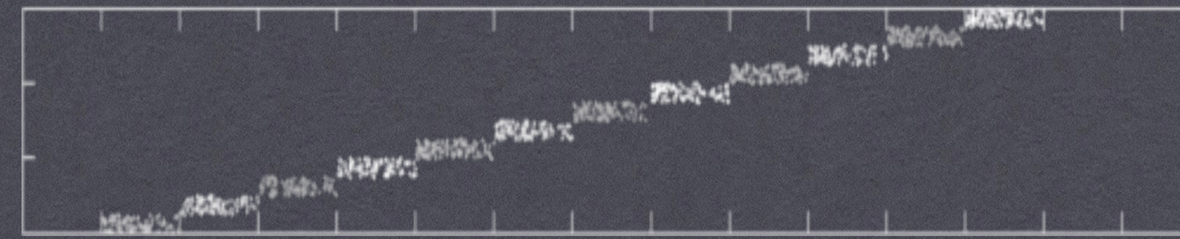
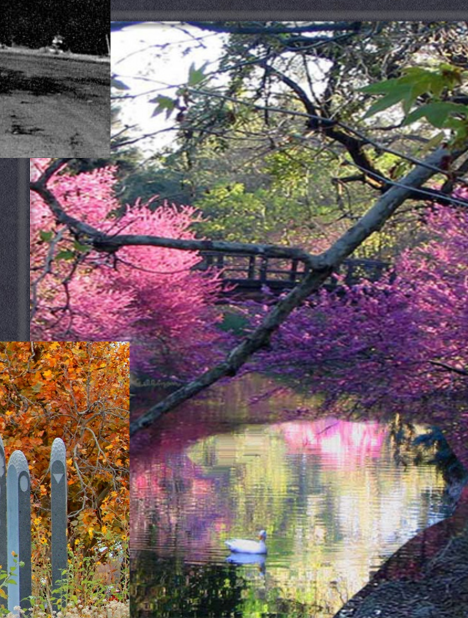


A Pulse-Gated Mechanism for Synaptic Copy Between Neural Circuits

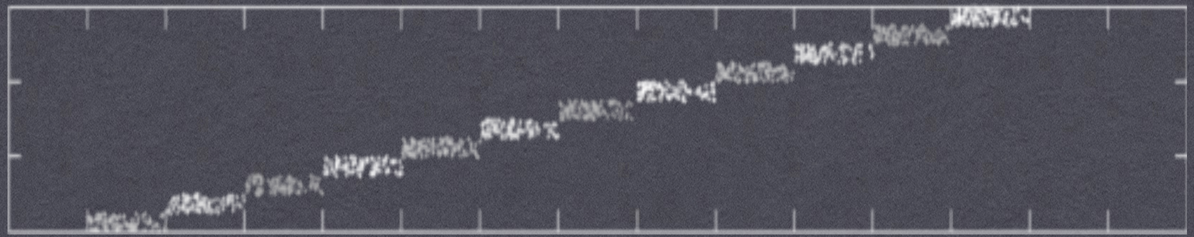
Andrew Sornborger

Los Alamos NATIONAL LABORATORY EST. 1943



NICE 2018, INTEL HILLSBORO

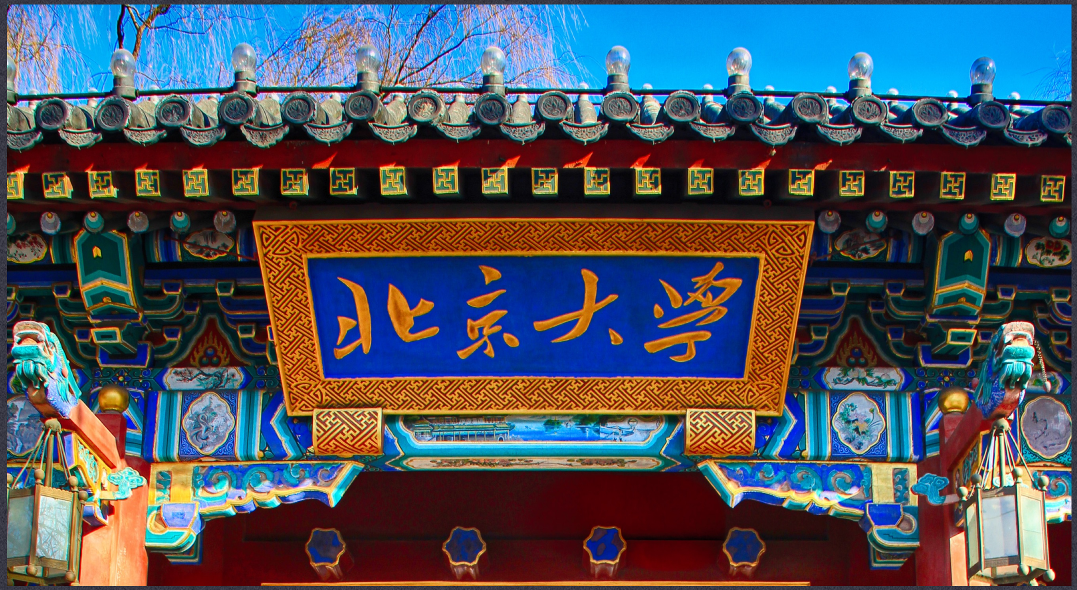
WHAT I CANNOT CREATE,
I DO NOT UNDERSTAND



Peking University

Beijing, China

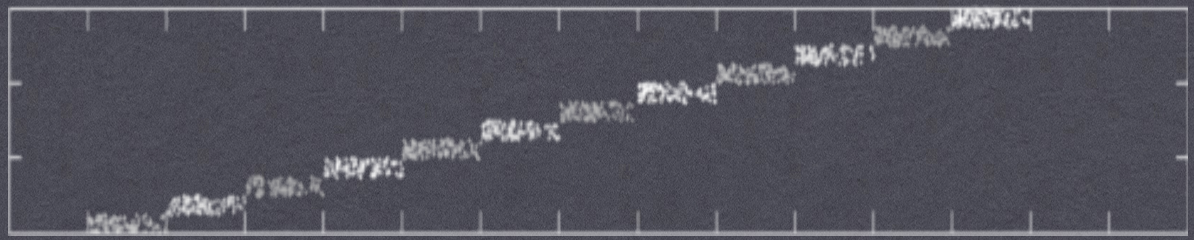
Louis Tao



Spencer Mathews, David Warland, Zhuo Wang, Zhuocheng Xiao, Jiwei Zhang, Yuxiu Shao, Cong Wang, Shubhankar Patankar

WHAT I CANNOT CREATE, I DO NOT UNDERSTAND

Motivation

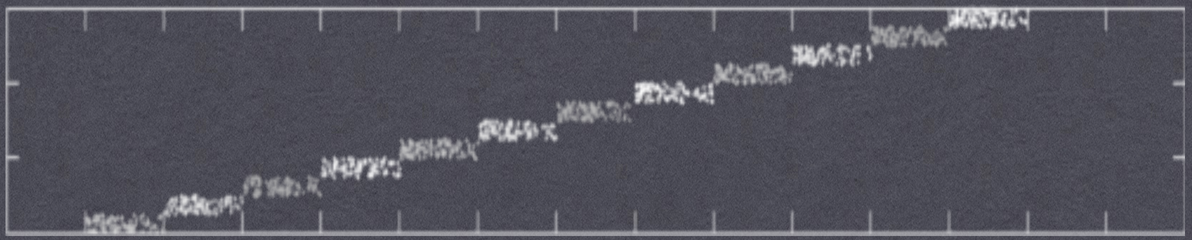


THE CASE OF H.M. (HENRY MOLAISON, AND MANY OTHERS) TELLS US THAT SHORT-TERM MEMORIES ARE FORMED IN THE HIPPOCAMPUS, BUT STORED, FOR THE LONG-TERM, ELSEWHERE.

EVIDENCE SHOWS THAT THALAMIC SPINDLES, HIPPOCAMPAL RIPPLES AND CORTICAL SLOW OSCILLATIONS ACT LIKE A COMMUNICATION CHANNEL THAT FACILITATES MEMORY CONSOLIDATION.

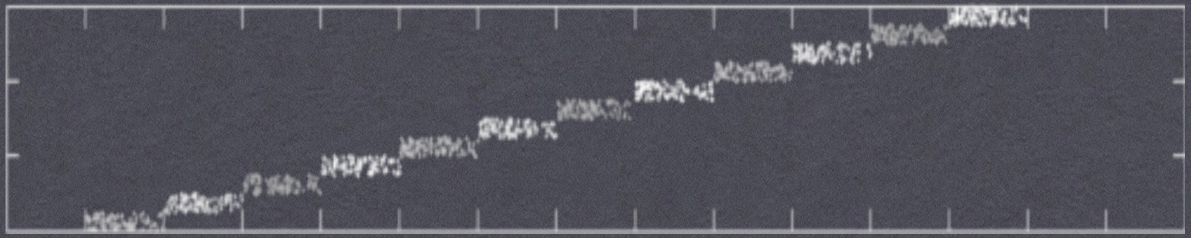
CLEARLY, IN A NEUROMORPHIC CIRCUIT, WE MIGHT ALSO WANT TO COPY SYNAPSES FROM ONE PLACE TO ANOTHER.

