Spiking Neural Network for Asset Allocation Implemented Using The TrueNorth System

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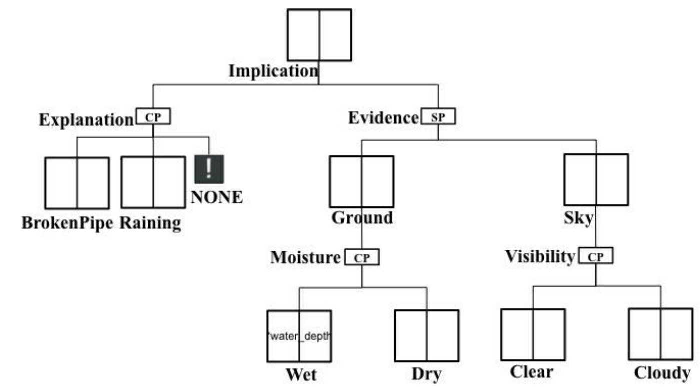
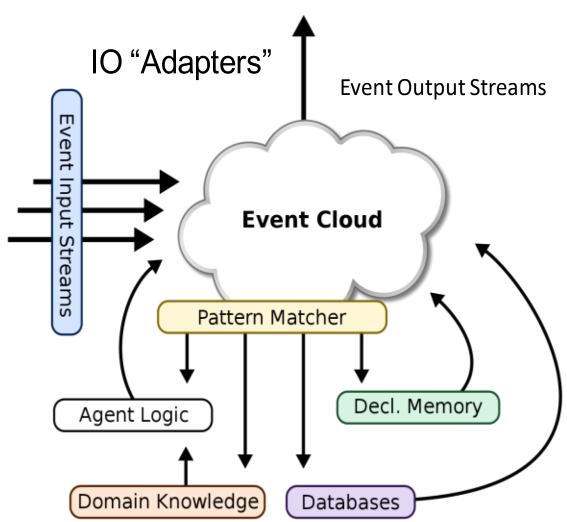
Chris Yakopcic (UD), Nayim Rahman (UD), Tanvir Atahary (UD), Md. Zahangir Alom (UD), Tarek Taha (UD), Alex Beigh (UDRI), Scott Douglass (711 HPW)

CECEP Architecture

- The CDO is the decision making engine within the CECEP architecture
- These very simple examples quickly become very complex in realistic systems
  - Billions of possible outcomes

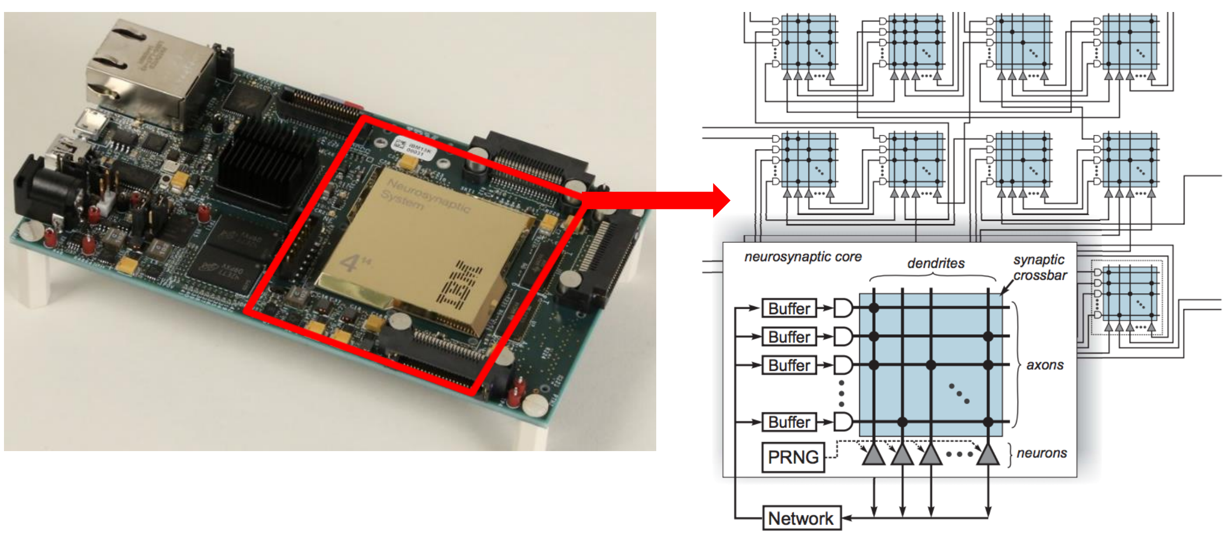




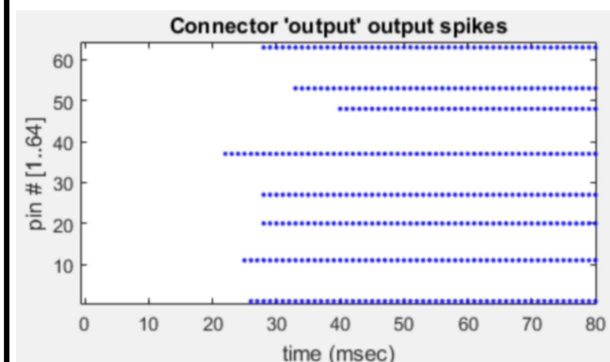
Name	Specification
Raining	IF Implication.explanation = Raining THEN Implication.evidence.Ground.moisture = Wet AND Implication.evidence.Sky.visibility = Cloudy
Broken Pipe	IF Implication.explanation = BrokenPipe THEN Implication.evidence.Ground.moisture = Wet OR (Implication.evidence.Sky.visibility = Clear AND NOT Implication.evidence.Ground.moisture = Dry)
Dry Ground	IFF NOT (Implication.explanation = Raining OR Implication.explanation = BrokenPipe) THEN Implication.evidence.Ground.moisture = Dry
Wet Ground	IFF Implication.evidence.Ground.moisture = Wet THEN Implication.explanation = Raining OR Implication.explanation = BrokenPipe

