Spaun

Kevin Ye

THE UNIVERSITY OF TENNESSEE KNOXVILLE

Kevin Ye

- 5-year Masters in Computer Science
  - Coursework-only
- Intern at Siemens Molecular Imaging

Large Scale Neural Simulations

“’If just reproducing the brain is the aim,
then there are better (presumably fun) ways to do that.
If we just want to simulate a real brain with all details,
maybe we should just reproduce.’ Anonymous[1]”

[1] M. Colombo, “Why build a virtual brain? Large-scale neural simulations as jump start for cognitive computing”, *Journal of Experimental & Theoretical Artificial Integlligence,* vol. 29, no. 2, Feb. 2016.

Large Scale Neural Simulations

What do you get out of a large scale neural simulation?

- Computational modeling experience[1]
- Solve complex problems by mimicking the brain[1]
- Model expression of physical changes to brains in behavior

[1] M. Colombo, "Why build a virtual brain? Large-scale neural simulations as jump start for cognitive computing", *Journal of Experimental & Theoretical Artificial Integlligence*, vol. 29, no. 2, Feb. 2016.

Large Scale Neural Simulations

- Human Brain Project
  - Centered around the IBM Blue Brain Project
  - 37 million neurons [2]
- DARPA Synapse Project
  - 500 million neurons, 5x more than human brain [2]
- Semantic Pointer Architecture Unified Network (Spaun)
  - 2.5 million neurons

[2] C. Eliasmith, and O. Trujillo, "The use and abuse of large-scale brain models", *Current Opinion in Neurobiology*, vol. 25, pp. 1-6, Apr. 2014.

Large Scale Neural Simulations

- Human Brain Project – Henry Markram
  - Centered around the IBM Blue Brain Project
  - 100,000 neurons [2]
- Semantic Pointer Architecture Unified Network (SPAUN) – Chris Eliasmith

[2] C. Eliasmith, and O. Trujillo, "The use and abuse of large-scale brain models", *Current Opinion in Neurobiology*, vol. 25, pp. 1-6, Apr. 2014.

SPAUN

- Focuses on link between brain and behavior
- Can perform 8 tasks
- Hardwired – cannot learn [3]
- Has an eye and 2 degree of f

Fig. 1. Spaun high level overview

[3] E. Waltz, “Brain Model Connects Neurons to Behavior”, *IEEE Spectrum*, 30, Nov. 2012. [Online]. Available: https://spectrum.ieee.org/tech-talk/computing/software/brain-model-connects-neurons-to-behavior. [Accessed: Apr. 24, 2018].

SPAUN Tasks

1. Copy Drawing
2. Image Recognition – given digit, reproduce (default handwriting)
3. 3-armed bandit trial
4. Serial Working Memory – reproduce list
5. Counting – essentially sum two values.
6. Answer Questions
7. Rapid Variable creation – given pattern, create new pattern
8. Fluid Reasoning – similar to Raven's Matrix test [4]

[4] C. Eliasmith, T. C. Stewart, et al., "A Large-Scale Model of the Functioning Brain", *Science*, vol. 338, no. 1202, Nov. 2012

Task Examples

- Tracing from memory
- Given digit in random handwriting style
- Reproduce digit from memory
- Treat different stimuli as same tokens
- Detect variation [5]

Fig. 2. As shown in [5, Fig. 3], Spaun is able to (given a digit in any handwriting), reproduce it from memory of 5 known copies of digits

[5] T. C. Stewart, Feng-Xuan Choo, and C. Eliasmith, "Spaun: A Perception-Cognition-Action Model Using Spiking Neurons", *Proceedings of the Annual Meeting of the Cognitive Science Society*, vol. 34, no. 34, 2012

Task Examples

- Fluid Reasoning
- https://youtu.be/qcZe-2eWaeM

Semantic Pointer Architecture

- Semantic Pointer hypothesis - “Higher-level cognitive functions in biological systems are made possible by semantic pointers. Semantic pointers are neural representations that carry partial semantic content and are composable into the representational structures necessary to support complex cognition.” [6]
- Spaun uses semantic pointers to store high-level, low-dimensional representations of images [5].
- Maintain relationships from image space
- “Dereferenced” to get motor commands

[6] University of Waterloo, “Semantic Pointer Architecture”, Computational Neuroscience Resesarch Group at Waterloo Centre for Theoretical Neuroscience [Online]. Available: http://compneuro.uwaterloo.ca/research/spa/semantic-pointer-architecture.html. [Accessed: Apr. 24, 2018].

