Per Christian Hansen

Professor of Scientific Computing, Dr Techn, Villum Investigator

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Born: July 9, 1957
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Citizenship: Danish
Not married, 2 children

Professor Per Christian Hansen has worked with numerical regularization algorithms for 30 years, has published 100+ papers in leading journals, and his books on numerical methods for inverse problems are widely used. He has developed several related software packages, of which Regularization Tools (now in its 4th version) is a popular toolbox for analysis and solution of discrete inverse problems. His h-index is **56** according to Google Scholar (July 2024) and he is a **SIAM Fellow**.

Specialization. Numerical analysis. Computational methods for inverse problems. Regularization methods. Computational uncertainty quantification. Iterative regularization. Matrix computations. Matlab packages.

Publications

- 5 books (2 as sole author)
- 1 edited book (with B. H. Jacobsen and K. Mosegaard)
- 3 invited chapters (one in *Handbook of Linear Algebra* and two in research monographs)
- 122 papers in refereed journals
- 58 conference papers etc.
- 7 software packages

Degrees

- 1996 Dr Techn in Scientific Computing, DTU
- 1985 PhD in Numerical Analysis, DTU
- 1982 MSc in Electrical Engineering, DTU

Employments

- Since 1996 Professor of Scientific Computing, DTU Compute
- 1988–1996 Senior Consultant, Danish University Computing Center, UNI•C
- 1985–1988 Research Associate, Astronomical Observatory, Copenhagen University
- 1985 Research Fellow, Department of Numerical Analysis, DTU

Research visits abroad

- 2020 2 weeks, National Institute of Informatics, Tokyo, Japan, supported by JSPS
- 2006 1 month, Dept. of Mathematics, Tufts University, Medford
- 2004 1 month, Dept. of Mathematics and Computer Science, Emory University, Atlanta
- 1992 1 month, Dept. of Mathematics, University of Berkeley, California
- 1990 1 month, Mathematics and Computer Science Division, Argonne National Laboratory
- 1989 7 months, Dept. of Mathematics, UCLA
- 1988 1 month, Dept. of Mathematics, Oak Ridge National Laboratory, Tennessee
- 1986 6 months, Dept. of Computer Science, Stanford University, supported by a Fulbright Grant

Awards

- 2015 SIAM Fellow in recognition of contributions to algorithms for rank-deficient and discrete ill-posed problems and regularization techniques

- 2005 ISI Web of Knowledge award as most cited Danish mathematician
- 1994 Statoil Prize in recognition of his work in numerical analysis
- 1990 BIT Prize for distinguished paper on numerical analysis in BIT Numerical Mathematics
- 1986 Fulbright Grant to visit Stanford University

Current Research Funding

Period	*Amount*	*Funding Inst.*	*Title of Project*	*Role*
2019–2015	4,674,925 €	Villum Fonden	CUQI: Computational Uncertainty Quantification for Inverse Problems	PI

Recent Research Funding

Period	*Amount*	*Funding Inst.*	*Title of Project*	*Role*
2016	28,000 €	Otto Mønsted	Visiting Professor: Todd Quinto	PI
2015–2017	100,000 €	H.C. Ørsted Postdoc COFUND	Post Doc Jürgen Frikel	Supervisor
2013–2016	190,000 €	Innovation Fund Denmark	Nano-Scale Design Tools for the Semiconductor Industry	Collaborator
2012–2017	2,250,000 €	European Research Council	High-Definition Tomography	PI
2014–2018	870,000 €	Danish Research Council	Improved Impedance Tomography via Hybrid Data	PI

Other Previous Research Projects (*Grant Holder)

- *Visiting Research Professorship: William Lionheart (2013–2014)
- *Desktop Scientific Computing on Consumer Graphics Cards (2010–2013)
- *Prior Information in Electrical Impedance Tomography (2009–2011)
- *Visiting Research Professorship: Lieven Vandenberghe (2008)
- *Computational Science in Imaging (2007–2012)
- Parallel Algorithms for Computational Nano-Science (2006–2010)
- Modelling, Estimation and Control of Biotechnological Systems (2006–2008)
- *Stabilization Algorithms for Large-Scale Inversion (2004–2007)
- Wavelets in Audio/Visual Electronic Systems (2002–2007)
- *Scientific Computing in Optimization, Simulation, and Inversion (2000–2003)
- Partial Differential Equations and Applied Functional Analysis (2000–2002)
- Danish Informatics Network in the Agricultural Sciences (1996–2000)
- Center for Applications of Parallel Computers (1992–1995)
- Efficient Parallel Algorithms in Optimization and Simulation (1996–1999)
- Danish Interdisciplinary Inversion Group (1992–1999)
- *Two NATO Collaborative Research Grants (1990–1996)

