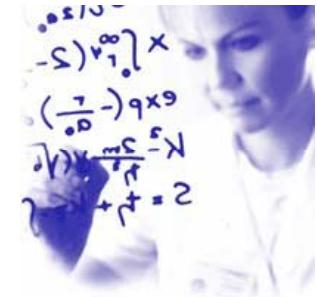


Fysikkforeningen, Univ i Oslo, 14.04.10



Fysikk i hjernen: Kan vi regne ut hvordan vi tenker?

Gaute T. Einevoll

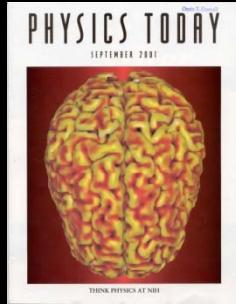
Institutt for matematiske realfag og teknologi
Universitetet for miljø- og biovitenskap, Ås
Gaute.Einevoll@umb.no

HARALD



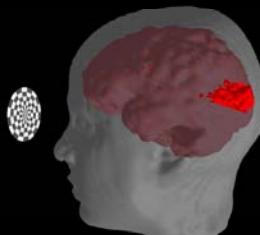
Avbildning av hjerneaktivitet på systemnivå

- *Hjernestruktur:*

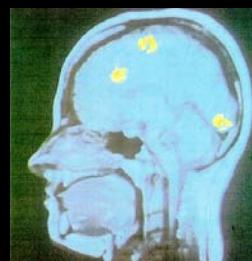


MRI → "vev"

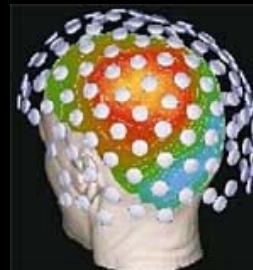
- *Hjerneaktivitet:*



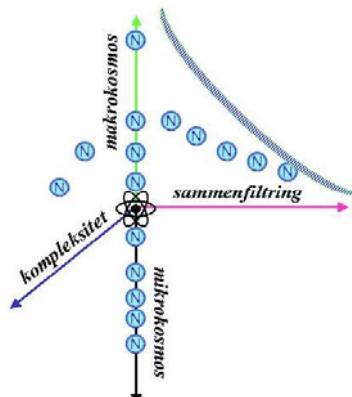
fMRI → "blod"



PET → "mat"



MEG/
EEG → "elektrisitet"



KOMPLEKS.

SAMMENFILT.

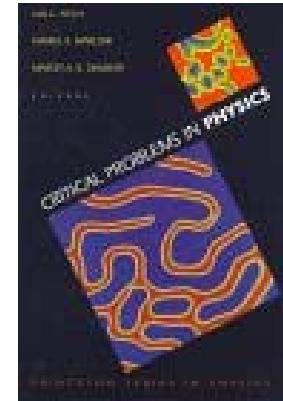
MAKRO

MIKRO

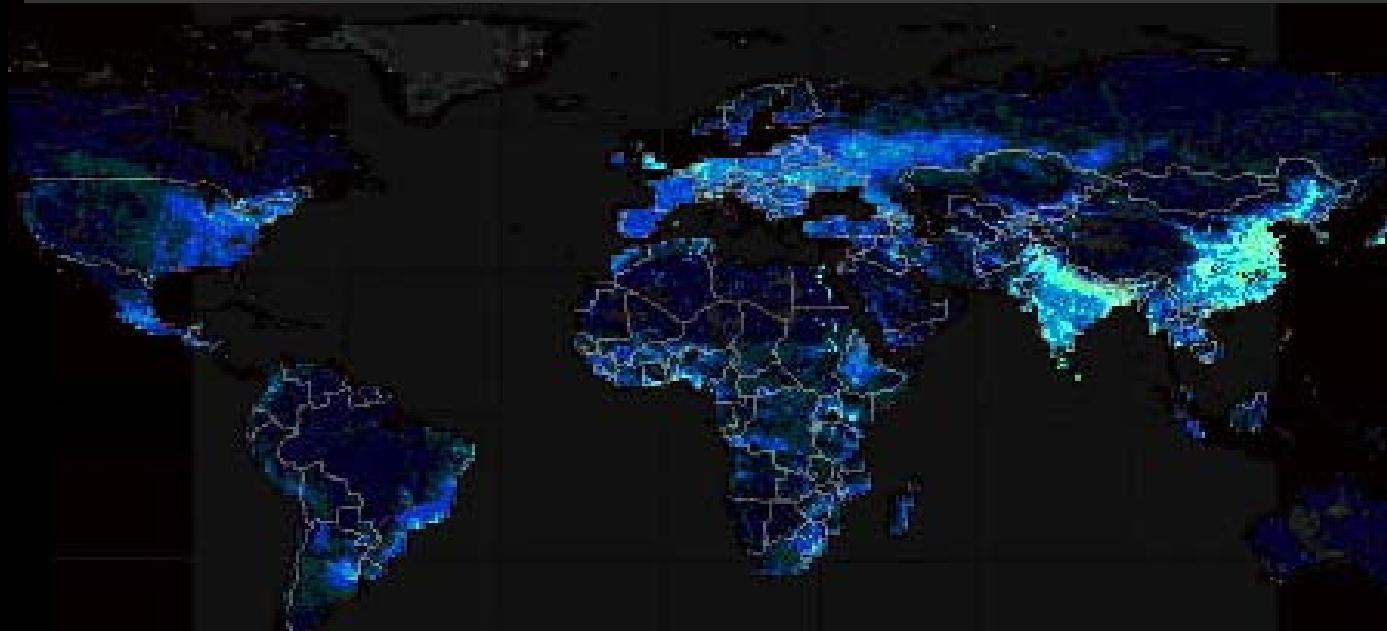
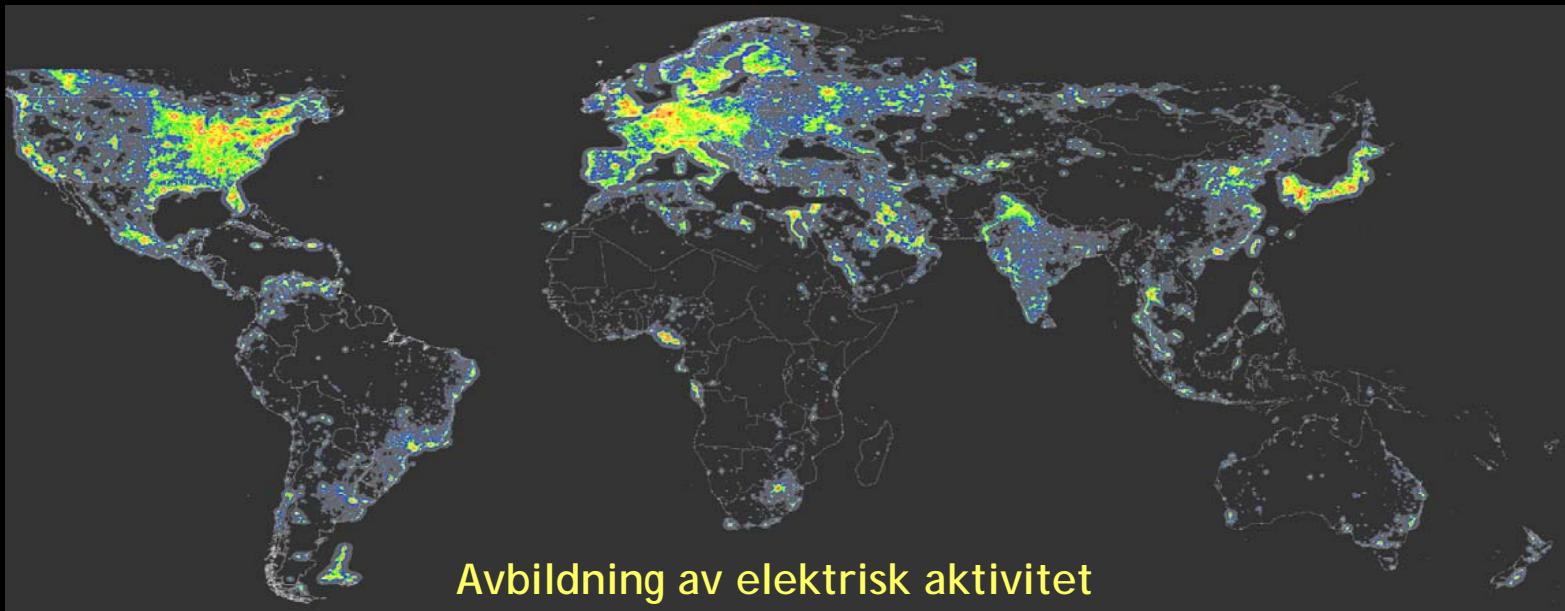
Bok: "Critical problems in physics"

INNHOLDSFORTEGNELSE

1. Introduction
2. Non-equilibrium physics
3. Dynamics, computation and neurobiology
4. Emergence and evolution of patterns
5. High-temperature superconductors
6. The on-going revolution in medical imaging
7. Cosmological challenges for the 21st century
8. Gravitation and experiment
9. Gravitational waves
10. Neutrino oscillations
11. The Tevatron
12. High energy colliders
13. Vistas in theoretical physics
14. The future of particle physics as a natural science



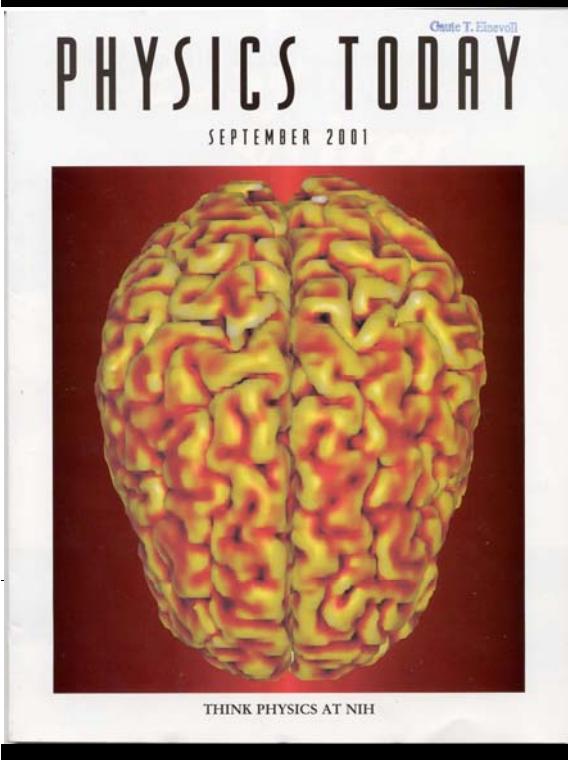
“Avbildning” av menneskehett fra verdensrommet



Avbildning av “hemodynamisk/metabolsk” aktivitet (antall mennesker)

