Application

2015-03-31

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Information about application

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Descriptive data

Project info

Project title (Swedish)*

Privat, adaptiv och diversifierad informationsfiltrering

Project title (English)*

Information Filtering with Privacy, Adaptivity, and Diversity

Abstract (English)*

The Internet is currently undergoing an important change where users more and more start to access information through a process best described as "discovery" instead of "search" (such as Google search). One of the central technologies in this discovery is the so-called recommender system that either provides concrete recommendations of, or more generally filters, information based on personal preferences. This filtering invariably implies some sort of curating of information, wherein personal preferences are in some sense lost to allow for generality. Yet, by aggregating many sources of information, current recommender systems are to a large extent able to determine much more about the user than most would feel comfortable with, such as largely revealing opinions on politics, religion, intelligence, or even sexual preferences. Another area of concern, which is well known to any user of such systems, is that they tend to give recommendations that are too predictable, basically tending to recommend items that are close to earlier observed behaviour, suggesting “more of the same”. A further challenge of recommenders is their ability to robustly deal with high degrees of sparcity in the data. Most current systems today exhibit a notable sparcity, but this sparcity is expected to become higher yet in future cross-domain applications, stressing the importance of systems able to handle such very sparse data sets.

The proposed research aims at addressing these challenges within a key component of a recommender system: the collaborative filter. The research project strives to develop algorithms for an adaptive and diversifying collaborative filter with some degree of privacy. This will be done by using a new collaborative filtering technique proposed by the applicant, which is based on a latent semantic analysis (LSA) but using a hidden Markov model (HMM) to create a layered filter structure. This structure is expected to provide a high degree of adaptivity and diversity together with some degree of privacy, and simultaneously allow for a highly parallelised implementation of the filter using general-purpose graphical processing units (GPGPUs).

As a result of an already initiated collaboration, the applicant is able to build up a unique data set from a large Scandinavian TV cable operator, containing detailed daily media behaviour for a large and diverse population. Using this, as well as publicly available data sets, we will research online data-local adaptive techniques to measure personalised preference scores given the user’s past and present media consumption and use these together with the proposed HMM-LSA collaborative filter. In this work, the applicant collaborates with the start-up company Quanox, which has agreed to provide access to other relevant data sets for the applicant’s research, as well as to provide access to their highly efficient parallelised implementations of an LSA collaborative filter. This collaboration will allow the applicant to focus on the conceptually novel aspects of the proposed research. Thus, in spite of the large implementation and computational requirements involved in the proposed algorithm, we will be able to leverage the standard components such as the LSA from Quanox, and to research in a focused manner on the novel components of the overall algorithm.

While this work takes its starting point in data from from online TV viewing, the research focus around the core collaborative filtering algorithm is planned to contribute to the general stage of knowledge in collaborative filtering. Improved properties in the filters ability to provide degrees of privacy, adaptivity, and diversity, as well as the filters robustness to sparseness of data, i.e., the key focus areas of the proposed research, is also expected to play a central role for collaborative filtering methods in these future application areas.

Popular scientific description (Swedish)*

Internet genomgår för närvarande en betydande förändring där användarna i en ökande utsträckning börjar komma åt information genom en process som bäst beskrivs som "upptäckande" istället för "sökt" (t.ex. Google-sökning). En av de centrala teknikerna inom denna upptäckande process är de så kallade rekommendationssystemen som antingen ger konkreta rekommendationer, eller, mer generellt, filtrerar informationen baserat på personliga preferenser. Denna teknik används ofta i samband med nyheter, musik, film och så vidare, och är dessutom banbrytande i samband med personlig radio och personlig tv, som för närvarande är på frammarsch i dagens medielandskap.

Matematiskt sett är rekommendationssystem baserade på algoritmer som lär sig användarnas personliga preferenser, intressen och smaker för att sedan kunna göra personliga rekommendationer för varje användare. Rekommendationerna görs utifrån i vilken mån användaren stämmer in på de matematiska strukturer som definierar preferenserna i fråga. Detta innebär dock oundvikligen någon form av selektion av informationen. I takt med att utbyggnaden av rekommendationssystem sprider sig i nästan alla typer av media blir det av största vikt att till fullo förstå på vilka värderingar och för vilka ändamål dessa rekommendationssystem faktiskt utformas. En sådan förståelse möjliggör en konstruktion av dessa system på ett sådant sätt att systemen gynnar slutanvändarna.

Huvudsakligen fokuserar vår forskning på utmaningen att utöka mångfalden i rekommendationsalgoritmerna för att ge fler oväntade, men välkomna, rekommendationer. I grunden är det en matematisk utmaning att modellera vad mångfald egentligen är och hur det värderas av användarna och att sedan ytterligare försöka utnyttja denna modell i algoritmerna. I vår forskning vill vi bygga på befintlig och ny kunskap från kognitionsvetenskap och använda denna för att förbättra den matematiska modelleringen. Ett andra fokus för vår forskning är att hitta algoritmer som gör rekommendationssystem snabbare att anpassa sig när användarnas intressen utvecklas och förändras.

De senaste åren har forskningen inom kognitionsvetenskap visat att vår information på internet inte bara kan användas för att analysera våra preferenser inom konsumtion, media och underhållning, utan även starkt kopplas till politik, personlighetstyper, arbetslämplighet, intelligens, sexualitet och så vidare. Detta uppfattas av många som ett allvarligt intrång i den privata sfären och ökar behovet av att utveckla metoder med fokus på anonymitet och personlig integritet.

Lager som skyddar den personliga integriteten kan inkluderas som en del av de matematiska modeller som definierar personers preferenser och de mått som används för att jämföra människors beteendemönster, något som är en viktig del i vår forskning. Denna förbättring av den personliga integriteten leder även till en övergripande långsiktig nytta för vårt samhälle som helhet.

Personlig integritet, mångfald och målet att kunna anpassa rekommendationer efter användarens förändrade beteende leder till utmanande matematiska problem och kräver att komplexa matematiska beräkningar görs på stora mängder data. Vår forskargrupp har därför fokuserat på att bygga upp en tvärvetenskaplig kompetens inom matematiska metoder och datavetenskap. Som en del av vår forskning föreslår vi algoritmer som är strukturerade på ett sätt som gör det möjligt att fördela de kapacitetskrävande beräkningarna på tusentals datorer distribuerade i molntjänster.

Project period

Number of project years*

4

Calculated project time*

2016-01-01 - 2019-12-31

Classifications

Select a minimum of one and a maximum of three SCB-codes in order of priority.

Select the SCB-code in three levels and then click the lower plus-button to save your selection.