Management Experience

- Head of CUQI research project funded by Villum Fonden, since 2019
- Head of HD-Tomo research project funded by an ERC Advanced Grant, 2012–2017
- Head of Section for Scientific Computing, DTU Compute 2006–2013
- Principal investigator of 4 grants from the Danish Research Council since 2000
- Director of MSc study line Mathematical Modelling and Computing, DTU, 2001–2007
- Director of PhD Studies, DTU 2000 (one year)

Memberships of Editorial Boards

- SIAM J. Sci. Comp. 2014–2022
- BIT Numerical Mathematics 2003–2012
- SIAM J. Matrix Anal. Appl. 2000–2006

Post Docs Supervision

- Current: Babak Maboudi Afkham (2020–2022, goal-oriented UQ), Amal M. A. Alghamdi (2021–2023, computational UQ for PDE problems), Felipe Uribe (2020–2021, non-Gaussian priors).
- Former: Hans Henrik B. Sørensen (2009–12), Fabrice Delbary (2010–12), Martin S. Andersen (2012–14). Jakob Sauer Jørgensen (2013–17), Lauri Harhanen (2015–17), Jürgen Frikel (2015–17), Hans Martin Kjer (2016–17), Bart van Lith (2018–20).

PhD Students

- Current: Katrine Bangsgaard (Prior modeling for CUQI), Lara Baalbaki (Bayesian inference for inverse problems).
- Former: Susanne M. Balle (1995), Søren Holdt Jensen (1995), Peter Søren K. Hansen (1998), Ole Møller Nielsen (1998), Rasmus Munk Larsen (1998), Tim Hultberg (2000), Andreas P. Schuhmacher (2000), Preben Kidmose (2001), Ann-Charlotte Berglund (2002), Thorkild F. Pedersen (2003), Michael Jacobsen (2004), Jan M. Rasmussen (2004), Esben Høgh-Rasmussen (2006), Toke Koldborg Jensen (2006), Peter Søndergaard (2007), Hans Henrik B. Sørensen (2008), Jesper Rasmussen (2009), Jakob Sauer Jørgensen (2013), Anders Skajaa (2013), Oscar Borries (2015), Sara Soltani (2015), Mikhail Romanov (2016), Hari Om Aggrawal (2018), Nicolai A. B. Riis (2021).

10-Year-Track-Record

Professional. In the period 2006–2010 Per Christian Hansen created and built the section for Scientific Computing with entirely new faculty, and the section grew again in 2013 when DTU Informatics and DTU Mathematics merged. The section currently consists of 10 faculty members, 8 post docs, and 15 PhD students.

Research. Per Christian Hansen's research has always been carried out in several directions and applications (not limited to inverse problems), and with strong interrelations among the various projects. The main focus of his research is on large-scale algorithms in inverse problems, matrix, computations, signal processing, and nano-science. He continues to work with leading experts and always seeks to combine insight and algorithms into practical algorithms for a range of applications. His activities have broadened considerably over the last 10 years to include, among others, optimization algorithms (convex optimization, first-order methods) and algebraic iterative methods. The most important current collaborators are:

- J. G. Nagy, Emory University: iterative algorithms and software for inverse problems
- S. Gazzola, Univ. of Bath: iterative algorithms and software for inverse problems
- M. E. Kilmer, Tuft University: tensor-dictionaries dictionary priors in image reconstruction
- T. Elfving, Linköping University: constrained algebraic iterative methods for tomographic imaging
- W. Lionheart, Manchester University: algebraic reconstruction in tomography
- K. J. Batenburg, Centrum Wiskunde & Informatica: algebraic reconstruction in tomography
- M. Hochstenbach, TU Eindhoven: iterative algorithms for inverse problems
- M. Salewski, DTU Physics: inverse problems in tokamak fast-ion tomography
- Oscar Borries, Ticra, Copenhagen: inverse problem in computational electromagnetism

