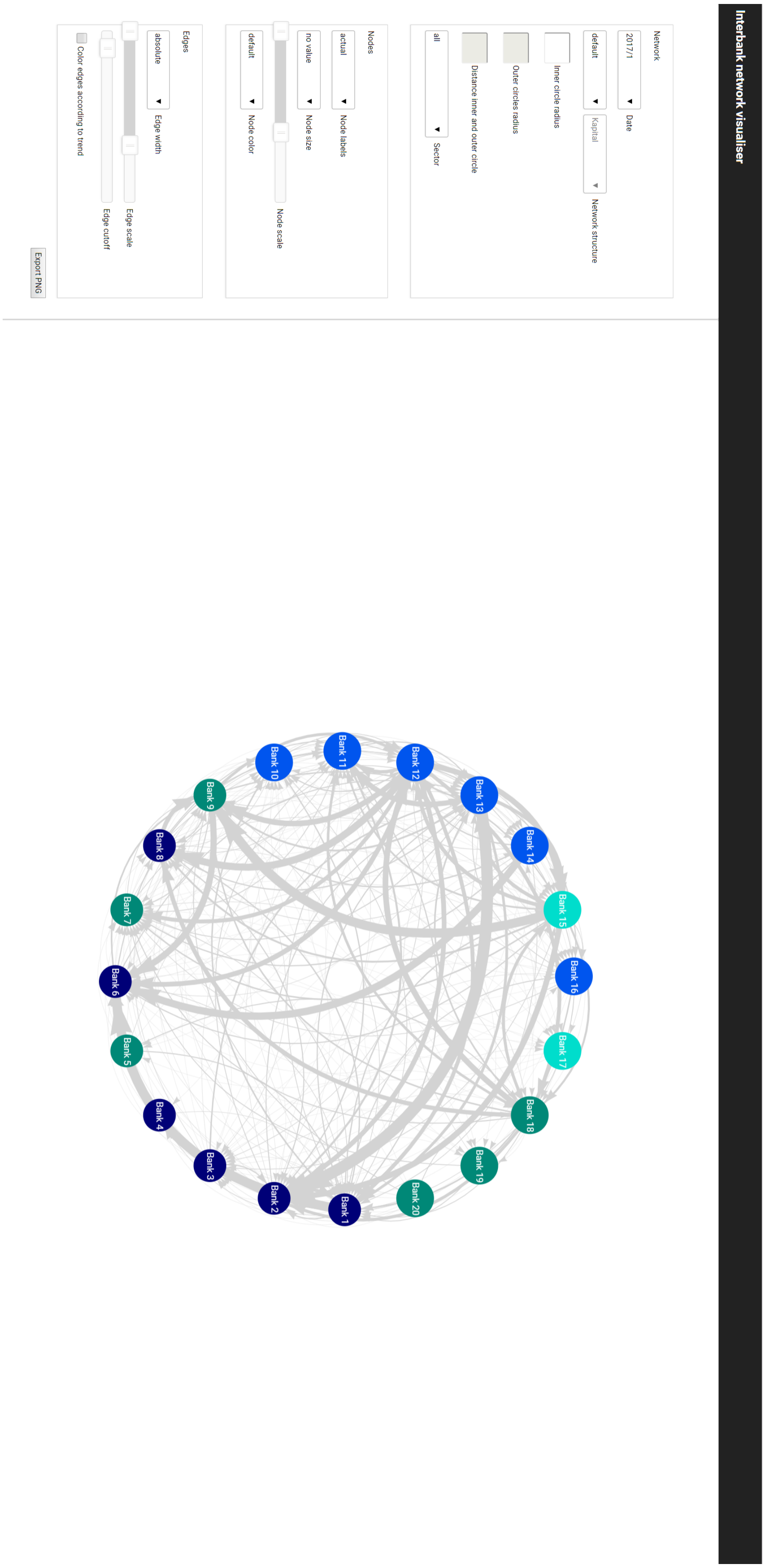


Figure 5.2: Interface Interbank Network Visualiser

In the default view, nodes are arranged on a circle. There is no random seed for the network, all node positions are calculated. The network renders exactly the same every time the data is uploaded, and node positions will remain the same if an updated dataset is displayed (as long as the number of nodes remains the same). Thus, all changes in the visualisation have meaning in the context of the data presented.

Alternative network structures are a core-periphery structure and a grouped view. The addition of the core-periphery structure is based on evidence by Craig and Peter, who show that interbank markets in Germany are tiered rather than flat [20], with a few banks emerging as central actors in the money market. In the core-periphery view provided in the Interbank Network Visualiser, one sector is placed at the centre with all others being spread around on a circle. The sector at the centre has the largest average value for a user specified numerical node characteristic (e.g. total assets, capital, RWAs or probability of default). Sizes of the circles on which the nodes in the core sector, the periphery sectors and the periphery sectors are placed, are adjustable in size.

The grouped view allows for analysis by sector. Understanding exposures by sector is relevant as, in the case of a banking crisis for instance, deposit insurance schemes vary by sector [25]. Further, regulatory responsibility depends on the sector. The sectoral dropdown allows for selecting sub-networks.

Per default, nodes show the name provided by the input data and are not sized to any specific numerical characteristic. As the range in size for German banks is very large (Deutsche Banks balance sheet has a volume of 1.5 trillion Euros [23] while 396 savings banks together have an aggregated balance sheet of 2.2 trillion Euros [21]), this allows for getting an initial overview of the network structure rather than just seeing dominant nodes.

Alternative settings for node sizing can be chosen based on all numerical node characteristics provided in the input data. The range of node sizes can be adjusted using the relevant slider. Node labels can be removed entirely or anonymised so that the generated visual can be used with an external audience. Per default, nodes are coloured according to their sector. Alternative options are a custom colour scheme provided in the input data or colouring all nodes in grey.

Edge width reflects the absolute size of the matrix value provided but can be switched to showing the magnitude of change to the preceding period. Edges can be coloured in to show the direction of change, giving policy makers a very quick overview over developments compared to the reference period. Increases in exposures are shown in green, decreases in red, and no change in grey. Again, the range of edge sizes is maximised to reflect the large range in changes. The range in edge sizes can be adjusted through a slider. As became evident early in the testing, interbank networks are very densely connected, resulting in visual clutter. Thus, a filtering option for edges was implemented as a slider, allowing the user to gradually eliminate small edges.

5.3.3 Process

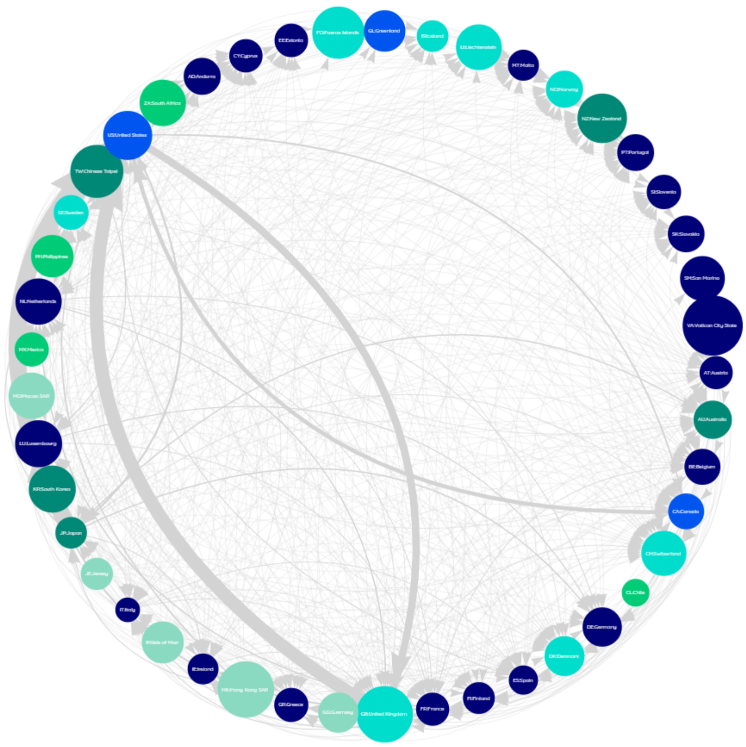
The Interbank Network Visualiser was implemented as the pilot for a larger network tool for the Financial Stability Department of the Bundesbank. Its design is based on a detailed specification provided by the department, which was then reduced to core features feasible for implementation in two months. The definition of initial requirements and all subsequent modifications thereof were developed in close collaboration with the final user, who provided precise guidance on the goals of the visualisation as well as the specific analytical aims to be achieved. Anonymised input data provided in early stages of testing allowed for the addition of crucial features to realise analytical goals such as filtering, scaling and sizing of circles.

5.4 Case study: Global bank/shadow bank exposures

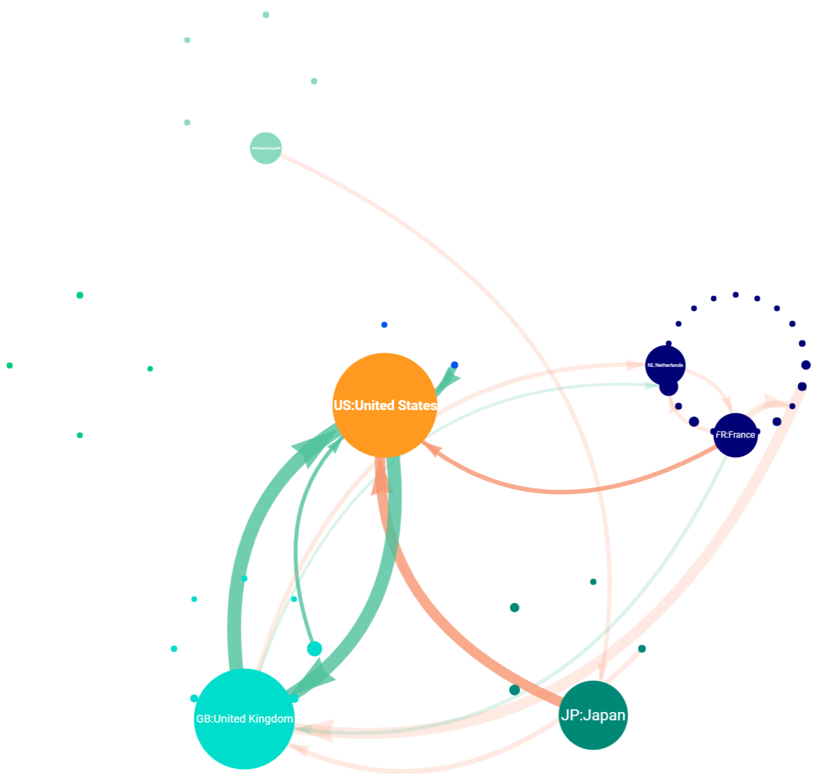
As data for interbank exposures is confidential, the visualisations presented below draw on public data from the BIS, showing global exposures of banks to non-banks for September 2016 and September 2017, aggregated by country. Non-banks are all financial institutions, which are not classified and regulated as banks, including large asset managers like Black Rock. As the financial crisis has shown, understanding banks' exposure to non-banks is crucial for monitoring financial stability [2]. Sectors in the context of this visualisation are replaced by economic regions provided in the input data.

In the default view, shown in figure 5.3 (a), all countries are aligned on a circle, coloured by economic region. Edges show total exposures of banks in one country to non-banks in another country as of September 2017. For example: The edge running from the United States to the United Kingdom shows the total investment of American banks into non-banks in the United Kingdom. No sizing option for nodes is chosen in the initial display.

The user can tailor the visualisation to a specific research question (figure 5.3 (b)). One of the most fundamental for financial stability is: What are the most significant changes in exposures for the largest banking sector in the global financial system? For this, the size of network nodes is changed to total asset size of the banking sector in each country. Node scale is adjusted to the maximum range so that nodes are visible, while still showing the large range in sizes from 0 trillion Dollar in Greenland to 11 trillion Dollar in the United States. In line with this, the core-periphery structure is chosen putting the economic region with the largest average asset size at the centre. Circle sizes are adjusted to minimise node overlap. The sizing of edges is changed from total value of outstanding asset to showing the change to the prior period and colouring adjusted to reflect the direction of change. Small changes are filtered out and the United States and edges connected to it are highlighted. Now it is very evident that connectedness between the United States and the United Kingdom has increased significantly from September 2016 to September 2017, while exposures from Japanese banks to American non-banks have been reduced considerably.



(a) Default visualisation



(b) Configured visualisation

Figure 5.3: Network of global banks exposures to shadow banking entities

Thus, the combination of filtering, scaling, highlighting and adapting the shown data to the specific research question allows us to go beyond aesthetics and actually use visualisation for analytical purposes.

5.5 Discussion and evaluation

5.5.1 Software architecture and tools

Selecting an architecture with minimal system requirements enabled compatibility with legacy versions of Chrome Enterprise, which emerged as crucial in the Bundesbank context. Modularity in architecture allowed for this tool to become the foundation of further visualisations, two instances of which are discussed below. Compared to development based on a D3 library, building on Vis.js was very fast, while still allowing for customisation.