SCB-codes*

2. Teknik > 202. Elektroteknik och elektronik > 20205. Signalbehandling

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Enter a minimum of three, and up to five, short keywords that describe your project.

Keyword 1*

Recommendation system

Keyword 2*

Adaptive systems

Keyword 3*

Privacy

Keyword 4

Keyword 5

Research plan

Ethical considerations

Specify any ethical issues that the project (or equivalent) raises, and describe how they will be addressed in your research. Also indicate the specific considerations that might be relevant to your application.

Reporting of ethical considerations*

Inga etiska överväganden är aktuella; arbetet är av en teoretisk natur.

The project includes handling of personal data

No

The project includes animal experiments

No

Account of experiments on humans

No

Research plan

1 Purpose and aims

The proposed research is concerned with the problem of information filtering by collaborative filtering, and in particular with the set of real world problems that occur, for example, when these filters are applied in recommender systems. While most works in this field have been approached from a computer science perspective, we will instead approach the emerging challenges from a signal processing viewpoint. Such an approach, using advanced statistical modeling and real-time adaptive systems, is becoming increasingly relevant due to the recent and expected future evolution of compute-server hardware, such as the integration of General Purpose Graphical Processing Units (GPGPUs) in next generation compute-server CPUs (often referred to as Accelerated Processing Units, APUs) and the dense and cost-effective connection of a large number of such APUs through the emerging fabric computing architectures for high-density compute-servers with low energy consumption.

In this context, we will develop a novel two-layered algorithm comprising hidden Markov modeling (HMM) and latent semantic analysis (LSA) in a way that lend itself advantageously to the massive parallelism available in future fabric computing servers equipped with APUs. While LSA have previously shown strong results in collaborative filtering (see, e.g., [1]), the use of HMMs in this context has only recently started to attract attention (see, e.g. [2–4] and the references therein). The proposed work will also address another of the key issues for recommender systems, namely that of privacy. Collaborative filtering invariably implies some sort of curating of information, wherein personal preferences are in some sense lost to allow for generality. However, by aggregating many sources of information, current recommender systems are to a large extent able to determine much more about the user than most would feel comfortable with, such as largely revealing opinions on politics, religion, intelligence, or even sexual preferences [5, 6]. In contrast, our technology will be constructed with an emphasis of privacy, both in the sense of the users direct privacy when using the system, but also in the sense that made recommendations should not be privacy infringing. As will be described in further detail later in this proposal, for new demanding applications of collaborative filtering it is important to effectively abstract the field from working with subjective user ratings, to work other data, such as direct time-stamps of user behaviour. Furthermore, it is important to develop methods for collaborative filtering that are robust to the increased data sparseness than can be expected in larger-scale deployments of collaborative filtering. Specifically, the proposed project aims to:

(i) derive adaptive online scoring functions directly from time-stamps for television media behavior, and optimize these jointly with the collaborative filter;

(ii) develop a two-layered collaborative filter using a LSA-based HMM model that allows for private, adaptive, and diversifying recommendations in a manner that is robust to data-sparseness; and

(iii) investigate and structure algorithmic formulations that may be efficiently implemented using massively parallelized multi processor compute-servers.

In particular, we will strive to combine these items to show a reliable real-time recommender system for online television. This will be done using a unique new dataset containing detailed daily media behavior for a large and diverse population. This dataset is a result of an already initiated collaboration with a large Scandinavian TV cable operator.

2 Survey of the field

Collaborative filtering is potentially of great importance in many areas of information filtering. However, until today, the most prominent application of these filters, and the main driver for research towards improved filters, has probably been their application in web-based applications and services aiming to offer a personalized subset of a large amount of information to be rendered to the user in the form of media recommendations[1]. The aim of such recommender systems is to provide suggestions that are cognitively processable by the user. In these applications, a user is shown suitable items based on earlier searches, purchases, and other forms of information about the user's behavior, and the relation of these behaviors to that of other users of the system (see, e.g., [1]). In general, such information is often combined with details regarding both the consumed items and the context in which they were consumed. With the maturing of the field, collaborative filtering is also beginning to show promising results in applications such as personalized real-time television programming, radio and news services. Subject to sufficient maturity of the field, many important novel applications of collaborative filtering are also expected to emerge. For example, we believe that collaborative filtering could in the future become central components in applications such as efficiency increasing health-care systems, autonomously driving energy-saving cars, stability monitoring systems in financial markets, and efficient match-making in business and employment markets.

In this work, we will focus on the most mature application of collaborative filtering, namely recommending items for media and e-commerce applications. In these applications, the filter optimization takes its starting point in a measure of fit, often formed using a 2-norm or a mean-squared error (MSE) distortion measure between the available user information and the available set of items in order to find the most suitable matches in the latter [7–16]. However, the way this type of recommendations are created, as any user of such a system will know, will often yield recommendations that are rather predictable, and only rarely offers recommendations with some degree of serendipity, i.e., yielding unexpected recommendations that suits the user well. Specifically, current recommender systems are limited or performing unsatisfactory on a range of issues:

(i) Typically, today's recommender systems take their starting point in a batch training on a large set of historic data (the training set) and is typically evaluated on a disjoint set (the test set). The result is recommender systems that typically remembers a user's preferences from a far past, and brings them into the present recommendation, but does not optimally follow the user in the present discovery process. In practice, certain past user behaviors will be more relevant for the next recommendation than others. However, recommendations ought not only be based on the user's most recent behaviors, and thus a model for adaptation comprising a more advanced modeling of the history of past behavior is called for. This aspect is referred to as the *adaptivity* of the recommender system.

(ii) Certain recommendations are of higher value to the end user than others - even if the two recommendations would have the same accuracy in a 2-norm or MSE-sense. As one example, a recommendation that holds an element of surprise can, if positively perceived,

[1] Typical examples include Facebook, YouTube, Netflix, Spotify, Zite, Bokus, and eBay, among many others.

be of higher value to a user than a (to the user) more predictable recommendation. This problem is referred to as the recommender systems ability to provide *diversity*, ideally fostering more serendipity in the users encounters with information items through recommendations. While there has been proposals to create increased diversity by add-on mechanisms to classical methods for recommender system design [10, 13–16], it is clear that the problem is not optimally addressed by these add-on solutions. Based on the above two observations, the applicant recently proposed a novel algorithmic structure as well as procedures for optimizing and adapting this structure striving to a address jointly the issues of adaptivity and diversity using a statistical signal processing mathematical modeling framework [17].