[5] T. C. Stewart, Feng-Xuan Choo, and C. Eliasmith, “Spaun: A Perception-Cognition-Action Model Using Spiking Neurons”, *Proceedings of the Annual Meeting of the Cognitive Science Society*, vol. 34, no. 34, 2012

Neural Engineering Framework

- NEF converts algorithms to spiking neuron models [6].
- Uses Leaky Integrate-and-Fire neurons*
  a) Neuron groups represent vectors
  b) Connections specify computation

* Subject to criticism from Markram

[5] T. C. Stewart, Feng-Xuan Choo, and C. Eliasmith, "Spaun: A Perception-Cognition-Action Model Using Spiking Neurons", *Proceedings of the Annual Meeting of the Cognitive Science Society*, vol. 34, no. 34, 2012

Leaky Integrate-and-Fire

- A simplified version of the Integrate and Fire model.
- $\tau_m \frac{du}{dt} = -[u(t) - u_{rest}] + RI(t)$
- If $u(t) = \Theta$ then $\lim_{\delta \to 0; \delta > 0} u(t + \delta) = u_r$ [7]

[7] W. Gerstner, W. M. Kistler, et al., *Neuronal Dynamics*. Place: Cambridge University Press, July 2014. [Online] Available: http://neuronaldynamics.epfl.ch/book.html.

