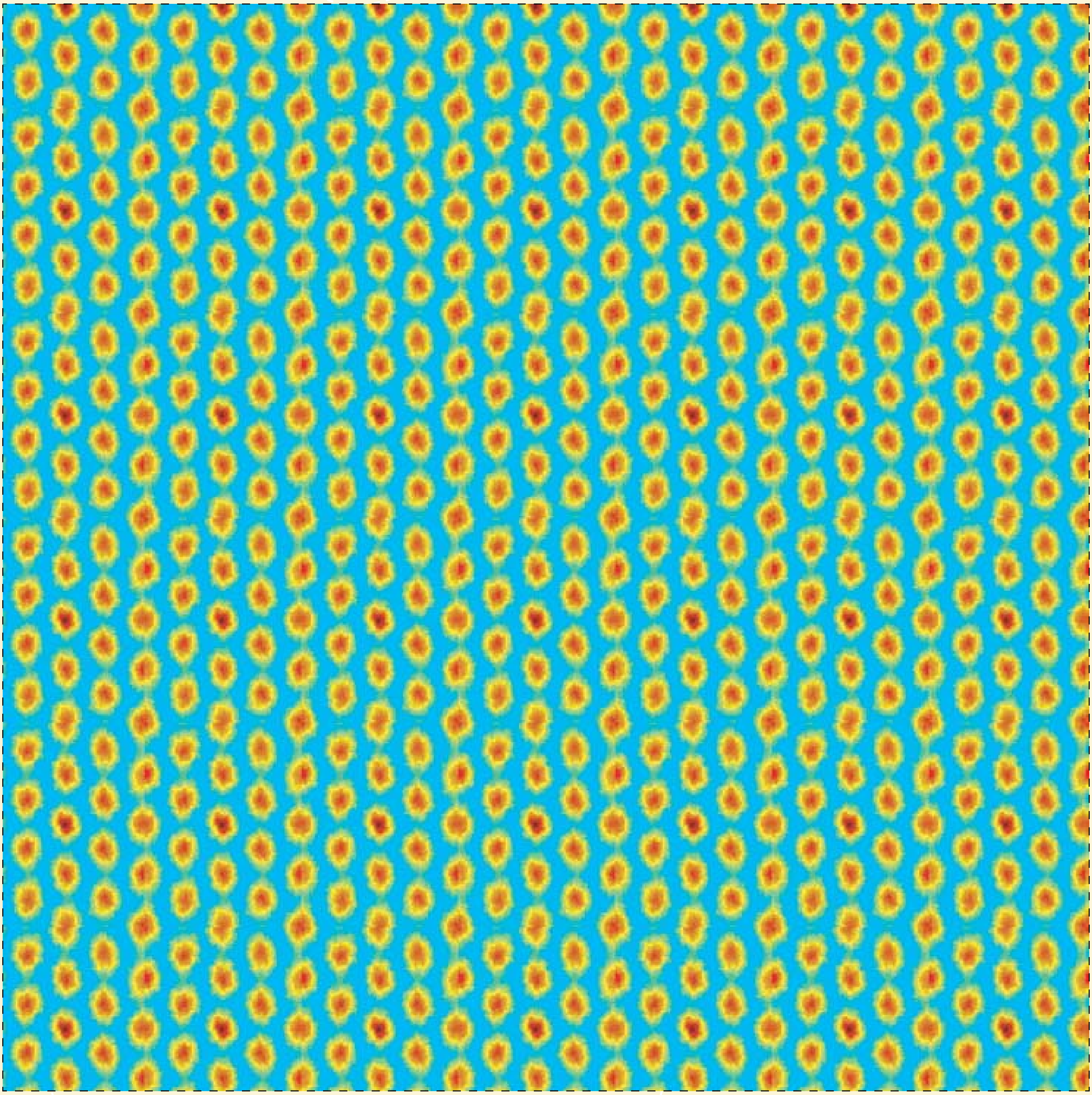
CBM
Centre for the Biology of Memory

Annual Report

Norwegian Centre of Excellence

NTNU
Innovation and Creativity



Cover page: Triangular grid outside the brain
Inside page: Triangular grid inside the brain

Norwegian Centre of Excellence

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Table of contents

The staff

The core activity of CBM is organized around the research group of professors May-Britt Moser and Edvard Moser. At the turn of the year (2005/2006), the group consisted of 2 regular professors (the Directors), 7 visiting professors, 9 researchers and post-docs, 5 Ph.D. students, 6 master students, 1 administrative staff, 10 technical staff (3 part-time) and 9 associated staff – a total of 49. The mean age of professors (including visiting professors), post-docs, graduate students and technical staff was 36 years. The median age was 32 years. Two out of 9 professors were women. Among post-docs and graduate students, the male: female ratios were 4:5 and 3:2, respectively.

Sample of people at the Centre

A landmark year for the biology of memory

The Centre for the Biology of Memory was established in 2002. In 2005, three years after its birth, the Centre has been able to provide some of the most groundbreaking insights so far into how spatial location and spatial memory are computed in the brain. The most remarkable insight was the discovery of grid cells in the entorhinal cortex, which immediately pointed to the entorhinal cortex as a hub for the brain network that makes us find our way through the environment. The discovery led to an immediate revision of well-established views of how the brain calculates position and how the results of these computations are used by memory networks in the hippocampus. Investigators at the Centre are convinced that their results will ultimately benefit the development of tools for diagnostics and treatment of Alzheimer's disease, which commonly begins in the brain area that contains the grid cells.

Adresseavisen

MANDAG

Gud og Allah er den samme

Invasjon fra Mars - igjen og igjen

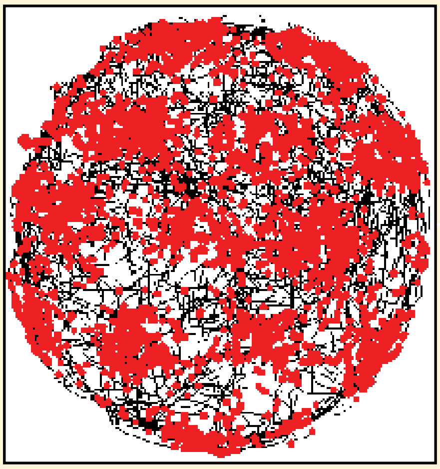
Kan bety nytt håp for Alzheimer-syke

Stedsansen i hjernen - sensasjonelt funn av NTNU-forskere

Del 1 side 5

The scientific goal of CBM is to understand the biological processes responsible for memory. Using memory as a window to analyse the basic functions of neural networks in general, the Centre aims to provide fundamental insights into how the brain computes. The ultimate goal is to understand how information is encoded, stored and used in cortical systems and microcircuits and, implicitly, how a disruption of those processes may lead to various forms of neurological disease or psychopathology. Reaching this ambitious aim requires a multidisciplinary and multilevel approach which can only be accomplished by close collaboration between experts in several disciplines. To enable the integration of methods and concepts across disciplines, seven internationally leading neuroscientists work at the Centre periodically each year. These scientists, coming from the United States, the U.K., the Netherlands, Germany and Italy, share an interest in how memory forms in cell assemblies and brain circuits. Their goal is to determine, using a combination of neurophysiological, behavioural, information theoretical and statistical methods, how neurons in the hippocampus and neocortex collectively give rise to specific memory operations such as encoding, storage, consolidation and retrieval, and how networks of neurons together encode and store information that can be recalled at a later time. Research during 2005 took important steps towards the realization of that goal. On the way towards the goal, scientists at the Centre also stumbled across what seems to be the brain's mechanism for calculating the subject's current location during movement in a spatial environment.

