PhD Dissertation

Randal A. Koene. *Functional requirements determine relevant ingredients to model for on-line acquisition of context dependent memory* PhD thesis, McGill University, 2001: [Compressed Postscript], [PDF].
(Formatting and layout particulars, such as the location of paragraphs on pages and page numbers, may differ due to differences in the typesetting of the character fonts used in the Postscript and PDF documents generated from the LaTeX source text.)

Abstract: Biophysical simulations of memory must choose which aspects of known neurophysiology and neuroanatomy to model. Relevant aspects were constrained by functional requirements determined for on-line acquisition in context dependent memory, memory that is retrieved by contextual cues. In an on-line task, the protocol of data presentation and the times at which encoding or retrieval in memory is needed are not predetermined. A sequence of neuronal spike patterns representing items may be presented only once. Yet, episodic memory of the sequence immediately encodes the temporal context of familiar items, a process known to depend on hippocampal function. For this, interference caused by overlapping spike patterns must be avoided, a requirement that suggested the relevance of coincidental spiking. Overlap in the input to the hippocampus was reduced by recruiting such spikes in a model of encoding in dentate gyrus. Durable encoding is required in the hippocampus, since hippocampal damage can cause retrograde amnesia in context dependent memory that spans years. Long-lasting synaptic changes involved modeling relevant neurophysiology concerning protein production elicited by the spaced reactivation of spike patterns. The likelihood of reactivation was increased by the well-known process of long-term potentiation of synaptic transmission. Such potentiation is elicited when a presynaptic spike precedes a postsynaptic spike within a specific time window repeatedly. The intervals in a sequence of spike patterns must be compressed and the sequence repeated, requirements that were achieved with a model of short-term memory based on persistent spiking. Retrieval may be concurrent with these encoding processes due to effects of different phases of a brain rhythm at theta frequency (3-12 Hz) that modulate transmission and plasticity. A model of short-term memory by Lisman and Idiart (Science 267:1512-15), extended by Jensen {\em et al.} (Learning and Memory 3:243-287), was a suitable framework for rapid sequence acquisition. Each functional requirement of on-line acquisition was met by adding relevant neurophysiology and neuroanatomy to the framework. Subsequent simulations had more parameters, but values were selected independently for each function. When simulating biological systems, a top-down focus on functional requirements deals with the problem that more components lead to more complex behaviour.

Oral Defense Presentation: Powerpoint, compressed postscript, presentation notes (compressed novelties postscript and my own compressed comments postscript with paragraph references as numbered in the pre-defense version of the Ph.D. thesis dissertation) and HTML.

Complementary materials to the thesis dissertation, as noted in Appendix B.

The Generic Enhanced Spiking Neuron models library, GESNlib, provides C++ software functions of modeling components used in experiments, with the goal of optimization for accuracy and computational efficiency. Recent developments involve Event-Predictive Emulation, rooted in spline-decomposition of neurobiological functions. As this optimization improves, simulations of more extensive and realistic neuronal circuitry become feasible.

[JLILTM] Improvements in Recall Behaviour of a Model Combining Oscillatory Short Term Memory and Long Term Potentiation-Depression

- **(2.2) Fig.2.1d**: Neuronal circuitry simulation program corrected (C program) with basic.ini (simulation initialization file), evaluated in Octave with jlioutput.m (Octave script).
- **(2.3.1) Fig.2.2 and Fig.2.3**: Numerical simulation jensencomp.m (Octave script) in Octave.
- **(2.3.2) Fig.2.4 and Fig.2.5**: Neuronal circuitry simulation program corrected (C program) with cued-low-GABA-reverberation (simulation configuration and initialization files), evaluated in Octave with jlioutput.m (Octave script).
- **(2.3.3) Fig.2.6**: Neuronal circuitry simulation program corrected (C program) with overlap4 (simulation configuration and initialization files), evaluated in Octave with jlioutput.m

(Octave script).

- **(2.3.4) Fig.2.7**: Neuronal circuitry simulation program corrected (C program) with overlap4 (simulation configuration and initialization files), evaluated in Octave with jlioutput.m (Octave script).

JLILTM: Continued Research

Further advances have been made in the design and evaluation of the STM model in the context of research conducted at Michael Hasselmo's Computatinal Neurophysiology laboratory at Boston University.

The STM model has been reimplemented with more detailed integrate-and-fire neurons that include explicit membrane capacitances and response dynamics that are computed from the changing potential differences over receptor channel conductances. This dual-oscillation short-term memory has been incorporated in a Catacomb model of a virtual rat, with learning and behaviour in a simulated environment directed by prefrontal cortex, entorhinal (ECII,ECIII) and hippocampal (CA3,CA1) networks (Cannon, Hasselmo and Koene, 2002; Koene, Cannon and Hasselmo, 2002).