One challenging aspect of working with Vis.js and global state variables is unit testing, which requires extensive mocks. Hence the testing framework Tape [54] was complemented by Sinon [60]. With respect to testing, there might be an advantage in implementing a React based solution, which has testing frameworks tailored to evaluating states. Yet, React implementations of static Javascript libraries such as React-vis-force.js [86] do not allow for the same level of control over individual elements of the network as static libraries such as Vis.js.

Limitations of the current architecture are mainly related to processing data in Python rather than in Javascript as needed for a given configuration. Given the limited size of datasets related to banking in Germany this does not appear as a major constraint but could be optimised in the future. Shifting data processing to Javascript also allows for more flexible representations as will be evident in the final visualisation presented in this dissertation. Further, limiting server-side processing to formatting and reshaping data rather than also computing visualisation specific parameters reduces dependencies between the different components of the Visualiser.

5.5.2 Interface

As outlined in the review of financial system visualisations, developing interactive tools with user provided data input, which are tailored enough to provide analytical insight seems very challenging. In the case of the Interbank Network Visualiser, three factors were crucial to enable the focused development of the pilot: Firstly, network visualisations are well developed. Vis.js was first published on Github in 2013. Hence the visualiser could leverage a very mature toolkit. Secondly, the meaning of financial networks are well understood as the usage of network visualisations increased significantly after the financial crisis. Hence, less experimentation was required. Finally, the data owner had already identified very specific use cases and research questions based on ongoing network analysis of the data.

However, functionality is certainly still limited: First, the Visualiser requires csv files in German formatting and there are several other requirements regarding data structure (as detailed in the user guide). Flexibility in data input is limited to numerical node attributes, the provision of names and custom colouring. For the pilot, a restrictive data input format was a design choice to ensure accurate output. However, as effort to adapt data structures to the required input format is a major impediment to adoption of the tool, adding functionality to the Visualiser to recognise certain data structures, or for the user to provide information on the structure and formatting of his or her data set would most likely expand use cases significantly.

Secondly, the visualisation itself could be further developed, especially by (1) expanding the options for visual analysis, (2) drawing more on numerical analysis to inform the visualisation and (3) providing complementary analytical measures. For (1), one obvious area for further development are additional measures of change. Currently, the tool only allows one to inspect change with reference to one period before. Yet, this is clearly insufficient for policy analysis as normally several different time frames are considered. The final visualisation presented in this dissertation draws on this learning. With respect to (2), developing analytical capability to recognise the likely network structure rather than choosing it manually could help to get closer to the goal of a faithful epistemic representation (without relying on the user to select the accurate structure). Equally, instead of choosing scales manually, statistical measures could be used to specify ranges for sizing edges and nodes. Visual representation in this area could also be enhanced as there is currently there is no functionality to identify actual ranges. Statistics on change and measures from network analysis could be displayed in the control panel, complementing the visual representation. The second visualisation presented in this dissertation aims to further develop this area.

Finally, the tool currently requires execution from the command line. Adding a GUI for starting up the visualiser will most likely significantly increase the potential user base.

Despite these limitations, the pilot of the Interbank Network Visualiser already seems to address the need for a finance specific network visualisation tool, which can be deployed without extensive set-up or clearing software auditing processes of public institutions and allows for faster visualisations than R, currently used by economists for most network visualisations.

6

Balance sheet visualisation

6.1 Context

As detailed above, there is not only a lack in tools for interactive data visualisation related to financial networks, but also a lack of visual encoding to describe the entities part of a financial system.

This seems particularly surprising as balance sheet comprehension is both, important for policy makers and very complex given its multidimensional nature: Balance sheets show the financial condition of an entity at a certain point in time and have two sides showing assets on the one and liabilities and equities on the other side. Each side of the balance sheet is then further divided up in sub-categories. Understanding the changing composition of balance sheets is crucial to answer questions on maturity mismatch and risk exposures, key factors for financial stability. Banking regulation as specified in the Basel III accords [4] focuses on metrics computed based on balance sheet positions. Yet, current presentations of balance sheets, such as the one for Deutsche Bank shown below in figure 6.1, neither provide an intuitive representation of their multilevel nature, nor do they facilitate understanding change in structure over time.

6.2 Requirements

6.2.1 Aims

This dissertation seeks to start addressing the gap in balance sheet visualisation by proposing a novel representation, drawing on the work by ONS in the UK, as described above. The aim is to see whether deploying such a novel visualisation for one actor in the financial system can generate valuable insights.

Deutsche Bank – Financial Data Supplement Q4 2017 (Based on Q1 2018 Segmental Structure)

Consolidated Balance Sheet - Assets

(in € m., unless stated otherwise)	Dec 31, 2016	Mar 31, 2017	Jun 30, 2017	Sep 30, 2017	Dec 31, 2017	Dec 31, 2017 vs. Dec 31, 2016
Assets:						
Cash and central bank balances	181,364	179,461	227,514	204,350	225,655	24 %
Interbank balances without central banks	11,606	10,467	9,109	10,727	9,265	(20)%
Central bank funds sold and securities purchased under resale agreements	16,287	14,058	11,025	10,580	9,971	(39)%
Securities borrowed	20,081	24,907	23,378	23,978	16,732	(17)%
Trading assets	171,044	185,926	188,192	186,716	184,661	8 %
Positive market values from derivative financial instruments	485,150	421,218	396,340	372,019	361,032	(25)%
Non-trading financial assets mandatory at fair value through profit or loss[2]	0	0	0	0	0	N/M
Financial assets designated at fair value through profit or loss	87,636	100,103	89,796	96,227	91,315	4 %
Total financial assets at fair value through profit or loss	743,830	711,248	674,328	654,962	637,008	(14)%
Financial assets at fair value through OCI[2]	0	0	0	0	0	N/M
Financial assets available for sale	56,178	55,155	53,863	51,466	49,356	(12)%
Equity method investments	1,027	980	948	916	866	(15)%
Loans, net	408,909	405,362	398,698	395,237	401,699	(2)%
Securities held to maturity	3,206	3,197	3,189	3,179	3,170	(1)%
Property and equipment	2,804	2,832	2,746	2,772	2,663	(5)%
Goodwill and other intangible assets	8,982	9,038	8,634	8,773	8,839	(2)%
Other assets	126,045	134,067	145,575	144,348	101,491	(19)%
Assets for current tax	1,559	1,567	1,248	1,265	1,215	(22)%
Deferred tax assets	8,666	8,427	7,983	7,829	6,799	(22)%
Total assets	1,590,546	1,564,756	1,568,734	1,521,464	1,474,732	(7)%

(a) Assets

Deutsche Bank – Financial Data Supplement Q4 2017 (Based on Q1 2018 Segmental Structure)

Consolidated Balance Sheet - Liabilities and total equity

(in € m., unless stated otherwise)	Dec 31, 2016	Mar 31, 2017	Jun 30, 2017	Sep 30, 2017	Dec 31, 2017	Dec 31, 2017 vs. Dec 31, 2016
Liabilities and equity						
Non-interest bearing deposits	200,122	206,772	221,860	224,230	226,339	13 %
Demand deposits	129,654	126,774	128,946	125,596	133,200	3 %
Time deposits	130,299	132,190	141,386	137,042	133,962	3 %
Savings deposits	90,129	89,704	89,207	87,823	87,241	(3)%
Interest-bearing deposits	350,082	348,668	359,618	350,460	354,473	1 %
Deposits	550,204	555,440	581,478	574,691	580,812	6 %
Central bank funds purchased and securities sold under repurchase agreements	25,740	18,488	21,343	18,499	18,105	(30)%
Securities loaned	3,598	4,508	5,122	6,508	6,688	86 %
Trading liabilities	57,029	63,300	66,392	74,201	71,462	25 %
Negative market values from derivative financial instruments	463,858	399,062	371,682	348,346	342,726	(26)%
Financial liabilities designated at fair value through profit or loss	60,492	65,798	64,112	49,758	63,874	6 %
Investment contract liabilities	592	607	601	600	574	(3)%
Financial liabilities at fair value through profit or loss	581,971	538,768	504,787	472,906	478,636	(18)%
Other short-term borrowings	17,295	20,109	20,232	18,279	18,411	6 %
Other liabilities	156,440	174,984	186,811	180,792	132,208	(15)%
Provisions	10,973	6,742	5,425	5,025	5,219	(52)%
Liabilities for current tax	1,329	1,111	1,081	1,074	1,001	(25)%
Deferred tax liabilities	486	474	450	396	346	(29)%
Long-term debt	172,316	172,964	165,070	159,091	159,715	(7)%
Trust preferred securities	6,373	6,354	5,684	5,583	5,491	(14)%
Obligation to purchase common shares	0	0	0	0	0	N/M
Total liabilities	1,525,727	1,499,905	1,497,524	1,450,644	1,406,633	(8)%
Common shares, no par value, nominal value of € 2.56	3,531	3,531	5,291	5,291	5,291	50 %
Additional paid-in capital	33,765	33,830	39,528	39,715	39,918	18 %
Retained earnings	18,987	19,491	19,383	19,787	17,454	(8)%
Common shares in treasury, at cost	0	(84)	(33)	(18)	(9)	N/M
Equity classified as obligation to purchase common shares	0	0	0	0	0	N/M
Accumulated other comprehensive income (loss), net of tax[3]	3,550	3,109	1,709	901	520	(85)%
Total shareholders' equity	59,833	59,886	66,258	65,676	63,174	6 %
Additional equity components[4]	4,669	4,675	4,674	4,669	4,675	0 %
Noncontrolling interests	316	292	278	265	250	(21)%
Total equity	64,819	64,852	71,210	70,609	68,099	5 %
Total liabilities and equity	1,590,546	1,564,756	1,568,734	1,521,464	1,474,732	(7)%

(b) Liabilities

Figure 6.1: Deutsche Bank balance sheet adapted from [23]

To meet this goal, the representation attempts the following: (1) Capture the multilevel nature of balance sheets, allowing us to conduct analysis at different levels of aggregation. More often than not, we are unsure where concentration risks are likely to occur, be it for instance on the asset class level or exposure to one country. Regulation and market conditions are constantly in flux, giving rise to unforeseen phenomena[1]. (2) Reflect the change in positions over time in context of the entire balance sheet as this is key to evaluating the impact of the former.

The achievement of these aims will be tested by implementing a balance sheet visualisation for the European banking sector and reviewing its changes in light of the ECB's unconventional monetary policy.

[1]An example for this is the home bias of Euro Area banks who tend to have a stronger exposure to sovereign debt of their own country than that of other Euro Area economies even though risk weights on all Euro Area sovereign debt is the same.

6.2.2 Specification

The specification for functionality evolved over the course of the project as software development and analysis went hand in hand. The final specification, the project arrived at was:

- Default layout
  - Display of all levels of the aggregated balance sheet for Euro Area bank for the latest time period available in a Sankey chart
  - Options for changing link colour to reflect total change or compound annual growth from the selected date to the latest available in the visualisation. Tooltips should show value of change
  - Option for changing the date (based on the input data provided)
  - Tooltips with values and names for hovered over balance sheet positions
  - Minimise white space for the latest time period available (as balance sheets have a large number of positions)
  - Minimise changes in node positions compared to the latest time period available when showing balance sheets for other periods
  - Option for reducing the number of links shown
- Analysis
  - Option for computing ratios of user selected balance sheet positions
  - Option for computing the Herfindahl index [56] for a given level of the balance sheet to measure concentration

6.3 Implementation

6.3.1 Software architecture and tools

The structure of the app is minimal consisting of a static webpage written in HTML and Javascript, which is deployed on Github Pages at `http://philippasigl.com/MFIsEuroArea` and tailored to Google Chrome. The R script 'euro_area_banks.R' uses the library ECB [74] to call on the ECB's API and outputs a single csv file. The csv file is then processed by the Python script 'views.py', which outputs data in json format. This in turn serves as input for the static website presented by 'index.html'. The visualisation is generated using Javascript and the D3-Sankey.js library. The structure is shown in figure 6.2.

The visualisation utilises D3-sankey.js. One possible alternative would have been the

Sankey implementation of React-vis[2]. This would have allowed for faster implementation but at the expense of control over node ordering as React-vis uses the iterative relaxation algorithm implemented by D3-Sankey.js to minimise whitespace. Yet, in the context of balance sheets minimising changes in node order is key. Hence a custom implementation of the node positioning algorithm in D3-Sankey.js was created.