(iii) Current design setups typically operate narrowly within a certain type of information items that are usually dictated by the direct interests of the business that applies the recommender system. However, there are likely links between a users discovery of e.g. books and films or of, say, music and clothing; such fundamental links that are generally overseen by current solutions. We refer to this as the *cross-domain operation* recommendation opportunity. This opportunity is generally unexplored due to the general lack of cross-domain datasets for training and validation of concrete methods. The potential of cross-domain operation is of particular interest in local (such as national) business ecosystems, allowing these a way to compete with the larger and global services. Recently, the applicant has proposed one method enabling cross-domain operation while respecting user privacy and ownership to data [17, 18]. Such a solution will imply that the collected cross-domain data sets will exhibit a very large degree of sparsity, thereby necessitating the below proposed work on algorithmic structures allowing for such a degree of sparsity.

(iv) Current recommender systems typically regard their users' preference data as a property of the business that collects the data and applies the recommender system. However, as these systems evolve, and especially if they are to evolve into cross-domain operation, the control and privacy of these preference data for the user, i.e., the user's ownership of their own preference data, becomes of paramount importance. Especially so, as malicious statistical analysis of user preferences can be abused to expose private traits that are clearly considered parts of the private sphere [5]. We refer to this important complex of problems by the general term *privacy*. Some efforts have been made to address this important problem; notably, one may use a system based on El Gamal cryptography [19] to implement strong privacy of preference data in recommender systems based on collaborative filtering [20]. However, these methods are associated with practically infeasible protocol and communication overhead if considered for applications with many users. As a potential alternative to such methods, the applicant has recently described an alternative light-weight privacy enhancing method [21]. As elaborated on below, we will in this work strive to develop this method further.

In the proposed research, we set out to rectify these shortcomings, aiming to develop mathematical principles for a novel collaborative filtering method and establish knowledge regarding its improved properties regarding adaptivity, diversity, privacy, and robustness to data-sparseness.

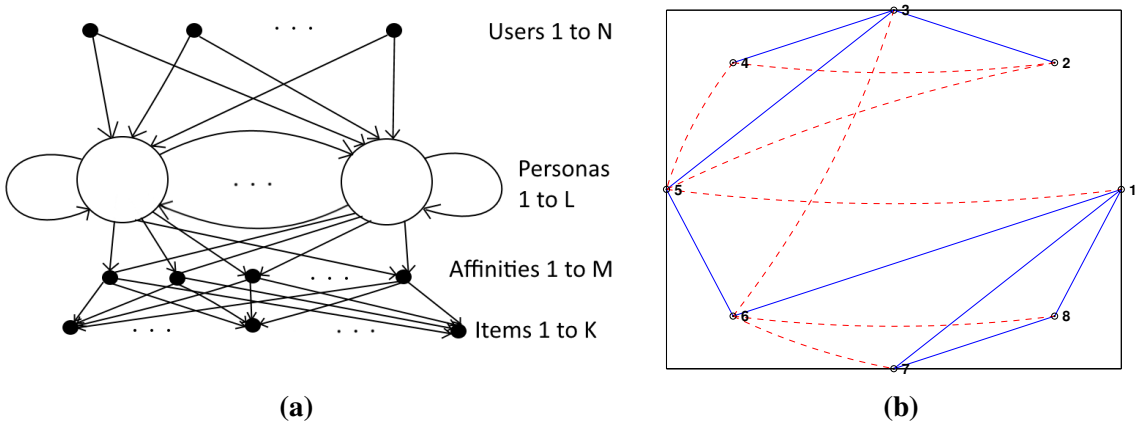

Figure 1: (a) The proposed HMM-LSA structure, and (b) the user-based nearest neighborhood (solid lines) and and the expanded neighborhood through neighbors of neighbors (dashed lines).

3 Project description and preliminary results

The proposed work is based on the applicants recent patent applications on recommender systems [17, 18, 21, 22], aiming to form a LSA-based system exploiting an HMM state transition structure. These filings outline the main concepts of the model and suggest procedures for its optimization. One of the main aims of the proposed work is to find new optimal solutions for these structures, and generate new knowledge regarding their performance. The main concept of the proposed structure for collaborative filtering is illustrated schematically in Figure 1(a), showing how each user is probabilistically mapped to a first range of internal states, termed personas, each of which is subsequently input to a traditional LSA part with affinities hidden nodes. This is probabilistically capturing the latent semantic affinities of the personas and the extent to which each item excites these affinities. Conceptually, this may be viewed as each user's personal preferences being modeled by a range of personas, each expressing different aspects of their preferences.

The use of the HMM as a preprocessing stage for the LSA, when appropriately initialized and jointly optimized together with the LSA, yields a probabilistically rigorous and efficient tool for dealing with unbalancedness and sparseness in the data. Furthermore, it provides a meaningful modeling of potential dynamics in the users behaviors, thus allowing for the construction of a collaborative filter that adapts to these dynamics. Additionally, the constructed aggregation effect of the persona states can be used as a tool for increasing diversity of the resulting recommendations, as the LSA now provides a soft-weighted recommendation for the personas, instead of just for a single user, which is the case in traditional LSA. These recommendations are thus formed from the behavior of many different users, rather than purely attempting to fit each user's own past behavior. The aggregation effect of the proposed personas is also useful a tool for privacy, in the sense that the rendered recommendation now results from many users behavior rather than a fit to the single user, and are thus a less direct function of the individual's past behavior. This can be clearly seen when considering an extreme case of a system consisting of only a single persona state; such a system would imply a total privacy for the users, but no

personalization for any user's preferences. By then gradually adding persona states, one is able to define the desired tradeoff level between privacy and personalization. Given this, some of the main topics of the proposed research are:

(i) *Construction of persona states, initial state probabilities for each user ,and state transition probabilities from user behavior*. Using users earlier behavior, we will strive to construct algorithms for computing appropriate persona states, initial state probabilities, and state transition probabilities. Since the following LSA is a probabilistic mapping, we can essentially accomplish this by treating the LSA a set of (collaboratively modeled) state emission probability mass functions in the context of classical HMM training. The algorithms should not only ensure that the appropriate personas are formed, but also that a new user's persona distribution is quickly adapted based on their early behavior. The later is of notable importance for the so-called cold start problem, ensuring that new users of a system quickly get relevant recommendations.

(ii) *Model order selection of hidden layered states*. In this work, we will specifically examine how one may optimally select the number of hidden states in each of the discussed layers, selecting both the number of personas and the affinities, to ensure that the resulting recommendations show improvements of their adaptivity, diversity, and privacy.

