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The search for R&D partners: Mapping collaborations and expertise in interorganisational networks.

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Project Management

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- uttak av masteroppgave

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Oppgavens (foreløpige) tittel **The search for R&D partners: Mapping collaborations and expertise in interorganisational networks.**	
Oppgavetekst/Problembeskrivelse By means of a literature review, the thesis will examine how companies and academic institutions traditionally has proceeded when searching for collaborative partners, and how these choices have affected their collaborations. The thesis addresses the case of Position Sensitive Solid State Detectors (PSSSDs) in modern High Energy Physics (HEP). Earlier HEP-collaborations between academia and industry will be analysed by looking at published material such as publications, patents and press cuttings. The largest databases of scientific publications on the internet holds additional information about each of their publications. Amongst other, information about organisations contributing to each publication is available. Similar databases for patents and press cuttings are also accessible through the internet, where the same type of additional information can be obtained. Information such as this will be used to map the expertise and collaborations on various PSSSD-technologies. By combining the results with qualitative case studies, the thesis examines whether, and possibly how, knowledge about other companies' and academic institutions' R&D activity in certain technological domains,...	
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4. Underskrift

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Partene er gjort kjent med avtalens vilkår, samt kapitlene i studiehåndboken om generelle regler og aktuell studieplan for masterstudiet.

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Preface

This Master Thesis is the concluding work of my studies at the Master's Degree Programme Project Management at The Norwegian University of Science and Technology, NTNU. The Thesis is based on research conducted at The European Organization for Nuclear Research, CERN.

I would like to thank my supervisor, associate professor Tim Torvatn, for help and support during my research. Even though we were working in different countries, you managed to steer me in the right direction when I needed guidance and advice.

I would also like to thank my supervisor PhD, DPhil Jean-Marie Le Goff for making my stay at CERN the amazing experience it has been. I feel exceptionally fortunate for being given this opportunity of working while studying at the world's largest scientific laboratory. I will never forget the inspiring and informal lectures you gave during lunches and coffee breaks, and all the interesting conversations on topics spanning from science to wine.

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Ole Vatsvåg

Abstract

Companies, academic institutions and not-for-profit organisations in the High Energy Physics community have recently expressed a need for a service or tool that can simplify and improve the partner selection process in research and development (R&D) -collaborations. Today, partner selection is carried through differently, from organisation to organisation. It is often an informal process, heavily influenced by managements' personal networks. The literature, however, suggests a more rational and systematic two-step approach called searching and screening. This document proposes a conceptual framework for partner selection in R&D-collaborations, as a solution to this challenge. The framework is based on prior literature, and empirical findings from CERN.

The most important organisational characteristics in any R&D-collaboration are capability and knowledge concerning the technological challenges of the collaboration. The success of the collaboration is dependent on these characteristics, and so are the prospects for knowledge transfer among the participating organisations. Thus the ideal partner for R&D-collaboration should be the most capable or knowledgeable organisation that is either applying or developing the technologies most relevant to the collaboration's central challenges. In addition, the organisation should preferably hold beneficial contacts throughout its organisational network, which the collaboration can draw benefits from.

Prior studies have suggested that capability and knowledge can be measured by the means of bibliometric documents, such as publications and patents. These documents contain details on their affiliated organisations. That information can be used to create graphical representations of interorganisational networks; so called sociograms. A set of sociograms based on publications and patents in a given technological field, can reveal the most capable and knowledgeable organisations in that field.

Five technologies related to Position-Sensitive Solid-State particle detectors are reviewed in this study. Sociograms of the organisations developing and using each of the technologies have been created, by the means of an IT tool. The IT tool constitutes the core functions of the conceptual framework. Several technical experts affiliated with CERN have evaluated the pertinence of the sociograms, and provided feedback on the methods of the framework and its corresponding IT tool.

Interorganisational R&D-collaboration is a significant driver for technological innovation. Many revolutionary discoveries in medical science, power production and computer technology have been developed and commercialised as a result of collaborative arrangements. It is therefore in the interest of humanity to promote and create incentives for this kind of cooperation.

Sammendrag

Bedrifter, akademiske institusjoner og ideelle organisasjoner i partikkelfysikk-miljøet har i senere tid uttrykt et behov for en tjeneste eller verktøy som kan forenkle og forbedre prosessen med å finne de mest ideelle organisasjonene til forskning og utvikling (FoU) -samarbeidsprosjekt. I dag blir valg av partner gjennomført på forskjellig måte, fra organisasjon til organisasjon. Det er ofte en uformell prosess, sterkt påvirket av ledelsens personlige nettverk. Flere vitenskapelige studier foreslår heller en mer rasjonell og systematisk to-trinns tilnærming som kalles søking (searching) og filtrering (screening). Som en løsning på denne utfordringen presenterer denne studien et konseptuelt rammeverk for valg av partner i FoU-samarbeid. Rammeverket bygger både på litterære kilder og empiriske erfaring fra CERN.

I ethvert FoU-samarbeidsprosjekt vil kompetanse og kunnskap rundt prosjektets teknologiske utfordringer være egenskapene som har størst positiv påvirkning på prosjektets resultater, og dermed viktigst at de involverte organisasjonene besitter. Disse er også avgjørende for hvor mye organisasjonene kan lære fra hverandre. Følgelig kan man si at den ideelle partner for et gitt FoU-samarbeidsprosjekt bør være den organisasjonen som rår over mest og best kompetanse og kunnskap rundt anvendelse eller utvikling av teknologier nært knyttet opp til hovedutfordringene i prosjektet. I tillegg vil det være svært fordelaktig om denne organisasjonen har gode og relevante kontakter i sitt organisatoriske nettverk fra før av, som samarbeidsprosjektet kan dra fordeler av.

Tidligere studier har antydet at kompetanse og kunnskap kan måles ved hjelp av bibliometriske dokumenter som publikasjoner og patenter. Slike bibliometriske dokument inneholder informasjon om organisasjonene de stammer fra. Dette er opplysninger kan brukes til å framstille grafiske modeller av interorganisjonelle nettverk; såkalte sociogrammer. Ved å analysere sociogrammer av et gitt teknologisk fagfelt kan man avdekke de mest kompetente og kunnskapsrike organisasjonene innen dette fagfeltet.

Fem teknologier nært tilknyttet Position-Sensitive Solid-State partikkeldetektorer er blitt nærmere undersøkt i denne studien. Sociogrammer av organisasjonene som anvender og utvikler disse teknologiene har blitt fremstilt med hjelp av et IT-verktøy. Flere tekniske eksperter med tilknytning til CERN har gitt tilbakemelding på sociogrammene, og fortalt hvor bra de har framstilt de virkelige nettverkene. IT-verktøyet utgjør kjernefunksjonene til studiens konseptuelle rammeverk.

Interorganisjonelle FoU-samarbeid er en betydelig drivkraft for teknologisk innovasjon. Mange revolusjonerende oppdagelser innen legevitenskap, kraftproduksjon og datateknologi har blitt utviklet og senere kommersialisert som et resultat av FoU-samarbeidsprosjekt. Det er derfor i menneskehetens interesse å promotere og skape insentiver for slike samarbeidsprosjekt!

Abbreviations

AIDA: Advanced European Infrastructures for Detectors at Accelerators.

ASIC: Application-Specific Integrated Circuit.

ATLAS: A Toroidal LHC Apparatus.

CEA: Commissariat à l'énergie atomique et aux énergies alternatives.

CERN: The European Organization for Nuclear Research (Conseil Européen pour la Recherche Nucléaire).

CMS: Compact Muon Solenoid.

CNRS-IN2P3: French National Centre for Scientific Research.

CTU: Czech Technical University.

DESY: Deutsches Elektronen-Synchrotron.

DLS: Diamond Light Source Ltd.

ESI: Early Supplier Involvement.

FoU: Forskning og utvikling.

FP7: Seventh Framework Programme.

GPS: Global Positioning System.

GSI: GSI Helmholtzzentrum für Schwerionenforschung (Gesellschaft für Schwerionenforschung).

HEP: High Energy Physics.

IMP: Industrial Marketing and Purchasing.

INFN: Istituto Nazionale di Fisica Nucleare.

IT: Information Technology.

JIT: Just In Time systems.

KT: Knowledge Transfer.

M&A: Mergers and Acquisitions.

MNE: Multinational Enterprises.

NGO: Nongovernmental Organisation.

NPD: New Product Development.

NPO: Not-for-Profit Organisation.

PRO: Public Research Organisation.

PSI: Paul Scherrer Institute.

PSSSD: Position-Sensitive Solid-State Detector.

R&D: Research and development.

SCM: Supply Chain Management.

SME: Small and Medium sized Enterprise.

SNA: Social Network Analysis.

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1 Introduction

The Swedish professor and business researcher Håkan Håkansson famously said *"No company is an island"* (Håkansson, 1990), an assertion that probably is true for all types of organisations. Every organisation is bound to interact with its environment throughout its endeavours, including other organisations. Research projects in several scientific professions such as biochemistry, computer science and high energy physics (HEP) are often extremely resource demanding, not only financially but also with respect to technology, production capacity, knowledge and intellectual property, to mention a few. Thus resource-intensive projects are only feasible by large international organisations (Salter and Martin, 2001). Even the largest companies, institutions or not-for-profit organisations (NPOs) cannot undertake the most difficult and challenging projects on their own (Vuola and Hameri, 2006). They need assistance and support from other organisations that can provide the necessary capabilities and knowledge; either as suppliers or collaborators, respectively vertically or horizontally in the supply chain.

This is also the case for the European Organisation for Nuclear Research (CERN) which hosts numerous HEP-laboratories at their locations along the Franco-Swiss border, just northwest from the Swiss city of Geneva. Large and complex research and development (R&D) projects at CERN are only feasible with the assistance of outside organisations. CERN cannot host experts on all the professions which are needed for the construction of their laboratories and experimental devices. They only hold the knowledge on how their devices must perform, and how to conduct and analyse the experiments after the devices are constructed. Thus CERN needs to complement their knowledge with technological expertise from other research institutions. The cost of developing knowledge and capabilities on each of these technologies very often exceeds the financial resources available for any scientific project, and can thus only be justified if the technology has a business potential (Le Goff, 2012a). This is due to the extreme development costs of high-tech devices, which in addition and most often, have a narrow range of obvious applicability. Because of that, mass production is ruled out; hence each unit becomes extremely expensive.

Among all the projects and experiments conducted at CERN, the largest one to date is the Large Hadron Collider (LHC). The total cost of the LHC project is estimated to be in the order of 5 billion Euros, of which approximately half the sum has already been spent on high-tech components from external companies (Le Goff, 2012a). This funding is provided by the governments of the CERN Member States, which by funding the research done at the CERN not only strengthen their own industry's knowledge and expertise, but also helps advancing science. In addition, research projects sometimes result in unforeseen findings, which in time can lead to new and revolutionary technologies. Some famous examples of unforeseen innovations stemming from research on HEP are the World Wide Web, PET/MRI/CT-scanners, proton therapy for cancer treatment, and thermal solar collectors (Le Goff, 2011). Unforeseen findings also occur in other scientific professions, like for example chemistry, biology and medicine. The famous British doctor and discoverer of penicillin Alexander Flemming once said *"When I woke up just after dawn on September 28, 1928, I certainly didn't plan to revolutionize all medicine by discovering the world's first antibiotic*". Revolutionary discoveries are almost impossible to conceive by conventional planning methods, but they are incredibly beneficial to both science and mankind (Martin and Tang, 2006, Salter and Martin, 2001). It is therefore in everyone's interest to stimulate interorganisational R&D-collaborations.

The main challenge for organisations in need of suppliers or strategic partners is to find the best suited organisation for what is needed. This challenge will be the main focus of this document, and is object to the first research question. How it is carried out in practice vary a great deal from one organization to another. It seems however, that partner selection is very often an informal process, heavily influenced by personal networks and conducted outside of the organization by project managers or other high ranked personnel (Hillemanns, 2012a). The aim of this document is to develop a conceptual framework for partner selection in interorganisational R&D-collaborations, based on prior research, existing frameworks and empirical research. A novel IT tool, which can be applied in real life cases, is to be developed and implemented into the framework. Its purpose is to function as a catalyst for increased R&D-collaboration, by providing high-tech organisations with information about the players in the technological community. Innovative organisations in the HEP-community have issued a need for such a utility, to help them locate specialised and rare capabilities and knowledge (Le Goff, 2012a). They will have a better picture of what is obtainable, and where to find it, if they know what the community can provide.

The IT tool is based on bibliometric data extracted from publications and patents. Through analysis, these data will unveil the organisational players in a given technological domain, and tell us who are collaborating. This analysis will be dependent on a method for measuring organisational capability and knowledge, and this challenge is object to the second research question. The results are converted into sociograms; interorganisational network maps that present the analysed data graphically instead of numerically. A big challenge related to the practical use of large and complex datasets is to render this information intuitively understandable. By using lines, simple figures and colours instead of numbers, the human mind can more easily interpret the information presented. This is one of the major strengths of the framework and IT tool proposed in this document, and the development of these sociograms is object to the third research question.

The study addresses five HEP-technologies as embedded units of analysis, all of which are closely associated with Position Sensitive Solid State Detectors (PSSSDs). PSSSDs are used to track particle collisions in particle accelerator detectors, such as ATLAS, CMS, ALICE and LHCb at CERN, but they are also applied for other x-ray imaging purposes such as astronomy, radiography and crystallography (Le Goff, 2012a). For each technology, quantified data obtained by the use of the conceptual framework is compared with qualitative expert judgement. The quality of the results is evaluated by the experts, to assess whether knowledge about other companies' and academic institutions' R&D activity in a given technological domain, and collaborations between organisations involved in this domain, can be applied in finding companies' or academic institutions' best suited collaborative partners.

Research questions	How can organisations find their ideal partners for R&D-collaboration, and why is this important?
	How can the organisational qualities of the ideal partner for R&D-collaboration be measured?
	How can interorganisational networks be mapped?

This document is organised as follows: Chapter 2 reviews the literature on partner selection in interorganisational collaborations. It starts with a broad view by explaining various types of collaborative arrangements, and continues by explaining the needs of organisations involved in R&D. This is important to know in order to understand why organisations bother to collaborate in the first place, and later recognise what type of collaboration fits each organisation best. The next subchapter addresses these questions and looks into how organisations should design their relationships according to their business. This is followed by a review of existing partner selection frameworks, in addition to methods for knowledge measurement and mapping. The last subchapter sums up the literature which will be used later in the document. Chapter 3 explains how the empirical part of the assignment has been conducted, including how literature have been gathered and how the scope of the research has been limited. The conceptual framework and the IT tool is also presented and explained in the end of this chapter. In Chapter 4 the empirical results are described and analysed. First a holistic view on partner selection processes in R&D-collaborations at CERN is presented. All the embedded technology-cases are then reviewed, discussed and evaluated by various technical experts. Chapter 5 summarises the analysis in respect to the problem formulation, and concludes. Possible consequences of the partner selection tool and its future prospects are also discussed.

2 Literature review

This chapter presents the literature that constitutes the theoretical fundament of this document. It begins with a holistic presentation of interorganisational collaborations, and narrows slowly down to a final focus on partner selection in R&D-collaborations. During this top-down approach many subjects on the topic are reviewed, and the first is organisational needs. This is followed by a section on collaboration design and composition. At the end of the chapter, a review of partner selection frameworks and methods for partner selection processes is presented, followed by a theoretical main model that sums up the theory used later in the document.

2.1 Interorganisational collaboration

All organisations must interact with other organisations within their environment; hence all organisations are involved in some sort of interorganisational network (De Wit and Meyer, 2010). How or if an organisation manages its external network is evidently its own prerogative, but according to De Wit and Meyer (2010) most managers today agree that a deliberate network strategy is vital for any organisation's well-being and therefore of high strategic importance.

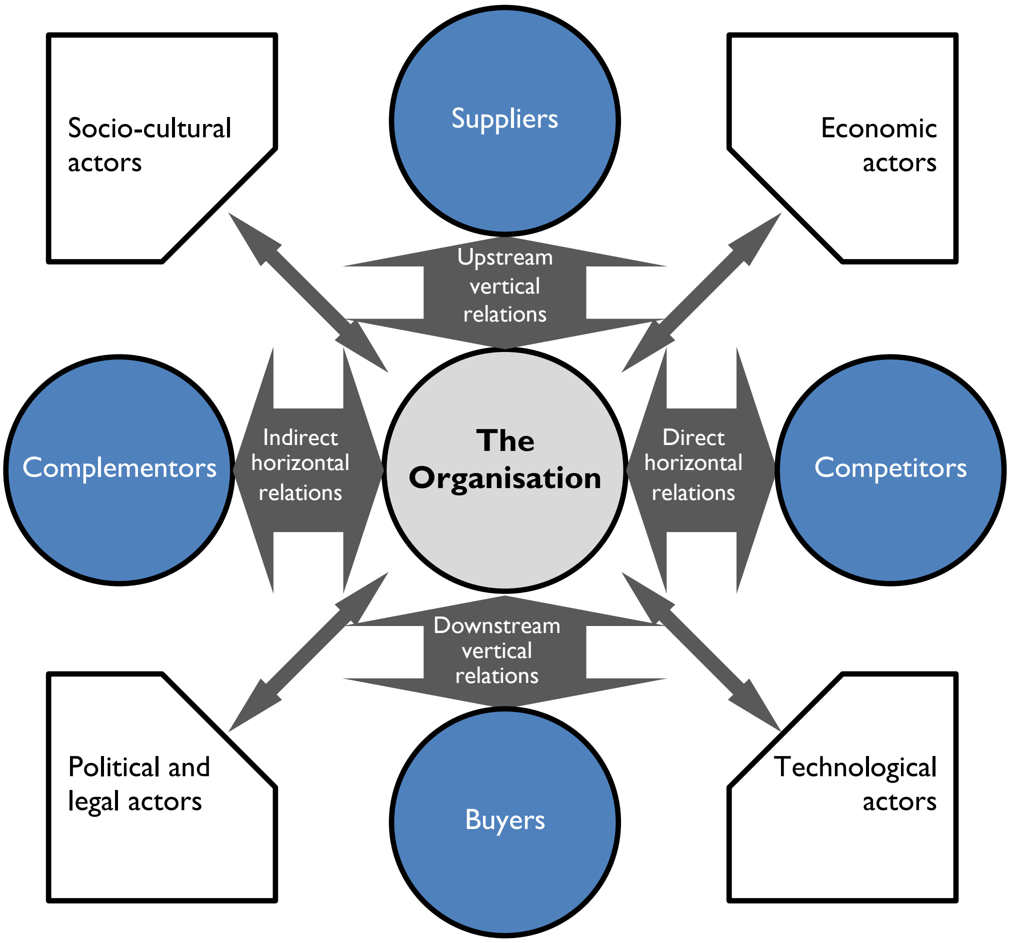


Figure I: Organisational actors. Source: De Wit and Meyer (2010).

De Wit and Meyer (2010) describe the organisational actors that constitute the environment. They distinguish between industrial actors, which either add value to or consume their products, and contextual actors, which dictate the conditions for the industrial actors. Figure 1 display the relationships among them.

The Industrial actors are those related to the core functions to the organisation:

- ***Suppliers:*** Providers of resources needed to realise their goals, either tangible like raw materials or equipment, or intangible like knowledge or capability. These are referred to as upstream vertical relations.
- ***Byers:*** The organisation's customers, which are either end users or the next joint in the supply chain. These are referred to as downstream vertical relations.
- ***Competitors:*** Organisations that provide the same products or services, and therefore can be considered as competitors. These are referred to as direct horizontal relations.
- ***Complementors:*** Organizations that are not providing the same products or services, but rather complementary products or services. These are referred to as indirect horizontal relations.

The contextual actors are those who act as stakeholders in the environment:

- ***Socio-cultural actors:*** Organisations that have great influence on the society at large. These include the media, community groups, charity and religious groups.
- ***Economic actors:*** Actors that influence the economic state of affairs that the organisations must deal with. These include the tax authorities, central banks, the stock exchange and unions.
- ***Political/legal actors:*** Actors that influence the political and legal state of affairs that the organisations must deal with. These include governments, political parties, special interest groups, regulatory bodies and international institutions.
- ***Technological actors:*** Actors that influence the pace and direction of technological development, and create new knowledge. These include universities, research institutes, patent offices, government agencies and standardisation bodies.

This study focuses on interorganisational R&D-collaborations, which concern the last contextual group of actors; the technological actors. Fritsch and Lukas (2001) have demonstrated that technological actors are not traditional buyers or suppliers, nor the typical competitor or providers of complementing products or services. The goals of academic institutions and companies are of a different nature, but they can both achieve considerable benefits by working together with each other.

2.1.1 Collaborative arrangements

Increasing globalisation and technological advancements have increased competitiveness all around the world (Cousins et al., 2008). To acquire the resources or capabilities organisations need to successfully execute their growth strategies, they are forced to choose between mergers-and-acquisition (M&A) and collaborations (Coallier, 2010). If financial resources are limited, or the M&A prospects are poor, collaboration is the only and best alternative for horizontally integrating the necessary resources into their supply chain.

De Wit and Meyer (2010) classifies interorganisational collaborations into six collaborative arrangements, according to two criteria. The first criterion regards the number of organisations involved in the collaboration. Bilateral arrangements are collaborations which include only two organisations, and multilateral arrangements are collaborations which include three or more organisations. Multilateral arrangements are commonly referred to as networks. The second criterion regards the type of formal relationships between the organisations. Non-contractual arrangements are collaborations which are not contracted by law, contractual arrangements are collaborations which oblige the organisations to act in accordance to a legal agreement, and equity-based arrangements are collaborations which involve a joint economic initiative. The non-contractual and contractual arrangements do not involve any joint financial actions. Table 1 displays a variety of collaboration types that fits into the six categories.

	Non-contractual arrangements	Contractual arrangements	Equity-based arrangements
Multilateral arrangements	-Lobbying coalitions. -Joint standard setting. -Learning communities.	-Research consortium. -International marketing alliance. -Export partnership.	-Shared payment system. -Construction consortium. -Joint reservation system.
Bilateral arrangements	-Cross-selling deal. -R&D staff exchange. -Market information sharing agreement.	-Licensing agreement. -Co-developing contract. -Co-branding alliance.	-New product joint venture. -Cross-border joint venture. -Local joint venture.

Table I: Collaborative arrangements. Source: De Wit and Meyer (2010).

This study is potentially addressing all of these arrangements, but no bilateral arrangements have been reviewed, or discovered for that matter. The author expects that the classification of collaborative arrangements by De Wit and Meyer (2010) is regarding formal collaborations. This seems like a very rough classification and not always the case in real life collaborations, compared to Håkansson and Snehota (1995) and Holmen and Pedersen (2003). Bilateral arrangements are only bilateral in a formal sense. Two organisations which are exchanging staff in a R&D-collaboration will both be involved in other arrangements. As Holmen and Pedersen (2003) explain, some of these arrangements can have a considerable impact on the formal collaboration, especially if their businesses are intertwined. The organisations that constitute the indirect relationships are what Håkansson and Snehota (1995) and Holmen and Pedersen (2003) refer to as third parties.

2.1.2 Academia/industry collaborations

Universities and other academic institutions play an important role in technological innovation today. Studies have demonstrated that they function as a catalyst for industrial innovation by collaborating with industrial partners (Vuola and Hameri, 2006). Nevertheless, high-tech companies seem not to be interested in basic research. The industry is discontent with the current market situation, which they regard as too small, specific and narrow (Vuola and Hameri, 2006). The market is also difficult to enter; thus financial results are more easily assessed elsewhere.

Vuola and Hameri (2006) explain that finances provided from governmental entities such as EU, are meant as an incentive for companies to collaborate with scientific institutions. Early innovations are publicly sponsored to make the development happen. Companies' technologies are tested, developed and commercialised in a collaborative setting. According to Martin and Tang (2006), publicly funded research is due to a "market failure" related to NPD and R&D. They explain that innovative processes are very expensive, and heavily influenced by uncertainty. It is therefore impossible for small and medium sized enterprises (SMEs) to undertake R&D intensive projects. Society, however, benefits greatly from NPD, and should therefore provide a cost and risk distribution system. The solution proposed by Martin and Tang (2006) is public funded NPD and R&D. When the environment, in this case the free market, is not perfect, the government must intervene to counter its natural flaws. According to Vuola and Hameri (2006), industry benefits from academia/industry collaborations by reduced R&D risk and cost, and science benefits from industry's production capabilities. In the past, large research institutions such as CERN could develop and produce all equipment in-house. This is not possible any longer explains Vuola and Hameri (2006), because of the scale and complexity of today's projects. Collaboration with industry is an absolute necessity for the realisation of large scientific experiments.

In recent years, science has promoted a "science push" of innovation, rather than a "demand pull" (Martin and Tang, 2006). This is a response to industry's reluctant interest in science's non-traditional methods of achieving benefits, requiring a far-sighted approach and long-time plans. Medicine and education are examples of scientific professions that easily show results. It is more difficult with basic research such as HEP, explains Martin and Tang (2006). One of the biggest challenges of basic research is to adequately measure its outputs. Any economic impact derived from these is produced indirectly: Knowledge allows for complex problem solving, trained people make a more effective work staff, and new medical treatments will keep people working. Martin and Tang (2006) also explain that it is problematic to quantify economic and social benefits from public funded research. It is therefore difficult to apply traditional economic measurement tools when evaluating the outputs from science. Nevertheless, empirical evidence demonstrates substantial benefits, especially in knowledge and competition intensive areas; Mansfield (1991) estimated the rate of return of scientific research to be 28%. The benefits can be classified as knowledge incorporated in new products, training of graduates and scientists, creation of novel scientific instrumentation and methodologies, development and access to learning networks, enhanced problem solving capabilities, creation of new firms, and provision of social knowledge (Martin and Tang, 2006).

University-industry partnerships have become more and more common since the 1980s (Fontana et al., 2006). It first started escalating in the US, and the main reason for this was the Bayh-Dole Act in 1980 (Siegel et al., 2003, Leydesdorff and Meyer, 2010). As explained by Siegel et al. (2003), this was an attempt to promote technology transfer between universities and industry. Universities could now own patents resulting from federal funded research, and collaborations between universities and companies were suddenly much more lucrative for the academic collaborator. Much research has later been done in order to understand these collaborations, and most of this work has been qualitative case studies (Fontana et al., 2006, Beise and Stahl, 1999).

The quantitative research survey done by Fontana et al. (2006) on R&D-collaborations between firms and public research organisations (PROs) in 7 European countries, reveals that academic attendance has a positive economic impact on collaborative R&D projects. PROs have accelerated innovation in many fields of research, and their scientific results have led to increased research productivity, sales and patenting activity. For companies, the PROs have proven to be an exceptional external source of knowledge and expertise (Fontana et al., 2006). Despite all these benefits, firms are still reluctant to cooperate with PROs. According to the research done by Cohen et al. (2002), PROs are often considered not to be as valuable as the companies' vertical supply chain, like their traditional suppliers and buyers, in terms of business importance. This attitude is probably a result of the conflicting strategic focuses of traditional buyer-seller relationships and R&D-collaborations.

Research also indicates that the size of the firm and its culture and norms are influencing its tendency of collaborating with PROs (Cohen et al., 2002, Lane et al., 2001). We learn from Cohen et al. (2002) that large firms and start-ups are much likely to benefit from academic research, in contrast to small and medium sized enterprises (SMEs). Moreover, the research done by Lane et al. (2001) shows that knowledge transfer (KT) is particularly frequent between culturally similar organisations.

In addition to the profit seeking companies and the academic institutions, which are considered to be the two most important actors in international business (Teegen et al., 2004), there is one other organisation type that has emerged as an increasingly significant player worth mentioning, namely not-for-profit organisations (NPOs). There are numerous organisations that fall under this category. Salamon and Anheier (1992) tried to define NPOs to be non-profit-distributing, self-governing, voluntary, private organisations. From Teegen et al. (2004) and Lambell et al. (2008) we learn that nongovernmental organisations (NGOs) are NPOs, constituting the "third sector" and representing civil society. They often interact with other NGOs, and some are even multinational enterprises (MNEs) like the United Nations. NGOs are known to advocate lobbying strategies for groups like consumers, firms, governments, research organisations, petitions, demonstrations, media etc.

2.2 Organisational needs

High-tech companies are constantly struggling to obtain more and better resources, and as explained by Daft (1989) this can be accessed through the means of other organisations. However, these companies also wish to be as independent and self-controlling as possible; consequently they do not want to be part of any business collaboration that is not beneficial to themselves. As put by Gadde et al. (2003), companies should work with other firms to expand their resource capabilities; although networking is good for business, having too many suppliers is not cost effective.

By nature, organisations in collaborations must have two-faced intentions if they are to survive. They are bound to have relationships with suppliers and buyers, but they also need to be competitive to gain their share of the benefits (De Wit and Meyer, 2010). This is in line with Hakansson and Ford (2002) in their study of companies in business networks. They present three paradoxes of interorganisational collaborations that companies in interorganisational network are faced with; opportunities and limitations given by the network, influencing and being influenced by the network, and controlling and being out of control of the network. According to Hakansson and Ford (2002), these paradoxes are intrinsic to the nature of interorganisational networks.

The act of balancing a company in respect to the paradoxes is a difficult skill to master, but it is necessary if the company is to sustain a working relationship with the other organisations (De Wit and Meyer, 2010, Hakansson and Ford, 2002). This is consistent with the research of Hakansson and Ford (2002) on paradoxes in networks. They conclude that firms in a network are not free to do as they want. The companies have to act in accordance to what is best for the group; if not they might jeopardise their relationships, which usually require a lot of resources to develop. Hakansson and Ford (2002) agree with Daft (1989) that the development of a firm, and it's capabilities of affecting other firms, is heavily affected by the firms network relations. These relationships will in addition, depending on their extensiveness, also limit the scope of business and flexibility of the firm.

Although interorganisational collaborations have their pitfalls, mainly because of opportunistic organisations that choose to exploit their partner's trust (Anderson and Jap, 2005), close relationships can provide some remarkably beneficial perks to the organisations involved. As explained by Andersson et al. (2002), the competitive ability of a firm is heavily influenced by its interorganisational network. A clever organisation can exploit the various resources available throughout its network, and use them as a competitive advantage.

2.2.1 Research and development

The need for advanced technologies, innovation and expertise in science and industry is emphasized by Stuart and Podolny (1996) and Cousins et al. (2008). They explain that new product development (NPD) and R&D is an increasingly important competitive advantage for companies. Vuola and Hameri (2006) describes NPD as management of R&D. The model by Vuola and Hameri (2006) includes the five stages of the NPD process. It starts with a business or product idea, and if successful, ends with a product or service ready for the market. The whole NPD process usually lasts for several years. Only 15% of new ideas succeed, and failures usually start at some point after the feasibility study.

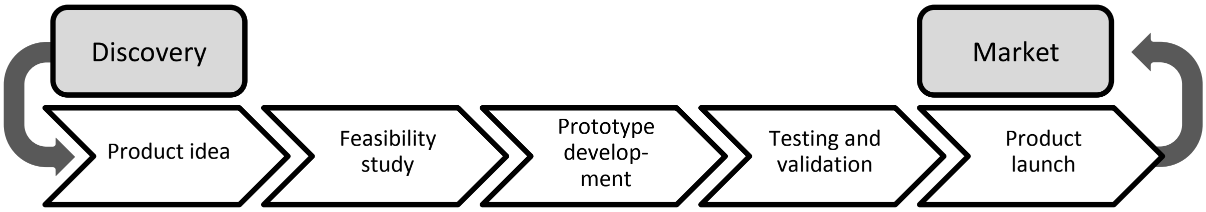


Figure II: The NPD process. Source: Vuola and Hameri (2006).