Objective

- Optimized resource allocation is extremely computationally expensive
- We need low SWaP alternatives, large problems are currently prohibitively expensive to solve.
- This is done using a series of spiking neurons that fire according to the most logical vehicle assignment options
- This work covers a MATLAB implementation of the spiking neuron based algorithm



True North Spiking Output



Vehicle 1 Goes to Target 1
Vehicle 2 Goes to Target 3
Vehicle 3 Goes to Target 4
Vehicle 4 Goes to Target 3
Vehicle 5 Goes to Target 5
Vehicle 6 Goes to Target 8
Vehicle 7 Goes to Target 5
Vehicle 8 Goes to Target 7

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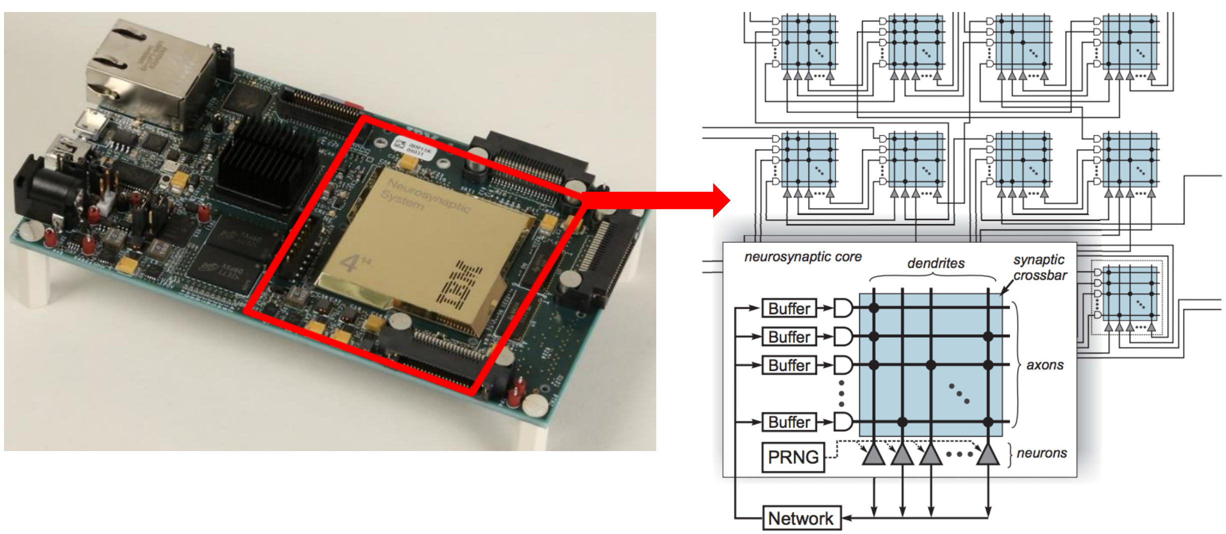

Allocation Problem Size	Number of Possible Solutions
2 × 2	9
4 × 4	625
6 × 6	117,649
8 × 8	43,046,721
10 × 10	25,937,424,601

Outline

- CECEP Applications

  - M by N Asset Allocation in SNNs
    - Method
    - Algorithm
    - TrueNorth Implementation
    - Results in TrueNorth
    - Latest Implementation and Results on Loihi