In working with this, we will take into account current research in cognitive science, which suggests that only very few factors (in the single digit range) are considered in human everyday choice [23]. It has even been proposed that such compact fast choice models evolutionally have made humans robust and adaptive to change [24]. This should be contrasted with current recommender systems, that typically employs several hundred coefficients in the affinities space to form their recommendations [7]. As the speed of adaptation of a system is directly related to the number of coefficients that needs to be adapted [25], it may be expected that a models involving significantly fewer coefficients in its recommendations will lend themselves significantly better to local online adaptation than current, less compact, model-based recommenders, while at the same time expose more robustness to data sparseness. It may be noted that similar ideas of sparse modeling of the LSA affinity space have been examined in the literature, but then treating the affinity weights as being the same for all behaviour of a given user [7]. This limitation makes the system fragile, yielding poor performance. However, via the here proposed persona structure, the relevant affinity states will instead be shared for personas, not for users, thereby allowing for a *different* sets of affinities to be activated by different personas for any given user.

Clearly, access to large and relevant data sets is of uttermost importance to studies of recommender systems. In order to ensure this, the applicant has initiated a collaboration with both the technology startup Quanox (`www.quanox.com`), based in Lund, and with a large Scandinavian TV cable operator. Via the latter, we are since June 2014 constructing a large data set of behavioral data from online television viewing, daily adding about 50 Mb of user data. This data set is ideally suited for the here proposed research, and also opens up another major area of research treated in this work; whereas most datasets in this field are based on subjective user ratings, the here measured dataset is characterized by containing the raw user behavior, i.e., recording the time when each user (in a large population) changes channel to start watching a new television program. Similar to some other related data sets, it does thus not contain

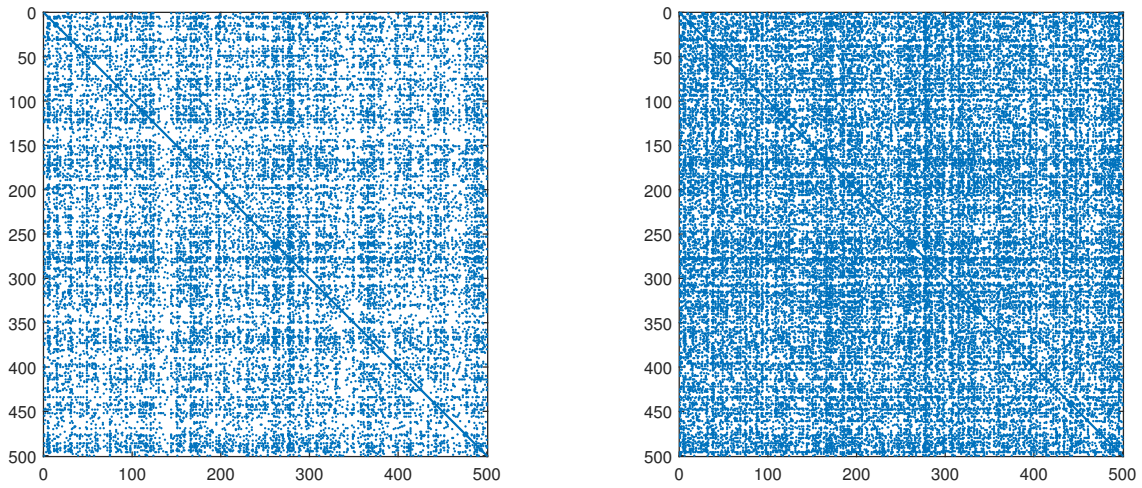

Figure 2: Distance measure between users using (a) a static scoring function, and (b) an initial version of an adaptive scoring function.

actual scores, but rather raw user behavior. This is in many ways more interesting, and we will therefore as a separate topic investigate:

(iii) *Construction of personalized scoring functions*. In this study, we will examine ways to formulate an automatic and adaptive scoring function, such that the scoring is generated not only as a function of the user's earlier behavior, but also as a result of the user's response to given recommendations. The personalized scoring function will be jointly optimized with the collaborative filter itself.

Earlier work has shown that subjective user ratings contains significant bias and noise components [1], and we will as part of this work compare the proposed individual and time-adaptive scoring function with more traditional scoring functions, including that of related subjective user ratings, to compare the resulting user bias and noise components of the scores. Our preliminary studies of the scoring function strongly affects the resulting recommendations, clearly highlighting the importance of the scoring function. This is illustrated in Figure 2, showing the cosine distance measure between users using two different such scoring functions, namely (a) the commonly used static scoring function used in [1], as well as (b) an initial version of an adaptive scoring function. As seen in the figures, the adaptive scoring function offers a notably denser mapping, thereby allowing for stronger connections between users, and thus an improved likelihood of a useful recommendation. The closer links will also be favorable in modeling the proposed persona structure. These results are generated using the 500 most active users' behavior during the fall of 2014 in our TV viewing dataset.

A further topic of interest is how one should proceed to form links between users. Typically, recommendations are formed by finding users that are in some sense close to the user of interest, sharing similar consumption behavior. Such users should not be too distant from each other,

but preferably have many shared connections. This is also how most current recommender systems are constructed. However, such a system has the drawback of neglecting secondary connections. For instance, users who have similar preferences but have not jointly consumed the same items will appear in the user-preference matrix as being entirely unconnected. To allow for an efficient construction of both of the considered hidden layers, it is important to also find such overlapping users. This may be done by extending the notion of closeness among users:

(iv) *Methods of determining closeness among users*. Typically, the closeness of users' are determined using the mapping of their consumption, finding users sharing a related consumption. In this work, we will examine techniques to expand the notion of closeness, to also find also less direct connected users.

Figure 1(b) illustrates this concept, showing two users (marked '1' and '2') that are seemingly unrelated. In the figure, the solid lines show how these users are connected to other users, and may be seen to only be distantly related to each other. However, but expanding on the notion of closeness, determining the neighborhood of each neighboring user, one is able to find other users which are close to both our users of interest, in spite of these not being close to each other in the traditional sense. Our initial studies of such an extension shows that one may in this way form a notably larger set of closely linked users, thereby also enabling better recommendations. We will further extend on this work by similarly forming a measure of closeness among items, such that the items shared by closely linked users will determine items closely related to the found items. From these found items, we will then find the users linking to these items, thereby finding users that share only links via the actual items. By doing this extension, we allow the user to find connections to items that indirectly related to those consumed, thereby allowing users to share some special interests with otherwise unrelated users.