Scientific highlights



The scientific highlights of the year were the discovery of entorhinal grid cells, published as a full Article in Nature (Hafting et al., 2005), and the subsequent dissociation of an orthogonal rate and location code in the hippocampus, published in Science (Leutgeb S et al., 2005). Both reports were accompanied by commentary papers in the news section of the journals (News and Views in Nature; Perspective in Science). A third advance was the demonstration of continuous representations in the hippocampus during morphing of one environment into another; this study, published in Neuron (Leutgeb JK et al., 2005), has important implications for models of attractor dynamics during episodic memory encoding in the hippocampus. A fourth paper, also published in Neuron (Steffenach et al., 2005), showed that the area that includes grid cells in medial entorhinal cortex is critical for spatial navigation and memory.

Fant stedsansen - i Trondheim

Kartene som tegnes i forsøksrottenes hjerner, er så nøyaktige at forskerne ved NTNU i Trondheim kan lese hvor rotten har vært.

LARS KLUGE

Alle har opplevd det. Du vet hvor du er, fordi du føler hvor langt du har beveget deg fra siste kjente landemerke, og i hvilken retning. Så runder du et par hjørner til i en by der du ikke er kjent, og så glipper det. I hvilken retning er egentlig hotellet? Er dere flere i følge, spriker oppfatningene vilt om hvilken gate som fører i riktig retning. Hva er det egentlig som er skjedd?

Det vet vi mer om nå, etter at forskergruppen

How do we find our way (or why do we get lost)?

Marianne Fyhn discovered grid cells together with Torkel Hafting (Nature, 2006)

The ability to find one's way depends on the brain's ability to integrate information about location, direction and distance. How this integration is performed in the neural networks of the brain is not known. In a paper in Nature this year (Hafting et al., 2005), the Centre reports the discovery of mammalian neurons that perform such integration. These neurons, located in the superficial layers of a brain area referred to as the entorhinal cortex, collectively form a neural map of the spatial environment. The discovery of grid cells paves the way for an entirely new and mechanistic understanding of how animals and humans find their way through space and will undoubtedly contribute to a better understanding of the early stages of Alzheimer's disease where impairments in the sense of locality is one of the first symptoms.

The key element of the neural map is the 'grid cell' – a cell type different from any other cell type reported anywhere in the nervous system. With the aid of small microelectrodes or sensors implanted in layer II of the entorhinal cortex of freely moving rats, Torkel Hafting, Marianne Fyhn and colleagues recorded neural activity simultaneously from a number of individually separable neurons in medial entorhinal cortex, the major interface between the hippocampus and the neocortex, while rats explored new and familiar spatial environments. A majority of the cells in this brain area were found to be active exclusively when the rat was at certain locations in the environment. These locations formed a surprisingly regular and repetitive pattern. For each cell, the set of active locations defined a regular hexagonal array covering the entirety of the animal's environment, like the cross-points of graphic paper rolled out over the surface of the test arena. Grids of different cells were offset relative to each other such that each position in the environment could be identified from the activity of a fairly small number of adjacent cells. Using the collective activity of a small set of grid cells, the team was able to show that it is possible to predict the animal's current location as it moves through space with a precision of a few centimetres, implying that information about location is available from neural activity in the network. These observations point to the network of entorhinal grid cells as a possible neuronal coordinate system used by mammals during spatial navigation.

A key property of the newly discovered entorhinal spatial map is its apparently universal nature. The map is activated in a stereotypic manner across environments, regardless of the environment's particular landmarks, suggesting that the same neural map is applied wherever the animal is walking. Information about position is apparently computed from the animal's own movement, using distance and direction of movement as the primary inputs, without reference to the external environment. Because of its grid-like nature, the map can potentially represent places not visited just as well as places that have been visited. Unlike maps based on single points, the grid map is potentially infinite, allowing the inclusion of all places and potential places. The existence of a single neural map of the environment that can be applied anywhere is economical and avoids the enormous capacity problems that might arise if the brain were to store rules about spatial interrelations for every single spatial context that the subject encountered.

A remarkable feature of the entorhinal map is its strikingly regular organization, with grids of neighbouring cells having a common spacing (distance between the activity spots) and a common orientation. The spacing of the grid increases monotonically as one gets deeper into the brain. The combination of grids at variable scales, within the entorhinal cortex or downstream in the hippocampus, provides an economical, high-resolution spatial coordinate system for navigation over a large space. If grid cells had a single, common scale, the population code would repeat itself at intervals corresponding to a single period of the grid of individual cells, and the place code would be ambiguous. If activity is integrated across grids with different spacings and orientations, however, the cycle for repetition might be very large, enabling each position within this radius to be expressed by a unique pattern of collective activity in the grid network. In contrast to the topographic organization of spacing and orientation, the phase of the grid – the relative displacement of grid vertices in different cells – is randomly distributed. These organizational features are all mirrored downstream in the

Francesca Sargolini discovered head direction cells and conjunctive grid x head-direction cells in entorhinal cortex (Science, 2006) hippocampus, in which neighbouring cells have different firing locations and properties and the scale of the place fields increases along the septal-to-temporal axis of the brain area.

The discovery of grid cells is a milestone in the investigation of the neural basis of spatial representation and memory. Thirty years of exclusive focus on spatial representation in the hippocampus has now been directed towards the entorhinal cortex and associated parahippocampal areas. As a major hub of the widespread network involved in spatial representation and navigation, the entorhinal cortex is well suited to integrate information about distance, direction and position into an environmentally invariant self-motion-based dynamic representation of current position. The Hafting et al. data, characterized by colleagues as the most important discovery in the field for many years, have brought us closer to understanding how the brain computes where we are.

The discovery of grid cells provides an example of how basic research may ultimately have direct implications for treatment of Alzheimer's disease. The entorhinal cortex is often the first brain area to be affected in Alzheimer's disease, and spatial and navigational problems are among the early symptoms appearing before a reliable diagnosis can be made. We are confident that studies outlining the function of the entorhinal cortex will aid the development of sensitive neuropsychological tests, with a potential for early diagnosis of Alzheimer's disease. Early diagnosis, in turn, may allow treatment of pathological processes at a stage when the disease can still be stopped.

Marianne Fyhn and Torkel Hafting receieved the Royal Norwegian Society of Sciences and Letter's price for young researchers in natural sciences (I.K.Lykke's award) for their work on spatial representation in entorhinal cortex

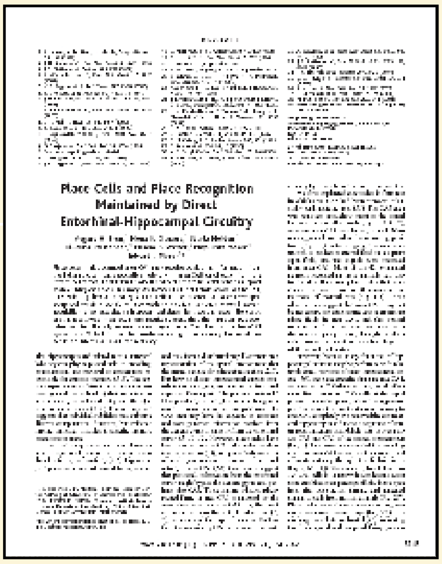
Dual codes and attractor dynamics in the hippocampus

Understanding the function of the hippocampus has been considered the gateway to understanding memory. Thousands of studies have tried to characterize the role of the hippocampus in mnemonic processes, but a wide-reaching consensus on the type of memory encoded by this structure has not been reached. Perhaps the most fundamental controversy has related to the role of the hippocampus in spatial representation vs. representation of episodic and other non-spatial information. Some groups have defended a principal role of the hippocampus in spatial cognition; others have argued for a broader involvement in episodic or declarative memory. Recent data from the Centre, published in Science (Leutgeb et al., 2005), shed new light on this controversy by suggesting that hippocampal neurons express both types of information. In collaboration with Bruce McNaughton and Carol Barnes – visiting professors of the Centre – Stefan Leutgeb, Jill Leutgeb and others have shown that hippocampal neurons possess independent coding schemes for spatial and non-spatial information. Changes in spatial location are represented as changes in location of firing in hippocampal place cells, whereas changes in cue configuration at a single location are represented by (substantial) changes in firing rate. These results point to possible orthogonal codes for location and what happens at a location. The results explain how differential results may have been obtained in previous studies, depending on the choice of dependent variables. The combination and integration of spatial and non-spatial information in the hippocampal output may form the neural basis for the role of the hippocampus in episodic memory.

