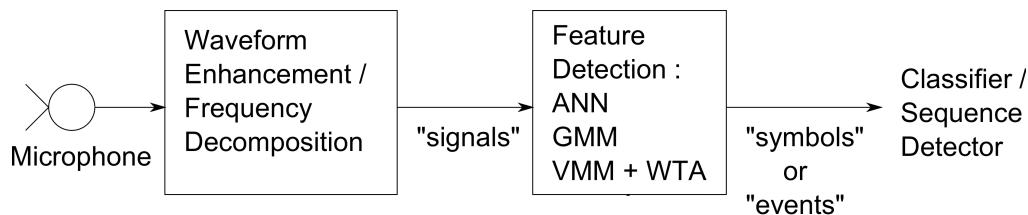


# Classifiers for Sensory Data



Key Signal to Symbol Refinement

Two layers: (VMM + nonlinear functions)

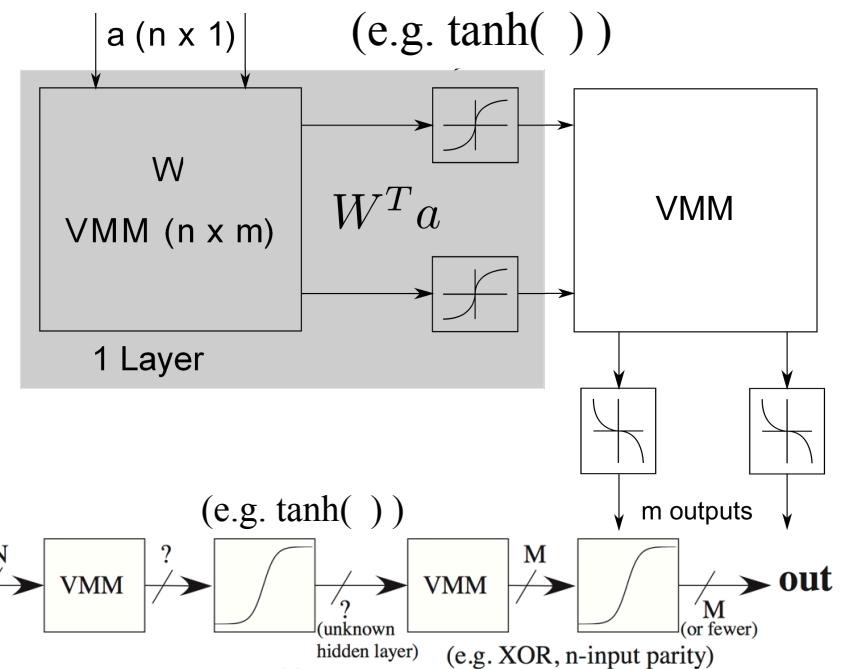
Required for Universal Approximator  
= arbitrary function approximation with infinite (countable) neurons

