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Neural Computing at Sandia National Laboratories

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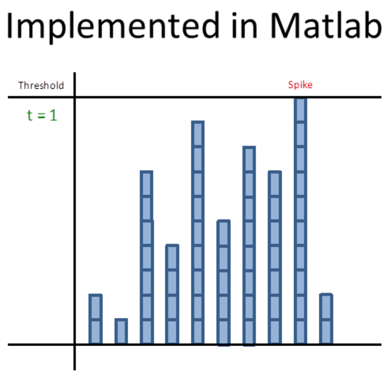
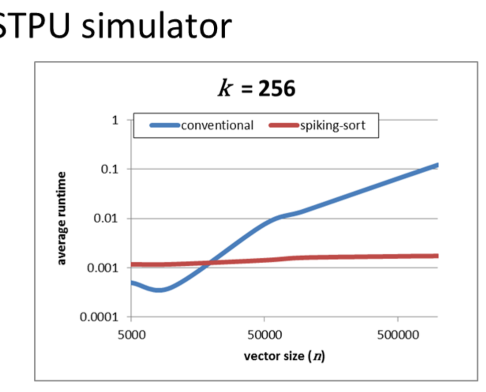
Neural Theory

Computing with Spikes

- Problem: Sort n numbers
- Solution: Units fire in sequence, indicating the correct ordering of the numbers
  - Load each unit with a charge proportional to its number – units either decay or charge up until they pass a threshold to fire
- Implemented in Matlab using STPU simulator

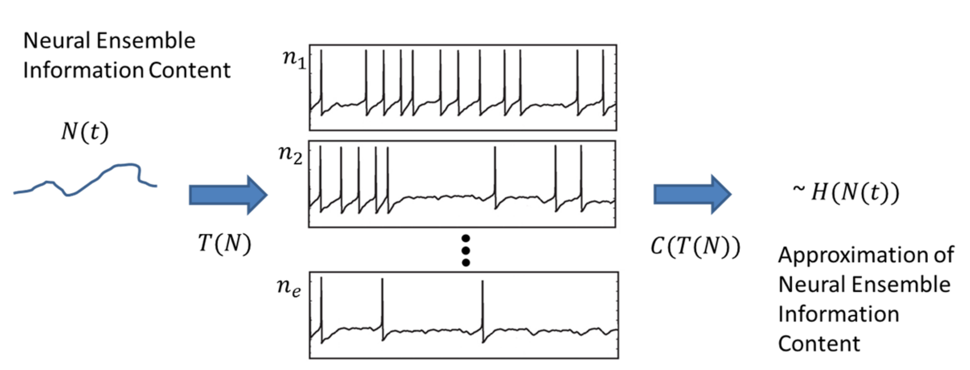




Neural Information Content

- Information theory provides entropy of a discrete random variable as a quantitative measure of information

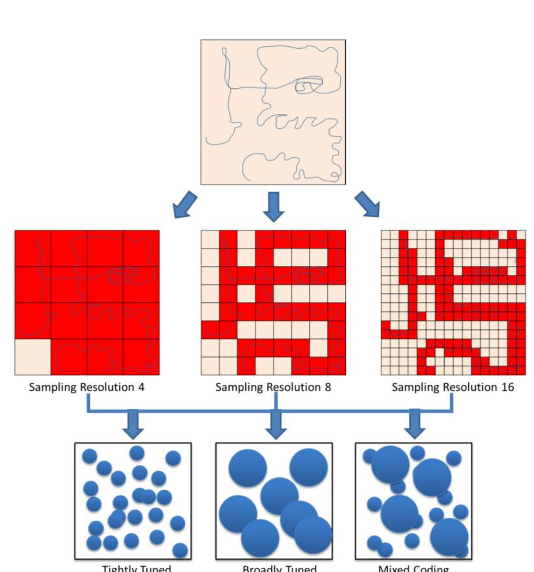
$$H(X) = \sum_{x \in X} p(x) \log\left(\frac{1}{p(x)}\right)$$