Neuron Model

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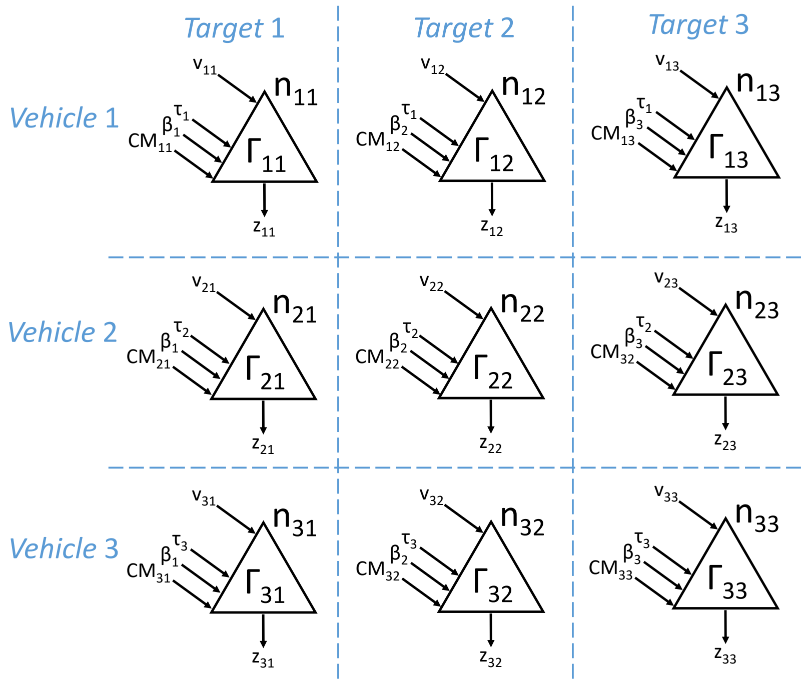
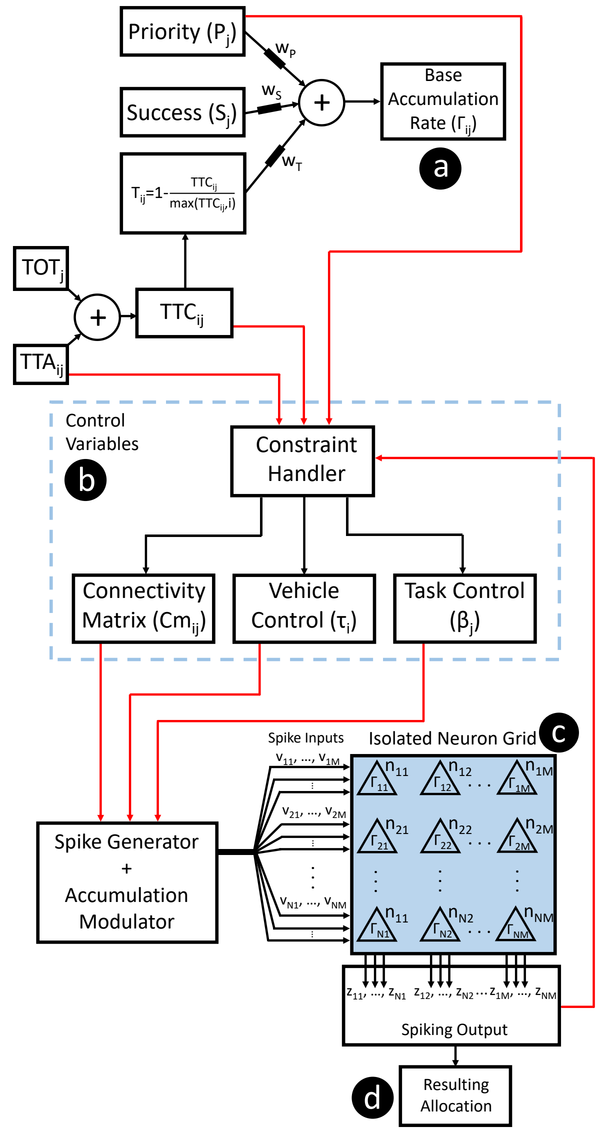
- Single neuron holds connection between one vehicle and one target
  - Capable of allocating N vehicles for M separate targets using N×M neurons
- Weight Parameters
  - TTA: Time to the target
  - Priority: Necessity of reaching target
  - TOT: Hold time for vehicle once target is reached
  - Probability of Success: Likelihood that a target will be completed by a certain vehicle
  - TTC = TOT + TTA
- Control Parameters
  - CM: Connectivity matrix hold vehicle-target compatibility
  - τ: A vehicle can only be assigned to one target
  - β: Penalize (but do not stop) multiple vehicles from reaching a single target



Algorithm Block Diagram

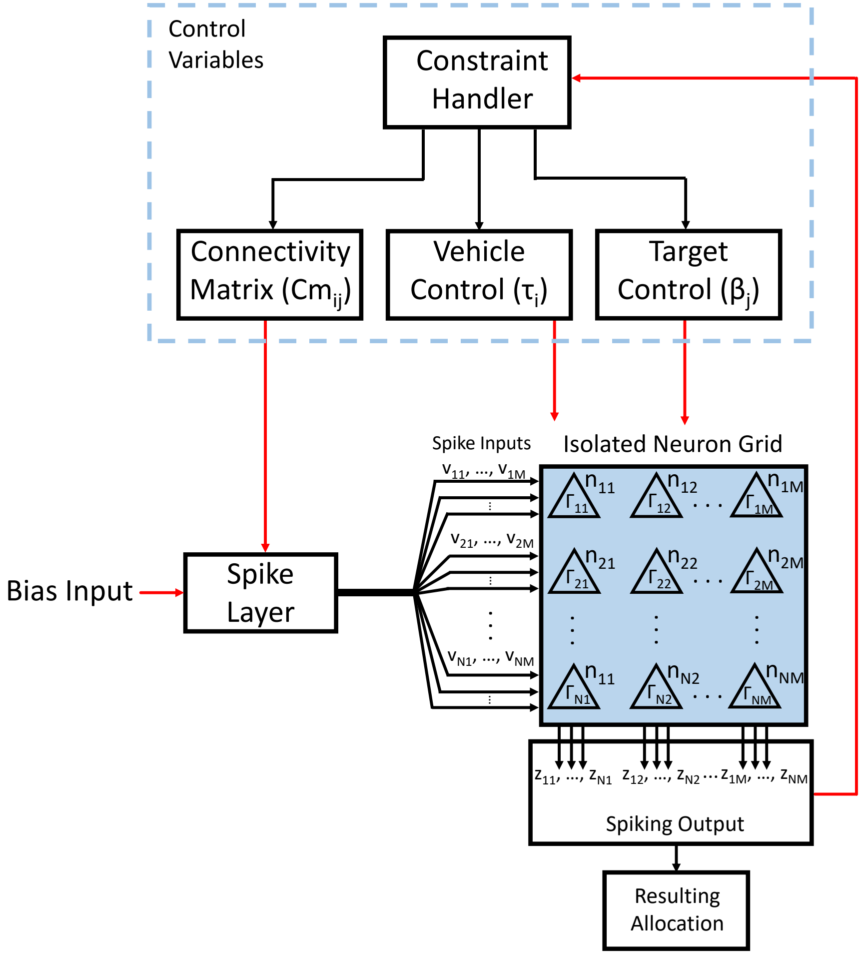
- Flow of inputs and outputs for the algorithm
  - Spike accumulation is proportional to a weighted sum of priority, success, and time
  - Spikes occur depending on compatibility, as well as vehicle and target status

  - a) Base Accumulation Rate
  - b) Control Variables
  - c) Neuron Grid
  - d) Allocation Result