VMM = Vector Matrix Multiplication

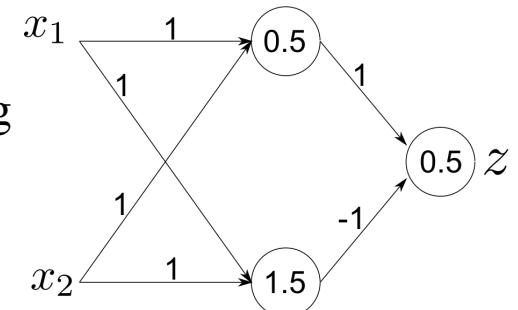
$$\mathbf{y} = \mathbf{W} \mathbf{x}$$

VMM often implemented in FPAAs

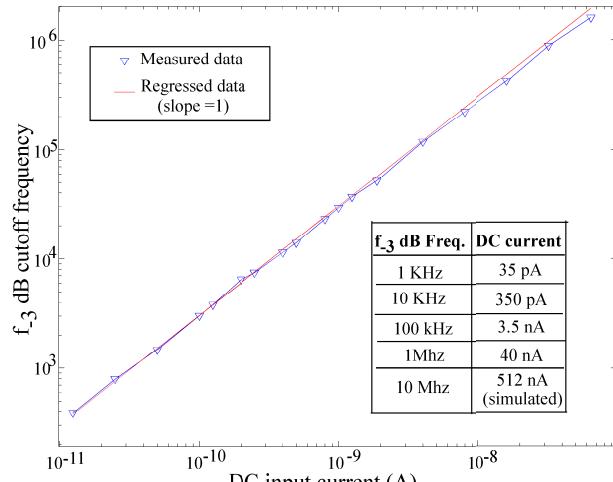
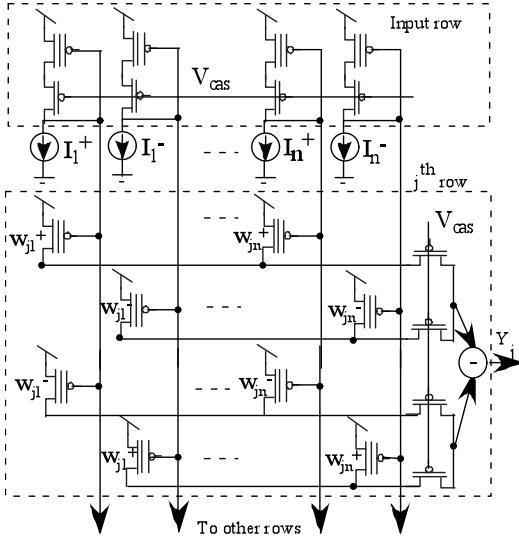
Nonlinear function (e.g. tanh) allows for decisions and nonlinear function approximation



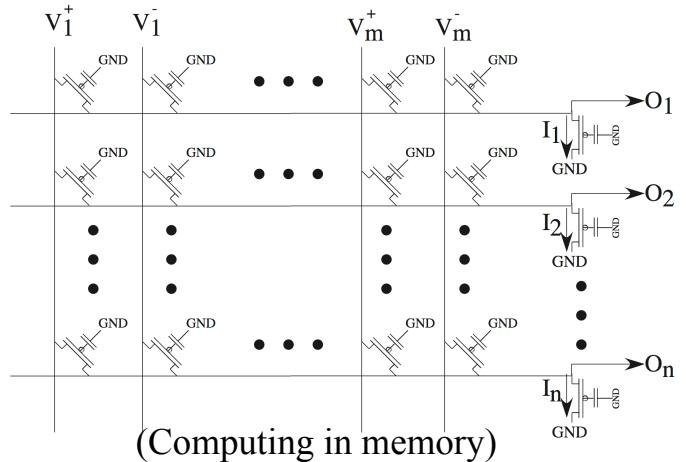
XOR: Classic function showing two layers required to fully implement



# FG VMM



## VMM in FPA Routing Fabric

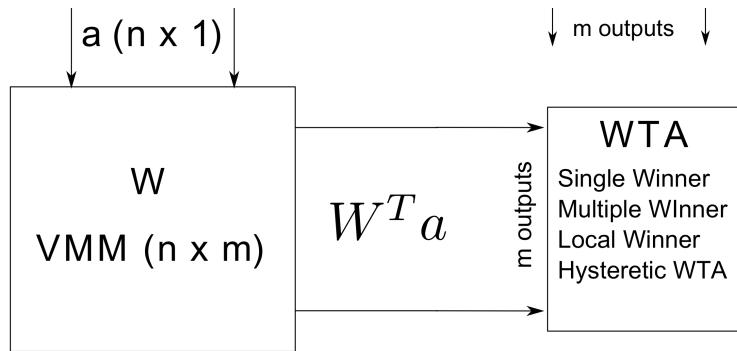


Analog (VMM): ~10-20MMAC/ $\mu$ W ~50-100 fJ / MAC      Digital ~ 10MMAC/mW @ yield

SUMMARY OF PERFORMANCE PARAMETERS A SOURCE-DRIVEN VMM DEVICE. N = 8, M = 8. V<sub>dd</sub> = 1V.