In a subsequent study, Jill Leutgeb, Stefan Leutgeb and others provided important further clues about network dynamics in the hippocampus during rate remapping. One of the challenges of the brain's episodic memory system is to recognize and encode novel inputs without interfering with similar, familiar items in memory. Together with Alessandro Treves, Bruce McNaughton and Carol Barnes – all visiting members of the Centre – the Leutgebs tested whether such functions are based on attractor networks in the hippocampus. Among the defining properties of an attractor network is the ability to undergo sharp and coherent transitions between pre-established representations. The Leutgebs

Who is the odd man out? Memory in humans and other mammals has a remarkable ability to retrieve the correct pattern (minister) in spite of enormous variability in the details of the input. This ability to generalize is accompanied by an equally remarkable ability to recognize patterns (ministers) as different from the template stored in memory.

tested this by recording from large cell assemblies in CA3 and CA1 while rats walked in a familiar square enclosure that was progressively morphed into a familiar circular enclosure, or vice versa. Briefly, when all training occurred in a single location, they observed a gradual, noncoherent progression from the initial to the final network state, accompanied by significant hysteresis in CA3. These results suggest that hippocampal cell assemblies are capable of incremental plastic deformation, with incongruous information being incorporated into pre-existing representations. This ability provides the hippocampus with a great potential for encoding sequences of new information without risking abrupt changes in network representations during the encoding. The results were published in Neuron (Leutgeb JK et al., 2005); the paper was highlighted by a Preview by Misha Tsodyks.



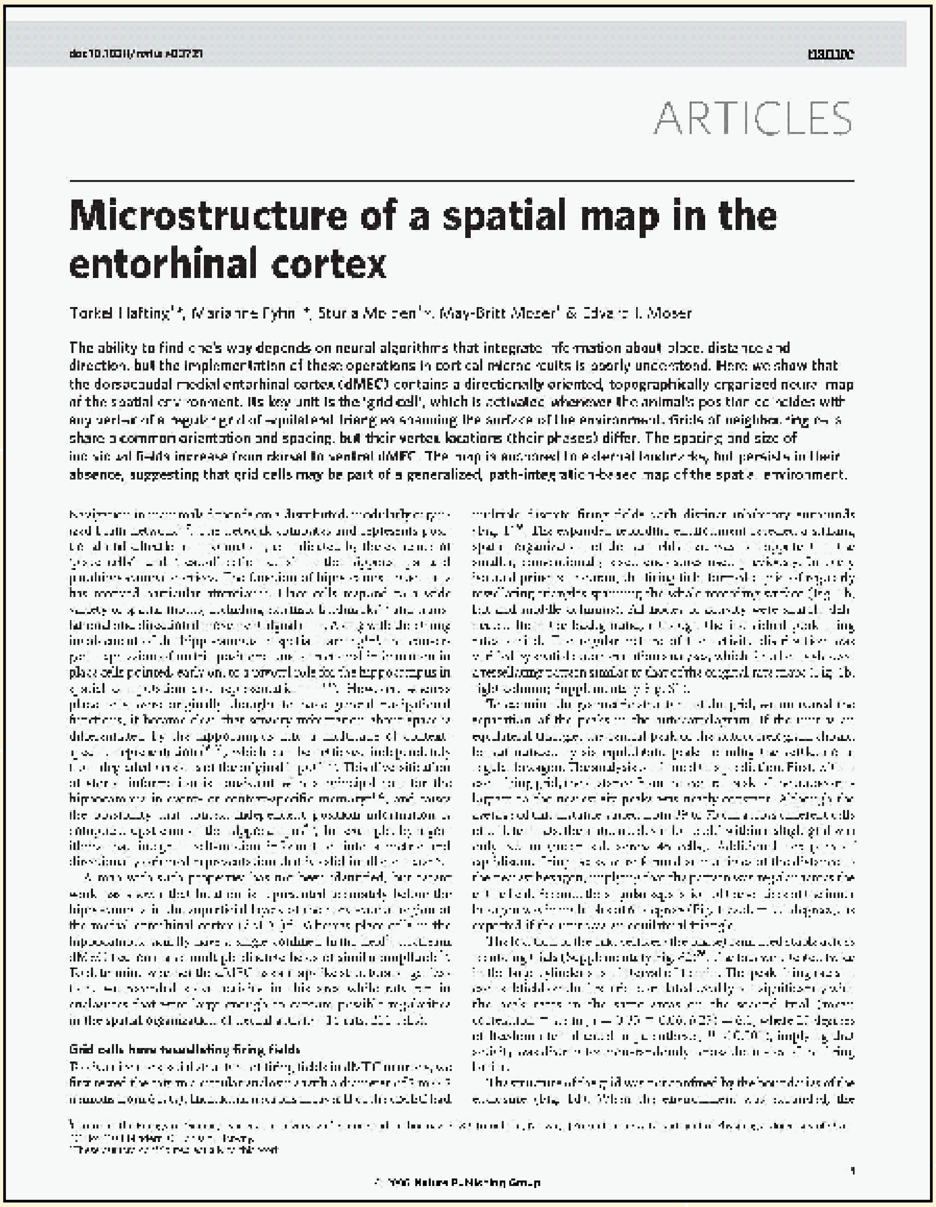
Place Cells and Place Recognition Maintained by Direct Entorhinal-Hippocampal Circuitry

Jill Leutgeb with morph box (square and circle)

Bibliometric footprints

The Hafting paper is perhaps the first Norwegian neuroscience study ever published in Article form in Nature. According to a search in PubMed, 30 papers with a Norwegian author address have been published in biomedical disciplines in Nature from 1970 onwards. The Hafting paper is the only of those papers that appears in the content category 'Article'; most of the remaining 29 papers are 'Letters'. A broader search in the Web of Science database (including Science citation index) identifies 203 papers in Nature with 'Norway' in the address of any of the authors. Seven of these papers appear as articles; none of those were published after 1990 and none in neuroscience.

The Hafting paper was rated as 'of exceptional interest' by Faculty of 1000, a peer-based evaluation system for papers in all fields of biology and medicine. Together with another paper from the Centre (Fyhn et al., 2004), this paper remains on the top 10 list for all papers selected by peers in neuroscience since Faculty of 1000 started in 2001. The Leutgeb papers in Science and Neuron were both rated as 'Must Read's.



doi:10.1038/nature03721

ARTICLES

Microstructure of a spatial map in the entorhinal cortex

Torkel Hafting[1]*, Marianne Fyhn[1]*, Sturla Molden[1], May-Britt Moser[1] & Edvard I. Moser[1]

The ability to find one's way depends on neural algorithms that integrate information about place, distance and direction, but the implementation of these operations in cortical microcircuits is poorly understood. Here we show that the dorsocaudal medial entorhinal cortex (dMEC) contains a directionally oriented, topographically organized neural map of the spatial environment. Its key unit is the 'grid cell', which is activated whenever the animal's position coincides with any vertex of a regular grid of equilateral triangles spanning the surface of the environment. Grids of neighbouring cells share a common orientation and spacing, but their vertex locations (their phases) differ. The spacing and size of individual fields increase from dorsal to ventral dMEC. The map is anchored to external landmarks, but persists in their absence, suggesting that grid cells may be part of a generalized, path-integration-based map of the spatial environment.