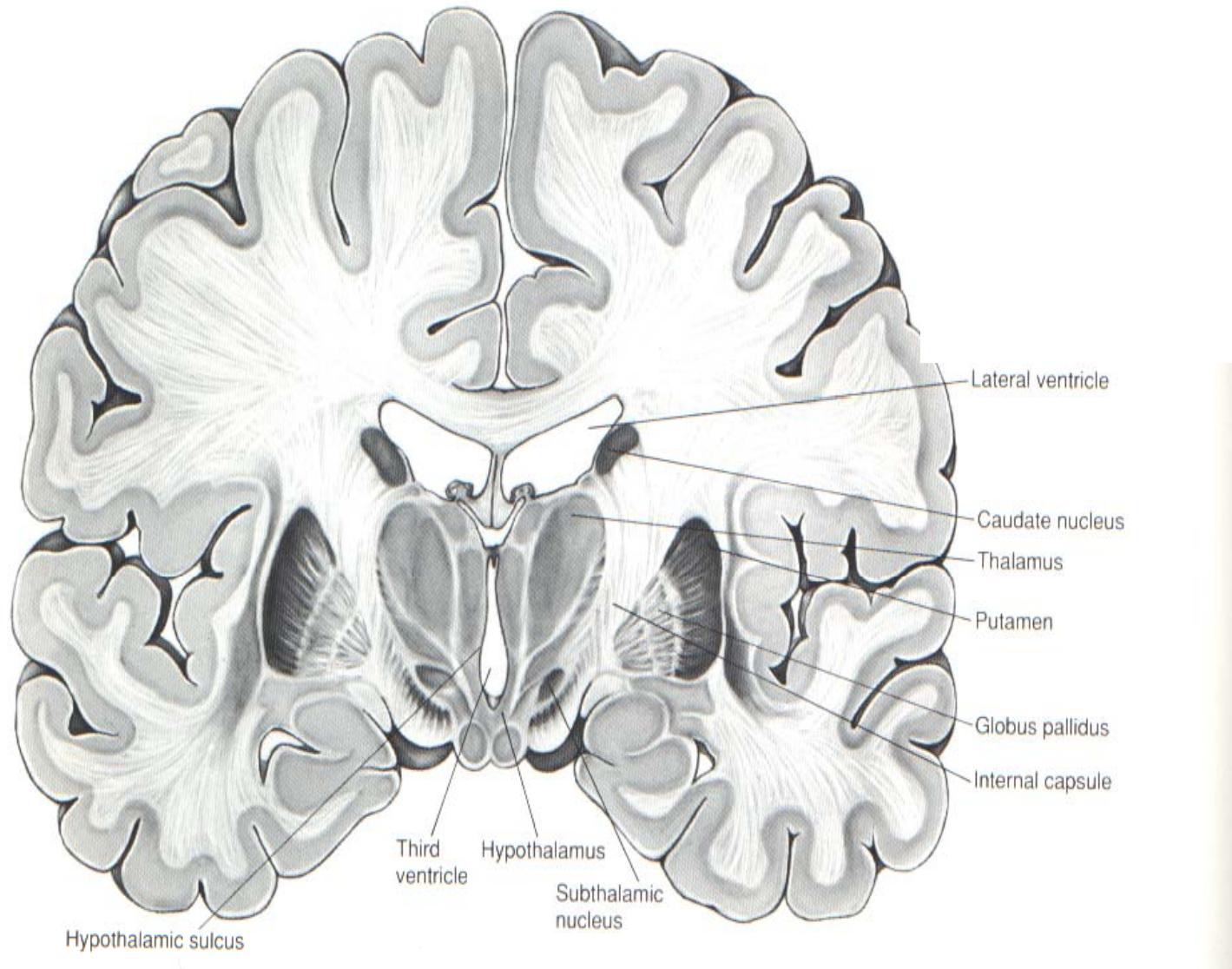
Kombinert bruk av MEG og MRI

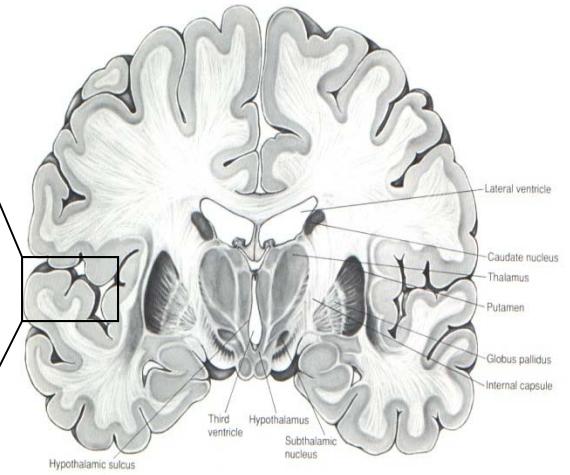
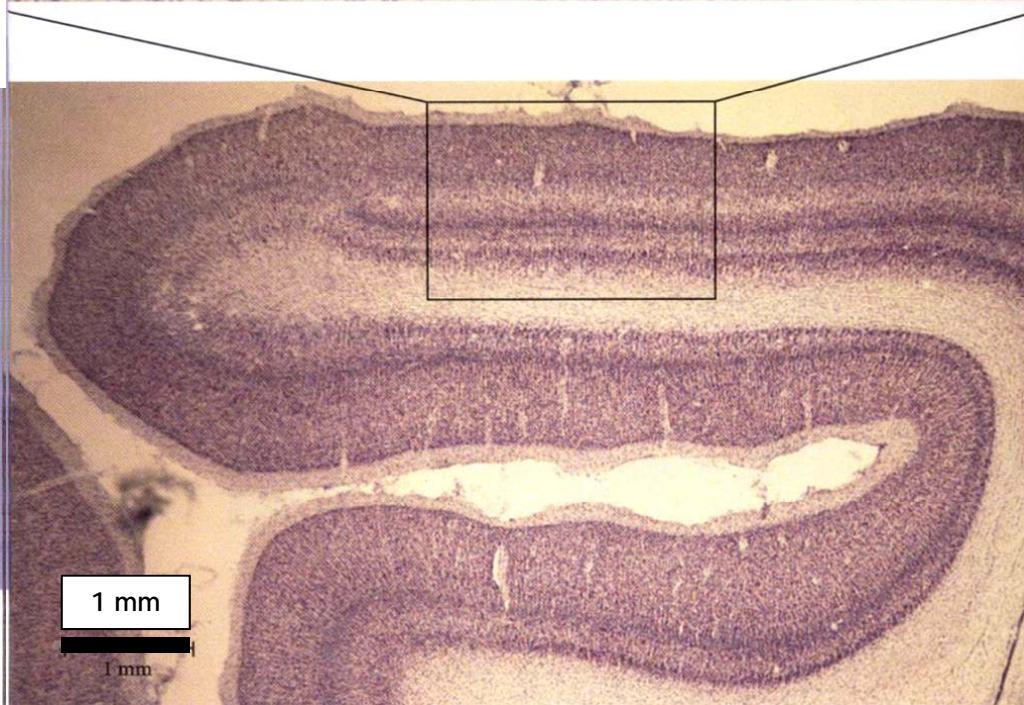
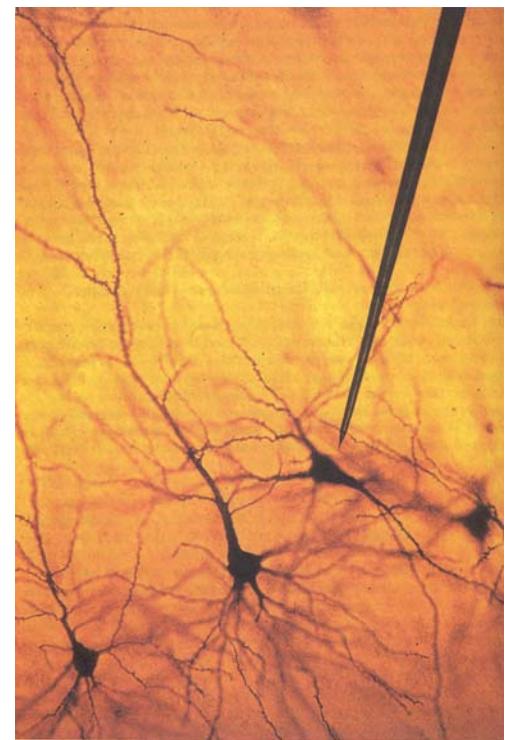
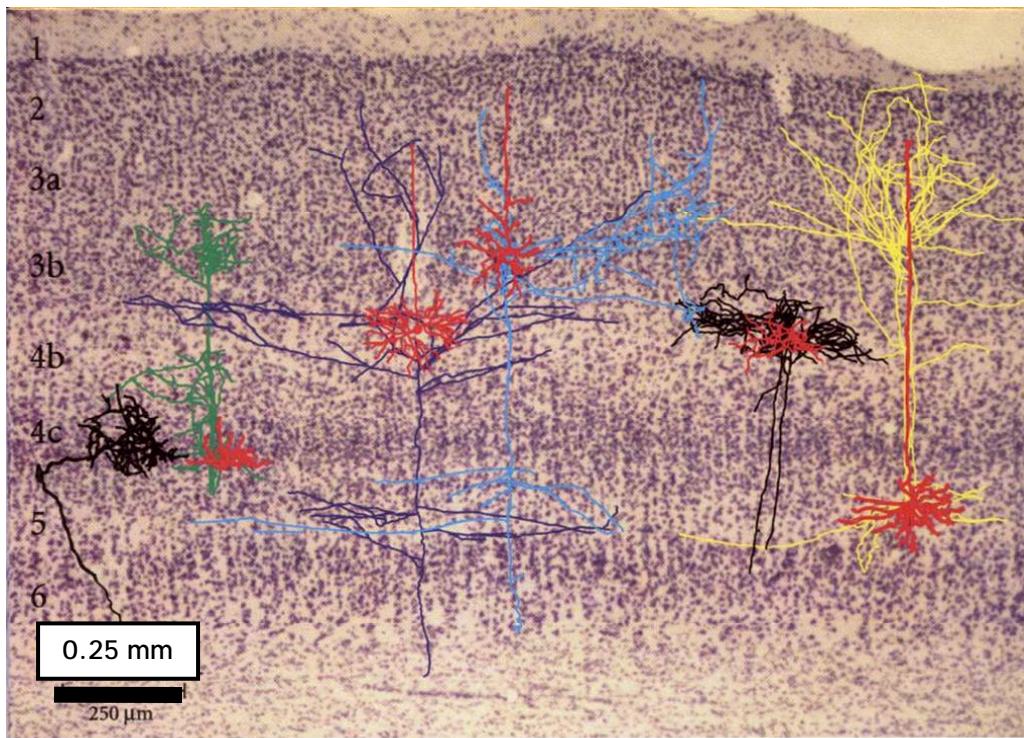
- Respons når en ser ord på en skjerm



000 ms

Analyse og animasjon av Anders Dale

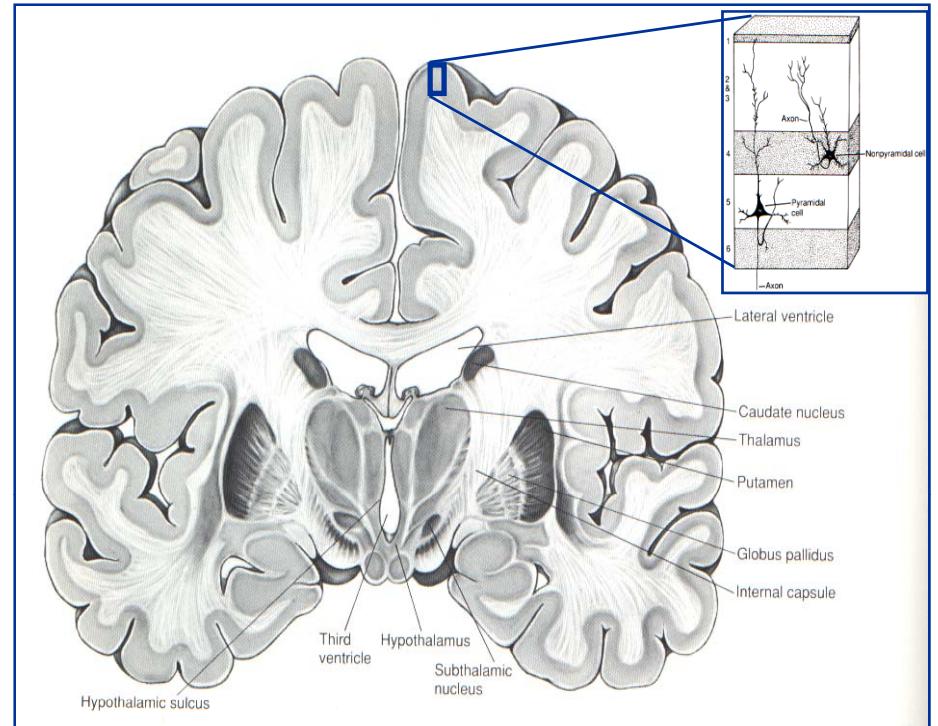




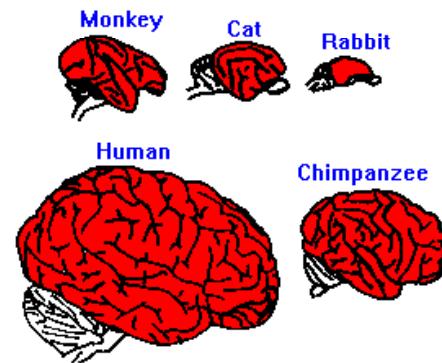
Hjernens byggesteiner

Mental aktivitet skyldes
nettverk av nerveceller

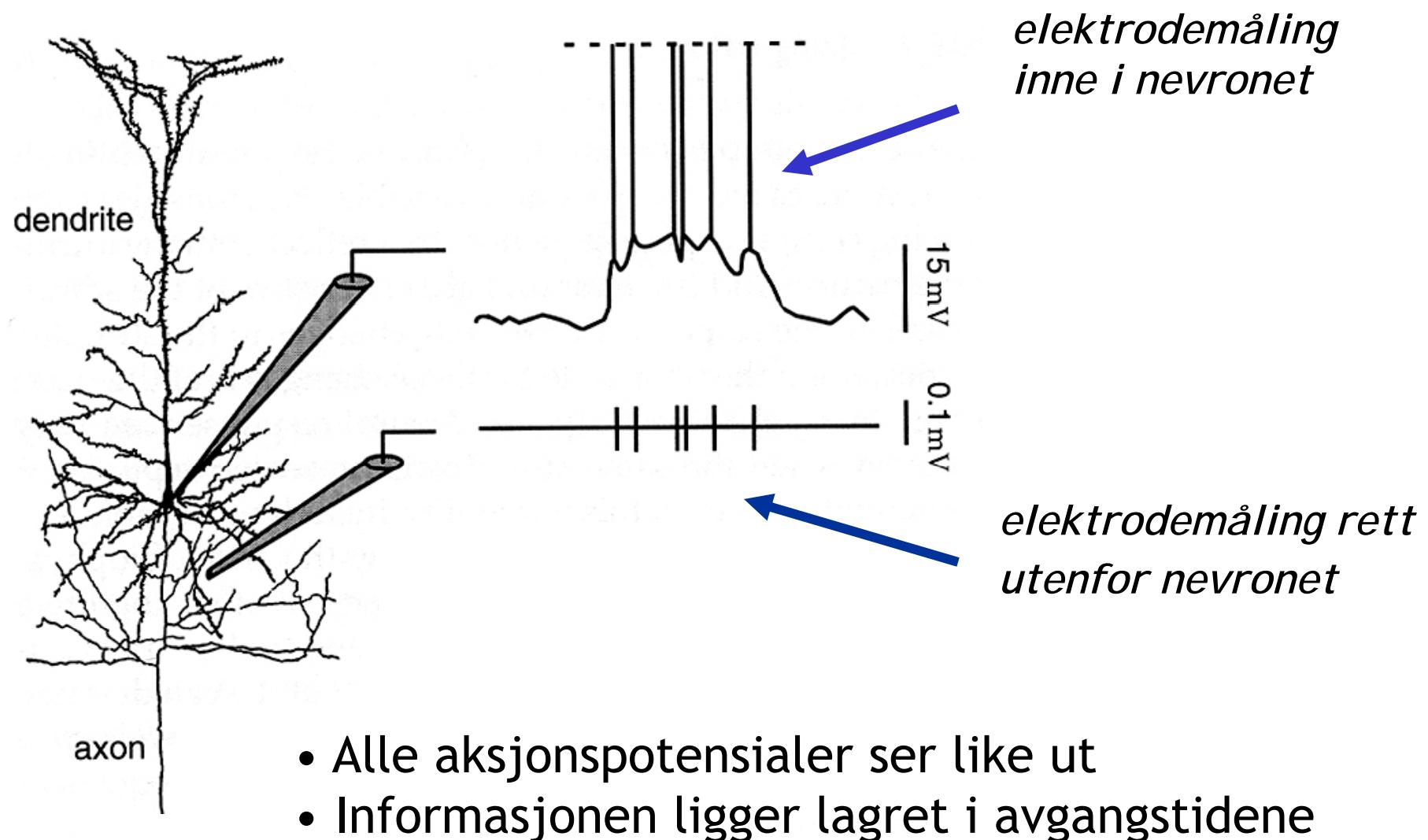
- ~ 10^{11} nerveceller (nevroner)
- ~ 10^{14} nevronkoblinger
(synapser)
- hjernebark (mennesker):
tykkelse ~ 2-4 mm
areal ~ 2000 cm^2



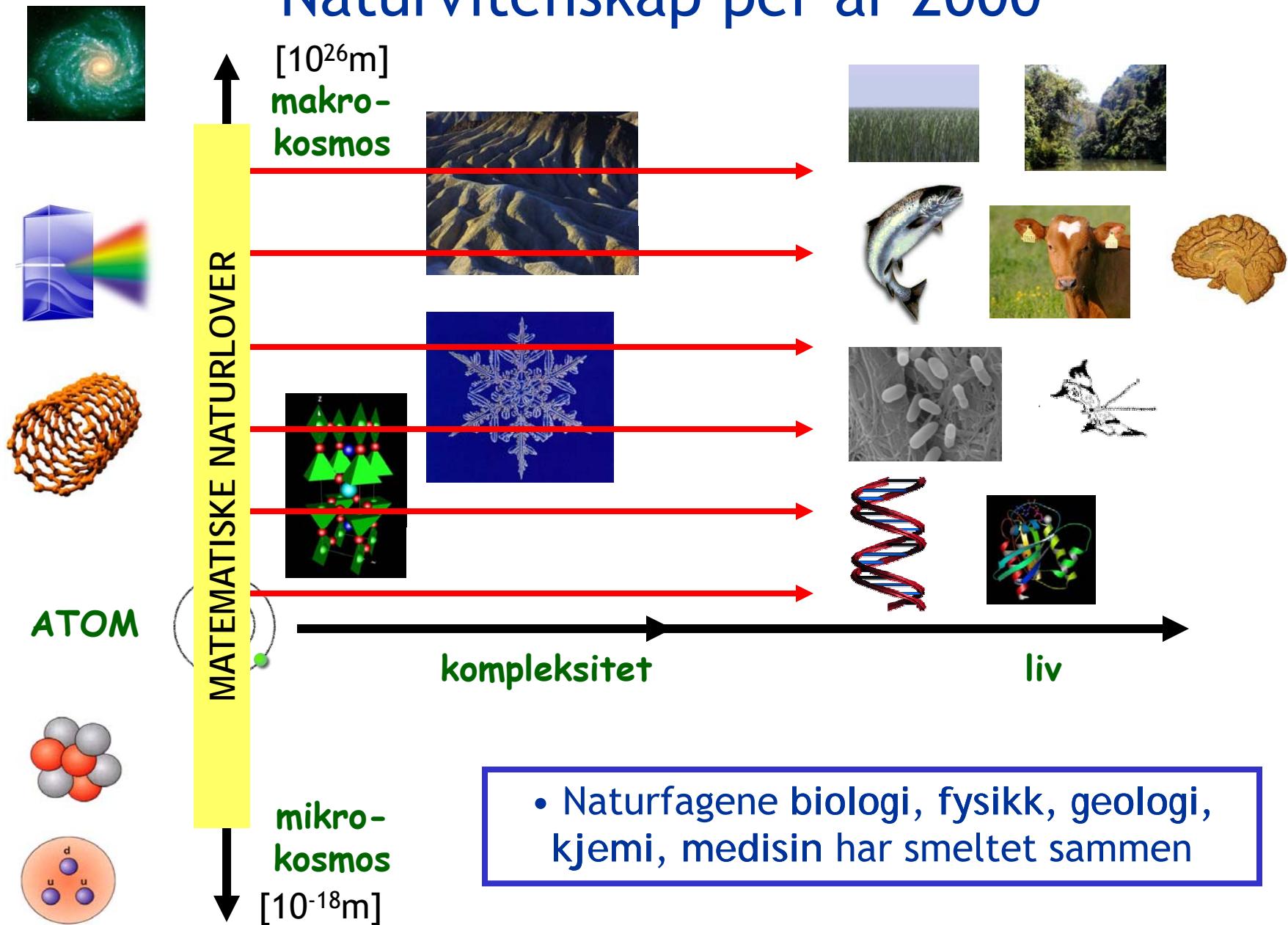
Mindre, men kvalitativ
lik, hjernebark i andre
pattedyr