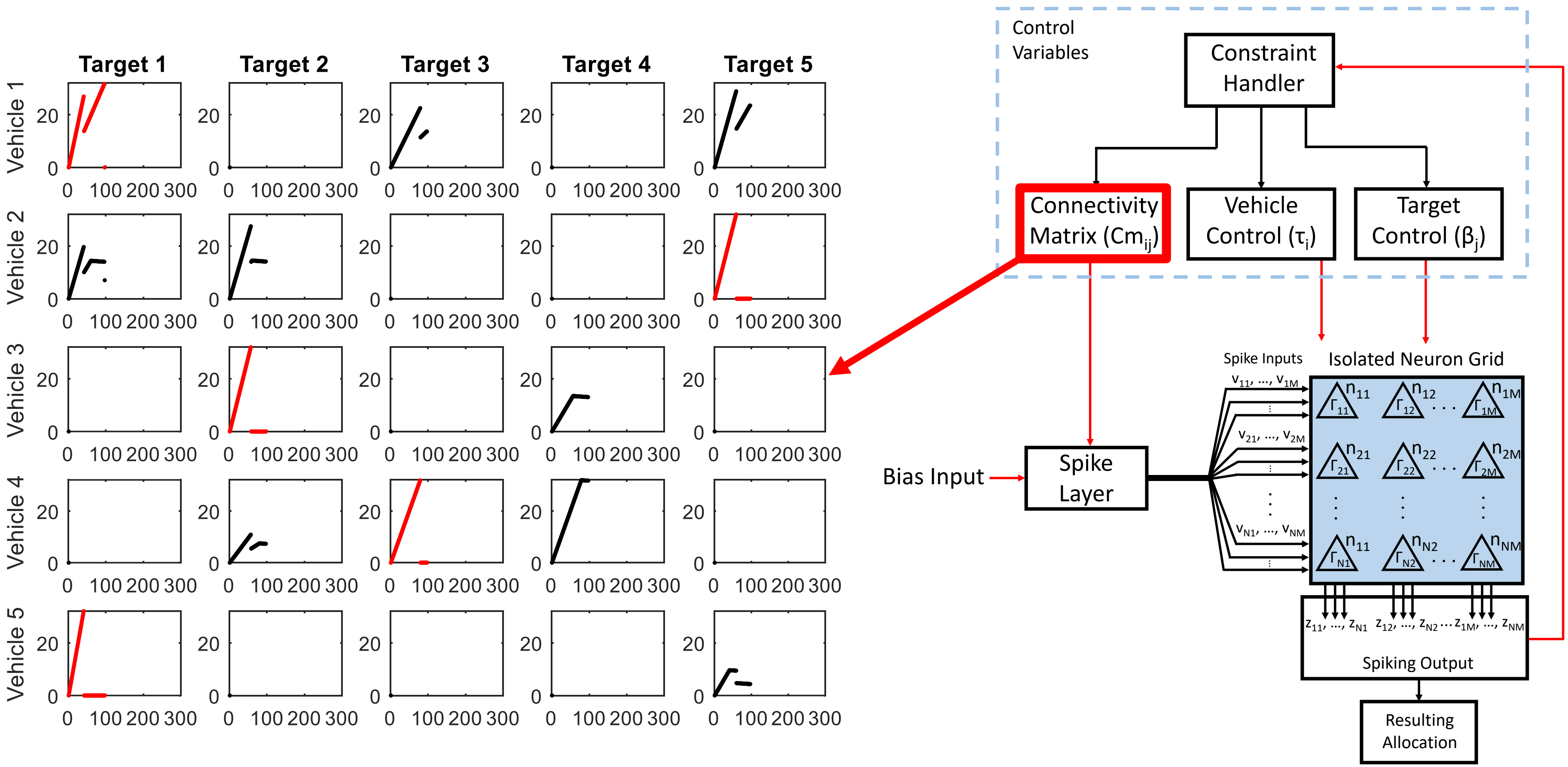
Simplified Algorithm Block Diagram

- Flow of inputs and outputs for the algorithm
  - Spike accumulation is proportional to a weighted sum of priority, success, and time
  - Spikes occur depending on compatibility, as well as vehicle and target status