The focus on innovation requires a large amount of resources, which often forces the firms to limit their scope of business (Narula, 2004). The organisations will then have to outsource their reminding workload, or to team up with other organisations to being able to fund the necessary R&D (Narula, 2004). Organisations engaged in R&D tend to seek out partners which hold novel technologies and resources that complement their own. By doing so, the organisations will have access to resources that will further strengthen their position in the market. Stuart and Podolny (1996) explains how high-tech firms traditionally specialize in certain technological niches, and try to perfect them. They claim this is the most reasonable business strategy, from a resource based view. They also suggest that the firm should take advantage of its (more or less) unique resources, and exploit them in collaborations with other firms. However, the long and difficult path to business excellence has often been the ruin of once prosperous companies. Change to the organisation becomes more difficult as the necessary alterations become more extensive. According to Stuart and Podolny (1996), numerous empirical studies show that companies often fail to acknowledge and act upon technological paradigm shifts, even if they deliberately try to do so.

In his study on buyer-seller relationships, Wilson (1995) states that these relationships are much different to those found in R&D-collaborations. In buyer-seller relationships the goal has been to reduce production costs. This favours a solution with a few key suppliers due to competitive pressure to develop just in time systems, increased product quality, and at the same time reduce transaction costs. This is not the main goal in most R&D-collaborations. They are mostly concerned about technological development, which in turn will lead to innovative results (Martin and Tang, 2006). Somewhat agreeing with Wilson (1995), Daft (1989) states that this paradox is more a dilemma for companies than for NPOs. NPOs often have the agenda of encouraging collaborations for the sake of a non-economic cause like the advancement of science.

Cousins et al. (2008) also underline the importance of involving suppliers at the optimal time in the NPD process. As a general rule, the more impact a supplier will have on the final product, the earlier it should be included in the process. According to Cousins et al. (2008), experiences from a wide variety of businesses show that supplier involvement, and especially early supplier involvement (ESI), is very advantageous in NPD projects. Suppliers of complex and critical components in high-tech R&D projects should therefore be included very early in the NPD process (Cousins et al., 2008). Organisations that exercise ESI can draw benefits both at the product level, and at the organisational and strategic level.

Cousins et al. (2008) describes four strategic benefits from ESI:

1. ***Learning effect:*** Suppliers are chosen for their unique skills. Through collaboration, the organisations can learn from each other.
2. ***Access to new capabilities:*** Specialised suppliers have superior capabilities in their field of business. These capabilities can be exploited by their partners through collaboration.
3. ***Technology road mapping:*** By having insight to a partners future plans, a supplier can better prepare for production of new products. This can speed up the development process in the supply chain.
4. ***Risk reduction:*** The risk of component incompatibility can be reduced by including suppliers early in the design process. Also NPD risk will be reduced by spreading the risk over several collaborators.

Although all of these benefits are very favourable to firms in R&D and NDP intensive industries, Cousins et al. (2008) emphasise that ESI also are known to have certain disadvantages. These are the five ESI disadvantages described in Cousins et al. (2008):

1. ***ESI is not always beneficial or appropriate:*** Sometimes early involvement simply is not beneficial or appropriate, either because the project cannot spare the sufficient resources, or because the partner or supplier lack certain critical resources.
2. ***Loss of bargaining power:*** The option of using competitive tendering will not be possible for the assignments given to a collaborative partner or supplier.

3. ***Leakage of key information:*** Disloyal partners can leak confidential information to competitors. It is important to appropriately monitor every relationship, and be prepared for unfaithful servants.
4. ***Financial burden on manufacturing:*** Too many cooks spoil the broth. A recurring effect to ESI in the design process is growing workload in the manufacturing department. This can result in an elevated need for financial resources, and declining performance.
5. ***Locked into wrong technological trajectory:*** By choosing a partner or supplier specialised in one specific technology, and involving the organisation early in the design process, the success of the collaboration is dependent how the market receives the organisation's technology. It is difficult to change the technological direction once one has chosen a partner or supplier.

2.2.2 Knowledge transfer

The most beneficial outcomes from R&D-collaborations is neither the possibility of sharing resources, nor risk and cost reduction, but the opportunity to build skills and learn new knowledge from the alliance (Hamel et al., 1989).

There are many challenges associated with the organisational absorption process of such assets, and organisations should take these into consideration when screening for potential collaborative partners (Lane et al., 2001). According to Lane et al. (2001), the three most crucial forces influencing KT in international joint ventures are the organisations' high-tech capabilities, their learning structures and processes, and their mutual trust: These elements are displayed in Figure III.

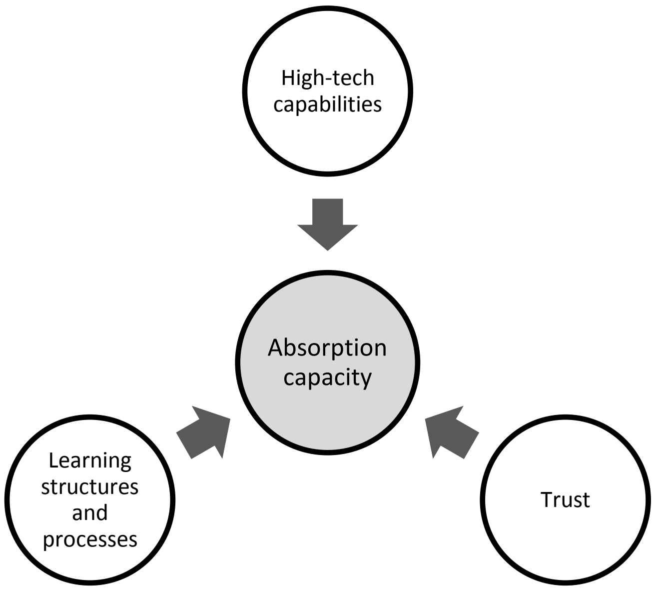


Figure III: Absorption capacity in interorganisational knowledge transfer. Source: Based on Lane et al. (2001).

The three forces influencing an organisation's absorption capacity is explained by Lane et al. (2001) as follows:

1. ***High-tech capabilities:*** Organisations with high investments in R&D are more likely to learn from other expert organisations in collaborations. As a student's ability to learn is greater when he/she is familiar to the taught subject from before and shares his/her teacher's cognitive structures, an organisation that is familiar with its partner's knowledge and operational priorities, is better suited to absorb new knowledge through their relationship.
2. ***Trust:*** In an interorganisational collaboration, the "teacher" organisation is more encouraged to tutor the "student" organisations if it trusts that its students are reliable to their obligations. Prerequisites for trust are willingness to risk vulnerability, and confidence that the other part will refrain from exploiting this vulnerability.
3. ***Learning structures and processes:*** Receptivity to learn and openness to new knowledge from other organisations is important for creating new skills and capabilities. If an organisation has its own support function that is able to recognise interesting knowledge and understand how it can be obtained, it can much more efficiently facilitate knowledge transfer.

Networks should ideally encourage interorganisational collaboration by providing a flow of information, which may affect the network's innovative potential (Gulati, 1998). As an example, research has shown that biotech firms have superior R&D performance when the knowledge creation process is linked to external alliance partners (Eisenhardt and Martin, 2000). Following this rationale, one can ask oneself why not more organisations are cooperating closely if collaborations can be this advantageous? To gain a better understanding of the interactions between firms, we must recognise which collaboration design is the most advantageous for each organisation. This is the topic of the next subchapter.

2.3 Collaboration design

"Inter- (between) and intra- (within) firm relationships management is one of the most discussed and potentially least understood topic areas within supply chain management" (Cousins et al., 2008). The confusion and lack of knowledge Cousins et al. (2008) is referring to is closely linked to the nature of inter- and intra- firm relationships. This study focuses on the first variant, namely the one dealing with multiple organisations. Interorganisational collaborations come in an almost infinite variety of designs, and none are exactly identical. Some are formal collaborations, with rules and contract agreements between the alliance partners (Wideman, 1992). Some are informal, and sometimes not even perceived by the organisations involved (Cousins et al., 2008).

The timespan of collaborations also vary to a great extent. Some only last for a very limited time, like short-term projects. These are temporary entities, only to be disbanded after completion. Cousins et al. (2008) refer to short time relationships as "tactical", and these have traditionally been associated with temporary competitive tactics such as cost reduction. Chen (1997), however, have suggested that R&D-collaboration is both a strategic and tactical activity. Tactical R&D projects are most often linked to development, while strategic R&D alliances are more focused on basic research. Strategic collaborations can be lasting for decades, like the case of NTNU and SINTEF in Norway (SINTEF, 2010). Long term relationships are referred to by Cousins et al. (2008) as "strategic" because of the collaborators' desire for a joint focus on supply chain management (SCM), sharing of resources, and joint NPD and R&D. This accords with Gulati (1998) and his definition of strategic alliances as voluntary arrangements between firms involving exchange, sharing, or co-development of products, technologies or services.

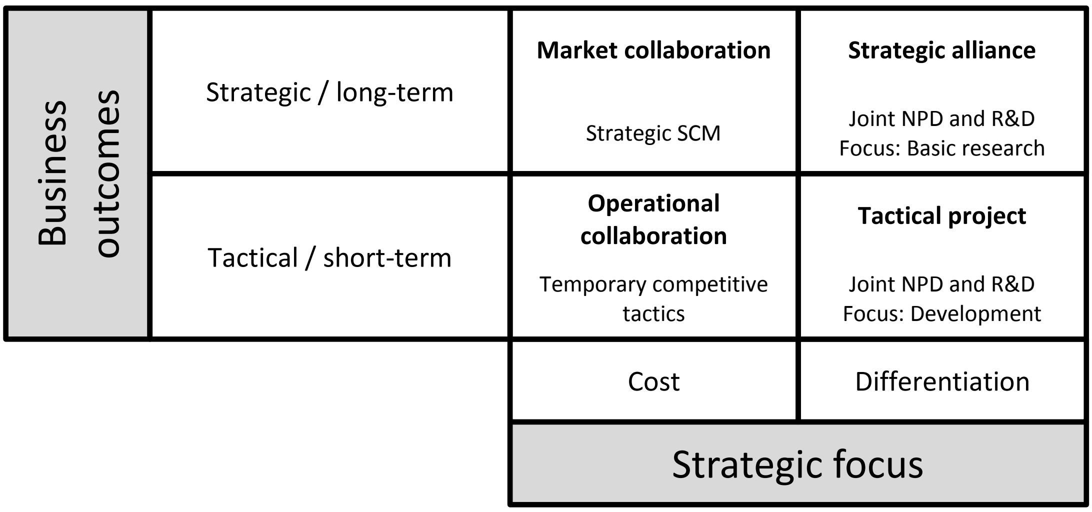


Figure IV: Strategic positioning model. Source: Cousins et al. (2008), Chen (1997) and Gulati (1998).

Cousins et al. (2008) also explains that strategic collaborations differ in their strategic focus, and choice of competitive advantages. For collaborations that seek differentiation more than cost reduction, strategic and long-term partnerships are the favourable solution, they claim. This is, according to Chen (1997), an overplayed assertion. He claims that such a view exclusively regards R&D partnerships as a corporate level task, and completely ignores near-market research (development) collaborations. According to Porter (1998), a differentiation strategy is about providing unique products or services highly sought-after in the market. Differentiated firms often pursue innovation and improving time-to-market, activities which are typical for NPD and R&D ventures.

According to Cousins et al. (2008), interorganisational collaborations are also known to be limited to a confined level in the organisations, and in some cases only pertinent for a certain product or service. Hence, it is not easy to define the nature of interorganisational relationships; and to make matters even more complex, collaborations are not static entities. They change over time, and will often be perceived differently from person to person. This is the reason why Cousins et al. (2008) define relationships as dynamic processes rather than entities, which require inputs and outputs. Inputs can be resources like knowledge, technology, finances and time. Outputs can be cost reduction, knowledge development or risk sharing. Closer relationships imply more extensive sharing of both inputs and outputs. As illustrated in Figure IV, R&D-collaborations are found in top right corner of the model, being both strategic and differentiated.

2.3.1 Organisational power and motives

Before initiating searches for potential collaborators, the searching organisations need to define the characteristics of their ideal partner. The literature of Håkansson and Snehota (1989), De Wit and Meyer (2010) and Cousins et al. (2008) proposes that the there is no universal solution to this enquire, but for each organisation the answer is heavily dependent of its strategic focus, power and motives. Das and He (2006) describes nine intrinsic motivational factors for collaborations between entrepreneurial SMEs and large established firms, as seen in Table II. Entrepreneurial and established firms are at the extremes in both ends of the organisational power scale in the private sector. Even so, it is the author's opinion that the intrinsic factors are relevant in any collaborative setting where the size of the organisation is a factor.

Entrepreneurial firms are short of financial, manufacturing, and marketing resources. They are, however, more creative and innovative. To survive and grow bigger, they need to possess such qualities to make up for their lack of resources, political power, and experience. Established firms have plenty of resources, but are more bureaucratic and less innovative. They have a long track record, and know their environment well. This has allowed them to gain political power and legitimacy in the market.

Intrinsic factors

	Entrepreneurial firms	***Established firms***
Resources	Short of financial, manufacturing, and marketing resources.	Affluent in financial, manufacturing, and marketing resources.
Innovativeness	More innovative.	Less innovative.
Status in competition	Challengers in competition.	Defenders, vulnerable to competition from newcomers.
Legitimacy	Less.	More.
History/track record	Scarce.	Sufficient.
Economic/political power	Little influence over the environment.	More economic and political power.
Organizational characteristics	Structure: clan, informal. Communication: fewer levels, frequent, informal, more horizontal. Decision making: speedy, flexible, informal, centralized from the top, keeping options open, and opportunist.	Structure: bureaucratic, formal, fragmented. Communication: more levels, slower, infrequent, open to distortion, barely horizontal. Decision making: slow, consensual, decentralized at the intermediate levels, and long-term strategies.
Business focus	Products and services.	Expansion in scale and scope.
Planning horizon	Speedy development.	Not in a hurry.

Table II: Intrinsic factors. Source: Das and He (2006).

Das and He (2006) argue that especially entrepreneurial firms should choose their partners carefully when entering into an alliance. Some established firms consciously seek alliances with entrepreneurial firms that possess new and innovative ideas, only for acquiring their resources to reduce possible competition in the market. If this is their agenda, the entrepreneurial firms risk ending up in an unfruitful collaboration together with an unmotivated partner. Smaller companies are also reported to take advantage of their alliance partners, especially when their supply is unique and indispensable to their alliance supply chain. Excessive exploitation of one's position is very undesirable for the whole supply chain. It is therefore crucial for any business alliance that the companies involved share the same motivations. Anderson and Jap (2005) further emphasises this, and also points out that alliances will face serious problems if some of the partners start off with selfish motives and only wishes to exploit the relationship. Still numerous case studies have reported that companies often choose immediate and short-term gains over long term benefits, by exploiting their partners trust (Anderson and Jap, 2005).

2.4 Partner selection

Selecting the right partner is the most crucial decision in the collaboration process (Varis et al., 2005). Collaborating organisations share a mutual interdependency, and the collaboration's health is dependent on the organisations' ability to cooperate (Cousins et al., 2008). How should they manage this task? Håkansson (1990) asked a similar, but far more basic question: Can one in fact plan organisational relationships?

Much research has been done on interorganisational collaborations and business alliances (Håkansson and Snehota (1989), Freel (2000), Hakansson and Ford (2002), Schilling and Phelps (2007) and Ritter and Gemünden (2003) to mention a few), including several case studies on the partner selection process. Case studies on partner selection have also been carried out by private businesses to improve their collaborations' efficiency and profitability. One example is Dow Chemicals, and how they formed a business alliance dealing with optical communications (De Wit and Meyer, 2010). They used the Spatial Paradigm for Information Retrieval and Exploration (SPIRE) database to find companies that held patents which complemented their own. Nevertheless, despite all the work conducted on this topic, few general tools for finding alliance partners exist (Dyer et al., 2001, Petersen et al., 2005). Usually all such aids are tailored to a specific business, and not applicable to other organisations or alliances. According to Varis and Salminen (2000), in their study of the turbulent environment of the Infocom business, the partner selection process represents a knowledge gap between the alliance partnering theory and practice.

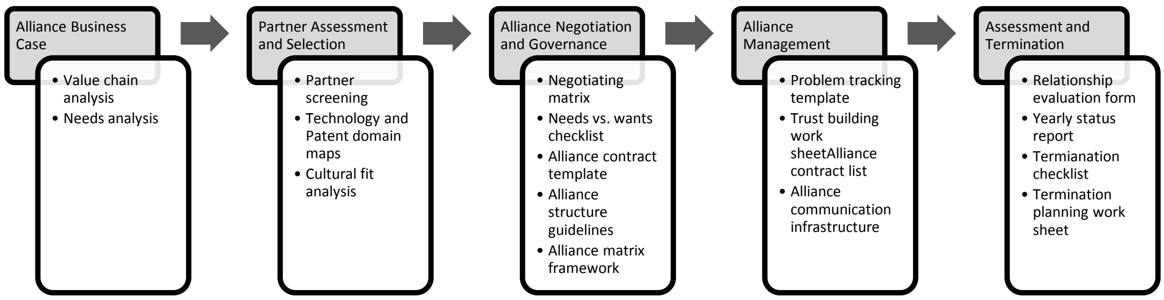


Figure V: Collaboration life cycle framework. Source: Dyer et al. (2001).

The conventional partner assessment and selection process is to follow the procedures as explained in the two first steps of the collaboration life cycle framework (Figure V) by Dyer et al. (2001). They suggest that the first step should be a value chain and needs analysis. After the organisation's needs have been defined, partner screening should be initiated in the second step. Fontana et al. (2006) suggest that this should be a two-step operation, which they call searching and screening. The first step (searching) should consist of a broad search for all possible candidates. The second and final step (screening) should be the identification of the best candidate. How these steps should be carried through is not specified by Fontana et al. (2006), but their study reveals that companies uses a variety of tools and sources for their searching and screening strategies; they subscribe to various journals, attend to conferences, searches the internet, looks through patents, and takes advantage of their suppliers' networks. The information reported to be most crucial for the partner selection decision were the organisations' reputation and their domains of capability. Especially universities were selected on the basis of their ability to solve specific problems, and their KT-capabilities.

According to Dyer et al. (2001), organisations should acquire technology and patent domain maps, before carrying through a cultural fit analysis. The cultural fit analysis will require a due diligence team to do a unique case study after a potential partner is acquired; in other words a post-search procedure. Dyer et al. (2001) deem it very important to assess the potential partners' corporate values and expectations, organisational structures, reward systems and incentives, leadership styles, decision making processes, patterns of human interaction, work practices, history of partnership, and human resources practices before entering into an alliance.

Fontana et al. (2006) also mention the importance of being visual to other organisations that are searching and screening for partners. This is called signalling, and it can be carried out by disclosing pieces of knowledge or to show off the organisation's special abilities, e.g. through publications, patents, conferences or other documents on the internet. Empirical research has shown that searching, screening and signalling are all effective methods of promoting R&D-collaborations (Fontana et al., 2006).

2.4.1 Measuring knowledge

Networks of organisations can be analysed empirically from various types of bibliometric data sources, such as articles, patents and press releases. Melin and Persson (1996), Balconi and Laboranti (2006), Fleming et al. (2007), Valentin and Jensen (2002), Sternitzke et al. (2008), Rafols et al. (2010), Porter and Rafols (2009), Rafols and Meyer (2010), Janssens et al. (2008) and Mislove et al. (2007) have all demonstrated that such bibliometric sources can be applied within their own organisational domain, and amongst various technological fields, to help strategist to obtain a better understanding of the players involved and the ties among them. The use of bibliometric information sources is especially advantageous when combined with Social Network Analysis (SNA) techniques and tools, which can be used to organize, interpret and present the network data.

Bibliometrics are written sources of information that have been quantified (Van Raan and Tijssen, 1993, De Bellis, 2009). Because it is quantified, this information can be applied in mathematical models, to for example produce statistics (DeSolla Price, 1976). Examples of bibliometric sources can be scientific publications, patents, press releases and interviews (Murray, 2002). Many network studies have been done by analysing bibliometric sources such as these, some examples are Rafols et al. (2010) and Porter and Rafols (2009) for publications, and Balconi and Laboranti (2006) and Sternitzke et al. (2008) for patents. Some studies have even applied combinations of sources, like Murray (2002). Jin et al. (2008) did a study on how to use a general purpose search engine for data mining purposes, which can be a method of gathering data from press releases. However, press releases seem to be a much less used source of data in bibliometric studies.

Although there are many different bibliometric sources, most of them possess some very similar types of data (Murray, 2002). Both a publication and a press release will have one or more authors, and a patent will have an owner. In addition, they will most likely site other publications, articles or patents. The most common bibliometric data types used in network analysis are:

- ***Name of authors/owners:*** Widely used in social network analysis for studying the roles and capabilitys of individuals in a group. By counting the numbers of publications or patents that is written or owned by individuals, within a limited technical or scientific scope, one can measure the influence of each person. Amongst other things, this information can reveal the true structure of information flow in an organisation (Burt, 1980, Murray, 2002, Rafols and Meyer, 2010).
- ***Name of authors' or owners' organisation:*** By crosschecking with a reference database, we can acquire the organisation type of the authors' affiliation. It is then possible to do the same analysis as mentioned for the publication authors or patent owners to obtain an overview of the roles and capabilitys of the organisations involved in a given technical or scientific area (Burt, 1980, Murray, 2002, Rafols and Meyer, 2010).
- ***Citations and co-citations:*** For publications, this measurement can give us a measurement of how "good" other authors consider each publication to be. However, as explained in DeSolla Price (1976), a publication which has been frequently cited is more likely to be cited again than an uncited publication. It is therefore an unfavourable method of measuring quality or relevance of publications. For patents, citations of prior art can tell us what earlier technological innovations and inventions that made this patent possible (Fleming et al., 2007).
- ***Time of publication:*** By looking at the time of publication we can observe the evolution of scientific and technological networks (Murray, 2002).

2.4.2 Visualising knowledge

Information about interorganisational networks engaged in a given technological field can serve as a valuable resource for organisations in many ways, and can be particularly beneficial in competition analysis, due diligence and when searching for partners in R&D projects (Sternitzke et al., 2008). An organisation's network is its connections throughout its environment. Information about interorganisational networks can be used as sources for strategic intelligence (Gulati, 1998). The pattern of ties amongst the organisations can be analysed to provide a descriptive map of their relationships. This map can assist in understanding how organisations or groups of organisations influence their network, how resourceful they are, or even describe the organisations resulting from a network (Gulati, 1998).

SNA is the field within Sociology which deals with the relationships between actors in a given environment (Sternitzke et al., 2008). Historically, SNA has generally been applied in studies on groups of people or animals and how they interact, but it's tools and well-established techniques can in principle be used for measuring role equivalences in any given network (Stuart and Podolny, 1996). The major strength of these tools is their intuitive and elegant way of visualizing huge amounts of information in a single "map" consisting of the network players and their relationships (Sternitzke et al., 2008, Ter Wal and Boschma, 2009, Newman, 2003). These maps are called *sociograms*, but are also often referred to as "maps", "graphs" or "diagrams". In the multi case study of Sternitzke et al. (2008) the researchers produced a unique sociogram for each network case they observed, most of them containing information from several thousand sources (in this case patents). The patent data could naturally have been presented as plain text, but this would almost be impossible to comprehend and make no sense to a human observer. Instead, a set of sociograms, representing each of the interorganisational networks, depicted the patent data in a simplistic and intuitive manner. Newman (2003) and Borgatti (2002) both explain that sociograms basically consist of two elements: *nodes* which represent the players in the network, and *edges* which represent their relationships. They describe the properties of *nodes* and *edges* as following:

- ***Nodes:*** Represents the fundamental unit of the network. Nodes may represent people, organisations, animals, products, neurons, etc. Attributes which often are used to describe the properties of nodes are colour, shape and size, e.g. companies can be represented as blue and universities red, and the number of published articles or patents on a given subject can be reflected by the size of the organisation's node. Nodes are also known as *vertices, sites* or *actors,* depending on the scientific subject area. In this document, nodes represent organisations. Their size represents how many publications or patents they hold, and their colours represent either organisation type (institutions are red, companies are blue, and

NPOs are yellow) or community affiliation (each community have their own colour), depending on the sociogram type.

- ***Edges:*** Represents the connections between nodes. If two nodes are connected in conjunction with the studied phenomena, a line will stretch from one node to the other; e.g. if we are studying co-published articles, and two professors have published a number of articles together, we draw a line between the professors. This line is called an edge, and the property of the edge is usually its thickness, representing the degree of connection (for the professors this would be the number of co-published articles). If there is no connection between the nodes, e.g. if the professors have not published any articles together, there will be no edge connecting them. Edges are also known as *bonds*, *links* or *ties*. In this document, edges represent co-patents and co-publications. Their thickness represent the amount of co-patents or co-publications each organisation-pair share.

There are several key observations that can be drawn from a sociogram. Newman (2003) and Burt (1980) explain that an observer will easily be able to spot the main players of the network by the size of the nodes. The relative influence of each player will be obvious to the human eye, by observing and comparing the size of the nodes. The organisations that are connected, and the strength of their connections, will be obvious by the size of the edges.

The structures of the relationships will also effortlessly be revealed by the observer of the sociogram. The literature distinguishes between *centralized* and *decentralized clusters* of nodes (He and Hosein Fallah, 2009, Bastian et al., 2009). Centralized clusters have a *network hub* which connects all the other nodes, and also is the connection to the rest of the network. Decentralized clusters are groups of well-connected nodes. These are not dependent of any single node to maintain the connection within the cluster, nor to the rest of the network. An illustration of centralized and decentralized clusters is seen in Figure VI; the dots are nodes, and the lines are edges.

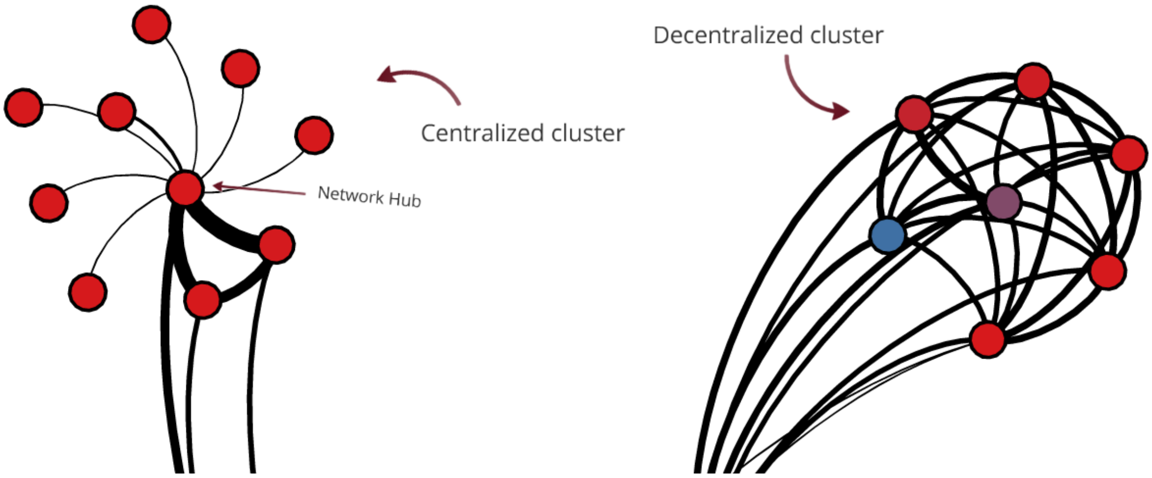


Figure VI: Centralized and decentralized clusters. Source: Own illustration based on He and Hosein Fallah (2009).

Another method which is extensively used in SNA is called *centrality* (Burt, 1980, Borgatti, 2002), which is also often referred to as *modularity* (Bastian et al., 2009). Centrality differs from the previously described approach by giving the same colour to nodes that interact more frequently together (Bastian et al., 2009). This can help an observer to easily spot communities and clusters of closely related players in a network. An example of centrality in a sociogram can be seen in Figure VII which displays the fictional characters of Les Misérables. We can observe the relational bonds between the characters by looking at the connecting edges, and we can distinguish the communities of frequently interacting individuals by looking at the colours of the nodes. The centrality of a network can be measured mathematically using a set of equations (Borgatti, 2002, Newman, 2006, Burt, 1980). Today we fortunately have computers that easily can calculate the centrality of a network for us, by means of specialised computer software like UCINET (Borgatti, 2002) or Gephi (Bastian et al., 2009).

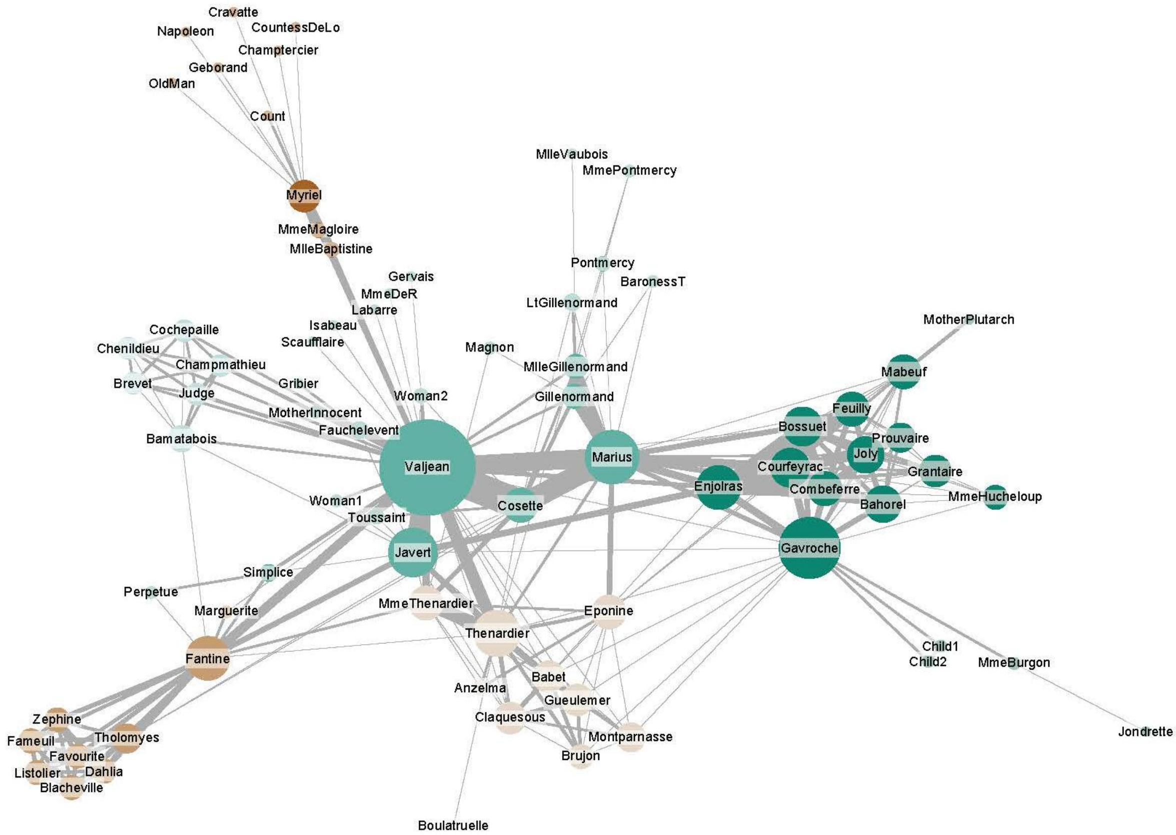


Figure VII, A centrality sociogram of the characters from Les Misérables. Source: Bastian et al. (2009).

Networks have been studied in several different scientific areas beside social sciences, including mathematics, where they play a significant role in discrete mathematics (Newman, 2003). Because of this extensive and broad appliance of network theory, there are many other ways to interpret sociograms in addition to the ones mentioned in this document. These additional methods will not be discussed further here, but an explanatory overview of sociogram functions, attributes and terms can be found in Newman (2003).

2.5 Theoretical main model

This last section of the literature review will sum up and conclude on the theory. It will touch upon the topics that have been most essential to the empirical research of this study, and fundamentally important for the understanding of the following chapters.