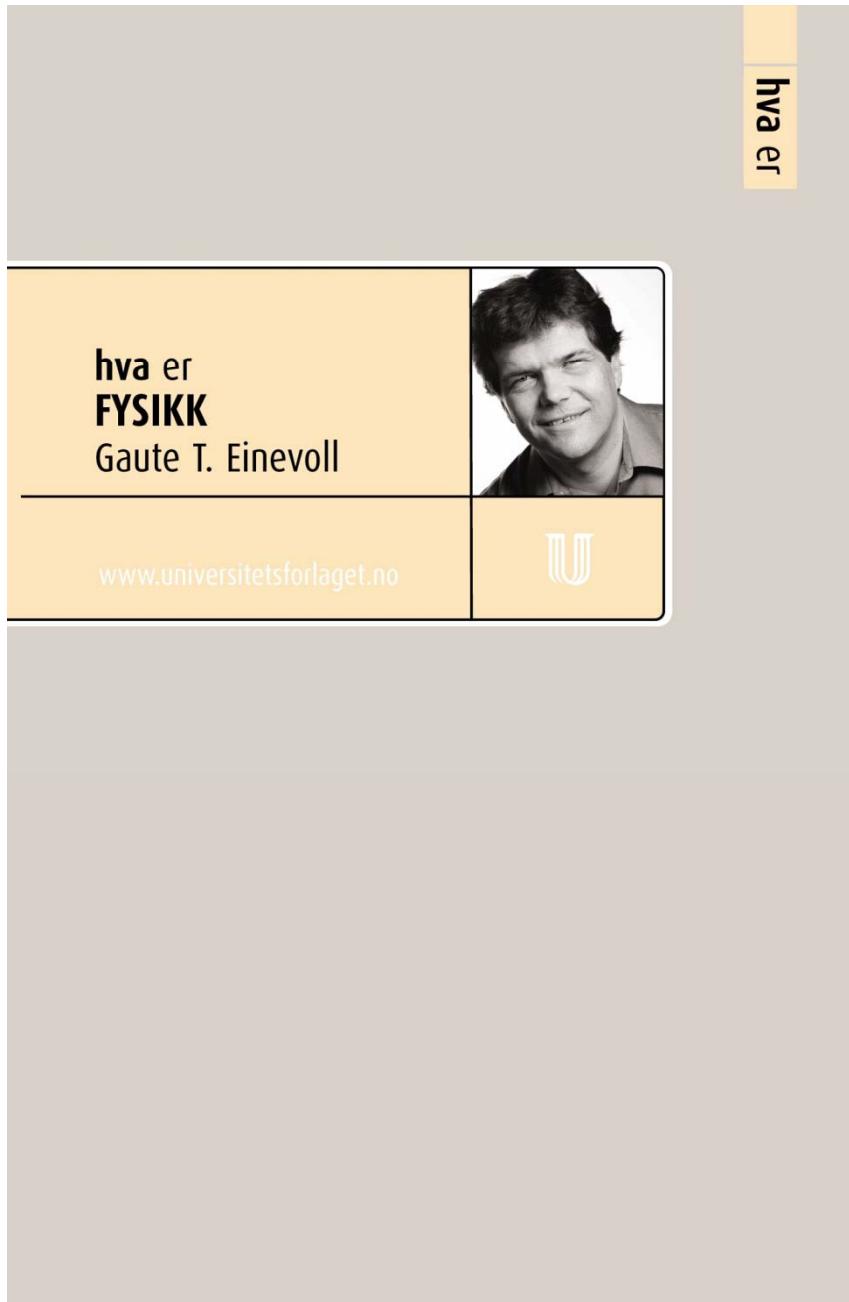


Elektrodemålinger: Aksjonspotensialer

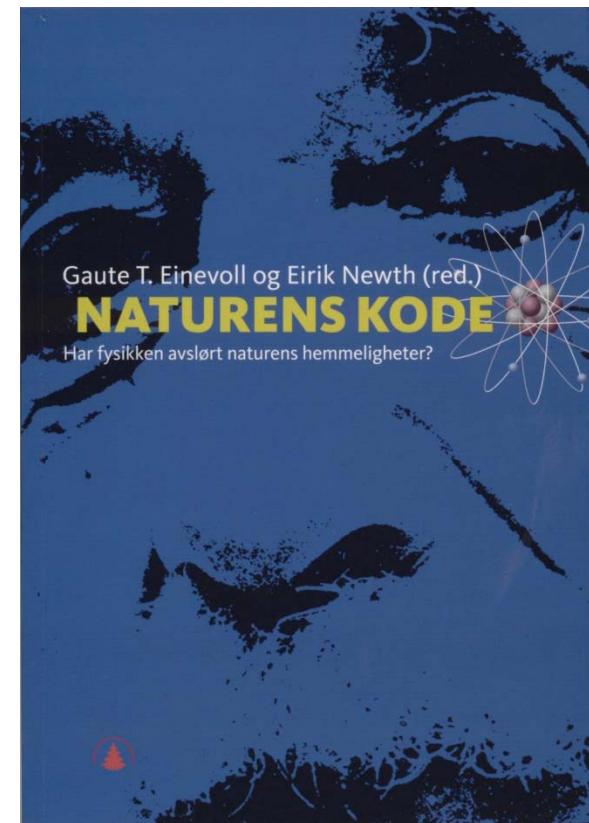


Naturvitenskap per år 2000

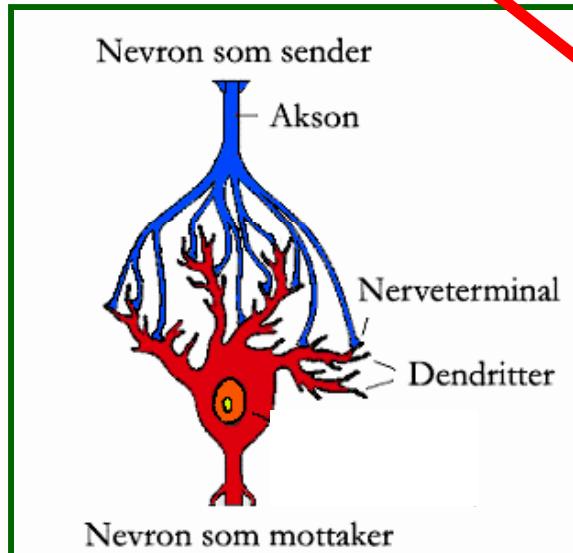
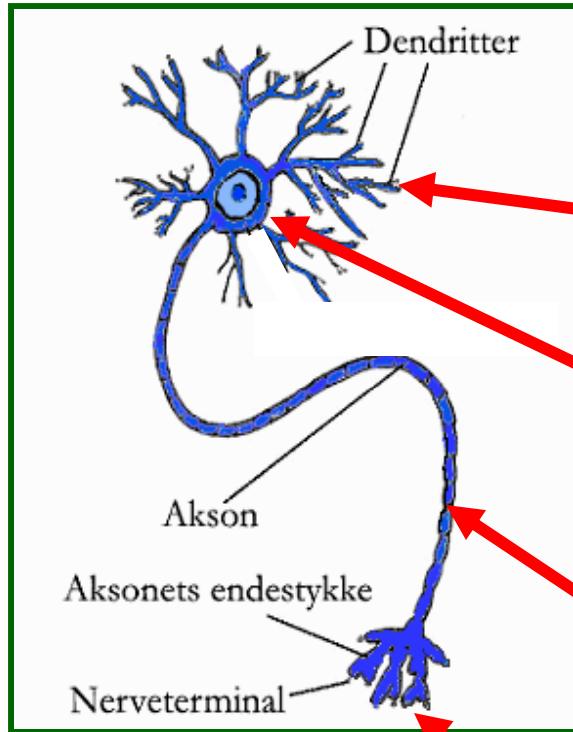




- Bok nr. 24 i
Universitetsforlagets
"hva er"-serie



- "Naturens kode",
Gyldendal Akademisk, 2005



Signalbehandling i nerveceller

DENDRITTER: Innkommende signal spres elektrisk til cellekropp (soma)

CELLEKROPP (SOMA): Fyrer et *aksjonspotensial* hvis membran- spenning passerer en terskel

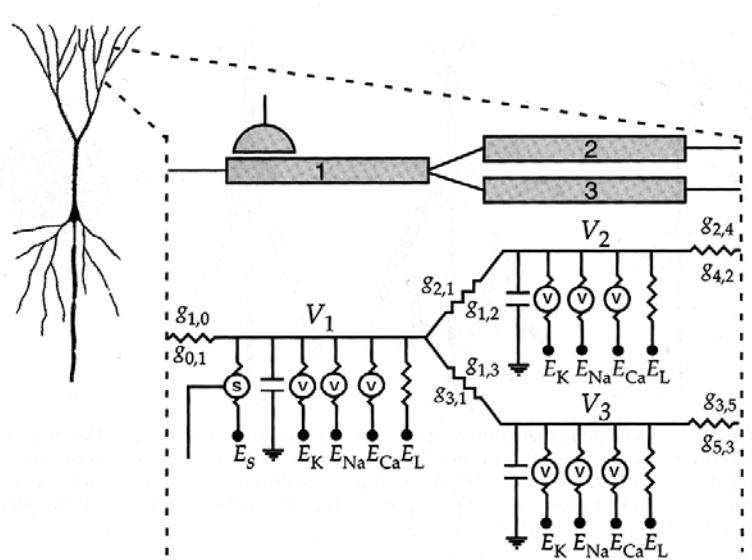
AKSON: Aksjonspotensialer propagerer uten demping til synapse (nerveterminal)

SYNAPSE: Diffusjon av signal- molekyler (over synaptisk kløft) endrer membranpotensial på mottakernevronet

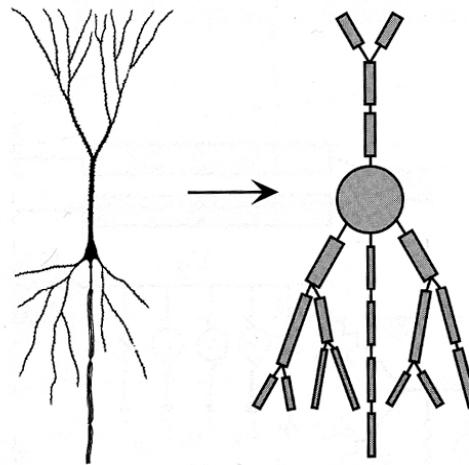
**MATEMATISKE BESKRIVELSER
FINNES FOR ALLE DELPROSESSEN**

Kompartimental modellering av nevroner

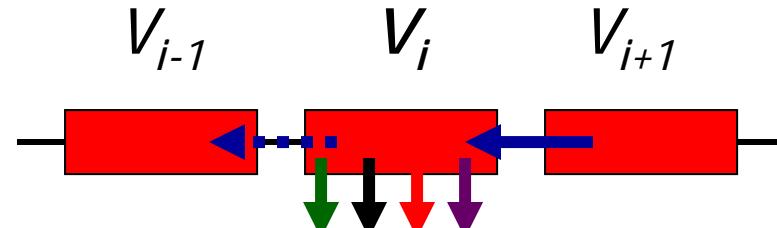
- Basert på beskrivelse av ekvivalent elektrisk krets
[Kirchhoffs lover]



- Strategi: Del nevronet i sylinderiske segmenter (spesifisert av *lengde*, *diameter*, *ionekanaltyper*, *ionekanalsettigheter*, etc.)