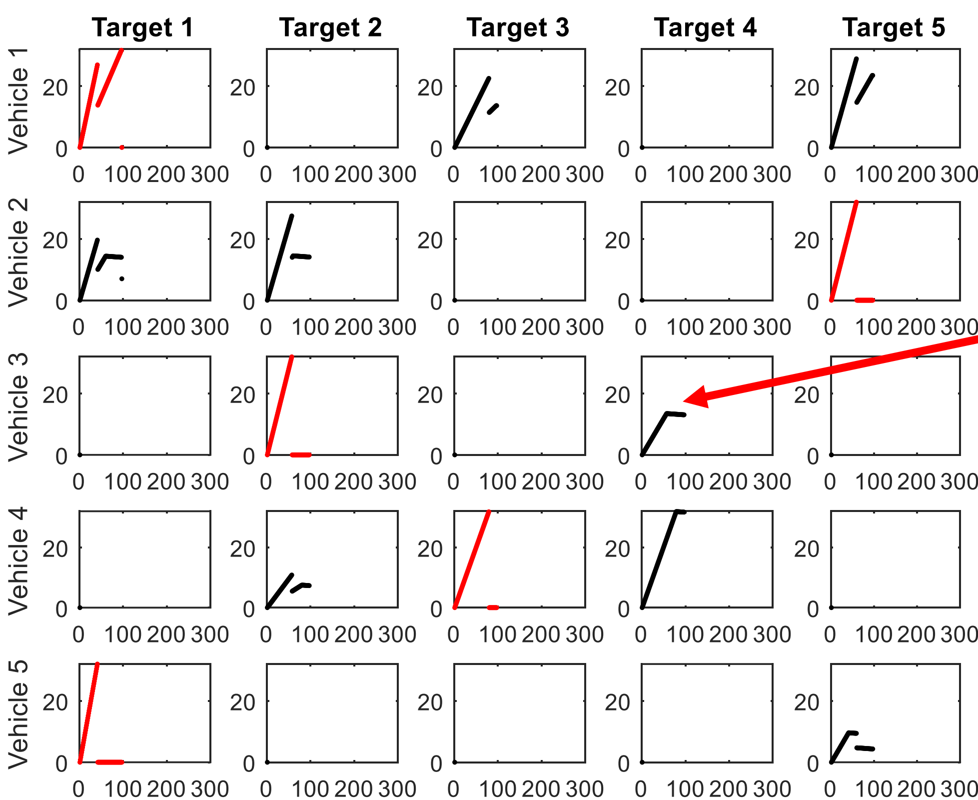
Example Allocation

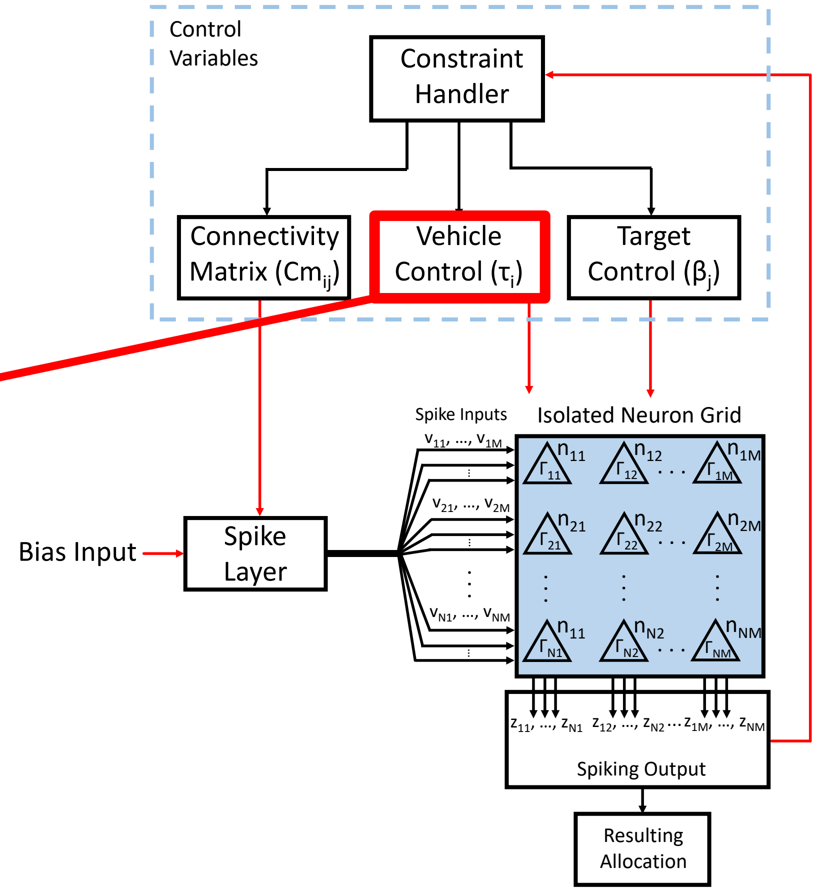
Connectivity Matrix Response



Example Allocation

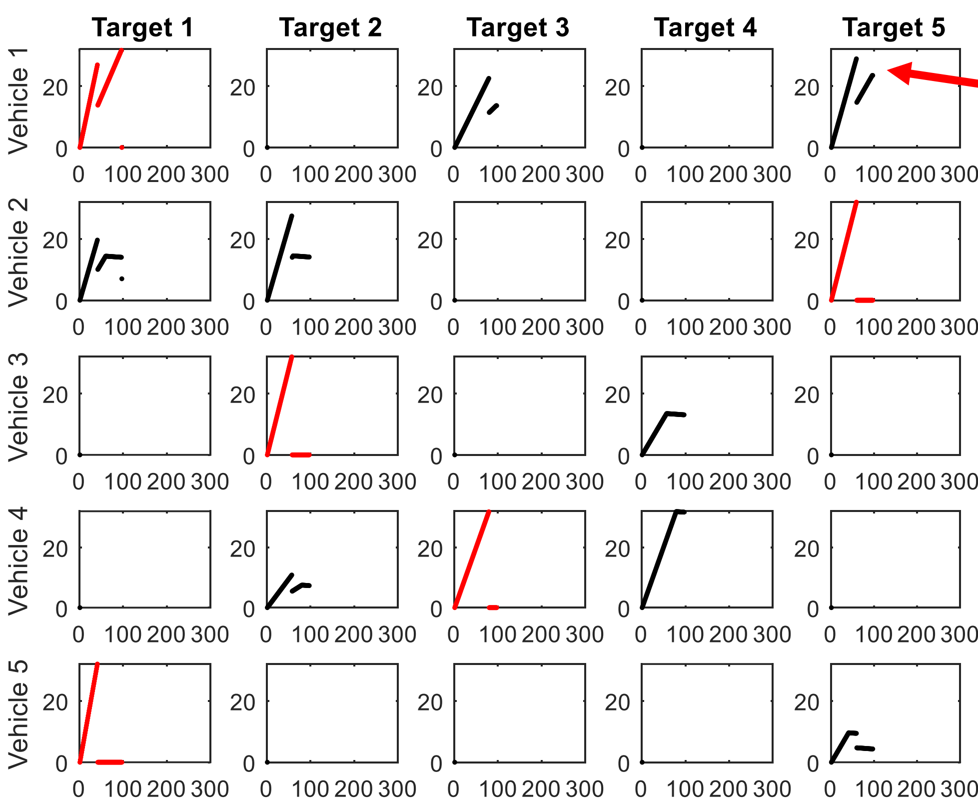
Vehicle Control Response

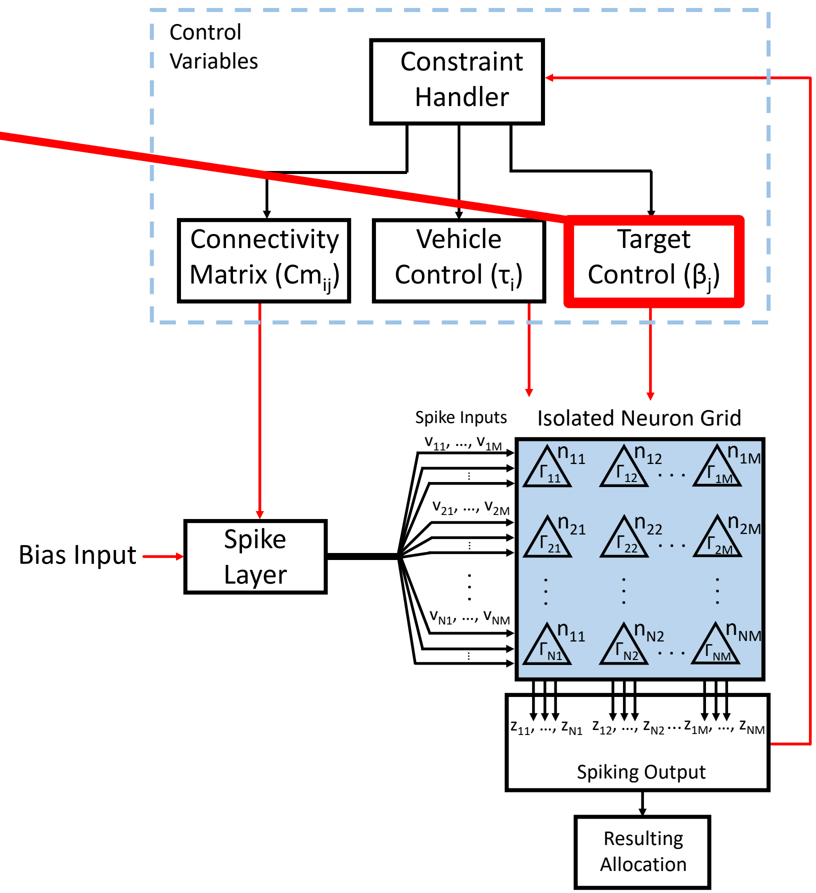




Example Allocation

Target Control Response

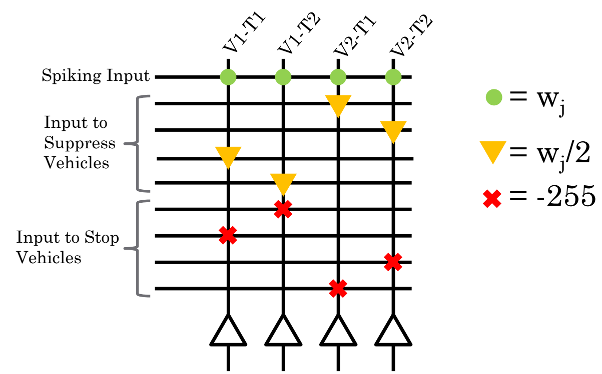