All organisations interact with their environment and its organisations. According to De Wit and Meyer (2010), these organisations can be sorted into two main categories; industrial actors and contextual actors. Industrial actors are suppliers, buyers, competitors, and complementors. The contextual actors are socio-cultural actors, economic actors, political/legal actors, and technological actors. This study is focusing on the technological actors.

R&D is very resource demanding, and often only obtainable through M&A or interorganisational collaboration. When M&A is not an option, organisations must consider joining their forces with others, in order to realise their growth strategies. There are many different forms of formal collaborative arrangements, such as international marketing alliances or joint ventures. More often organisations are not aware of their relationships; at least not those of their partners. Third party organisations can have a great impact on the interorganisational network.

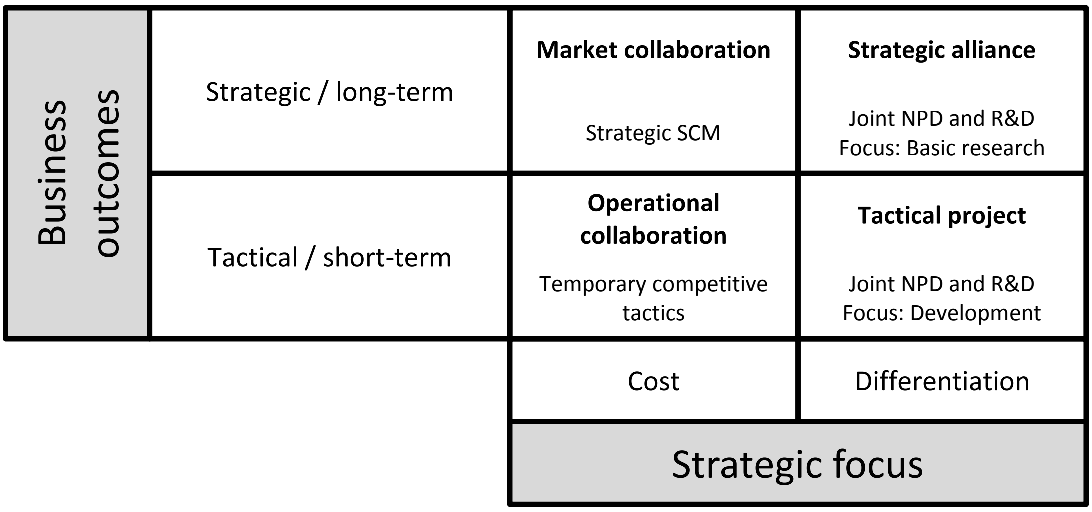


Figure VIII: Strategic positioning model. Source: Cousins et al. (2008), Chen (1997) and Gulati (1998).

Companies and academic institutions each have their strengths in high-technological NPD and R&D. In general, companies have superior production capabilities, and are often very specialized in their business. Academia has superior and broad knowledge, but lacks the means of producing prototypes and instruments. Academia/industry collaborations have been, and still are, rare. Studies have, however, demonstrated that such collaborations are extremely beneficial not only to academia and industry, but also to society at large. KT among organisations seems to be stimulating technological innovation; a highly requested asset in today’s society.

When planning for collaboration, the organisation needs to align its strategy with that of the collaboration's design, or vice versa. R&D-collaborations are very different from market collaborations such as buyer-seller relationships. Differentiation is the main goal of NPD and R&D-collaborations. Long term strategic alliances are superior for basic research; tactical projects are favourable for near-market development projects (see Figure VIII). Organisations should also be aware of their partners' agendas, to avoid being exploited. Clinches between entrepreneurial and established firms are a common problem, and will have a negative impact on the collaboration.

The partner selection process of a R&D-collaboration should be initiated after an initial needs analysis, and end before contacting and negotiating with any potential partners. The process is a two-step operation called searching and screening (Fontana et al., 2006) (see Figure IX). The first step (searching) involves a broad search to catch all possible candidates. In the second step (screening) the most promising candidates are filtered out, on the basis of criteria from the needs analysis. In R&D alliances and projects, high-tech capabilities are paramount to the success of the collaboration. A cultural fit is also vital in an interorganisational relationship, and should also be assessed in the screening process.

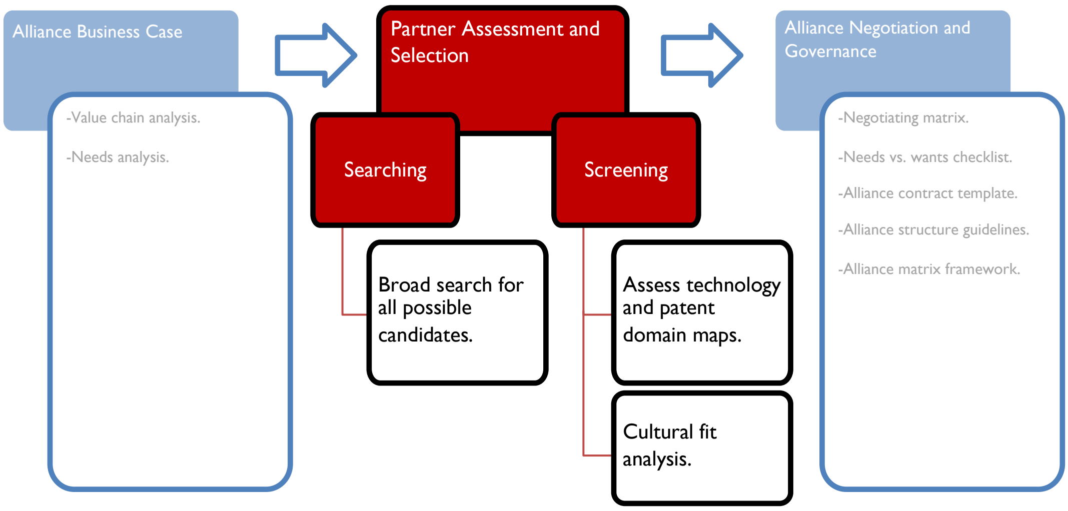


Figure IX: Searching and screening in partner selection. Source: Dyer et al. (2001) and Fontana et al. (2006).

Organisational high-tech capabilities and knowledge can be measured by means of bibliometric documents such as publications, patents and press releases. Bibliometric data can be assessed from online databases. By extracting bibliometric data on a specific technological subject, it is possible to create sociograms displaying the network of organisations affiliated with the bibliometric documents. The most capable and knowledgeable organisations can be revealed by studying the sociograms.

3 Methodology

This chapter considers the methodology of this study. It presents the rationale and procedures applied in the empirical part of the study, and explain how data has been conducted. The decision making process of choosing a case study design is discussed, along with the iterative process on developing the conceptual framework. This is followed by an explanation of how the necessary literature has been gathered, and why this literature has been selected. The study's validity and reliability is also accounted for and discussed. The chapter ends with an explanation of the conceptual framework and the IT tool.

3.1 The case study

This study uses an embedded single-case design (Yin, 2009), as displayed in Figure X. Its context is partner selection in R&D-collaborations, the case is PSSSDs, and the embedded units of analysis are five technologies associated with PSSSDs. All three research questions begin with "how", resembling what Yin (2009) refers to as explanatory questions. This is true, although the study also bears some resemblance of an exploratory nature. While it tries to explain an organisational process, namely partner selection in R&D-collaborations, it also proposes a conceptual framework for this task. There is one additional feature about this case study design worth noticing; although all the reviewed technologies are associated with PSSSDs, some are more exclusively applied in this technological category than others. This is further discussed and explained in Chapter 3.4.3. An illustration of the embedded single-case design is displayed in Figure X.

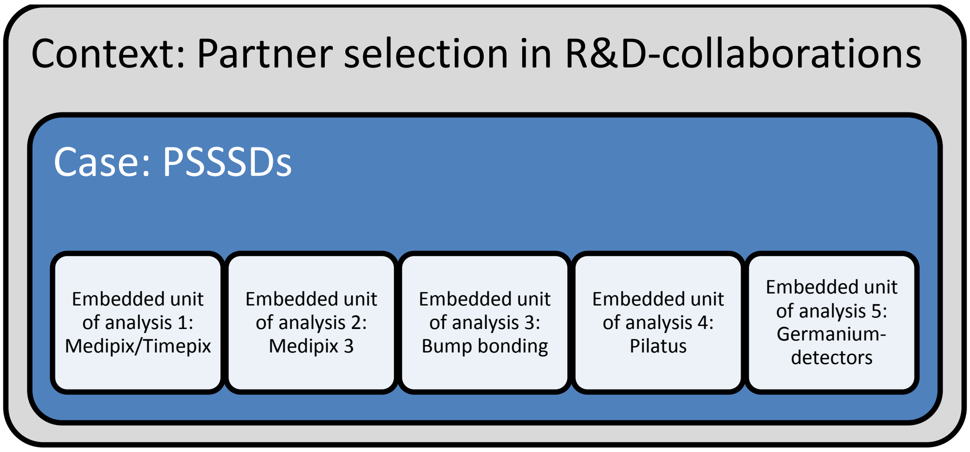


Figure X: Embedded single-case design. Source: Yin (2009).

According to Yin (2009), one of the major pitfalls of an embedded case study design is to focus too heavily on the subunits, thus failing to describe the holistic view of the case. This study has been structured to counter this potential issue by splitting its empirical part into two components; one concerning the holistic view of partner selection in R&D HEP-collaborations, and one reviewing the five PSSSD technologies. The first part is purely qualitative, relying on interviews and document analysis. The second part is a combination of quantitative data-analysis and qualitative expert judgement. The quantitative findings, obtained by the use of the conceptual framework, are reviewed by technology-experts. Their judgement is the fundament for both the evaluation of the framework, and the study's finale conclusions.

Partner selection in R&D-collaborations is a complex subject. Its many uncertainties, variables and practical implications, are the rationale behind conducting a case study in this research project. It is probably impossible to prove which exact organisation is another organisation's best suited collaborative partner in a discreet collaboration case. It might however be possible to make a statistical description of the ideal organisation by the means of a survey (Yin, 2009). This would require the study of dozens or even hundreds of collaborations over a timespan of several years. In doing so, one could try to isolate the organisational properties of the collaborations that proved to be successful, and thus create a framework that could model the average organisation's perfect partner. However, even if this is practical conceivable it would require an enormous amount of time, and effort. Far less is needed to obtain a satisfactory holistic view, by performing a qualitative case study.

3.2 Limitation of research

The written works needed for the literature review were gathered from internet databases such as Scopus and Web of Knowledge. Books from the CERN library were also read and studied, along with the author's own collection of books.

A great deal of research has been done on interorganisational collaborations, and one of the most recognised authors on this subject is the Swedish professor Håkan Håkansson. He is one of the main contributors to the Industrial Marketing and Purchasing (IMP) perspective; a theory on inter-firm relationships and technological innovation (Holmen et al., 2005).

This study focuses on a special part of interorganisational collaborations, namely the partner selection phase. The study is also in the context of R&D-collaborations, which is very different from e.g. buyer-seller relationships. The majority of research on interorganisational collaborations, including nearly all the works of professor Håkansson, focuses on events posterior to the partner selection. Håkansson has also written much about industrial networks, and some of this has been included in the literature review of this study.

Literature on early-phase partner selection in both academic and industrial R&D-collaborations was mainly selected for review in this study, in addition to some of the classical works on interorganisational collaborations. The theory needed to back up the research questions was picked out on the basis of a set of questions. In line with the suggestion by Scholz and Tietje (2002), for situations when the researcher has conceptual ideas about the future of the case, a top-down approach was used to structure the literature review, as seen in Figure XI. The plan was to start out as broad as possible, and slowly limit the scope to match the main subject.

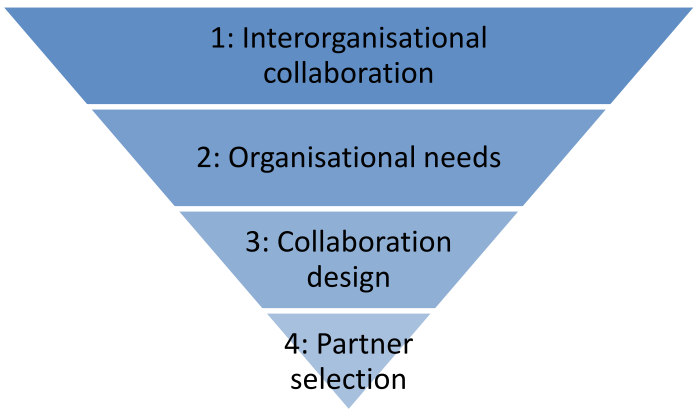


Figure XI: Top-down approach of literature review. Source: Scholz and Tietje (2002).

The rationale behind the selection of literature can be described as follows:

1. Initially it was deemed necessary to explain what interorganisational collaborations are, and what types of collaborations that exist. This subchapter would also include an explanation of university/industry collaborations; a particularly favourable concept in R&D-collaborations.
2. The next section should look into why and when interorganisational collaborations are needed. Organisational needs would be the central issue in this chapter. Drawbacks and benefits of interorganisational collaboration would be examined to acquire an understanding of the situational conditions that favours collaboration over other horizontal integration strategies. The scope of the theory would be further limited through a review of the nature of high-tech and the issues of KT.
3. The third section should examine different collaborative designs, and which of these each collaboration should choose. The answer to this question is heavily influenced by the nature of the organisation's strategy, power and motives.
4. The last section would concern the qualities which organisations seek in their collaborative R&D partners. This would require a closer look on the challenges associated with measurement of organisational competence and knowledge, how this can be applied in a partner selection process, or if any of that is even possible. The necessity of understanding the structural properties of interorganisational networks would be underlined, along with an explanation of the sociogram.

3.3 Interviews and observations

The qualitative sources referred to in this study can be divided into two main categories; interviews and participant-observations (Yin, 2009). Two types of interviews were conducted; focused interviews, and in-depth interviews. The participant-observations were collected during the author's stay at CERN, which lasted throughout the whole study.

The focused interviews were all related to the reviewed technologies. The experts were asked to give feedback on the sociograms produced for each technology, and judge the quality of them. They were also asked to comment on the procedures and methodology of the conceptual framework and the IT tool. The three interviewees were Dr Stanislav Pospisil, director of Czech Technical University in Prague (Pospisil, 2012), Dr Michael Moll, physicist and detector developer at CERN (Moll, 2012), and Dr Marc Winter, physicist at CERN and member of the Medipix collaboration (Campbell, 2012).

The in-depth interviews were those of the author's supervisor Dr Le Goff, at the CERN finance and procurement department (Le Goff, 2012a, Le Goff, 2012b, Le Goff, 2012c), and Dr Hartmut Hillemanns, at the CERN KT-department (Hillemanns, 2012a, Hillemanns, 2012b). Although the author spoke weekly with both Dr Le Goff and Dr Hillemanns, some concluding and summarizing discussions, dedicated exclusively to the subjects of the study, were also conducted. All the in-depth interviews with Dr Le Goff referred to the technologies, the conceptual framework, and the IT tool. The first interview with Dr Hillemanns (Hillemanns, 2012a) was regarding partner selection in R&D-collaborations and KT. The second (Hillemanns, 2012b) was about the reviewed technologies.

The participant observations are linked to the author's stay at CERN. By conducting this study at the heart of CERN's KT-centre, he got an excellent opportunity to experience how interorganisational R&D-collaborations are managed in European HEP-projects. The key informants have been Dr Le Goff and Dr Hillemanns at the CERN KT-department. Weekly informal discussions gave continuous insight from the inside of the organisation; information that was invaluable to this study. Yin (2009) explains that participant observation is an extremely valuable source of evidence, but it is also associated with some methodological issues. Because the author participates in the observed environment, or even the case itself, he/she might be biased towards it. This has also been a potential issue in this study. Both the author and his supervisor Dr Le Goff have had close connections to the KT staff at CERN. The other interviewed experts have, however, had no connection to the author, although some of them work in the same organisation.

3.4 Strengths and weaknesses of the study

Yin (2009) explains that four special tests are often used to measure the quality of case studies. These are called *construct validity*, *internal validity*, *external validity*, and *reliability*. In this subchapter, all of these will be discussed in accordance to this study.

3.4.1 Construct validity

The qualitative empirical data in this document was gathered from several interviews with experts on each of the reviewed technologies. Like for most case studies, the construct validity of this study suffers from subjective judgements. An attempt to reduce this weakness has been to interview several experts in the field of PSSSDs. Each expert has been asked to comment on all of the sociograms, allowing the author to triangulate their evaluations. Any differences in the experts' view on the technologies were brought up and discussed during the interviews. The risk of an interviewee being either biased or having an alternative understanding of the situation, thus providing misstatements which could lead to false results, was hopefully reduced this way. However, most of the interviewed experts are working at CERN, which might pose a risk to the study's construct validity. People in a community sometimes succumb to groupthink, but because CERN is such a large organisation, and the fact that the project organisation behind the reviewed technologies are not actively working together, the author does not regard this as a substantial issue for this study.

The quantitative empirical data used in this document was gathered from two large internet databases. Patents were gathered from Thomson_Innovation (2012), and publications were gathered from the Web_of_Knowledge (2012). Both of these services are owned by Thomson Reuters, and they are regarded as very reliable sources by the HEP-community (Le Goff, 2012a). Thomson_Innovation (2012) is a world-wide patent database which both provides a search engine that supports full text searches, and allows the users to extract his/her search results. Web_of_Knowledge (2012) is the database most frequently used by the HEP-community (Le Goff, 2012a), and it holds more than eleven thousand scientific journals (Web_of_Knowledge, 2012). The extracted bibliometric documents used in this study were processed by a computer algorithm. It sorted and prepared the data for the sociogram software (Borgatti, 2002, Bastian et al., 2009). This process is explained in Chapter 3.5.1. Pre-defined values were selected for both this process and the finale analysis of the results. The same method with the same rules was applied for all the technology reviews, to support the construct validity of the framework.

It is also worth mentioning that both the creation of the sociograms, and the qualitative expert judgements were discussed with the author's supervisor Dr Le Goff on several occasions throughout the study.

3.4.2 Internal validity

By following the logic of Yin (2009), the best tactic for achieving satisfactory internal validity is a solid explanation building, logic models and pattern matching. The methods used to gather and process the quantitative data in this study is explained in Chapter 3.5.1. The conceptual framework is explained in Chapter 3.5.

The accuracy and quality of the conceptual framework and the IT tool is almost impossible to measure precisely by statistical methods. It would require hundreds of case studies, carried out over a time period of several years. Instead of measuring the internal validity statistically, various experts have been consulted to comment on the results made by the IT tool. These experts are the best qualified persons to judge if the methods used are appropriate or not.

A central part of this study, namely the process of making sociograms from bibliometric documents, has some similarities to an exploratory quasi-experiment (Campbell et al., 1966, Shadish et al., 2001). Bibliometric data is processed by the means of various computer algorithms and software, with the finale goal of producing sociograms mapping the network of affiliated organisations behind the bibliometric documents. As explained by Yin (2009), Campbell et al. (1966) and Shadish et al. (2001), quasi-experiments demands an extra attention regarding their internal validity. This is due to their lack of random assignments, which is true for this study as well. As an embedded case study, it addresses only a few hand-picked technologies. However, the IT tool applied in this study is building on prior research and a defined set of rules. The linking between bibliometrics and organisational characteristics such as knowledge and capability is also confirmed by other scientist, and so are the properties of the conceptual framework. This is explained in this document's literature review and further elaborated throughout the discussions with the consulted experts. The methods and tools used in this study are not new themselves, but the combination of them, and the domain in which they are applied, is a novel approach to the challenges of interorganisational partner selection.

3.4.3 External validity

The applicability of the conceptual framework is limited to interorganisational R&D-collaborations. As long as competence and knowledge are main factors of the collaboration's success (which is the case in R&D-collaborations), the framework will be relevant for the partner selection process. The reviewed technologies were selected to cover as many different situations as possible. This would help estimating the framework's range of applicability. The technologies are all connected to PSSSDs, but some of them are also used in many other technological domains. A screening of alternative technologies was conducted in the beginning of the study, but the ones undergoing analysis were selected after the pilot case of Medipix/Timepix. It was decided that the technologies should be distributed evenly along the dimensions of the properties selected as situational variables. These were "purpose of the technology" and "scope of the technology". All the technologies underwent evaluation based on these properties, and were weighted against each other during the selection process. The purpose of the technology, spanning from scientific to commercial, would consider the priorities of the different organisation types. The scope of the technology, spanning from specific product to technology category, would consider how specific the technology search must be. Five technologies, which can be seen in Figure XII, were selected on these premises.

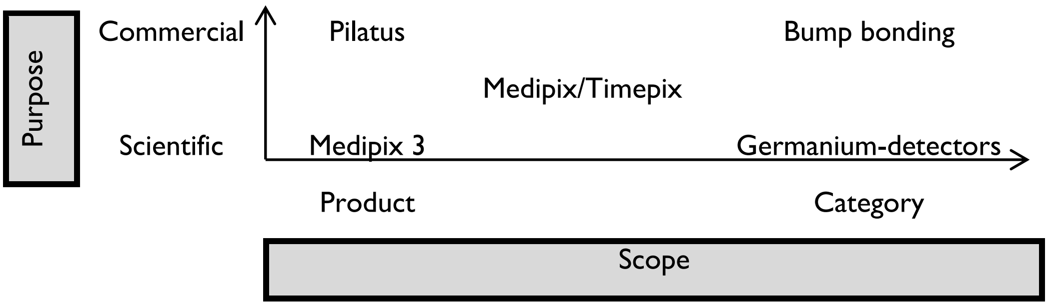


Figure XII: Technology selection rationale.

3.4.4 Reliability

The quantifiable data used in this study is still available at the databases from where they were extracted, and they will most likely stay available for a very long time. If one would try to replicate the study by using a similar, but different database, the results could deviate from the ones presented in this study. However, the largest databases of scientific publications share many, if not most, of their articles. It is therefore highly likely that the publication searches would turn out quite similarly for other databases. The case of the patent searches is somewhat different. The quality of the services provided by online patent databases are fluctuating, to say the least. The database applied in this study is one of relatively few international patent databases that provide an advanced search engine which allows for full text searches and extraction of bibliometric information (Le Goff, 2012a). Nevertheless, if the same or a very similar database were to be used, identical results would be obtainable.

There are some potential reliability issues related to the use of the conceptual framework and the IT tool. First, the bibliometric searches are heavily dependent on the search queries. To be able to formulate a constructive search query, substantial pre-knowledge is required on the field of interest. Nevertheless, even if the user is familiar with the technological topic, there is still a chance of error due to unforeseen topics that share the same words as those listed in the search query. While developing, using and perfecting the IT tool throughout this study, three recursive and closely linked issues constantly required the author's attention. These issues are related to the first step in the IT tool, and they represent a potential pitfall to the reliability of the search results. In this document the issues are referred to as *fault exclusion, pertinence inclusion* and *purpose*:

- ***Fault exclusion:*** The first issue is about limiting the results to only include bibliometric documents pertinent to the technology topic. If one is to search for bibliometrics on the particle detector called "Pilatus", which is the case in this study, one would not like to end up with results relating to zoology. This can, however, easily happen because a famous zoologist is named Pilatus. If this unfortunate misunderstanding was not discovered, it would create a wrong picture of the technological topic in the finale sociograms.
- ***Pertinence inclusion:*** The second issue is about including as many of the pertinent bibliometric sources as possible. It might be tempting to exclude every search word that leads to faulty hits, but this might also result in the exclusion of many pertinent hits. If too many search words and phrases are excluded from the search, it will result in an immensely distorted image of the real situation. The consequence will be a network representation free of irrelevant organisations, but also missing many pertinent organisations. Thus the challenge is to balance the specification of the search query to both include the relevant and exclude the irrelevant bibliometric documents. This has to be a manual and iterative process.
- ***Purpose:*** The third issue is whether the bibliometric document is concerned with development or application of the technology topic. This does not necessarily have to be a problem, but it will have an impact on the information displayed in the sociogram.

There are two obvious solutions to these issues. The first is to be proactive by pre-defining and specifying the search phrase as good as possible before searching. An expert's assistance would be a great aid for this task. The second solution is to analyse the search hits, and afterwards perfect the search. This is an iterative process, and can potentially be quite time consuming for searches with thousands of hits. One solution can be to limit the test samples to a small and random selection, if the number of results is insuperably large. If this is not possible, one can accept the possibility of faulty hits, and only check a portion of the search hits. Consequently, the results could contain some errors, but likely only a limited amount. The faulty result would be possible to filter out in the process of creating sociograms by only including organisations holding a certain amount of publications or patents. The searcher would not get the full picture of the organisational network on the technological topic, but he/she would be able to spot the most dominant players.

3.5 The conceptual framework

This case study proposes a conceptual framework for partner selection in interorganisational R&D-collaborations. The framework is benefiting from both literature, and empirical data gathered at CERN. Its fundament is based on prior frameworks and theory on partner selection, interorganisational collaboration, and strategic R&D alliances. The most influential prior theories and frameworks are those of Dyer et al. (2001), Fontana et al. (2006) and Cousins et al. (2008). After the preparation of the initial theory-based framework, the second operation was to perfect this by adding knowledge from observations of real-word R&D projects and collaborations. Lessons were learned and changes were made to the framework, while carrying out these assignments. After the pilot case, however, it seemed necessary to include even more theory into the framework. The two-step operation had become an iterative process, as proposed and described by Yin (2009).

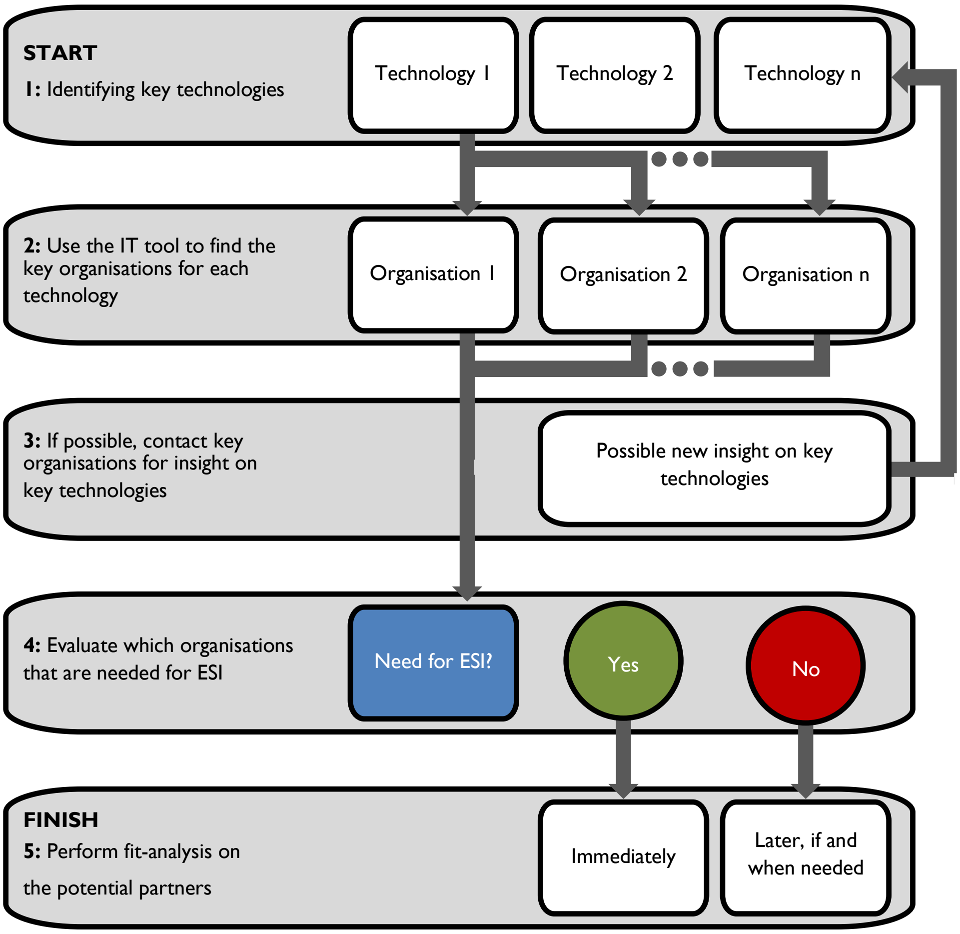
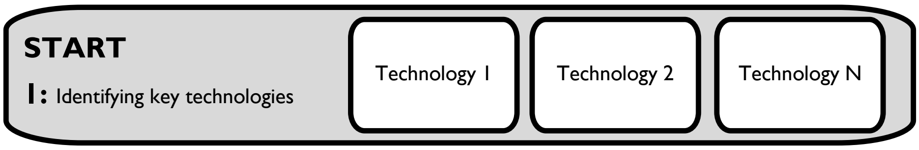


Figure XIII: The conceptual framework.

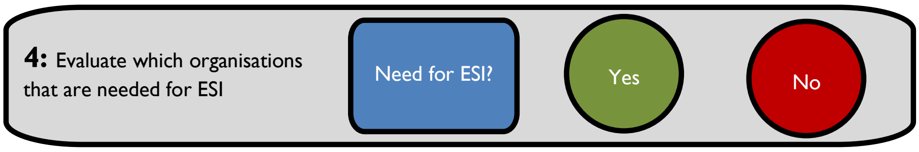
As displayed in Figure XIII, the conceptual framework consists of five activities. It is mainly a linear process, with the exception of the feedback loop in activity 3. The equivalents of the searching and screening operations suggested by Fontana et al. (2006) would be section 1 to 3 for searching, and 2 to 5 for screening. They overlap mainly because of the IT tool's internal processes, which are presented and explained in the next subchapter. The activities of the conceptual framework can be explained in the following manner:



The first section is about defining the technological needs giving grounds for the collaboration. Because of the extreme need for knowledge and capability in R&D and NPD, the basis of the collaboration should be related to its technological needs. An example could be the development of a new particle detector. The main concern of a collaboration undertaking such a challenge would be to find organisations with knowledge or capabilities on the different parts of the detector, and the scientific principles exploited in the detector design. Other concerns such as location, size, nationality, culture, location and finances are all important, but not as critical as capability and knowledge. In R&D of cutting edge technologies almost any other concern can be dealt with, if an organisation holds unique technological capabilities or knowledge considered invaluable to the collaboration (Le Goff, 2012c).

The second section deals with the IT tool presented in Chapter 3.5.1, and the selection of potential partners. Each technology deemed important in section 1 need to be investigated. After sociograms have been made from the IT tool, the interorganisational network must be analysed to find the most capable and knowledgeable organisations. This is done by examining the sociograms. These will display the organisations holding the most bibliometric documents on the technological topic, and their ties to other organisations. The framework links capability and knowledge to bibliometric documents. The idea is that capabilities and knowledge can indirectly be measured, by measuring bibliometric documents, such as publications and patents. This concept has been proposed in the literature (Melin and Persson, 1996, Balconi and Laboranti, 2006, Fleming et al., 2007, Valentin and Jensen, 2002, Sternitzke et al., 2008, Rafols et al., 2010, Porter and Rafols, 2009, Rafols and Meyer, 2010, Janssens et al., 2008, Mislove et al., 2007), and it is also recognized as a reasonable method of benchmarking organisational knowledge and capability by scientist interviewed in this study (Le Goff, 2012b, Hillemanns, 2012a, Moll, 2012, Pospisil, 2012).

The third section is optional, but might be very helpful in understanding the challenges which the collaboration is faced with. One can obtain crucial and possibly unanticipated insights in the technology topic, by consulting the main players on the technology. Section I should be reassessed if new key insights are acquired.