- Fokuserer på dendrittisk segment [uten forgrening]:

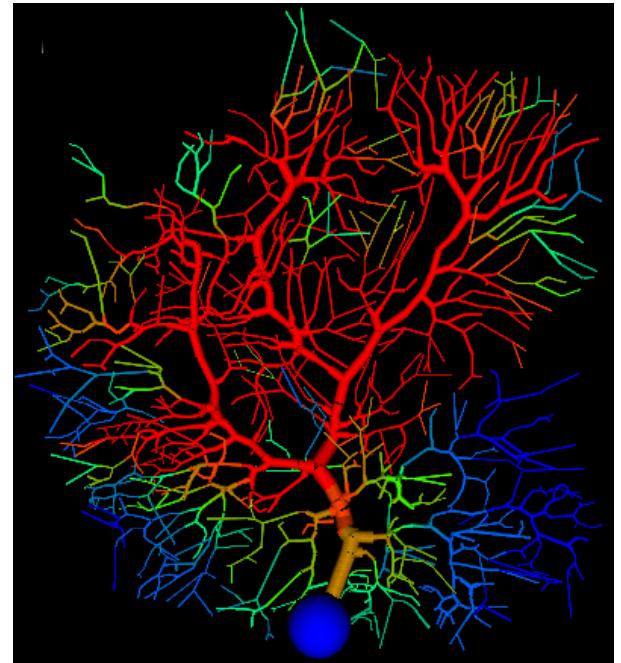


- Kirchhoffs strømlov ("strømmer summer til null"):

$$g_{i,i+1}(V_{i+1} - V_i) - g_{i-1,i}(V_i - V_{i-1}) = c_i \frac{dV_i}{dt} + g_i^m(V_i - V_r) - I_i^e + \sum_j I_i^j + \sum_s I_i^s$$

STRØMMER TIL NABOSEGMENTER
 PASSIVE MEMBRAN-STRØMMER
 INJISERT ELEKTRODE-STRØM
 AKTIVE MEMBRAN-STRØMMER (K^+ , Na^+ , ...)
 SYNAPTISKE STRØMMER

- Hvis en spesifiserer *alle* parametre for *alle* strømbidrag i *alle* segmenter [stort problem!], er den matematiske løsningen i prinsipp grei

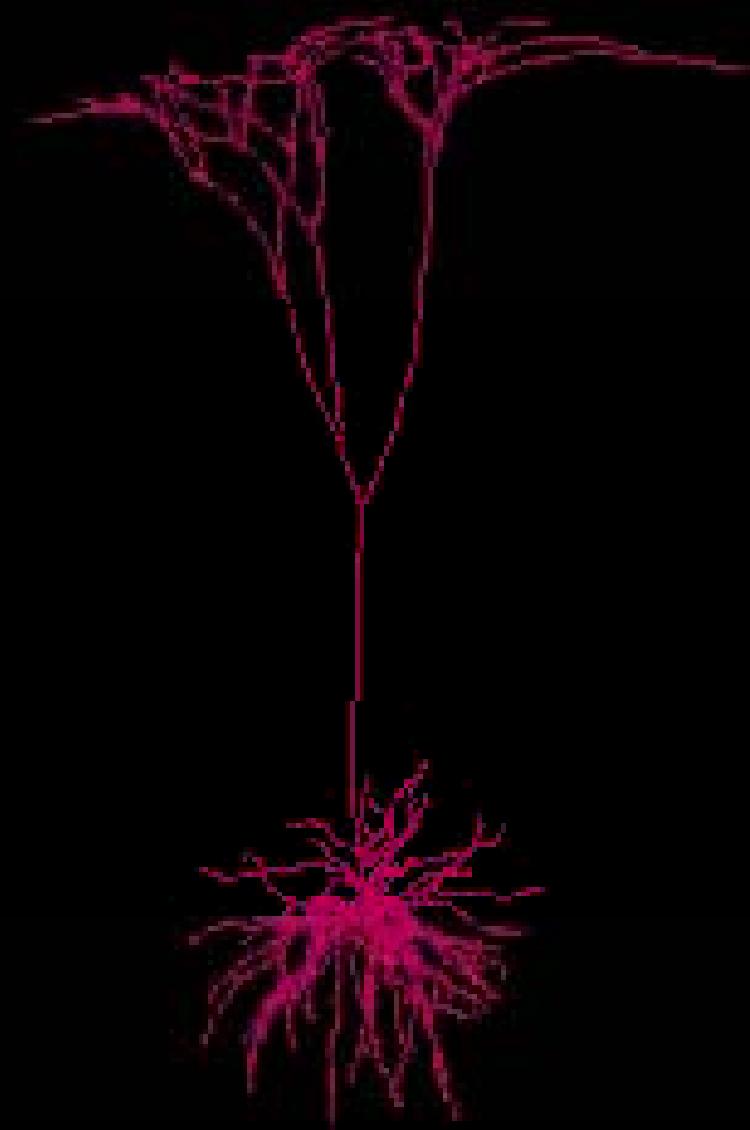


- Skreddersydde matematiske simulatorer er tilgjengelig (gratis!):

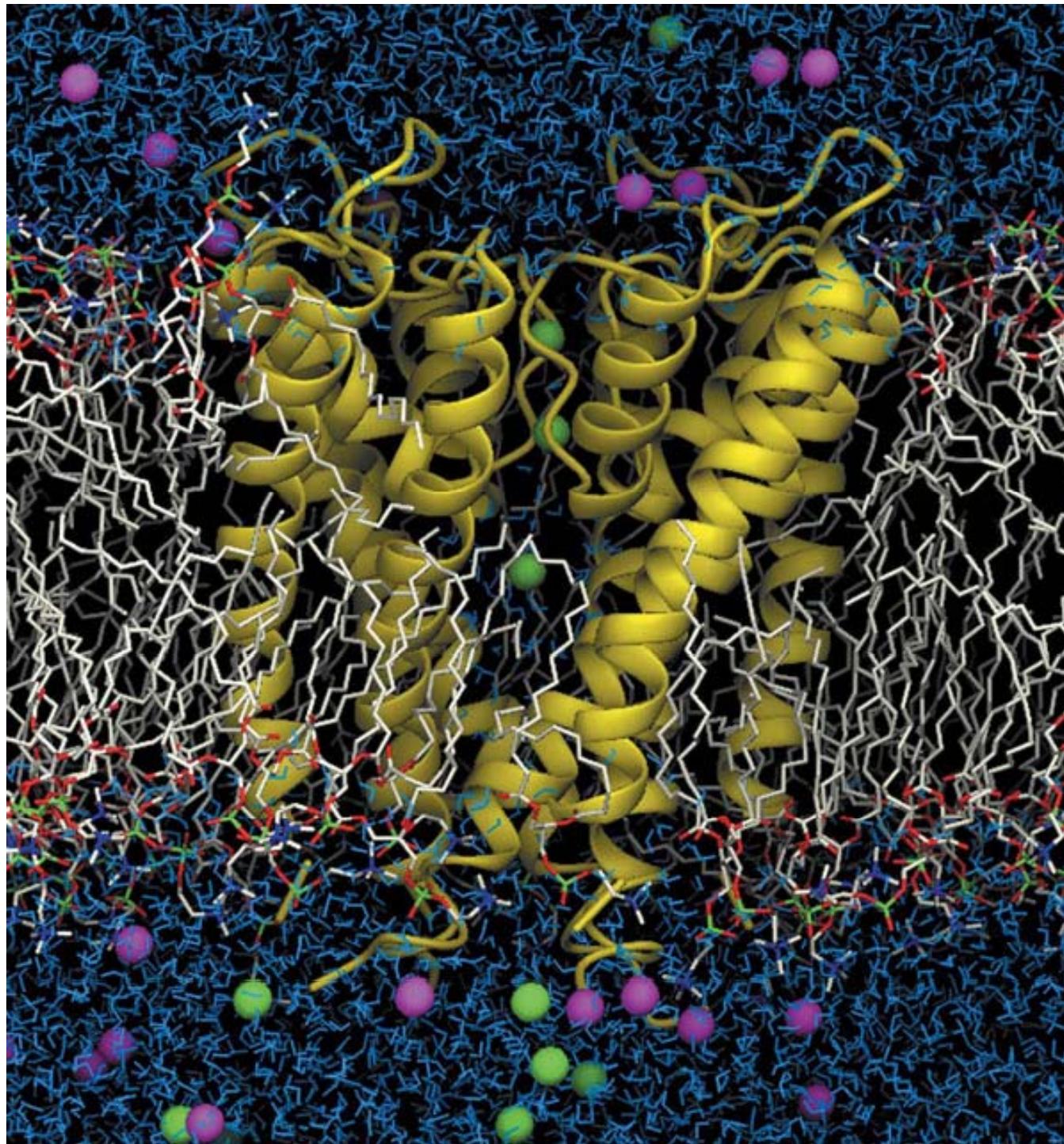
Eks:

- NEURON [<http://neuron.duke.edu/>]
- GENESIS [<http://www.genesis-sim.org/GENESIS/>]

Pyramidal-
celle i visuell
hjernebark hos
katt

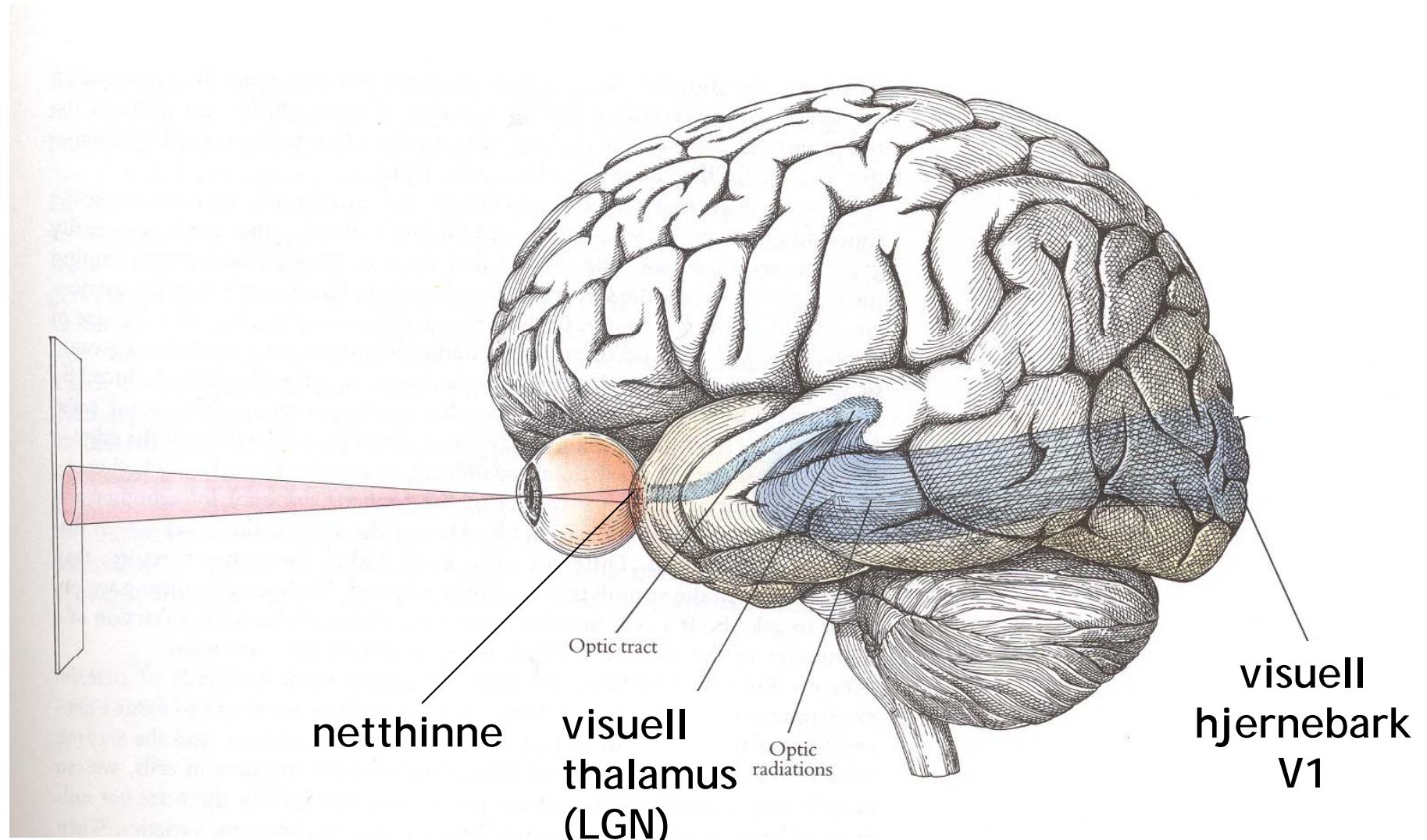


Fra hjemmeside til Alain Destexhe
[http://cns.iaf.cnrs-gif.fr/alain_movies.html]



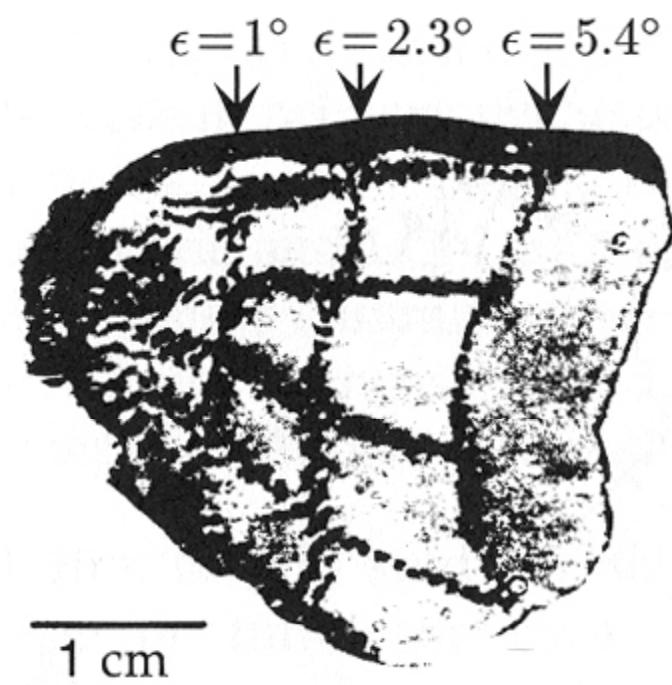
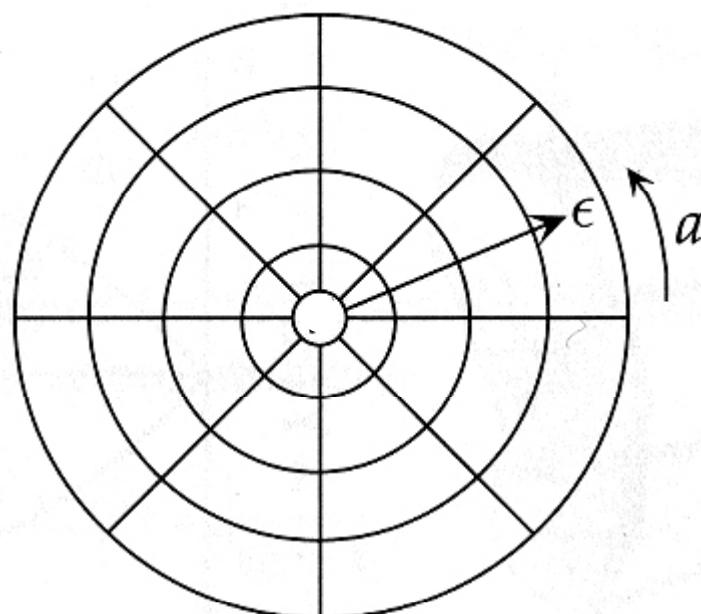
*Mekanistisk modell
av K⁺ ionekanal
inkorporert i
cellemembran
(Berneche & Roux,
Nature, 2001)*