Outline



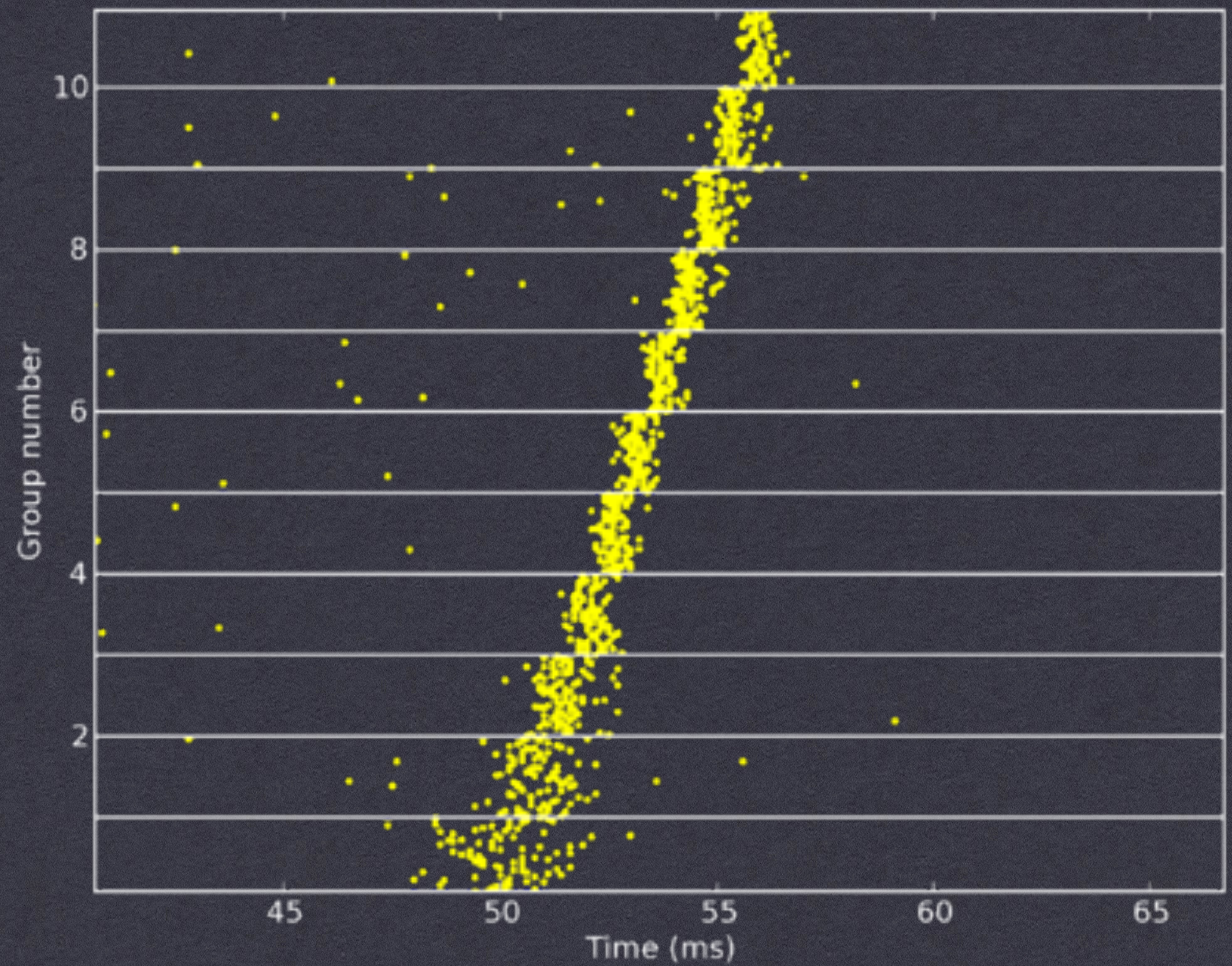
- BACKGROUND: SYNFIRE CHAINS
- SYNFIRE-GATED SYNFIRE CHAINS FOR GRADED INFORMATION PROPAGATION
- HOW TO COMPUTE WITH SGSCS
- LEARNING
- TRANSFERRING SYNAPSES