Grid cells have tessellating firing fields

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Organization of the Centre

Like its two twin Centres of Excellence at NTNU, CBM is placed directly under the University Director. Until August 2005, the Faculty of Social Science and Technology Management served as hosts of the Centre. From August, this function was taken over by the Medical Faculty as part of a long-term strategic plan for neuroscience at NTNU. Financial and other administrative matters are taken care of by the Central administration of NTNU, in collaboration with the Centre.

In agreement with the contract with the Research Council, the Board of the Centre consists of an external representative (Chairman), the Faculty Directors of Medicine and Social Science, and either University Director, Rector or Prorector. Professor Arnstein Finset has been Chairman since the start of the Centre. Prorector Julie Feilberg represents the rector trio. Present Deans of Medicine and Social Science are professors Stig Slørdahl and Jan Morten Dyrstad; these are also members of the Board.

In addition, the Centre has an external Advisory Board consisting of 3-4 internationally outstanding neuroscientists, professors Larry Squire (University of California San Diego; chairman), Terry Sejnowski (Salk Institute, San Diego), Erin Schuman (Caltech, Los Angeles) and Earl Miller (MIT, Boston). The Advisory Board meets with the Centre members in Trondheim every 3-4 years, reviews their scientific progress and gives advice on future directions. The first meeting was held in June 2005.


Arnstein Finset


Stig Slørdahl


Jan Morten Dyrstad


Julie Feilberg

First evaluation by CBM's Advisory Board

A meeting of the Advisory Board of the Centre for the Biology of Memory convened on June 26 and 27, 2005, in Trondheim, Norway, at the Norwegian University of Science and Technology. Attending members of the Advisory Board were Larry R. Squire, Ph.D. (Chair), Erin Schuman, Ph.D., and Terry Sejnowski, Ph.D. The Advisory Board was charged with considering the aims of the Centre, its scientific progress, and its organizational structure. The Board was also invited to make such suggestions and recommendations as might seem useful and, lastly, to indicate whether in the Board`s view funding for the Centre should be extended for an additional five years.

In their report on scientific progress, the Board concluded that "the Centre has, in a remarkably short time, established itself as a leading Centre for the biological study of memory", and that "one can only be impressed by the quality of the work that has come to fruition during the past few years and that has appeared in the very best international scientific journals, including four papers in Science, one in Nature and one in the Proceedings of the National Academy, USA". The Board was "uniformly impressed with the scientific work of the Centre, and notes that the Centre is already being identified as a magnet that can attract high quality students and postdoctoral scholars from around the world."

Larry Squire, Erin Schuman, Terry Sejnowski, Earl Miller

The Board provided a number of recommendations for development of neuroscience at a broader level at NTNU. Although the current structure of CBM is suitable for its purpose, the Board recommended NTNU to consider whether it would be desirable, in the long term, to extend the neuroscience community at the level of tenured positions, i.e. to increase the number of faculty positions in the field. According to the Board, "the addition of new faculty who share or complement the research interests of the Moser team will be critical for sustaining the success and productivity of the Centre as well as for improving neuroscience at the University. In addition to enhancing the research mission of the Centre, new faculty will aid in the successful recruitment of high-quality students and postdoctoral scholars." The Board also offered a number of suggestions for increasing international collaboration and recruitment, and they pointed to the great potential of some recent advances in molecular technology for addressing questions of interest to the Centre. The introduction of viral techniques for gene silencing or expression is one such example. Their advice in this respect is now being followed up by the Centre.

CBM in an international context

Edvard Moser

During 2005, visiting scientists spent 154 days at the Centre, in addition to active collaboration over the internet during the rest of the year. This includes regular working visits by the 7 visiting professors, external visitors, and postdoctoral and predoctoral staff from the laboratories of the visiting professors and elsewhere.

Since 1 January 2004, Edvard Moser, the Director of CBM, has served as a member of the Board of Reviewing Editors in Science. The journal has approximately 10 neuroscientists on its Board. Their task is, on a daily basis, to provide input on papers submitted to the journal and, more occasionally, to advice the Editors on matters related to the direction of neuroscience and science in general. From 1 January 2005, the Director of CBM was also elected as Reviewing Editor for the Journal of Neuroscience, as well as Chairman of the Programme Committee of the Federation of European Neuroscience Societies (FENS) for the Society's next biannual meeting to be held in Vienna in July 2006 (FENS Forum 2006). All three elections may be regarded as recognition of the work performed at the Centre.

The Directors of the Centre received the 2005 Alden Spencer award "for outstanding research contributions in neural science". "The 2005 Spencer Award jointly recognizes May-Britt Moser and Edvard Moser for their extraordinary contributions to our understanding of information processing in the medial temporal lobe", according to the nominators. Another highlight during the year was the invitation to Edvard Moser to give one of the three Presidential Lectures at

2005 Alden Spencer award to May-Britt Moser and Edvard Moser

the Society's annual meeting in Washington D.C. More than 5.000 neuroscientists attended the lecture.

During 2005, Carol Barnes, one of the visiting professors of CBM, served as President for the Society of Neu-

May-Britt Moser

roscience (SfN). SfN is the American equivalent of FENS. It has more than 34.000 members from around the world. Another CBM visiting professor, Richard Morris, is current President-elect of FENS; his Presidential period begins in July 2006. Both elections further enhance the visibility of CBM among neuroscientists in general.

Recruitment

The post-docs represent an important international anchor of CBM. Stefan Leutgeb is from Austria, Jill Leutgeb and Laura Colgin are from the United States, Francesca Sargolini is from Italy, Paul Ganter from Germany, Karel Jezek from the Czech Republic. Contracts were signed during 2005 with two additional post-docs, Dori Derdikman (Israel), who came as a postdoc on January 1, 2006, and Ayumu Tashiro (Japan), who will arrive at CBM in June 2006. A few former Ph.D. students from CBM have continued in postdoctoral positions (Marianne Fyhn, Torkel Hafting, and Vegard Brun). The post-docs were recruited through personal contact and international competition. The collective conceptual and methodological expertise of the postdoctoral team is a major reason for the Centre's ability to compete internationally.

Several of CBM's Ph.D. students defended their thesis in 2005: Sturla Molden, Hill-Aina Steffenach, Frode Tuvnes, Marianne Fyhn, and Vegard H. Brun. Sturla Molden is now a post-doc at the University of Oslo, Hill-Aina has a research position at the MR Centre at NTNU. Frode Tuvnes, Marianne Fyhn, and Vegard H. Brun continued to work at the Centre. New Ph.D. students recruited to the Centre during 2005 were Trygve Solstad (Norway) and Hanne Lehn (Norway; co-supervised with Olav Haraldseth at the MR Centre), Cathrin Canto (Germany; supervised jointly from CBM and the University of Amsterdam (Witter)) and Charlotte Boccara (France), who began at CBM in January 2006.