Compression

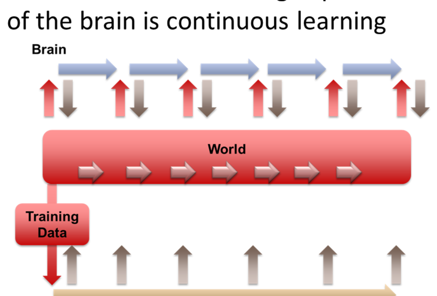
- Use complexity as a measure of compressibility in order to estimate entropy to quantitatively assess the information content of a signal
- Once the spike signal is converted into a binary signal, where an action potential is encoded as a one and the absence of activity by a zero, the normalized complexity may then be computed as follows:

$$c_\alpha(x^n) = \frac{C_\alpha(x^n)}{n} * \log_\alpha n$$



Adaptive Learning

One of the differentiating capabilities of the brain is continuous learning



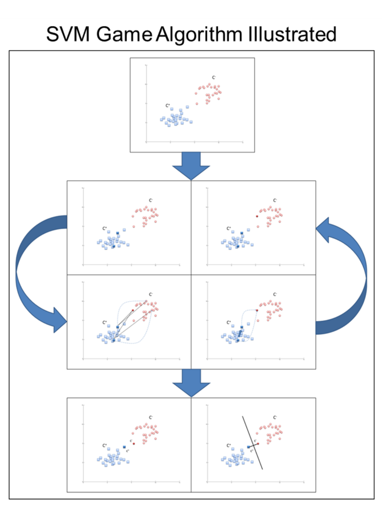
So the question becomes where are we with respect to machine learning?

- Most data-driven algorithms in ML do not continuously adapt

An exemplar adaptive algorithm with some desirable properties we've been developing is the SVM Game

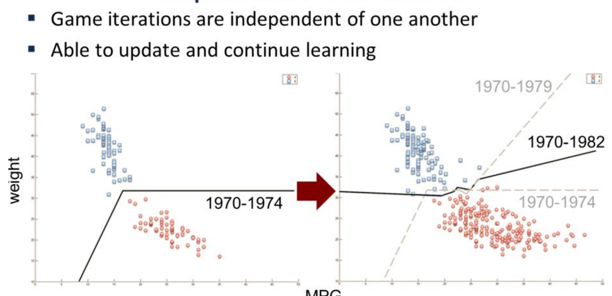
- Support Vector Machine (SVM)
- Game-theoretic approach for adaptive machine learning
- Iterated game approach able to address linear, piecewise-linear, overlapping, and ***non-stationary data*** distributions through ***online learning***

SVM Game Algorithm Illustrated



Repeated SVM Game

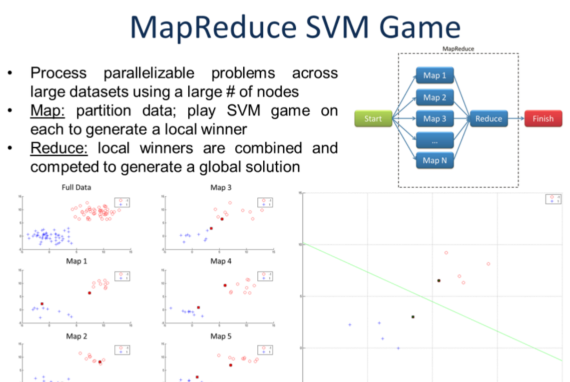
- Game iterations are independent of one another
- Able to update and continue learning



Vineyard et al. "Repeated play of the SVM game as a means of adaptive classification." IJCNN 2015

MapReduce SVM Game

- Process parallelizable problems across large datasets using a large # of nodes
- Map: partition data; play SVM game on each to generate a local winner
- Reduce: local winners are combined and competed to generate a global solution



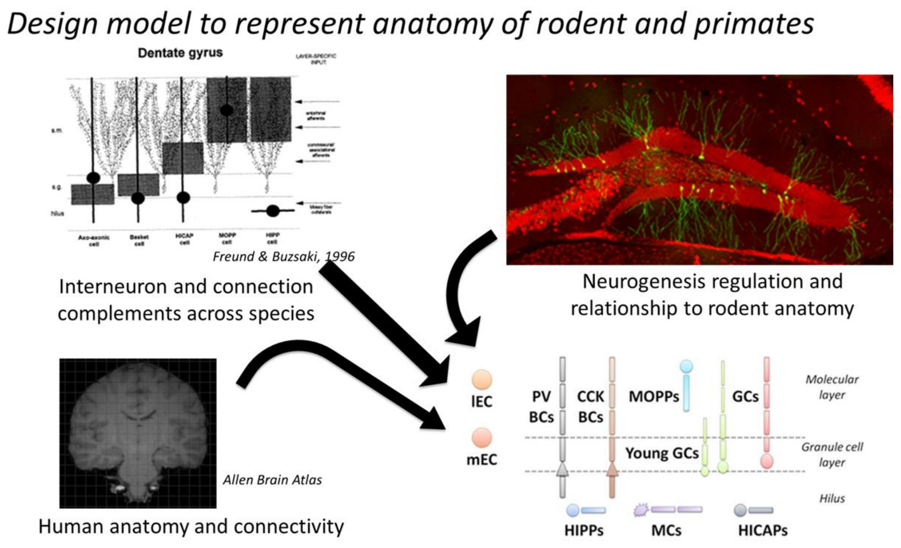
Vineyard et al. "MapReduce SVM game." Procedia Computer Science 2015, 53, 298-307