Selected Invited Presentations at International Meetings since 2005

- Edge-Preserving CT with Uncertain View Angles, RWTH Aachen University, Virtual Feb. 7, 2023
- Convergence and Non-Convergence of AIR Methods, UC Irvine, Virtual May 19, 2022.
- Numerical Methods and Scientific Computing, CIRM, Luminy, Virtual, Nov. 8-12, 2021.
- One World IMAGINE seminars, Virtual, Nov. 3, 2021
- Second Workshop on Numerical Algebra, Algorithms and Analysis, Tokyo, March 16-17, 2021
- Modern Challenges in Imaging, Boston, August 5–9, 2019.
- SIAM Conference on Applied Linear Algebra, Hong Kong, May 4–8, 2018.
- Conference on Scale Space and Variational Methods in Computer Vision, June 4–8, 2017.
- Numerical Linear Algebra and Applications, Luminy, October 24–28, 2016.
- Mathematical Imaging and Emerging Modalities, Osnabrück, June 2016

- Oberwolfach workshop on Mathematics and Algorithms in Tomography, August 10–16, 2014
- Householder Symposium XIX, Spa, Belgium, June 8–13, 2014
- SCI Distinguished Lecture, Univ. of Utah, Feb. 28, 2014
- Lorentz Center: Advanced X-Ray Tomography, Feb. 10–14, 2014
- UCL Centre for Inverse Problems: Opening Meeting, March 18–21, 2013
- Manchester Image Reconstruction and Analysis, Nov. 19–23, 2012
- Lectures on Inverse Problems, Tokyo and Nagoya, March 16–22, 2012
- Thirty-Sixth Woudschoten Conference, Zeist, The Netherlands, October 5–7, 2011
- Inverse Problems, Computation and Applications, CIRM Luminy, France, May 31–June 4, 2010
- Workshop on A-Priori Information in Tomography, Copenhagen, June 26, 2009
- New Directions in Tomographic Image reconstruction, Manchester, UK, June 30–July 1, 2008
- Applied and Numerical Linear Algebra, Hamburg, Germany, Sept. 11–12, 2008
- Optimization and Inverse Problems in Electromagnetism, Ilmenau, Germany, Sept. 14–17, 2008
- Inverse Problems and Applications, Norrköping, Sweden, Dec. 16, 2008
- Numerical Linear Algebra in Signals and Systems, Bari, Italy, Sept. 11–15, 2006
- ICCG, BiCGSTAB, and Jacobi-Davidson, Utrecht, Netherlands, July 22, 2006
- Applied Parallel Computing, Umeå, Sweden, June 18–21, 2006
- Least Squares and Optimization, Umeå, Sweden, Nov. 16–17, 2005
- Thomáš Havránek Lecture, Academy of Sciences of the Czech Republic, Prague, Oct. 10, 2005

Scientific Leadership Profile

Professor Per Christian Hansen works in numerical analysis, regularization algorithms, matrix computations, and high-performance scientific computing. Since 1996, he has been professor of scientific computing at DTU Informatics, where he has established the section for Scientific Computing. He has published 5 books and 116 papers in leading journals, he has 30,716 citations, and his h-index is 53 according to Google Scholar.

Per Christian Hansen is highly recognized for his research in rank-deficient and discrete ill-posed problems, with many novel contributions that cover practical algorithms and software as well as the underlying theory. Through his research papers, books and software packages, he has played an important role in the growth of the research field of large-scale numerical regularization algorithms.

Per Christian Hansen is currently heading a large research initiative on computational uncertainty quantification for inverse problems, funded by the Villum Foundation. This project builds on his accumulated experience, which he brings into a research field that also involves computational Bayesian inference. The goal of the project is to create a framework for modeling and computations, suited for non-experts, to be used in many different industrial and academic inverse problems.