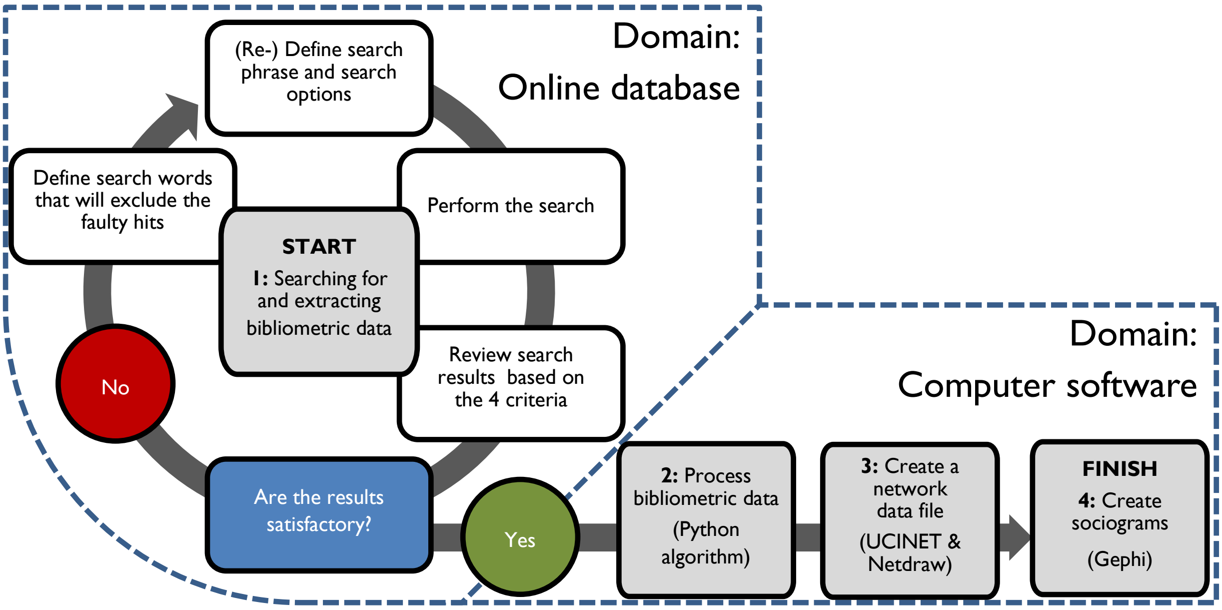


The fourth section deals with ESI, and whether to involve the selected organisations early on or not. Those who hold critical expertise needed in the development of the technology should be selected for ESI. Organisations that have experience from familiar projects would also be advantageous to include early on. They are likely to have a qualified sense on when to include other necessary organisations into the project, as they have encountered similar challenges before.

The fifth and final section is the last step before inviting the organisation into the collaboration. Not all organisations are fit for mutual cooperation, and some might be better suited than others. Sometimes cooperation is not possible due to issues related to resources, culture, values, expectations, history or location. It is often a matter of how critical the organisation's capabilities and knowledge are to the R&D challenges. If no one else can provide the same expertise, the collaboration might have to find a more flexible collaborative solution.

3.5.1 The IT tool

The process of creating sociograms from bibliometric documents constitutes the quantitative part of this study. It is a four-step operation, mostly carried through by computer software and algorithms. Only the first and second steps require any significant cognitive effort by the user. This is due to the necessary iterative process of checking the pertinence of the search results, in addition to allocating and documenting the bibliometric documents' affiliated organisations. Prior to using the IT tool, the user must also have chosen a technological subject to analyse, and defined a search query. To obtain the best possible results, the user must either have thorough knowledge on the subject, or get assistance from an expert, in order to define an adequate search query.



The Figure XIV: The four-step process of the IT tool.

The process is the same for any bibliometric source. The only difference is that each source will require its own database. The four steps, which can be seen in The Figure XIV, can be described as follows:

The first step is done at the database's internet sites. In this study, Thomson Innovation has been used for patents, and Web of Knowledge has been used for publications. Search operators, such as AND, OR and NEAR (Thomson_Innovation, 2012, Web_of_Knowledge, 2012) should be applied to the search queries to make them as precise as possible. The operators are often explained on the databases' internet sites, and may vary in form from site to site. In addition to the search operators there are some other options one must set, such as lemmatization. With lemmatization enabled, the database's search engine will include search words that resemble those of your search query. Timespan is another option, and it defines the period in time covered by the search. The option to search for single patents or patent families is of no concern to publication searches, but it has a huge impact on the results of patent searches. This study has focused exclusively on patent families. The last option of high importance is the search field. This will limit the search to specific sections in the patent or publication. Full text searches, covering the whole text of the document, often return a large amount of faulty hits, and should therefore be avoided. At the opposite extreme, searching only in the document's headings will return more pertinent hits, but also ignore many valid documents. After numerous iterations of several search queries, the author has concluded that the "Abstract/Title", "Abstract/Title/Keywords" or "Topic" (which is equivalent to "Abstract/Title") is the optimal compromise. After the search query has been perfected through several iterations, the search results can be extracted to a file in plain text format. This file should include information on the publications' or patents' affiliated organisations, and their date of publication. The latter is only necessary if one wishes to examine the evolution of the corresponding interorganisational network.

2: Process bibliometric data (Python algorithm)

This step and the next are both purely dedicated to the task of processing the bibliometric data in the text file extracted from the internet database. In this study, a custom made Python algorithm was created for this task. All digitally stored patents and publications come with bibliometric data on their affiliated organisations; information that can be sorted by a computer algorithm. This is, however, not a straight forward task. The main problem is that the names of the affiliations often are slightly modified in each document. There is no standard bibliometric representation of the names of the affiliations. To solve this problem, three digital libraries were created; one for each organisation type, namely academic institutions, companies, and NPOs. While processing each bibliometric document extracted from the search engine, the Python algorithm would check the three libraries if the current document's affiliated organisations already were documented and classified as a specific organisation type. If they were, the algorithm would sort the data accordingly. If not, it would ask the user to classify the organisations. The author would then have to figure out the organisation type of each affiliation by either checking the organisations' internet sites or consulting Dr Le Goff.

3: Create a network data file (UCINET & Netdraw)

The bibliometric data had to be structured in a two dimensional matrix, representing the connections between the patents' and publications' affiliated organisations, to make it compatible with the sociogram software used in this study. This was carried through by the means of the two open source computer programs UCINET and Netdraw (Borgatti, 2002). The procedure was almost entirely automated, and only required a few mouse clicks from the author.

FINISH
4: Create sociograms (Gephi)

The last step is all about the creation of the sociograms. The bibliometric data from step three is applied in the open source computer program Gephi (Bastian et al., 2009). Two types of sociograms are created; one displaying the different organisation types (academic institutions are red, companies are blue, and NPOs are yellow), and one sorting the organisations according to a centrality algorithm (see Chapter 2.4.2). Both types visualises the relative influence of each organisation by varying the size of the organisational nodes according to its number of publications or patents. The size of the connection between every two nodes is also set according to the number of co-patents or co-publications. Key-player sociograms, which includes only the organisations that hold a certain number of publications or patents, is created for the technologies that result in a great number of nodes.

Some of the sociograms contain hundreds or thousands of nodes. This will cause a problem for the sociogram analysts, because the network will be crowded and chaotic. The holistic view, which is the quality of the sociogram, is not obtainable for such a sociogram. One example from this case study is the situation on Germanium-detectors. The sociogram displaying organisations with publications on Germanium-detectors is based on a dataset of almost three thousand publications. Figure XV displays the full network of organisations. An organisation that are looking for a collaborative partner is probably just interested in the most knowledgeable organisations, and would therefore be better off with a sociogram of organisations with a certain number of publications. Figure XVI displays the organisations with more than 40 publications, and is far more intuitive and easier to comprehend.

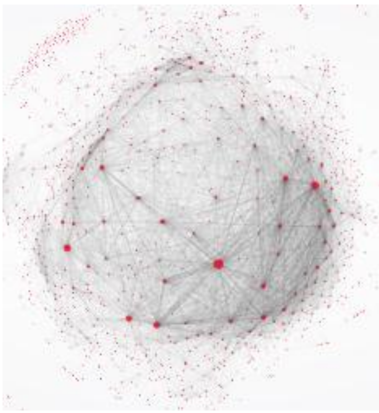


Figure XV: All organisations with publications on Germanium-detectors.

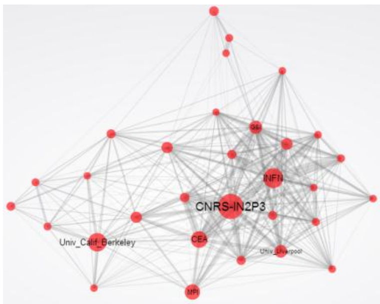


Figure XVI: Organisations with more than 40 publications on Germanium-detectors.

4 Results and discussion

This chapter consist of two main parts. First a description of academia/industry collaborations, measurement and transfer of knowledge, and partner selection processes in R&D projects is presented. This purely qualitative part will provide the reader with an understanding of how these subjects are dealt with in the HEP-community and at CERN. Secondly, the five technologies selected as embedded units of analysis are examined. Each embedded unit of analysis will begin with an explanation of the technology topic, followed by a quantitative and a qualitative description of the network of organisations using and developing the technology. The quantitative description is based on bibliometric searches on both publications and patents associated with each technology. The search results are presented in tables and discussed. The sociograms associated with the technologies are also discussed and explained. Each sociogram is referred to from the appendix section, where they can be found as individual appendixes. The qualitative description includes both an expert's assessment on the technology, and his/her reaction to the quantitative results.

4.1 Academia/industry collaborations

According to Le Goff (2012a), PSSSDs represent a classical HEP-technology case. It is a technology applied almost exclusively in scientific equipment; thus almost completely limiting its market to scientific laboratories. In addition, these technological devices are extremely advanced, and therefore expensive to both develop and produce. To deal with this issue, academic institutions and HEP-laboratories seek the support of industrial partners to develop new PSSSD technologies (Le Goff, 2012b). The HEP-community's technological needs are met by the establishment of R&D-collaborations with industry and applied science. Le Goff (2012c) agrees with Salter and Martin (2001) when they claim that this symbiosis is advantageous for both academia and industry, in addition to its function as a vital link for innovation. Interorganisational R&D-collaborations are the means to fusion basic research from academia with applied science from industry. Quoting Le Goff (2012b): *"While it's true that basic research drives innovation, it's especially true that applied science fuels basic research".*

CERN is the European hub for HEP-research, and the organisation is involved in many interorganisational R&D-collaborations and projects (Le Goff, 2012a). Nevertheless, CERN is not the main driver for collaborative projects, with the exception of particle accelerators. It has traditionally functioned as a meeting place for academic institutes, according to Hillemanns (2012a). This is changing, however, as both CERN and the HEP-community are recognising the need of implementing a high-tech push strategy towards interorganisational R&D-collaborations (Le Goff, 2012b).

Most of CERN's partners are from academia, but they occasionally collaborate with companies. Although the CERN staff hold great knowledge on the physics involved in particle detectors, they do not have the knowledge or competence required to develop or produce their technical equipment (Le Goff, 2012a). This is specially the case in prototype production. All electronics and IT expertise come from academic institutions and companies outside of the organisation (Hillemanns, 2012b).

Hillemanns (2012a) explains that it is very different to collaborate with industry than with academia. Academic partners usually do not care so much about financial resources, as long as they have enough to realise their projects. Many of the academic representatives in CERN's R&D-collaborations are not employed in the actual development or production processes. They are only participating in technical and scientific discussions, to exchange ideas and learn from the others. According to Hillemanns (2012a), the academics have no feel for business; they only crave technology excellence. This is very much in contrast to the desires of their industrial partners; their man focus is financial resources. In collaborations with academia, companies can obtain financial benefits through acquiring intellectual property, and more indirectly by learning from their partners through KT. Hillemanns (2012a) stresses that the main challenge in collaborations among both academic and industrial organisations is management. It is hard to make both sides cooperate when they have such different agendas.

At CERN there is no rule of thumb on how collaborations are structured; the role of each organisation is unique in every project (Hillemanns, 2012a, Le Goff, 2012b). It is the project sponsors that decide how the projects are governed and structured, as they are representing the need for the project. They are also responsible for the specification of the devices which are to be developed or produced. In projects where CERN is the sponsor, management consists of both scientific and administrative representatives. According to Hillemanns (2012a), administrative generalists know how to structure and manage projects, but they do not always understand how slow and unpredictable scientific R&D processes can be. Too much control over the staff is destructive to creativity, which is a vital element of any R&D process. The scientific specialists, on the other hand, are too chaotic to effectively delegate assignments and manage projects. The most effective solution is for them to be working together. Quoting Hillemanns (2012a): *"If you place a group of smart people together, they will produce beautiful results after a time; but only if they work together towards a common goal".*

4.2 Measuring knowledge

Knowledge and capabilities are both intangible traits, and they cannot be measured directly (Moll, 2012). A set of other measureable variables, closely linked to knowledge and capabilities, is needed for this task. The literature suggests using bibliometric data (Melin and Persson, 1996, Balconi and Laboranti, 2006, Fleming et al., 2007, Valentin and Jensen, 2002, Sternitzke et al., 2008, Rafols et al., 2010, Porter and Rafols, 2009, Rafols and Meyer, 2010, Janssens et al., 2008, Mislove et al., 2007), which is the method applied in the conceptual framework presented in this study. The interviewed experts have agreed that this is a reasonable solution, and they have all expressed an interest in the framework (Le Goff, 2012b, Hillemanns, 2012a, Moll, 2012, Pospisil, 2012, Campbell, 2012). Moll (2012) explicitly said he could not think of any other way to measure academic knowledge. He proposed an additional measuring technique that currently is not included in the IT tool: Some bibliometric documents are more important than others, and should therefore be weighted higher in the visual representation of the interorganisational networks. As a solution, the number of citations could be a measurement of the importance of both publications and patents. Moll (2012) also suggested that the IT tool could be used for benchmarking the efficiency and productivity of both scientists and academic institutes. Both his suggestions are closely related to the subject of this study. Moll (2012) thought the conceptual framework could be an excellent method to either find the best suited collaborative partners, or to filter out the ones you absolutely do not want to work with.

According to Le Goff (2012b), the measurement approach of the conceptual framework will require the searching organisation to possess some technical information relating to its needs, before initiating the search for the capability or knowledge it craves. The needs have to be translated into technological categories, which will require a substantial insight on the technical topics of the needs. In situations where production capacity is needed, and not knowledge, Le Goff (2012b) explains that it is less of a problem to define the searching and screening criteria. This is because the organisation will understand how the technology functions, what it is composed of, and what expertise is required to produce it. This knowledge will allow the organisation to define its bibliometric search, which is the base of the framework's searching and screening procedures. If knowledge is needed, on the other hand, the organisation will not understand how to define its search query, because it does not know enough about the nature of its technological needs (Le Goff, 2012b). Bibliometric searches are of limited use if the searcher is incapable of defining a relevant search query. This will become apparent later in the PSSSD analyses, especially in the case of Germanium-detectors and bump-bonding. The problem is relating to *fault exclusion, pertinence inclusion* and *purpose* (see Chapter 3.4.4). To counter this issue, the searching organisation will need to consult technical experts capable to describe what knowledge is needed to meet their needs.

4.3 Knowledge transfer

Hillemanns (2012a) explains that KT between organisations is beneficial for society in several ways. Interorganisational R&D-collaboration brings people, organisations and nations together by providing them with an arena of scientific discussion, completely stripped from cultural differences. It also accelerates the development of new technological aids, in fields such as medicine, microelectronics and energy production.

Although KT is in line with what Hillemanns (2012a) refer to as "the scientific spirit" and the good of humanity, it is often and easily limited or crippled. The most substantial reason for this is related to financial resources. If KT has no purpose or impact on a project's deliveries, the project sponsors will seldom provide the necessary finances. Hillemanns (2012a) claims that this is logical from a project manager's point of view, but in a long-term perspective it might not be the optimal solution for the organisation. Le Goff (2012b) explains that this is why CERN promotes KT through their technology push strategy. They strive to create incentives for organisations to form collaborations. This will encourage organisations to cooperate over a long period of time, and not only limited to single projects. Long-term relationships will open up for more extensive KT, hence boosting their innovative capabilities (Hillemanns, 2012a).

Another challenge to KT is intra organisational politics (Hillemanns, 2012a). There are many strong personalities with their own agendas high up in the organisational hierarchy of large organisations like CERN. Many of these are more interested in heightening their personal visibility and boosting their pride, rather than to assist the actual projects. Solid leadership and conflict management is necessary to counter these challenges.

A third challenge is to know who is doing what. Organisations are able to collaborate across continental boarders today, and this opens up new possibilities. The challenge is to know who to contact if one wish to promote KT (Le Goff, 2012a). Spreading knowledge is advantageous to humanity, and it is more efficient when more organisations are collaborating.

As seen in Chapter 2.2.2, Hamel et al. (1989) claim that the most beneficial outcome from interorganisational collaborations is the opportunity to build skills and to learn new knowledge from the other organisations. This is in accordance with Le Goff (2012a) and Hillemanns (2012a), which underlines the importance of KT in interorganisational R&D-collaborations. The model provided by Lane et al. (2001) on absorption capacity in interorganisational KT displays the most important attributes, from a KT point of view, in a potential collaborative partner. By combining the model with the properties of the sociograms and the feedback from Le Goff (2012b), Le Goff (2012c), Hillemanns (2012a) and Moll (2012), we can make a new model (Figure XVII) that can help us grasp the opportunities and limitations of the conceptual framework.

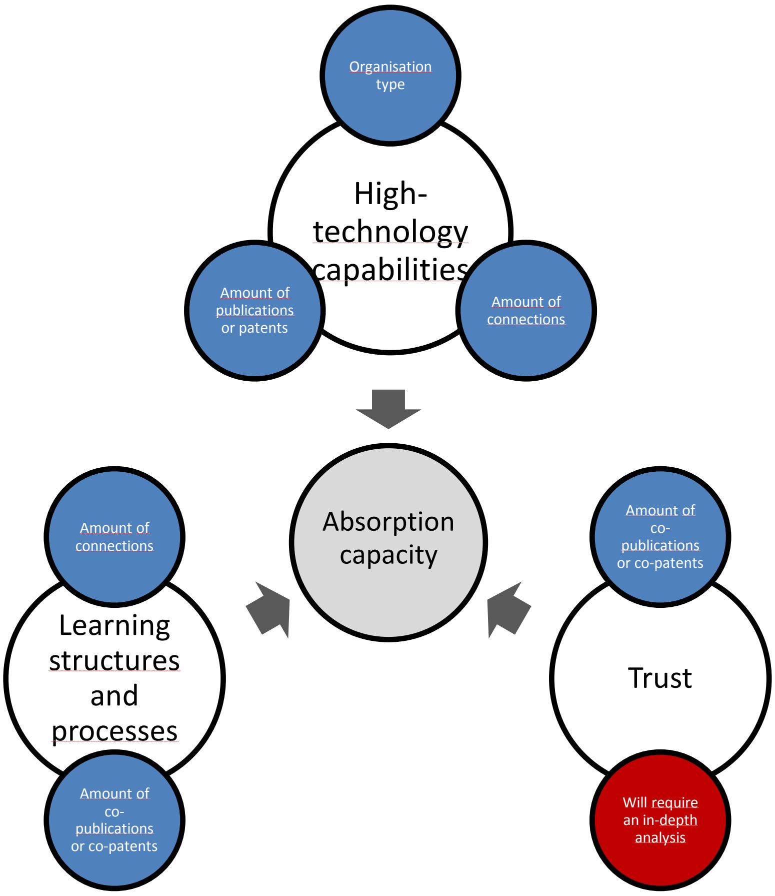


Figure XVII: Explanation of absorption capacity in interorganisational knowledge transfer, by means of sociogram properties. Source: Le Goff (2012b), Le Goff (2012c), Hillemanns (2012a) and Moll (2012).

The elements of the new model can be explained as follows:

- ***High-tech capabilities:*** The organisation type will indicate what kind of capabilities the organisation has: A university will most likely not be able to mass produce a product, but it will be able to provide knowledge. Furthermore, if an organisation is well connected or connected to certain key organisations, it could open up to new resources and possibilities through its network. The number of publications or patents will also be an indicator of the organisation's capabilities.
- ***Learning structures:*** A well connected organisation with many co-publications and co-patents is likely to prioritise learning structures, because of its importance in interorganisational KT.
- ***Trust:*** An organisation that holds many co-publications or co-patents is likely to be functioning well in other collaborations. To be certain of this, a due-diligence team should perform an in-depth fit-analysis of the organisation, prior to establishing the collaboration.

The strength of the conceptual framework is its ability to identify organisations' high-tech capabilities. Information of learning structures and trust, on the other hand, is not that easily obtained from its method. Because of the immense need of high-tech capabilities in NPD and R&D processes, the framework might be very advantageous in such a setting. It will probably not, however, be equally advantageous in other interorganisational collaborative settings, where the two other parameters might play a bigger role.

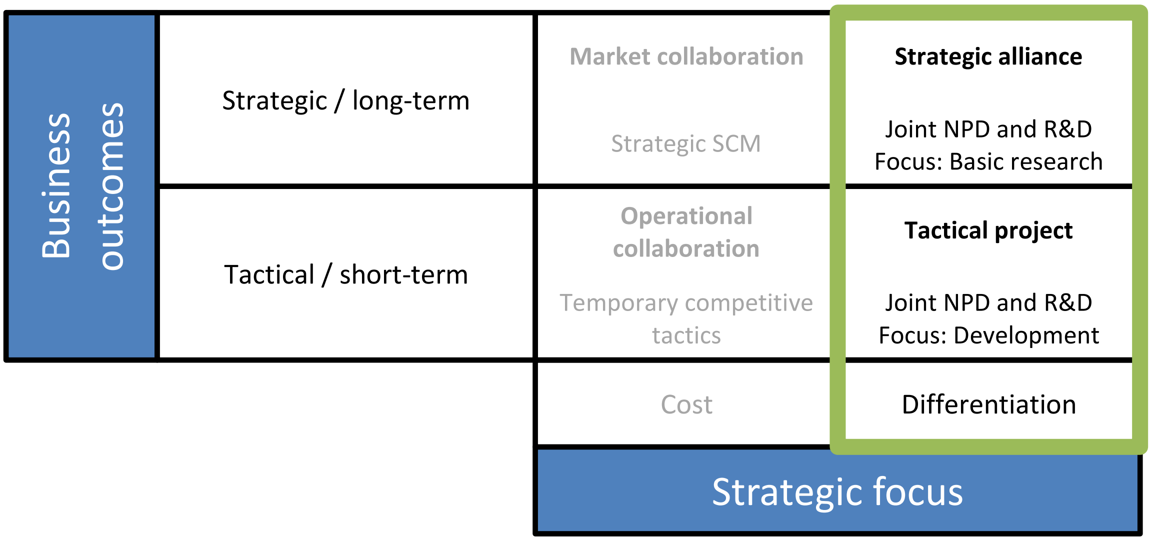


Figure XVIII: Strategic focus relevant to the conceptual framework.

For these reasons, the conceptual framework is aimed at collaborations with a strategic focus on differentiation, rather than cost reduction (see Figure XVIII). Both strategic long-term alliances with a focus on basic research, and tactical sort-term collaborative development projects could benefit from applying the framework in their partner selection processes.

4.4 Partner selection at CERN

In almost every make or buy decision in any of CERN's projects, the choice is to buy (Hillemanns, 2012a). However, when there is no other alternative than to make the necessary equipment themselves, they initiate a project to do so. According to Le Goff (2012a), the bigger projects are often financed by the European commission under the Seventh Framework Programme (FP7). Organisations involved in FP7 are all possible collaborative partners for these projects. The organisations use FP7 as a meeting place where collaborative discussions can be initiated (Le Goff, 2012a).

Other HEP-projects are initiated and carried through at CERN. Hillemanns (2012a) explains that early stage project management in R&D-projects, including the process of partner selection, is a very complex sociological process. He claims that it is not possible to make a manual on how to create R&D-collaborations; the process is just too unpredictable and intricate. In interorganisational academic collaborations it is more often the staff of the organisations that initiate the collaborations. CERN has no strict protocol or routines that dictate these processes, and the outcomes are often heavily influenced by the personal networks of the project managers (Hillemanns, 2012a).

Usually, Hillemanns (2012a) explains, the network of experts needed in an interorganisational R&D project must recognize and accept the project manager before they start providing him/her with knowledge. The experts seldom cooperate if they do not think it is worth their time. In other words, the project manager needs credibility in the community. Factors that influence this and relating challenges are how well the project manager communicates with others, and how skilled he/she is at motivating and convincing the right people. Many academic experts will not cooperate with industry, unless they are either commanded or properly persuaded. In addition, it is often a considerable challenge to motivate experts to participate in projects that are not specifically related to their own scientific field. To persuade them to join the project will require a convincing and cunning project manager. Such skills cannot be mimicked by the means of a manual; they are rare personal traits that are hard to develop (Hillemanns, 2012a).

It is the general perception in the HEP-community, according to Hillemanns (2012a), that everybody knows who is doing what. When special knowledge or capability is needed, project managers either use their previous sources, or they consult their colleagues. The knowledge of each project manager grows constantly by his/her experience, by working in the field. CERN do not have a catalogue containing key organisations and their affiliated resources. Hillemanns (2012a) admits, however, that such an archive would be interesting, and possibly advantageous for early stage project management. By adding the knowledge of every collaborative venture into a database available to all project managers, every project would know which organisations to contact when special knowledge and capabilities are required. Such a service have been requested by the HEP-community (Hillemanns, 2012a, Le Goff, 2012a). The conceptual framework in this study is intended as an answer to this need.

Le Goff (2012c) is planning to apply the IT tool in the preparation of future collaborative academia/industry HEP-events, in his work for the Advanced European Infrastructures for Detectors at Accelerators (AIDA). AIDA is an EU-funded project, under the FP7 Research Infrastructures programme (2005). It aims to upgrade and develop European research infrastructures and particle accelerators. One of their objectives is to promote interorganisational R&D-collaborations that can foster new technological innovations. As a means to this objective, the IT tool will be used to identify the main players on the technologies addressed by the HEP-events. Le Goff (2012c) believes that if the main players are incorporated into interorganisational HEP R&D-collaborations, SMEs will also be attracted to join; thus benefiting science through increased innovation. In addition to be an enormous incentive for SMEs to join the collaborations, the established firms could also be consulted on the technical topics of the HEP-events. They could express their needs, and propose unforeseen strategies benefiting both science and industry (Le Goff, 2012c).

Le Goff (2012c) has also proposed to use the IT tool for measuring the effects of collaborative stimuli like that of FP7. By studying the evolution of the interorganisational networks by the means of sociograms, one could study the effects of collaborative initiatives such as AIDA's HEP-events. The sociograms could reveal networks that include organisations outside of the official collaborations; an early indicator that the technology is being disseminated. This is KT, and according to the theory of Martin and Tang (2006) and Vuola and Hameri (2006), and the statements of Le Goff (2012c) and Hillemanns (2012a), that is very beneficial not only to academia and industry, but also to society.

4.5 Position-Sensitive Solid-State Detectors

The five technologies reviewed in this subchapter are all related to PSSSDs. Three of them are PSSSDs, one has some of the features of a PSSSD, and one is applied in PSSSDs. Le Goff (2012a) explains that PSSSDs are technological devices able to detect single subatomic particles interacting with their sensors. They are also position-sensitive, meaning that they can detect where the particle hit on their sensor. The sensor is capable of this because it is divided into a two dimensional grid of many small sensors. The resolution of the PSSSD is equivalent to the resolution of its sensor-grid. PSSSDs are also solid-state, meaning that they have no moving parts. All their functions are done through microprocessors that communicate via electric circuits.

4.5.1 Medipix/Timepix: The well-known technology

During the last twenty years, the Medipix chip family has been one of the most known and widely used photon counting pixel detector technologies in the world, and still is today. The family includes Medipix 1 (1997), Medipix 2 (2000), Timepix (2004), and Medipix 3 (2005). Some examples of their applications are medical imaging, HEP, material analysis, nuclear power plant decommissioning, education, optics and astronomy. Medipix 1 was designed and developed at CERN by the Medipix collaboration (CERN, University of Freiburg, University of Glasgow, Universities and INFN of Napoli and Pisa). Medipix 2 and its sister-chip Timepix were designed and develop by the Medipix 2 collaboration (CERN, Institut de Física d'Altes Energies IFAE Barcelona, University of Cagliari, University of California, Berkeley, Commissariat à l'Energie Atomique CEA, Czech Academy of Sciences, Czech Technical University in Prague CTU, Friedrich-Alexander-Universität Erlangen-Nürnberg FAU, European Synchrotron Radiation Facility ESRF, Albert-Ludwigs-Universität Freiburg-i.B., University of Glasgow, University of Houston, Medical Research Council MRC, Mid-Sweden University MSU, Università di Napoli Federico II, NIKHEF, Università di Pisa).

As the most novel member of the Medipix family, the Medipix 3 chip represents the future for this technology. This pilot case will not include the Medipix 3 chip; this specific technology will instead be studied separately, because of its evolutionary state. In contrast to its predecessors, Medipix 3 is still undergoing further development.

Medipix/Timepix publications

The search on Medipix/Timepix was defined with the assistance of Le Goff (2012b), to get the most relevant results as possible. The search has several hundred hits, which is favourable from a statistical viewpoint. The relatively huge amount of hits is probably due to the wide use of the Medipix/Timepix-family chips, and their lengthy operational history. The results are the same with or without lemmatization enabled.

Publications: Medipix/Timepix		Top 10 organisations Org. name	Org. type	#Publications
Query	(medipix* OR timepix*) NOT (dosepix OR	Univ_Czech_Tech_Prague	Institution	81
	medipix3 OR medipix-3 OR "medipix 3"	CERN	Institution	55
	OR timepix3 OR timepix-3 "timepix 3")	NIKHEF	Institution	28
#Publications	370	Univ_Erlangen-Nuernberg	Institution	27
		INFN	Institution	26
Lemmatization	On/Off	Univ_Glasgow	Institution	22
		Univ_Freiburg	Institution	21
Timespan	All Years	Univ_Mid_Sweden	Institution	15
		Univ_Montreal	Institution	15
Date	09.08.2012	Univ_Napoli_Federico_2	Institution	15

Table III: Publications on Medipix/Timepix. Source: Web_of_Knowledge (2012).

From the sociograms, which can be found in Appx 7.1 and Appx 7.2, even more information on both the main players and their relationships can be obtained. There are relatively few companies and NPOs amongst the one hundred and thirty organisations; fourteen and three to be exact. In addition, only a single cluster is present. It is decentralized and well connected, although the main players are more connected than most of the smaller organisations.

Le Goff (2012b) confirmed the situation displayed in the sociograms (Appx 7.1 and Appx 7.2). In addition to the collaboration members, other key players are having a prominent role. The latter ones are organisations applying the technology, not developing it (Le Goff, 2012b). This also explains the many companies taking an interest in the Medipix chip. Le Goff (2012b) told that Siemens, Oxford Instruments, IMEC and CAEN have all worked together with CERN on applications of the technology. He was, however, surprised of seeing that the University of Montreal is so closely connected to the Czech Technical University (CTU). It is not a member of the formal collaboration, but still the organisation which shares the most co-publications with CTU. Pospisil (2012), director of CTU, later confirmed this situation when he was presented with the sociograms. The chairman of the Medipix collaboration, Campbell (2012), explained that the link is due to a personal connection between two professors at CTU and the University of Montreal, working on applications of the Medipix chip.

The centrality sociogram (Appx 7.3) visualizes the more connected groups of organisations, and there seems to be five major cliques, gathered around some of the largest players: the CTU, CERN, NIKHEF, the University of California Berkeley and INFN seem to be influencing most of the organisations. According to Le Goff (2012a), there are three major cliques working on and with the

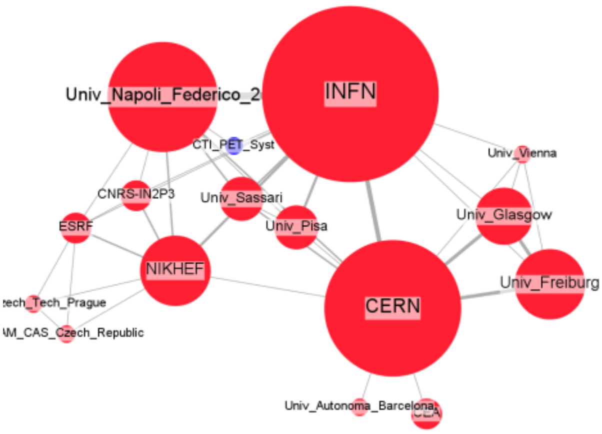


Figure XIX: Organisations with publications on Medipix/Timepix, 1998-2002.