4 Significance

The proposed work is concerned with improving the performance and the privacy of recommender systems. In particular, we will here examine ways of providing reliable recommendations for online television consumption. This problem share many of the key problems shared by most recommenders, and is in this sense a good candidate to examine when striving to improve on the general structure of recommenders. Furthermore, this data set offers further challenges in the form measuring user's actual consumption behavior, rather than subjective user-rating based data. Subjective ratings have been the main focus for the field as a result of the famous Netflix challenge, wherein the company offered a significant sum to the researchers able to improve on their movie recommendations. However, given the subjective nature of the user's recommendations, the found methods, although focusing the research field, suffers from largely modeling the users rating biases, and not their actual preferences. By here instead focusing on the user's actual behavior, we avoid this problem, but instead face the challenge of constructing meaningful and adaptive measures of preference for a user's behavior. The work also aims at addressing the critical aspect of privacy, being a growing concern for many users. As of today, the aggregation of user data is so profitable that new markets have emerged, including the

possibilities to buy contact information to small subgroups of users, such as, say, those of the currently pregnant Christian women with a certain income in a given city. This development is seen with concern by many, although some have instead noted that this also enables users to actually sell their own behavioral data to interested data brokers. By driving to construct a recommendation system that allows the user to retain control of their behavioral data, our hope is that we can help in letting each user select the amount of personal information they wish to share.

5 Equipment and collaborations

The proposed project benefits from several already established collaborations. Firstly, given our shared interest in the area, the company Quanox has already made dedicated hardware comprising strong GPGPU capacity available to our research, as well as allow us to create the above noted data set of online television behavior. Further to this, as a part of our collaboration, the company has also agreed to make their GPGPU optimized LSA source code modules available to the proposed research project. Furthermore, the applicant's group have collaborations with the Lund University Humanities Laboratory in the study of the cognitive processes of everyday choice making, and it is deemed that the here proposed work will also have implications in this area, allowing for several interesting topics of inter-disciplinary collaboration.

Further to this, the applicant is in collaboration with Prof. Søren Holdt Jensen, Aalborg University, Denmark, Prof. Jan Larsen, the Danish Technical University, Denmark, Prof. Søren Bech, Bang & Olufsen, Denmark, and Dr. Kim Ngo, Quanox, Sweden. Together, we work towards a joint EU funding applications related to the use of content and context analysis as basis for recommendations. This study will complement the here proposed work, instead focusing on gaining knowledge of potential interactions, integrations, and joint optimizations of content and context analysis approaches to recommender systems, but will allow for the study of recommendations from a larger context, and will thereby benefit the here proposed work as well.

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[12] Y. Koren, "Factorization Meets the Neighborhood: a Multifaceted Collaborative Filtering Model," in *KDD*, Las Vegas, Nevada, USA, Aug. 24–27 2008.

[13] X. Li and T. Murata, "Using Multidimensional Clustering based Collaborative Filtering Approach Improving Recommendation Diversity," in *IEEE/WIC/ACM Int. Conf. on Web Intelligence and Intelligent Agent Technology*, Macau, Dec. 4–7 2012.

[14] M. Nazim, J. Shrestha, and G. S. Jo, "Enhanced Content-based Filtering using Diverse Collaborative Prediction for Movie Recommendation," in *First Asian Conf. on Intelligent Information and Database Systems*, Dong Hoi, Quang Binh, Vietnam, April 1–3 2009.

[15] Y. Song, S. Dixon, and M. Pearce, "A Survey of Music Recommendation Systems and Future Perspectives," in *Proc. 9'th Int. Symp. Computer Music Modelling and Retrieval*, London, United Kingdom, June 19–22. 2012.

[16] Y. X. Zhu, W. Zeng, and Q. M. Zhang, "The Effect of Rating Variance on Personalized Recommendation," in *5th Int. Conf. on Computer Science & Education*, Hefei, China, Aug. 24–27 2010.

[17] S. V. Andersen, "A method for providing a recommendation and a recommendation apparatus," Patent submitted to EPO, EP14 151 878, 2014.

[18] ——, "A method for providing recommender information in a recommendation apparatus," Patent submitted to EPO, EP14 151 878, 2014.

[19] T. P. Pedersen, *Advances in Cryptology*. Springer, 1991, ch. A Threshold Cryptosystem without a Trusted Party, pp. 544–526.

[20] J. Canny, "Collaborative Filtering with Privacy," in *Proc. IEEE Symp. Security and Privacy*, 2002.

[21] S. V. Andersen, "A method for enhancing privacy in a recommendation system," Patent submitted to EPO, EP14 151 883, 2014.

[22] ——, "A method for operating a recommendation apparatus," Patent submitted to EPO, EP14 154 298, 2014.

[23] K. Gidlof, A. Wallin, and R. D. adn K. Holmqvist, "Using Eye Tracking to Trace a Cognitive Process: Gaze Behaviour During Decision Making in a Natural Environment," *Journal of Eye Movement Research*, 2013.

[24] P. M. Todd and G. Gigerenzer, "Precis of Simple Heuristics that make us Smart," *Behavioral and Brain Sciences*, vol. 23, pp. 727–780, 2000.

[25] U. Mahbub and S. A. Fattah, "Gradient Based Adaptive Filter Algorithm for Single Channel Acoustic Echo Cancellation in Noise," in *7th Int. Conf. Electrical and Computer Eng.*, Dhaka, Bangladesh, Dec. 22–22 2012.

Interdisciplinarity

My application is interdisciplinary

☐

An interdisciplinary research project is defined in this call for proposals as a project that can not be completed without knowledge, methods, terminology, data and researchers from more than one of the Swedish Research Councils subject areas; Medicine and health, Natural and engineering sciences, Humanities and social sciences and Educational sciences. If your research project is interdisciplinary according to this definition, you indicate and explain this here.

Click here for more information

Scientific report

Scientific report/Account for scientific activities of previous project

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Budget and research resources

Project staff

Describe the staff that will be working in the project and the salary that is applied for in the project budget. Enter the full amount, not in thousands SEK.

Participating researchers that accept an invitation to participate in the application will be displayed automatically under Dedicated time for this project. Note that it will take a few minutes before the information is updated, and that it might be necessary for the project leader to close and reopen the form.

Dedicated time for this project

	Role in the project	Name	Percent of full time
1	Applicant	Sören Vang Andersen	20
2	Participating researcher	Andreas Jakobsson	10
3	Participating researcher	Stefan Ingi Adalbjörnsson	10
4	Other personnel without doctoral degree	Doktorand	100

Salaries including social fees

	Role in the project	Name	Percent of salary	2016	2017	2018	2019	Total
1	Applicant	Sören Vang Andersen	20	342,991	353,281	363,880	374,796	1,434,948
2	Participating researcher	Andreas Jakobsson	10	76,200	78,486	80,841	83,266	318,793
3	Participating researcher	Stefan Ingi Adalbjörnsson	10	63,017	64,907	66,855	68,860	263,639
4	Other personnel without doctoral degree	Doktorand	100	480,728	513,137	545,545	558,149	2,097,559
	Total			962,936	1,009,811	1,057,121	1,085,071	4,114,939

Other costs

Describe the other project costs for which you apply from the Swedish Research Council. Enter the full amount, not in thousands SEK.