Synfire chains



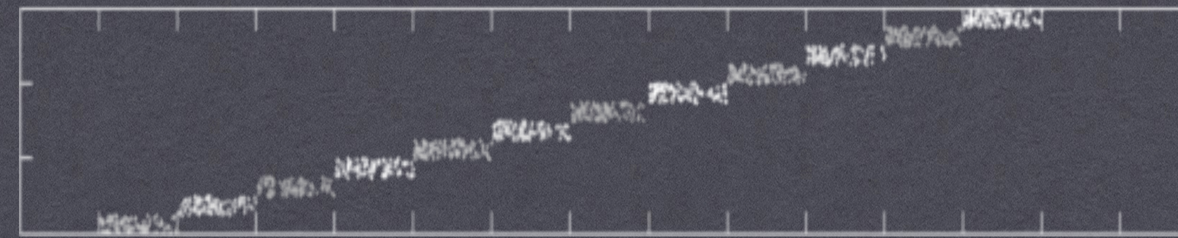
SYNFIRE CHAIN

ABELES 1982



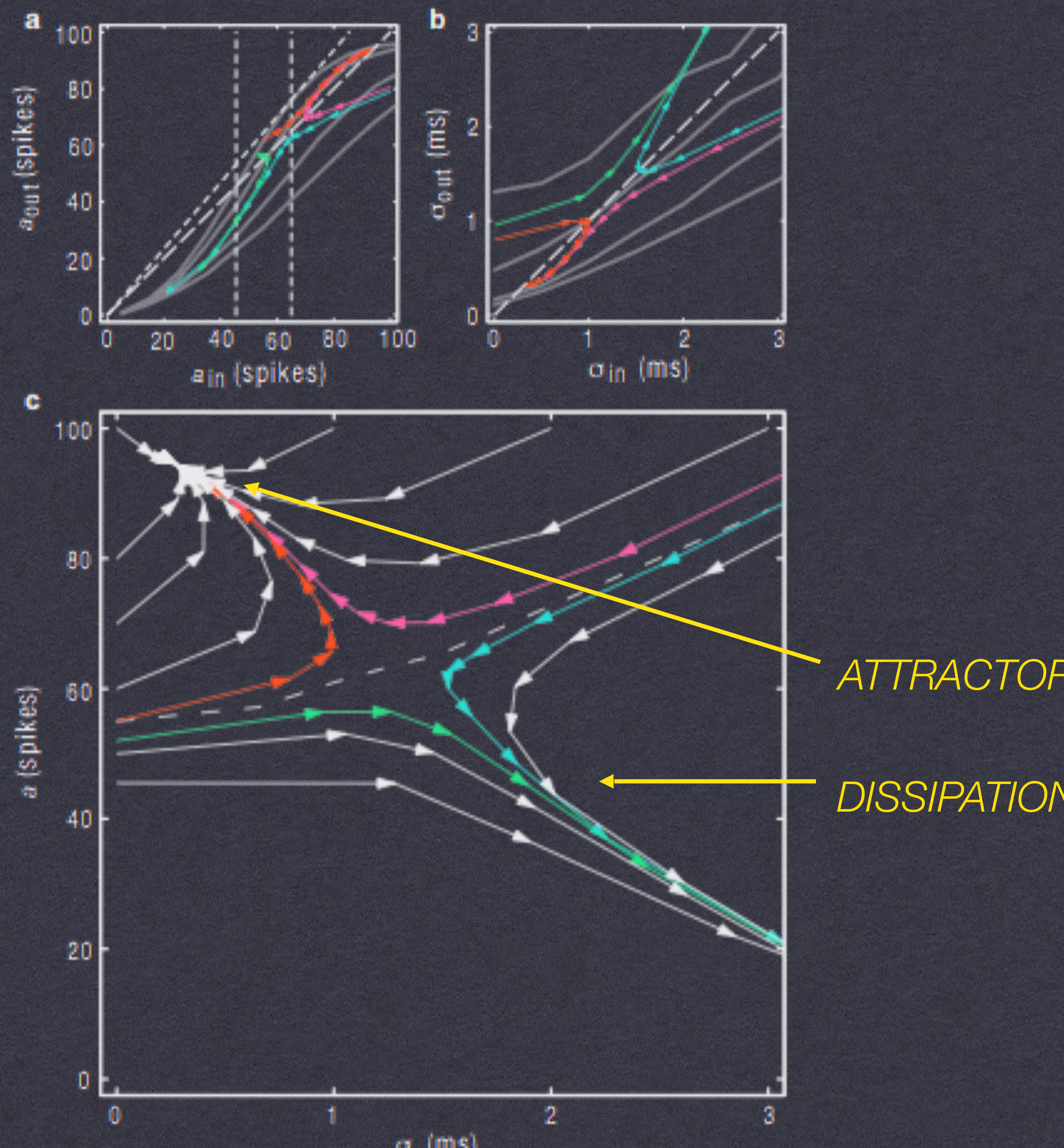
BRIANSIMULATOR.ORG

Synfire chains



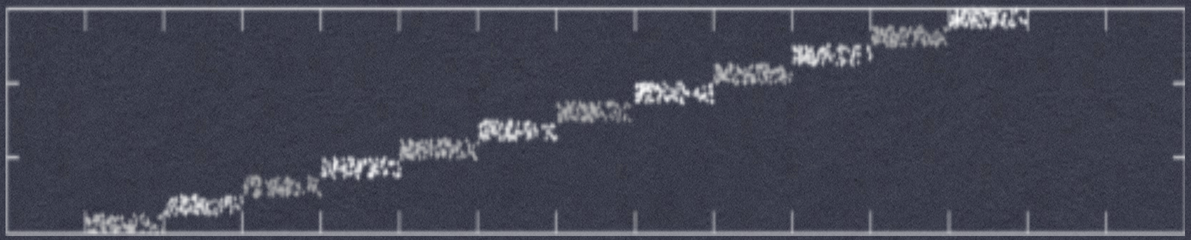
ORIGINAL HOPE:
TO PROPAGATE
GRADED INFORMATION
WITH SYNFIRE CHAINS

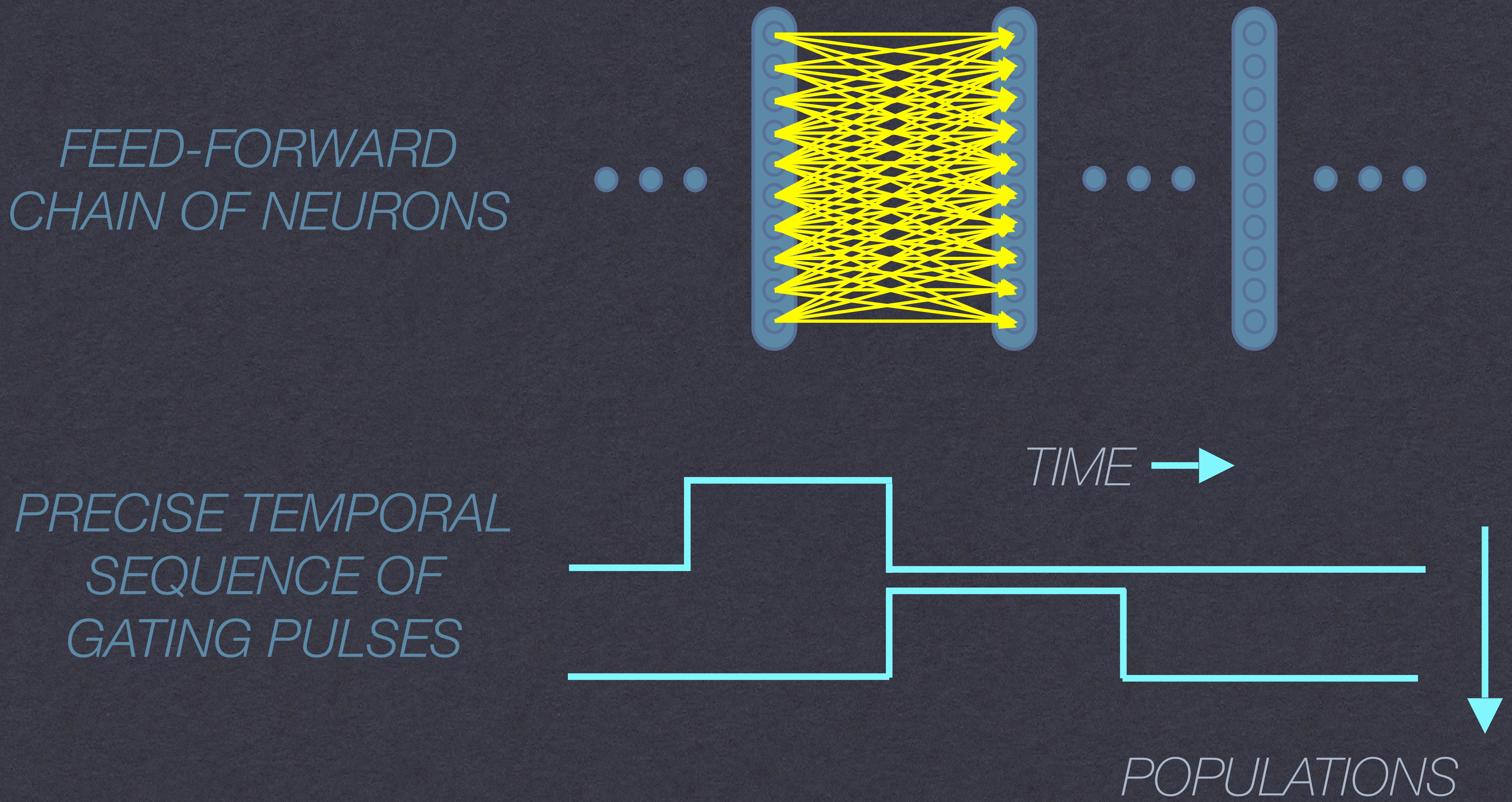
- CAN'T PROPAGATE
GRADED INFORMATION
THIS WAY



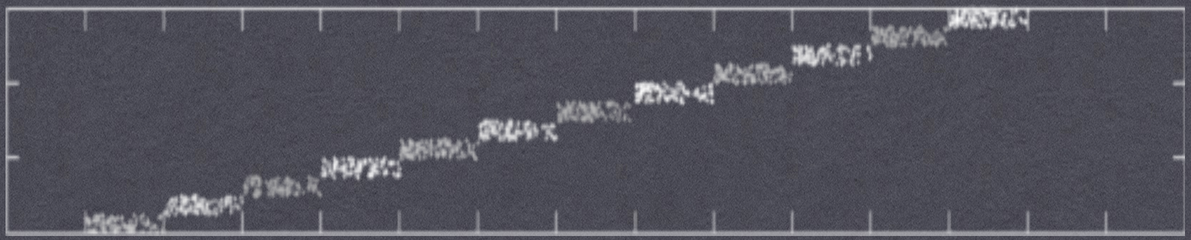
DIESMANN, GEWALTIG, AERTSEN, NATURE, 1999