Throughout his career, he has collaborated with many leading experts: G. H. Golub and M. A. Saunders (Stanford University), T. F. Chan and K. Yao (UCLA), D. P. O'Leary (Univ. of Maryland), J. G. Nagy (Emory Univ., Atlanta), M. E. Kilmer (Tufts University), M. Hanke (Univ. of Mainz), L. Reichel (Kent University), L. Eldén and T. Elfving (Linköping Univ.), and K. Hayami (Natl. Inst. Informatics, Tokyo). With these experts, he co-wrote some of the earliest papers on rank-revealing decompositions, look-ahead Levinson algorithms, preconditioned regularizing iterations, and regularized total least squares. His current research involves large-scale algorithms for 3D and 4D tomographic imaging, algebraic reconstruction methods, and iterative algorithms for imaging.

His research focuses on insight and algorithms, and his impact has been through theoretical work as well as algorithm development. A central theme in his work has always been to make the theory and methods of practical use, e.g., via software packages and scholarly expositions for non-experts.

A. He has provided fundamental *theoretical insight* of regularizing properties of several regularization techniques such as standard-form transformations and iterative minimum-residual methods.

B. He has developed many new *algorithms*, e.g., MTSVD, PP-TSVD, T-TTLS, several parameter-choice methods, smoothing preconditioners, and stopping criteria for regularizing iterations.

C. He has developed six *software* packages, of which Regularization Tools (downloaded 4000+ times) is a standard toolbox for analysis and solution of discrete inverse problems.

D. His four *books* are widely recognized research monographs, and they are also used by many scientists and engineers outside mathematics due to their clear and applicable expositions.

Among Per Christian Hansen's most well-known research contributions are the "Regularization Tools" software package, the L-curve parameter-choice method, and smoothing preconditioners for regularizing iterations. His top publications are:

5214 citations: P. C. Hansen, *Rank-Deficient and Discrete Ill-Posed Problems*, SIAM, Philadelphia, 1998. This best-selling monograph was among the first dedicated to a thorough description of the numerical aspects of regularization methods, and it is used worldwide as an advanced textbook as well as a scientific reference (see **A**, **B**, **D** above).

4479 citations: P. C. Hansen, *Analysis of discrete ill-posed problems by means of the L-curve*, SIAM Review, 34 (1992), 561–580. The L-curve criterion is among the most successful methods for choosing the regularization parameter (see **A**, **B** above).

3418 citations: P. C. Hansen and D. P. O'Leary, *The use of the L-curve in the regularization of discrete ill-posed problems*, SIAM J. Sci. Comp., 14 (1993), 1487–1503 (see previous paper and **A**, **B** above).

2305 citations: P. C. Hansen, *Regularization Tools: A Matlab package for analysis and solution of discrete ill-posed problems*, Numer. Algo., 6 (1994), 1–35. This is the original publication of the Matlab package that made regularization methods available for a wide audience in the application sciences. It is now in its 4th updated and expanded version (see **C** above).

1142 citations: P. C. Hansen, *Discrete Inverse Problems; Insight and Algorithms*, SIAM, Philadelphia 2010. This monograph is written for a wide audience; it includes many examples and exercises based on Regularization Tools, and it is used as both a reference and a textbook (see **A**, **B**, **C, D** above).