[2]used for instance in this visualisation of sovereign bank exposures in the Euro Area: `http://philippasigl.com/BankSovereignExposures/templates/`

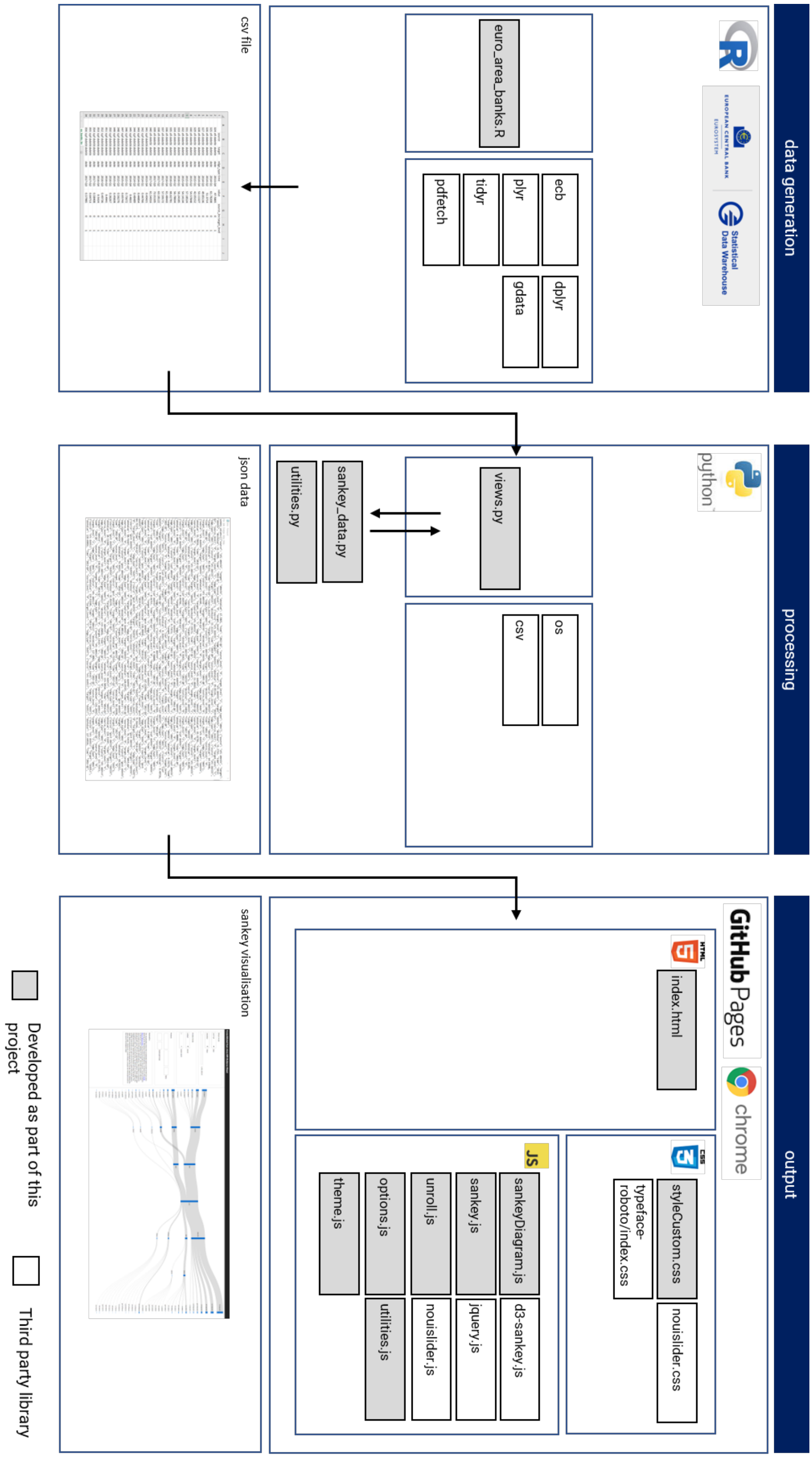


Figure 6.2: Structure of the Euro Area banking sector balance sheet visualisation

6.3.2 Interface

The interface, displayed in 6.4, shows a control panel and a Sankey diagram representing the balance sheet for one period.

The visualisation follows the schematic described in figure 6.3. Assets are on the left side of 'core', liabilities to the right. The first level to the left and right of 'core' shows balance sheet positions by item (e.g. 'debt', 'loan'), the second level by maturity (where applicable), and the third further divides up individual positions by counterparty.

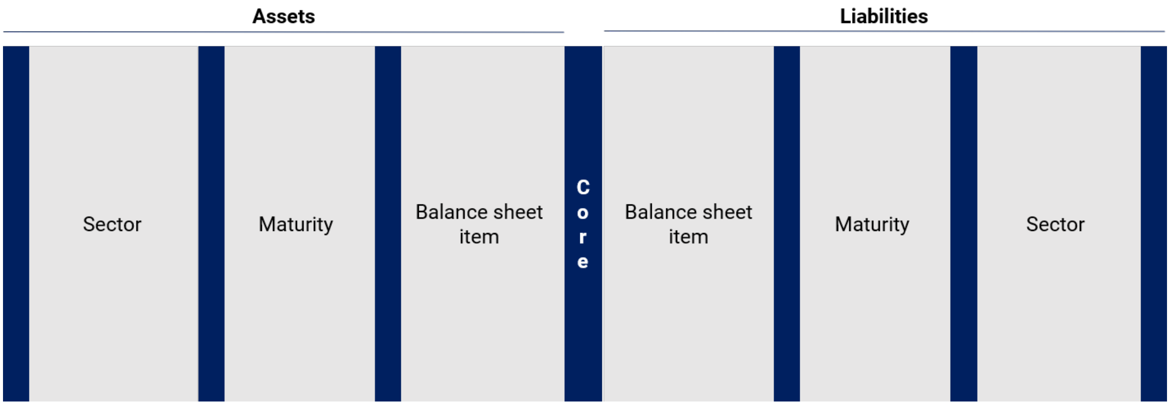


Figure 6.3: Logic of the Euro Area banking sector balance sheet visualisation

Width of links represents the size of the exposure the link runs towards. Links can be coloured in to reflect absolute growth or the compound annual growth rate (CAGR) from the first to the selected period. Balance sheet positions which have grown in volume are shown in green, declining ones in red. The intensity of the colour corresponds with the magnitude of change. In order to reduce visual clutter, small links can be eliminated using the slider. The analysis section shows the ratio of the last two nodes clicked on by the user. Further, when clicking on a node, the Herfindahl index for this level of the balance sheet is computed, reflecting concentration. The visual is accompanied by a short explanation. Tooltips when hovering over the graph show trend or absolute values, depending on the selected options.

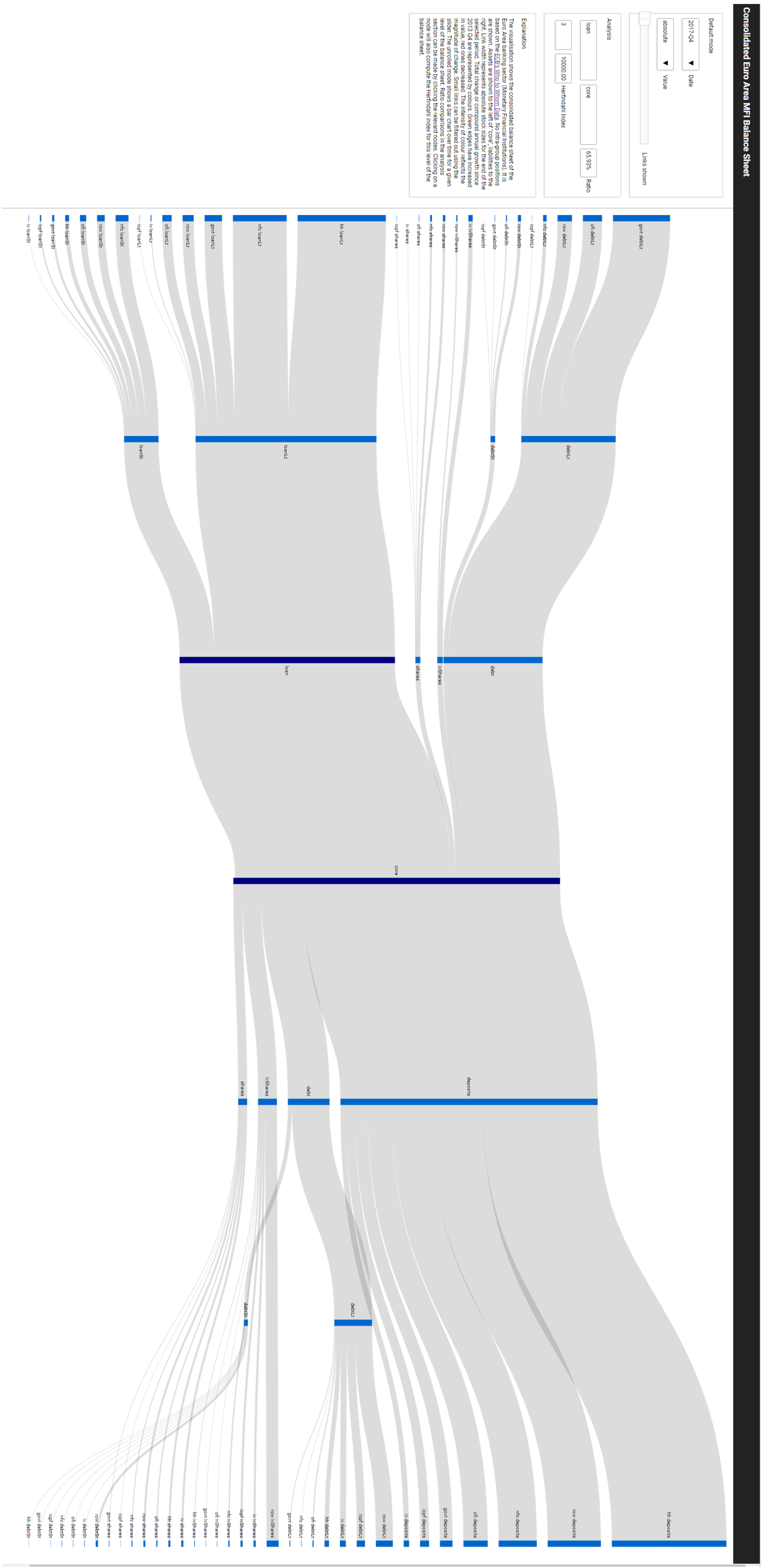


Figure 6.4: Default interface of the Euro Area banking sector balance sheet visualisation

6.4 Case study: The Euro Area banking sector during a period of unconventional monetary policy

The visualisation looks at the banking sector in the Euro Area. It is based on the ECB's who to whom statistics for monetary financial institutions (MFI). MFIs include commercial banks, the ECB and national central banks of the Eurosystem as well as money market funds (MMF). The visual shows the consolidated balance sheet excluding any intra-group positions from Q4 2013 to Q4 2017.

Why banks? Banks play a special role in modern economies: They create money in the form of deposits by making new loans. In the Euro Area, 85% of broad money takes the form of bank deposits [28]. The quantity of money provided to households and companies is not an exogenous variable but, as Godley states, "banks' remaining transactions must be passive responses to the transactions of other sectors" [49, p.9]. The banking sector node in the financial system could be viewed as a money pump, whose valves are regulated by the rest of the economy (and regulators). Thus, expanding the banking node of the financial network gives at least a glimpse into the workings of all other sectors.

In recent years, bank balance sheets have risen to even higher prominence as Euro Area policy makers made them a key part of the chain supposed to transmit policies stimulating the economy: They opted for a range of unconventional monetary policies[3] including targeted longer-term financing operations (TLTROs) and quantitative easing (QE). TLTROs support long-term lending by banks [38]. Under QE, the central bank buys bonds from banks and credits banks with central bank reserves. According to the theory of the money multiplier[4], this leads to an increase in broad money as more loans are provided by banks. More money circulates in the economy, while the value of available goods has remained constant, inflation is pushed back up towards its target. For TLTROs, the argument is slightly different: It is not the overall quantity of money in the system, but cheaper funding for certain loan patterns, which should incentivise banks to lend to corporates. In the following, I will examine to what extent the Sankey visualisation can (1) give us an intuitive picture of the pump valves as well as (2) providing some intuition about the transmission mechanism of some aspects of the ECB's unconventional monetary policy.

What happened? Figure 6.4 shows the default visualisation, which displays the full MFI balance sheet for Q4 2017. Loans contribute 65.9% to total assets, deposits 78.7% to total liabilities, reflecting the core function of banks as described above. The dominance of traditional bank business is also reflected in the concentration of assets at the sector (i.e. most granular) level, which is significantly higher than for non-MMF investment funds (IV) [81] with a Herfindahl index of 1455 compared to 727[5].

[3]for a summary of policies see [16]

[4]the ratio of commercial bank money to central bank money in a system with fractional reserve banking as for instance described by [47]

[5]The figure for investment funds is adjusted to reflect a consolidated rather than aggregate balance

Further, long term loans to households on the asset side and deposits by households on the liability side represent the largest individual positions. Yet, the second largest position on the asset side is long term debt of governments, rather than loans to non-financial corporations. Loans to non-financial corporations are a key position as business investment, much of which is traditionally financed through credit, has a major impact on the business cycle [26]. Sustainable recoveries should ideally be driven by companies investing more, hence building up capital stock, leading to permanently higher income. The large position in government bonds is a result of the ECB's quantitative easing (QE) policy and leads to a corresponding increase in central bank reserves held by commercial banks[6]. If the money multiplier framework applies, this increase in reserves should lead to an increase in broad money as commercial banks issue more loans.