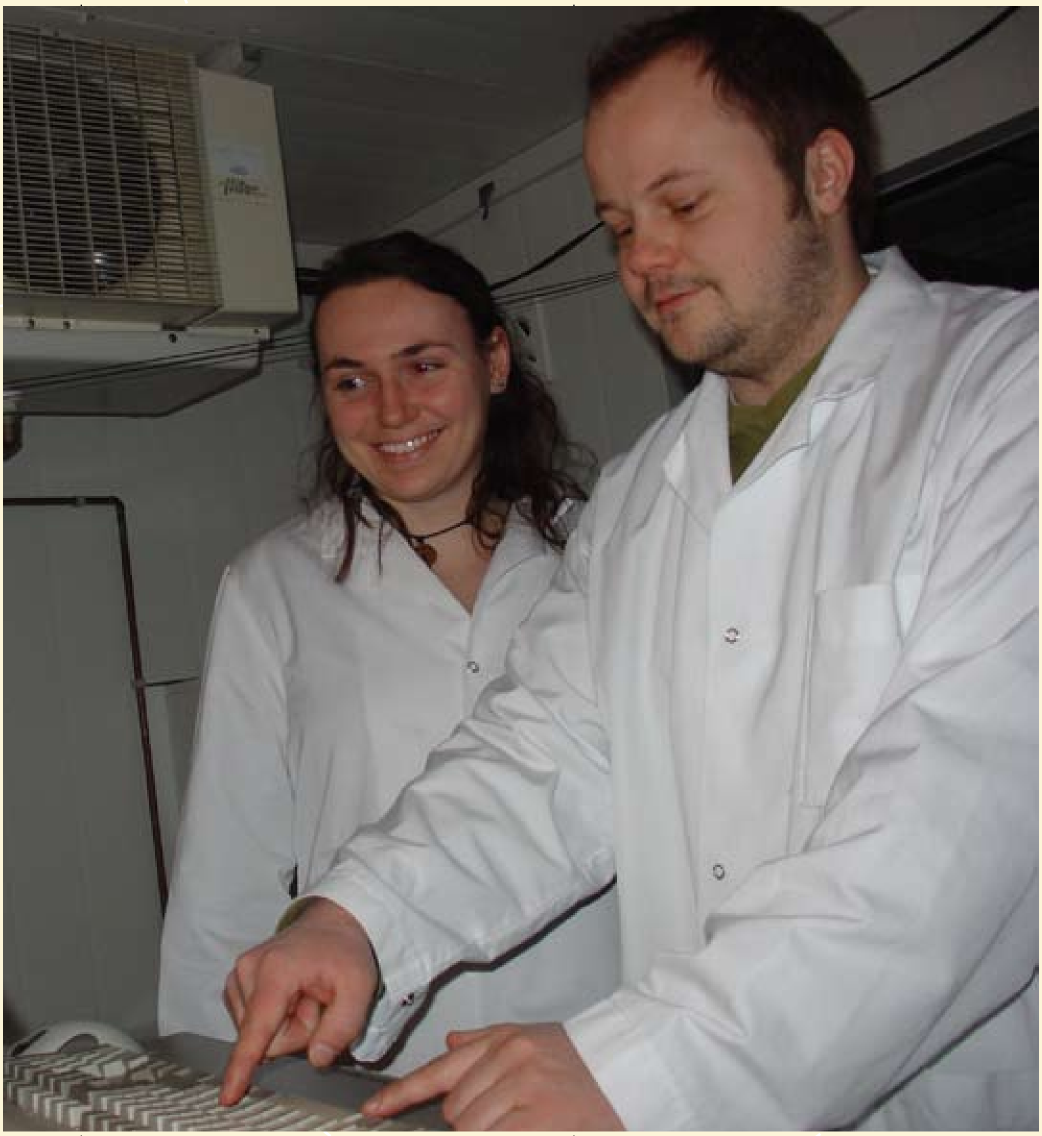
A major platform for recruitment to CBM and to neuroscience in Norway more generally is the newly established Master's degree in Neuroscience at NTNU. Students admitted to this program are motivated for a future in neuroscience and follow an advanced curriculum with extensive theoretical and practical training. Visiting professors at CBM participate in the teaching.

Francesca Sargolini, Karel Jezek and Paulo Girao at work in new microdrive wiring facility

Training programmes

NTNU's programme in neuroscience leads, within 2 academic years of study, to a Master's degree in Neuroscience. Students receive training across all levels of the field, from molecules to behaviour, but with a particular emphasis on systems neuroscience and network mechanisms. Students with a Master from this programme are qualified for taking a PhD in neuroscience at NTNU, at other universities in Norway, or abroad. Training in systems neuroscience is linked to the Centre for the Biology of Memory. Visiting professors and post-docs at CBM participate in courses and direct training of Master and Ph.D. students, providing the students with first-hand knowledge of the wide diversity of thoughts and techniques in the field.

NTNU is currently finalizing the integration of the Master and Ph.D. programmes in neuroscience with sister programs at the VU Medical Center in Amsterdam. Teaching is in English, and course structure has been adapted to enable easy inclusion of courses at one university in the curriculum of the other. A fixed number of students from VU will be given priority access to courses and lab training at NTNU, and vice versa. The collaboration will mutually enrich the MSc and Ph.D. programmes at the two universities as their expertise in research and training have a different but complementary emphasis (a focus on systems neuroscience and networks at NTNU vs. a stronger focus on neurogenetics, neuroanatomy and clinical neuroscience at VU).



Master students in the lab (Amela Felic and Espen Joakim Henriksen)

Local and national collaboration

While the research aim of CBM is strongly focused, the Centre tries to develop a limited number of links to other research groups. The Centre has collaborations with Robert Biegler at the Department of Psychology (on path integration and spatial memory) and with Hanna Mustaparta at the Department of Biology (through Randolf Menzel, a visiting professor at the Centre). In addition, a new collaboration has been initiated with the Magnetic Resonance Centre at NTNU. Building upon new knowledge about the organization of memory at the systems level established at CBM, the collaboration aims to use fMRI to determine whether similar operational principles derived from animal studies underlie human episodic memory. CBM shares a Research Council-funded graduate student (Hanne Lehn) with the MR Centre; professor Olav Haraldseth is the main advisor. The first results from the collaboration will be presented at the international Human Brain Imaging meeting in 2006.

At the national level, CBM has established new collaborations with neuroscientists at the Universities of Oslo and Bergen. CBM participates in a large-scale Research Council funded project on the function of direct entorhinal inputs to the hippocampus ("Storforsk", awarded in 2005), coordinated by professor Johan Storm at the Centre for Molecular Biology and Neuroscience, CBM's twin Centre at the University of Oslo. A smaller functional-genomics project was initiated between the same partners at the beginning of 2004.

May-Britt Moser, co-director of CBM, serves as the chairman of the FRIBOFYS physiology and anatomy group of the Norwegian Research Council. One of her ambitions is to improve the funding situation for basic research in biomedicine.

Hanna Mustaparta's group

Expansion of laboratory and office areas

The main challenge confronting the Directors of the Centre and the Board has been lack of space. During 2005, the Centre was generously awarded additional lab and office space from the Medical Faculty. This has provided the Centre with an entirely new histology lab, an electronics lab, a microdrive wiring facility, a microscopy room, a meeting room, and several new offices – allowing existing laboratories to be rebuilt to give more space for animal experiments. The Centre is most grateful to the Faculty for providing the new research facilities at the time when the availability of lab space is generally very limited.

Klaus Jenssen in the new electronics lab

Ann Mari Amundsgård and Kyrre Haugen in new histology lab

Annual accounts

Income *(Inntekter)*	**Accounts** *(Regnskap)*	**Budget** *(Budsjett)*
Grants *(Bevilgninger)*		
Norwegian Centre for Excellence *(SFF)*		9 600 000
Other External projects *(Andre eksterne prosjekt)*		2 651 000
Contribution from the Norwegian University of Science and Technology *(Bevilgning fra NTNU)*		
Transferred from 2004 (Overført fra 2004)		2 595 868
S/O funding *(S/O-midler)*		1 766 203
Operational grants *(Driftsbevilgning)*		2 978 929
Scientific equipment *(Vitenskapelig utstyr)*		1 012 000
Salaries *(Lønnsmidler)*		1 813 000
Other benefits *(Naturalytelse)* **Note 1**		2 168 000
Total Income *(Sum inntekter)*		24 585 000
Expenses *(Utgifter)*		
Net personnel costs (including social benefits)	9 280 000	
(Netto faste lønnsmidler inkl sosiale kostnader)		
Scientific equipment *(Vitenskapelig utstyr)*	1 071 000	
Laboratory consumables *(Drift av laboratoriet)*	6 645 000	
Other expenses *(Naturalytelse)*	3 981 000	
Transferred to 2006 for new equipment in expanded lab areas *(Resultat overført til 2006)*	3 608 000	
Total expenses *(Sum utgifter)*	24 585 000	

Note 1 - Other benefits
Server operations and backup, rooms and general operation, compensation for the use of administrative services.
Drift og backup av server, areal og drift, bruk av sentrale tjenester.

