A general theory of learning and memory with Complex Synapses
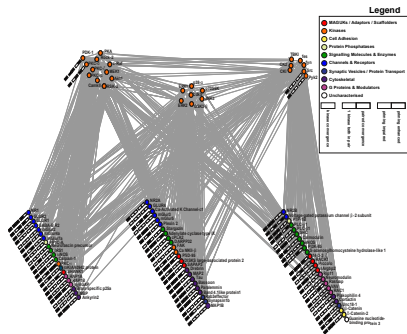
Subhaneil Lahiri

Stanford University, Applied Physics
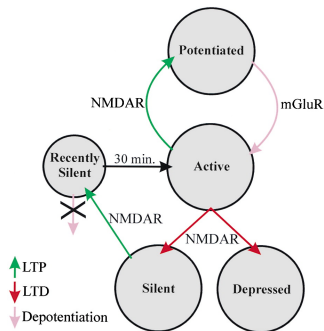
September 1, 2014

see: S. Lahiri and S. Ganguli, "*A memory frontier for complex synapses*,"
Advances in Neural Information Processing Systems 26, pages 1034–1042. 2013.
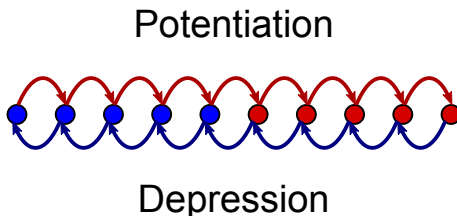
Synapses are complex

[Coba et al. (2009)]

[Montgomery and Madison (2002)]
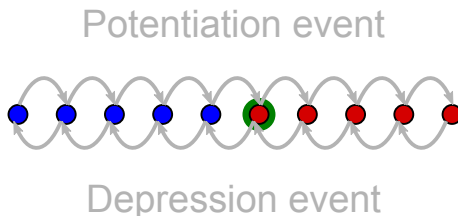
Models of complex synaptic dynamics

- Internal functional state of synapse $\rightarrow$ synaptic weight.
- Candidate plasticity events $\rightarrow$ transitions between states

● weak
● strong

Potentiation

Depression

[Fusi et al. (2005), Fusi and Abbott (2007), Barrett and van Rossum (2008)]
[Lahiri and Ganguli (2013)]

- Internal functional state of synapse $\rightarrow$ synaptic weight.   ● weak
- Candidate plasticity events $\rightarrow$ transitions between states   ● strong

Potentiation event

Depression event

[Fusi et al. (2005), Fusi and Abbott (2007), Barrett and van Rossum (2008)]
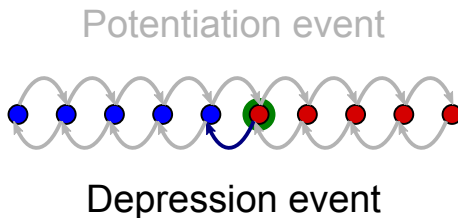[Lahiri and Ganguli (2013)]

- Internal functional state of synapse $\rightarrow$ synaptic weight.
- Candidate plasticity events $\rightarrow$ transitions between states

● weak

● strong

Potentiation event

Depression event

[Fusi et al. (2005), Fusi and Abbott (2007), Barrett and van Rossum (2008)]
[Lahiri and Ganguli (2013)]

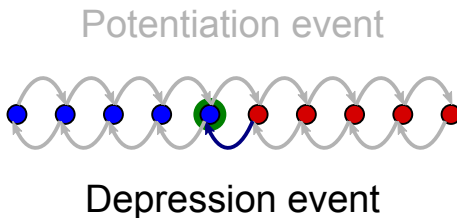# Models of complex synaptic dynamics

- Internal functional state of synapse $\rightarrow$ synaptic weight.
- Candidate plasticity events $\rightarrow$ transitions between states

● weak
● strong

Potentiation event

Depression event

[Fusi et al. (2005), Fusi and Abbott (2007), Barrett and van Rossum (2008)]
[Lahiri and Ganguli (2013)]

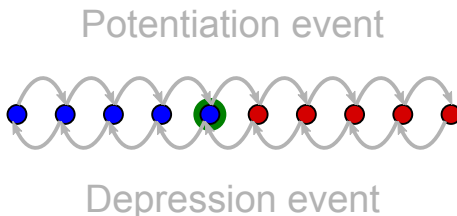# Models of complex synaptic dynamics

- Internal functional state of synapse $\rightarrow$ synaptic weight.
- Candidate plasticity events $\rightarrow$ transitions between states