Leaky Integrate-and-Fire

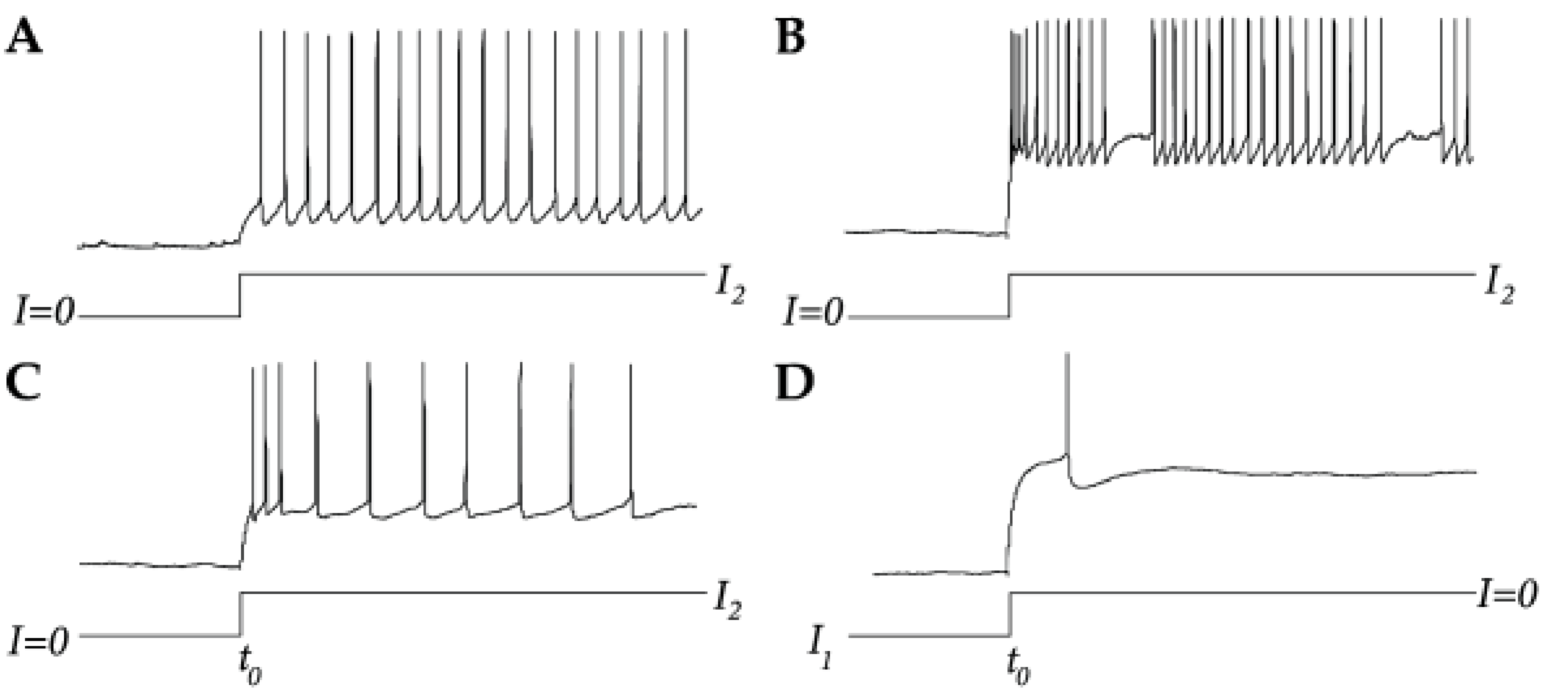

Fig. 3. As seen in [7, Fig. 1.10], (A) shows neurons with short intervals and no adaption. (B) shows neurons with short spiking intervals with a "stutter". (C) Shows more regular neuron spiking with adaptation. (D) shows a neuron that also has a inhibitory rebound spike.

[6] W. Gerstner, W. M. Kistler, et al., *Neuronal Dynamics*. Place: Cambridge University Press, July 2014. [Online] Available: http://neuronaldynamics.epfl.ch/book.html.

Neural Engineering Framework

1. $J = \alpha e \cdot x + J_{bias}$
2. $d = \Gamma^{-1}\Upsilon$
    - $\Gamma_{ij} = \int a_i a_j dx$
    - $\Upsilon_j = \int a_j x dx$
3. $\omega_{ij} = \alpha_j e_j M d_i$
4. $d^{f(x)} = \Gamma^{-1}\Upsilon,$
    - $\Gamma_{ij} = \int a_i a_j dx,$
    - $\Upsilon_j = \int a_j f(x) dx$

- [5, eq(1), eq(2), eq(3), eq(4)]

[5] T. C. Stewart, Feng-Xuan Choo, and C. Eliasmith, "Spaun: A Perception-Cognition-Action Model Using Spiking Neurons", *Proceedings of the Annual Meeting of the Cognitive Science Society*, vol. 34, no. 34, 2012