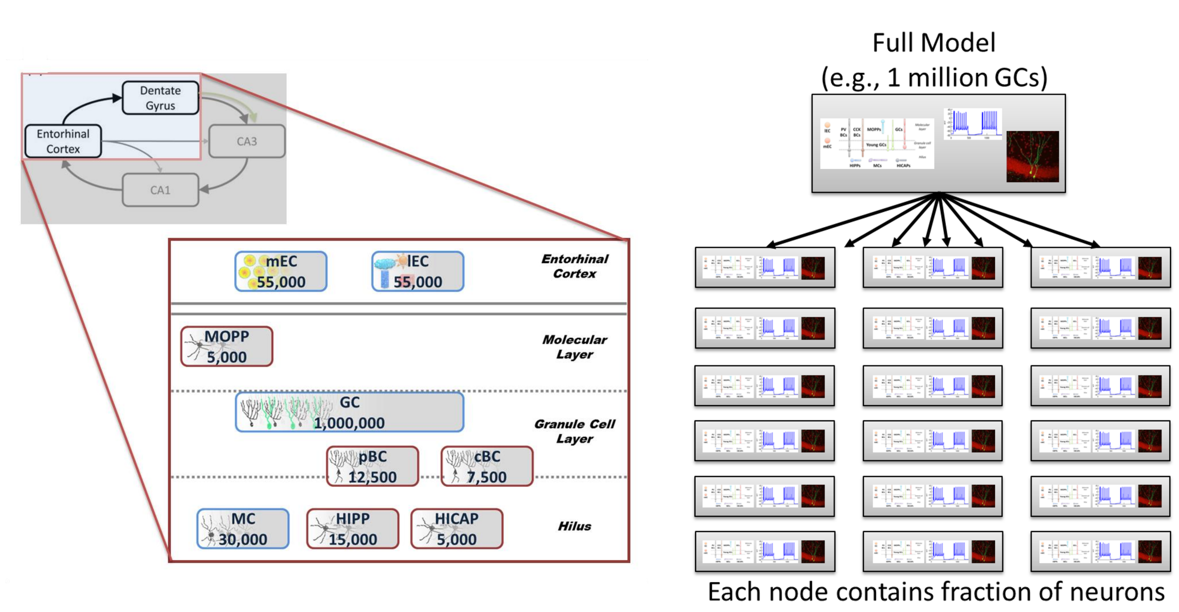
Modeling and Simulation

Large Scale Modeling

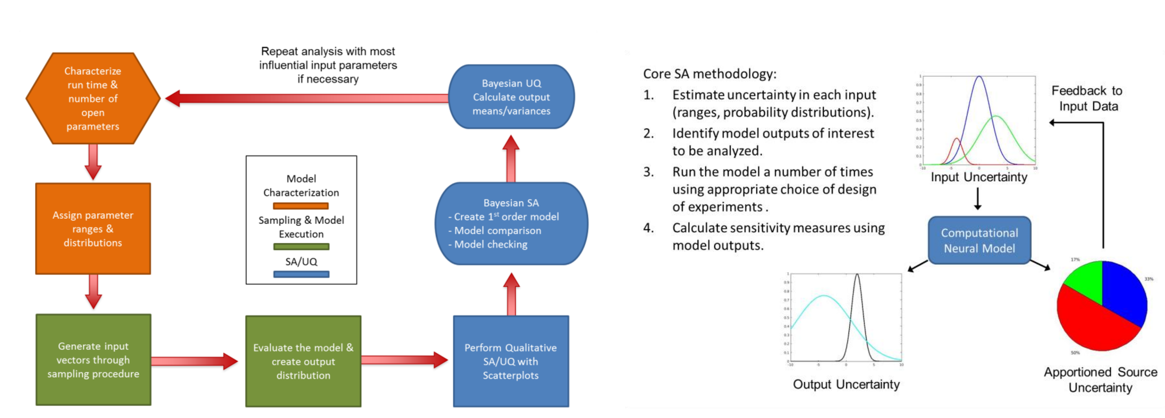
Overview of model process

Design model to represent anatomy of rodent and primates





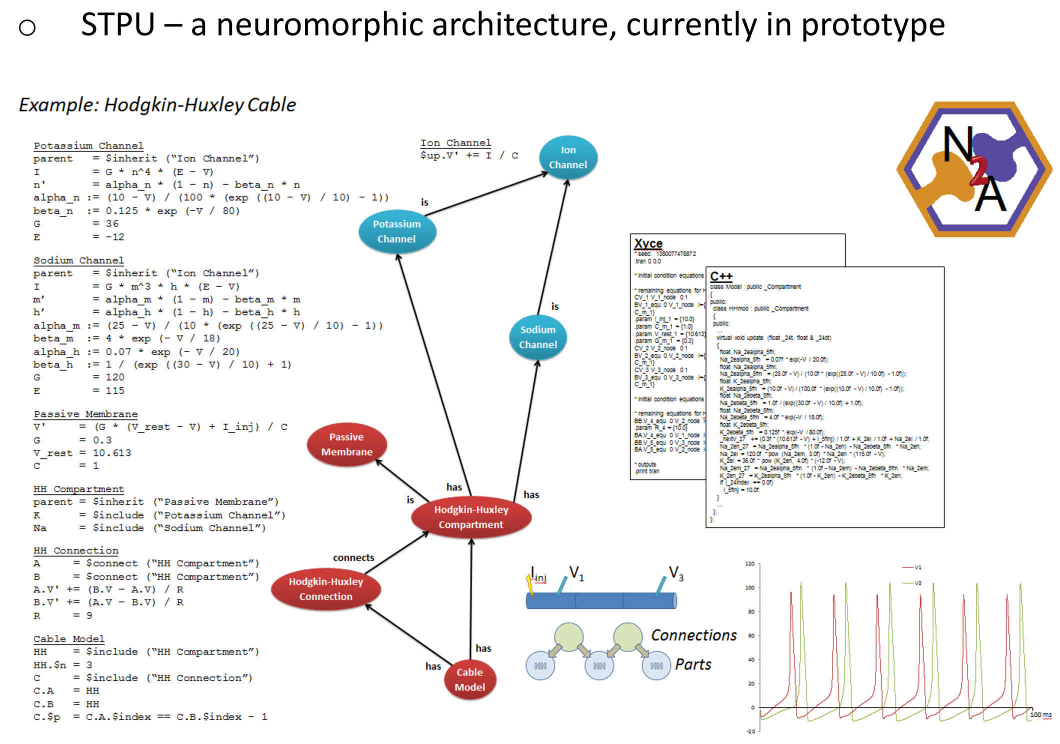
Uncertainty Quantification & Sensitivity Analysis



Neurons to Algorithms (N2A)

- N2A is a language and tool for coding neural algorithms. Like other simulator-independent languages, it saves effort by enabling the same model to compile on a range of platforms.
- Scalable object-oriented language.
- Each part (or *class* in OO terminology) is a set of equations.