Yet, colouring in links by CAGR since Q4 2013 and eliminating small links from the visualisation, allows one to identify a stark difference in growth dynamics for loans and government debt (figure 6.5): While growth in loans is barely visible, long term government debt holdings expanded by 12.3%, all of which is attributable to the ECB's asset purchases[7].

sheet as shown in the referenced visualisation. Further, the comparison is certainly imperfect, as some balance sheet items for investment funds cannot be split up on the sectoral level. Yet, that only biases the investment fund number up, i.e. the difference in concentration might be even larger in reality than observed here.

[6]The ECB buys bonds from commercial banks in exchange for central bank reserves

[7]Excluding Eurosystem purchases, MFI holdings in long term government debt declined by 29% from Q4 2013 to Q4 2017

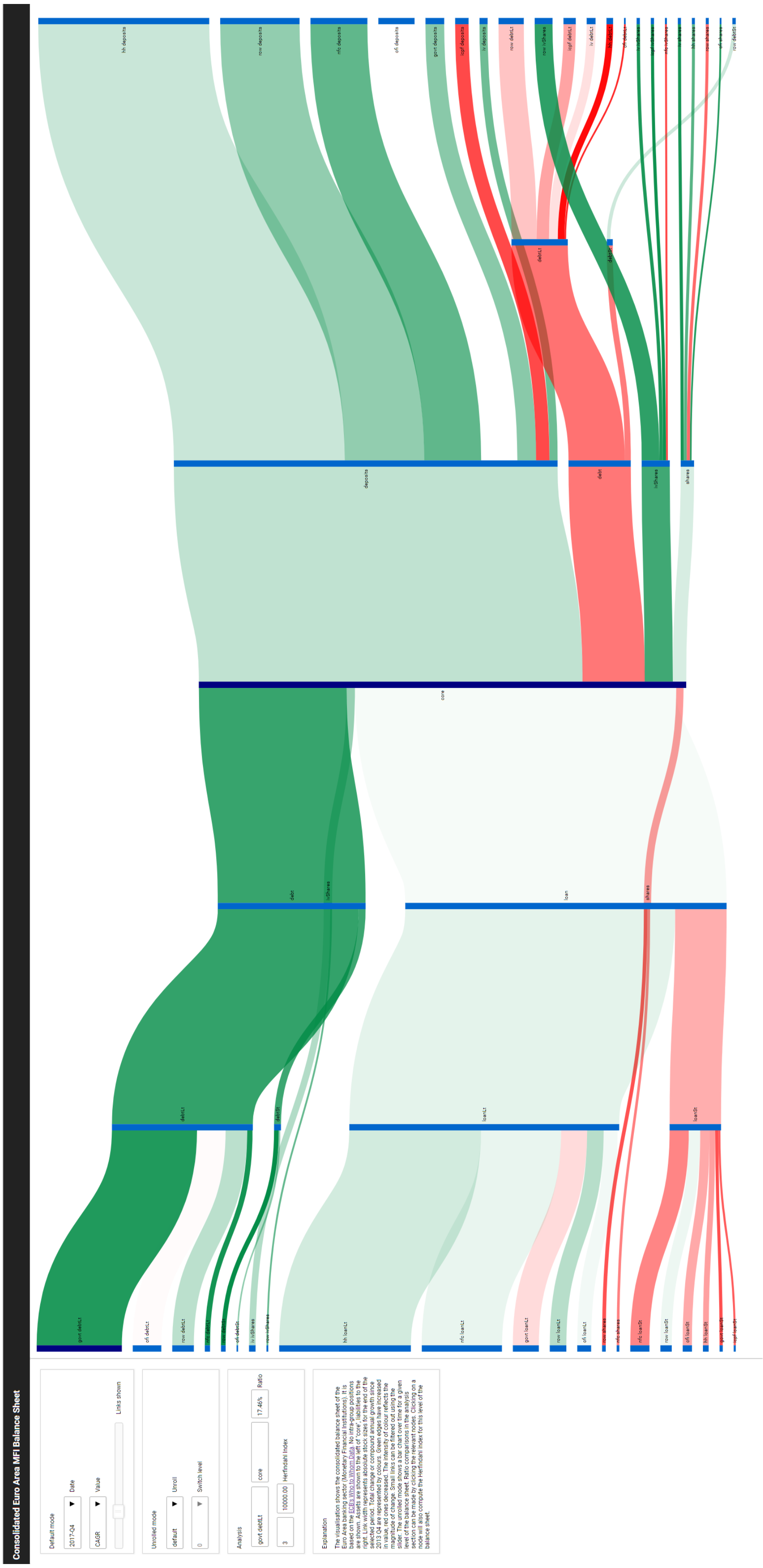


Figure 6.5: Interface of the Euro Area banking sector balance sheet visualisation with filtering and colour

This confirms Goodhart, who states: "The remarkable feature of the recent episode of quantitative/credit easing was that this money multiplier totally failed to work" [51]. The valve releasing central bank reserves into the banking system had no effect on the valve for broad money, which is used in the real economy.

Identifying what determined lending growth Q4 2013 to Q4 2017 is more difficult, especially without the balance sheet of the relevant counter-parties[8]. Figure 6.5 suggests largely homogeneous trends across sectors though, with differences coming in at the maturity level only. One explanation for this might have been TLTROs, which specifically supported long-term lending by banks. In this case, it seems possible that the increase in long-term financing of companies by 139 billion Euros is a policy induced substitution of short-term loans, whose volume declined by 103 billion.

Hence the visualisation suggests that quantitative easing (QE) did not drive loan growth through the money multiplier, while TLTROs did incentivise a shift to long-term lending. Obviously, a visualisation can only provide a first intuition and no proof of a certain mechanism being at work.

On a sectoral level, one actor defies the pattern in figure 6.5: Financing provided to non-Euro Area investors ('ROW' for rest of the world) increased across all categories, even short-term loans. Further, as figure 6.5 shows a significant increase in government bond holdings of the consolidated banking sector, the question of who sold these bonds emerges[9]. Kojien et al. find that 70% the ECBs purchases came from foreign investors [61]. On the liability side of the balance sheet, figure 6.5 also shows the growing role of foreign investors: Issuance of investment funds by money market funds to foreigners increased by 8.8%. According to Deutsche Bank Research, most of this increase in money market fund holdings is attributable to investors from outside the Euro Area and 78% of the net inflows were invested outside the Euro Area [24]. The increase in money market fund shares issued contrasts markedly with the decline in debt issuance by the domestic banking sector. Thus, the visualisation also gives some indication of the changing relationship with financial actors outside the Euro Area, whose importance as counter-parties seems to have risen in the analysed period.

6.5 Discussion and evaluation

The case study shows both, the possibilities and the limitations of visual balance sheet analysis using Sankey graphs. One of its main advantages is the ability to simultaneously consider several levels of aggregation. Instead of pre-determining the unit of analysis at the sectoral, maturity or instrument level, one can explore patterns across all of them. In combination with colouring and filtering, this allows for the observation of trends. As such, Sankey graphs can help gaining intuition about

[8] This could show debt overhang and hence limited capacity to borrow [63]

[9] If it had been Euro Area banks, total holdings of bonds of the MFI sector should have remained unchanged

the dynamics of balance sheets, especially when supplemented with interactive analytics, key to confirming one's visual perception.

Yet, there are several limitations of the visualisation, some of which could be addressed in the future: First, the algorithm for placing nodes on the vertical axis requires further optimisation. In the visualisation presented above, the algorithm is aimed at minimising white space and retaining nodes in fixed positions across time periods. Both goals are key to enable presenting an entire balance sheet on a standard screen and allow for comparability across periods. But focusing on the former clearly came at the expense of link crossings and overlaps, which make graphs harder to read. The specific trade-off between white space, link crossings and stationary node positions could be made context dependent, optimising for the given input data.

Secondly, while the user is already able to calculate ratios of balance sheet positions in a flexible manner, the selection of measures of change is still very restrictive. There is no possibility for changing the starting point. This would have been very useful in the above analysis, allowing one to compare developments before and after the onset of QE.

Third, working with D3.js enables tight control over the visualisation but also requires a lot more granular code than implementing a network with Vis.js for instance. If balance sheet visualisations with Sankey graphs are to be expanded on, developing a Sankey library with an API to enable more efficient development seems crucial. The same applies to the generation of input data, which requires manually coding the balance sheet hierarchy. Automatising this process would allow for significantly faster deployment.

But even with fast data processing, a further significant constraint is data availability. The visualisation above for instance, cannot be reproduced for commercial banks only. For the visualisation of non-banks, this problem would be even more significant: Over 50% of the sectors assets are held by unclassified financial institutions, which includes a wide range of business models, from captive subsidiaries of non-financial corporates to hedge funds.

In addition, an isolated balance sheet can always just tell one side of the story. In the visualisation shown above, it was evident that borrowing by non-financial corporations and households was still sluggish in Q4 2017. But the constraints are not obvious. In particular, is not possible to differentiate between insufficient demand and balance sheet constraints of counter-parties. To allow for this, one would have to draw a network (or at least a subsection of a network) of interlinking balance sheets. Given the density and complexity of the visualisation, this would most likely go beyond what can be displayed in a browser and require more evolved visual representation describing the topology of the system.

Finally, the sizing of the Sankey graph should also be optimised for Firefox.

7

Euro Area financial system visualisation

7.1 Context

The use of stock and flow matrices to represent economies at the systems level has a long tradition in policy making, going back to Copeland who developed national accounts for the US [19], and Godley [48], who developed a macroeconomic model based on national accounts. The ECB has been developing flow of funds since 1993 and projections thereof since 2003 [30].

However, when it comes to policy analysis, the availability of interactive tools to visually explore this kind of data is still very limited. Thus, to understand the effect of QE on the real economy, a novel policy whose modeling is very difficult and highly dependent on assumptions [27], I developed a first visualisation of financial flows in the Euro Area economy at `http://philippasigl.com/FinancialFlowsEuroArea/`. Yet, there are a number of limitations of this visualisation, both in economic and architectural terms: The visual is built using R and Shiny [14], which is not tailored to complex interactive interfaces. Second, interactive features are limited to a time slider, allowing one to move between periods. Third, the network only displays flows at the Euro Area level, and doesn't show direct who to whom relationships but who invested in which asset and through which asset an entity was financed. The visual also does not show in- and outflows from non-Euro Area actors. Finally, the network shows transaction flows rather than stocks of exposures. Without a visual representation of change, this is the only possible way to show movement over time (as stocks change very slowly). But, as transactions are subject to large fluctuations, any one period of flows displayed might not be representative of a broader pattern, providing useful information about the topology of the system. The aim of the visualisation presented in this dissertation is to address these shortcomings, making progress towards a tool that might one day find use in the policy making process.

7.2 Requirements

7.2.1 Aims

The high-level aim is to provide a tool which can be used by policy makers and economists (possibly also in an educational setting) to gain intuition about the topology and patterns of financial systems in the Euro Area. At a design level, the visualisation should allow for sufficient analytical flexibility to carefully dissect changes over time.

Secondly, the visualisation needs to reduce visual clutter enough to allow for pattern spotting while still maintaining a faithful representation. Its scope should cover all Euro Area countries for all asset classes[1], allowing policy makers to interrogate every relevant dimension of the Euro Area financial system.

The achievement of these aims is tested in two ways: First, the effectiveness of design features enhancing pattern recognition is verified through a user survey. This is complemented by an analysis of the secular rise in non-bank finance in the Euro Area based on the visualisation, illustrating how the former can generate relevant insights for policy makers.

7.2.2 Specification

- Default layout
  - Display the network of total sectoral exposures in the Euro Area for the latest period available
  - A zoomable network, which can be repositioned
  - Layout with fixed node positions reflecting the role of each sector in the economy
  - Options for changing date, region and balance sheet instrument for which the network is shown
  - Tooltips with values and names for hovered over nodes and edges
  - Legend for node names
- Nodes
  - Colouring by economic group
  - Option for switching node size between 'assets' and 'liabilities'
  - Option for node scaling
- Edges

[1] Excluding deposits, which are mainly important for the banking sector

  - Grey edges with width reflecting size of exposure in the default setting
  - Option for changing edge width to change between two periods specified by the user
  - Option for colouring in edges according to trend relative to reference period
  - Option for eliminating small edges
  - Option for highlighting the largest three edges
- Analysis
  - Herfindahl index for the displayed network
  - Option for computing ratios between exposures, balance sheets and exposures and balance sheets

7.3 Implementation

7.3.1 Software architecture and tools

The structure of the app is minimal consisting of a static web page written in HTML and Javascript. It is deployed on Github Pages at `http://philippasigl.com/WhomToWhom`. Input is served in json format. Data was obtained through the ECB API, using R and the R library ECB to produce csv files for each network. R scripts have to be adjusted by country as the availability of data varies depending on the geography. The csv files were then reshaped and processed in Python to produce the json data consumed by the static website. The structure is shown in figure 7.1.