Spaun Anotomical Architecture

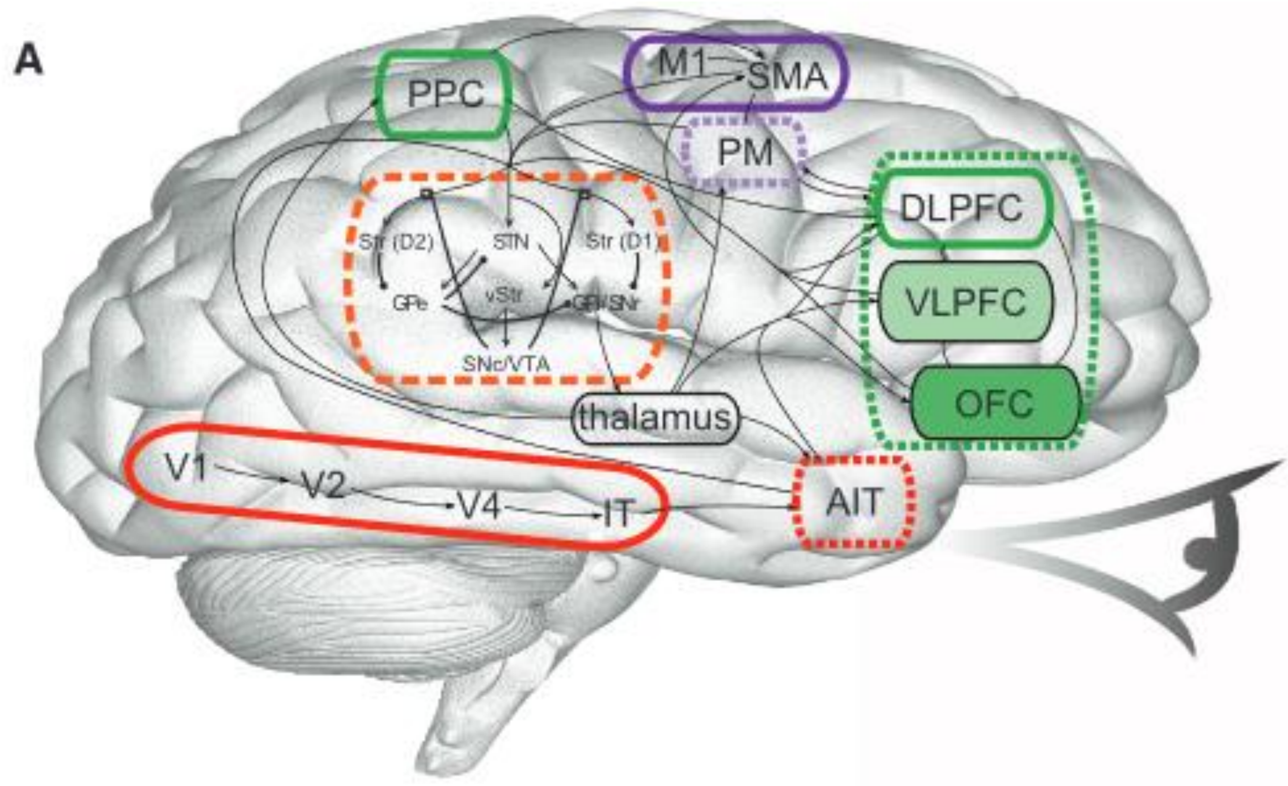

Fig. 4. [4, Fig. 1.] The anatomical structure of Spaun.

[4] C. Eliasmith, T. C. Stewart, et al., "A Large-Scale Model of the Functioning Brain", *Science*, vol. 338, no. 1202, Nov. 2012

Spaun Functional Architecture

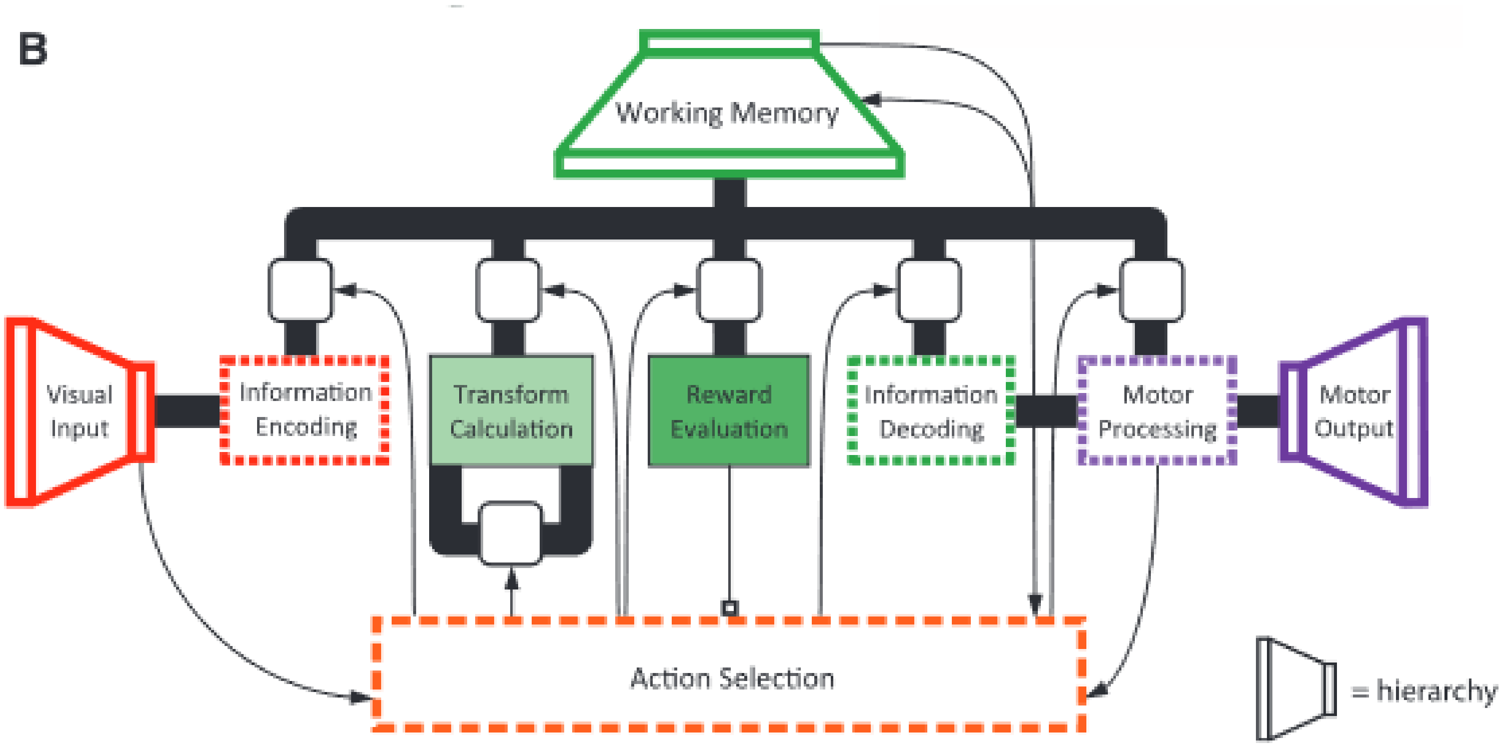

Fig. 5. [4, Fig 1B] Spaun functional architecture.