Synfire-gated synfire chains

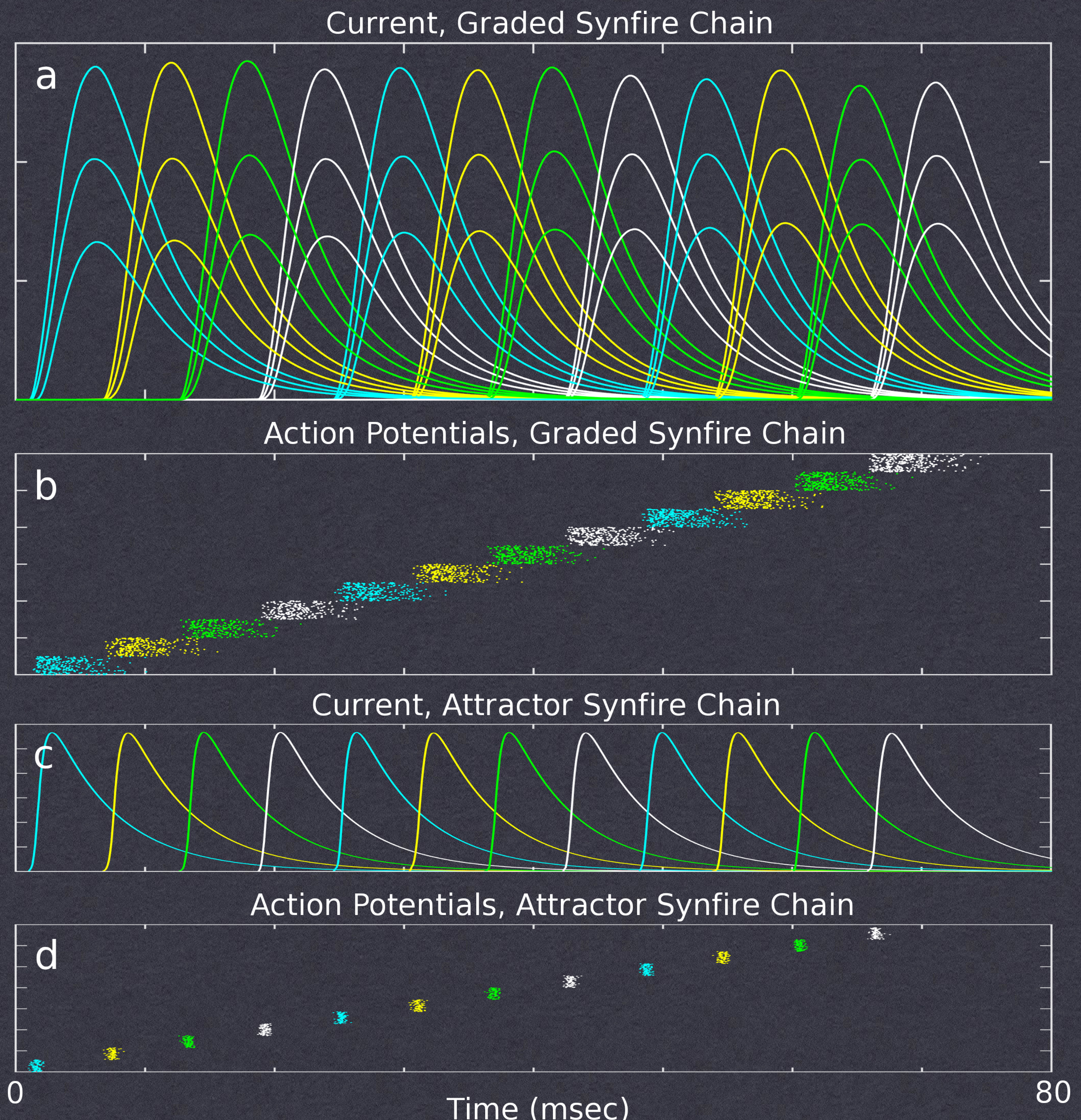




Synfire-gated synfire chains

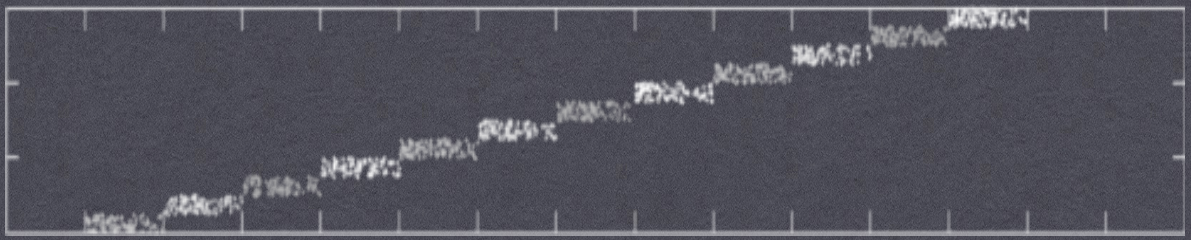


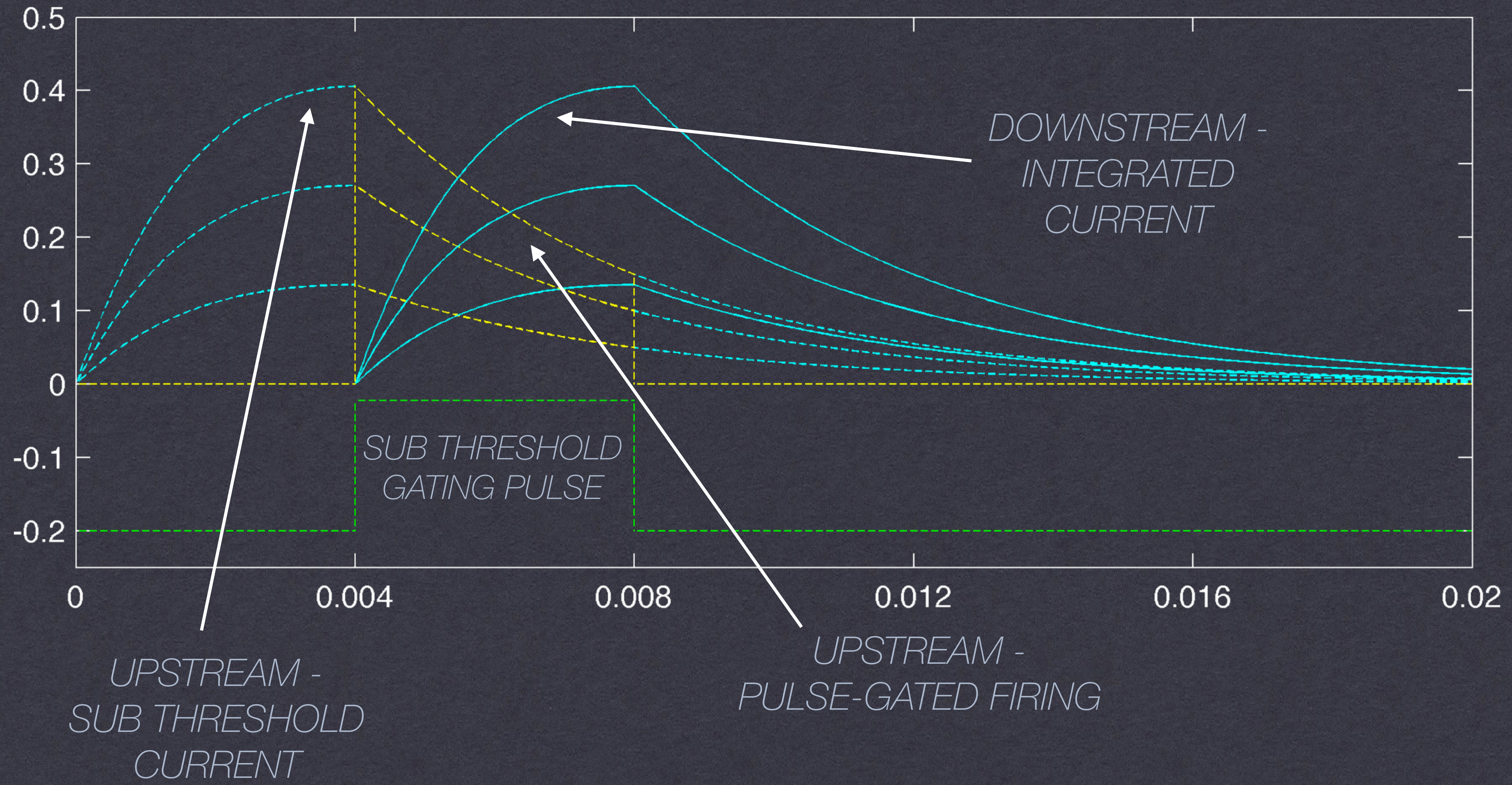
MECHANISM: USE NEURAL POPULATIONS IN A CONVENTIONAL SYNFIRE CHAIN (I.E. ONE THAT APPROACHES AN ATTRACTOR) AS A PULSE GENERATOR TO PUSH SECONDARY POPULATIONS ABOVE THRESHOLD



WANG, SORNBORGER, TAO
PLOS COMP BIO (2016)

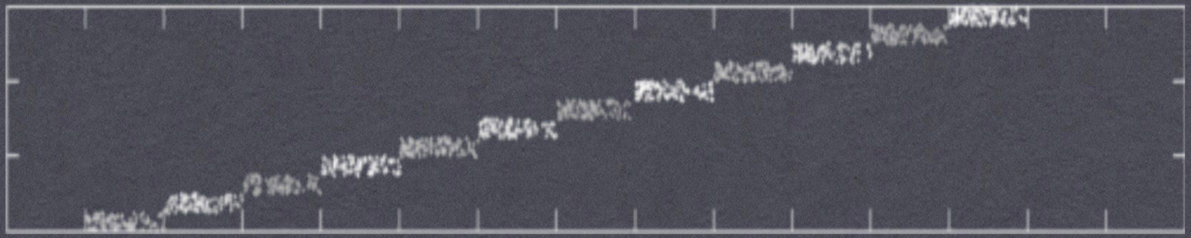
SGSC: A mean field model





SORNBORGER, WANG, TAO, JCNS (2015)

SGSCs

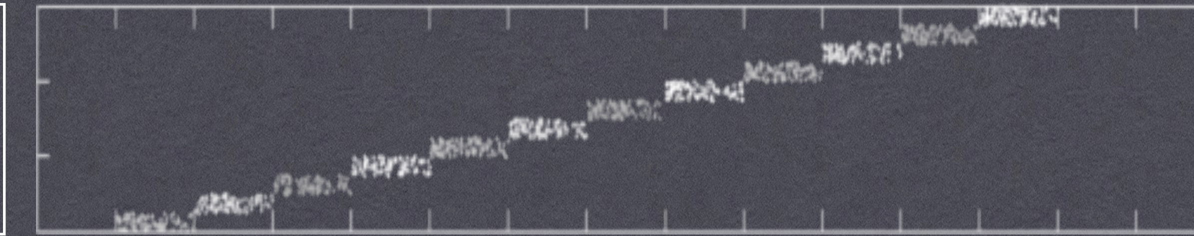


IMPLICATIONS:

- *SEPARATION OF*
  INFORMATION CONTROL - GATING PULSES
  INFORMATION CONTENT - GRADED FIRING RATES

- *SGSCS MAY BE USED AS BUILDING BLOCKS*
  FOR CONSTRUCTING NEURAL CIRCUITS

Computing with SGSCs



PULSE-GATED PROPAGATION
BETWEEN VECTORS OF POPULATIONS

$$\tau \frac{d}{dt} I^d = -I^d + S\,[K I^u + p^u(t)]^+$$

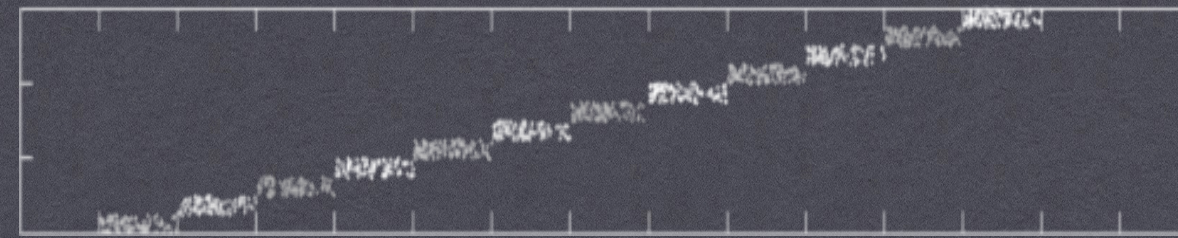
FIXED CONNECTIVITY **DYNAMIC ROUTING**

LEADS TO FEED-FORWARD NEURAL CIRCUITS
WITH ACTIVELY GATED LINEAR MAPS

$$\mathbf{I}^u(t) \xrightarrow{K} \mathbf{I}^d(t)$$

SORNBORGER, WANG, TAO, JCNS (2015)