- Currently supported backends include:
  - Xyce – a supercomputer version of the Spice circuit simulator.
  - C++ – generated code that gets compiled
  - Internal – a reference simulator written in Java
  - STPU – a neuromorphic architecture, currently in prototype

Example: Hodgkin-Huxley Cable



Rothganger, et al. "N2A: a computational tool for modeling from neurons to algorithms." Frontiers in neural circuits 8 (2014).

Application Development

Neural Inspired Machine Learning

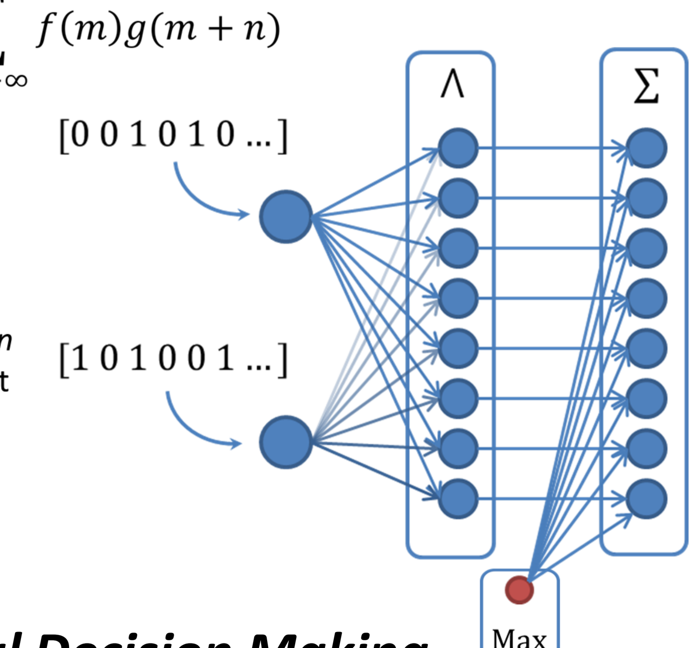
Particle Image Velocimetry (PIV) estimates flow fields using dispersed particles