The visualisation utilises Vis.js and builds on the code base developed for the Interbank Network Visualiser. In contrast to the Network Visualiser, change values are not included in the edge data served to the app but computed as the user interacts with the visualisation, reducing dependencies between input data and app and enhancing flexibility.

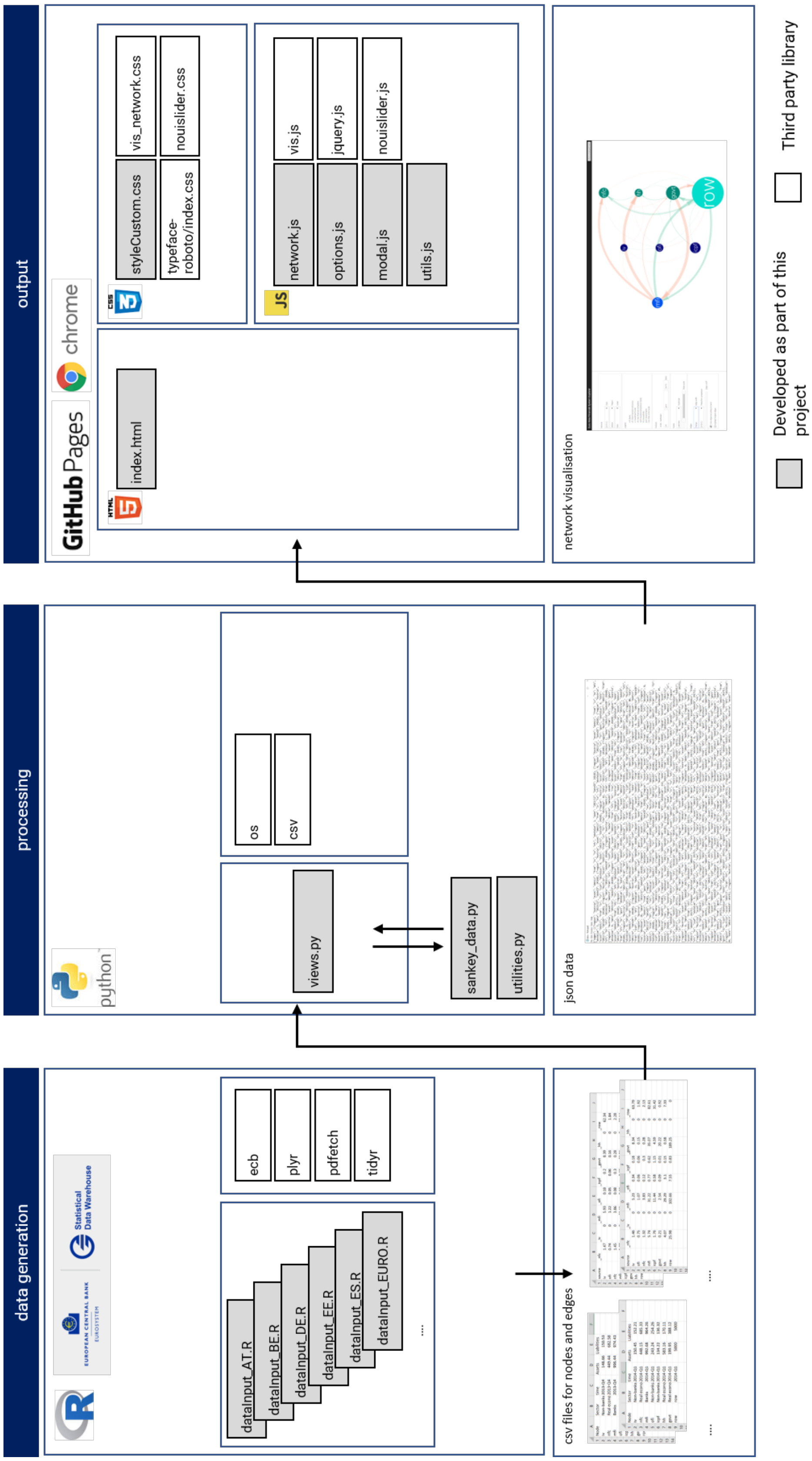


Figure 7.1: Structure of the Euro Area financial system visualisation

7.3.2 Interface

The interface, as shown in figure 7.2, includes a control panel and a network representing exposures in the given financial system. The user can select the geography, time period and balance sheet item for which the network is displayed. In addition to individual balance sheet items and individual Euro Area countries, networks for total exposures and the entire Euro Area can also be selected. A pop-up window in the top right corner explains the visualisation.

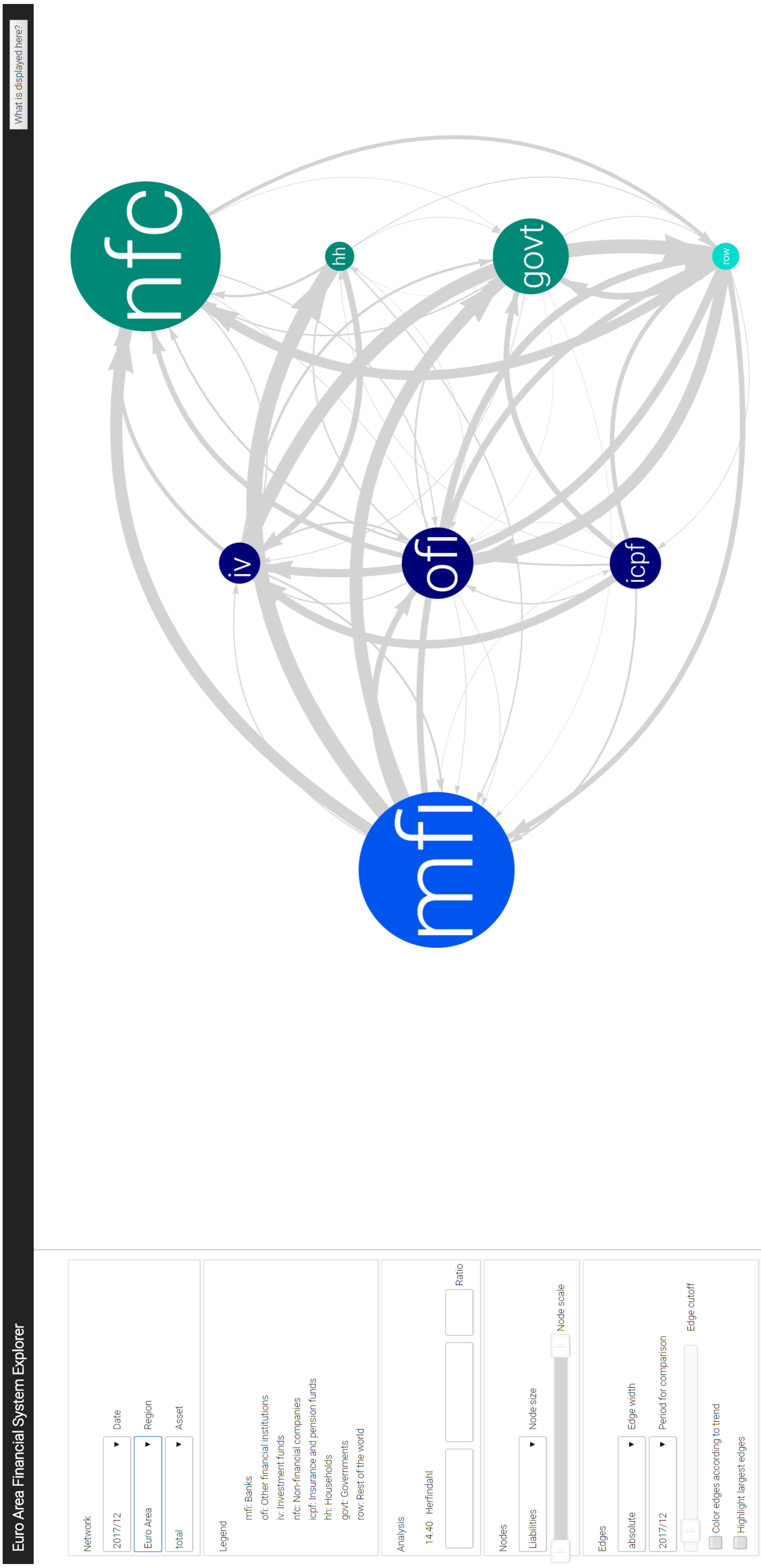


Figure 7.2: Default interface of the Euro Area financial system visualisation

Node positions are fixed. The network has a hierarchical layout from left to right, reflecting the role of individual sectors in the economy: monetary financial institutions (MFI) creating money take the leftmost position. The financial sector including non-MMF investment funds (IV), other financial intermediaries (OFI), insurance and pensions funds (ICPF) allocates capital and is hence placed in the intermediate layer. Finally, the real economy including non-financial corporations (NFC), households (HH), government (GOVT) take the rightmost position, as they should, in theory, be net recipients of financing from the financial system. Further, the node for rest of the world (ROW) is placed in the bottom right corner, representing the 'gate' to other financial systems. Nodes are also coloured according to their role in the economic system. Thus, the visualisation follows gestalt laws of grouping which dictate that elements similar in one or more visual dimensions and found in proximity to each other will be identified as part of the same group [46]. Layout design focuses on encoding underlying semantics, rather than following syntactic aesthetics as the first has been shown to play a more important role in graph comprehension [6].

Node size is defined by the user, who has the choice between showing total assets and total liabilities. One exception is sizing of the node representing the foreign sector (ROW): Its value is fixed across all representations since (1) the true balance sheet size of the entire foreign sector cannot be shown here, would not contribute towards the goal of understanding a given financial system and (2) if its value is fixed, the ROW node can serve as implicit scale by which to compare the absolute sizes of other nodes across all views of the visualisation. When displaying Germany for instance, the ROW node becomes very small, while for Greece the ROW node is significantly larger than all nodes for the domestic financial system. Node scaling can be adjusted to accommodate for varying ranges and deal with very small or very large node values which otherwise become indistinguishable due to the scaling imposed by the ROW node.

The width of edges in the default visual represents the total value of exposures. Colouring is uniform, minimising cognitive load as the user first interacts with the visual. Edge width can be switched to showing change in exposures over time with the width of the edge indicating the magnitude in change. The directionality of change can be represented by selecting edge colouring by trend. Building on the discussion of the balance sheet visualisation, this visual now includes the possibility to select the period for comparison, allowing the user to inspect changes over varying time windows. As in previous visualisations, small edges can be filtered out to reduce visual clutter. Finally, there is the option for highlighting the largest three edges in yellow. This is intended to aid pattern recognition as it focuses the users' attention on the dominant capital flows in a financial system.

Analytics build upon those developed for the balance sheet visualisation. They include a Herfindahl index for all exposures in the displayed network, giving an indication of how concentrated exposures are, a key aspect when considering financial stability. Secondly, there is the option to compute ratios between various stocks. Ratios can be computed between any elements of the network, giving the user flexibility in his analysis.

The interface has been optimised for Chrome but is also designed to display well in other browsers and for smaller screen sizes, including smartphones. This seemed important if the aim for the tool was to be used in a policy or possibly educational context, where availability on multiple devices is likely to expand use.

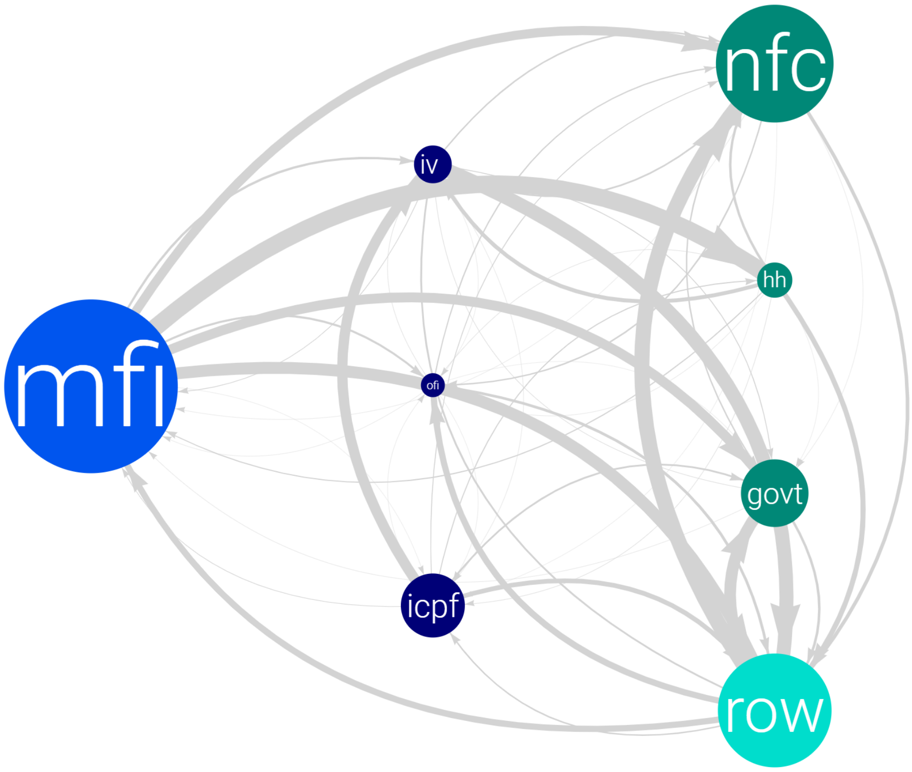
7.4 User survey

An effective visualisation of financial systems has to facilitate pattern recognition and the identification of topologies. To achieve this, it has to reduce cognitive load resulting from the complexity of the represented object. As described in the design principles, filtering and highlighting are two key methods for this. The following user survey tests the effectiveness of employing these two techniques in the visualisation of the Euro Area financial system.