Learning a Process

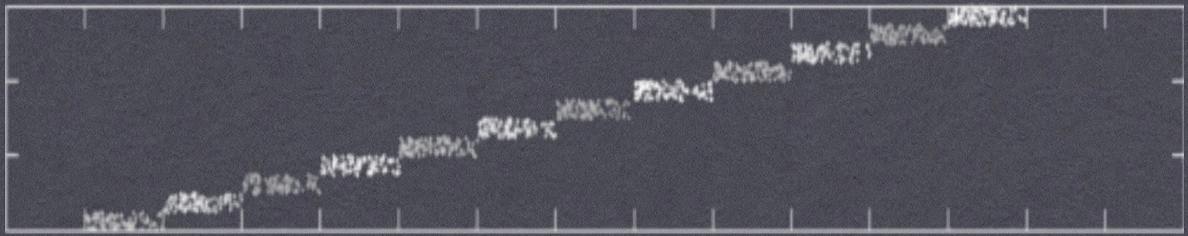


A SIMPLE EXAMPLE: AN AUTOREGRESSIVE (AR) PROCESS

NEED NEURAL CIRCUITS TO

- *ESTIMATE COVARIANCE MATRIX*
- *ESTIMATE PROCESS COEFFICIENTS FROM COVARIANCE*
- *PREDICT FUTURE PROCESS VALUES*

Learning a Process

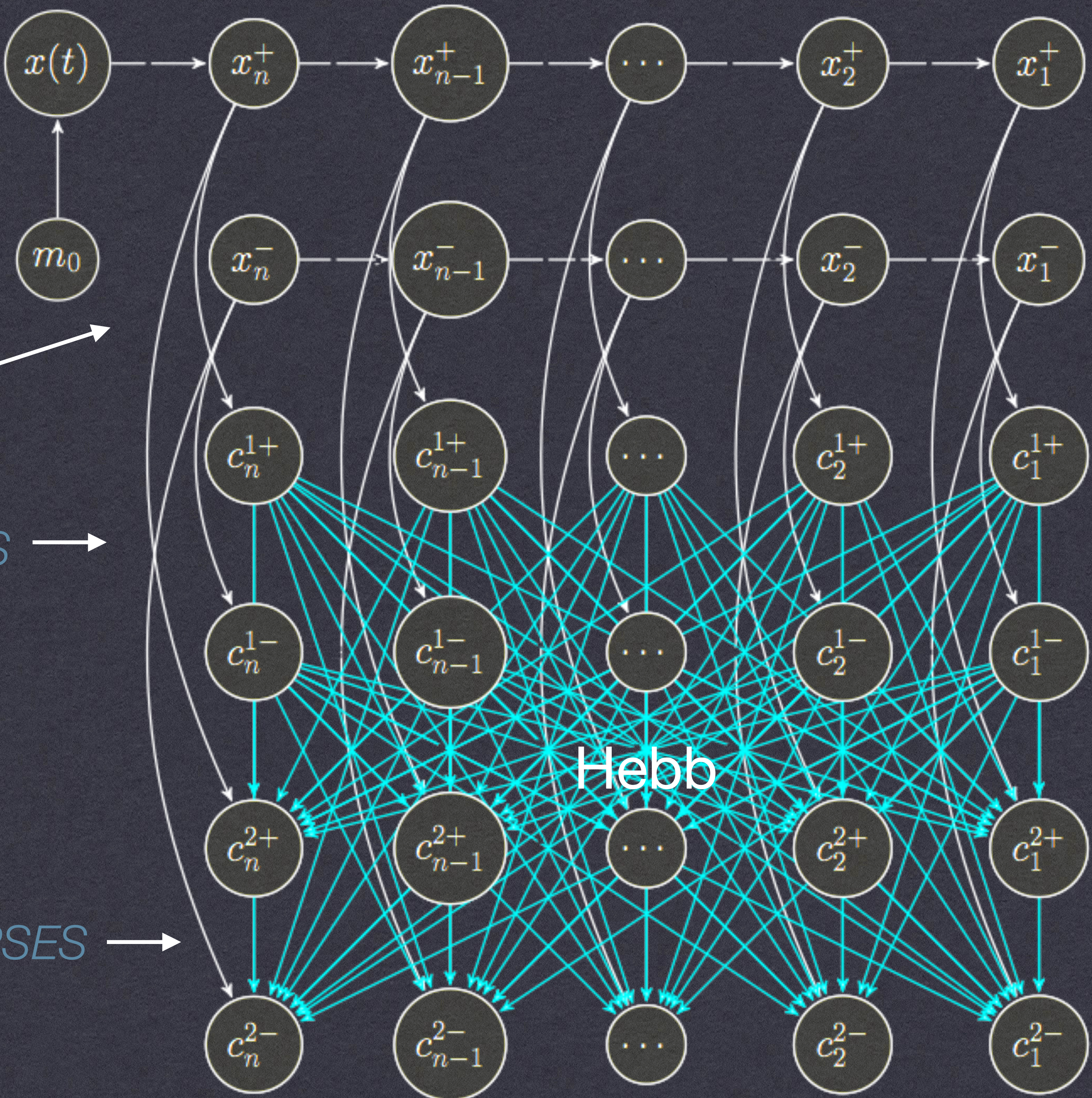


STOCHASTIC TIME SERIES DIVIDED INTO POS AND NEG PARTS

SHORT-TERM MEMORY

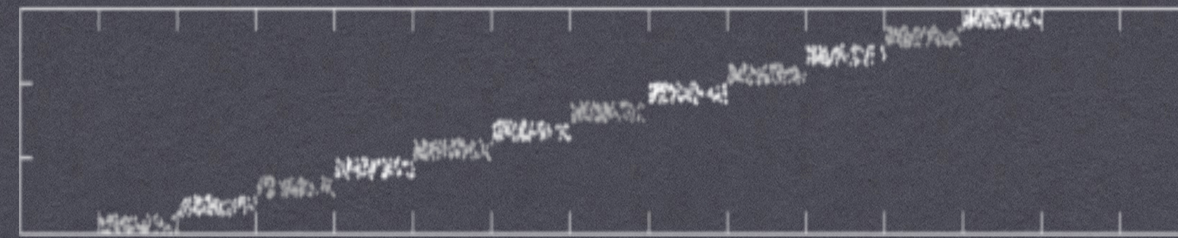
INPUT TO HEBBIAN SYNAPSES

OUTPUT FROM HEBBIAN SYNAPSES

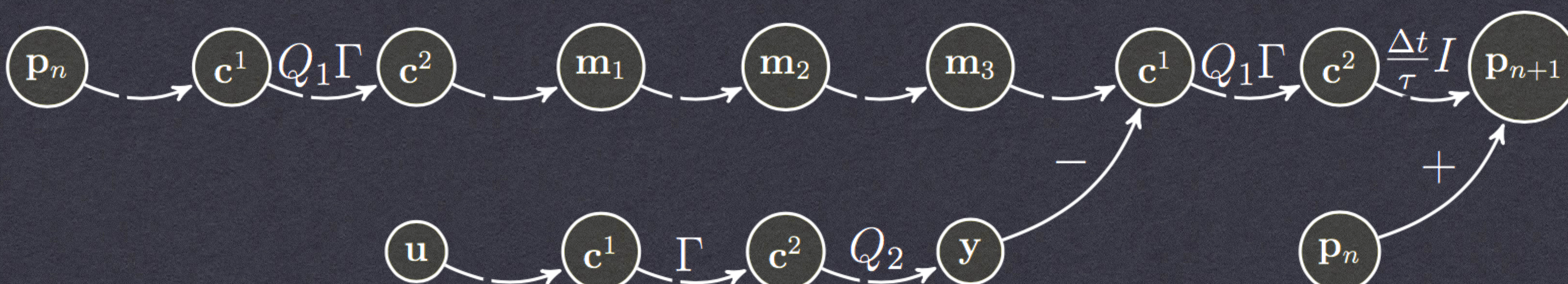


SHAO, SORNBORGER, TAO, *50th Asilomar Conference* (2016)

Gradient Descent/PMPY

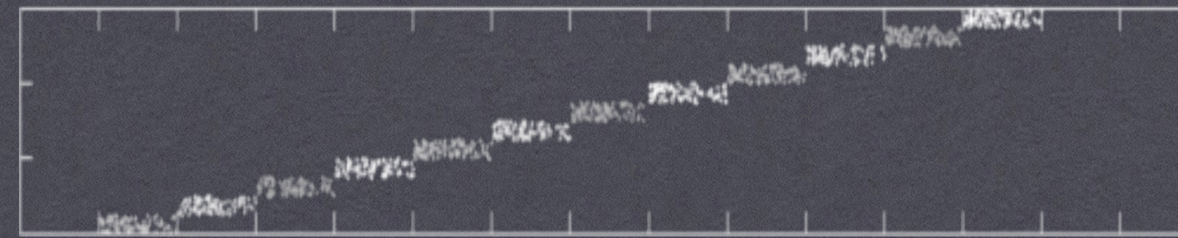


$$\mathbf{p}'_{n+1} = \mathbf{p}'_n + \frac{\Delta t}{\tau} Q_1 \Gamma' \left(\boldsymbol{\gamma}' - Q_1 \Gamma' \mathbf{p}'_n\right)$$

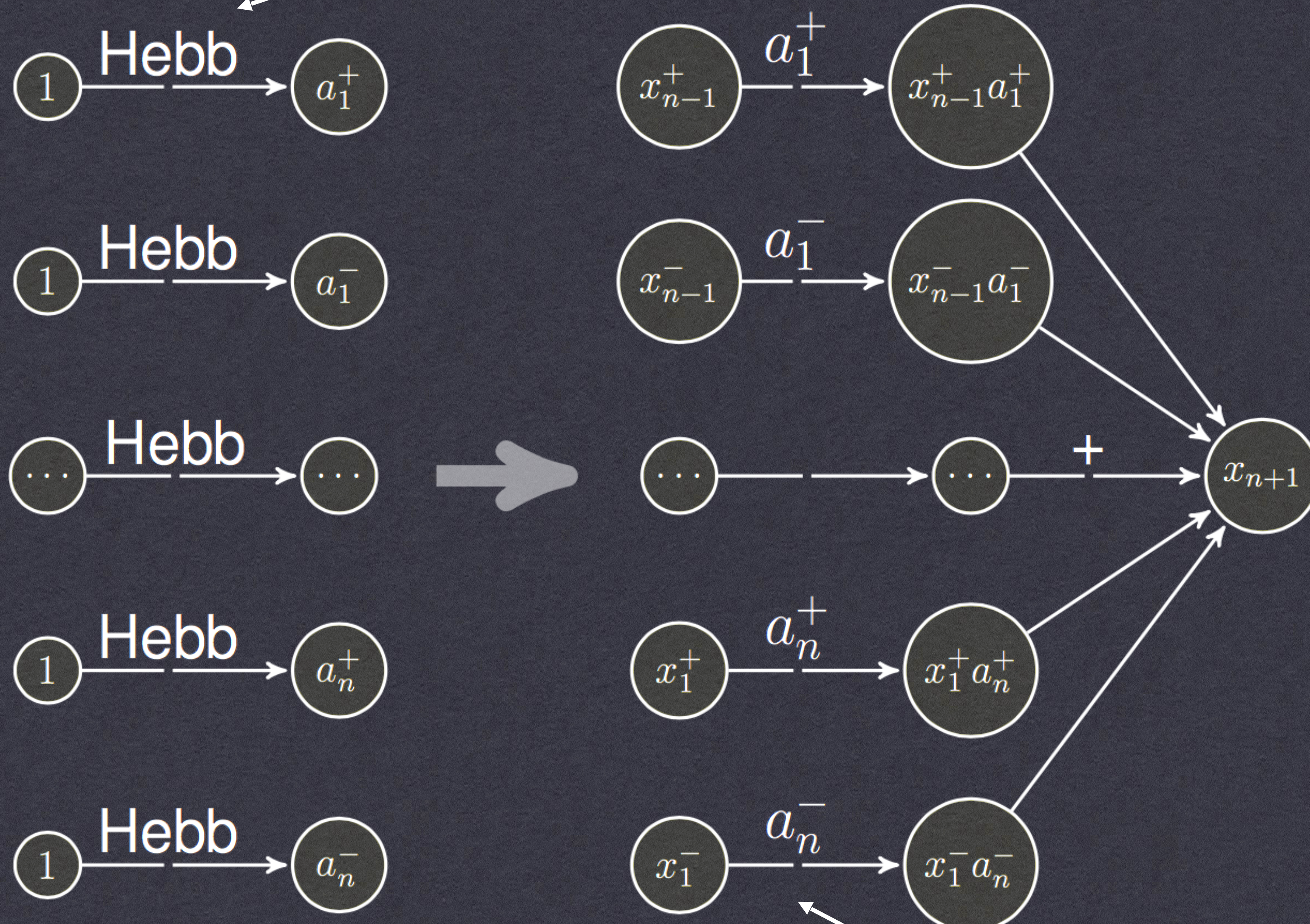


SHAO, SORNBORGER, TAO, *50th Asilomar Conference* (2016)