Criticism for Spaun

- Markram criticized Spaun due to the simplified Leaky-Integrate-And-Fire neurons.
- “It is not a brain model” [8].

[8] C. Eliasmith, J. Gosmann, and X. Choo, “BioSpaun: A large-scale behaving brain model with complex neurons” *CoRR* abs/1602.05220, Feb. 2016.

The Ultimate Showdown

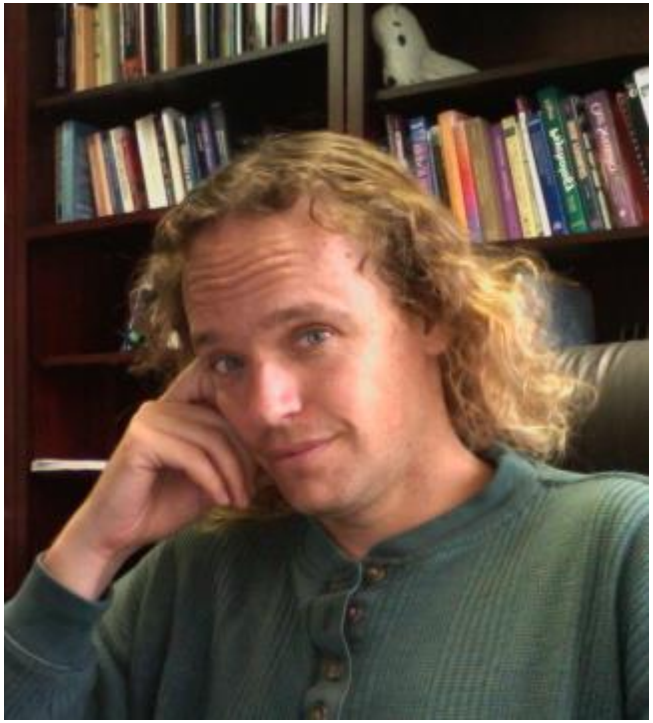

Fig. 6. Chris Eliasmith, professor University of Waterloo, creator of Spaun [9].

VS.

Fig. 7. Henry Markram, professor of Neuroscience at the Swiss Federal Institute of Technology, founder and director of the Big Blue Brain Project (Human Brain Project) [10].

[9] University of Waterloo, “Christ Eliasmith”, University of Waterloo, Nov. 2012. [Online] http://arts.uwaterloo.ca/~celiasmi/. [Accessed: Apr. 25, 2018].

[10] Ecole Polytechnique Federale De Lausanne, “Henry Markram”. [Online] Available: https://bluebrain.epfl.ch/people/henrymarkram. [Accessed: Apr. 25, 2018].

BioSpaun

- Replaced neurons in the model
- HBP Neurons:
  - 13 ion channels and 4 compartments
- BioSpaun Neurons
  - Pyrimidal Cell model
  - 20 compartments
  - 27 parameters and 9 ion channels [8].

[8] C. Eliasmith, J. Gosmann, and X. Choo, "BioSpaun: A large-scale behaving brain model with complex neurons" *CoRR* abs/1602.05220, Feb. 2016.