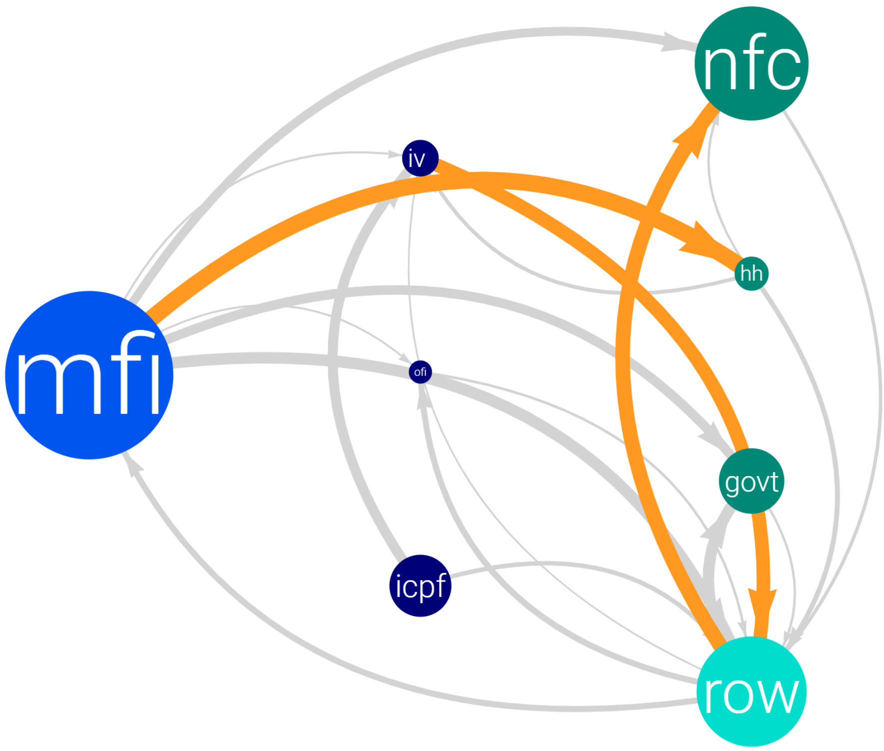
The experimental set-up was as follows: Survey participants had to accomplish the task of identifying the country for which they were shown a financial network of total exposures with nodes representing total liabilities. Participants had to identify three countries in a multiple-choice setting. One group of participants was presented with networks which had the three largest edges highlighted and small edges filtered out. The second group was presented with the same networks without any highlighting and filtering. The two representations are shown in figure 7.3 for Germany, one of the countries included in the survey.

Besides the difference in layout, the survey presented to both groups was the same. The three countries shown were Germany, Italy and the Netherlands. The 25 survey participants included economists, political economists, central and commercial bankers.

Median response time was 3 minutes for the visually enhanced representation and 4 minutes for the plain version. This could indicate a lower cognitive load for the enhanced version, as a clear pattern is presented. Figure 7.4 shows the share of correct responses for each survey. Overall, highlighting and filtering led to an increase in correct responses of 11 percentage points, indicating that the layout enhancements improve identification of topologies. The results varied significantly by country though: For Germany, highlighting and filtering resulted in a *reduction* of accuracy by 7 percentage points. One possible explanation could be, that a large banking and a small government sector are the most recognisable features of the German financial system. Thus, correct identification of the country most likely hinges on observing node sizes rather than the edges highlighted in the enhanced visualisation. For Italy and the Netherlands on the other hand, highlighted edges did mark out particularly distinctive features of the respective financial system: In Italy, they emphasised the important role of banks in financing both, non-financial companies, and the government: Bank funding represents 20.5% of total liabilities by non-financial companies, compared to 12.8% across the entire Euro Area. In the Netherlands, they reflected the major role of the shadow banking sector. Hence the



(a) No visual enhancements



(b) With filtering and highlighting

Figure 7.3: Total exposures in the German financial system, Q4 2017

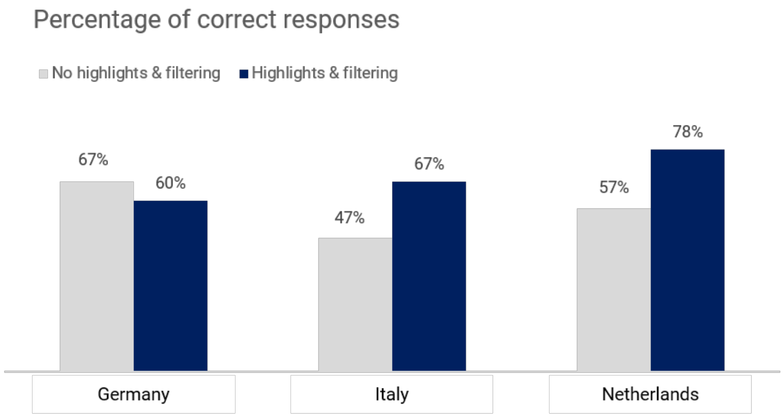


Figure 7.4: User survey results

results suggest that the visual enhancements are effective. How they affect users cognition depends on whether they focus attention on the distinguishing features of the topology in question.

7.5 Case study: The rise of shadow banking

European financial systems show significant heterogeneity but there seems to be a common thread binding them all together: The secular rise of the non-bank financial sector, reflected in figure 7.5. Financing from investment funds (IV) to outside the Euro Area (ROW) grew 16% p.a., from outside the Euro Area to other financial intermediaries (OFI) 10% p.a. and from insurance and pension funds (ICPF) to investment funds 11% p.a. from Q4 2013 to Q4 2017. In Q4 2013, bank financing to non-financial companies (NFC) equaled 150% of investment funds' funding going to the non-Euro Area. By Q4 2017, growth in exposures of the Euro Area to investment funds eclipses the increase in bank financing to non-financial companies by 15 percentage points.

The visualisation provides evidence for two underlying phenomena: First, there has been a significant increase in financing for investment funds (IVs), mainly from insurance and pension funds (ICPFs), which they reinvested in abroad. In Germany (shown in figure 7.6) for instance, 37% of insurance and pension fund assets went to investment funds who in turn invested 67% of their funds abroad in Q4 2017. This is most likely a result of the low yield environment.

Secondly, investments from abroad into other financial intermediaries increased markedly. Upon querying the visualisation it becomes clear that this is nearly entirely attributable to Luxembourg and the Netherlands. Figure 7.7 shows the change from Q4 2013 to Q4 2017 for Luxembourg (a) and the Netherlands (b). No edge filter has been applied to the visualisations to reflect the dominance of the non-bank financial sector in both jurisdictions. 86% of other financial intermediaries

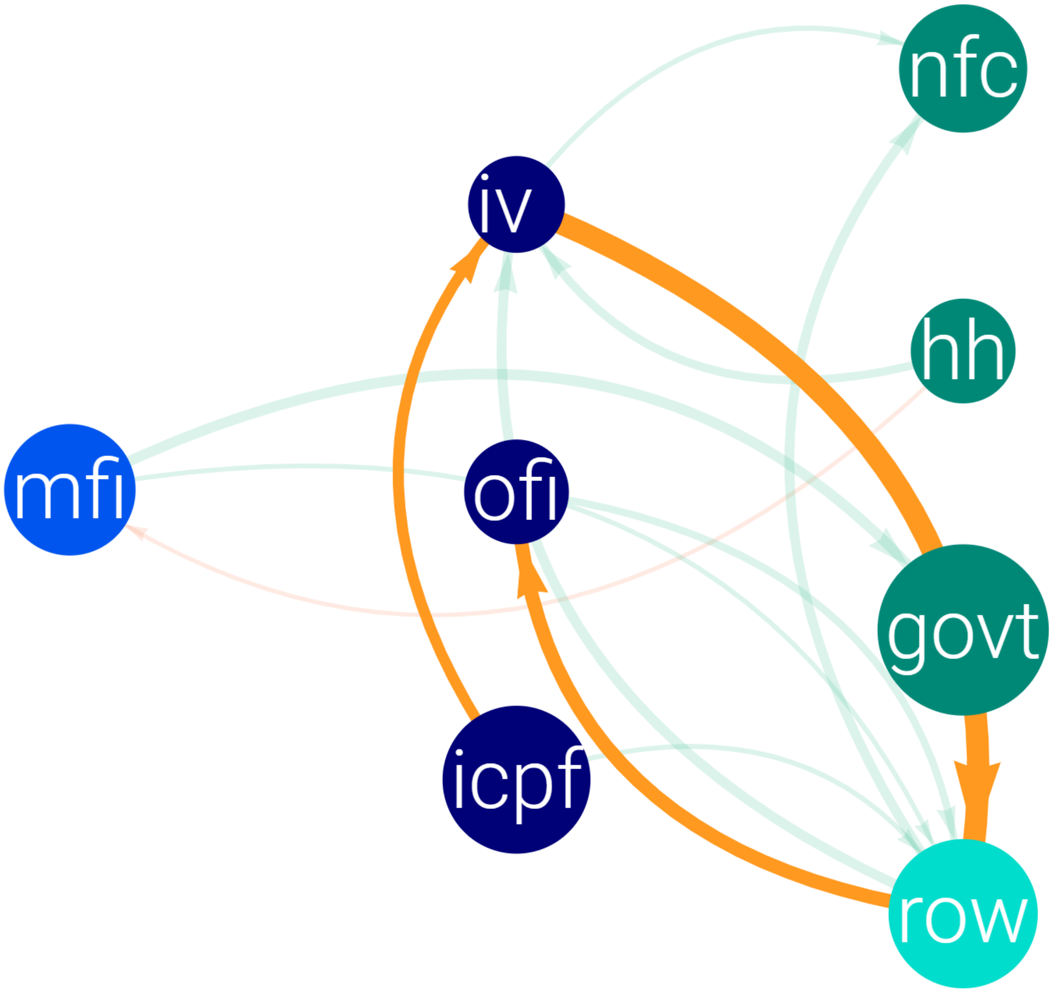


Figure 7.5: Total exposures in the Euro Area, edge width reflects exposure size, colouring according to direction of change from Q4 2013 to Q4 2017; nodes size reflects total liabilities of the respective sector

in Luxembourg and 72% in the Netherlands respectively are part of non-financial multinational corporations. According to the ECB, these companies are typically set up "to benefit from a favorable tax regime and financial technology"[37, p. 31].

Hence the visualisation can help us trace heterogeneous drivers of change: In the above example of the non-bank financial sector, a low yield environment led to shifting investing patterns of financial firms while non-financial companies sought to optimise tax by channeling funds through Luxembourg and the Netherlands.