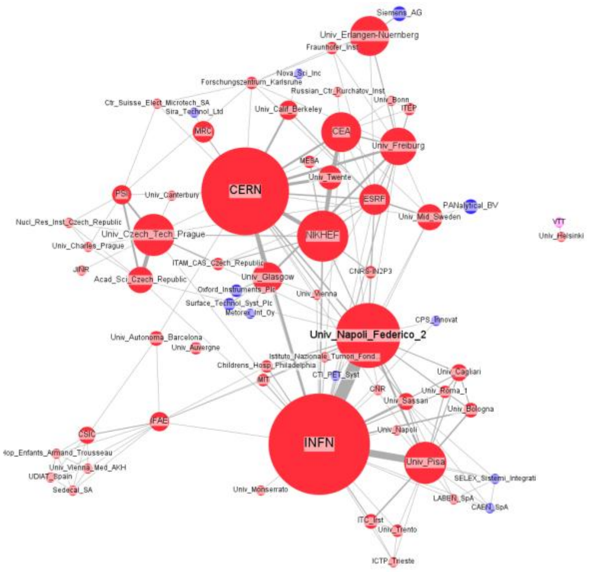


Figure XX: Organisations with publications on Medipix/Timepix, 1998-2007.

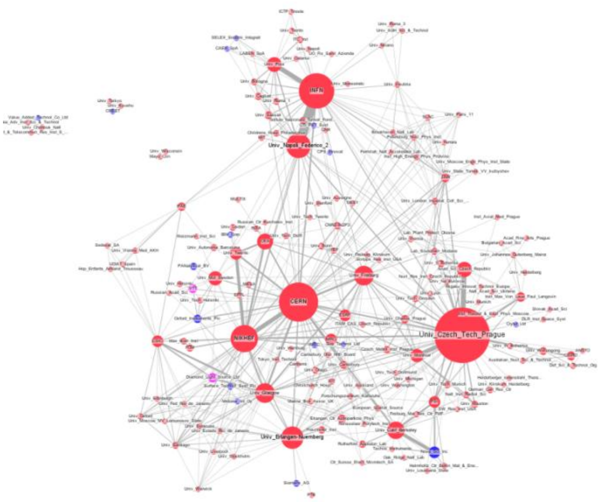


Figure XXI: Organisations with publications on Medipix/Timepix, 1998-2012.

Medipix chips. These are CERN, INFN and CTU, and from the centrality sociogram we can see that CTU and CERN are the absolutely largest nodes. Le Goff (2012c) imply that CTU and CERN are absolutely necessary partners if an organisation is to use the Medipix chip.

By sorting the patents by date, we can create sociograms that depicts the evolution of the interorganisational network working on the Medipix chips. This can be seen in Figure XIX, Figure XX, and Figure XXI/Appx 7.1. The sociograms have been confirmed by Le Goff (2012b) and Pospisil (2012). Here we can see how new organisations have joined the network, although most of them are not a part of the official collaboration. It is also interesting to see how the influence of the organisations involved from the beginning have either stagnated or increased over the years. It is very apparent that CTU, the most influential organisation in 2012, have grown considerably during the last five years. It has also become the best connected central node in the network during this time period.

Pospisil (2012) and Campbell (2012) were both impressed with the representation of the publication networks, and said it is very much like what they consider the real situation to be. Pospisil (2012) suggested that the sociograms could be useful for scientists working on the technology, to make them better understand who to contact if special expertise is needed.

Medipix/Timepix patents

After looking at each individual patent resulting from the search, it became apparent that the choice of search field would greatly influence the pertinence of the hits. The search resulted in forty two hits when the search field was set to *Text field*. The hits were studied individually, and all of them were at least related to the Medipix/Timepix chip in some way. Some were about similar chips, and others were about devices that could be used together with the chips. For the record, the search resulted in a single hit when the search field was set to *Title/Abstract/Claims*.

Patents: Medipix/Timepix		Top 10 organisations		
		Org. name	Org. type	#Patents
Query	(medipix* OR timepix*) NOT (dosepix OR medipix3 OR "medipix-3" OR "medipix 3" OR timepix3 OR "timepix-3" "timepix 3")	Philips	Company	15
		Arradiance_Inc.	Company	2
		CEA	Institution	2
#Patent Families	42	CSEM	Not-for-profit	2
		Univ_Johannesburg_Wit..	Institution	2
Search field	Text fields	AJAT_Ltd	Company	1
		BAE_Syst	Company	1
Timespan	1900 - search date	CERN	Institution	1
		CMT-Medical_Technolog..	Institution	1
Date	14.08.2012	EASTMAN_KODAK	Company	1

Table IV: Patents on Medipix/Timepix. Source: Thomson_Innovation (2012).

Philips is the dominant organisation with its fifteen patents, followed by four organisations with only two patents each. Campbell (2012) explained that Phillips is not a part of the Medipix collaboration, nor have they any contractual agreement with the collaboration. They are merely applying the technology in their medical scanning equipment. It is also interesting to see that only half of the top ten organisations are companies. A frequent observation throughout this study has been that companies more often file patents, institutions are mostly concerned with publications, and NPOs are generally rare for both patents and publications. The sociogram of the full search (Appx 7.4) reveals that there are only two co-patents amongst the organisations; one between Epispeed_AG and CSEM, and the other between CTU and CERN. Le Goff (2012a) confirmed that this is correct, and that these patents are two early Medipix 1 patents. The intellectual property of the all the Medipix/Timepix chips are protected by copyright rather than patents. All other patents are on application of the chips. By looking at the sociogram for organisations with more than two patents (Appx 7.5), it is apparent that none of the organisations share patents, and that there is a good mix of organisation-types holding patents; two companies, two institutions and one NPO.

4.5.2 Medipix 3: The state of the art

Medipix 3 is the successor of Medipix 2, and it is a pixel detector readout chip like its predecessors. It was conceived at CERN in 2005 by the Medipix 3 collaboration (CERN, University of Canterbury, CEA, DESY, Diamond Light Source, Albert-Ludwigs-Universität Freiburg, University of Glasgow, Institute for Synchrotron Radiation, Leiden University, NIKHEF, Mid-Sweden University, Czech Technical University, ESRF, Universität Erlangen-Nürnberg, Space Sciences Laboratory, VTT, Universität Bonn, Universidad de los Andes, ITER, AMOLF, University of Houston), and is still being developed further today (Pospisil, 2012, Le Goff, 2012c).

Medipix 3 is the case of the novel state of the art technology. The relatively short time this technology has been accessible for use and study may significantly affect the amount of data available on it, which in turn may affect the accuracy of a bibliometric analysis.

Medipix 3 publications

Table V displays the publication search on the Medipix 3 chip, which has relatively few hits. This might result from Medipix 3 being a new technology. All the hits are checked and confirmed as pertinent. The results are the same with or without lemmatization enabled.

Publications: Medipix 3		Top 10 organisations		
		Org. name	Org. type	#Publications
Query	"medipix 3" OR "medipix3"	CERN	Institution	16
	OR "medipix-3"	Univ_Canterbury	Institution	7
		Univ_Otago	Institution	7
#Publications	23	Univ_Czech_Tech_Prague	Institution	5
		Canterbury_Dist_Hlth_Board	Institution	3
Lemmatization	Off	DESY	Institution	3
		Diamond_Light_Source_Ltd	Not-for-profit	3
Timespan	All Years	KIT	Institution	2
		Univ_Erlangen-Nuernberg	Institution	2
Date	10.08.2012	Univ_Freiburg	Institution	2

Table V: Publications on Medipix 3. Source: Web_of_Knowledge (2012).

The corresponding sociogram (Appx 7.6) illustrates the results, and reveals that there is only one node of organisations. CERN is the obvious main player, followed by three universities and Canterbury district health board. The thick edges between CERN, the University of Canterbury and the University of Otago visualize the co-publications between these organisations, and can be interpreted as a collaboration between the triangle. Le Goff (2012c) explains that Canterbury and

Otago are collaborating in a project called MARS, where they are developing a medical imaging device applying the Medipix 3 chip. Although most of the organisations are connected to more than one organisation, CERN is clearly the central hub for the whole network. Only the Technical University of Munich is connected to the network through a single organisation.

The centrality sociogram (Appx 7.7) displays three cliques: The largest around CERN, one around the two universities of Canterbury and Otago in New Zealand, and the last amongst DESY and the Technical University of Munich. Campbell (2012) and Le Goff (2012c) confirmed that the sociogram is an plausible representation of the real network, and they were both particularly amazed by the highly active New Zealand cluster. Campbell (2012) said it was probably due to their R&D-collaboration on the novel CT-scanner for pets previously mentioned.

Medipix 3 patents

From Table VI we see that the patent search on the Medipix 3 chip result in very few hits. Like the publication search, this is probably due to the novelty of the technology. The search field is set to *Text fields*, which results in less specific hits. All the search hits were checked to be pertinent. Three of the patents were affiliated to individuals, and were therefore excluded from the review.

Patents: Medipix 3		Top 10 organisations		
		Org. name	Org. type	#Patents
Query	"medipix 3" OR "medipix3" OR "medipix-3"	BAE_Syst	Company	2
		Siemens	Company	1
#Patent Families	6			
Search field	Text fields			
Timespan	1900 - search date			
Date	14.08.2012			

Table VI: Patents on Medipix 3. Source: Thomson_Innovation (2012).

The two organisations BAE Systems and Siemens are both companies involved in several high-tech professions and businesses. The Medipix 3 patent sociogram (Appx 7.8) illustrates the situation very clearly. There are only two players, and they do not share any co-patents. Le Goff (2012c) explains that the Medipix 3 collaboration holds a copyright on the chip, and that is probably why there are only industrial players in the patent sociogram. These patents are on application of the device, not development, he explains.

4.5.3 Bump bonding: Not exclusively for detectors

When electronic devices (i.e. the pixel sensor and the ASIC electronics in a particle detector) are to interact with each other, they need to communicate through some sort of interconnection. For microelectronics, like those we find in modern PSSSDs, the interconnections are metal conductors. These are of a very small size to match the pixel resolution of the ASIC in a PSSSD. The traveling length of the electric signals that passes through the interconnections are made as short as possible by "sandwiching" the electrical devices on top of each other. The most efficient way to interconnect such a stack of microelectronic devices is to have small solder bumps of a conducting material between the electronic circuits of each layer. This technique is called "bump bonding", and is widely used in microelectronics today, including PSSSDs.

Because bump bonding is frequently used in technologies other than PSSSDs, it can be interesting to see if the bibliometric search can reveal previously unknown information to the HEP community. In addition, bump bonding is a service that is provided by industry and therefor might be an interesting candidate for the patent searches; perhaps the publications and patents will tell two different stories?

Bump bonding publications

In contrast to Medipix 3 which is a very specific technology, bump bonding results in many search hits. The search has more than three hundred hits, and the results are displayed in Table VII. *Lemmatization* is turned off, which should result in more pertinent hits.

Publications: Bump bonding		Top 10 organisations		
		Org. name	Org. type	#Publications
Query	"bump-bonding" OR	INFN	Institution	82
	(bump NEAR/0 bond*)	CERN	Institution	64
		Univ_Napoli_Federico_2	Institution	28
#Publications	364	Univ_Glasgow	Institution	26
		Univ_Pisa	Institution	22
Lemmatization	Off	PSI	Institution	17
		Rutherford_Appleton_Lab	Institution	15
Timespan	All Years	CNRS-IN2P3	Institution	14
		Fermilab_Natl_Accelerator_La	Institution	14
Date	13.08.2012	Univ_Bonn	Institution	14

Table VII: Publications on Bump bonding. Source: Web_of_Knowledge (2012).

It is interesting to see that all the top ten organisations are institutions. The sociogram of all the bump bonding publications (Appx 7.9) contains 322 organisations. It provides a holistic view of the

Figure XXII: ATLAS/CMS collaboration.

situation: The largest organisations are easy to spot, and the organisational clusters are revealed. When presented to Campbell (2012) he immediately recognised one of the big clusters as the ATLAS/CMS collaboration (Figure XXII). It is interesting to see that a bibliometric search on a single technology topic can reveal an interorganisational collaboration applying this technology. The whole bump bonding network consists of one large and nine small independent clusters, in addition to some unconnected organisations. Finding a specific organisation or measure the relative weight between the lower ranked organisations is however almost impossible in this sociogram. The +10 publications sociogram (Appx 7.10) makes this easier by displaying only the highest ranked organisations. The whole network consists of one cluster, and INFN is the best connected and most central organisation.

The centrality sociogram of all the organisations (Appx 7.11) is not easy to interpret on first sight, because of the many organisations and colours that illustrates their relationships. Nevertheless it is possible to see at least two main cliques: One around INFN and CERN, and one around what Campbell (2012) recognised as the ATLAS/CMS collaboration. The +10 publications centrality sociogram (Appx 7.12) offers a more intuitive picture on the situation. Here we see five cliques, and it is obvious that INFN and CERN are less connected at this scale. This is because they have stronger connections with other organisations; this is easily recognised by the thick edges linking INFN and the other Italian universities.

Le Goff (2012b) suggested that either INFN or CERN should be contacted if one needed expertise on bump bonding. He explained that these two organisations are the two main R&D-players on bump bonding in the world today, and he was therefore not surprised when he saw the publication sociograms.

Moll (2012) commented on the bump bonding publication and patent sociograms, and he thought the purpose of the technology was very unclear in both cases. He was confused if the sociograms were displaying organisations applying the technology, or developing it. Moll (2012) also explained that bump bonding is a very general term, and that there are many bump bonding techniques with different purposes. If an organisation needs special capability on a bump bonding technique, they need to find someone who knows the correct technique. This might indicate that the subject "bump bonding" is too general for a practical purpose, and that the search should be further refined. Le Goff (2012b) agrees with Moll (2012), and suggests that a conceptual model of the technology should be created, so that the sub-technologies which constitutes the main technology can be identified. This would help the analyst to understand what capability and knowledge that actually are needed in the R&D-project. The sub-technologies might be necessary to explore individually to get a clear picture of the organisations engaged in them.

Bump bonding patents

The Bump bonding search on patents (Table VIII) result in several hundred hits, even with the search field set to *Title/Abstract/Claims*. This could improve the pertinence of the search immensely. Only a fraction of the hits were controlled posterior to the searches. The four hundred and thirty four hits are a rich sample of patents compared to many of the other technologies reviewed in this study, which might be resulting from the technology's wide applicability in many microelectronic devices. Nine of the top ten organisations are companies.

Patents: Bump bonding		Top 10 organisations		
		Org. name	Org. type	#Patents
Query	bump-bonding OR "bump bonding"	Micron_Technology_Inc.	Company	26
	OR "bump-bonded" OR "bump bonded"	Motorola_Inc.	Company	22
		Matsushita	Company	17
#Patent Families	434	Texas_Instruments_Inc	Institutior	17
		Murata_Manufacturing_Co._Ltd.	Company	11
Search field	Title/Abstract/Claims	Taiwan_Semiconductor_Manufa	Company	11
		Samsung_Corp	Company	9
Timespan	1900 - search date	Nec_Corporation	Company	8
		Panasonic_Corp	Company	8
Date	14.08.2012	Seiko	Company	7

Table VIII: Patents on Bump bonding. Source: Thomson_Innovation (2012).

The sociogram of all the patents (7.13) gives an overview of the situation. There are only five co-patents in the whole network. Most of the organisations are companies, with the exception of seven institutions and four NPOs. This indicates that industry is needed to produce bump bonded devices. Le Goff (2012b) confirms that this is the real situation, even for devices with research applications. The +5 patents sociogram (Appx 7.14) visualises the main players for bump bonding patents. There are no co-patents in this view, and Micron Technology Inc is the biggest organisation. Centrality sociograms are not conceivable, because of the low amount of co-patents.

What Le Goff (2012b) thought to be most interesting was the results from combining the bump bonding and Medipix/Timepix sociograms. This would display the organisations that were active in both bump bonding and Medipix/Timepix; organisations that Le Goff (2012b) considered strategically important and beneficial to include in any collaboration dealing with these two technologies. The Medipix/Timepix collaboration is such a collaboration. The results can be seen in Figure XXIII, and the picture speaks for itself. Even though Samsung is the only organisation connected with both technologies, it is not engaged in the Medipix/Timepix collaboration, nor has it any publications on any of the subjects.

Figure XXIII: Patents on both bump bonding and Medipix/Timepix.

4.5.4 Pilatus: A spin-off from HEP-research

Originally developed at the Paul Scherrer Institute (PSI) in Switzerland, the first Pilatus PSSSD was commercialised by the spin-off company Dectris (Le Goff, 2012b). Dectris was initially conceived for this purpose and to further develop the Pilatus detector. Like Medipix, Pilatus later developed into a whole family of detectors, and now consists of 6 different units. It is applied in both scientific and commercial contexts. Examples are synchrotrons, industrial x-ray applications and biochemistry.

Because of the commercial aspects of the detector, Pilatus will be particularly interesting as a business-case. It is a product developed and produced by a private firm, for financial purposes (Le Goff, 2012b). PSSSDs are usually made for a purely scientific purpose, although every technical device requires a variety of resources to be developed and produced. How this will affect the amount of information that can be acquired from publications and patents will be interesting to see.

Pilatus publications

The publication search on Pilatus (Table IX) has more hits than the Medipix 3 search, but less than the Medipix/Timepix search. The search hits are controlled, and confirmed as pertinent.

Publications: Pilatus		Top 10 organisations		
		Org. name	Org. type	#Publications
Query	Pilatus AND detector*	PSI	Institution	28
		Dectris_AG	Company	12
		SPring_8	Institution	7
#Publications	53	Univ_Copenhagen	Institution	5
		Diamond_Light_Source_Ltd	Not-for-profit	4
Lemmatization	Off	Univ_Melbourne	Institution	4
		Univ_Tech_Munich	Institution	4
Timespan	All Years	Austin_Hosp	Institution	2
		Australian_Synchrotron	Institution	2
Date	13.08.2012	CEA	Institution	2

Table IX: Publications on Pilatus. Source: Web_of_Knowledge (2012).

PSI and Dectris AG, which are the organisations behind the Pilatus detector, stand out as the two main players. Eight of the organisations are institutions, one is a company and one is a NPO. The publication sociogram of all the patents (Appx 7.15) displays all the organisations: fifty one institutions, two companies and a single NPO. The latter is the British synchrotron facility Diamond Light Source Ltd (DLS), which Le Goff (2012b) explains is studying the structures of proteins for medical drugs analysis. He also explains that DLS has not played a part of the development of the Pilatus chip as they have with the Medipix 3 chip, but is rather a leading end user. The fact that DLS has publications and patents on both the Medipix chips and the Pilatus chip insinuates that they are positioning themselves strategically vis-à-vis the two competing leading brands of PSSSDs (Le Goff, 2012b).

Apart from some solitary organisations, there are one large and four small clusters. PSI and Dectris AG are the central hubs of the large cluster, although most of its organisations are connected to more than one node. Spring-8 the University of Copenhagen are also functioning as central hubs in their own centralised sub-clusters, connecting many of their neighbour organisations to the rest of the network. The +3 publications sociogram (Appx 7.16) reveals the main players and their relationships. The central hubs previously mentioned are all included in this map.

The centrality sociogram (Appx 7.17) show the more closely connected nodes in the main cluster. Le Goff (2012b) was impressed to see that the sociogram confirms the close connection between PSI and Dectris. He also thought it was interesting to look at the clique around the University of Copenhagen; it is composed of Danish, Norwegian, French, Swiss, and US organisations. With the exception of the University of Lund, this is the only cluster with Scandinavian organisations. Also the Japanese clique composed of JASRI, RIKEN, the University of Tokyo and the University of Osaka, and the French clique composed of the University of Paris 11, the University of Paris 13, the University of Poitiers and CNRS-IN2P3 is easily recognised, and confirmed by Moll (2012). As one might have expected, closely located organisations are more often collaborating.

Pilatus patents

The patent search on Pilatus (Table X) results in zero hits when the search field is set to *Title/Abstract/Claims*. The search has twenty two hits when the search field is set to *Text fields*. To compensate for the expected loss of pertinence, an additional word was added to the search query. All the hits were checked to be relevant.

Patents: Pilatus		Top 10 organisations Org. name	Org. type	#Patents
Query	Pilatus AND detector*	Biotest_Ag	Company	3
		PSI	Institution	2
		Bristol-Myers_Squibb_Company	Company	1
#Patent Families	22	CNR	Institution	1
		CNRS-IN2P3	Institution	1
Search field	Text fields	F._Hoffmann-La_Roche_Ag	Company	1
		Heptares_Therapeutics_Ltd	Company	1
Timespan	1900 - search date	INRA	Institution	1
		Institut_Pasteur	Not-for-profit	1
Date	14.08.2012	MIT	Institution	1

Table X: Patents on Pilatus. Source: Thomson_Innovation (2012).

Half of the top ten organisations are institutions, and four are companies. Most of the organisations hold only one patent. Only Biotest Ag and PSI hold more than that; three and two respectively. Both Moll (2012) and Le Goff (2012b) were not surprised to see these two companies dominating the patent search, as Biotest Ag is applying the Pilatus chip, and PSI was its initial developer. For the record, Dectris AG are not listed as a patent holder. This might not be the real situation, but in this search they do not turn up. Some patents concerning a device do not explicitly mention the device in the patent text. Another explanation could be that a copyright have been filed instead of a patent.

The sociogram of all the patents (Appx 7.18) reveals three co-patents, one even shared between three organisations. The +2 patent sociogram (Appx 7.19) draws a very clear picture of the top organisations, only including Biotest Ag and PSI. According to Le Goff (2012b), the situation with Pilatus is much in contrast to that of Medipix in one major way: The Medipix collaboration is focusing on developing its technology, whilst Dectris is focusing on exploiting it financially.

Both Moll (2012) and Le Goff (2012b) suggest that Biotest AG and Dectris are the preferred organisations to include in a interorganisational R&D-collaboration using the Pilatus chip. Dectris is the main developer of the technology, and Biotest AG is probably the most experienced user.

4.5.5 Germanium-detectors: A whole group of different technologies

Germanium-detectors come in many shapes and sizes, and they are mainly applied in HEP-spectroscopy. The term “Germanium-detector” is as general and unspecified as “silicon-detector”, hence one can imagine the wide variety of designs. Germanium-detectors present significant advantages over silicon-detectors for neutron-detection. They are, however, a less established technology, more costly, and significantly rarer applied than silicon-detectors (Le Goff, 2012b). There are several manufacturers of Germanium-detectors.

Opposite to the other technologies studied in this document, Germanium-detectors make up a whole group of different detectors, including PSSSDs. It is a less specific case, covering a broader field of products, applications and designs. This fact certainly represents a possible reliability challenge for the bibliometric search. In addition, it might also require a broader selection of qualitative expert-input.

Germanium-detectors publications

The publication search on Germanium-detectors (Table XI) gets almost three thousand hits with *lemmatization* turned off, and even more if not. The search query was predefined with the assistance of Hillemanns (2012b) and Le Goff (2012b).

Publications: Germanium-detectors		Top 10 organisations		
		Org. name	Org. type	#Publications
Query	(germanium or ge) NEAR/0 ((detector*) OR (("solid state" OR solidstate) NEAR/0 detector*) OR (passivation) OR (shaping))	CNRS-IN2P3	Institution	191
		INFN	Institution	145
		Univ_Calif_Berkeley	Institution	135
#Publications	2924	CEA	Institution	119
		MPI	Institution	109
Lemmatization	Off	GSI	Institution	89
		Univ_Liverpool	Institution	85
Timespan	All Years	Univ_Cologne	Institution	76
		Argonne_Natl_Lab	Institution	74
Date	13.08.2012	JINR	Institution	74

Table XI: Publications on Germanium-detectors. Source: Web_of_Knowledge (2012).

All the top ten organisations are institutions, and CNRS-IN2P3 is the top organisation. Bordais (2012), which is from CNRS-IN2P3, confirmed that his organisation is one of the leading developers of Germanium-detectors. The sociogram of all the publications (Appx 7.20 and Figure XXV) is so difficult to grasp that it almost does not provide any insight on the network, aside from demonstrating its complexity. Both Pospisil (2012) and Le Goff (2012b) said they expected this, due to the versatility of Germanium-detectors, and how popular it has become during the recent years. Moll (2012) expressed his scepticism towards the applicability of the sociogram in a partner selection process. The subject is too undefined to know what kind of knowledge each organisation possesses. A firm which specializes in Germanium-detectors in spectroscopy will not be an ideal partner if one needs special knowledge on Germanium-detectors in PSSSDs.

The +40 publications sociogram (Appx 7.21 and Figure XXIV) provides a more practical view on the more dominant organisations. Even when all organisations with less than forty publications are filtered away there are still thirty one organisations left in the sociogram. There is only one well connected cluster, although some of the nodes are considerably better connected than the others. These are the University of Milano, INFN, the University of Cologne, GSI, CNRS-IN2P3, the University of Paris 11 and CEA. One of the bigger nodes, representing the University of California Berkeley, obviously has many publications on the subject, but rather few co-publications. If the sociogram is filtered even further to +60 publications (Appx 7.22), a fair number of organisations still remain in a well-connected cluster.

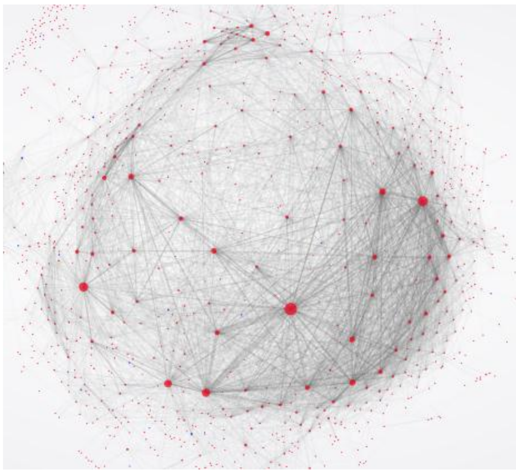


Figure XXV: All organisations with publications on Germanium-detectors.

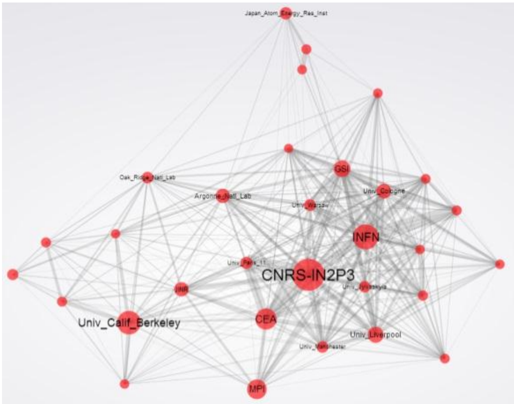


Figure XXIV: Organisations with more than 40 publications on Germanium-detectors.

The centrality sociogram of all of the publications (Appx 7.23) is as chaotic as the original publication sociogram, although it does display the close connection between many of the larger organisations. The +40 publications centrality sociogram visualises the groupings of the dominant organisations. There are four cliques: An European around INFN, another European around CNRS-IN2P3, one US around the University of California Berkeley, and one Japanese around the University of Kyoto. Bordais (2012) could confirm the connections to CNRS-IN2P3, and was quite impressed with the picture drawn from the sociogram.

Le Goff (2012b) and Bordais (2012) suggested prior to the presentation of the sociograms that CNRS-IN2P3 is the European organisation which hold the most knowledge and capability on Germanium-detectors. It is therefore the obvious choice of collaborative partner, for R&D projects which deal with Germanium-detector. This is confirmed by the sociograms, which also recommends the Italian institute INFN and the North American University of California, Berkely. Pospisil (2012) was impressed with these results, and confirmed the academic network drawn from the publication sociograms. Moll (2012) was more sceptical, and thought the *purpose* of the technology was confusing; it is not clear what kind of Germanium-detectors the organisations are working on, or if they are developing or applying the technology. He recommended a more specific search if the results were to be used in a partner selection process.

Germanium-detectors patents

The patent search on Germanium-detectors (Table XII) results in relatively many hits. The search field is set to *Title/Abstract/Claims*, which is optimal for the pertinence of the hits. The search query was composed with the assistance of Dr. Dorothée Rueck at GSI and Le Goff (2012b) at CERN. The NEAR4 operator is used to allow phrases like "Germanium position sensitive solid state detectors".

Patents: Germanium-detectors		Top 10 organisations		
		Org. name	Org. type	#Patents
Query	(germanium or ge) NEAR4 ((detector*) OR (passivation) OR (shaping))	NASA	Institution	22
		Texas_Instruments_Inc	Company	8
		MIT	Institution	6
#Patent Families	275	Bechtel	Company	4
		IBM_Corp	Company	4
Search field	Title/Abstract/Claims	Philips	Company	4
		Sharp	Company	4
Timespan	1900 - search date	Westinghouse	Company	4
		Battelle	Not-for-profit	3
Date	14.08.2012	CEA	Institution	3

Table XII: Patents on Germanium-detectors. Source: Thomson_Innovation (2012).

NASA is by far the main player, with over twice the amount of patents than that of Texas Instruments on second place. The top-ten list also includes three institutions, one NPO and six companies. Le Goff (2012b) explained that one of NASA's biggest space-flight challenges is related to the Sun's radiation, or rather how to deal with it. Germanium-detectors are ideal for detecting such radiation, hence the interest from NASA. They are collaborating with Lockheed martin on this subject, and Le Goff (2012b) was pleased to see that the sociograms are displaying the real situation. The sociogram of all the patents (Appx 7.25) reveals eleven co-patents and several other independent patents. The +3 patent sociogram (Appx 7.26) even displays two co-patents, although most of the patents are held by a single organisation. It is interesting to observe that in addition to the many companies there are several institutions and even a NPO amongst the top patent holders. Le Goff (2012b) suspects the academic co-patents are filed for licensing purposes, or possibly for establishing background intellectual property with a view of creating future R&D projects with industry. He adds that it is hard to say if the patents are on development or use of the technology, as Moll (2012) suggested.

5 Conclusion

The partner selecting process in interorganisational R&D-collaborations is carried through differently from organisation to organisation. The literature suggests a two-step operation called searching and screening, subsequent to an initial needs analysis (Fontana et al., 2006). The first step is to search broadly for all possible candidates, and the second step is to sort out the best candidates. The screening process is based on pre-defined criteria assessed from the needs analysis. In R&D-collaborations, the most paramount criteria are high-tech capabilities and knowledge (Hamel et al., 1989). A cultural fit is also important to the collaboration, but not as critical as the organisations' high-tech capabilities and knowledge.

In practice, however, the partner selection process is not always carried though in such a rational manner. CERN-governed R&D projects are often heavily influenced by the project managers' personal experience and interpersonal relationships, rather than formal searching and screening procedures (Hillemanns, 2012a). It is the general understanding in the academic HEP-community that everybody knows who is doing what, thus partner selection is perceived as an insignificant task. This attitude did not lead to any unfavourable consequences some decades ago, when all technical equipment could be made in-house. Due to the mere scale of the experiments currently conducted at high-tech institutions such as CERN, that is not feasible today (Vuola and Hameri, 2006). Academic institutions need the production capabilities of their industrial partners, and the knowledge of academic experts from dissimilar scientific professions, to realise their most complex R&D projects. Procurement of technicians with expert knowledge in every technology critical to the project will be necessary to successfully accomplish such tasks (Stuart and Podolny, 1996). Very few, if any, single academic institute holds such expertise in-house, and must therefore obtain it elsewhere, outside of the organisation.