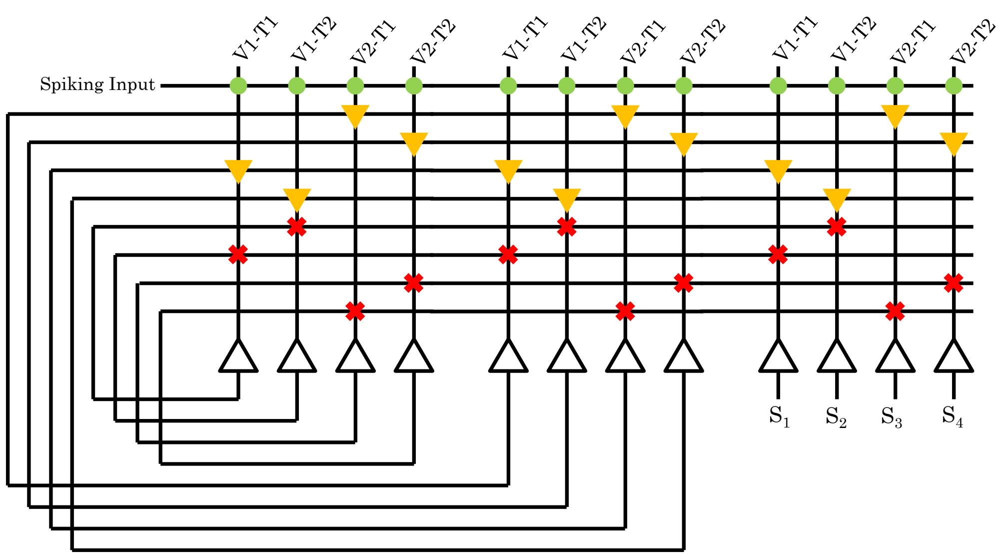
TrueNorth Implementation

- Circuits display the 2 by 2 scenario
  - Simple example mainly for demonstration
- 9 Inputs
  - 1 Uniform Spiking
  - 4 Vehicle Control
  - 4 Task Control
- 12 Outputs
  - 4 Vehicle Control Send
  - 4 Task Control Send
  - 4 Final Outputs
    - 3 Duplications of the same circuit