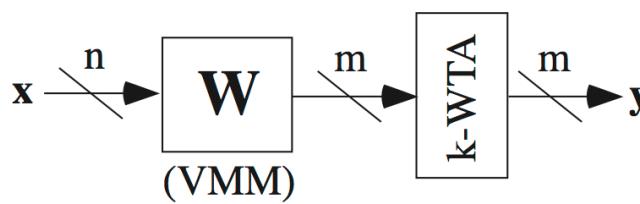
Property	Expression	25pA	2.5nA	250nA	25 $\mu$ A*
Bandwidth (f)	$\frac{I_{so}}{4\pi C_d U_T}$	3.86kHz	386kHz	38.6MHz	3.86GHz
Computation	2 N M f	500kMAC/s	50MMAC/s	5GMAC/s	500GMAC/s
Power (P)	2NMI <sub>so</sub> V <sub>dd</sub>	3.2nW	320nW	32 $\mu$ W	3.2mW
MMAC/ $\mu$ W	$\frac{1}{8\pi C_d U_T V_{dd}}$	33MMAC/ $\mu$ W	33MMAC/ $\mu$ W	33MMAC/ $\mu$ W	33MMAC/ $\mu$ W
Noise ( $\hat{i}_{out}/(2NI_{so})$ )	$\sqrt{q/C_d U_T N}$	0.6%	0.6%	0.6%	0.6%
SNR	$10\log_{10} \left( \frac{2U_T C_{in}}{3qA} \right)$	44.1dB	44.1dB	44.1dB	44.1dB

# VMM + k-WTA: Experimental Measurements of a Universal Approximator

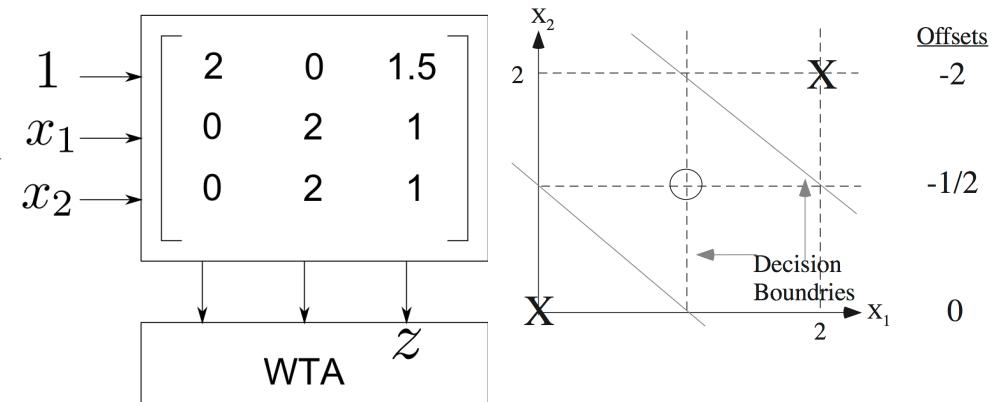
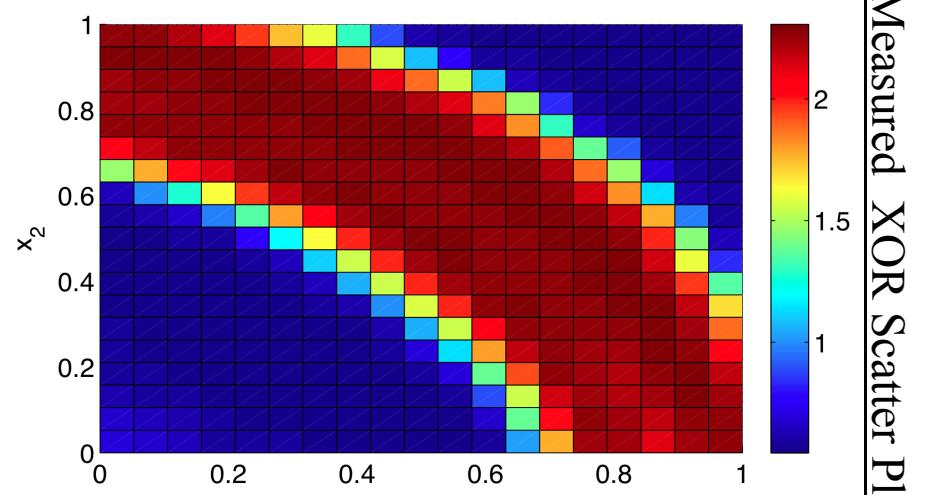