Selected Recent Publications

- P. C. Hansen, J. S. Jørgensen, W. R. B. Lionheart, M. S. Andersen, K. J. Batenburg, Y. Dong, E. T. Quinto, and J. Sijbers, *Computed Tomography: Algorithms, Insight, and Just Enough Theory*, SIAM, Philadelphia, 2021 (336 pages).
- N. A. B. Riis, Y. Dong, and P. C. Hansen, *Computed tomography with view angle estimation using uncertainty quantification*, Inverse Problems, 37 (2021), 065007. doi: 10.1088/1361-6420/abf5ba.
- B. S. van Lith, P. C. Hansen, and M. E. Hochstenbach, *A twin error gauge for Kaczmarz's iterations*, SIAM J. Sci. Comp., 43 (2021), pp. S173-S199, doi: 10.1137/20M1349011.
- B. Madsen, J. Huang, M. Salewski, H. Järleblad, P. C. Hansen + 19, *Fast-ion velocity-space tomography using slowing-down regularization in EAST plasmas with co- and counter-current neutral beam injection*, Plasma Physics and Controlled Fusion, 62 (2020), 115019, doi: 10.1088/1361-6587/abb79b.
- N. A. B. Riis, Y. Dong, and P. C. Hansen, *Computing tomography reconstruction with uncertain view angels by iteratively updated model discrepancy*, J. Math. Imag. Vision, 63 (2021), pp. 133-143, doi: 10.1007/s10851-020-00972-7.
- J. M. Bardsley and P. C. Hansen, *MCMC algorithms for computational UQ of nonnegativity constrained linear inverse problems*, SIAM J. Sci. Comput., 42 (2020), pp. A1269-1288, doi: 10.1137/18M1234588.
- Y. Dong, P. C. Hansen, M. E. Hochstenbach, and N. A. B. Riis, *Fixing nonconvergence of algebraic iterative reconstruction with an unmatched backprojector*, SIAM J. Sci. Comput., 41 (2019), pp. A1822–A1839. doi: 10.1137/18M1206448.
- Y. Dong, P. C. Hansen, and H. M. Kjer, *Joint CT reconstruction and segmentation with discriminative dictionary learning*, IEEE Trans. Computational Imaging, 4 (2018), pp. 528–536, doi: 10.1109/TCI.2018.2858139.

- S. Gazzola, P. C. Hansen, and J. G. Nagy, *IR Tools: a MATLAB package of iterative regularization methods and large-scale test problems*, Numerical Algorithms, 81 (2019), pp. 773–811. doi: 10.1007/s11075-018-0570-7.
- M. Salewski, M. Nocente, B. Madsen, I. Abramovic, M. Fitzgerald, G. Gorini, P. C. Hansen + 19, *Alpha-particle velocity-space diagnostic in ITER*, Nuclear Fusion, 58 (2018), 096019 (16pp), doi: 10.1088/1741-4326/aace
- T. Elfving and P. C. Hansen, *Unmatched projector/backprojector pairs: perturbation and convergence analysis*, SIAM J. Sci. Comput., 40 (2018), pp. A573–A591.
- N. A. B. Riis, J. Frøsig, Y. Dong, and P. C. Hansen, *Limited-data X-ray CT for underwater pipeline inspection*, Inverse Problems, 34 (2018), 034002 (16pp).
- V. Dahl, A. B. Dahl, Anders, and P. C. Hansen, *Computing segmentations directly from X-ray projection data via parametric deformable curves*, Measurement Science and Technology, 29 (2018), 014003.
- P. C. Hansen and J. S. Jørgensen, *AIR Tools II: algebraic iterative reconstruction methods, improved implementation*, Numerical Algorithms, 79 (2018), pp. 107{137, doi: 10.1007/s11075-017-0430-x.
- S. Soltani, M. S. Andersen, and P. C. Hansen, *Tomographic image reconstruction using training images*, J. Comp. Appl. Math., 313 (2017), pp. 243–258.
- M. Salewski, B. Geiger, A. Jacobsen, P. C. Hansen + 12, *High-definition velocity-space tomography of fast-ion dynamics*, Nuclear Fusion, 56 (2016), DOI: 10.1088/0029-5515/56/10/106024.
- T. Elfving, P. C. Hansen, and T. Nikazad, *Convergence analysis for column-action methods in image reconstruction*, Numerical Algorithms (2016), DOI: 10.1007/s11075-016-0176-x.
- R. D. Kongskov, J. S. Jørgensen, H. F. Poulsen, and P. C. Hansen, *Noise robustness of a combined phase retrieval and reconstruction method for phase-contrast tomography*, J. Optical Society of America A, 33 (2016), pp. 447-454, DOI: 10.1364/JOSAA.33.000447.
- S. Soltani, M. E. Kilmer, and P. C. Hansen, *A tensor-based dictionary learning approach to tomographic image reconstruction*, BIT Numer, Math., 56 (2016), pp. 1425-1454.
- M. Romanov, A. B. Dahl, Y. Dong, and P. C. Hansen, *Simultaneous tomographic reconstruction and segmentation with class priors*, Inverse Problems in Science and Engineering (2015), DOI: 10.1080/17415977.2015.1124428 (open access).