Searching and screening is more commonly applied in the industry, although their need for this might be even less than that of academia. Industry tends to be more engaged in near-marked developments, than in basic research (Chen, 1997). Such projects are generally of a smaller scale than those of basic research, and will therefore not need to be as multidisciplinary. The argument that the organisation knows all the players in their profession, and therefore does not need an advanced searching method to find their partners, is more valid as a reason to disregard the importance of partner selection in this case. Nevertheless, searching and screening are regarded by industry as the optimal solution for partner selection in early-phase management of collaborations, and are therefore much applied. Companies will benefit from interorganisational R&D-collaborations by learning from their partners (KT), and by obtaining intellectual property which can be commercially exploited.

It is also worth mentioning that society will benefit from interorganisational R&D-collaborations (Vuola and Hameri, 2006). The development of new technological innovations such as medical apparatus, energy production, and computer technologies will make the lives of people more comfortable, and our civilization more sustainable. A need for means to improve the partner selection process of interorganisational R&D-collaborations has been reported by both industrial and academic players in the HEP-community. The conceptual framework presented in this thesis will hopefully help to meet this need.

Prior research has demonstrated that capability and knowledge can be measured by the means of bibliometric data (Melin and Persson, 1996). This belief was shared by the scientists interviewed in this study. Moll (2012) even claimed it is the only plausible method of measuring an organisation's capability and knowledge. Publications, patents and press releases are bibliometric documents. Each one of these contains information on its affiliated organisations, and the documents can be looked up and extracted from online databases. By acquiring and processing all existing bibliometric documents on a given technological subject, the network structure of their affiliated organisations can be modelled. The resulting network model will illustrate the interorganisational network of organisations either developing or applying the technology. By merging the previous logic connection between bibliometrics and capability and knowledge, together with the principle that capability and knowledge is the most important organisational traits for a R&D-collaboration, one would expect that this network would reveal the ideal partners for a R&D-collaboration working on the given technology. This idea is the fundament for this document's conceptual framework.

By the means of a case study on PSSSDs, the method described above is proven plausible; not only in theory, but in a real-life setting. A conceptual framework which exploits the method has been developed for use in the partner selection process of R&D-collaborations. Bibliometric data on five technologies related to PSSSDs were obtained, processed, and analysed in accordance with the early theory-based conceptual framework. Publications were acquired from Thomson Reuters Web of Knowledge, and patents from Thomson Innovation. No easy method from obtaining press releases was discovered, and they were therefore discarded as a bibliometric source. The conceptual framework was initially based on the findings of prior studies, but got continuously improved by the results from the empirical research. Sociograms displaying the organisations engaged in each technology were created, allowing technical experts to intuitively grasp the organisations' relative influence and their relationships. The experts were asked to evaluate the pertinence of each sociogram, and how well these portrayed the actual interorganisational networks. The area of application, limitations, and opportunities of the conceptual framework were determined by triangulating the experts' judgement.

The feedback from the technical experts was amazingly concurrent, and can be summarised as follows:

- The publication based sociograms depict what can be said to be the research networks. Scientific publications are the measurement of knowledge, and academic institutions are the dominant sources. The publication sociograms of the more specific technology subjects Medipix/Timepix, Medipix3 and Pilatus were evaluated by the technical experts to be the most correct and useful network representations. The experts were amazed at the accuracy of the sociograms, and most of the flaws they reported turned out to be unknown, but real, unofficial interorganisational connections. The centrality sociograms of these technologies were also reported to be very accurate, depicting both official and unofficial collaborations. The sociograms of the far more general subjects bump bonding and Germanium-detectors were evaluated as less easy to interpret. The experts reported that it is hard to understand what knowledge the organisations in these sociograms possess, due to the wide range of sub-technologies each technology is composed of. Sociograms composed of more than 500 bibliometric documents fall under this category. They might provide some insights on organisational clusters, but their business would still be unclear to the observer. A solution to this issue is to identify the sub-technologies, and pursue those which are relevant to the current project. Sociograms composed of 50 to 300 bibliometric documents seem to be ideal.
- The patent based sociograms portray the development networks. This is mainly the domain of the industrial players; organisations which have the necessary capabilities to produce the technology in large quantities. The patent sociograms are not composed of as many bibliometric documents as their publication-based counterparts, and therefore have less detailed sociograms. It is more difficult to obtain patents than publications on the same technology topic. Some patents do not explicitly mention the technology in the patent text. The patent based sociograms were, however, evaluated by the experts as good indicators on organisational capabilities, although not as accurate as the publication based sociograms.
- In a partner selection process, the experts recommended two properties to specifically look for in the sociograms. First, it is favourable to team up with the number-one player in the field, and therefore pick the organisation with the largest node. A large node is synonymous with many bibliometric documents, which indicates high-tech capabilities. Second, it is also very beneficial to collaborate with an organisation which has strategic connections in the interorganisational network. In addition to facilitate new connections with other key organisations, it also indicates that the organisation is aware of its learning structures and processes, and is likely to recognise its importance. In addition to trust, high-tech capabilities and learning structures are the most vital ingredients to KT; the most valuable asset in interorganisational R&D-collaborations.

5.1 Implications and future prospects

Several companies, academic institutes and NPOs engaged in HEP R&D have issued a need for a utility that can help them to identify potential collaborative partners. The conceptual framework presented in this document is meant as a solution to this challenge. Technical experts have assisted in defining its qualities, which are listed in the SWOT-diagram in Figure XXVI.

Figure XXVI: SWOT analysis of the conceptual framework.

The main advantage of the conceptual framework is its ability to provide a good approximation of the interorganisational network on almost any high-tech topic, and not to portray the exact true picture. The whole process can in principle be done on an ordinary computer, if the analyst has access to the necessary bibliometric databases. The weaknesses of the framework are primarily related to the limitations of its bibliometric sources, and the prerequisite knowledge required of the user. The searching and screening procedures will likely be insuperable without satisfactorily technological insight on the search topic. The user will have to know what to search for, which bibliometric sources should be included and which should be excluded, and whether expertise on development or application of the technology is needed. This can, however, be countered by consulting technical experts. The other central issue is related to the measurement of the bibliometric documents. It is widely accepted by scholars that some publications and patents have higher quality or are more valuable than others, and a method to measure this quality should be incorporated into the framework's IT tool. This could perhaps be solved by taking into account the number of citations, when measuring the relevance of each organisation.

If these challenges are tackled, it is possible that the conceptual framework can function as a catalyst for increased interorganisational R&D-collaboration, which probably will result in more technological innovation. Numerous studies, including this one, suggest that technological innovation is beneficial to mankind, and should therefore be prioritised by the society (Vuola and Hameri, 2006). It is also possible that capable, skilful and knowledgeable organisations, which are not capable to signal (Fontana et al., 2006) their own qualities, can become more visible, if organisations on the search for collaborative partners apply the methods of the conceptual framework. Perhaps it might even be possible to accelerate the overall global innovation by helping these organisations become more visible?

For future studies, it would be interesting to explore the opportunities of introducing geological maps to the sociograms, and pin the organisations to their GPS-locations. This could reveal where the capabilities and knowledge are physically located. By limiting the search to a country, one could find the preferred national organisations. It would also be interesting to further study how different sociograms can be combined to reveal organisations that hold capabilities and knowledge on several of the technologies sought after by the searching organisations. The finale collaboration can thus be limited to a small number of organisations, if each partner is proficient with a large number of technologies. The timeline sociograms might also reveal unforeseen evolutionary characteristics of the interorganisational networks; patterns which might lead to knowledge on how to predict the progress of R&D-collaborations. This last suggestion is of course only speculations, but if this was feasible it could open up for new methods of analysing and understanding interorganisational collaborations. Such information would certainly be beneficial to governmental incentive programs for increased academia/industry collaboration, but also have financial value to stockbrokers and business analysts.

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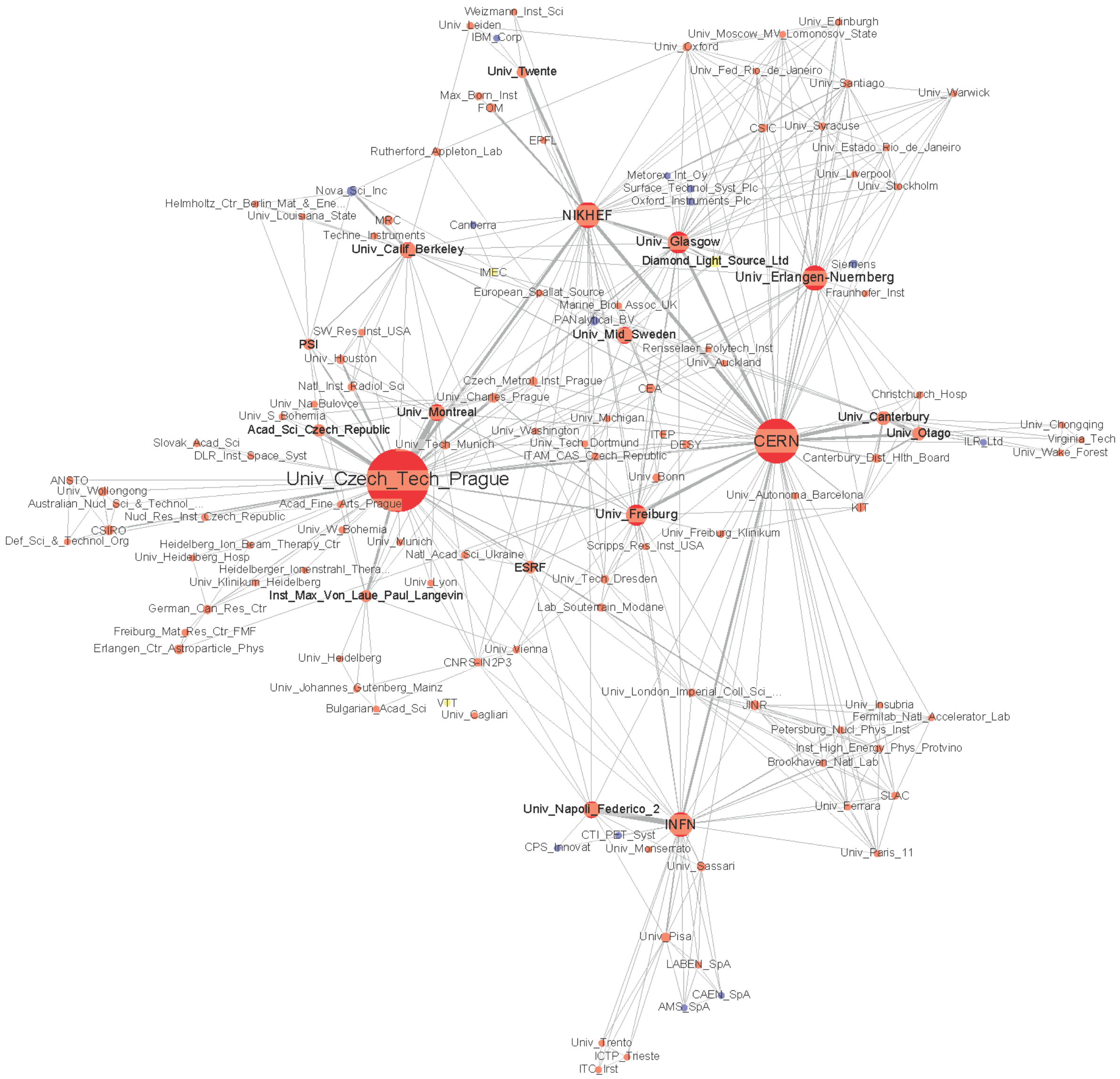
7 Appendix

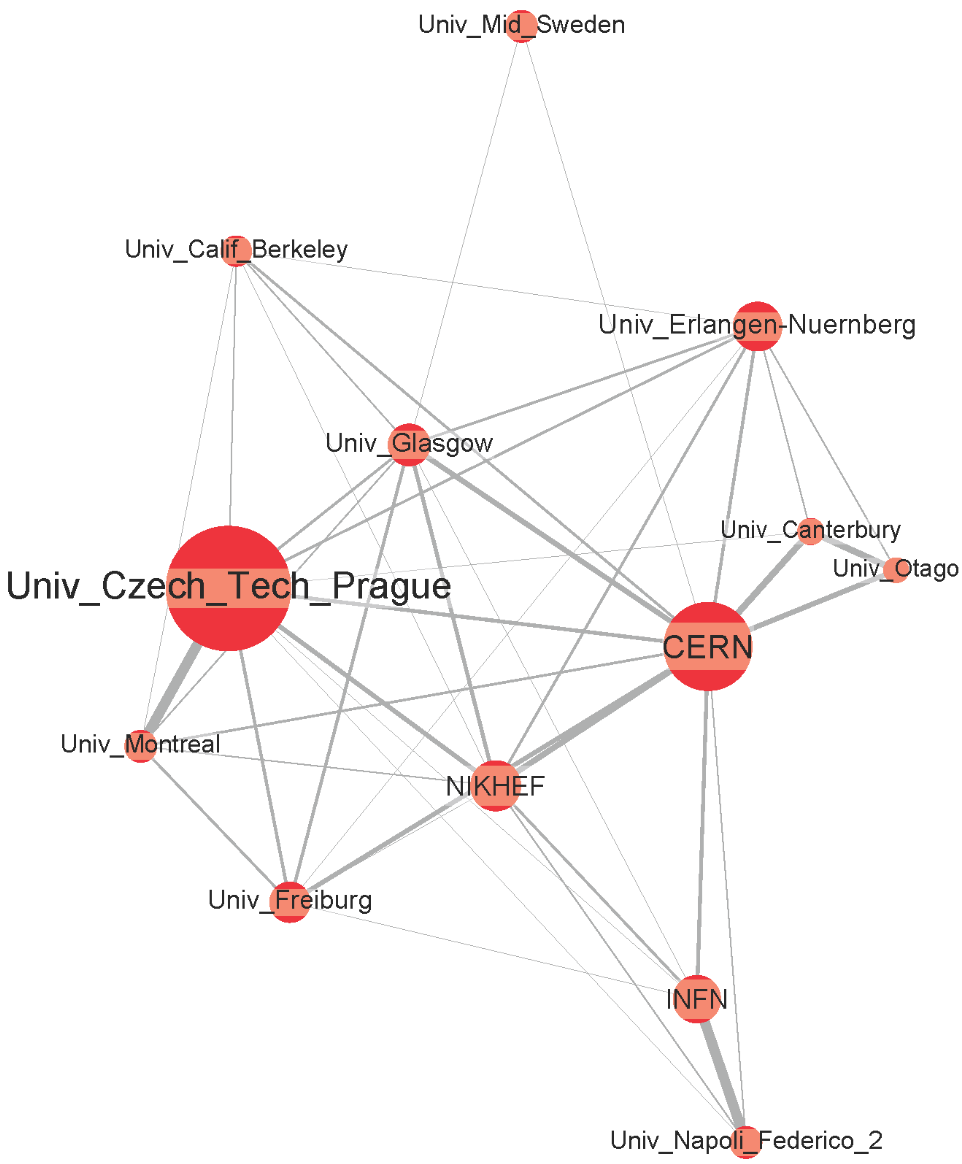
7.1 Sociogram: Medipix/Timepix, all publications

This sociogram displays all the organisations found in publication search on Medipix/Timepix. The nodes are coloured according to organisation type: Academic and governmental institutions are red, companies are blue, and NPOs are yellow. The edges are all grey, and their thickness is scaled according to the number of co-published publications between the connected nodes: More co-publications result in thicker edges.



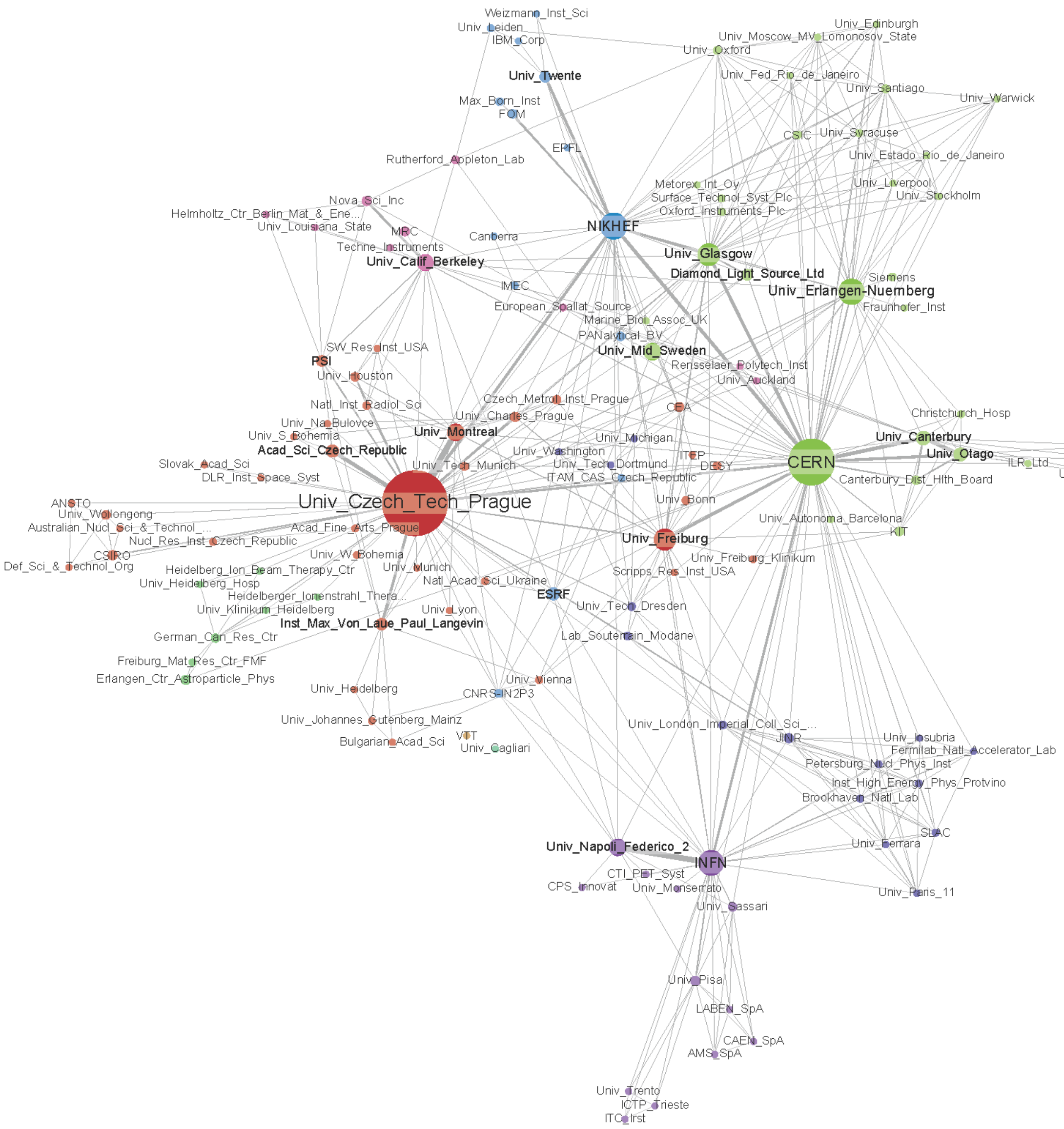
7.2 Sociogram: Medipix/Timepix, +10 publications

This sociogram displays the organisations with more than 10 publications found in the publication search on Medipix/Timepix. The nodes are coloured according to organisation type: Academic and governmental institutions are red, companies are blue, and NPOs are yellow. The edges are all grey, and their thickness is scaled according to the number of co-published publications between the connected nodes: More co-publications result in thicker edges.



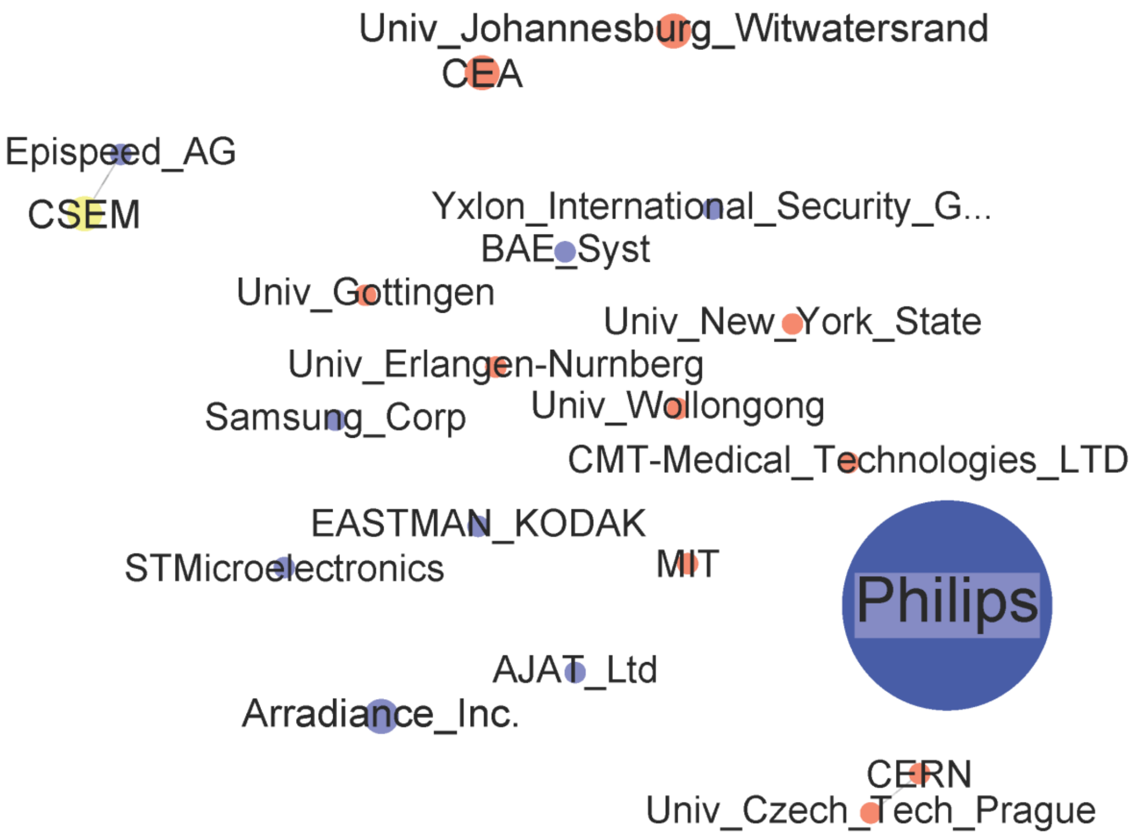
7.3 Sociogram: Medipix/Timepix, centrality

This sociogram displays all the organisations found in the publication search on Medipix/Timepix. The nodes are coloured according to which organisations they are more closely related: The more co-publications the organisations share, the more do they share the same colour. The edges are all grey, and their thickness is scaled according to the number of co-published publications between the connected nodes: More co-publications result in thicker edges.



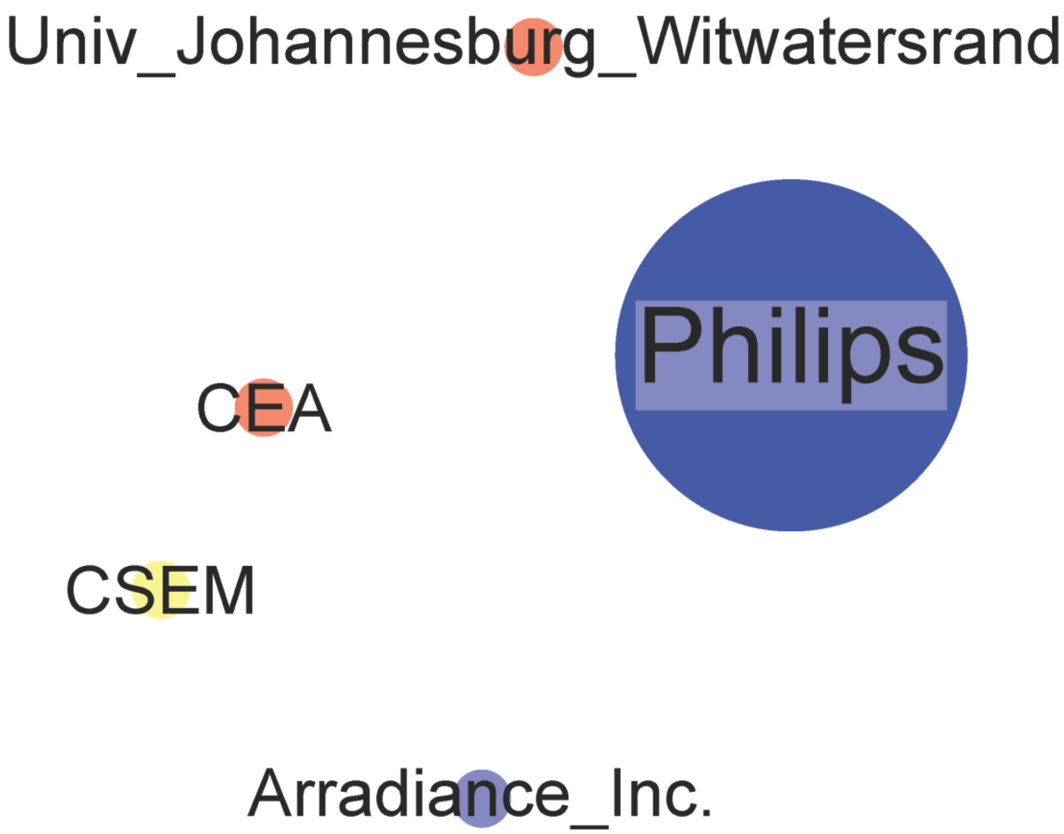
7.4 Sociogram: Medipix/Timepix, all patents

This sociogram displays all the organisations found in the patent search on Medipix/Timepix. The nodes are coloured according to organisation type: Academic and governmental institutions are red, companies are blue, and NPOs are yellow. The edges are all grey, and their thickness is scaled according to the number of co-patents shared between the connected nodes: More co-patents result in thicker edges.



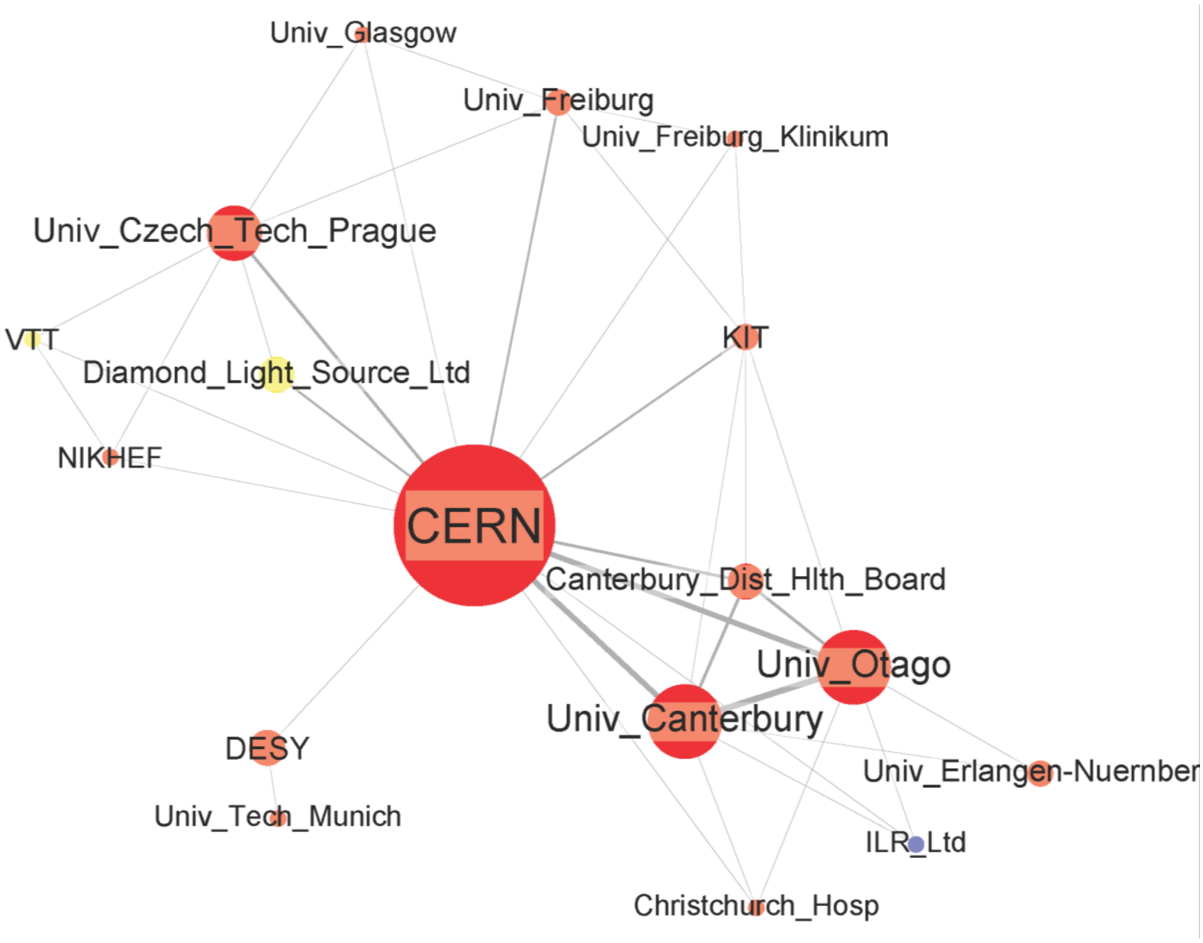
7.5 Sociogram: Medipix/Timepix, +2 patents

This sociogram displays the organisations with more than 2 patents found in the patent search on Medipix/Timepix. The nodes are coloured according to organisation type: Academic and governmental institutions are red, companies are blue, and NPOs are yellow. The edges are all grey, and their thickness is scaled according to the number of co-patents shared between the connected nodes: More co-patents result in thicker edges.



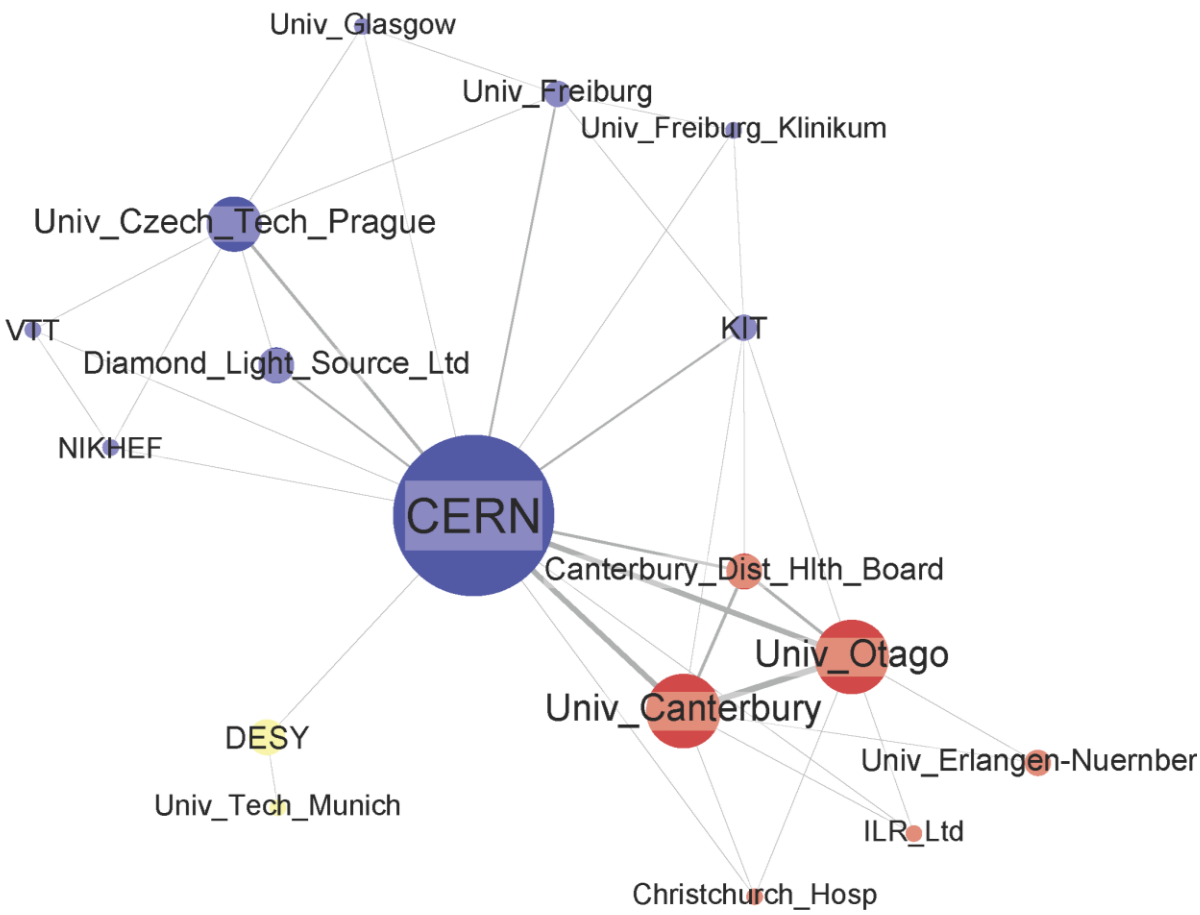
7.6 Sociogram: Medipix 3, all publications

This sociogram displays all the organisations found in the publication search on Medipix 3. The nodes are coloured according to organisation type: Academic and governmental institutions are red, companies are blue, and NPOs are yellow. The edges are all grey, and their thickness is scaled according to the number of co-published publications between the connected nodes: More co-publications result in thicker edges.