● weak
● strong

Potentiation event

Depression event

[Fusi et al. (2005), Fusi and Abbott (2007), Barrett and van Rossum (2008)]
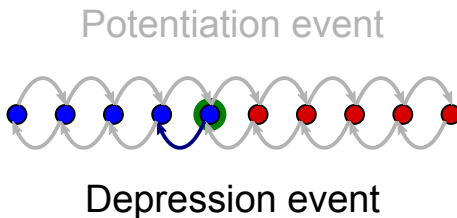[Lahiri and Ganguli (2013)]

- Internal functional state of synapse $\rightarrow$ synaptic weight.
- Candidate plasticity events $\rightarrow$ transitions between states

● weak
● strong

Potentiation event

Depression event

[Fusi et al. (2005), Fusi and Abbott (2007), Barrett and van Rossum (2008)]
[Lahiri and Ganguli (2013)]
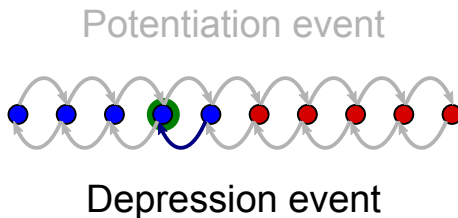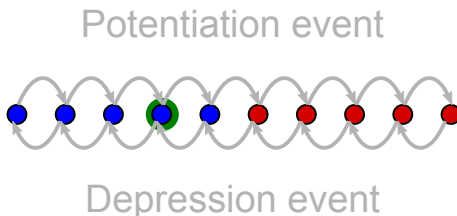
Models of complex synaptic dynamics

- Internal functional state of synapse $\rightarrow$ synaptic weight.
- Candidate plasticity events $\rightarrow$ transitions between states

● weak

● strong

Potentiation event

Depression event

[Fusi et al. (2005), Fusi and Abbott (2007), Barrett and van Rossum (2008)]
[Lahiri and Ganguli (2013)]

Models of complex synaptic dynamics

- Internal functional state of synapse $\rightarrow$ synaptic weight.
- Candidate plasticity events $\rightarrow$ transitions between states

● weak
● strong

Potentiation event

Depression event

[Fusi et al. (2005), Fusi and Abbott (2007), Barrett and van Rossum (2008)]
[Lahiri and Ganguli (2013)]

- Internal functional state of synapse $\rightarrow$ synaptic weight.
- Candidate plasticity events $\rightarrow$ transitions between states

● weak
● strong
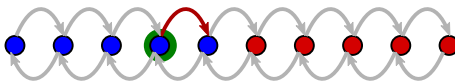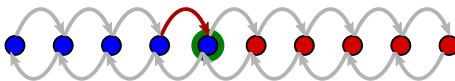
Potentiation event

Depression event

[Fusi et al. (2005), Fusi and Abbott (2007), Barrett and van Rossum (2008)]
[Lahiri and Ganguli (2013)]

Models of complex synaptic dynamics

- Internal functional state of synapse $\rightarrow$ synaptic weight.
- Candidate plasticity events $\rightarrow$ transitions between states
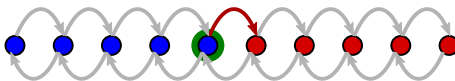
● weak

● strong

Potentiation event

Depression event

[Fusi et al. (2005), Fusi and Abbott (2007), Barrett and van Rossum (2008)]
[Lahiri and Ganguli (2013)]

Models of complex synaptic dynamics

- Internal functional state of synapse → synaptic weight.
- Candidate plasticity events → transitions between states

● weak
● strong
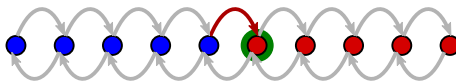
Potentiation event

Depression event

[Fusi et al. (2005), Fusi and Abbott (2007), Barrett and van Rossum (2008)]
[Lahiri and Ganguli (2013)]

Models of complex synaptic dynamics

- Internal functional state of synapse $\rightarrow$ synaptic weight.
- Candidate plasticity events $\rightarrow$ transitions between states
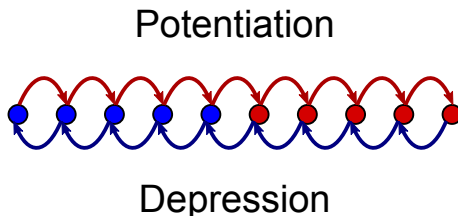
● weak

● strong

Potentiation event

Depression event

[Fusi et al. (2005), Fusi and Abbott (2007), Barrett and van Rossum (2008)]
[Lahiri and Ganguli (2013)]
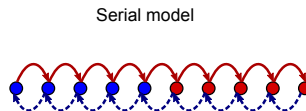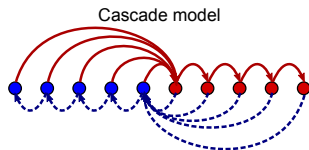
Models of complex synaptic dynamics