Premises

	Type of premises	2016	2017	2018	2019	Total
1	Kontor	58,361	59,314	61,987	63,566	243,228
	Total	58,361	59,314	61,987	63,566	243,228

Running Costs

	Running Cost	Description	2016	2017	2018	2019	Total
1	Direkta kostnader	Dator	30,000				30,000
2	Direkta kostnader	Konferensresa	40,000	40,000	40,000	40,000	160,000
	Total		70,000	40,000	40,000	40,000	190,000

Depreciation costs

	Depreciation cost	Description	2016	2017	2018	2019

Total project cost

Below you can see a summary of the costs in your budget, which are the costs that you apply for from the Swedish Research Council. Indirect costs are entered separately into the table.

Under Other costs you can enter which costs, aside from the ones you apply for from the Swedish Research Council, that the project includes. Add the full amounts, not in thousands of SEK.

The subtotal plus indirect costs are the total per year that you apply for.

Total budget

Specified costs	2016	2017	2018	2019	Total, applied	Other costs	Total cost
Salaries including social fees	962,936	1,009,811	1,057,121	1,085,071	4,114,939		4,114,939
Running costs	70,000	40,000	40,000	40,000	190,000		190,000
Depreciation costs					0		0
Premises	58,361	59,314	61,987	63,566	243,228		243,228
Subtotal	1,091,297	1,109,125	1,159,108	1,188,637	4,548,167	0	4,548,167
Indirect costs	471,432	479,134	500,726	513,482	1,964,774		1,964,774
Total project cost	1,562,729	1,588,259	1,659,834	1,702,119	6,512,941	0	6,512,941

Explanation of the proposed budget

Briefly justify each proposed cost in the stated budget.

Explanation of the proposed budget*

In the proposed project, funding is sought for one Ph.D. student as well as funds for the applicants' participation in the project.

The costs include 50.04% employment costs (where appropriate). The indirect costs are computed at 45.64% of the budget. Rooms are included at 5.65%. The costs include a projected salary increase of 3% for the applicants, as well as the expected salary increase according to the Ph.D. salary scheme.

Other funding

Describe your other project funding for the project period (applied for or granted) aside from that which you apply for from the Swedish Research Council. Write the whole sum, not thousands of SEK.

Other funding for this project

	Funder	Applicant/project leader	Type of grant	Reg no or equiv.	2016	2017	2018	2019	Total
1	Crafoordska stiftelsen	Sören Vang Andersen	Sökt projektbidrag		391,552				391,552
	Total				391,552	0	0	0	391,552

CV

Professor Søren Vang Andersen

Curriculum Vitae, March 28, 2015

1. **Higher education degrees:**
   - Ph.D., Electrical and Electronic Engineering, Aalborg University, 1999.
   - M.Sc., Electrical and Electronic Engineering, Aalborg University, 1995.
2. **Doctoral degree:**
   - "Quantization Noise Modeling in Predictive Speech Coding", Ph.D. thesis, Aalborg University, December 1998. Advisor: Prof. Søren Holdt Jensen.
3. **Postdoctoral work:**
   - Post-doc, Royal Institute of Technology, Sweden, 1998-1999.
4. **Appointments as docent/professor:**
   - Professor in Applied Mathematics, Lund University, Sweden, 2013.
   - Associate Professor in Signal Processing, Aalborg University, Denmark, 2002.
5. **Current position:**
   - Professor in Applied Mathematics, Lund University, Sweden, permanent position. Position includes 50% research during 2015.
6. **Previous positions:**
   - [2009-2012] Director of Research, Head of SkypeLabs, Skype, Luxembourg, Luxembourg.
   - [2006-2008] Research Architect, Skype, Luxembourg, Luxembourg.
   - [2004-2006] Founder and CTO, Sonorit, Aalborg, Denmark.
   - [2002-2008] Associate Professor at the Department of Communication Technology, Aalborg University, Aalborg, Denmark.
   - [1999-2002] Senior Researcher at Global IP Sound, Stockholm, Sweden (80%).
   - [1999-2002] Assistant Professor at the Department of Speech, Music and Hearing, Royal Institute of Technology, Stockholm, Sweden (20%).
   - [1998-1999] Postdoctoral researcher at the Department of Speech, Music and Hearing, Royal Institute of Technology, Stockholm, Sweden.
7. **Interruptions in research:**
   - [1999-2002] An 80% leave from position at Royal Institute of Technology to focus on transferering of research results into industrial deployment in the company Global IP Sound. Gaining experience in patenting of research results and product innovation.
   - [2004-2006] A 100% leave from position at Aalborg University to focus on founding of startup Sonorit, leading technical development of its product as its CTO, and sale of the company to eBay/Skype in 2006.
   - [2006-2012] Full time employment in industry (Skype) first as Research Architect. Later as the Director of Research for the company. Focusing on technology strategy and leading of SkypeLabs, the research division of Skype. Gaining experience in leading a larger team of researchers, driving invention and innovation, protection of results via patents, integration of results into product through collaboration with the companys product divisions.

- [2012-2013] Innovation, business planning, and fundraising for the company Quanox. Company is today developing a new technology for recommender systems from its R&D office in Lund, Sweden.
- [2013-2014] Full time Professor at Lund University, but with an initial emphasis on getting up-to-speed and quality on teaching side of the appointment as well as broad pre-studies to converge into my new research direction as laid out in the research plan for this funding application. I am funded 25% of full time on this research direction through my permanent position.

8. Supervision - Ph.D. students:

- Thomas Arildsen, Öptimization of Coding of AR Sources for Transmission Across Channels with Loss", graduated from Aalborg University in February 2010. Now with Aalborg University.
- Morten Holm Larsen, Multiple Description Coding for Wireless Transmission of Video", graduated from Aalborg University in September 2007. Now with Widex.
- Steffen Præstholm, Öptimization of VoIP over GERAN/UTRAN Mobile Networks", graduated from Aalborg University in September 2007. Now with Conscius.
- Chunjian Li, Phase and Residual Modeling Methods in Speech Enhancement", graduated from Aalborg University in March 2006. Now with Widex.
- Karsten Vandborg Sørensen, Spectral Estimation Methods in Speech Enhancement", graduated from Aalborg University in February 2006. Now with Skype.
- Mads Græsbøll Christensen, Sinusoidal Audio Compression", graduated from Aalborg University in November 2005. Now with Aalborg University (As co-supervisor).
- Christoffer Rødbro, Sinusoidal Speech Modeling for Packet Based Transmission", graduated from Aalborg University in January 2005. Now with Skype (As co-supervisor).