7.7 Sociogram: Medipix 3, centrality

This sociogram displays all the organisations found in the publication search on Medipix 3. The nodes are coloured according to which organisations they are more closely related: The more co-publications the organisations share, the more do they share the same colour. The edges are all grey, and their thickness is scaled according to the number of co-published publications between the connected nodes: More co-publications result in thicker edges.

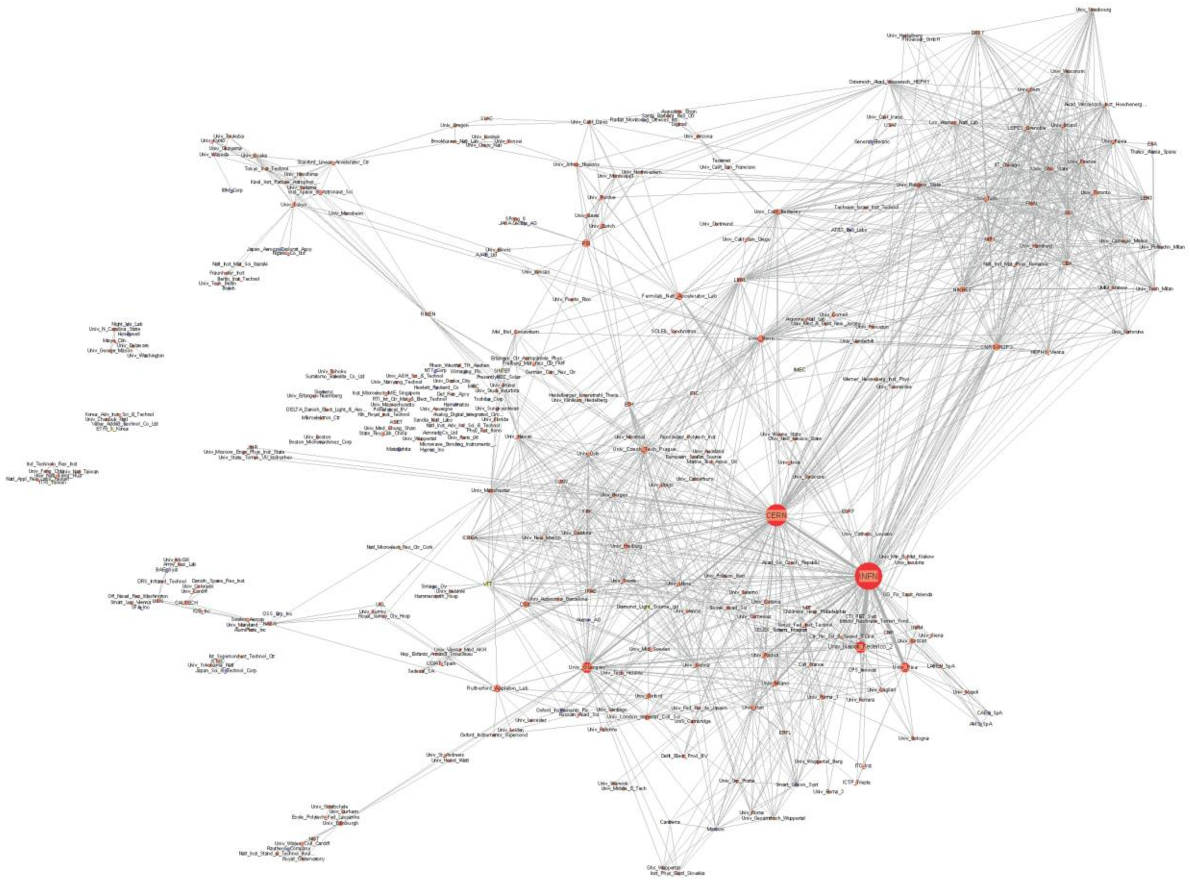


7.8 Sociogram: Medipix 3, all patents

This sociogram displays all the organisations found in the patent search on Medipix 3. The nodes are coloured according to organisation type: Academic and governmental institutions are red, companies are blue, and NPOs are yellow. The edges are all grey, and their thickness is scaled according to the number of co-patents shared between the connected nodes: More co-patents result in thicker edges.

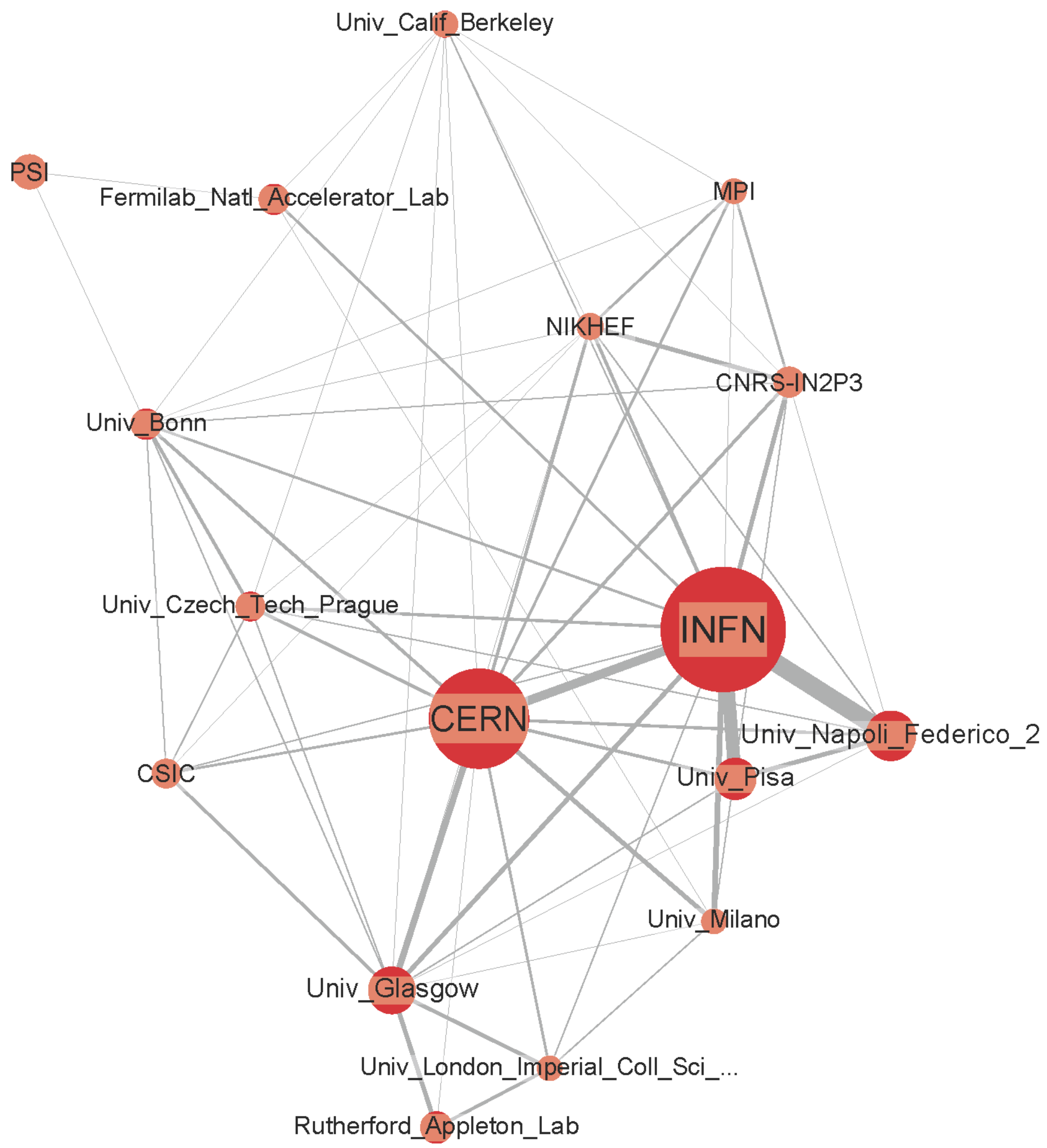
7.9 Sociogram: Bump bonding, all publications

This sociogram displays all the organisations found in the publication search on bump bonding. The nodes are coloured according to organisation type: Academic and governmental institutions are red, companies are blue, and NPOs are yellow. The edges are all grey, and their thickness is scaled according to the number of co-published publications between the connected nodes: More co-publications result in thicker edges.



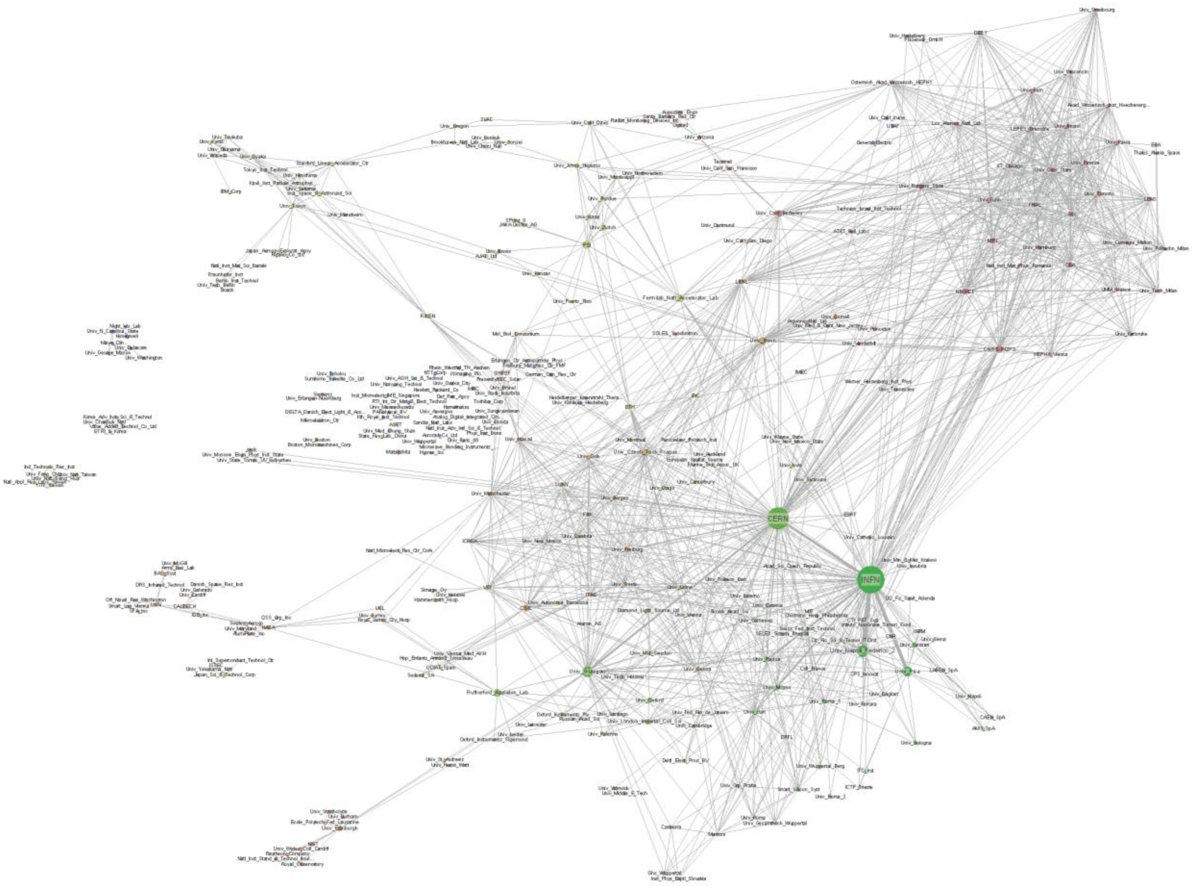
7.10 Sociogram: Bump bonding, +10 publications

This sociogram displays the organisations with more than 10 publications found in the publication search on bump bonding. The nodes are coloured according to organisation type: academic and governmental institutions are red, companies are blue, and NPOs are yellow. The edges are all grey, and their thickness is scaled according to the number of co-published publications between the connected nodes: More co-publications result in thicker edges.



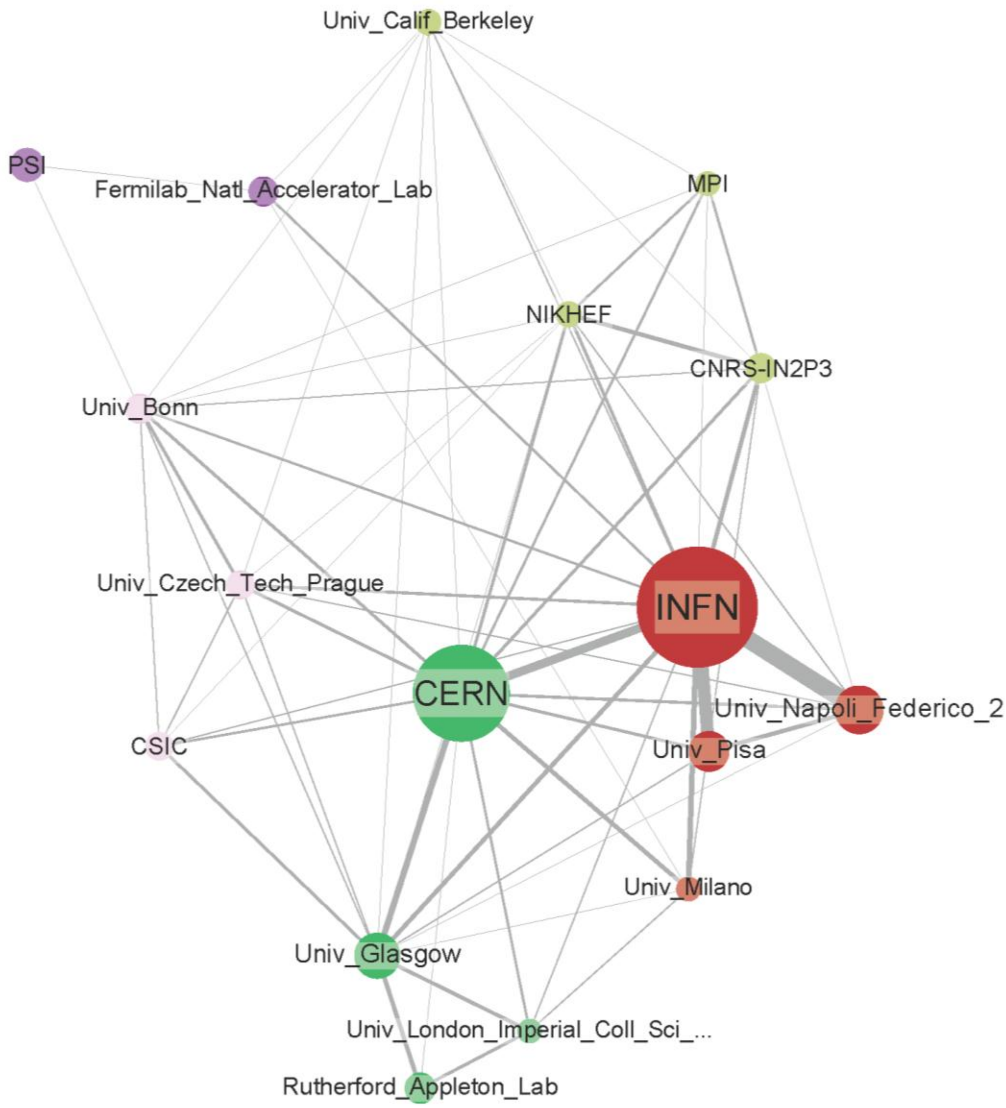
7.11 Sociogram: Bump bonding, centrality

This sociogram displays all the organisations found in the publication search on bump bonding. The nodes are coloured according to which organisations they are more closely related: The more co-publications the organisations share, the more do they share the same colour. The edges are all grey, and their thickness is scaled according to the number of co-published publications between the connected nodes: More co-publications result in thicker edges.



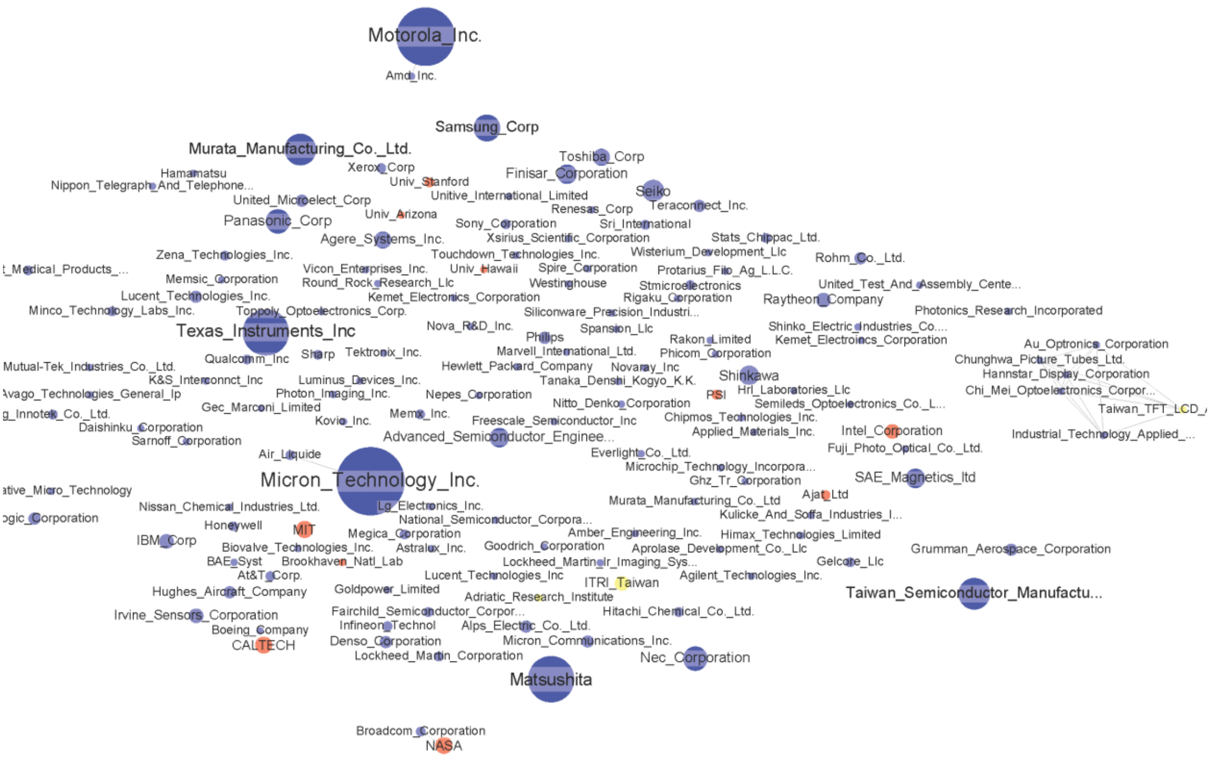
7.12 Sociogram: Bump bonding, +10 centrality

This sociogram displays the organisations with more than 10 publications found in the publication search on bump bonding. The nodes are coloured according to which organisations they are more closely related: The more co-publications the organisations share, the more do they share the same colour. The edges are all grey, and their thickness is scaled according to the number of co-published publications between the connected nodes: More co-publications result in thicker edges.



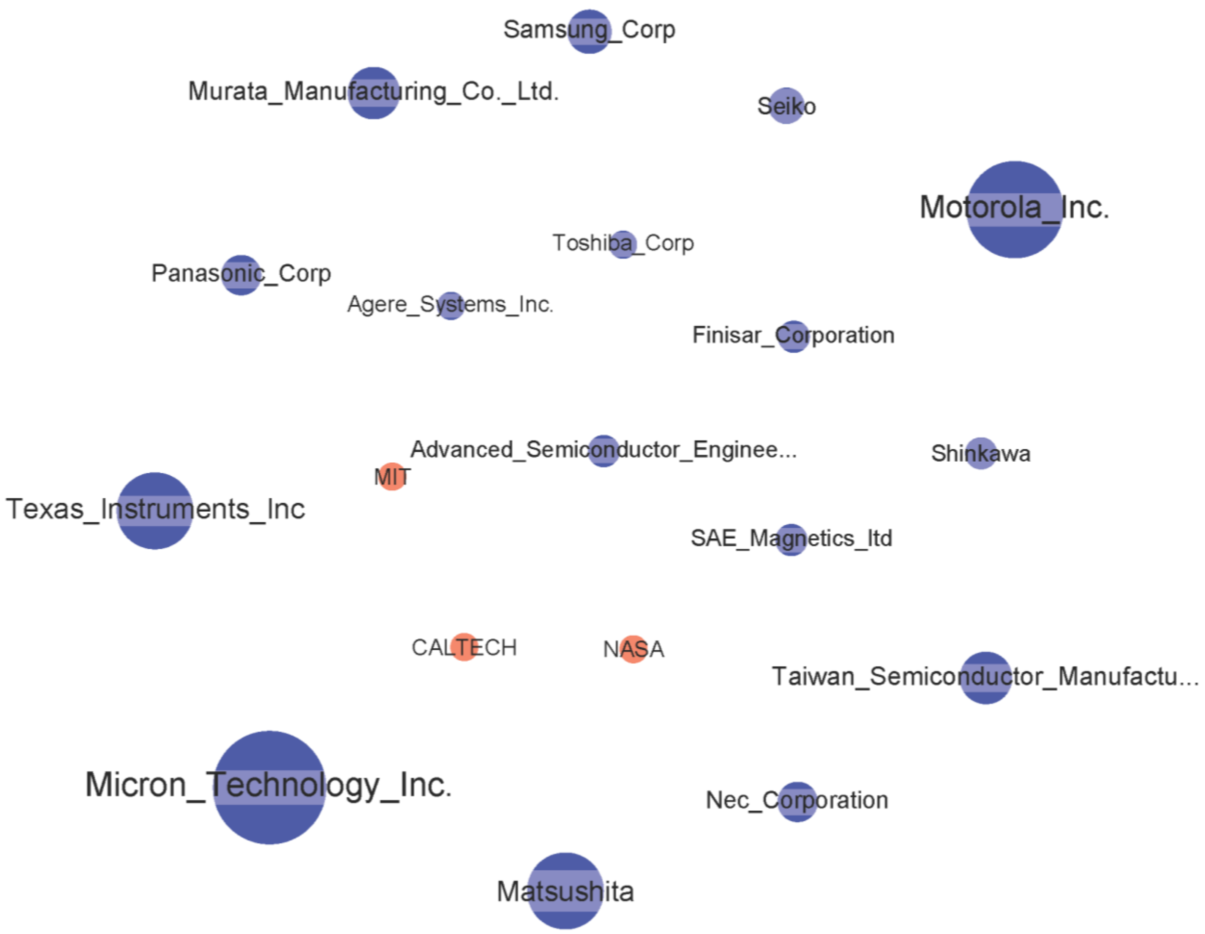
7.13 Sociogram: Bump bonding, all patents

This sociogram displays all the organisations found in the patent search on bump bonding. The nodes are coloured according to organisation type: academic and governmental institutions are red, companies are blue, and NPOs are yellow. The edges are all grey, and their thickness is scaled according to the number of co-patents shared between the connected nodes: More co-patents result in thicker edges.



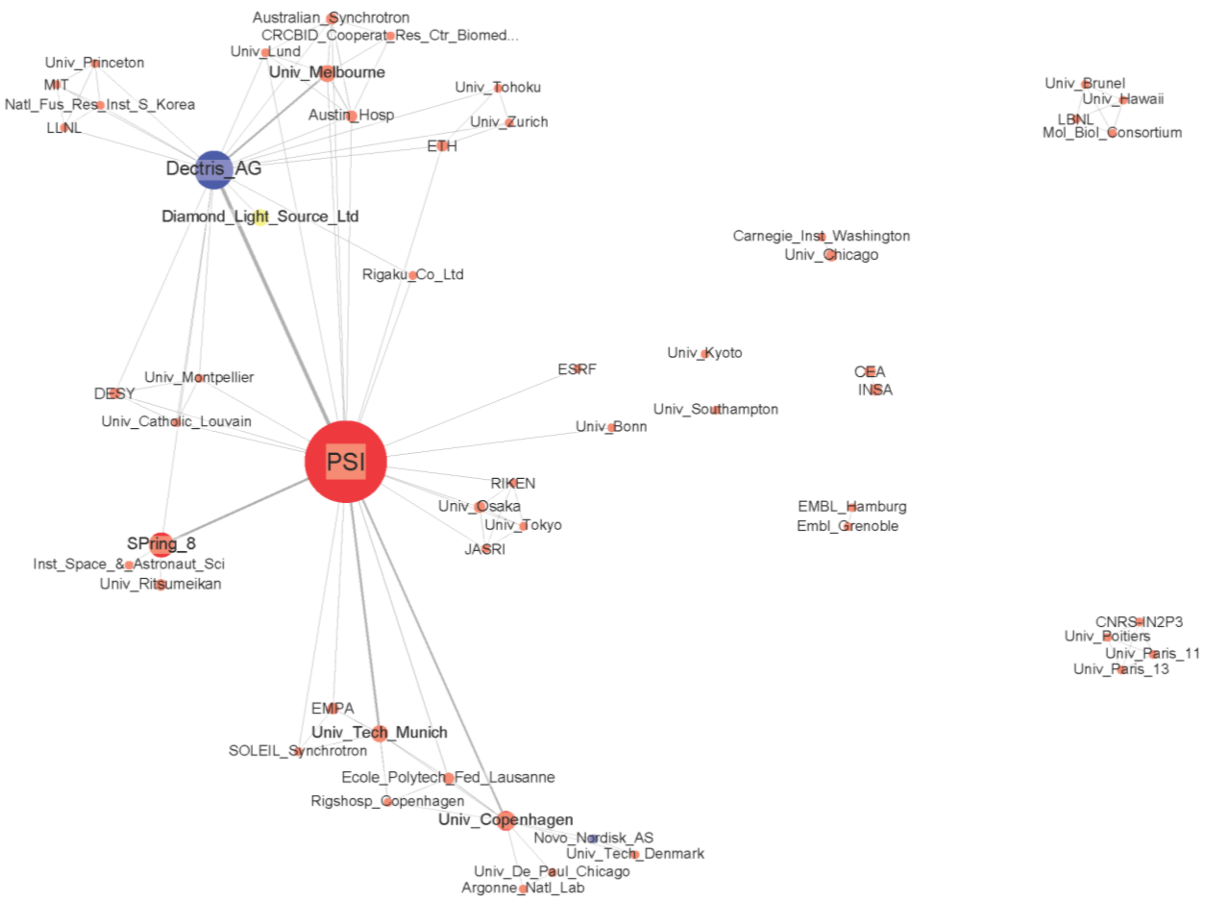
7.14 Sociogram: Bump bonding, +5 patents

This sociogram displays the organisations with more than 5 patents found in the patent search on Bump bonding. The nodes are coloured according to organisation type: Academic and governmental institutions are red, companies are blue, and NPOs are yellow. The edges are all grey, and their thickness is scaled according to the number of co-patents shared between the connected nodes: More co-patents result in thicker edges.



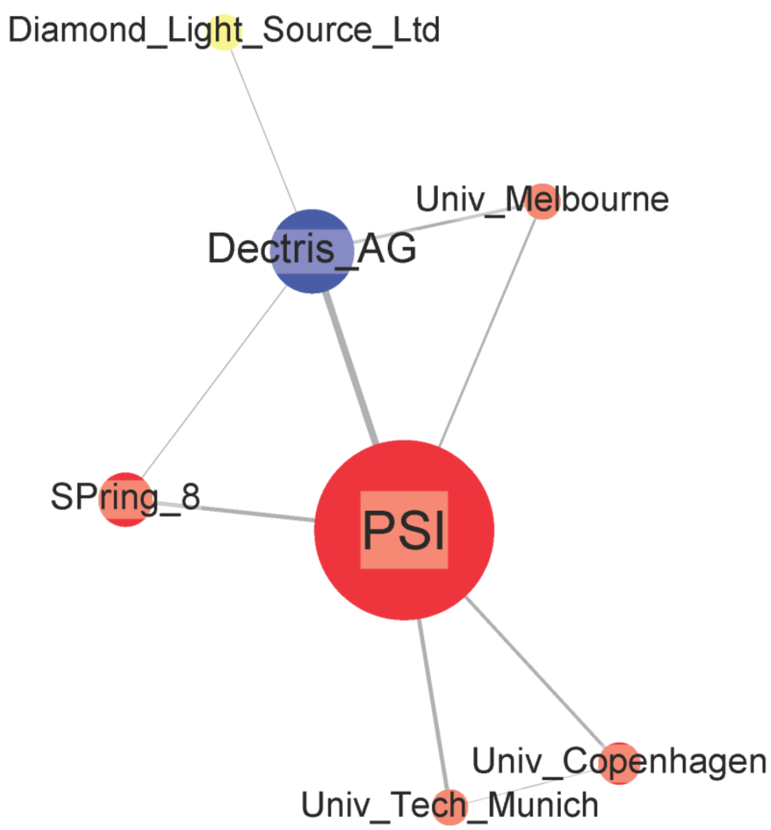
7.15 Sociogram: Pilatus, all publications

This sociogram displays all the organisations found in the publication search on Pilatus. The nodes are coloured according to organisation type: Academic and governmental institutions are red, companies are blue, and NPOs are yellow. The edges are all grey, and their thickness is scaled according to the number of co-published publications between the connected nodes: More co-publications result in thicker edges.