Neuron Accumulation

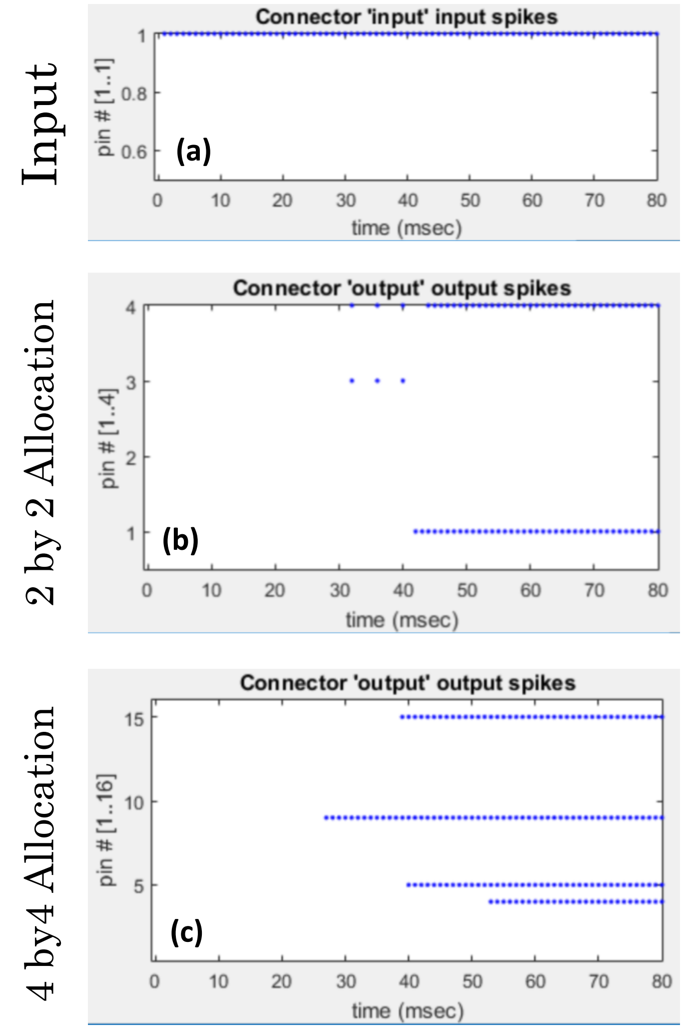


Neuron Accumulation with Control Variables



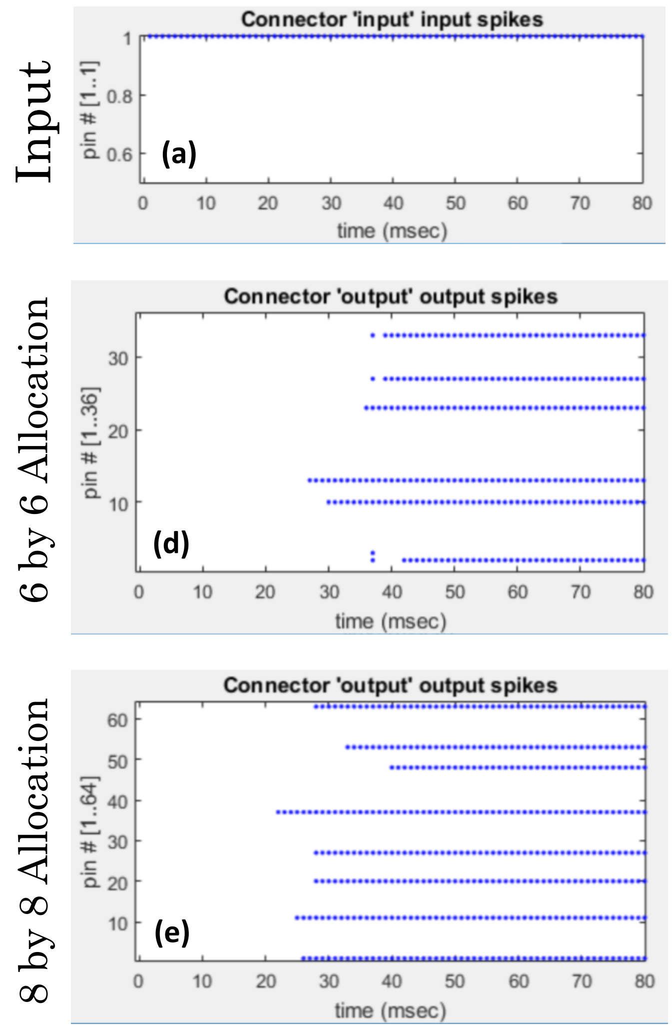
TrueNorth Allocation Results

- Allocation results show which neuron numbers are spiking at the end of an allocation execution
- 2 by 2
  - Neurons: 1 4
  - Result [1 2]
- 4 by 4
  - Neurons: 4 5 9 15
  - Result [4 1 1 3]



TrueNorth Allocation Results

- Allocation results show which neuron numbers are spiking at the end of an allocation execution
- 6 by 6
  - Result [2 4 1 5 3 3]
- 8 by 8
  - Result [1 3 4 3 5 8 5 7]



Algorithm Comparison

	Exhaustive Search Using K80 GPU		TrueNorth Spiking System			
Allocation Size	**Baseline CDO Reward**	**Baseline CDO Result**	**Effective Reward**	**Allocation Result**	**Answer Rank**	**Answer Percentile**
3×3	18.8703	[2 1 1]	18.4807	[2 1 2]	2 of 64	98.44%
4×4	11.377	[4 1 1 3]	11.377	[4 1 1 3]	1 of 625	100%
5×5	22.6219	[1 5 2 4 1]	22.6203	[1 5 2 3 1]	2 of 7776	99.99%
6×6	31.2628	[2 4 1 5 3 3]	31.2628	[2 4 1 5 3 3]	1 of 117649	100%
7×7	48.448	[4 2 2 6 5 6 7]	40.6019	[4 6 4 2 5 5 7]	6847 of 2.09M	99.67%
8×8	40.8782	[1 3 4 7 5 3 6 8]	39.1283	[1 3 4 3 5 8 5 7]	111 of 43.0M	~100%