Learning



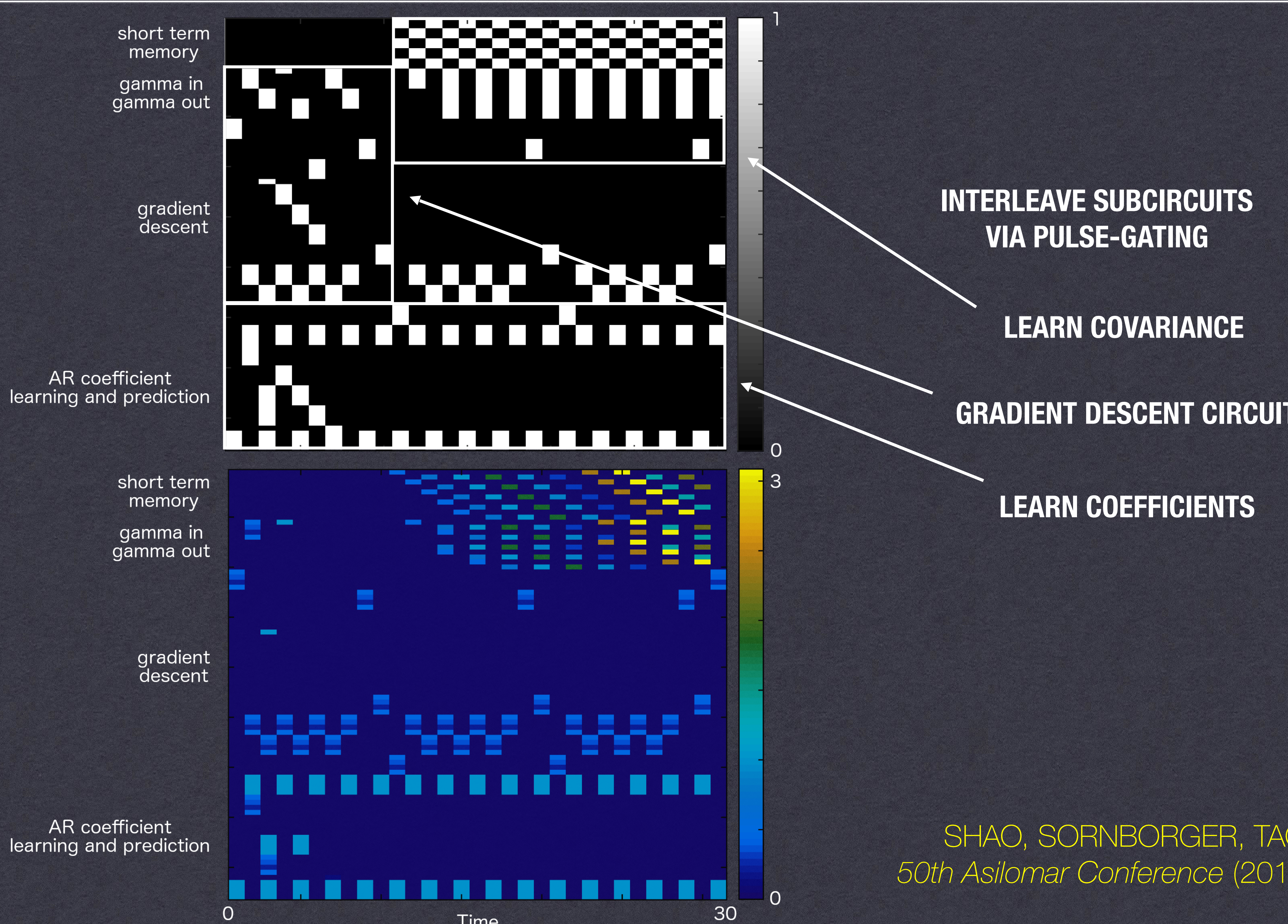
"BURN IN" OF PROCESS COEFFICIENTS WITH HEBBIAN SYNAPSES



USE PROCESS COEFFICIENTS FOR PREDICTION

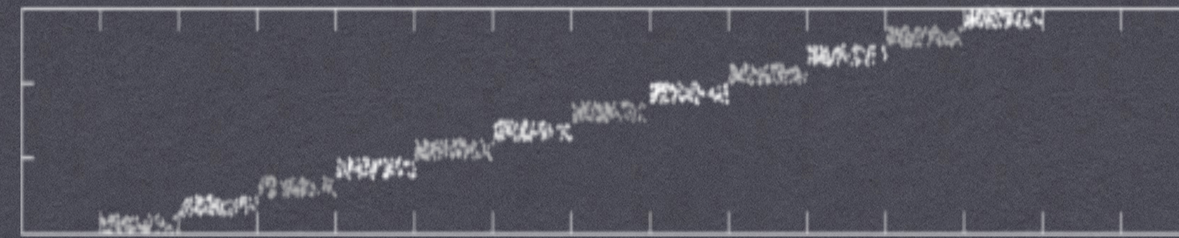
SHAO, SORNBORGER, TAO, *50th Asilomar Conference* (2016)

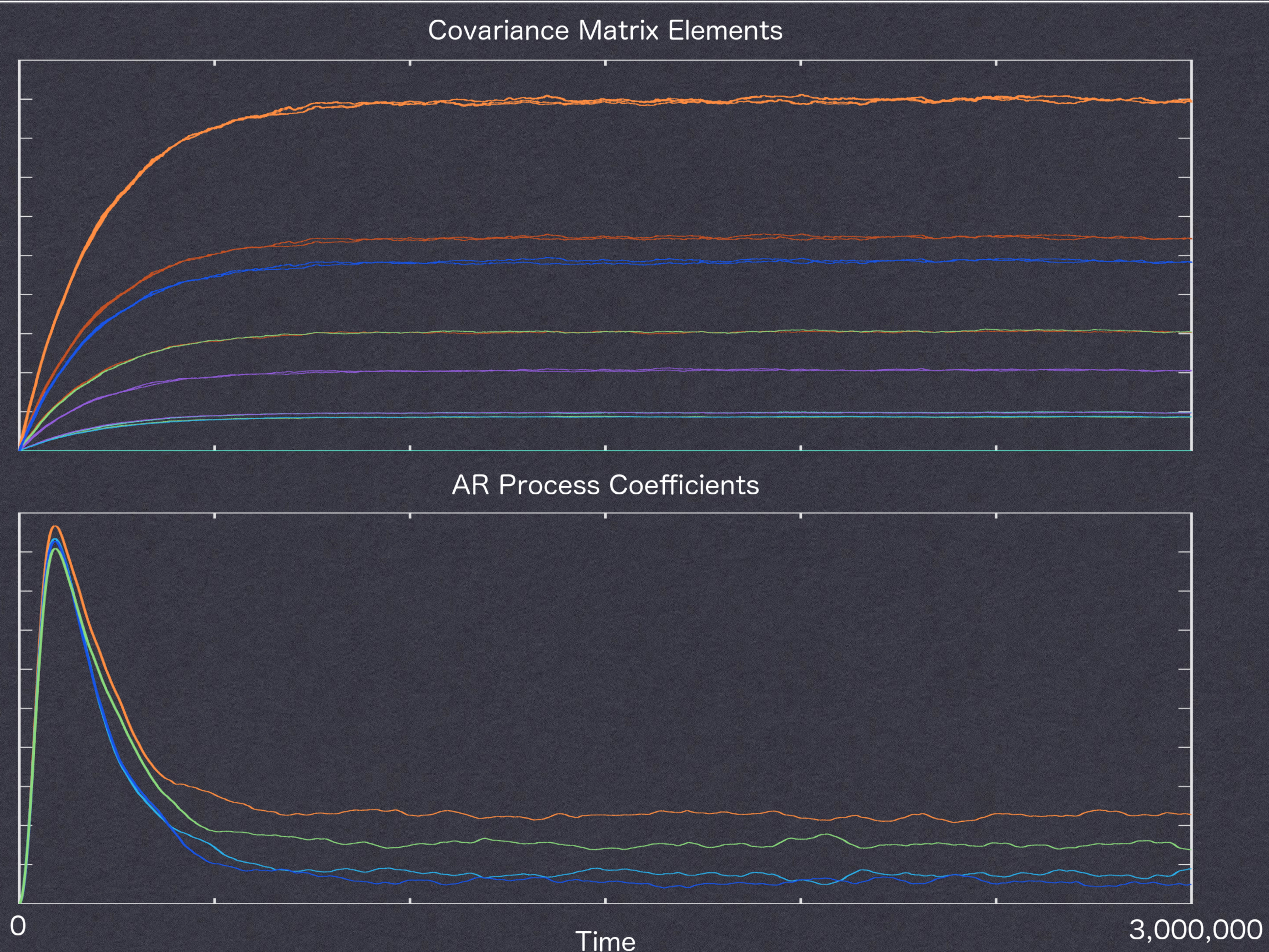
Learning



SHAO, SORNBORGER, TAO,
50th Asilomar Conference (2016)

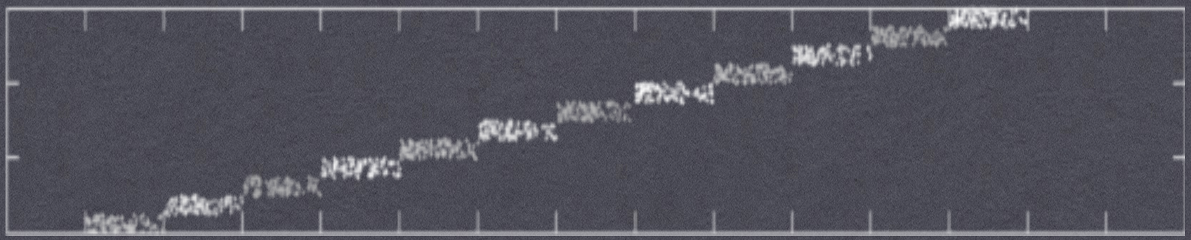
Learning





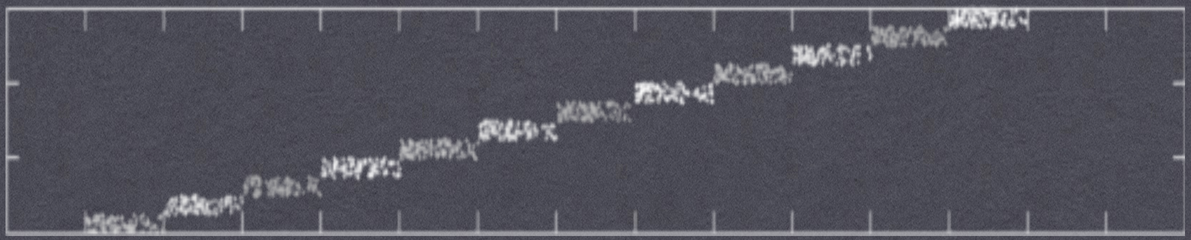
SHAO, SORNBORGER, TAO, *50th Asilomar Conference* (2016)