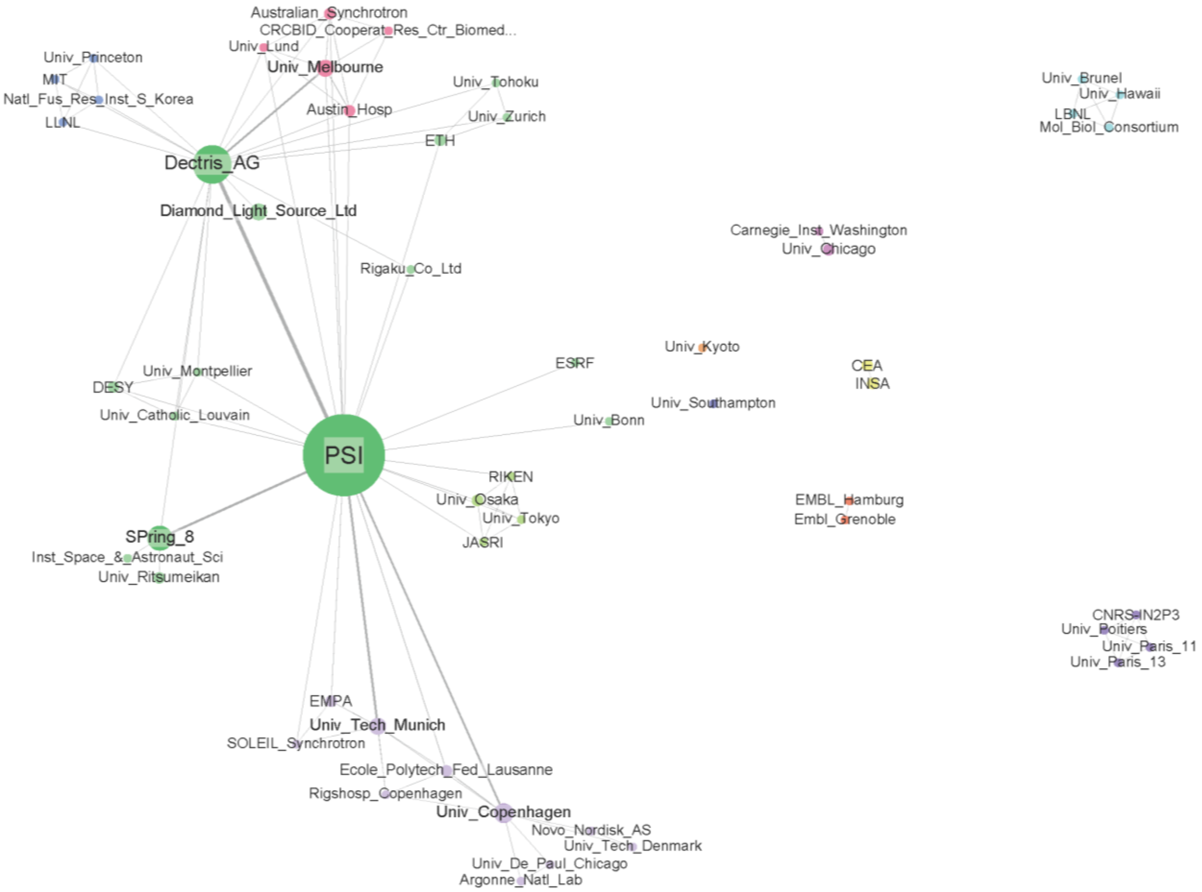
7.16 Sociogram: Pilatus, +3 publications

This sociogram displays the organisations with more than 3 publications found in the publication search on Pilatus. The nodes are coloured according to organisation type: Academic and governmental institutions are red, companies are blue, and NPOs are yellow. The edges are all grey, and their thickness is scaled according to the number of co-published publications between the connected nodes: More co-publications result in thicker edges.



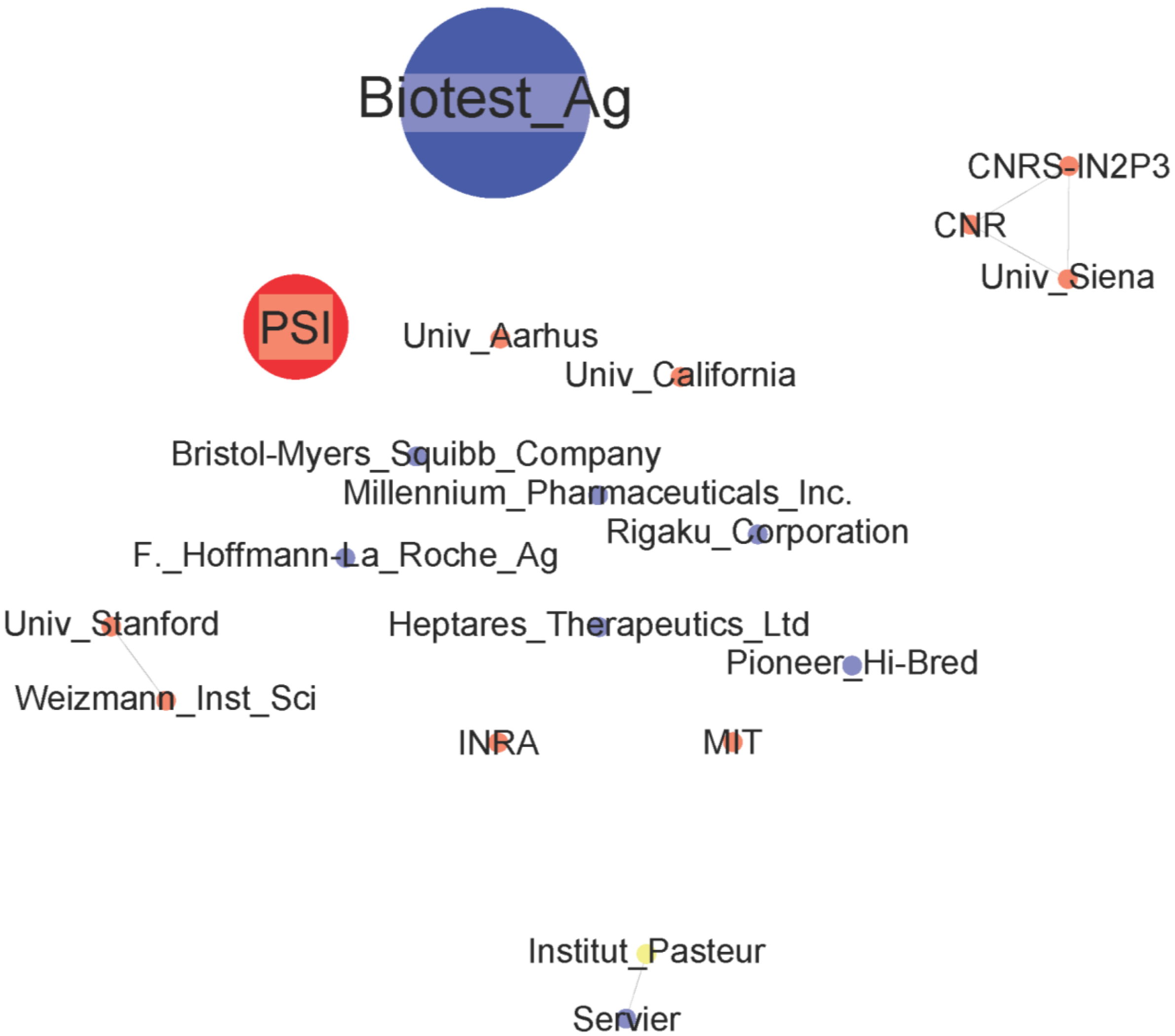
7.17 Sociogram: Pilatus, centrality

This sociogram displays all the organisations found in the publication search on Pilatus. The nodes are coloured according to which organisations they are more closely related: The more co-publications the organisations share, the more do they share the same colour. The edges are all grey, and their thickness is scaled according to the number of co-published publications between the connected nodes: More co-publications result in thicker edges.



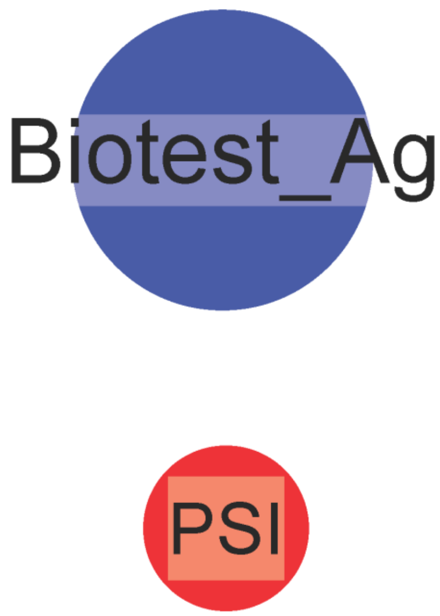
7.18 Sociogram: Pilatus, all patents

This sociogram displays all the organisations found in the patent search on Pilatus. The nodes are coloured according to organisation type: Academic and governmental institutions are red, companies are blue, and NPOs are yellow. The edges are all grey, and their thickness is scaled according to the number of co-patents shared between the connected nodes: More co-patents result in thicker edges.



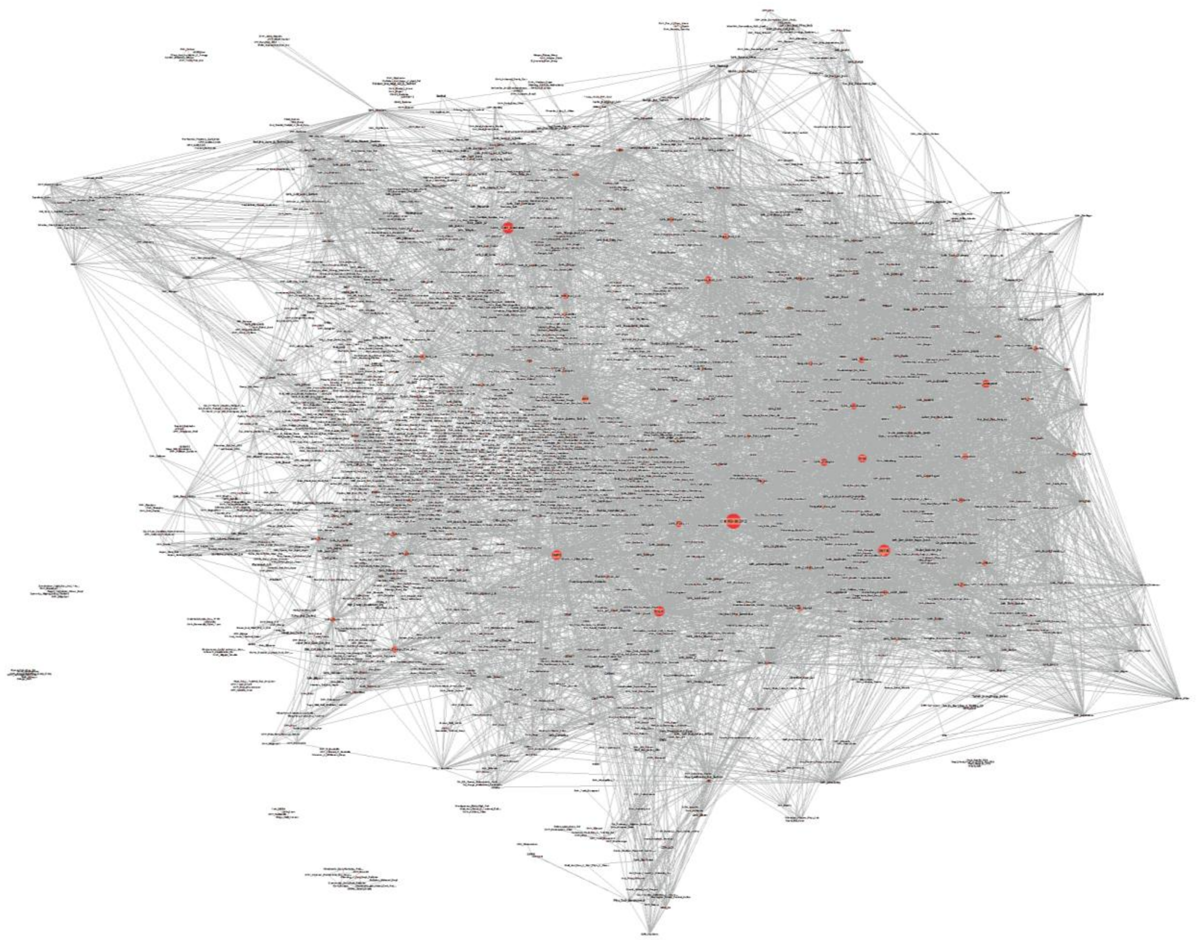
7.19 Sociogram: Pilatus, +2 patents

This sociogram displays the organisations with more than 2 patents found in the patent search on Pilatus. The nodes are coloured according to organisation type: Academic and governmental institutions are red, companies are blue, and NPOs are yellow. The edges are all grey, and their thickness is scaled according to the number of co-patents shared between the connected nodes: More co-patents result in thicker edges.



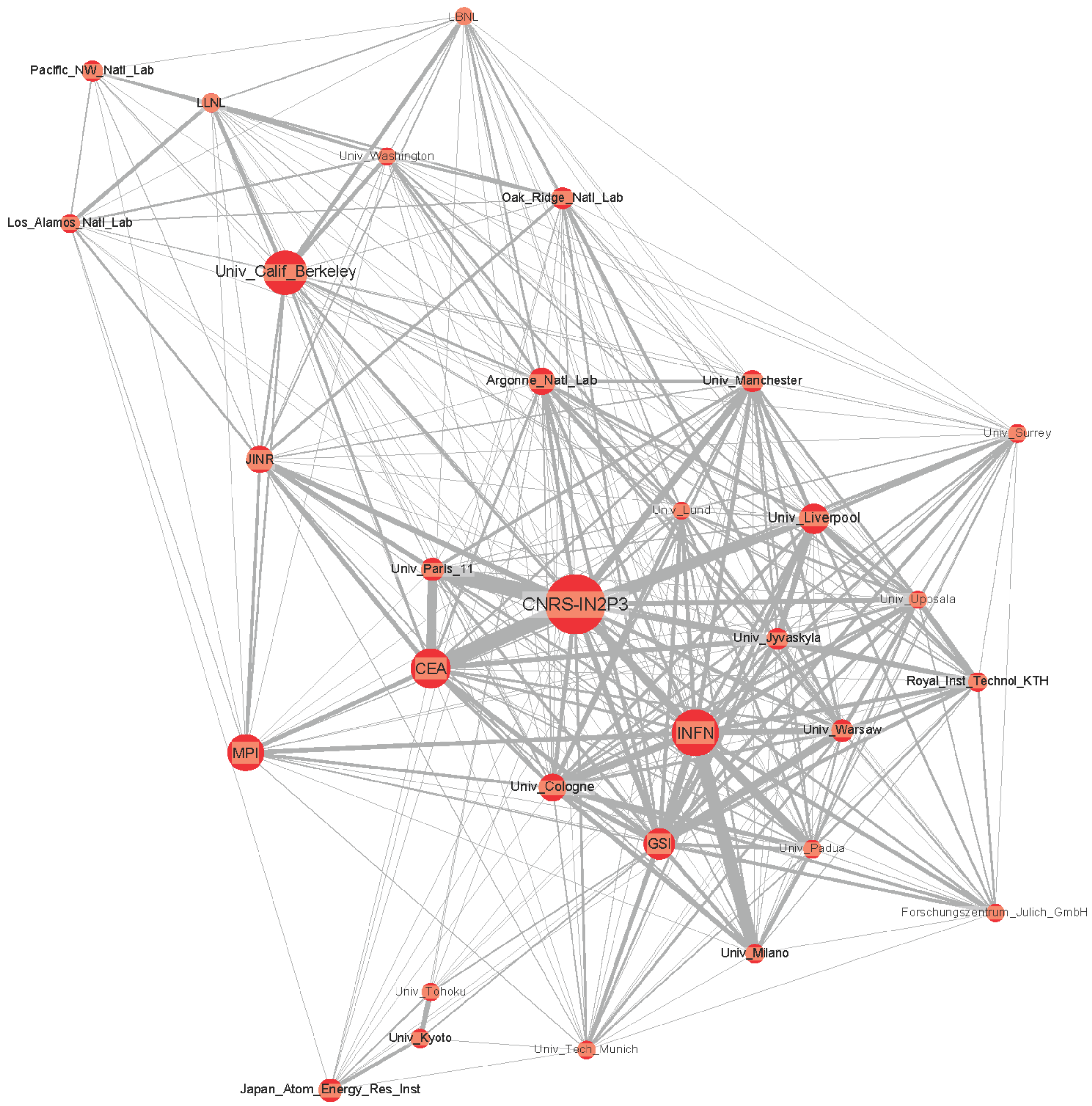
7.20 Sociogram: Germanium-detectors, all publications

This sociogram displays all the organisations found in the publication search on Germanium-detectors. The nodes are coloured according to organisation type: Academic and governmental institutions are red, companies are blue, and NPOs are yellow. The edges are all grey, and their thickness is scaled according to the number of co-published publications between the connected nodes: More co-publications result in thicker edges.



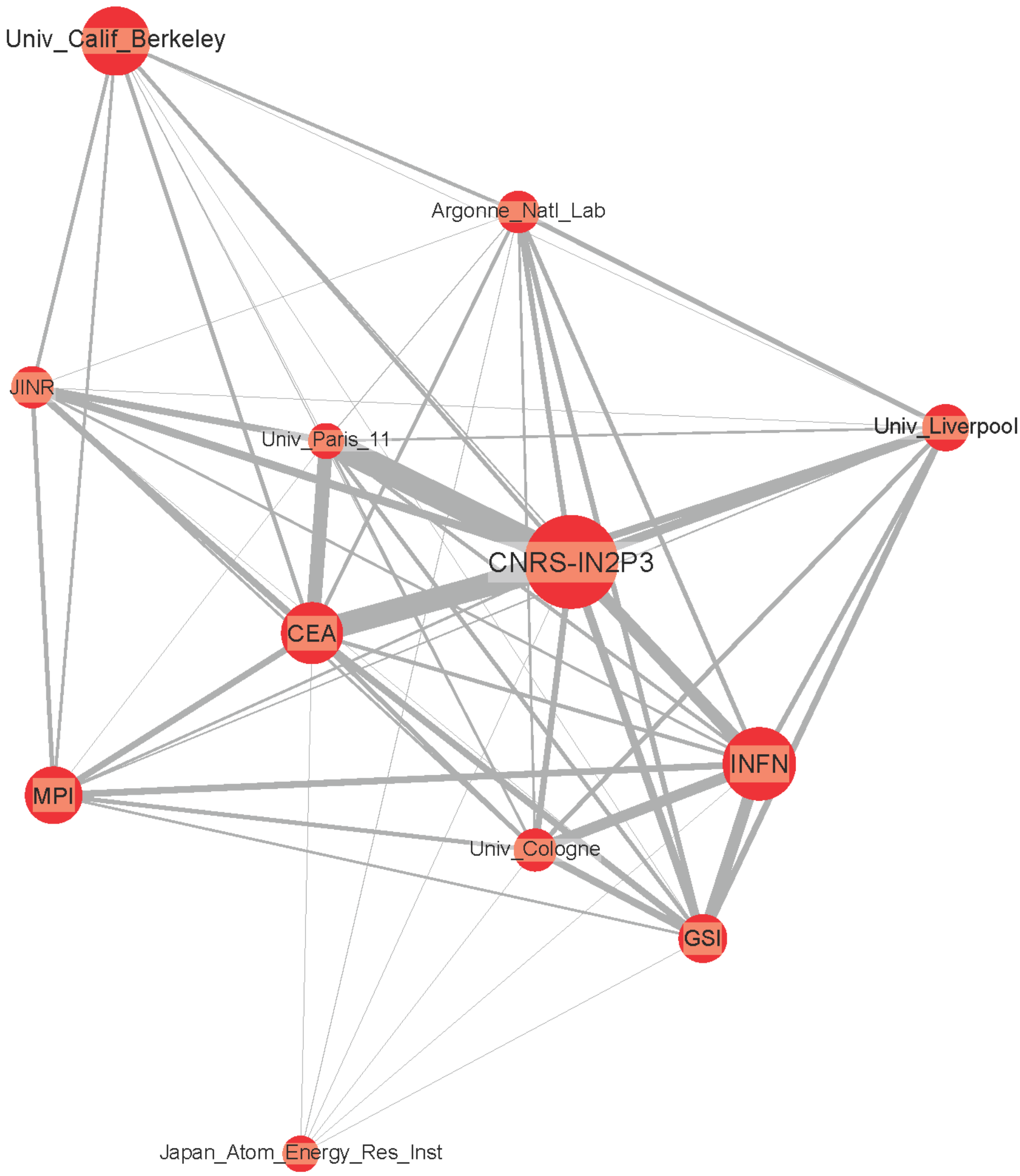
7.21 Sociogram: Germanium-detectors, +40 publications

This sociogram displays the organisations with more than 40 publications found in the publication search on Germanium-detectors. The nodes are coloured according to organisation type: Academic and governmental institutions are red, companies are blue, and NPOs are yellow. The edges are all grey, and their thickness is scaled according to the number of co-published publications between the connected nodes: More co-publications result in thicker edges.



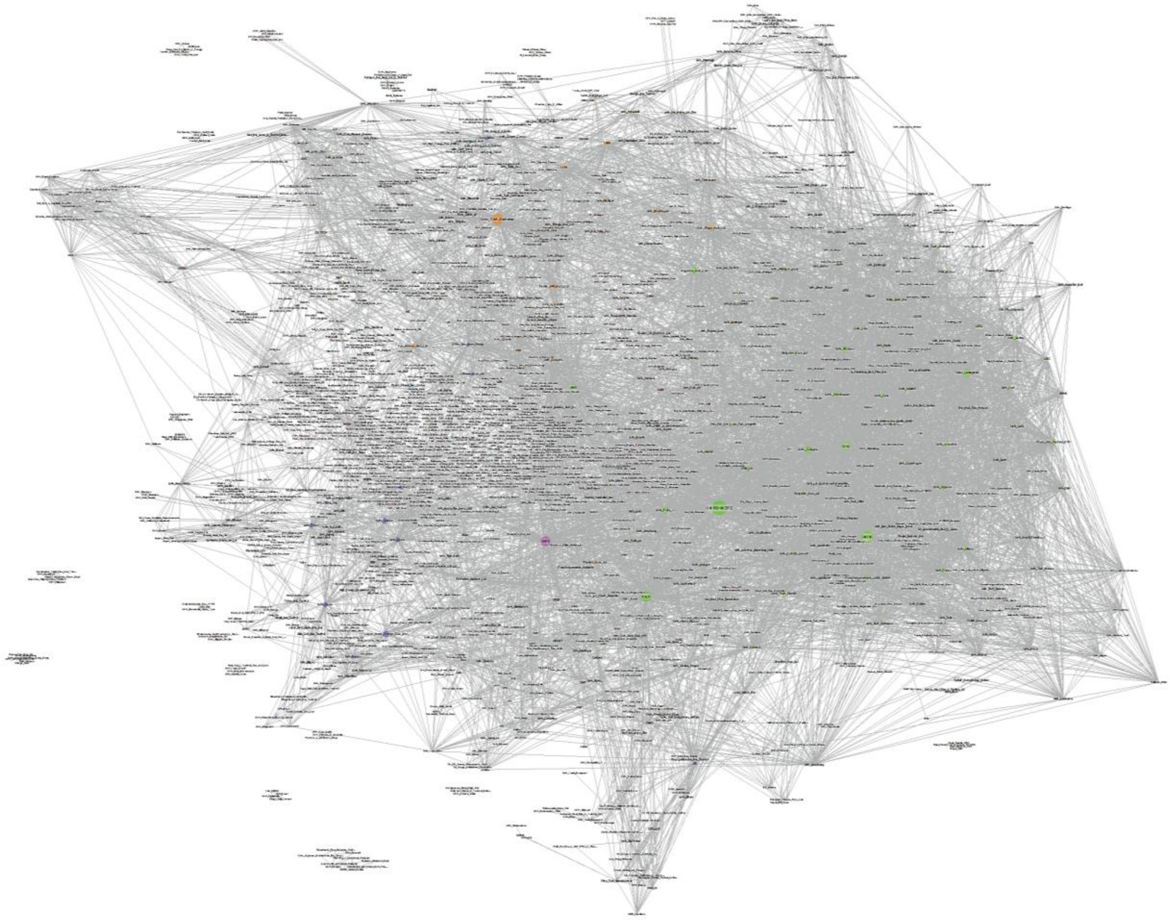
7.22 Sociogram: Germanium-detectors, +60 publications

This sociogram displays the organisations with more than 60 publications found in the publication search on Germanium-detectors. The nodes are coloured according to organisation type: Academic and governmental institutions are red, companies are blue, and NPOs are yellow. The edges are all grey, and their thickness is scaled according to the number of co-published publications between the connected nodes: More co-publications result in thicker edges.



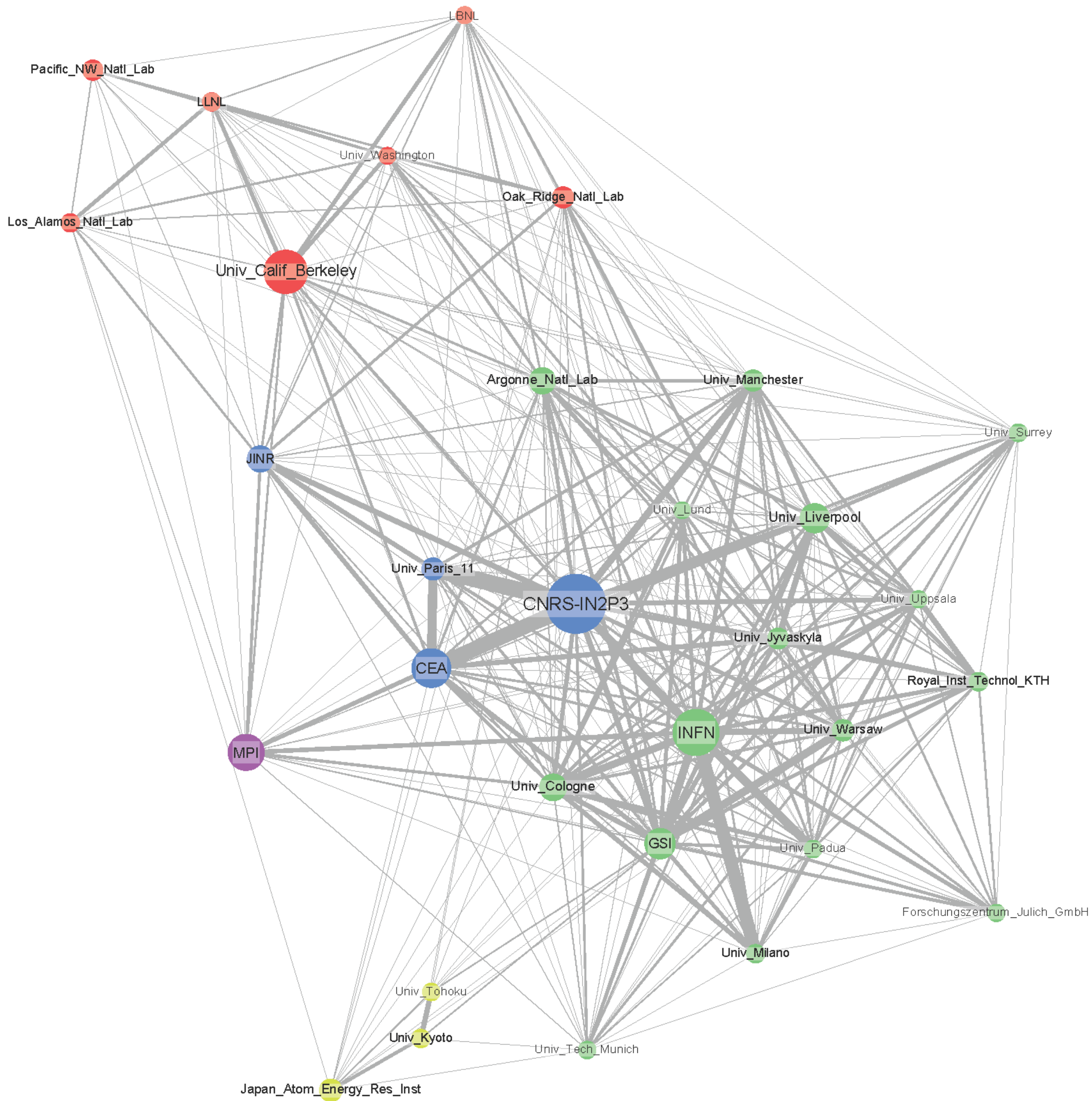
7.23 Sociogram: Germanium-detectors, centrality

This sociogram displays all the organisations found in the publication search on Germanium-detectors. The nodes are coloured according to which organisations they are more closely related: The more co-publications the organisations share, the more do they share the same colour. The edges are all grey, and their thickness is scaled according to the number of co-published publications between the connected nodes: More co-publications result in thicker edges.



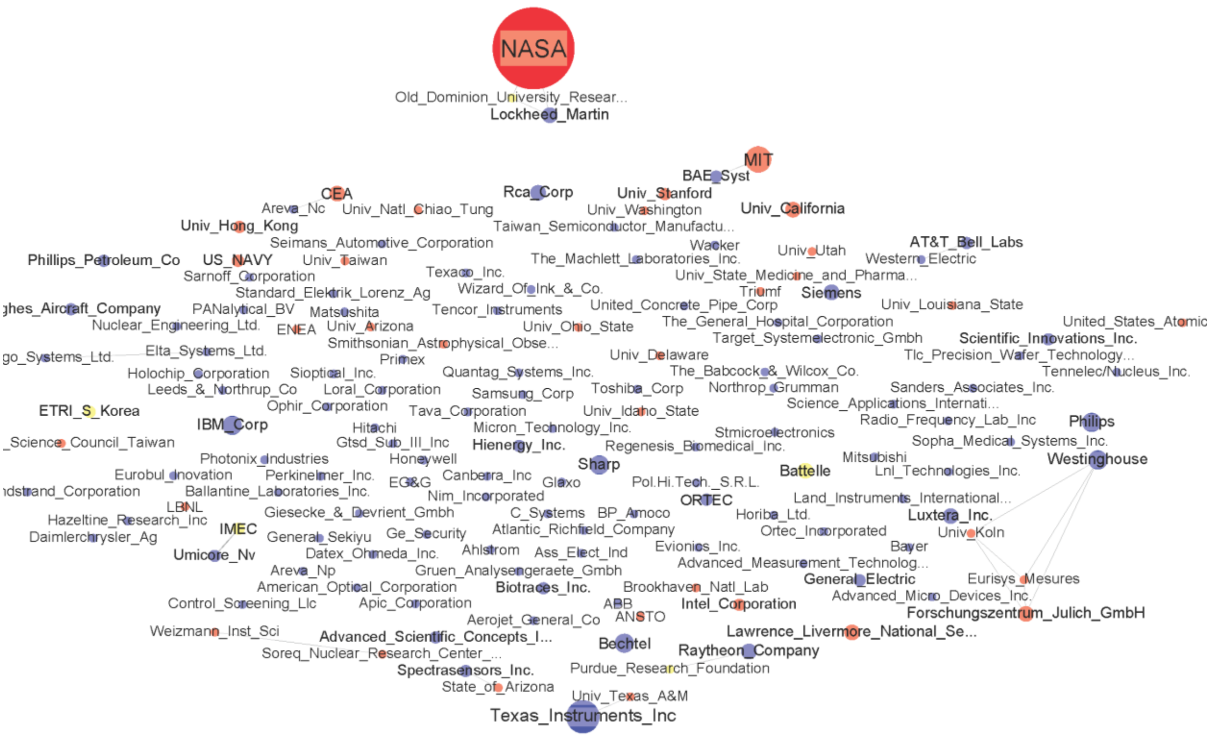
7.24 Sociogram: Germanium-detectors, +40 centrality

This sociogram displays the organisations with more than 40 publications found in the publication search on Germanium-detectors. The nodes are coloured according to which organisations they are more closely related: The more co-publications the organisations share, the more do they share the same colour. The edges are all grey, and their thickness is scaled according to the number of co-published publications between the connected nodes: More co-publications result in thicker edges.



7.25 Sociogram: Germanium-detectors, all patents

This sociogram displays all the organisations found in the patent search on Germanium-detectors. The nodes are coloured according to organisation type: Academic and governmental institutions are red, companies are blue, and NPOs are yellow. The edges are all grey, and their thickness is scaled according to the number of co-patents shared between the connected nodes: More co-patents result in thicker edges.



7.26 Sociogram: Germanium-detectors, +3 patents

This sociogram displays the organisations with more than 3 patents found in the patent search on Germanium-detectors. The nodes are coloured according to organisation type: Academic and governmental institutions are red, companies are blue, and NPOs are yellow. The edges are all grey, and their thickness is scaled according to the number of co-patents shared between the connected nodes: More co-patents result in thicker edges.