Research detailing a plausible first-in-first-out (FIFO) item replacement mechanism for the STM queue that relies on the conditional and synchronized activation of a population of interneurons, as well as detailed derivations of the dependencies between parameter constraints in the STM model are nearing completion and are scheduled for presentation.

[Connectivity] Localized Distribution of Connectivity and $GABA_B$ Control of Learning and Recall Modes in an Oscillatory Model of Memory

- **(3.1.2) Fig.3.1**: Numerical simulation gabab.m (Octave script) in Octave.
- **(3.2) Fig.3.4d**: Neuronal circuitry simulation program corrected (C program) with basic.ini (simulation initialization file), evaluated in Octave with jlioutput.m (Octave script).
- **(3.3.1) Fig.3.5 and Fig.3.6**: Neuronal circuitry simulation program connectivity (C program, version 0.9.5) with connectivity2 (simulation configuration and initialization files), evaluated in Octave with jlioutput.m (Octave script).

Connectivity: Continued Research

Additional details about the mossy fibre connections between dentate gyrus and CA3 and the role of presynaptic LTP (Maccaferri, Toth and McBain, Science, 1998) at those large synapses are being investigated. The experimental results may add support to the hypothesis that separate regions of the hippocampus are specialized for autoassociative and heteroassociative learning involving the same selected sparse encoded representations.

[ITM] Sparse Hippocampal Memory Encoding. Attentional Gain-Control of Memory Formation with Multiple Instantiation

- **(4.3) Fig.4.2**: Neuronal circuitry simulation program connectivity (C program, version 0.9.5) with interference and interleaved (simulation configuration and initialization files) and model preparation with proccfg (C++ preprocessor version 0.8.5, generates model neuronal circuitry from a configuration file), evaluated in Octave with jlioutput.m (Octave script).
- **(4.3) Fig.4.3**: Neuronal circuitry simulation program connectivity (C program, version 0.9.5) with minststm and minststm2 (simulation configuration and initialization files) and

model preparation with proccfg (C++ preprocessor version 0.8.5, generates model neuronal circuitry from a configuration file), evaluated in Octave with jlioutput.m (Octave script).

- **(4.3) Fig.4.4**: Neuronal circuitry simulation program connectivity (C program, version 0.9.5) with minstitm (simulation configuration and initialization files) and model preparation with proccfg (C++ preprocessor version 0.8.5, generates model neuronal circuitry from a configuration file), evaluated in Octave with jlioutput.m (Octave script).
- **(4.3) Fig.4.5**: Neuronal circuitry simulation program connectivity (C program, version 0.9.5) with minstitm2 (simulation configuration and initialization files) and model preparation with proccfg (C++ preprocessor version 0.8.5, generates model neuronal circuitry from a configuration file), evaluated in Octave with jlioutput.m (Octave script).
- **(4.3) Fig.4.6**: Neuronal circuitry simulation program connectivity (C program, version 0.9.5) with minstitm3 (simulation configuration and initialization files) and model preparation with proccfg (C++ preprocessor version 0.8.5, generates model neuronal circuitry from a configuration file), evaluated in Octave with jlioutput.m (Octave script).

[LTM] Sparse Hippocampal Memory Consolidation. Formation of Long-Term Memory Traces under Attentional Guidance

- **(5.1.1) Fig.5.1**: Numerical simulation ltpltm.m (Octave script) in Octave.
- **(5.3.1) Fig.5.5**: Numerical simulation ltmexp1.m (Octave script) in Octave.
- **(5.3.1) Fig.5.6**: Numerical simulation ltmexp2.m (Octave script) in Octave.

[DenseLTM] Dense Neocortical Memory Consolidation. Selective Transfer from Hippocampus with Multiple Instantiation through Recruitment