Personnel at CBM

The Board


Professor
Arnstein Finset,
University of Oslo
(chairman)


Associate Professor
Julie Feilberg,
ProRector,
NTNU


Professor
Stig Slørdahl,
Dean, Faculty of Medicine,
NTNU


Associate Professor
Jan Morten Dyrstad,
Dean, Faculty of Social
Science and Technology
Managment, NTNU

The Advisory Board

Professor Larry Squire,
University of California San Diego,
USA (chairman)

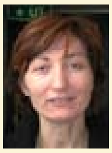
Professor Terry Sejnowski,
Howard Hughes Med Inst,
Salk Institute, San Diego, USA

Professor Erin Schuman,
California Institute of Technology
Los Angeles, USA

Professor Earl Miller,
Masachusetts Institute
of Technology, Boston, USA

Directors


Edvard I Moser,
Professor and director

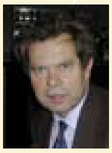

May-Britt Moser,
Professor and co-director

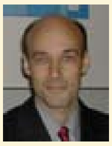
Visiting professors


Carol Barnes,
Professor
University of Arizona,
USA


Bruce McNaughton, *Professor*
University of Arizona,
USA


Randolf Menzel,
Professor
Free University of Berlin,
Germany


Richard G. M. Morris,
Professor
University of Edinburgh, UK


Ole Paulsen,
Professor
Oxford University,
UK


Alessandro Treves,
Professor
International School for Advanced
Studies, Italy


Menno P. Witter,
Professor
Free University of Amsterdam,
Netherlands

Research scientists

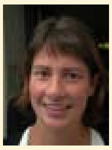

Stefan Leutgeb,
Research Scientist


Jill Leutgeb,
Research Scientist


Paul Ganter,
Research Scientist

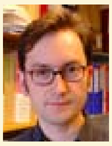

Francesca Sargolini,
Research Scientist


Vegard Heimly Brun,
Post doc


Marianne Fyhn,
Post-doc

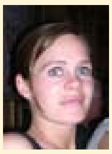

Torkel Hafting Fyhn,
Post-doc


Laura Colgin,
Post-doc


Karel Jezek,
Post-doc

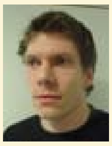
Graduate students


Cathrin Barbara Canto,
Ph.D. student


Mona Kolstø Otnæss,
Ph.D student


Kirsten Gjerstad Kjelstrup,
Ph.D student


Paulo Girão,
Ph.D. student

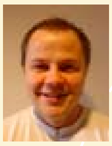

Trygve Solstad,
Ph.D. student

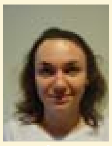
Project students


Tora Bonnevie,
Project student

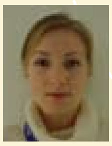
Master students


Kamilla Medås,
Master student


Espen Joakim Henriksen,
Master student


Amela Felic,
Master student


Beathe Christin Haatveit,
Master student

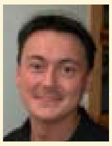

Ingrid Funderud,
Master student


Karoline Einarsen,
Master student

Technical team


Ingvild Hammer,
Bioengineer


Kyrre Haugen,
Histology technician


Klaus Jenssen,
Electronics engineer


Raymond Skjerpeng,
Programmer


Haagen Waade,
Computer engineer


Ingunn E. Bakken,
Senior executive officer


Knut S. Grøn
Animal technician (part-time)


Ingolf Hanssen,
Veterinary (part-time)


Espen Sjulstad,
Histology and electrode wiring


Bjørn Håvard Solem,
Electronics technician (part-time)


Ann Mari Amundsgård
Histology and animal care (part-time)

Associated members

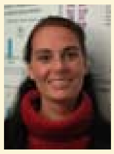

Boleslaw Srebro,
Associate professor, Master Study in Neuroscience


Frode A. Tuvnes,
Dr.philos.

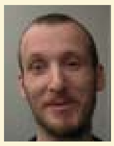

Gerit Pfuhl,
Ph.D. student


Hanna Mustaparta,
Professor NTNU, Norway


Hanne Lehn
Ph.D. student


Hill-Aina Steffenach,
Ph.D


Sturla Molden
Ph.D


Robert Biegler,
Associate professor NTNU (Psychology), Norway


Stig Hollup,
Associate professor NTNU (Psychology), Norway

Seminars

January 19
Professor Menno Witter
(1) The thalamus and cognition; connectivity and fuction of the midline/intralaminar thalamus.

(2) Functional organization of the cortico-hippocampal learning and memory network.

January 21
Professor Richard Morris
Behavoural studies of age-related cognitive impairment in animal models of Alzheimer´s Disease: therapeutic implications.

February 21
Professor John Lisman
The hippocampal-VTA loop: prediction, novelty detaction and entry into long-term memory.

March 10
Dr. Dori Derdikman
Active sensing in the rat somatosenory system.

March 17
Dr. Emma Wood
The role of the hippocampus in memory.

April 19
Professor Clive Bramham
Depression, synaptic plasticity and neurogenesis.

May 23
Professor Terje Lømo
The discovery of LTP – thoughts and after-thoughts.

June 28
Dr. Andre Fenton
Cognitive cooordination and disorganization in hippocampus.

September 30
Dr. Alessandro Sale
Enriched environment and acceleration of visual system development.

October 3
Dr. Livia de Hoz
The influence of the room next door on spatial representation in CA1.

October 12
Dr. Ole Jensen
Of rats and men: The role of oscillatory brain activity in memory encoding and recall.

October 18
Professor Randolf Menzel
Serial learning in navigation.

November 28
Dr. Ayumu Tashiro
Competition for survival: NMDA receptor-mediated integration of new neurons in adult dentate gyrus.

Doctoral defenses

February 23
Sturla Molden
Quantitative analyses of single units recorded from the hippocampus and entorhinal cortex of behaving rats.
External Committee:
Professor John Lisman
Professor Gaute Einevoll

Mars 16
Hill-Aina Steffenach
Memory in hippocampal and cortico-hippocampal circuits.
External Committee:
Dr. Emma Wood
Professor Jan Gunnar Bjålie

April 29
Frode A. Tuvnes
The role of the hippocampus in behavioural and endocrine response to fear.
External Committee:
Dr. Livia de Hoz
Professor Håkan Sundberg

May 24
Marianne Fyhn
Spatial maps in the hippocampus and entorhinal cortex.
External Committee:
Professor Terje Lømo
Dr. James J. Knierim

June 29
Vegard H. Brun
Routes to spatial memory in hippocampal place cells.
External Committee:
Dr. Andre Fenton
Professor Johan Fredrik Storm

Publications

1. Scientific journals: Work performed at the Centre

Hafting, T., Fyhn, M., Molden, S., Moser, M.-B., and Moser, E.I. (2005). Microstructure of a spatial map in the entorhinal cortex. **Nature**, 436, 801-806.

Leutgeb, S., Leutgeb, J.K., Barnes, C.A., Moser, E.I., McNaughton, B.L., and Moser, M.-B (2005). Independent codes for spatial and episodic memory in the hippocampus. **Science**, 309, 619-623.

Leutgeb, J.K., Leutgeb, S., Treves, A., Meyer, R., Barnes, C.A., McNaughton, B.L., Moser, M.-B., and Moser, E.I. (2005). Progressive transformation of hippocampal neuronal representations in 'morphed' environments. **Neuron**, 20, 345-358.

Steffenach, H.-A., Witter, M.P., Moser, M.-B., and Moser, E.I. (2005). Spatial memory in the rat requires the dorsolateral band of the entorhinal cortex. **Neuron**, 45, 301-313.