BioSpaun Neuron Comparison

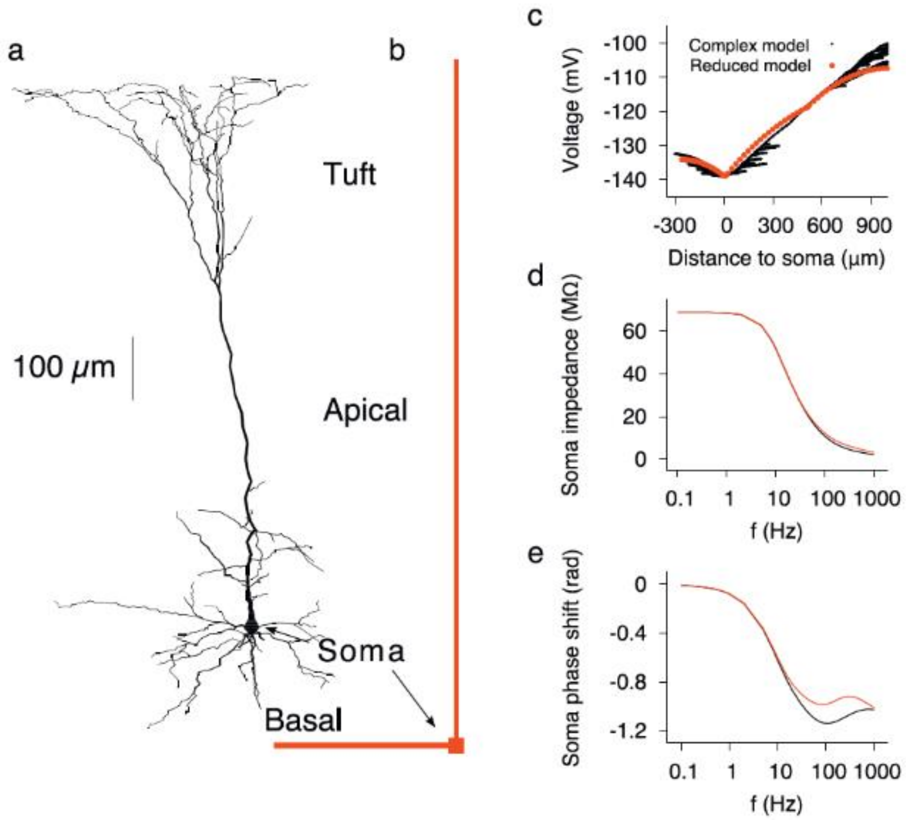

Fig. 8. [8, Fig. 2]. A) Neuron. C) Voltage at different locations in the cell. D) Somatic impedence. E) Somatic phase shift as a function of oscillatory input currents and membrane currents.

[8] C. Eliasmith, J. Gosmann, and X. Choo, "BioSpaun: A large-scale behaving brain model with complex neurons" *CoRR* abs/1602.05220, Feb. 2016.

BioSpaun Communication Comparison

- Circuit was constructed
- 200 input neurons
- 50 output neurons [8]
- Compartmentalized Neurons slightly noiser
- RMS Error
  - LIF – 0.1%
  - Compartment – 0.21%

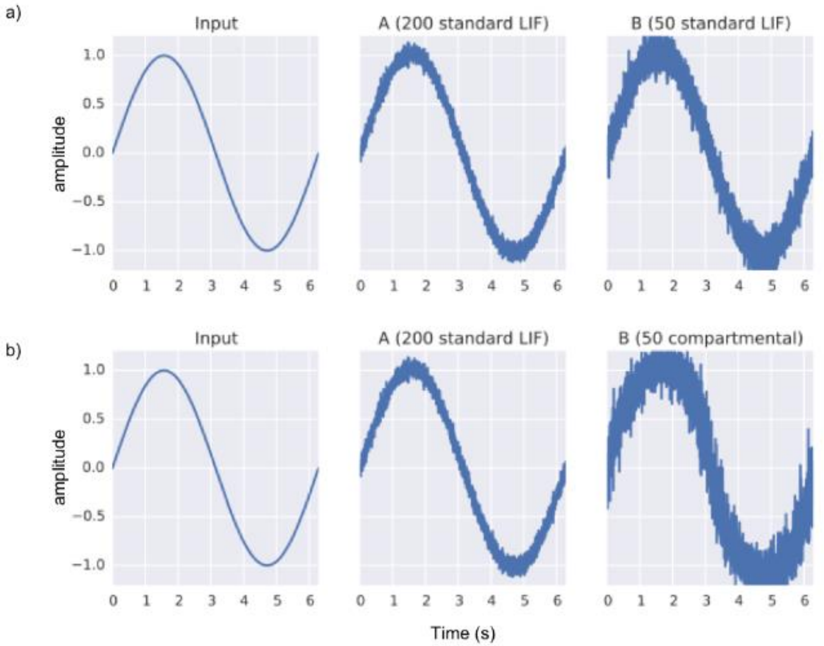

Fig. 9. Reproduced from [8, Fig. 3], a) shows information processing through a channel of LIF neurons whereas b) represents the same communication but via BioSpaun's compartmentalized neurons.

[8] C. Eliasmith, J. Gosmann, and X. Choo, "BioSpaun: A large-scale behaving brain model with complex neurons" *CoRR* abs/1602.05220, Feb. 2016.

BioSpaun Task Comparison

- Spaun had 94% accuracy in handwritten digit recognition.
- BioSpaun maintained that accuracy.
- TTX reduces performance.