Første del av synsbanen

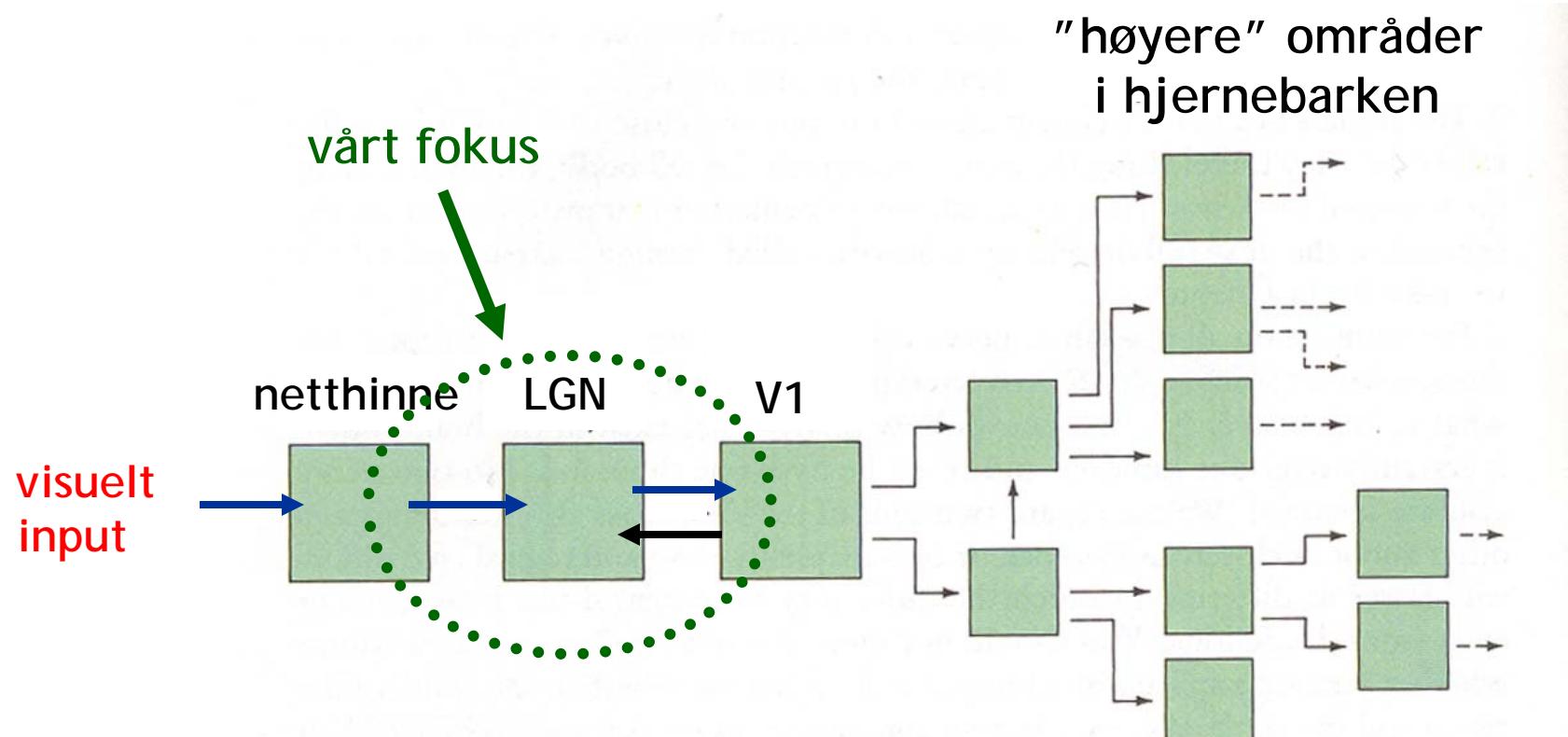
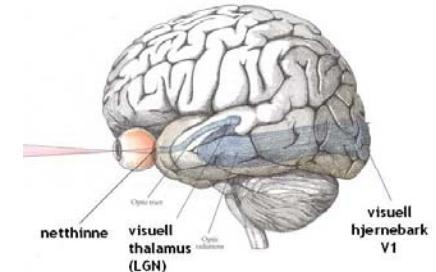


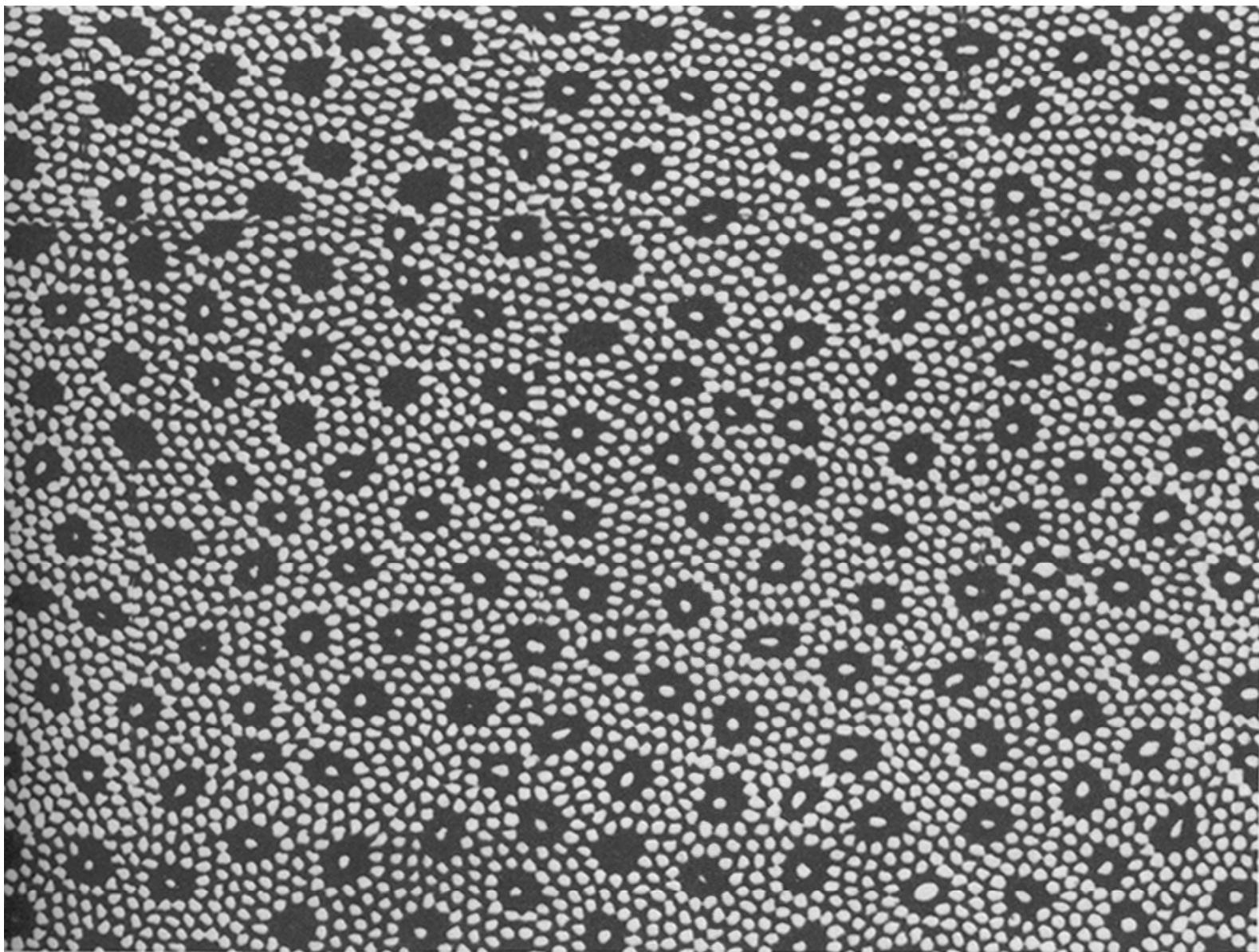


Hjernens "kamera"



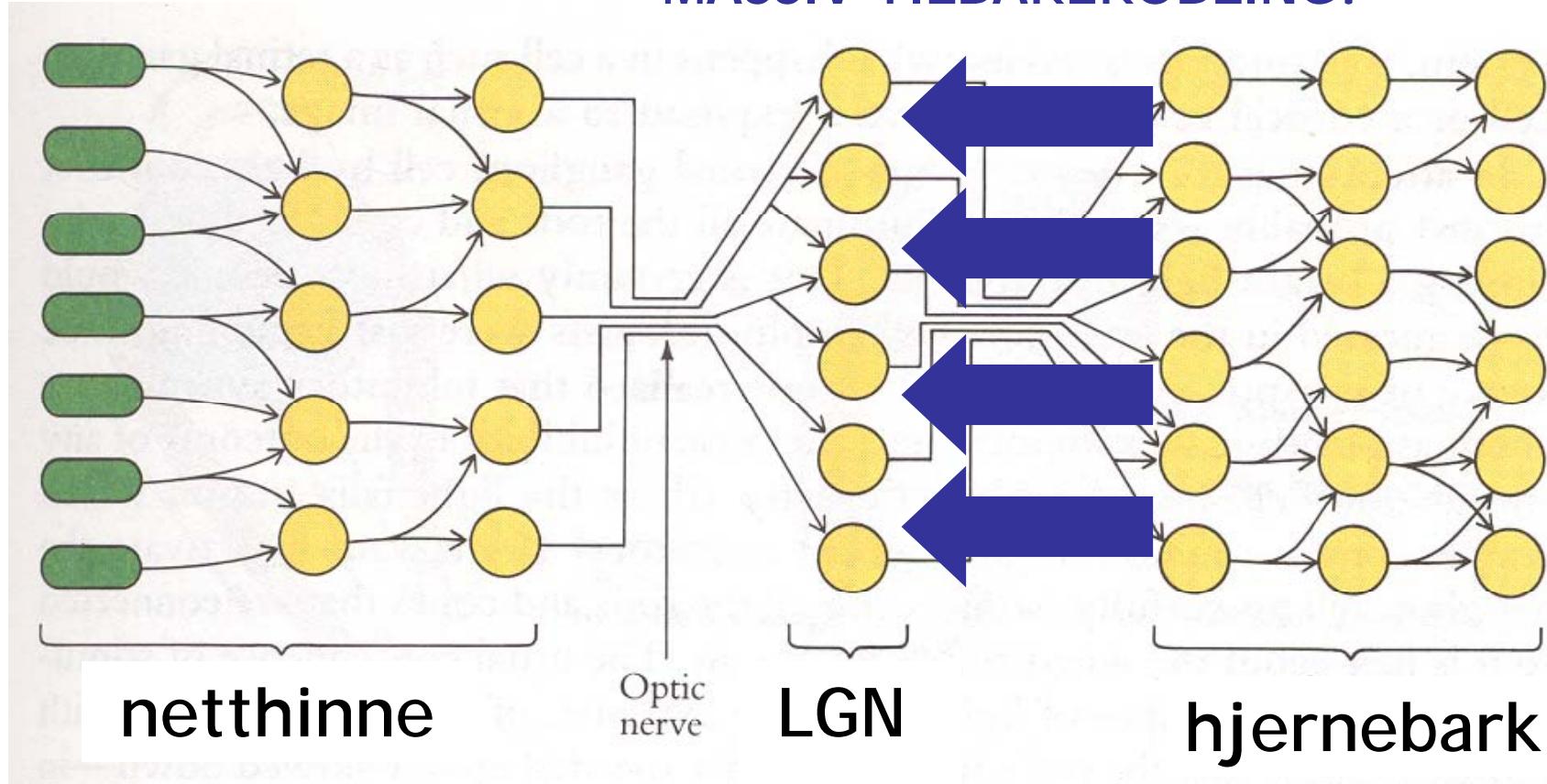
Matematisk modellering på UMB av første del av synsbanen



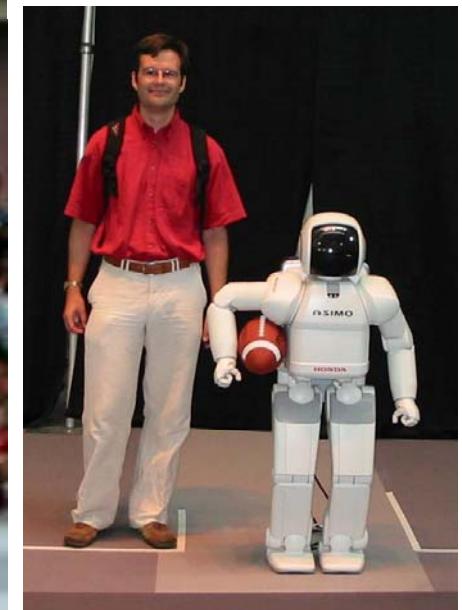
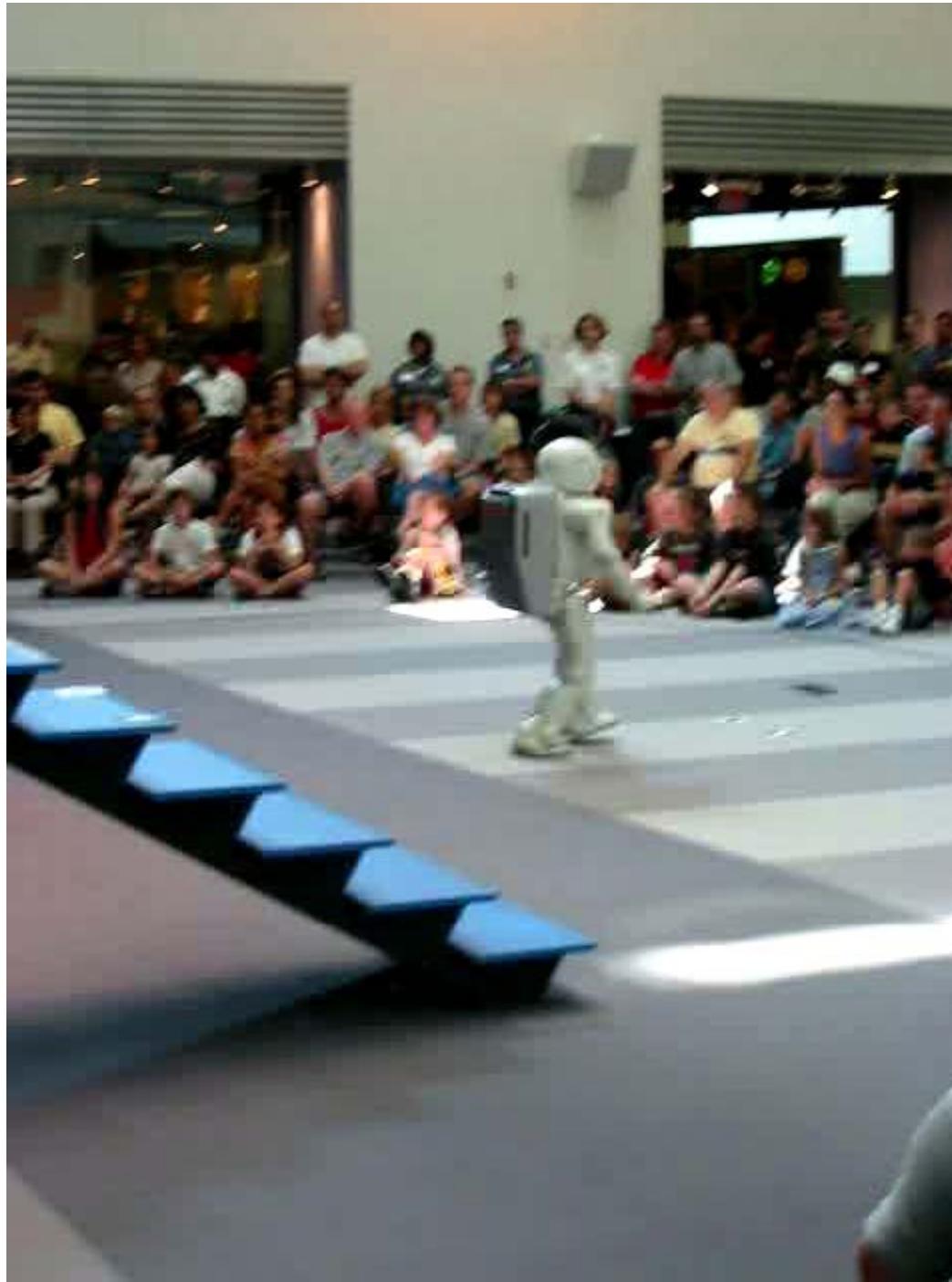


Skjematisk illustrasjon av nettverk

MASSIV TILBAKEKOBLING!