1 single VMM + n-WTA layer =  
universal approximator  
[Maass, et. al, 2000]

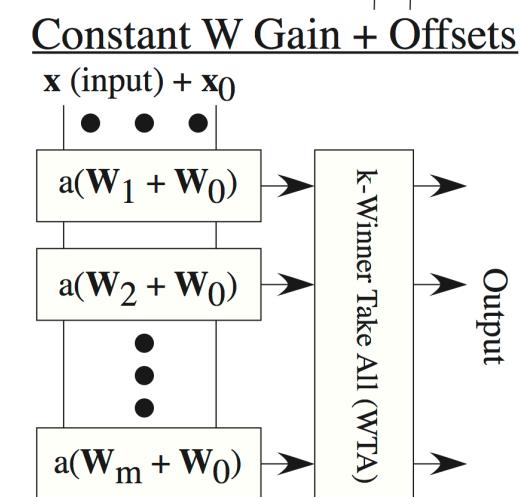
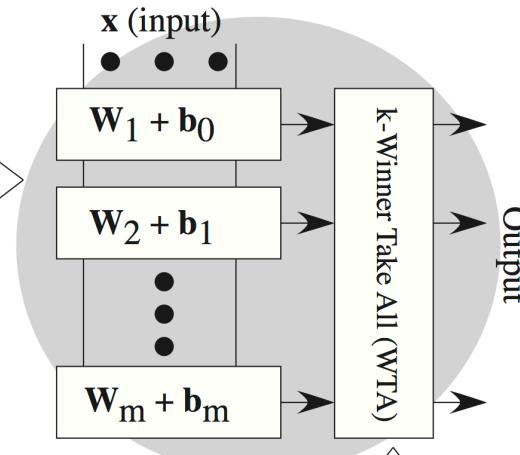
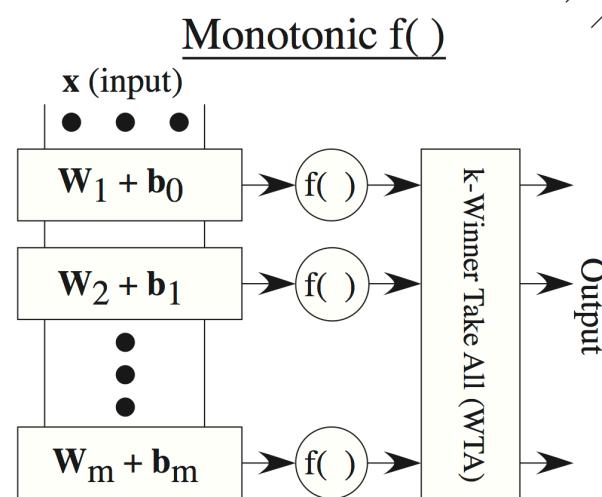
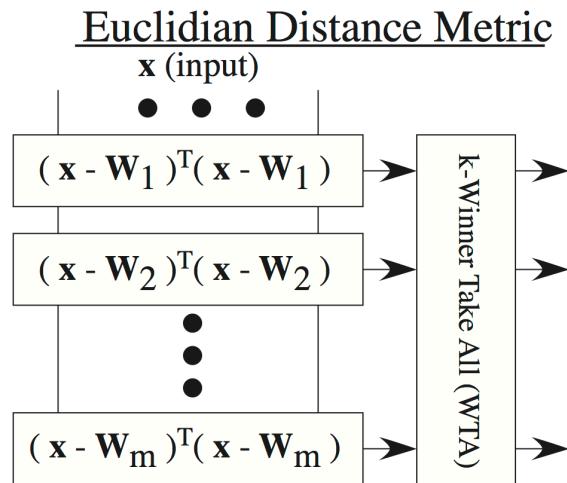
VMM+WTA Classifier