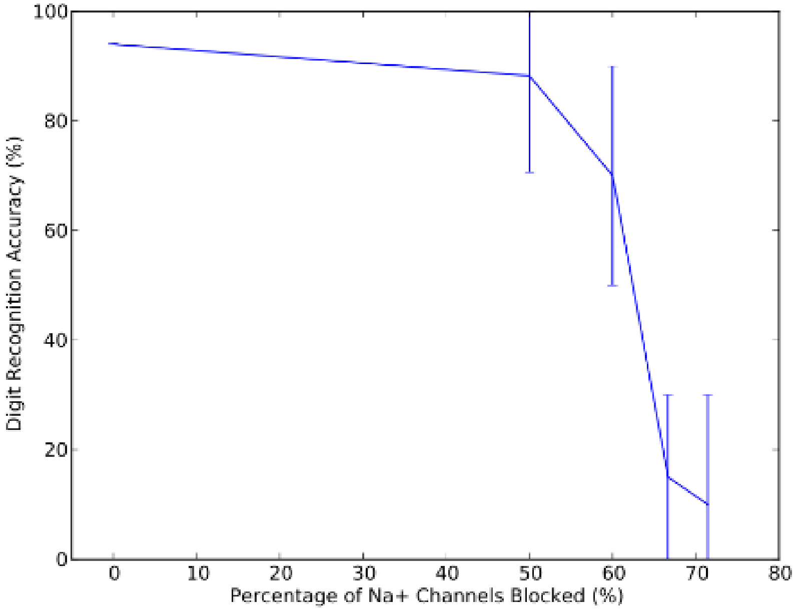

Fig. 10. Digit recognition accuracy. Leftmost value represents baseline accuracy. Reproduced from [8, Fig. 5.].

[8] C. Eliasmith, J. Gosmann, and X. Choo, "BioSpaun: A large-scale behaving brain model with complex neurons" *CoRR* abs/1602.05220, Feb. 2016.

Simulating Drug Effects

- Tetrodotoxin (TTX) blocks voltage gated sodium-ion channels.
- TTX effects were simulated in BioSpaun[8]

[8] C. Eliasmith, J. Gosmann, and X. Choo, "BioSpaun: A large-scale behaving brain model with complex neurons" *CoRR* abs/1602.05220, Feb. 2016.

Simulating Drug Effects

- Introducing TTX results in poorer performance
- Expected

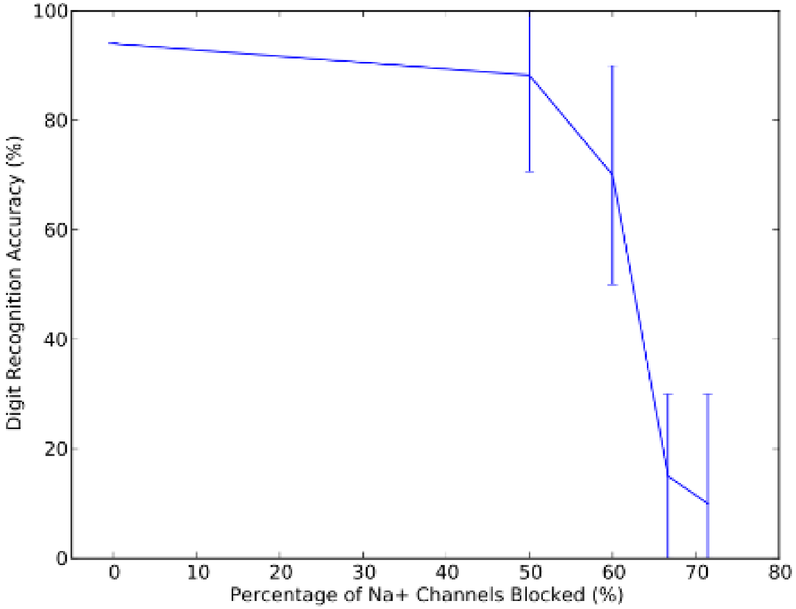

Fig. 11. Digit recognition accuracy. Leftmost value represents baseline accuracy. Reproduced from [8, Fig. 5.].

[8] C. Eliasmith, J. Gosmann, and X. Choo, "BioSpaun: A large-scale behaving brain model with complex neurons" *CoRR* abs/1602.05220, Feb. 2016.