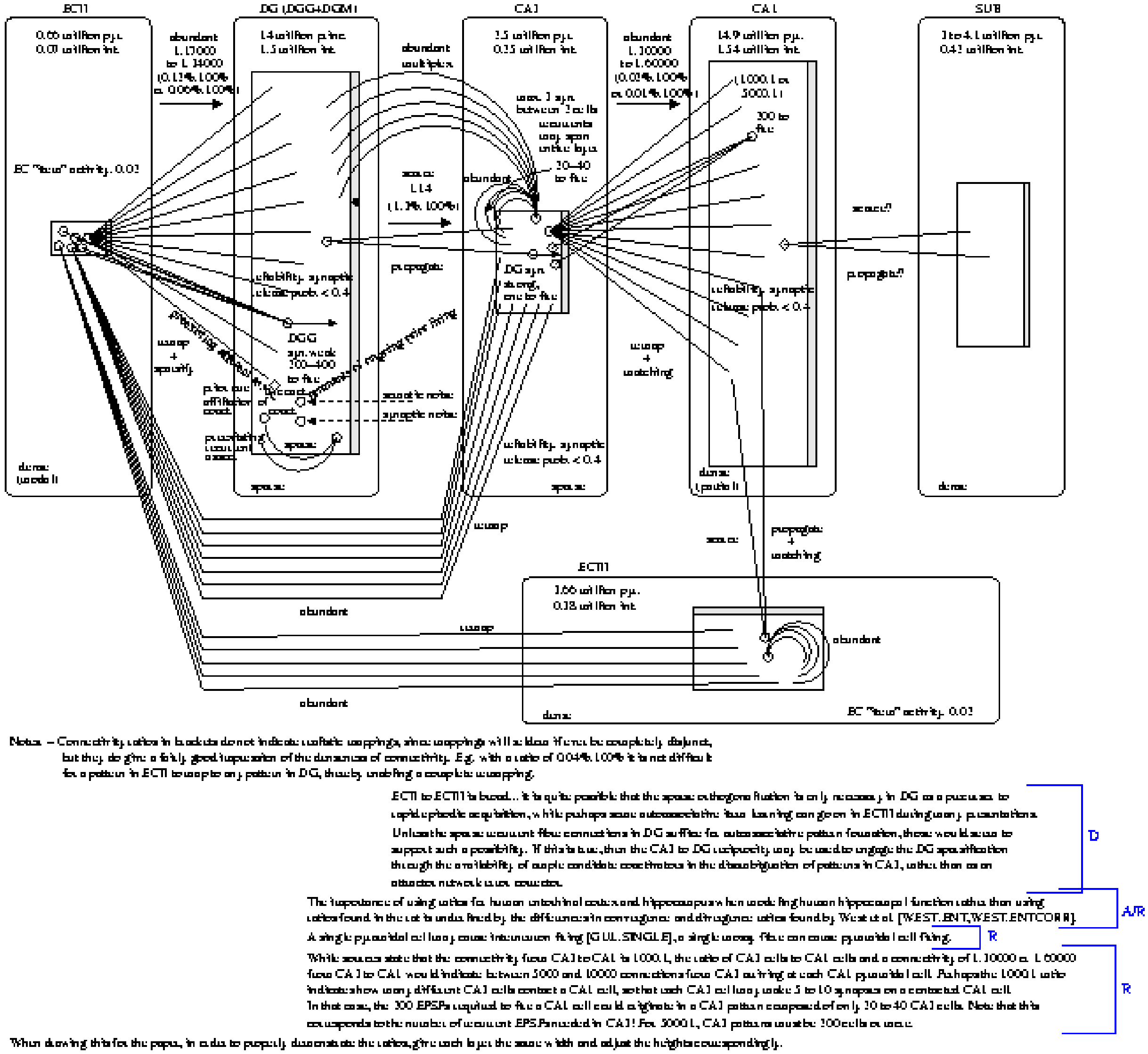

Figure B-6.1: Human neuronal cell population and connection numbers used as a template for the ratios in modeled circuitry from entorhinal cortex layers through the hippocampal layers to the subiculum.

- **(6.2.1) Fig.6.3**: Neuronal circuitry simulation program connectivity (C program, version 1.0) with denseltm1 (simulation configuration and initialization files) and model preparation with proccfg (C++ preprocessor version 1.0, generates model neuronal circuitry from a configuration file), evaluated in Octave with jlioutput.m (Octave script).
- **(6.2.1) Fig.6.4**: Numerical simulation denseltm2.m (Octave script) in Octave.
- **(6.2.5) Fig.6.8**: Numerical simulation reactivationshift.m (Octave script) in Octave.
- **(6.3.3) handwritten note reference**: ``early development possible model for adult neurogenesis''.

DenseLTM: Continued Research

(6.2.1)

(6.2.3)

Further related simulation program files may be found in the archival collection ``simulations-additional''. These were used in addition to or in preparation of the experiments shown in the results. Several also connect to ongoing research.

The neuronal circuitry simulations included are:

- connectivity
- connectivity3
- corrected-cue
- corrected-cue2
- corrected-max
- denseltm-hyp2-1
- fullSTM-nonoise
- hierarchyhetero
- jensen-max
- jensen-max2
- jensen.overlap-1
- jensen.overlap-2
- multiple1
- original-cue
- overlap
- overlap2
- overlap3
- pairednegator
- recall-full-gij
- stminterference

The numerical simulations included are:

- ADPtest.m
- ADPtest.evolutionary-tuning.m
- iris.m
- irisback.m
- sahptest.m
- learnwindow.m
- tpspi.m
- vmvthres.m

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