WTA: biologically inspired,  
good framework for  
further bio-inspired computing



# Classifiers Equivalences With VM+WTA



Invariance:

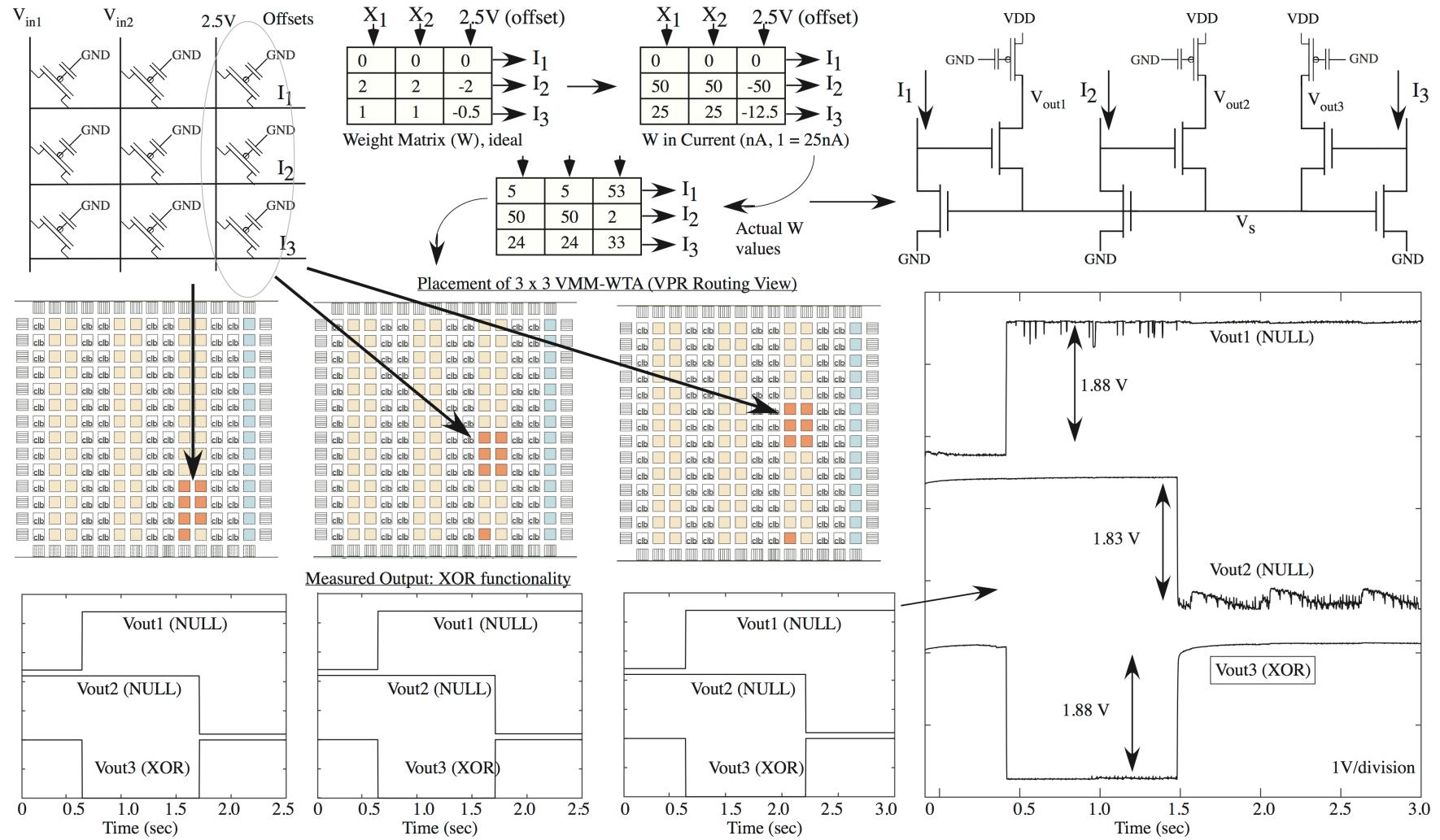
- Constant Weight Offsets
- Constant Weight Scaling
- Constant Input Offsets