Leutgeb, S., Leutgeb, J.K., Moser, M.-B., and Moser, E.I. (2005). Place cells, spatial maps and the population code for memory. **Current Opinion in Neurobiology**, 15, 738-746.

Moser, E.I., Moser, M-B., Lipa, P., Newton, M., Houston, F.P., Barnes, C.A and McNaughton, B.L. (2005). A test of the reverberatory activity hypothesis for hippocampal place cells. **Neuroscience**, 130, 519-526.

De Hoz, L., Moser, E.I., and Morris, R.G.M. (2005). Spatial learning with unilateral and bilateral hippocampal networks. **European Journal of Neuroscience**, 22, 745-754.

2. Conference abstracts: Work performed at the Centre

Witter M.P., Hammer, I.M.F, Haugen, K., Moser, E.I. (2005). Three-dimensional cytoarchitectonic atlas of the rat parahippocampal region. Society for Neuroscience Abstracts 31, 198.1.

Brun, V.H., Leutgeb, S., Wu, H.Q., Schwarcz, R., Witter, M.P., Moser, E.I., Moser, M-B. (2005). Direct input from entorhinal cortex is necessary for spatial representation in hippocampal area CA1. Society for Neuroscience Abstracts 31, 198.2.

Hafting, T., Fyhn, M., Molden, S., Moser, M-B., Moser, E.I. (2005). Topografic organization of a spatial map in the entorhinal cortex. Society for Neuroscience. Abstracts 31, 198.3.

Moser, M-B., Sargolini, F., Fyhn, M., Hafting, T., Witter, M.P., Moser, E.I. (2005). Grid cells in medial entorhinal cortex; indications of columnar organization. Society for Neuroscience Abstracts 31, 198.4.

Leutgeb, J.K., Leutgeb, S., Moser, E.I. (2005). Pattern separation in the dentate gyrus during morphing of two environments. Society for Neuroscience Abstracts 31, 198.5.

Fyhn, M., Hafting, T., Treves, A., Moser, M-B., Moser, E.I. (2005). Preserved spatial and temporar firing structure in entorhinal grid cells during remapping in the hippocampus. Society for Neuroscience Abstracts 31, 198.6.

Sargolini, F., Fyhn, M., Hafting, T., Moser, E.I., Moser, M-B. (2005.) Head direction cells in dorsocaudal-medial entorhinal cortex. Society for Neuroseience Abstracts 31, 198.7.

Leutgeb, S., Leutgeb, J.K., Colgin, L., Jezek, K., Barnes, C.A., Moser, E.I., McNaughton, B., Moser, M-B. (2005). Independent codes for spatial and episodic memory in hippocampal neuronal ensembles. Society for Neuroscience Abstracts 31, 198.8.

Ganter, P., Leutgeb, J.K., Leutgeb, S., Moser, M-B., Moser, E.I. (2005). Identification of CA1 interneuron types in single-unit recordings from freely behaving rats. Society for Neuroscience Abstracts 31, 198.9.

Bonnevie, T., Ganter, P., Moser, E.I., Moser, M-B. (2005) Interneurons in CA1 stratum oriens respond differentially to specific input patterns. Society for Neuroscience Abstracts 31, 198.10.

3. Work performed by Centre members in other contexts

Carol Barnes

Lin, G., Chawla, M.K., Olson, K., Guzowski, J.F., Barnes, C.A., and Roysam, B. (2005) Hierarchial, model-based merging of multiple fragments for 3-D segmentation of nuclei. Cytometry, 63A:20-33.

Ramirez-Amaya, V. Vazdarjanova, A., Mikhael, D., Rosi, S., Worley, P.F., and Barnes, C.A. (2005) Spatial exploration-induced Arc mRNA and protein expression: evidence for selective, network-specific reactivation. The Journal of Neuroscience, 25:1761-1768.

Burke, S.N., Chawla, M.K., Penner, M.R., Crowell, B.E., Worley, P.F., Barnes, C.A., and McNaughton, B.L. (2005) Differential encoding of behavior and spatial context in deep and superficial and layers of the neocortex. Neuron, 45:667-674.

Chawla, M.K., Guzowski, J.F., Ramirez-Amaya, V., Lipa, P., Hoffman, K.L., Marriott, L.K., Worley, P.F., McNaughton, B.L. and Barnes, C.A. (2005) Sparse, environmentally selective expression of Arc RNA in the upper blade of the rodent fascia dentate by brief spatial experience. Hippocampus, 15:579-586.

Terrazas, A., Krause, M., Gothard, K.M., McNaughton, B.L. and Barnes, C.A. (2005) Self-motion and the hippocampal spatial metric. The Journal of Neuroscience, 25:8085-8096.

Guzowski, J.F., Timlin, J.A., Roysam, B., McNaughton, B.L., Worley, P.F. and Barnes, C.A. (2005) Mapping behaviorally relevant neural circuits with immediate-early gene expression. Current Opinion in Neurobiology, 15:599-606.

Burke, S.N., and Barnes, C.A. (2006) Neural plasticity in the ageing brain. Nature Reviews Neuroscience, 7:30-40.

Guzowski, J.F., Miyashita, T., Chawla, M.K., Sanderson, J., Maes, L.I., Houston, F.P., Lipa, P., McNaughton, B.L., Worley, P.F., and Barnes, C.A. (2006) Recent behavioral history modifies coupling between cell activity and Arc gene transcription in hippocampal CA1 neurons. Proceeding of the National Academy of Sciences, USA, 103:1077-1082.

Alexander, G.E., Chen, K., Santerre-Lemmon, L.E., Aschenbrenner, M., Rapp, P.R., Buonocore, M.H., and Barnes, C.A. (2005) Age-related regional network pattern of MRI gray matter in the rhesus macaque. Program No. 317.3. 2005 Abstract Viewer/Itinerary Planner. Washington, DC: Society for Neuroscience, Online.

Ramirez-Amaya, V., Letts, P.A., Gage, F.H., Worley, P.F., and Barnes, C.A. (2005) Newborn granule cells show behaviorally induced Arc expression: Evidence for integration into hippocampal networks. Program No. 317.4. 2005 Abstract Viewer/Itinerary Planner. Washington, DC: Society for Neuroscience, Online.

Vazdarjanova, A., Rosi, S., Insel, N., Ramirez-Amaya, V., Olson, K., Guzowski, J.F., Worley, P.F., and Barnes, C.A. (2005) Differential Arc expression in the lateral versus basal amygdala nuclei following electroconvulsive seizure but not spatial exploration. Program No. 317.5. 2005 Abstract Viewer/Itinerary Planner. Washington, DC: Society for Neuroscience, Online.

Insel, N., Vazdarjanova, A., Ramirez-Amaya, V., Burke, S.N., Rosi, S., Chawla, M.K., McNaughton, B.L., and Barnes, C.A. (2005) Arc is expressed in both direct and indirect striatal projection neurons across different behaviors. Program No. 317.6. 2005 Abstract Viewer/Itinerary Planner. Washington, DC: Society for Neuroscience, Online.

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Penner, M.R., Milliken, H.L., Chawla, M.K., Nematollahi, S., Worley, P.F., and Barnes, C.A. (2005) Arc gene expression in the entorhinal cortex and CA3 field of aged rats versus adult rats following environmental exploration. Program No. 317.10. 2005 Abstract Viewer/Itinerary Planner. Washington, DC: Society for Neuroscience, Online.

Rosi, S., Vazdarjanova, A., Ramirez-Amaya, V., Marchalant, Y., Worley, P.F., Barnes, C.A., and Wenk, G.L. (2005) The consequences of neuroinflammation upon hippocampal immediate-early gene expression can be reversed by the NMDA receptor antagonist memantine. Program No. 317.11. 2005 Abstract Viewer/Itinerary Planner. Washington, DC: Society for Neuroscience, Online.