- Internal functional state of synapse $\rightarrow$ synaptic weight.
- Candidate plasticity events $\rightarrow$ transitions between states

● weak
● strong

Potentiation

Depression

[Fusi et al. (2005), Fusi and Abbott (2007), Barrett and van Rossum (2008)]
[Lahiri and Ganguli (2013)]

Example models
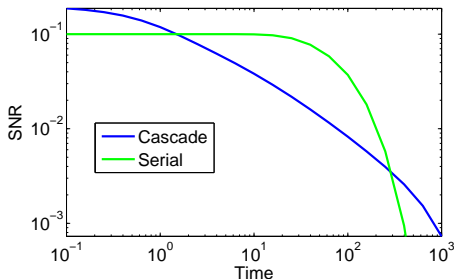
Two example models of complex synapses.

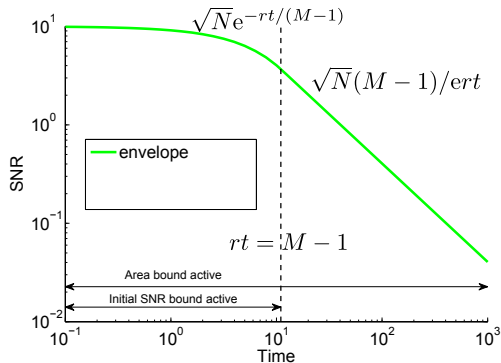Cascade model   Serial model

[Fusi et al. (2005), Leibold and Kempter (2008), Ben-Dayan Rubin and Fusi (2007)]

These have different memory storage properties

Memory curve envelope
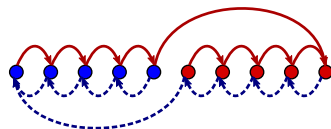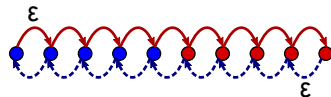
Memory curve envelope
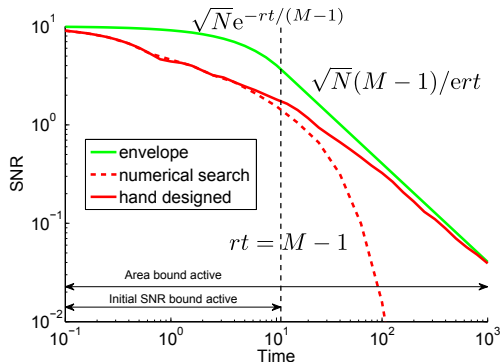
M. P. Coba, A. J. Pocklington, M. O. Collins, M. V. Kopanitsa, R. T. Uren, S. Swamy, M. D. Croning, J. S. Choudhary, and S. G. Grant.

"Neurotransmitters drive combinatorial multistate postsynaptic density networks".

Sci Signal, 2(68):ra19, (2009) .

2

Johanna M. Montgomery and Daniel V. Madison.

"State-Dependent Heterogeneity in Synaptic Depression between Pyramidal Cell Pairs".

Neuron, 33(5):765 – 777, (2002) .

2

S. Fusi, P. J. Drew, and L. F. Abbott.

"Cascade models of synaptically stored memories".

Neuron, 45(4):599–611, (Feb, 2005) .

3 4 5 6 7 8 9 10 11 12 13 14 15 16

S. Fusi and L. F. Abbott.

"Limits on the memory storage capacity of bounded synapses".

Nat. Neurosci., 10(4):485–493, (Apr, 2007) .

3 4 5 6 7 8 9 10 11 12 13 14 15

A. B. Barrett and M. C. van Rossum.

"Optimal learning rules for discrete synapses".

PLoS Comput. Biol., 4(11):e1000230, (Nov, 2008) .

3 4 5 6 7 8 9 10 11 12 13 14 15

📄 Subhaneil Lahiri and Surya Ganguli.

"A memory frontier for complex synapses".

In C.J.C. Burges, L. Bottou, M. Welling, Z. Ghahramani, and K.Q. Weinberger, editors, *Advances in Neural Information Processing Systems 26*, pages 1034–1042. 2013.

(3) (4) (5) (6) (7) (8) (9) (10) (11) (12) (13) (14) (15)

📄 Christian Leibold and Richard Kempter.

"Sparseness Constrains the Prolongation of Memory Lifetime via Synaptic Metaplasticity".

Cerebral Cortex, 18(1):67–77, (2008) .

(16)

📄 Daniel D Ben-Dayan Rubin and Stefano Fusi.

"Long memory lifetimes require complex synapses and limited sparseness".

Frontiers in computational neuroscience, 1(November):1–14, (2007) .

(16)