- Two images are taken and subdivided into smaller windows
- Maximum cross-correlation is best estimate of local flow

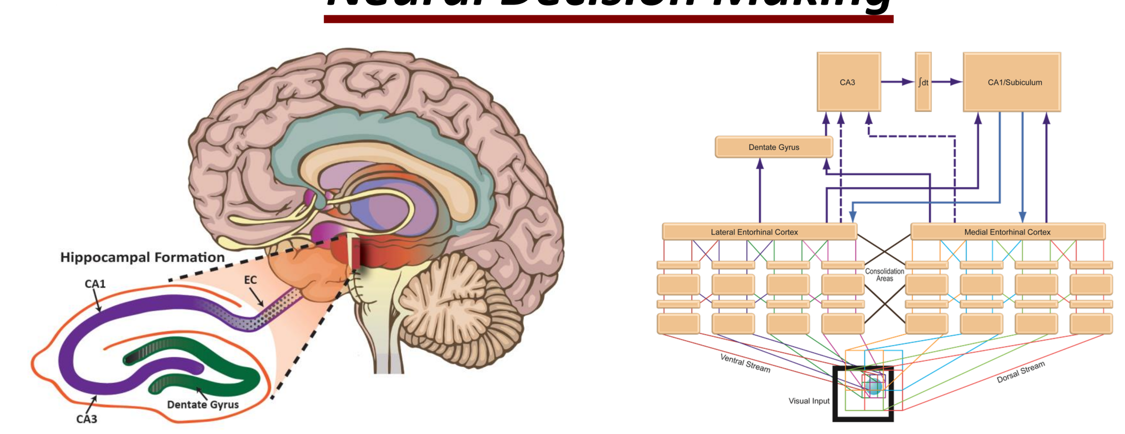
$$(f \star g)(n) = \sum_{m=-\infty}^{\infty} f(m) g(m+n)$$

Neural Inspired Algorithm

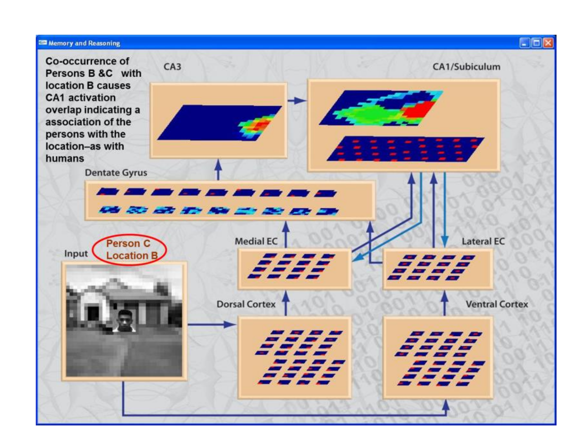
- Temporally coded inputs
- Inner neurons fire on simultaneous input
- Graduated delay for each n
- Integrating neurons collect cross-correlation value
- $O(n \log n) \rightarrow O(n)$



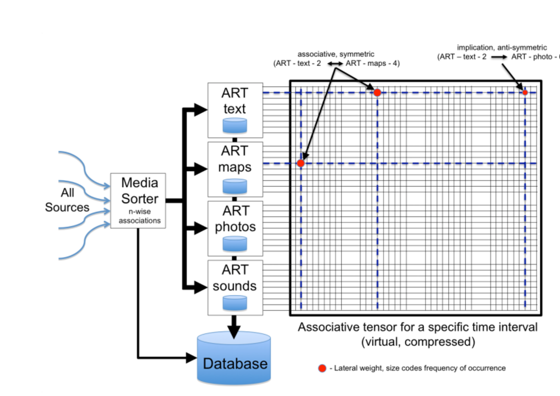
Neural Decision Making



Vineyard, et al. "A cortical-hippocampal neural architecture for episodic memory with information theoretic model analysis." World Multi-Conference on Systemics, Cybernetics and Informatics. 2010.