- The best allocation for each case was determined using a GPU exhaustive search
- The table compares this result to the approximate result obtained from the Loihi spiking system

Timing Comparison

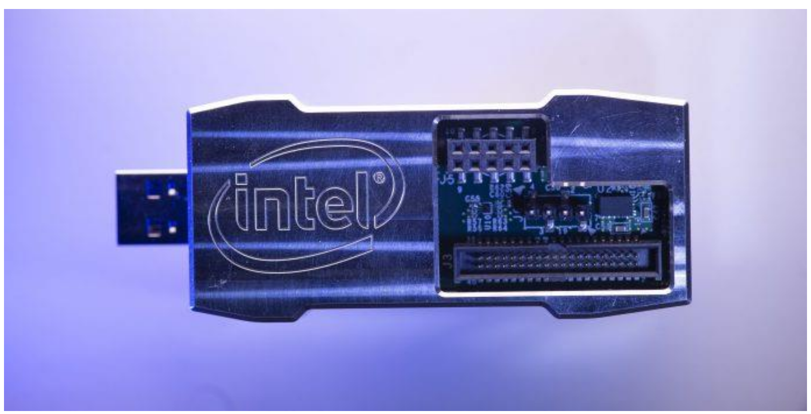
- Runtime comparison between the exhaustive search and spiking system

Allocation Size	CDO Search Time (GPU)	TrueNorth Execution Time	TrueNorth System Speedup
3×3	224 ms	47 ms	4.76×
4×4	231 ms	53 ms	4.36×
5×5	233 ms	52 ms	4.48×
6×6	234 ms	43 ms	5.44×
7×7	269 ms	56 ms	4.80×
8×8	955 ms	40 ms	23.88×

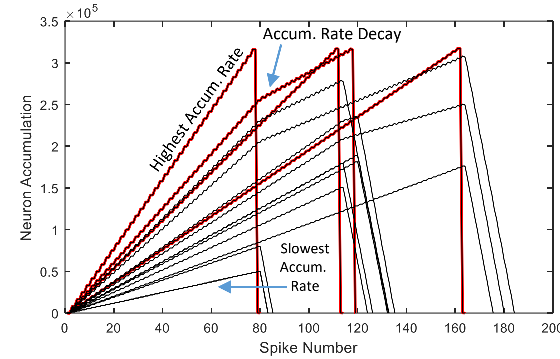
- Solution space on an asset allocation problem grows with problem size
  - Neuron utilization grows at a much smaller rate

Allocation Problem Size	Number of Possible Solutions	Number of Acc. Neurons
2 × 2	9	4
4 × 4	625	16
6 × 6	117,649	36
8 × 8	43,046,721	64
10 × 10	25,937,424,601	100

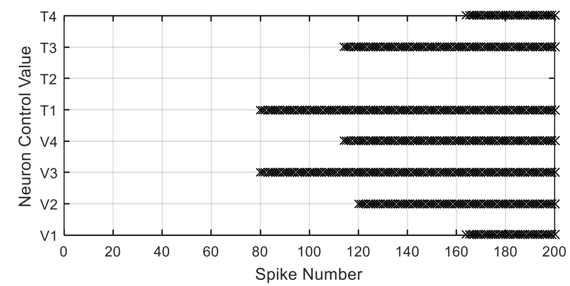
- Loihi implementation of the same algorithm
- Loihi photo shows portable USB stick
  - This work was performed via remote login



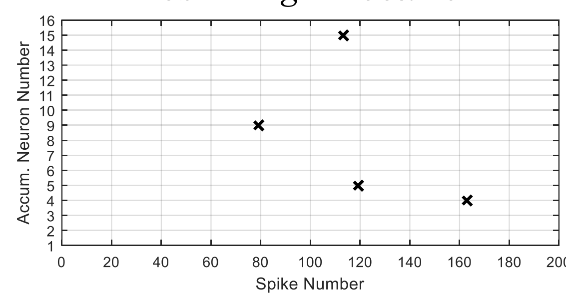
Neuron Grid Accumulations



Control Variable Spiking Layer



Resulting Allocation



Spiking System Comparison

- Loihi demonstrates significant speedup of TrueNorth
  - Mainly due to shorter cycle time and non uniform intervals

Allocation Size	CDO Search Time (GPU)	Loihi Execution Time	Loihi System Speedup	TrueNorth Execution Time	TrueNorth System Speedup
3×3	224 ms	0.312 ms	717×	47 ms	4.76×
4×4	231 ms	0.384 ms	601×	53 ms	4.36×
5×5	233 ms	0.319 ms	730×	52 ms	4.48×
6×6	234 ms	0.414 ms	565×	43 ms	5.44×
7×7	269 ms	0.428 ms	629×	56 ms	4.80×
8×8	955 ms	0.737 ms	1296×	40 ms	23.88×

SWaP Comparison

- General System Comparison
  - Exhaustive/Traditional vs. Embedded/Approximate
  - Approximate solution leads to dramatic increase in efficiency
  - In general, this result shows how the proposed algorithm enables portability of inference algorithms

	Trad. CPU / GPU System	Spiking Systems	Ratio
Size	2240 in^3	24 in^3	93×
Weight	20 lb	0.5 lb	40×
Power	500 W	< 70 mW	7142×
Accuracy	100%	99%	-

Next Steps

- Asset Allocation
  - More complete algorithm comparison
  - Study of maximum scalability
  - Comparison of methods for large scale allocation problems

- Loihi
  - Energy Benchmark
  - Maximum Scalability