7.6 Discussion

The strength of the visualisation seems to lie in enabling pattern recognition by users familiar with the subject. There have been suggestions to also use it in an

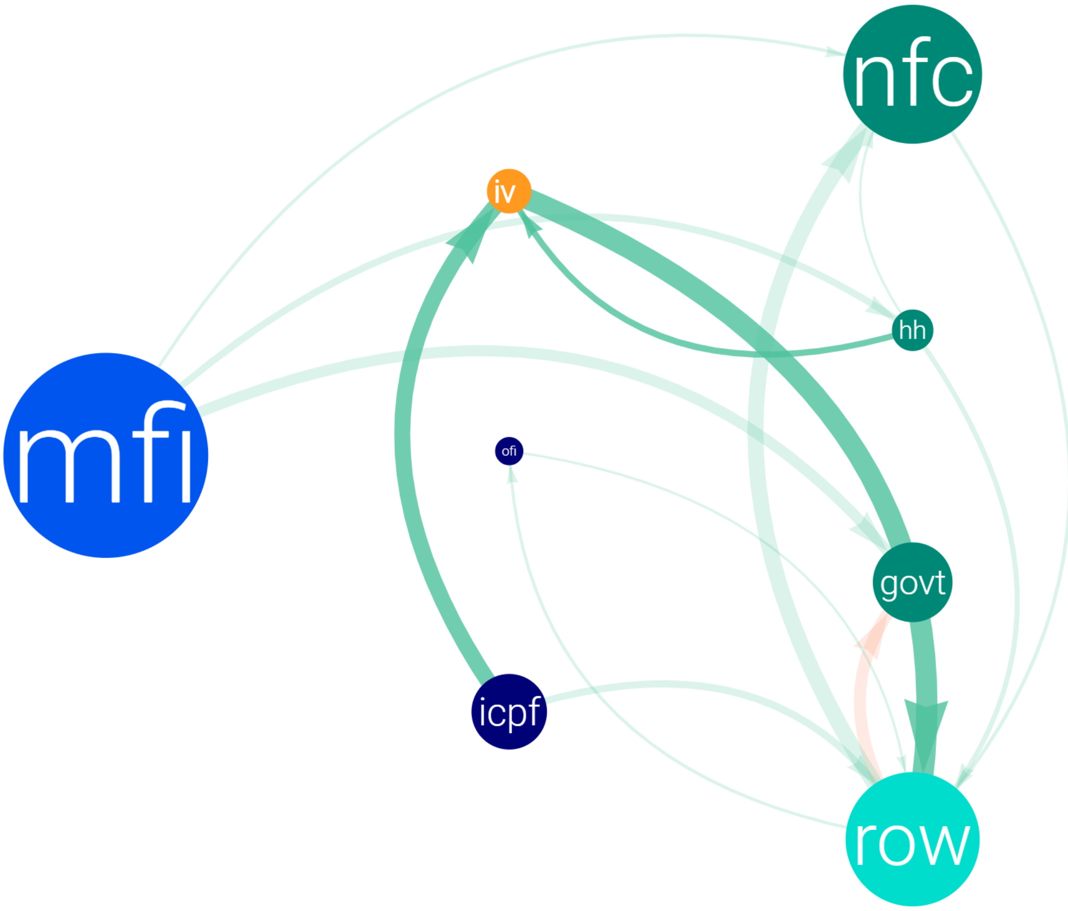
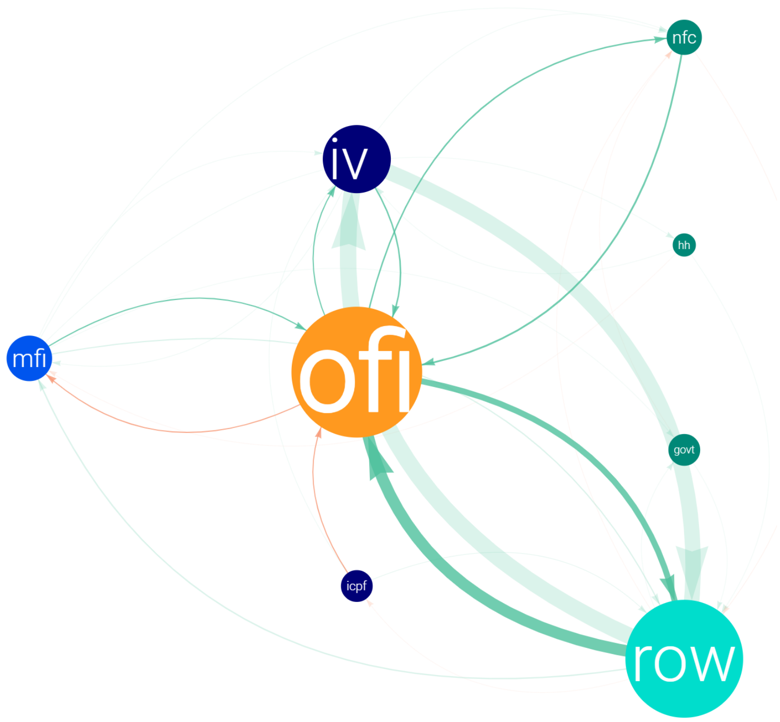


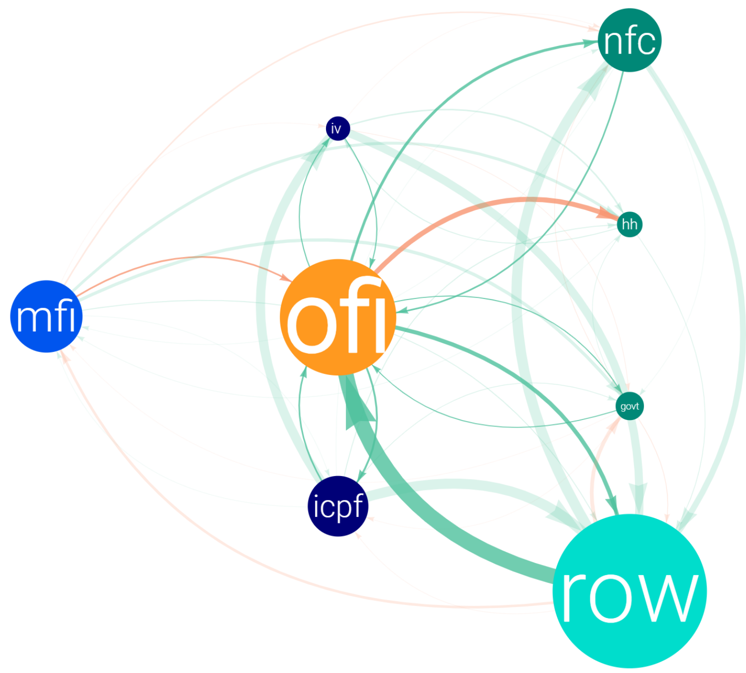
Figure 7.6: Total exposures in Germany, edge width reflects change in exposure, colouring direction of change from Q4 2013 to Q4 2017; nodes are sized according to liabilities

educational context, familiarising students with the differing structures of Euro Area financial systems, a topic seen as increasingly important given the experience from the financial crisis. While this has not been verified quantitatively, qualitative feedback suggests that the structure of the layout plays an important role for enabling pattern recognition. The survey indicated that filtering and highlighting further support this goal *if* visual enhancements direct users' focus to the distinguishing features of the system.

The strength in supporting pattern recognition can also be very problematic as the visualisation risks no longer providing a faithful epistemic representation. Hence exercising caution in applying visual enhancements is crucial, especially in the analytical use case. As a visualisation designer, this means walking a tightrope between ensuring representativeness and guiding users' attention. One possible way might be to keep the default visualisation as simple as possible. A second line of defense against the biases baked into the visualisation by the designer might be deploying interactive visual and analytical measures which can be chosen by *the user*. The visualisation presented above tries to incorporate both. It applies minimal default



(a) Luxembourg



(b) The Netherlands

Figure 7.7: Total exposures, edge width reflects change in exposures; nodes are sized according to liabilities

settings, allows the user to inspect varying time windows and gives the option of numerically verifying proportions of any two elements of the network. These measures are certainly still limited and could be expanded upon in the future. Two obvious additions would be network specific metrics such as centrality measures and further measures of change, especially compound annual growth. Further, a visual representation of the change in node sizes should be added so users can choose to focus on total balance sheet size or individual exposures.

Finally, adding the possibility of freezing networks and comparing them side by side in small multiples[2], could significantly accelerate the workflow when comparing different networks.

Besides the visualisation itself, there are significant limitations rooted in the data: The Eurosystem, commercial banks and money market funds are all grouped under monetary financial institutions, despite playing very different roles in the economy and operating under very different rules. Secondly, as mentioned above, other financial institutions include a significant number of captive non-banks whose sole purpose is financing of their parent company. This bears only very limited relationship with financial intermediation and blurs the picture on non-banks. Beyond the issue of sectoral split, the ECB's who to whom data does not include a division in changes in stocks due to revaluations and transactions. In times of significant repricing of assets like during quantitative easing (QE) this can again obscure behavior of actors in the market.

[2]"Small multiples resemble the frames of a movie: a series of graphics, showing the same combination of variables, indexed by changes in another variable." [85, p. 170]

8

Conclusions and future work

8.1 Summary of achievements

This dissertation reviewed the rationale for financial systems visualisation and described use cases for the former. I have proposed evaluating visualisations with reference to the concept of faithful epistemic representation. Effectiveness was hence defined with respect to input data, user and aim of the visualisation. The implications of this definition for designing visualisations targeting humans were discussed, especially with regards to the need for limiting cognitive load. Thus, this dissertation hopes to have shown that (1) designing effective financial systems visualisations is crucially dependent on a precise specification of its context and (2) that the debate on visualisation in macroeconomics should move from global statements to much more nuanced arguments about where to use what kind of visualisation for what aim.

Further, I developed a matrix taxonomy for categorising visualisation of financial systems and its components, differentiating based on the unit of analysis and its interactivity. The state of financial systems visualisation has been reviewed and gaps identified: (1) interactive tools for repeat visualisations, (2) the visual encoding of balance sheets and (3) a visualisation of the Euro Area financial system which allows for the identification of topologies and dynamics over time.

I specified a set of design principles based on the definition of an effective visualisation as a faithful epistemic representation and the discussion of the current landscape of financial data visualisation. For the interface, these included the deployment of appropriate filtering and highlighting to limit cognitive load and enable pattern recognition, a fully controlled layout without randomly generated components, the deployment of numerical and visual analytics, defining representation based on economic meaning rather than aesthetics and putting a special focus on the ability of the visualisation to reflect change. With regards to software architecture, compatibility with institutional requirements (where relevant), security, separation of concerns, simplicity of architecture and deploying the right tools for the right use case were identified as key.

The Interbank Network Visualiser was developed based on a specification from the Financial Stability Department of the Bundesbank. The tool allows users to generate network visualisations through uploading their own dataset and modifying the default visual in a graphical interface, significantly reducing the time required for creating network visualisations. The Visualiser is developed as a Flask app, which consumes a flexible number of csv files, processes them and returns an interactive visualisation the user can modify through a GUI. All server side data processing is done in Python, while the front end is written in Javascript and optimised for Google Chrome. The network visualisation draws on Vis.js. The Visualiser's functioning was illustrated using the example of global bank/non-bank exposures. Even if the functionality of the Visualiser is still limited and the current version should be viewed as a pilot, it seems to address the general problem of generating visualisations for networks with up 100 nodes and a circular, core-periphery or grouped structure in a time effective manner. This will include most visualisations related to globally systemically important banks and banks supervised by the ECB.

Next, I introduced a novel way of presenting balance sheets in the form of Sankey charts. The addition of colours and opacity scales allowed for representing change as well as multiple levels of aggregation in one visualisation. The concept was tested by creating an interactive visualisation of the Euro Area banking sector. The data for the visualisation was generated with a R script calling the ECB's API and outputting a csv file. The csv file is processed to json formatting in Python and displayed using Javascript and the D3-sankey.js library. The visualisation is deployed on Github Pages. I used the visualisation to analyse the changes in balance sheet composition for the Euro Area banking sector from 2013 to 2017, with a particular focus on the effects of QE and TLTROs. The dynamics found in the visualisation suggested that growth in broad money was not a necessary consequence of an increase in central bank reserves in the commercial banking sector, resulting from asset purchases. They did however suggest that there was a shift from short-term to long-term loans, possibly reflecting the lower cost of financing for corporate loans through TLTROs and an increasingly strong connection to non-Euro Area investors on both, the asset and the liability side.

Finally, I developed an interactive visualisation of the Euro Area financial system. The data for the visualisation is generated with R scripts for each geography, which call the ECB's API and output csv files. The csv output is processed to json files in Python and displayed using Javascript and the Vis.js library. The website is deployed on Github Pages. The visualisation builds on the who to whom visualisation of the ECB and the flow of funds visualisation of ONS but adds visual enhancements facilitating the identification of topologies. It further deploys several numerical and visual analytical tools, enabling the in-depth study of dynamics over time. A user survey verified the effectiveness of visual enhancements and pointed to potential risks of the former. I illustrated the ability of the visualisation to generate relevant insights by means of analysing the growth of the non-bank sector in the Euro Area from 2013 to 2017. The visualisation can most certainly be further enhanced with visual and numerical analytics and would significantly benefit from input data splitting out financial entities with fundamentally different roles such as commercial and central banks. Yet, the biggest limitation actually seems to lie in the economic domain, as our knowledge about the role and functioning of financial systems is still very limited [7]. Hence the process of developing such a visualisation is akin to drawing a map while simultaneously exploring what is actually relevant for that map and developing the language to talk about the former.

8.2 Future work

8.2.1 Interbank Network Visualiser

The most significant expansions in use cases would most likely result from (1) adding a GUI through which the visualiser can be launched, so users do not have to use the command line and (2) allowing for more flexibility in the formatting and structure of input data. On the interface side, enhancing the ability to deal with large scale networks could expand use-cases.

8.2.2 Balance sheet visualisation

Context specific balance sheet visualisations could be enhanced by metrics of particular importance to the object of representation, e.g. regulatory ratios for banks under Basel III. But to accelerate progress on balance sheet visualisation more broadly, the development of a Sankey library with an API for common operations seems even more important. This library should also include an alternative to the current node positioning algorithm of D3-sankey.js, accounting for the importance of minimising node movement between individual representations, while also attempting to minimise link crossing, overlaps and white space.

8.2.3 Euro Area financial system visual

There are several potential layout improvements such as minimising overlap of nodes and edges. Further visual and numerical analytical depth should be enhanced as well as options for highlighting and representing dynamics over time: For highlighting, there should be more differentiated displays than marking out the largest edges. With regards to dynamics, the visualisation is currently missing a way of showing the change in balance sheet size of nodes. Further, following Castrén and Racan [12] in connecting the visualisations of individual countries is likely to yield interesting insights.