9. Supervision - Post-docs:

- Stefan Ingi Adalbjörnsson, Lund University, 2015-2016.

10. Other points of merit:

- Prof. Andersen is a member of The Royal Swedish Physiographic Society, and a member of the board of the Danish Sound innovation network. He has previously been a member of the Technical Research Council at Centre for Tele Infrastructure at Aalborg University, and a secretary in the Signal Processing Chapter of the Danish branch of IEEE.
- Prof. Andersen is a reviewer for IEEE Trans. Speech, Audio, and Language Processing, IEEE Signal Processing Letters, IEEE Trans. Signal Processing, EURASIP Journal of Applied Signal Processing, and AES International Conference.
- Prof. Andersen has served as Special Sessions Chair for EUSIPCO; been invited speaker at Asilomar Conference on Signals, Systems, and Computers, special session on speech coding; and been an invited panel speaker in broad audience panel discussions at ICT, Amcham, and Global Innovation Forum.
- Prof. Andersen has contributed to Internet Standards in the IETF Audio/Video Working Group through contributions to RFC 3951 and RFC 3952.

Publication list

Professor Søren Vang Andersen

List of Publications, March 28, 2015

The following list contains the applicant's work published since 2007. Conference papers on work also published in journal papers have been excluded from the list. Citations have been computed using the Google Scholar, and thus include self-citations.

As laid out in his CV, Prof. Andersen have spent significant parts of the last five years on work with inventions, innovation, and deployment of these in industry. This work is mainly visible in the publication list through granted patents. Only US granted patents have been included here due to more broadly available and updated databases on citations of US granted patents.

Please note that the process of patent granting and citation is significantly slower than for other types of publications. Currently, most cited patent by Prof. Andersen has obtained 20 citations, since because of the patent process, patents granted during the last five years will in practice show up with very few citations. Please notice that grants in other jurisdictions than US have not been included in this publication list

Furthermore, because of the slowness of the patent process, Prof. Andersen currently have more than 50 pending patents that have been filed during the last five years. With four exceptions of particular relevance for the proposed research project, these pending patents have not been included in the publication list because the tracking of their granting and citation is unreliable until grant.

1. Peer-reviewed articles

1. S. Subasingha, M. N. Murthi, and S. V. Andersen,"Gaussian Mixture Kalman Predictive Coding of Line Spectral Frequencies", *IEEE Trans. Audio, Speech, and Language Processing*, 2009. *Number of citations: 10*
2. T. Arildsen, M. N. Murthi, S. V. Andersen, and S. H. Jensen, "On Predictive Coding for Erasure Channels Using a Kalman Framework", *IEEE Trans. Signal Processing*, 2009. *Number of citations: 8*
3. K.V. Sørensen and S. V. Andersen, "Rayligh Mixture Model Based Hidden Markov Modeling and Estimation of Noise in Noisy Speech Signals", *IEEE Trans. Audio, Speech, and Language Processing*, 2007. *Number of citations: 7*
4. C. Li and S. V. Andersen, "Efficient Blind System Identification of Non-Gaussian Auto-Regressive Models with HMM Modeling of the Excitation". *IEEE Trans. Signal Processing*, 2007. *Number of citations: 6*

2. Peer-reviewed conference contributions

1. J. Zhu, R. Vannithamby, C. Rodbro, M. Chen, and S. V. Andersen, "Improving QoE for Skype Video Call in Mobile Broadband Network". Proceedings of Globecom 2012. *Number of citations: 3*

2. T. Arildsen, J. Østergaard, M. N. Murthi, S. V. Andersen, and S. H. Jensen, "Fixed-Lag Smoothing for Low Delay Predictive Coding with Noise Shaping for Lossy Networks". Proceedings of Data Compression Conference, DCC-2010. *Number of citations: 1*

3. T. Arildsen, M. N. Murthi, S. V. Andersen, and S. H. Jensen, "On Predictive Coding for Erasure Channels Using a Kalman Framework". Proceedings of the 17th European Signal Processing Conference. Eurasip, EUSIPCO 2009. *Number of citations: 8*

4. S. Subasingha, M. N. Murthi, and S. V. Andersen, "On Gaussian Mixture Kalman Predictive Coding of LSFs for Packet Loss", International Conference on Acoustics, Speech, and Signal Processing (ICASSP), 2009. *Number of citations: 9*

5. S. Subasingha, M. N. Murthi, and S. V. Andersen, "A Kalman Filtering Approach to GMM Predictive Coding of LSFs for Packet Loss Conditions", Digital Signal Processing, Santorini, Greece, 2009. *Number of citations: 1*

6. S. Subasingha, M. N. Murthi, and S. V. Andersen, "Gaussian Mixture Kalman Predictive Coding of LSFs", in IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP), 2008. *Number of citations: 3*

7. C. Li and S. V. Andersen, "Efficient Implementation of the HMARM Identification and its Application in Speech Analysis", Procedings of IEEE International Conference on Acoustics, Speech, and Signal Processing, 2007. *Number of citations: 0*

8. S. Præstholm, H. P. Schwefel, and S. V. Andersen. "A Comparative Study of Forward Error Correction and Frame Accumulation for VoIP over Congested Networks". Proceedings of the twentieth International Teletraffic Congress, 2007. *Number of citations: 1*

9. S. Præstholm, H. P. Schwefel, and S. V. Andersen. "Packet Voice Rate Adaptation Through Perceptual Frame Discarding". IEEE Global Communications Conference, 2007. *Number of citations: 3*

4. Books and book chapters

1. S. Præstholm, H. P. Schwefel, and S. V. Andersen. “A Comparative Study of Forward Error Correction and frame Accumulation for VoIP over Congested Networks”, in “Managing Traffic Performance in Converged Networks”, Lecture Notes in Computer Science, Vol. 4516, Springer 2007, pp 374-385. *Number of citations: 3*

