Artificial astrocyte networks

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Table of contents.

Goal

- Use models and proof methods from artificial intelligence to try and set an upper bound on astrocyte computation.

ANNs

What are ANNs?

- By example.
- Sparse networks.

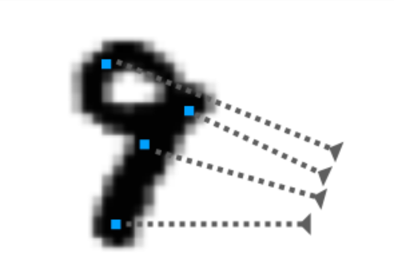
Classic example: visual digit recognition.

= 1,2,3,4,5,6,...

What are ANNs?

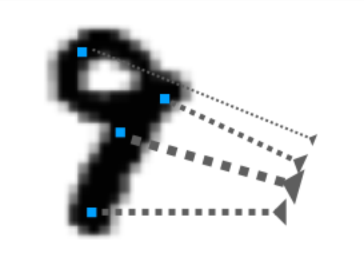
$= 9?$

What are ANNs?



$$\sum x_{ij} = 9$$

What are ANNs?



$$\sum w_{ij} x_{ij} = 9$$

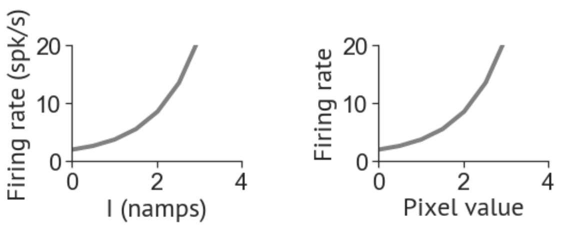
What are ANNs?

$$\sum w_{ij} x_{ij} + b_i = 9$$

What are ANNs?

$$\phi(\sum w_{ij}x_{ij} + b_i) = 9$$

What are ANNs?



FI-curve (left) ≈ ϕ nonlinearity (right)

What are ANNs?

A deep ANN network. Each box is a *layer*: $\phi(\sum w_{ij}x_{ij} + b_i)$

AANs

Basic astrocyte properties

- $[Ca^{2+}]$ dynamics
- Gliotransmission

Assumption 1 (ϕ).

- $[Ca^{2+}]$ dynamics $\leftrightarrow$ firing rate

Basic astrocyte limits.

- No synapses
- No axons

Basic astrocyte limits.

- No w_i
- No $\sum$

Assumption 2 (w_i).

- Directional $[Ca^{2+}]$-dependent gliotransmission.
-

Assumption 3 ($\sum$).

- Directional $[Ca^{2+}]$ waves, driven by gliotransmission.

In theory.

Computational calcium waves.

- Let’s treat neurons only as a source of input; glia do all the computation!
- Let’s study a forward moving $[Ca^{2+}]$ wave.
- Prove: it is a universal function approximator.
- (With Assumptions 1-3)

A universal function approximator?

$$|F(x) - f(x)| < \epsilon$$

A universal function approximator?

$|F(x) - f(x)| < \epsilon$

$F(x)$: any target function (whose domain is bounded)

A universal function approximator?

$|F(x) - f(x)| < \epsilon$

$F(x)$: visual recognition system in cat (target)

A universal function approximator?

$|F(x) - f(x)| < \epsilon$

$F(x)$: visual recognition system in cat (*target*)

$f(x)$: an ANN (*approximator*)

A universal function approximator?

$$|F(x) - f(x)| < \epsilon$$

$F(x)$: visual recognition system in cat (*target*)

$f(x)$: an ANN (*approximator*)

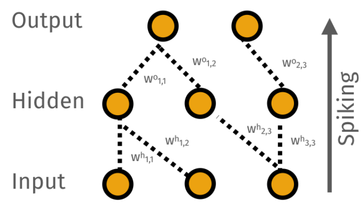
ϵ : the max error boundary

A universal function approximator?

$|F(x) - f(x)| < \epsilon$

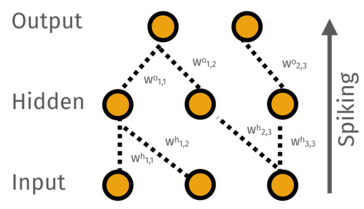
It is possible the target F and learned function f can be made arbitrarily close to ϵ.

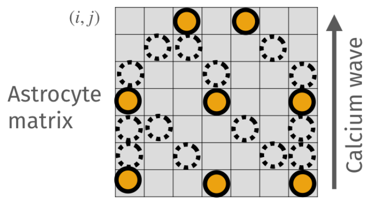
Proof sketch.



- Bölcskei *et al* (2019) F can be approximated by f in $M < N$ connections.
- $f : \phi(\sum w_{ij} x_{ij} + b_i)$

Proof sketch.





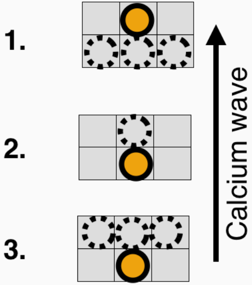
- Bölcskei *et al* (2019) F can be approximated by f in $M < N$ connections.
- $f : \phi(\sum^{M} w_{ij}x_{ij} + b_i)$

- Approximation of the universal approximator
- $w^{o}_{1,1} = \sum w^{o}_{i,j}$
- Astrocyte Sudoku

In practice.

Three astrocyte layers.

1. Gather
2. Slide
3. Spread



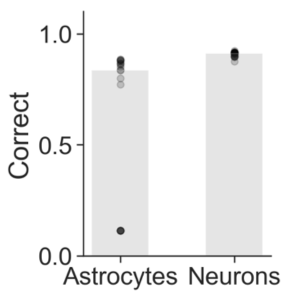
A fundamental limit?

- For astrocyte computation width requires depth.

Methods.

- Task: MINST digits
    1. VAE, $N = (784, 20)$
    2. Perceptron, $N = (20, 30, 10)$
- Loss: Cross-entropy
- Optimizer: ADAM

Results.



Conclusions.

Conclusions.

- AANs $\rightarrow$ universal function approximator.
- AANs can solve hard vision problems.
- An upper bound for the performance of real astrocytes?

Future work.

- Upper bound $\rightarrow$ biological upper bound (help)
- Recurrent waves (in collaboration)
- Better motivated tasks (help)

Open science.

Code `github.com/CoAxLab/glia_playing_atari`

Talk `github.com/parenthetical-e/glia-talk-sfn-2019`

Thank you!