Vineyard, et al. "A Neurologically Plausible Artificial Neural Network Computational Architecture of Episodic Memory and Recall." BICA. 2010.

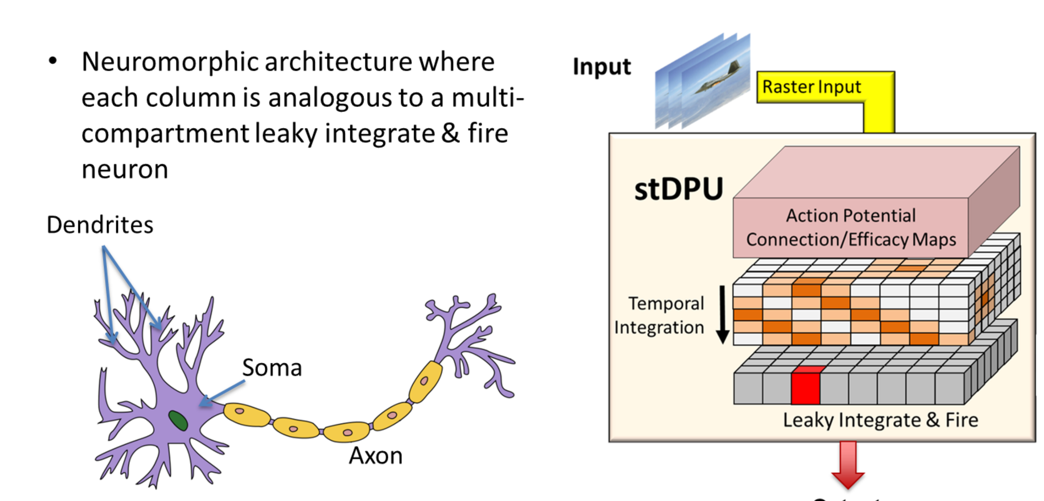


Vineyard, et al. "A multi-modal network architecture for knowledge discovery." Security Informatics 1.1 (2012): 1-12.

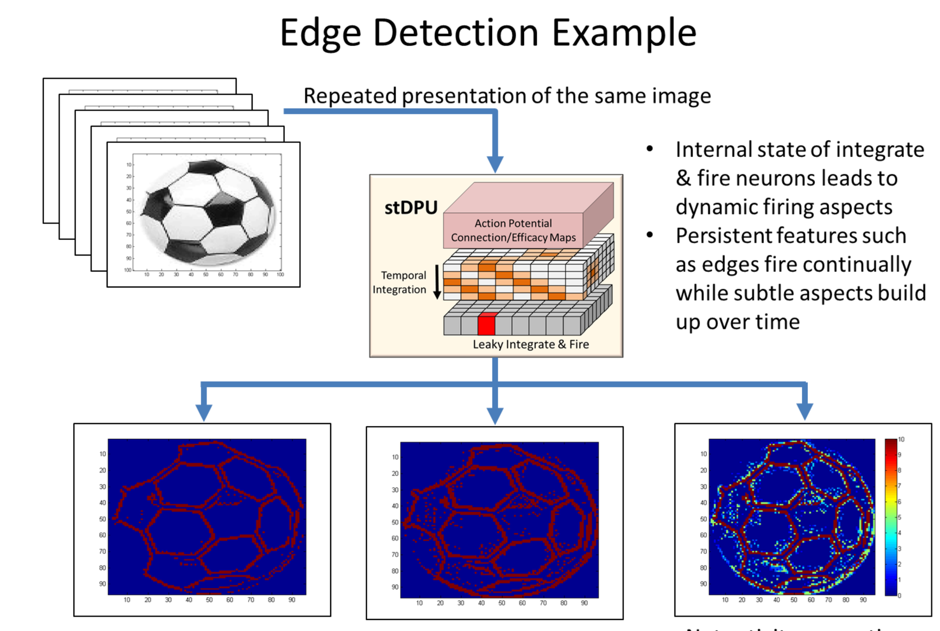
Neural Inspired Computer Architectures

Spiking Temporal Processing Unit (STPU)

- Neuromorphic architecture where each column is analogous to a multi-compartment leaky integrate & fire neuron



Edge Detection Example



- Internal state of integrate & fire neurons leads to dynamic firing aspects
- Persistent features such as edges fire continually while subtle aspects build up over time

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NNSA National Nuclear Security Administration

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