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Maurer, A.P., Cowen, S.L., Burke, S.N., Meltzer, J., Dees, J.A., McNaughton, B.L., and Barnes, C.A. (2005) Lack of hysteresis of place fields during radial maze rotations. Program No. 317.13. 2005 Abstract Viewer/Itinerary Planner. Washington, DC: Society for Neuroscience, Online.

Bruce McNaughton

Bower, M.R., Euston, D.R., McNaughton, B.L. (2005) Sequential-context-dependent hippocampal activity is not necessary to learn sequences with repeated elements, The Journal of Neuroscience, 25:1313-1323.

Burke, S.N., Chawla, M.K., Penner, M.R., Crowell, B.E., Worley, P.F., Barnes, C.A., and McNaughton, B.L. (2005) Differential encoding of behavior and spatial context in deep and superficial layers of the neocortex. Neuron, 45:667-674.

Chawla, M.K., Guzowski, J.F., Ramirez-Amaya, V., Lipa, P., Hoffman, K.L., Marriott, L.K., Worley, P.F., McNaughton, B.L. and Barnes, C.A. (2005) Sparse, environmentally selective expression of Arc RNA in the upper blade of the rodent fascia dentate by brief spatial experience. Hippocampus, 15:579-586.

Terrazas, A., Krause, M., Gothard, K.M., McNaughton, B.L. and Barnes, C.A. (2005) Self-motion and the hippocampal spatial metric. The Journal of Neuroscience, 25:8085-8096.

Fuhs, M.C., VanRhoads, S.R., Casale, A.E., McNaughton, B.L. and Touretzky, D.S. (2005) Influence of path integration vs. environment orientation on place cell remapping between visually identical environments. Journal of Neurophysiology, 94:2603-2616.

Maurer, A.P., VanRhoads, S.R., Sutherland, G.R., Lipa, P. and McNaughton, B.L. (2005) Self-motion and the origin of differential scaling along the septo-temporal axis of the hippocampus. Hippocampus, 15:841-852.

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Lin, G., Olson, K., Chawla, M.K., Burke, S.N., Sutherland, V.L., McNaughton, B.L., Worley, P.F., Guzowski, J.F., Roysam, B., and Barnes, C.A. (2005) Advances in 3-D nuclear segmentation and catfish analysis. Program No. 317.7. 2005 Abstract Viewer/Itinerary Planner. Washington, DC: Society for Neuroscience, Online.

Burke, S.N., Maurer, A.P., Insel, N., Navratilova, Z., McNaughton, B.L., Wenk, G.L., and Barnes, C.A. (2005) Effects of memantine on experience-dependent place-field expansion in aged rats. Program No. 317.12. 2005 Abstract Viewer/Itinerary Planner. Washington, DC: Society for Neuroscience, Online.

Maurer, A.P., Cowen, S.L., Burke, S.N., Meltzer, J., Dees, J.A., McNaughton, B.L., and Barnes, C.A. (2005) Lack of hysteresis of place fields during radial maze rotations. Program No. 317.13. 2005 Abstract Viewer/Itinerary Planner. Washington, DC: Society for Neuroscience, Online.

Cowen, S.L., Ruiz Luna, M.L, Martin, J.P., Burke, S.N., and McNaughton, B.L. (2005) Delay activity in the medial prefrontal cortex of the rat discriminates between stimulus sequences that predict future reward. Program No. 317.14. 2005 Abstract Viewer/Itinerary Planner. Washington, DC: Society for Neuroscience, Online.

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VanRhoads, S.R., Maurer, A.P., Sutherland, G.R., Lipa, P., and McNaughton, B.L. (2005) Self-motion and the origin of the hippocampal spatial metric. Program No. 317.16. 2005 Abstract Viewer/Itinerary Planner. Washington, DC: Society for Neuroscience, Online.

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Ole Paulsen

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Menno Witter

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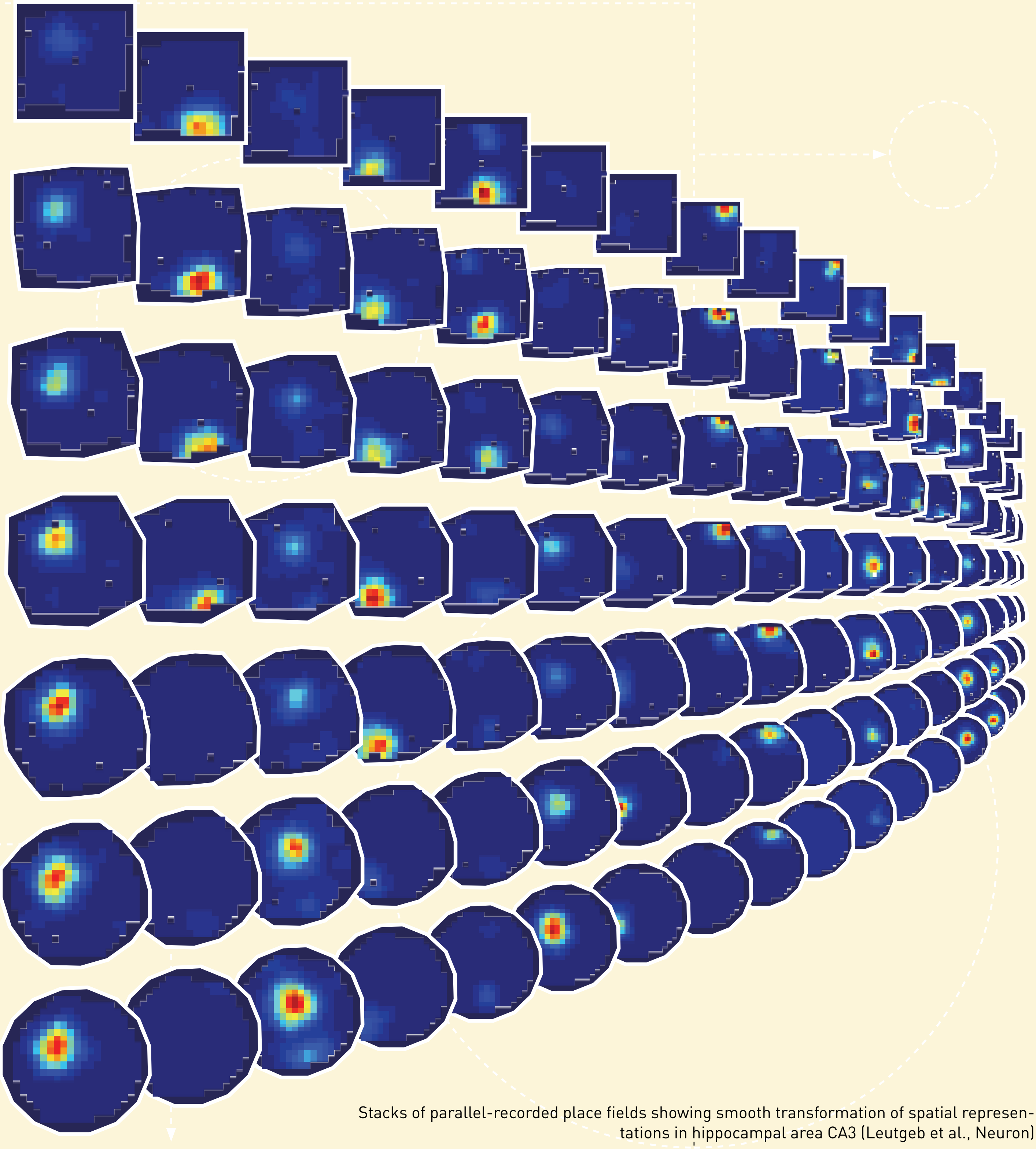

Stacks of parallel-recorded place fields showing smooth transformation of spatial representations in hippocampal area CA3 (Leutgeb et al., Neuron)

Photo: Haagen Waade

Annual Report for CBM 2005

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