8.2.4 Integrating visualisations

The balance sheet visualisation and the sectoral financial system visualisation both represent pieces of the same puzzle: The balance sheet visualisation shows the nodes of the financial systems visualisation with the difference that it displays all exposures and liabilities at the same time. Integrating the balance sheet representation with the systems visualisation would allow us to have the full picture of the state of the agent providing funding, the state of the agent receiving the funding and the exposure itself. As such, one could maybe start to empirically trace which constraints to funding bind in what situation: Is the financier limited by his balance sheet in funding he can extend? Or is the recipient in question already overstretched in terms of debt, hence being unable to apply for more funding? Or is there a reason related to market conditions, e.g. lack in demand, distrust between market players or market structures preventing financing being extended? Yet, given the amount of detail present in such a visualisation, even with slightly aggregated balance sheets, this requires a display size beyond a regular screen. Further, options for smart filtering would have to be developed, allowing the user to eliminate visual elements irrelevant to his task.

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Glossary

Application programming interface (API) A set of clearly defined methods of communication between various software components. 32

Basel III International regulatory framework for banks. 34, 46, 74

Broad money Money that can be used outside the banking system. 53, 54, 56, 73

Chord Chord diagrams are very similar to networks but their nodes are arranged on a circle. 21, 24, 25

Government (GOVT) General government sector including central, state and local government. 64

Graphical user interface (GUI) An interface which allows the user to interact with software based on graphical representations rather than text based input. 6

Households (HH) Households and non profits serving households. 64

Insurance and pension funds (ICPF) Foreign sector. 64

Iterative relaxation In the context of this dissertation, the iterative minimisation of link distance for each node going from left to right and in reverse. 29, 49

Javascript An interpeted programming language, used for the vast majority of websites. 6, 33, 37, 44, 48, 60

Macro-prudential policy Supervision and regulation of the financial system geared at maintaining stability of the system as a whole . 22

Monetary financial institutions (MFI) Central bank, financial corporations with access to central bank reserves (including commercial banks) and money market funds. 53, 64

Monetary policy Actions of the central bank affecting the amount or prize of central bank reserves available to the banking sector . 3, 11, 24, 47, 53

Money market funds (MMF) An open investment fund, investing in short term debt securities. 53

Network density Network density is measured as the number of edges present divided by the number of potential edges. 25

Non-banks See shadow banks. i

Non-financial corporations (NFC) Commercial companies whose principal objective is the production of non-financial goods or services. 64

Non-MMF investment funds (IV) Financial companies issuing investment fund shares and investing the proceeds in financial assets. 53, 64

Other financial intermediaries (OFI) Financial companies, whose principal liabilities are not investment fund shares (as for investment funds and money market funds) or deposits (as for banks). 64

Probability of default which gives the average percentage of obligors that default in a rating grade in the course of one year. 41

Python An interpreted programming language particularly suited to data processing. Anaconda is one very popular and free of charge distribution of Python. 6, 32, 33

Quantitiative easing (QE) The central bank swapping financial assets (e.g. government bonds) against central bank reserves. i, 11, 26, 53, 54, 56, 71

R Programming language focused on statistics. 48

React Javascript library for building user interfaces, which requires the developer to describe the state of the user interface, while React takes care of the transactions. 33, 39, 44

Rest of the world (ROW) Foreign sector. 64

Risk weighted assets (RWAs) The sum of on and off-balance sheet assets weighted by risk. 1, 7

Sankey Sankey diagrams show the strength of connection between two nodes according to a specified criterion (e.g. total financing from the left node to the right). The width of the link between the nodes indicates the strength of connection. They are popular for illustrating energy flows or voter migration. 6, 10, 21–25, 27, 30, 48, 49, 51, 53, 56, 57, 73, 74

Shadow banks Financial institutions, which do not normally have access to central bank reserves (including investment funds and other financial intermediaries). 11, 17, 18

Targeted longer-term financing operations (TLTROs) The provision of funding by the ECB to banks for periods up to four years, with the interest rate depending on the share of loans the bank issues to corporations and households, excluding mortgages. The higher the share of corporations and households excluding mortgages, the lower the interest rate. 53

Transaction matrix A transaction matrix records all financial transactions split by income/expenditure category in a given period for each sector of the economy. All transactions for each sector need to sum to zero, as do all transactions for each category as money can't come from nowhere or disappear (assuming a closed economy). 16

Acronyms

BIS Bank of International Settlements. 10, 21, 33, 42

CAGR compound annual growth rate. 51, 54

ECB European Central Bank. i, 3, 11, 21, 24, 33, 47, 53, 54, 60, 68, 71, 73

ESRB European Systemic Risk Board. 3, 26

FSB Financial Stability Board. 3

OECD Organisation for Economic Development. 24, 33

ONS Office of National Statistics. 21, 22

9

Appendices

A User guide Interbank Network Visualiser

Requirements

- Python 3.6 (available through Anaconda at the Bundesbank)
- Ideally Chrome for displaying the app (alternatively, Firefox also works)
- The application runs offline

Workflow

- On the command line, navigate to the location of the programme file 'bank_network'
- Run python app.py
- In a browser window, navigate to the address provided on the command line
- Select all input files using the 'browse' button
- Press 'submit'
- The name of all processed files will appear in the command window
- The initial network will appear
- Terminate the programme with ctrl+c

Data specification

Input files

1. General file format
    - Only csv files are recognised
    - Files follow the German format, i.e. using semicolons as delimiter and commas for decimal points

- Quotation marks at the beginning and end of line are allowed and will be ignored
- To check the file format, open the file in Notepad, which will show you the underlying format
- Example

1. File names
    - The filenames need to contain 'Matrix' and 'Bank' and Year as well as a date in the format of yyyymm (e.g. '201609')
    - File names can't contain a space
    - Files names have to end in '.csv'
2. Edge files
    - Edges are specified in a matrix format, going from column to row ID
    - Column IDs have to be unique and can be alphanumeric
    - Row IDs are the same as the column IDs with an added '_' in front (e.g. '_1')
    - No duplicate uses of IDs in columns or rows are allowed
    - All matrix entries have to be numeric
    - The cell A1 needs to contain a term (e.g. 'GeberNr' or 'ID')
    - Example

1. Node files
    - The first column has to contain unique IDs which correspond to those in the edge files. They can be alphanumeric
    - Any columns to the right of the ID column, which can be interpreted as numbers, will be interpreted as numbers and available as categories in the interface
    - A grouping can be provided in a column called 'Bankengruppe' (e.g. Kreditbanken, Sparkassen etc.)
    - Names diverging from IDs can be provided in a column called 'Bankname'. Otherwise, the programme will default to the ID value
    - A custom color can be provided in a column called 'Color'. Values can be color names (e.g. 'blue') or hex values (e.g. '#333'). A full list of colors and corresponding names can be found here: https://htmlcolorcodes.com/color-names/
    - If no column contains numeric values, node size will default to 1

- The column headers have to be the same for all node sheets
- Example

Interface

1. General
   - The network is zoomable and can be moved around on the canvas
   - It can be saved using the 'Export PNG' button, which will generate a file-name reflecting the current network settings and appear in downloads
   - Alternatively right-clicking on the network allows for saving the image
2. Network
   - The network defaults to the most recent date, this can be changed per dropdown
   - The default structure is a single circle. Alternatively, a core-periphery structure can be chosen with one sector (Bankengruppe) at the centre. The dropdown becoming available once core-periphery is activated includes all categories supplied in the input files. The group at the centre will be the group with the highest average value for the selected category
   - As default, all sectors are shown. Alternatively, individual sectors can be selected per dropdown
3. Nodes
   - Labels: These are shown at the centre of the nodes if they have sufficient size. Labels can show the actual name provided, an anonymised value ('Item 1', 'Item 2' etc) or show nothing
   - Node size is per default set to 1 and can be scaled to all category values provided. The range of node sizes can be changed through the slider below the dropdown
   - Node color can be set to the default (coloring by sector), none (grey) or custom if a custom value has been provided in the input file
   - Nodes and their adjacent edges can be highlighted by clicking on them (ctrl+click allows highlighting several)
4. Edges
   - Edges with 0 value are hidden
   - Edges can be scaled to the absolute size provided for the current period or the change compared to last period. If the network shows the first period of input files provided, this setting will show no edges as no change can be calculated
   - The range in edge sizes can be affected through the slider

- The 'Edge cutoff' slider allows one to select only the largest edges. It cuts off the percent of edges to the left of the selected point on the slider
- Edges can be coloured according to trend, with a decrease from last period showing in red, an increase in green and no information or no change in grey

B Expert interviews

- Philipp Haenle, Financial Stability Department, Deutsche Bundesbank - 16.01.2018
- Pawel Fiedor, Market Based Finance division, Central Bank of Ireland - 16.01.2018
- Grzegorz Halaj, Financial Stability and Macroprudential Policy Directorate, European Central Bank - 17.01.2018
- Hannes Schild, Research Data Centre, Deutsche Bundesbank - 18.01.2018
- Kimmo Soramaki, Founder of Financial Network Analytics (FNA) and founding Editor in Chief of the Journal of Network Theory in Finance - 18.01.2018
- Peter Sarlin, Executive Chairman and Chief Scientist of Silo.AI, Professor of Practice at Hanken School of Economics and Director of RiskLab Finland at Arcada - 18.01.2018
- Sören Friedrich - Financial Stability Department, Deutsche Bundesbank - 19.01.2018
- Piotr Kusmerczyk, European Systemic Risk Board - 22.01.2018
- Marco D'Errico, Department of Banking and Finance (Center for Financial Networks and Sustainability), University of Zurich and European Systemic Risk Board - 25.01.2018

C Ethical and professional considerations

The project involved humans for the testing of the interactive network visualiser and the Euro Area network visualisation. The interactive network visualiser was developed at the request of the person testing the application who also asked to test the former on a regular basis. Thus, explicit consent was given. For the Euro Area network visualisation, survey participation was voluntary and no personal information was collected. Overall, the project hopes to make a small contribution towards filling the methodological gap in macroeconomics, which became apparent in the financial crisis when the conventional models offered little help.

D Ethics checklist

Table 9.1: Ethics checklist

	Yes	No
Section 1: HUMAN EMBRYOS/FOETUSES		
Does your project involve Human Embryonic Stem Cells?		x
Does your project involve the use of human embryos?		x
Does your project involve the use of human foetal tissues / cells?		x
Section 2: HUMANS		
Does your project involve human participants?	x	
Section 3: HUMAN CELLS / TISSUES		
Does your project involve human cells or tissues? (Other than from Human Embryos/Foetuses i.e. Section 1)?		x
Section 4: PROTECTION OF PERSONAL DATA		
Does your project involve personal data collection and/or processing?		x
Does it involve the collection and/or processing of sensitive personal data (e.g. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?		x
Does it involve processing of genetic information?		x
Does it involve tracking or observation of participants? It should be noted that this issue is not limited to surveillance or localization data. It also applies to Wan data such as IP address, MACs, cookies etc.		x
Does your project involve further processing of previously collected personal data (secondary use)? For example Does your project involve merging existing data sets?		x
Section 5: ANIMALS		
Does your project involve animals?		x
Section 6: DEVELOPING COUNTRIES		
Does your project involve developing countries?		x
If your project involves low and/or lower-middle income countries, are any benefit-sharing actions planned?		x
Could the situation in the country put the individuals taking part in the project at risk?		x
Section 7: ENVIRONMENTAL PROTECTION AND SAFETY		
Does your project involve the use of elements that may cause harm to the environment, animals or plants?		x
Does your project deal with endangered fauna and/or flora /protected areas?		x
Does your project involve the use of elements that may cause harm to humans, including project staff?		x
Does your project involve other harmful materials or equipment, e.g. high-powered laser systems?		x
Section 8: DUAL USE		
Does your project have the potential for military applications?		x
Does your project have an exclusive civilian application focus?		x
Will your project use or produce goods or information that will require export licenses in accordance with legislation on dual use items?		x
Does your project affect current standards in military ethics e.g., global ban on weapons of mass destruction, issues of proportionality, discrimination of combatants and accountability in drone and autonomous robotics developments, incendiary or laser weapons?		x
Section 9: MISUSE		
Does your project have the potential for malevolent/criminal/terrorist abuse?		x
Does your project involve information on/or the use of biological-, chemical-, nuclear/radiological-security sensitive materials and explosives, and means of their delivery?		x
Does your project involve the development of technologies or the creation of information that could have severe negative impacts on human rights standards (e.g. privacy, stigmatization, discrimination), if misapplied?		x
Does your project have the potential for terrorist or criminal abuse e.g. infrastructural vulnerability studies, cybersecurity related project?		x
SECTION 10: LEGAL ISSUES		
Will your project use or produce software for which there are copyright licensing implications?		x
Will your project use or produce goods or information for which there are data protection, or other legal implications?		x
SECTION 11: OTHER ETHICS ISSUES		
Are there any other ethics issues that should be taken into consideration?		x