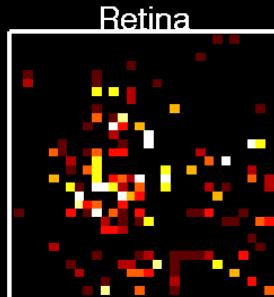
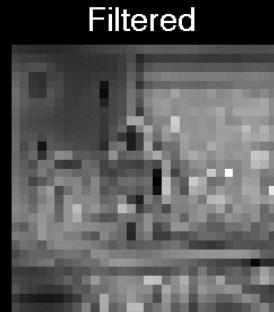
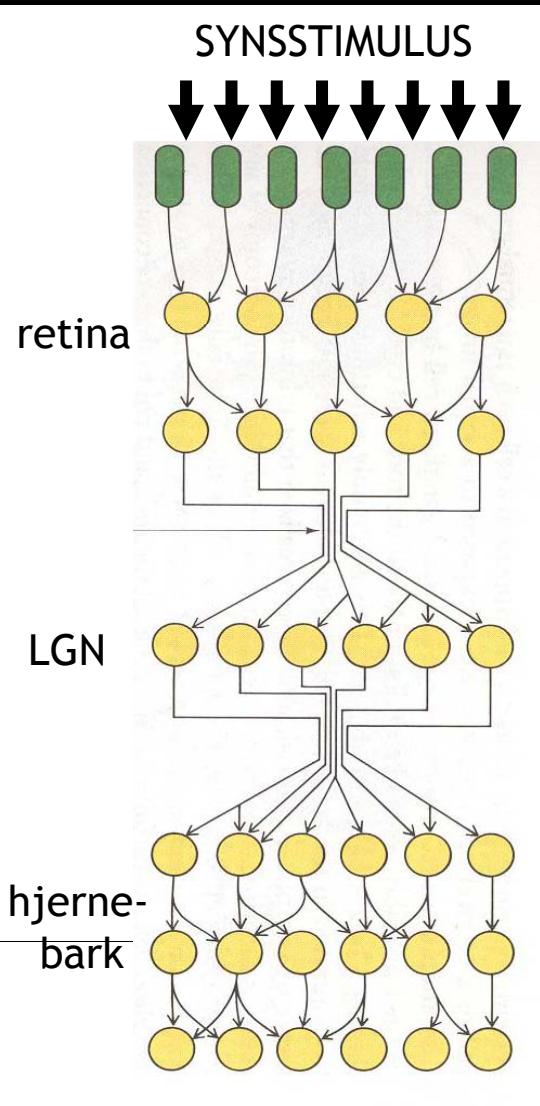
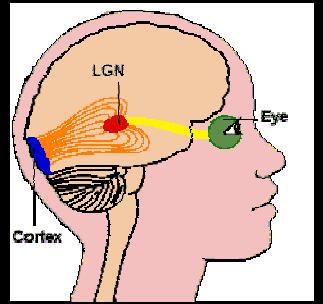


HONDA



Hans E. Plessner
& Asimo

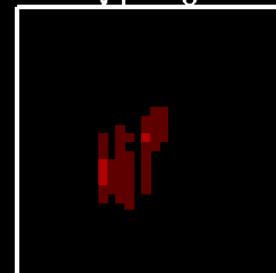
Eksempel: Simulering av biologisk signalbehandling i det tidlige synssystem ved bruk av NEST



0

Firing rate [Hz]

V1 --- 0°



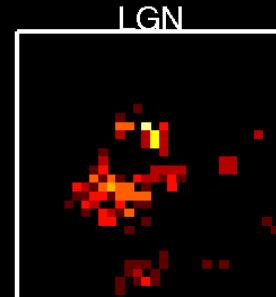
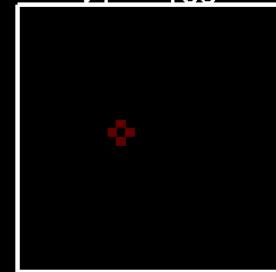
V1 --- 90°



V1 --- 45°

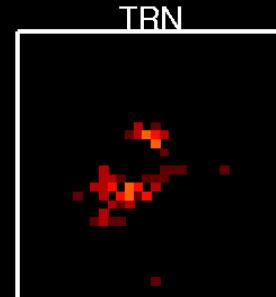


V1 --- 135°



LGN

Time: 40 ms



TRN

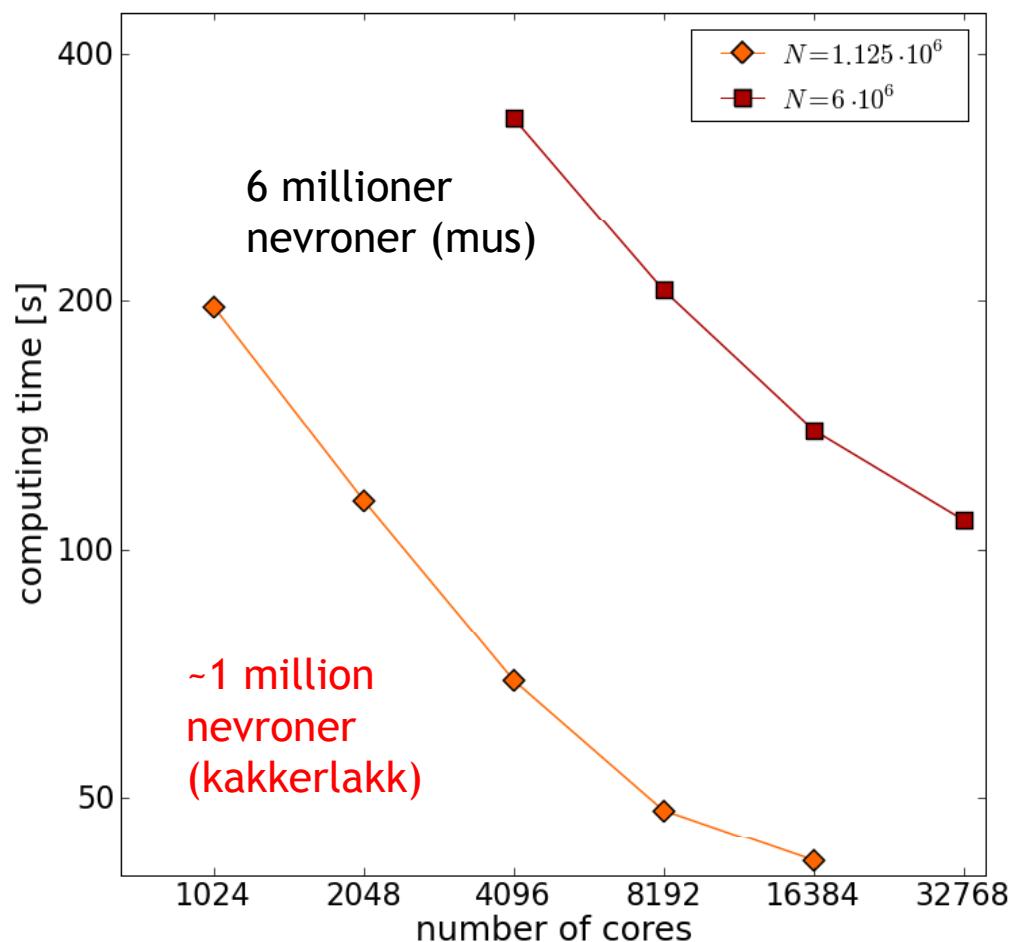
Superdatamaskiner

- Nettverksberegninger krever stor regnekraft,
eVitenskap
- I Norge: Spleiseland (NOTUR)
 - Titan - Oslo
 - Stallo - Tromsø
 - Njord - Trondheim
 - Hexagon - Bergen

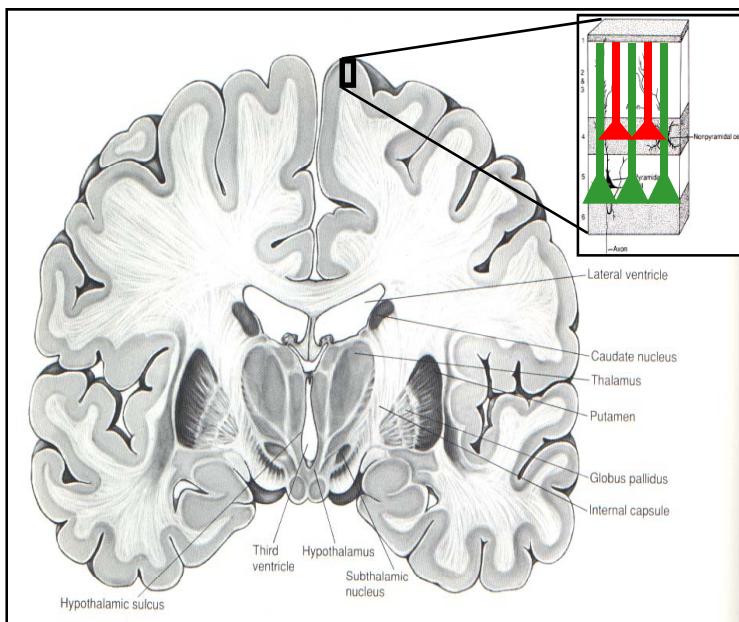
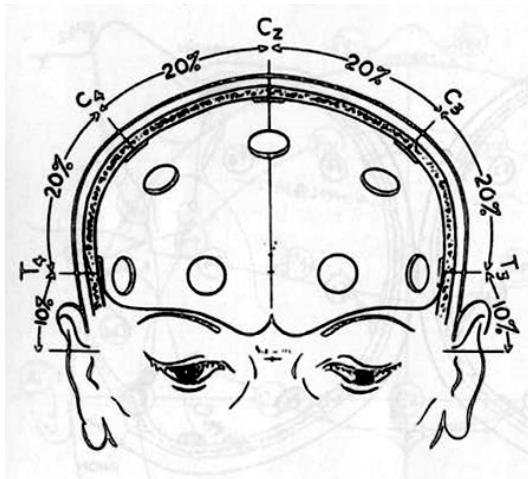


NEST development

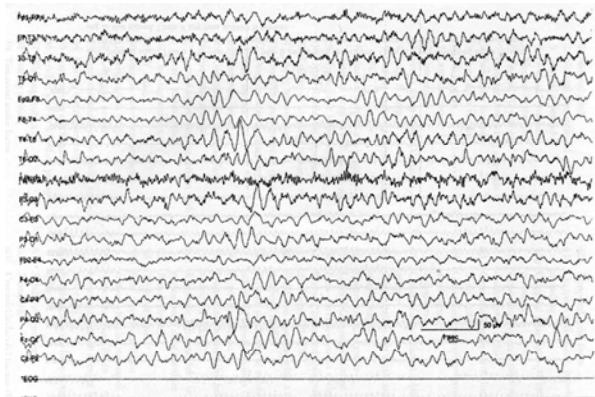
- Parallelisering av NEST (JUGENE, BlueGene/P):



EEG



frisk baby
på 7
måneder

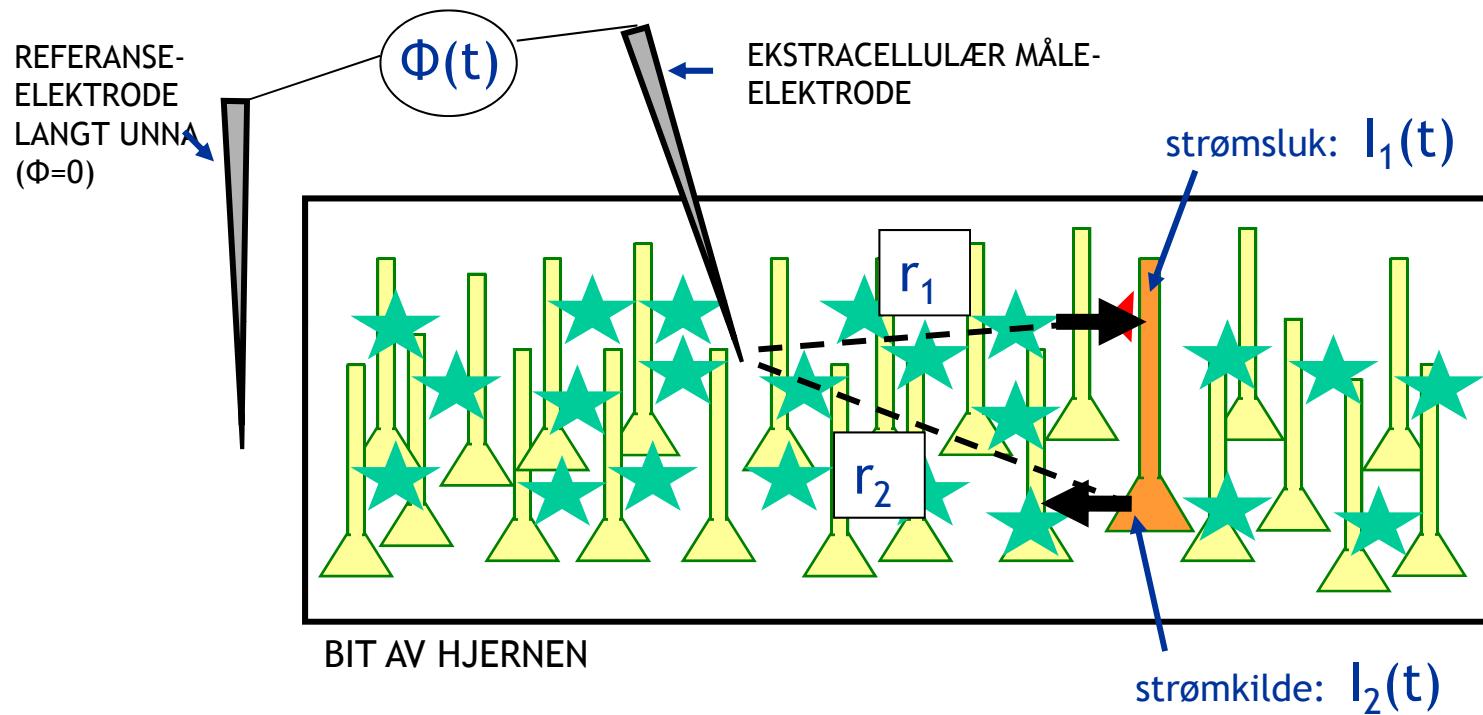


dame (71 år)
med
Creutzfeldt-
Jacobs
sykdom



Fysisk opphav til elektriske potensialer

- Kilder til ekstracellulært potensial: Transmembrane strømmer



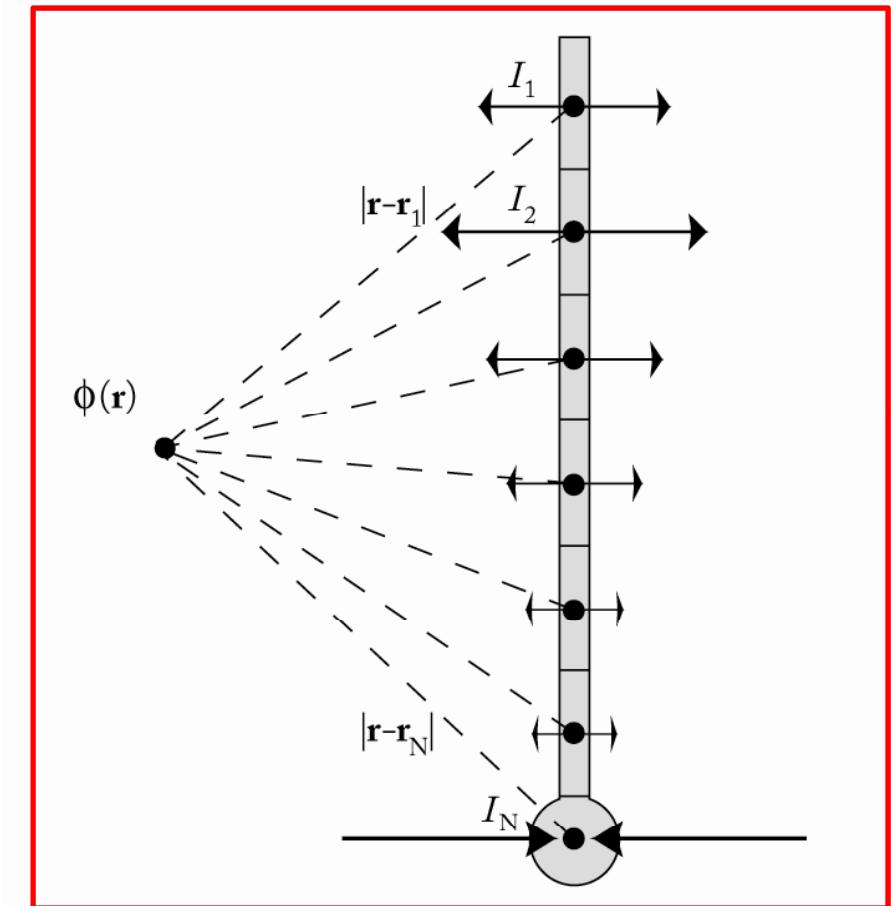
FRA ELEKTROSTATIKK:

$$\phi(t) = \frac{I_1(t)}{4\pi\sigma r_1} + \frac{I_2(t)}{4\pi\sigma r_2}$$

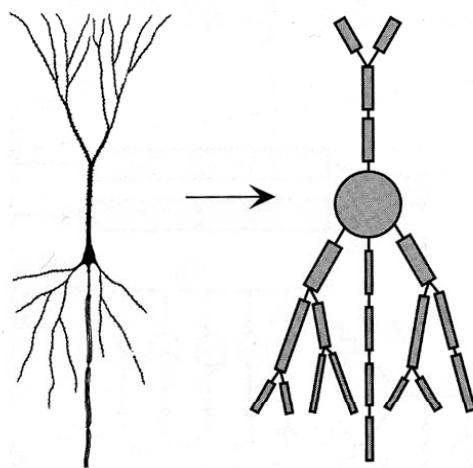
σ : elektrisk ledningsevne

- Generalisering til kompartmental nevronmodell

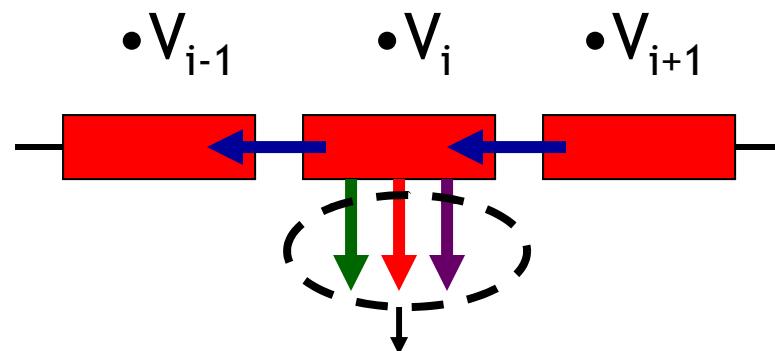
$$\phi(\mathbf{r}, t) = \frac{1}{4\pi\sigma} \sum_{n=1}^N \frac{I_n(t)}{|\mathbf{r} - \mathbf{r}_n|}$$



Kompartimental modellering av potensialer



- Eksempel dendritisk segment:



- Kirchhoff's strømlov:

$$g_{i,i+1}(V_{i+1} - V_i) - g_{i-1,i}(V_i - V_{i-1}) = c_i \frac{dV_i}{dt} + g_i^m(V_i - V_r) + \sum_j I_i^j + \sum_s I_i^s$$

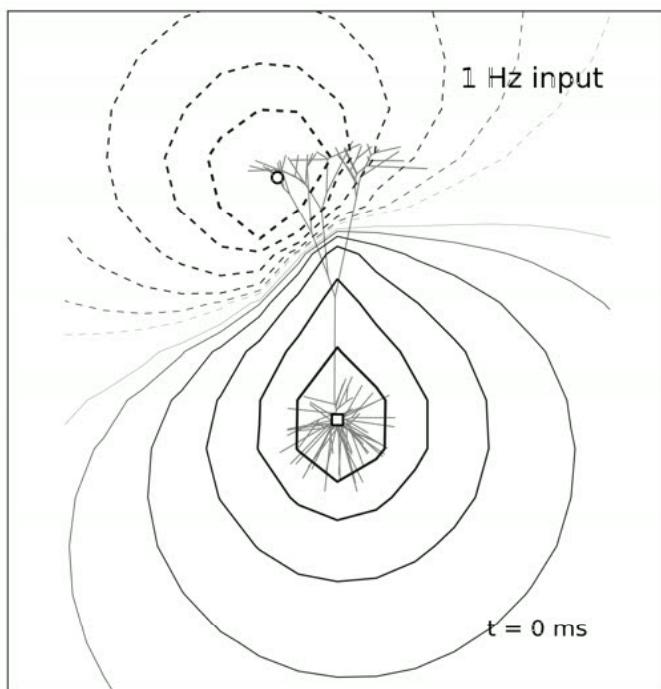
STRØMMER TIL NABOSEGMENTER

PASSIVE MEMBRAN-STRØMMER

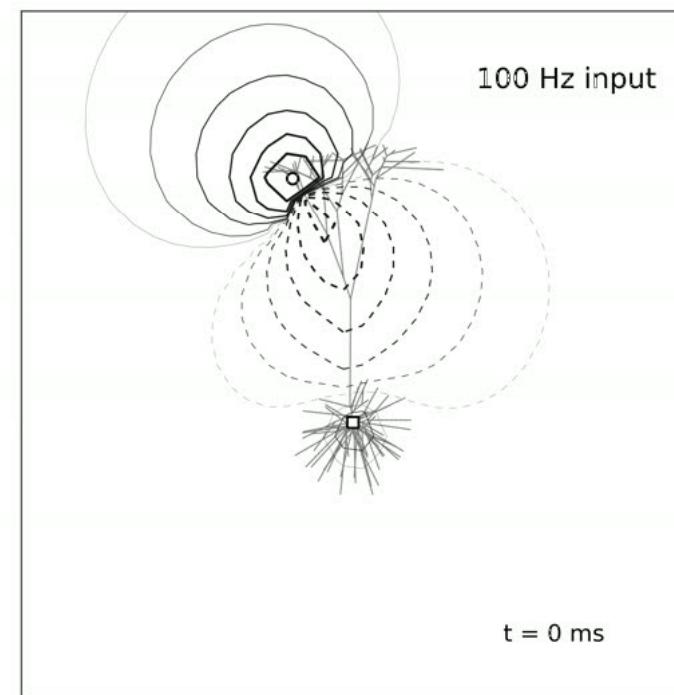
AKTIVE MEMBRAN-STRØMMER

SYNAPTISKE STRØMMER

Beregning av elektriske potensialer

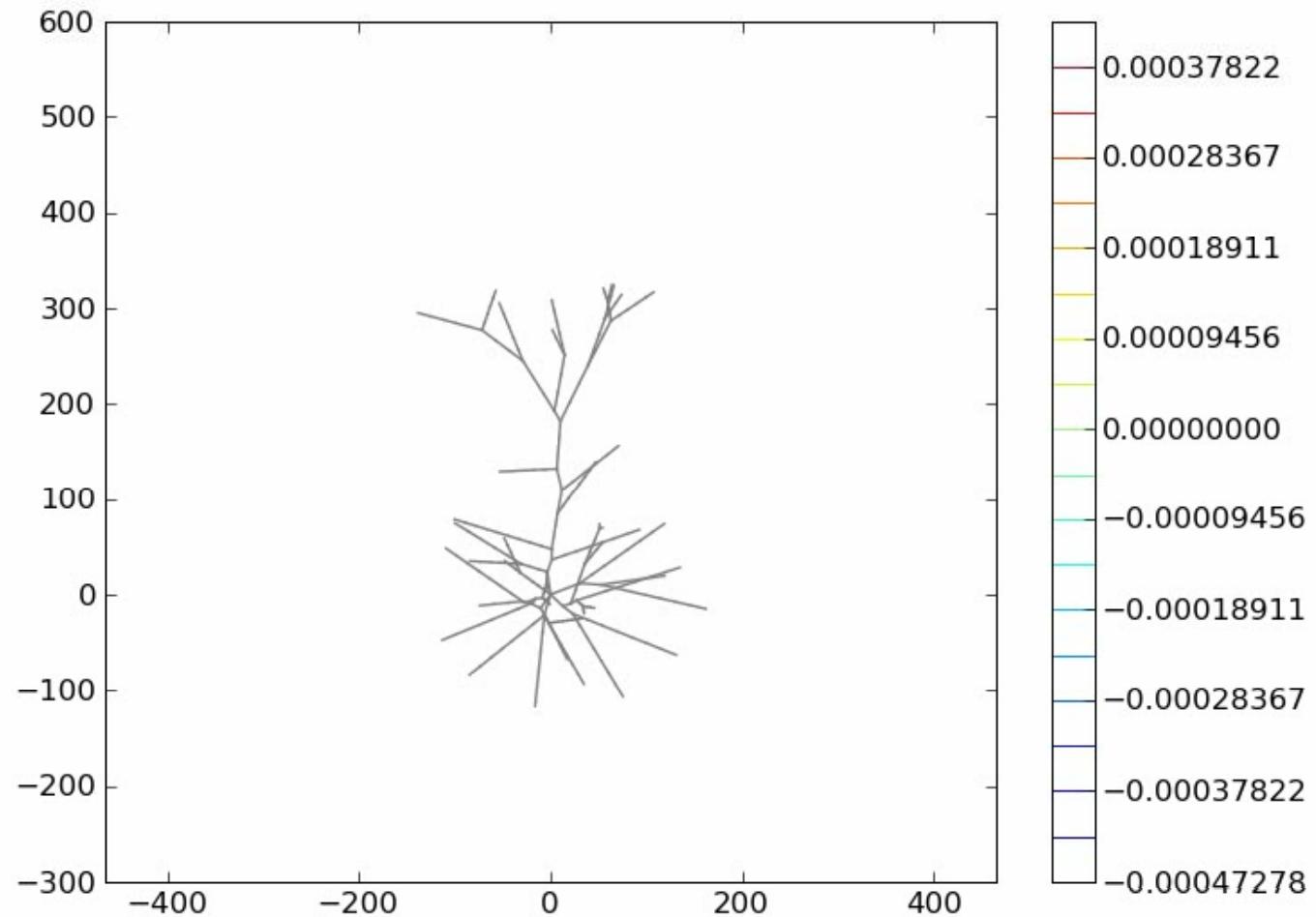


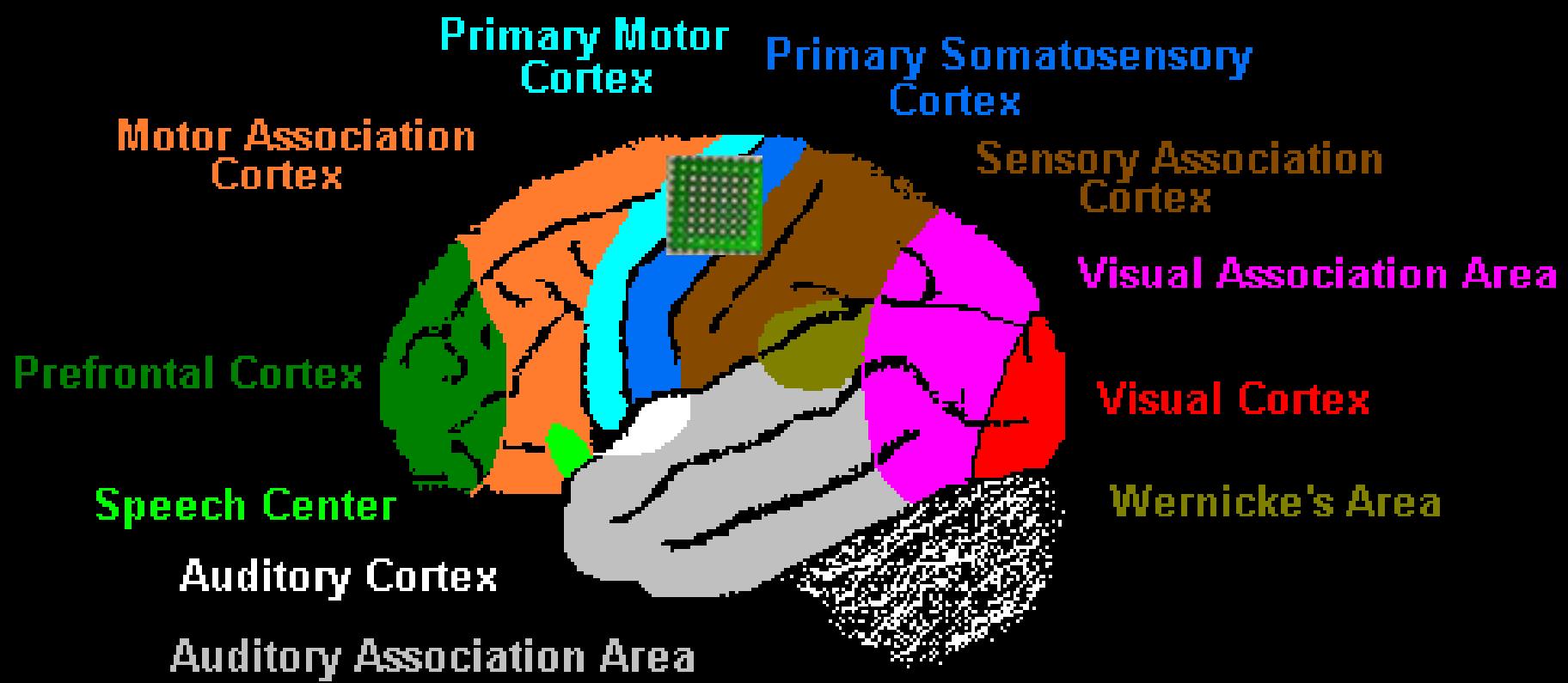
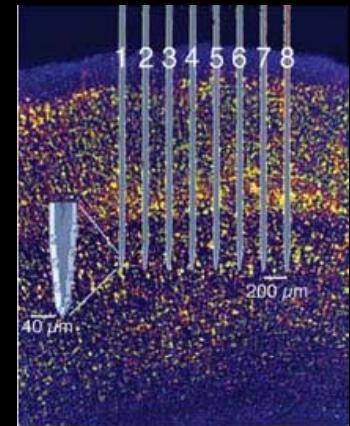
1 Hz