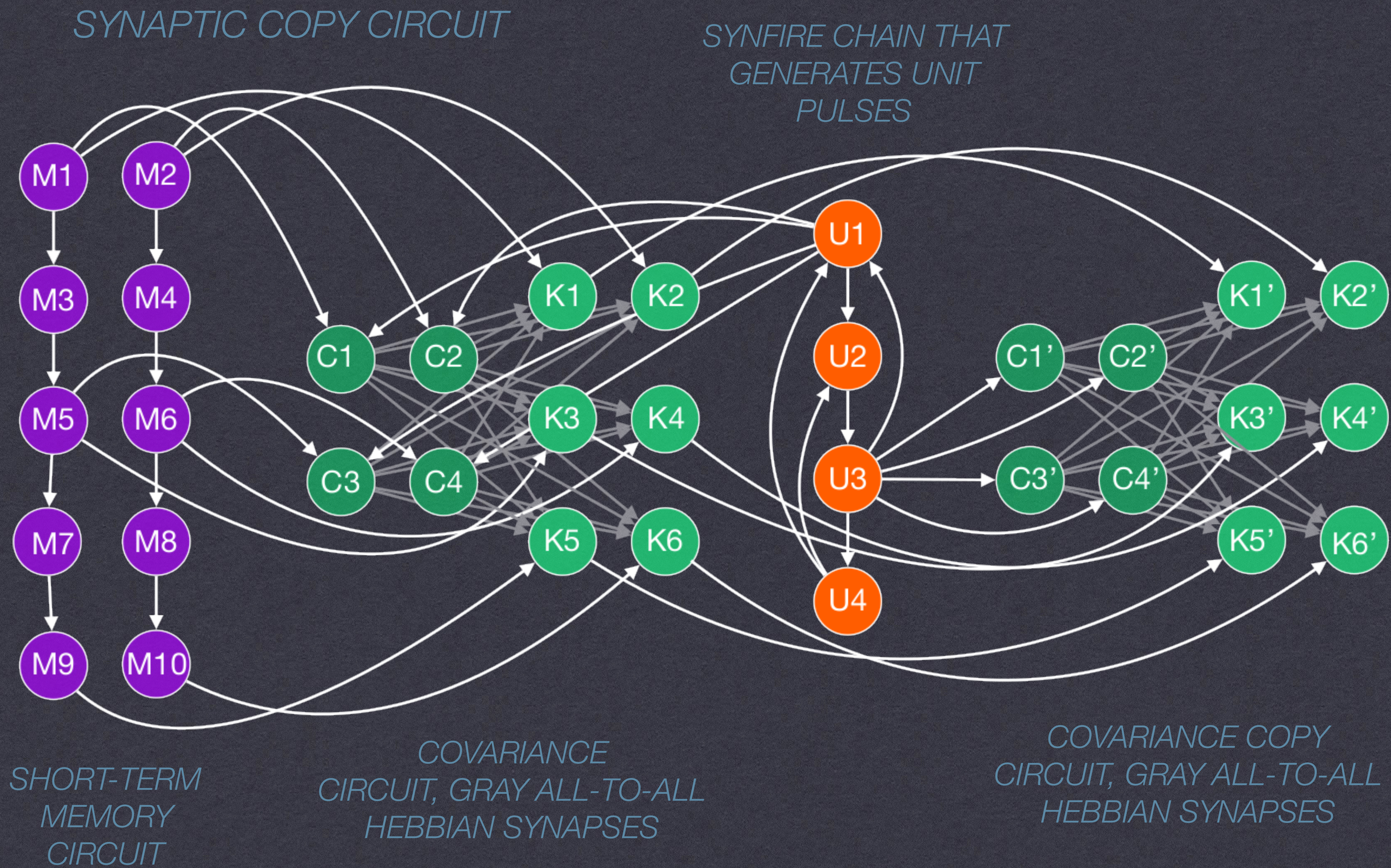
Synaptic Copy



WE WILL USE ESSENTIALLY THE SAME MECHANISMS THAT WE USED TO LEARN AN AR PROCESS IN THE SYNAPTIC COPY CIRCUIT, WITH ONE ADDITION.

Synaptic Copy





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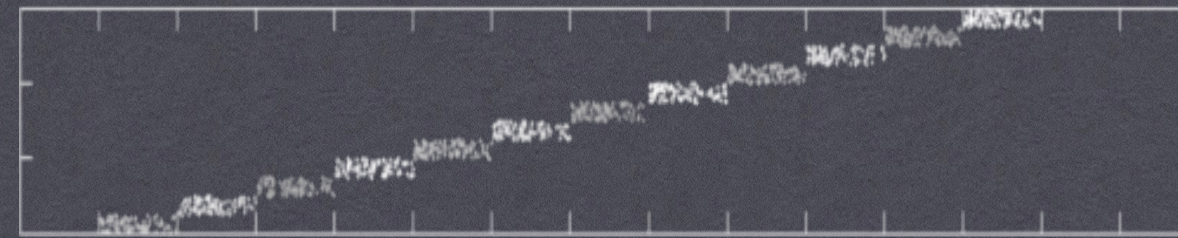
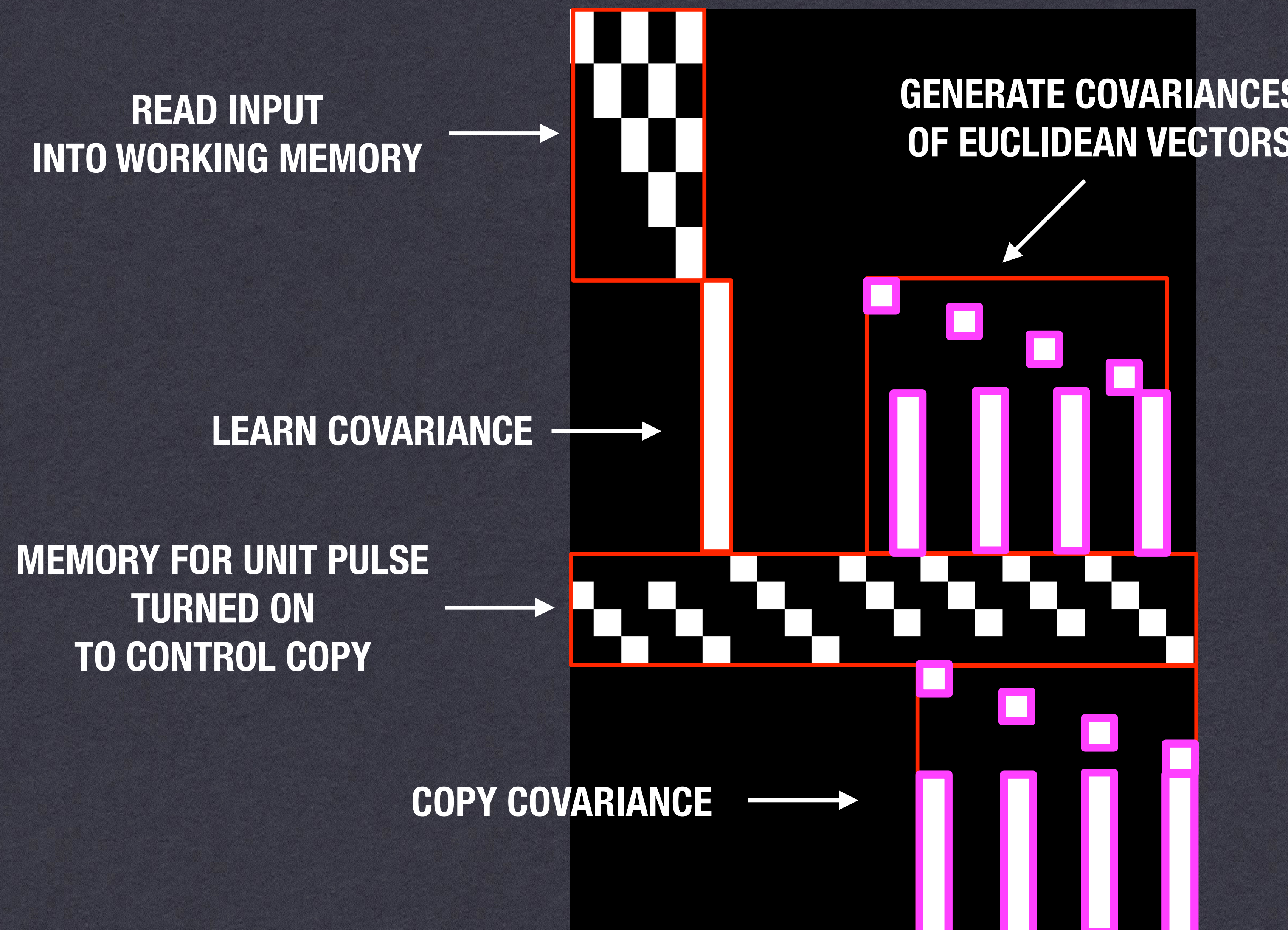