5. Selected patents and patent applications

1. S. V. Andersen, “A method for providing a recommendation and a recommendation apparatus”, Patent application submitted to EPO 2014, EP14151878. *Number of citations: 0*
2. S. V. Andersen, “A method for enhancing privacy in a recommendation system”, Patent application submitted to EPO 2014, EP14151883. *Number of citations: 0*
3. S. V. Andersen, “A method for operating a recommendation apparatus”, Patent application submitted to EPO 2014, EP14154298. *Number of citations: 0*
4. S. V. Andersen, “A method for providing recommender information in a recommendation apparatus”, Patent application submitted to EPO 2014, EP14154294. *Number of citations: 0*
5. L. Bivolarsky, R. Vafin, M. Nilsson, S. V. Andersen, “Motion estimation using block matching indexing”, Patent granted 2014, US8913661. *Number of citations: 0*
6. M. Nilsson, R. Vafin, S. V. Andersen, “Video coding”, Patent granted 2014, US8908761. *Number of citations: 0*
7. C. Rodbro, S. S. Jensen, J. Lindblom, R. Vafin, S. V. Andersen, “Method of transmitting data in a communication system”, Patent granted 2014, US8885672. *Number of citations: 0*
8. M. Chen, C. Rodbro, S. V. Andersen, “Controlling power saving mode in radio”, Patent granted 2014, US8886132. *Number of citations: 0*
9. S. V. Andersen, R. Hagen, B. Kleijn, “Low bit rate codec”, Patent granted 2014, US8880414. *Number of citations: 0*
10. M. Hiie, S. V. Andersen, A. Heinla, S. Keskkula, “Optimising communications”, Patent granted 2014, US8873568. *Number of citations: 2*
11. C. Rodbro, M. Chen, S. V. Andersen, “Controlling transmission of data”, Patent granted 2014, US8868003. *Number of citations: 0*

12. R. Vafin, M. Nilsson, S. V. Andersen, A. Jefremov, “Jitter buffer”, Patent granted 2014, US8855145. *Number of citations: 0*
13. M. Nilsson, R. Vafin, S. V. Andersen, “Video coding”, Patent granted 2014, US8804836. *Number of citations: 0*
14. L. Bivolarsky, M. Nilsson, R. Vafin, S. V. Andersen, “Data compression for video”, Patent granted 2014, US8681873. *Number of citations: 2*
15. M. Nilsson, S. V. Andersen, K. B. Vos, “Regeneration of wideband speech”, Patent granted 2013, US8386243. *Number of citations: 0*
16. C. Rodbro, S. S. Jensen, S. V. Andersen, “Method of transmitting data in a communication system”, Patent granted 2012, US8340136. *Number of citations: 1*
17. M. Chen, C. Rodbro, S. V. Andersen, “Method of estimating congestion”, Patent granted 2013, US8422367. *Number of citations: 0*
18. M. Nilsson, S. V. Andersen, “Regeneration of wideband speech”, Patent granted 2012, US8332210. *Number of citations: 2*
19. C. A. Rodbro, S. V. Andersen, K. B. Vos, “Controlling packet transmission”, Patent granted 2012, US8315164. *Number of citations: 1*
20. M. Hiie, S. V. Andersen, A. Heinla, S. Keskkula, “Optimising communications”, Patent granted 2012, US8289979. *Number of citations: 0*
21. C. A. Rodbro, S. V. Andersen, K. Vos, “Systems and methods for controlling packet transmission from a transmitter to a receiver via a channel that employs packet queuing when overloaded”, Patent granted 2012, US8259570. *Number of citations: 3*
22. M. Nilsson, J. Lindblom, R. Vafin, S. V. Andersen, “Speech coding system and method”, Patent granted 2011, US8069049. *Number of citations: 2*
23. S. V. Andersen, “Method for generating concealment frames in communication system”, Patent granted 2011, US8068926. *Number of citations: 2*

6. Open access computer programs

1. S.V. Andersen et al., “Internet Low Bit Rate Codec”, IETF Audio/Video transport working group, RFC 3951, 2004. *Number of citations:76*
2. A. Duric and S.V. Andersen, “RTP Payload Profile for Internet Low Bit Rate Codec”, IETF Audio/Video transport working group, RFC 3952, 2004. *Number of citations:6*

The five overall most cited works

1. S. V. Andersen *et. al*. “iLBC - A Linear Predictive Coder with Robustness to Packet Losses”. In 2002 IEEE Speech Coding Workshop Proceedings, Tsukuba, Japan, Oct. 2002. *Number of citations: 88*
2. S.V. Andersen et al., “Internet Low Bit Rate Codec”, IETF Audio/Video transport working group, RFC 3951, 2004. *Number of citations: 76*
3. M. Nilsson, H. Gustafsson, S. V. Andersen and W. B. Kleijn. “Gaussian Mixture Model based Mutual Information Estimation between Frequency Bands in Speech”. Proc. IEEE Int. Conf. Acoust. Speech Sign. Process, Orlando, USA, 2002. *Number of citations: 74*
4. C. A. Rødbro, M. N. Murthi, S. V. Andersen, and S. H. Jensen, “Hidden Markov Model Based Packet Loss Concealment for Voice over IP”, IEEE Trans. Speech and Audio, 2005. *Number of citations: 46*
5. M. Nilsson, H. Gustafsson, S. V. Andersen and W. B. Kleijn. “Gaussian Mixture Model based Mutual Information Estimation between Frequency Bands in Speech”. Proc. IEEE Int. Conf. Acoust. Speech Sign. Process, Orlando, USA, 2002. *Number of citations: 33*

CV

Name:Sören Vang Andersen	**Doctorial degree:** 1999-02-26
Birthdate: 19681103	**Academic title:** Professor
Gender: Male	**Employer:** No current employer

Research education

Dissertation title (swe)

Dissertation title (en)

Quantization Noise Modeling in Predictive Speech Coding

Organisation	Unit	Supervisor
Aalborg university, Denmark Not Sweden - Higher Education institutes		Sören Holdt Jensen

Subject doctors degree	ISSN/ISBN-number	Date doctoral exam
20299. Annan elektroteknik och elektronik	87-985750-9-0	1999-02-26

Publications

Name:Sören Vang Andersen	**Doctorial degree:** 1999-02-26
Birthdate: 19681103	**Academic title:** Professor
Gender: Male	**Employer:** No current employer

Andersen, Sören Vang has not added any publications to the application.

Register

Terms and conditions

The application must be signed by the applicant as well as the authorised representative of the administrating organisation. The representative is normally the department head of the institution where the research is to be conducted, but may in some instances be e.g. the vice-chancellor. This is specified in the call for proposals.

The signature*from the applicant*confirms that:

- the information in the application is correct and according to the instructions form the Swedish Research Council
- any additional professional activities or commercial ties have been reported to the administrating organisation, and that no conflicts have arisen that would conflict with good research practice
- that the necessary permits and approvals are in place at the start of the project e.g. regarding ethical review.

The signature *from the administrating organisation* confirms that:

- the research, employment and equipment indicated will be accommodated in the institution during the time, and to the extent, described in the application
- the institution approves the cost-estimate in the application
- the research is conducted according to Swedish legislation.

The above-mentioned points must have been discussed between the parties before the representative of the administrating organisation approves and signs the application.

Project out lines are not signed by the administrating organisation. The administrating organisation only sign the application if the project outline is accepted for step two.

Applications with an organisation as applicant is automatically signed when the application is registered.