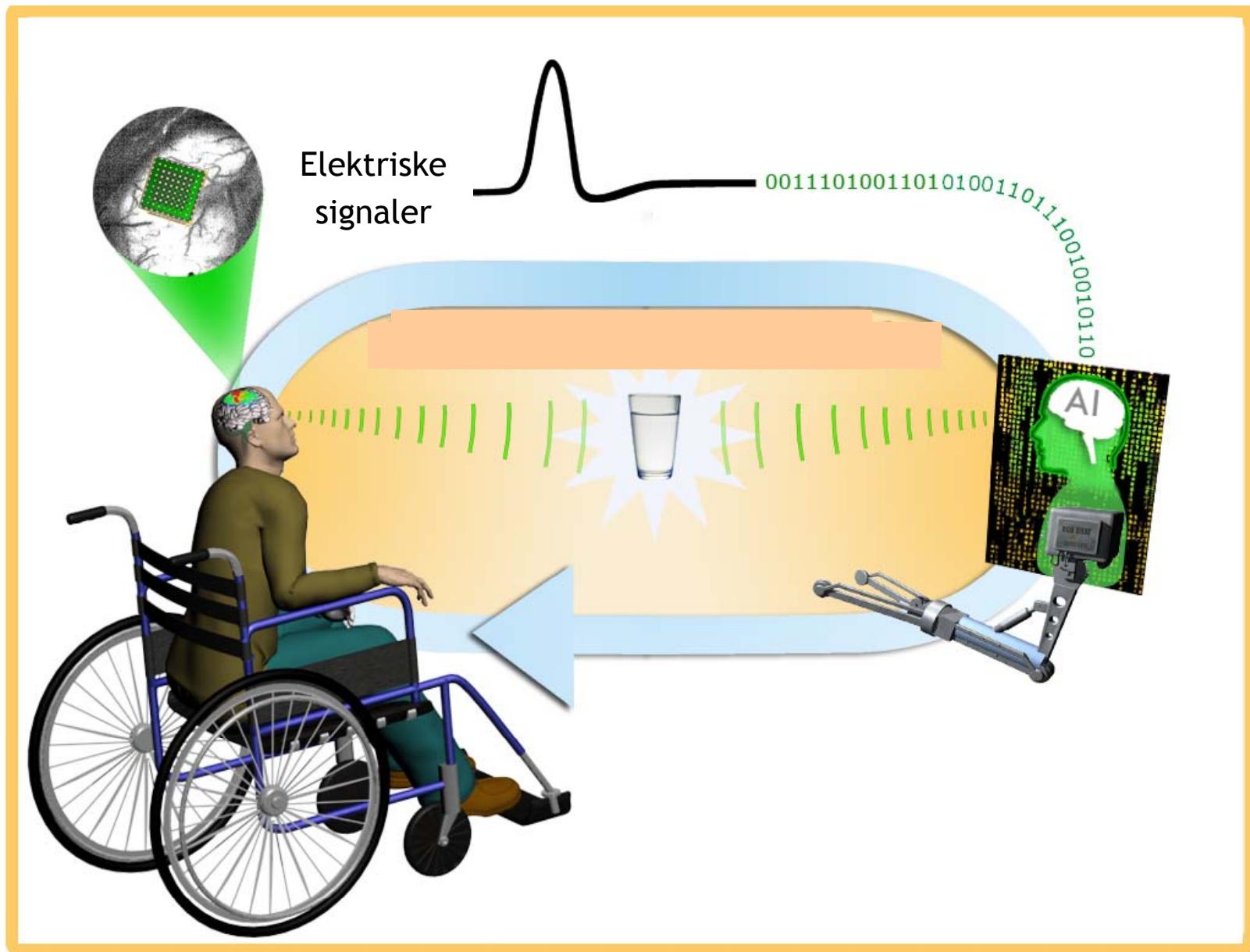


100 Hz

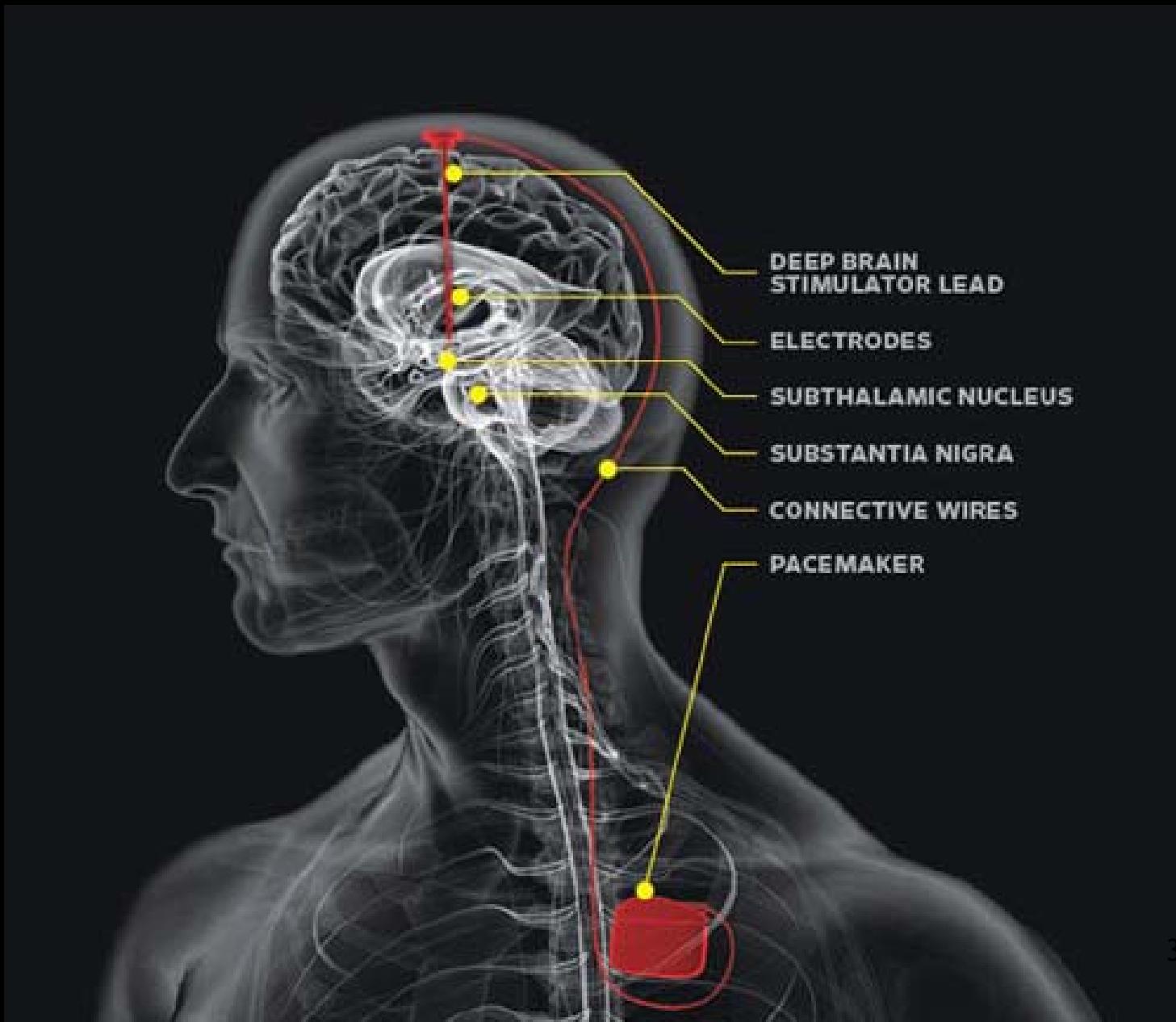
Beregning av elektriske potensialer







"Deep brain stimulation"



Mr Joseph Larkin Austin, eldest son of Mr Kleazer Austin, was found drowned near the south bridge in Salem; it is supposed he fell overboard between 2 and 3 o'clock in the morning, while fishing.

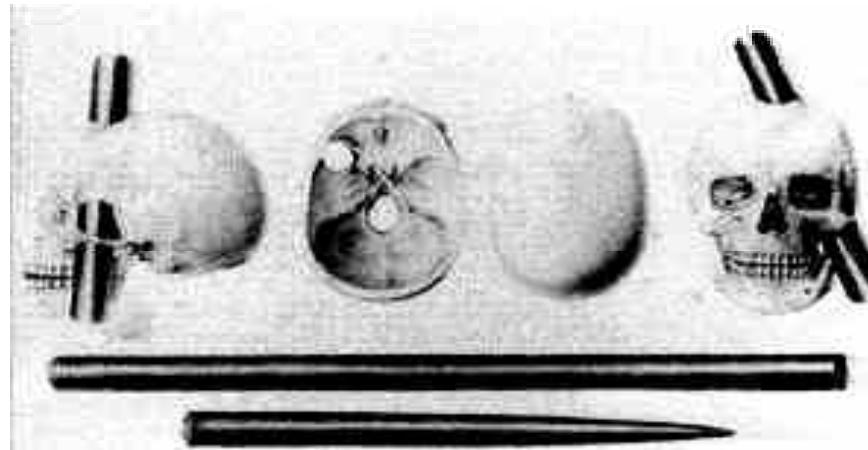
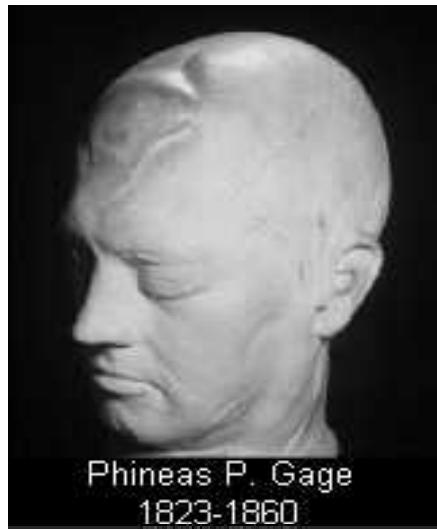
Horrible Accident.—As Phineas P. Gage, a foreman on the railroad in Cavendish, was yesterday engaged in tamkin for a blast, the powder exploded, carrying an iron instrument through his head an inch and a fourth in circumference, and three feet and eight inches in length, which he was using at the time. ~~The iron~~ entered on the side of his face, shattering the upper jaw, and passing back of the left eye, and out at the top of the head.

The most singular circumstance connected with this melancholy affair is, that he was alive at two o'clock this afternoon, and in full possession of his reason, and free from pain.—*Ludlow, Vt., Union.*

The chief of the Philadelphia dogkillers, a black man named George Horsey, attempted to kill his wife. He broke into her room armed with a pistol and knife; she threw herself out of the second story window to escape, breaking her leg in the fall; he pursued her, and attacked and injured her severely. She was taken to the hospital. Horsey was fully committed for trial.

*Fra Boston
Post, sept. 1848*

Phineas P. Gage



- Arbeidsleder ved jernbaneanlegg
- 1848: Jernstang gjennom hodet i ulykke
- Før: Til å stole på, effektiv, balansert
- Etter: Ikke til å stole på, utålmodig, profan(!)

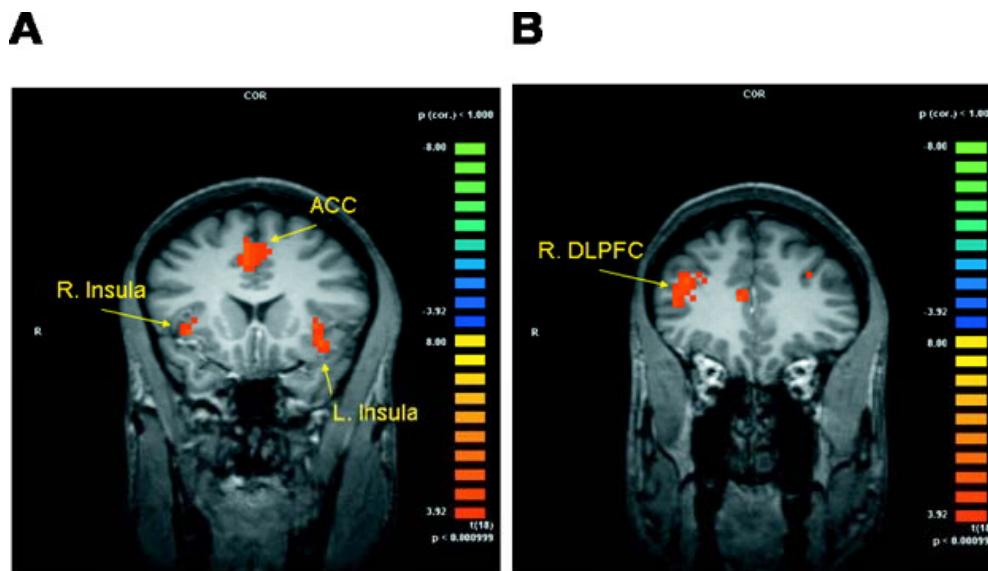
The Neural Basis of Economic Decision-Making in the Ultimatum Game

Alan G. Sanfey,^{1,3*} James K. Rilling,^{1,*} Jessica A. Aronson,² Leigh E. Nystrom,^{1,2} Jonathan D. Cohen^{1,2,4}

The nascent field of neuroeconomics seeks to ground economic decision-making in the biological substrate of the brain. We used functional magnetic resonance imaging of Ultimatum Game players to investigate neural substrates of cognitive and emotional processes involved in economic decision-making. In this game, two players split a sum of money; one player proposes a division and the other can accept or reject this. We scanned players as they responded to fair and unfair proposals. Unfair offers elicited activity in brain areas related to both emotion (anterior insula) and cognition (dorsolateral prefrontal cortex). Further, significantly heightened activity in anterior insula for rejected unfair offers suggests an important role for emotions in decision-making.

'Ultimatumspillet' og fMRI

- To personer får 1000 NOK på deling
- Men: En av dem bestemmer hvordan pengene skal deles; ingen får noe, hvis mottager avslår
- Observasjon: Den andre nekter ofte å motta penger hvis mindre enn ~200 NOK tilbys

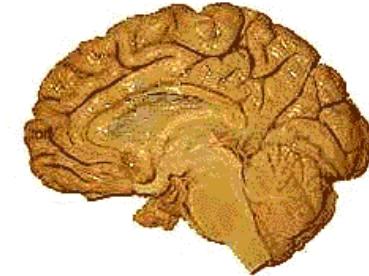


*Forskjell mellom
fMRI-signaler for
'urimelige' og
'rimelige'
delingsforslag*

- Følelsesdelene av hjernen involvert!

Bevissthet

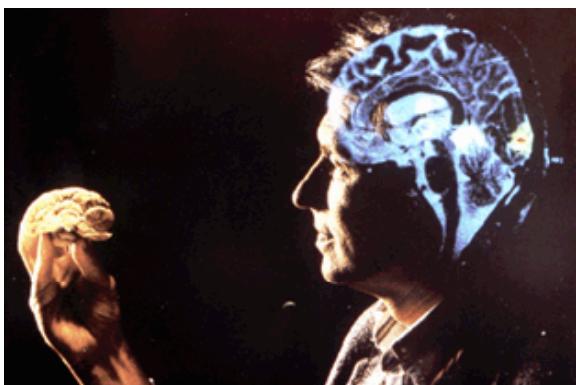
- Hvordan kan bevissthet oppstå i en samling atomer?



- Kan den subjektive oppfattelsen av bevissthet studeres vitenskapelig?



- Kan datamaskiner noen gang bli bevisste?
[Hvis ja, hvordan vil vi kunne finne det ut?]



Mankind is a catalyzing enzyme for the transition from a carbon-based to a silicon-based intelligence (G.Bricogne)

Matematisk nevrovitenskap på UMB vår 2010

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