PULSE SEQUENCE TO COPY SYNAPTIC VALUES FROM ONE NEURAL REGION TO ANOTHER

GENERATE TRANSFORMS OF EUCLIDEAN VECTORS AND COPY TO EITHER SIDE OF NEW HEBBIAN SYNAPSES

EFFECTIVELY A GREEN'S FUNCTION TECHNIQUE



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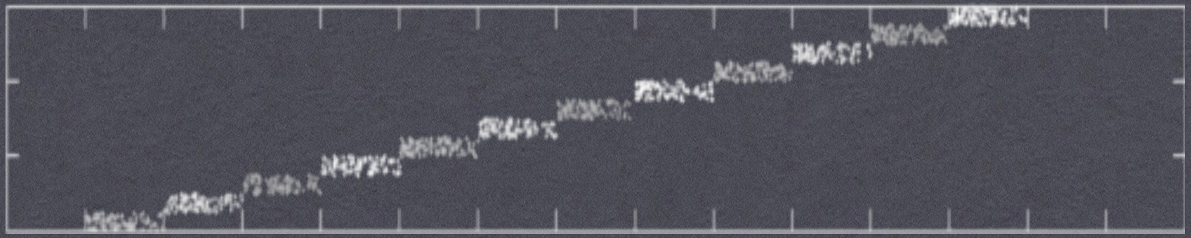
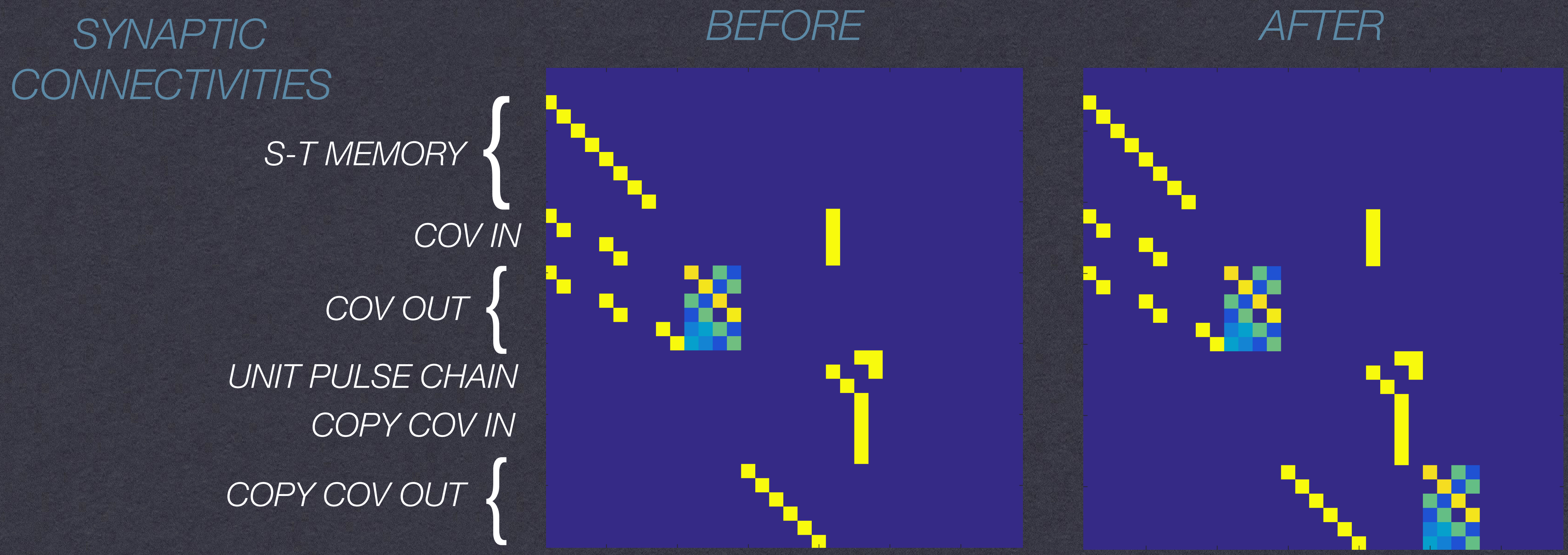
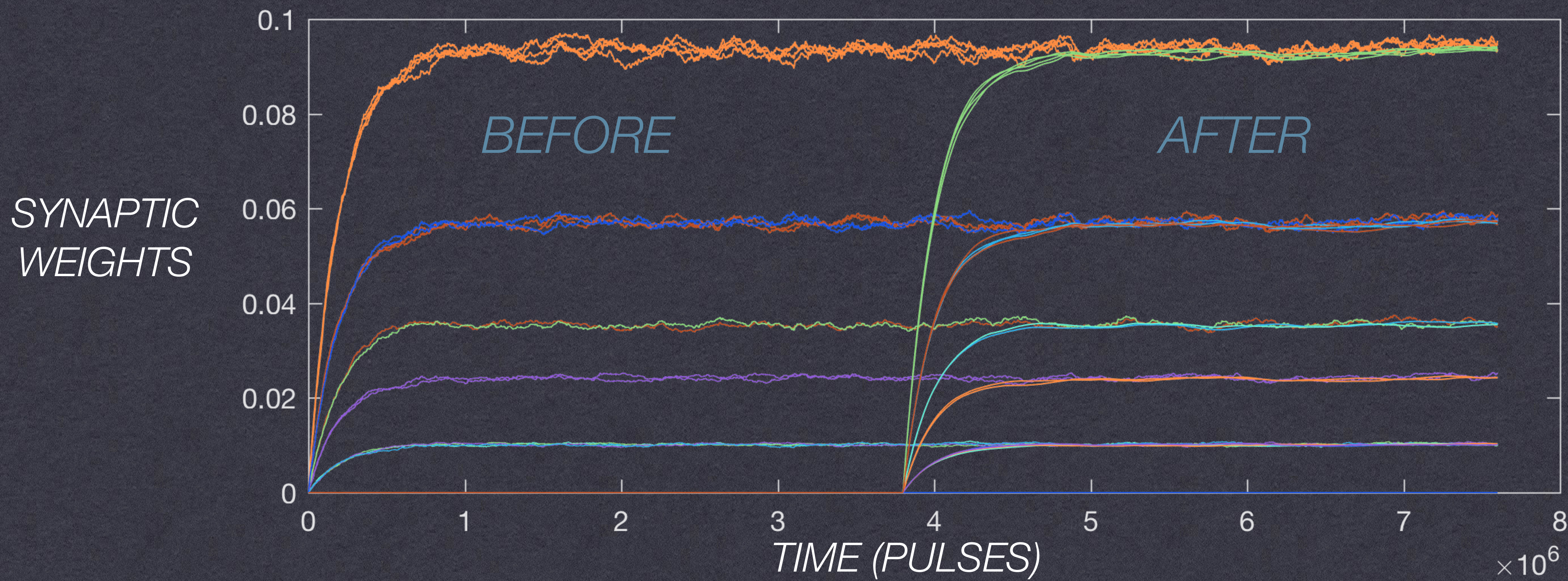
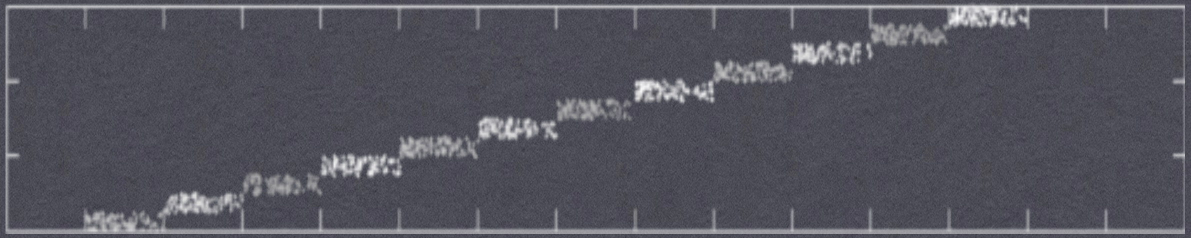






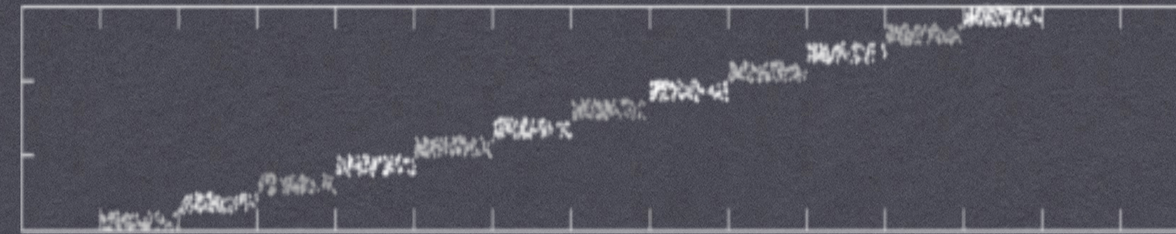
Conclusions

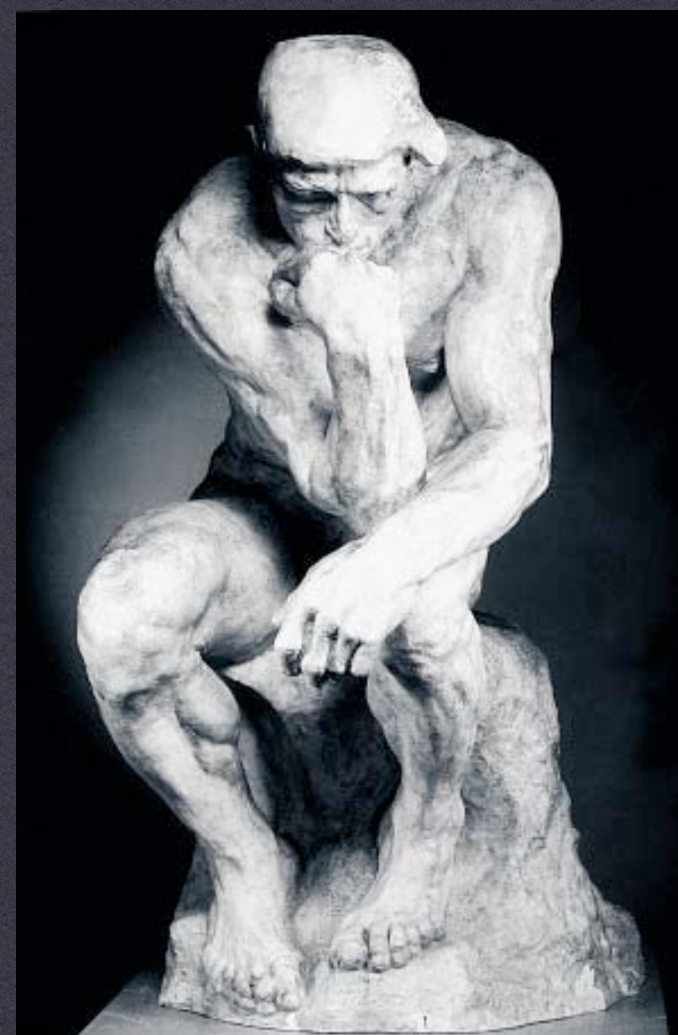


- *USING PULSE-GATING TO PRECISELY CONTROL INFORMATION PROPAGATION, WE HAVE IMPLEMENTED A CIRCUIT CAPABLE OF FIRST LEARNING A STOCHASTIC PROCESS, THEN TRANSFERRING THE LEARNED SYNAPSES TO A SECONDARY CIRCUIT.*

- *THE TRANSFER CIRCUIT MAKES USE OF NESTED OSCILLATIONS AND OPERATES INDEPENDENTLY OF THE PROCESS USED TO LEARN THE INFORMATION THAT IS TRANSFERRED, TWO CHARACTERISTICS OF SLEEP CONSOLIDATION OF MEMORY*

Questions?





WHAT I CANNOT CREATE,
I DO NOT UNDERSTAND