Simulating Drug Effects (Counting)

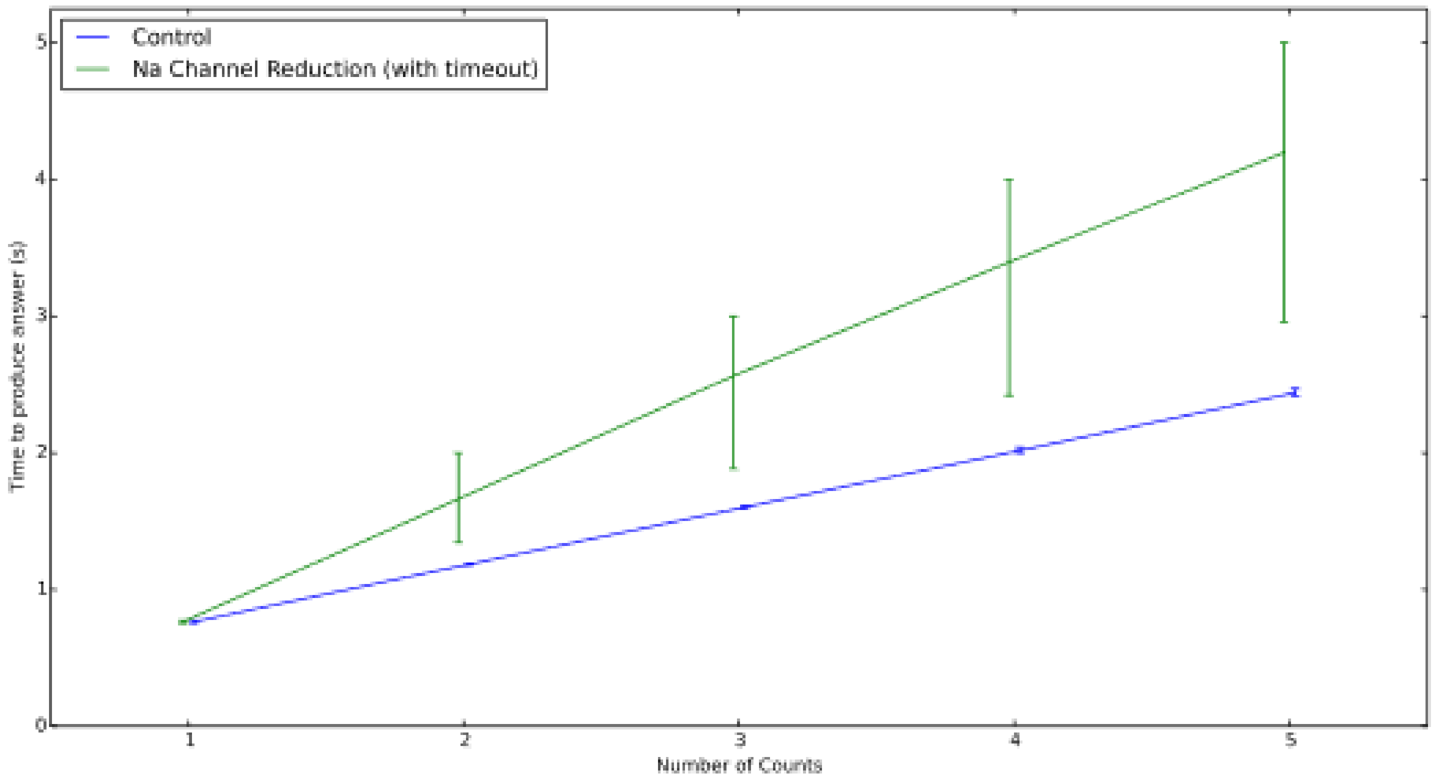

Fig. 12. Introducing TTX results in BioSpaun encoding start digit and end digit, but “forgetting” states before finishing [8, Fig. 6].

[8] C. Eliasmith, J. Gosmann, and X. Choo, “BioSpaun: A large-scale behaving brain model with complex neurons” *CoRR* abs/1602.05220, Feb. 2016.

BioSpaun Summary

- Maintained the performance of original Spaun
- Closer to physiological model
- Increased testing capability [8]

[8] C. Eliasmith, J. Gosmann, and X. Choo, "BioSpaun: A large-scale behaving brain model with complex neurons" *CoRR* abs/1602.05220, Feb. 2016.

Conclusions

- Spaun accomplishes its goals of connecting physciological structure to behavior.
- Testing of hypotheses on large-scale models.

[8] C. Eliasmith, J. Gosmann, and X. Choo, "BioSpaun: A large-scale behaving brain model with complex neurons" *CoRR* abs/1602.05220, Feb. 2016.