→ Only requires 1 quadrant mult

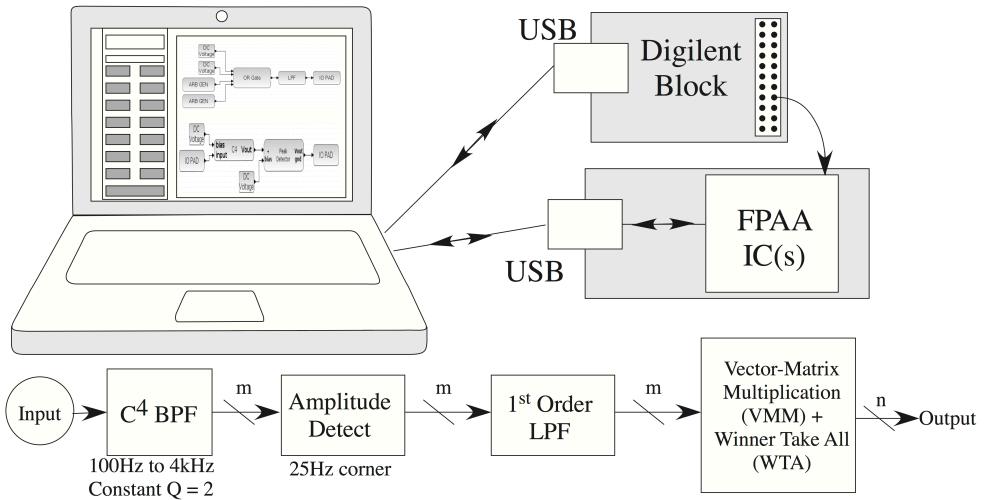
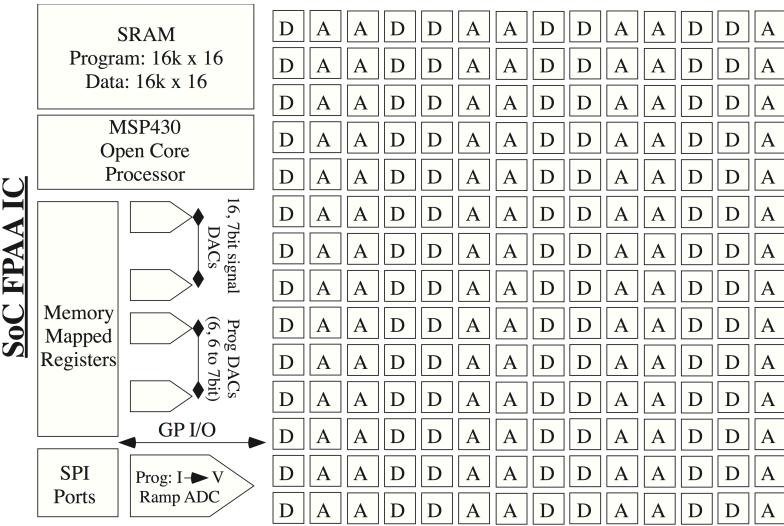
Equivalence:

- VQ
- SOM
- GMM

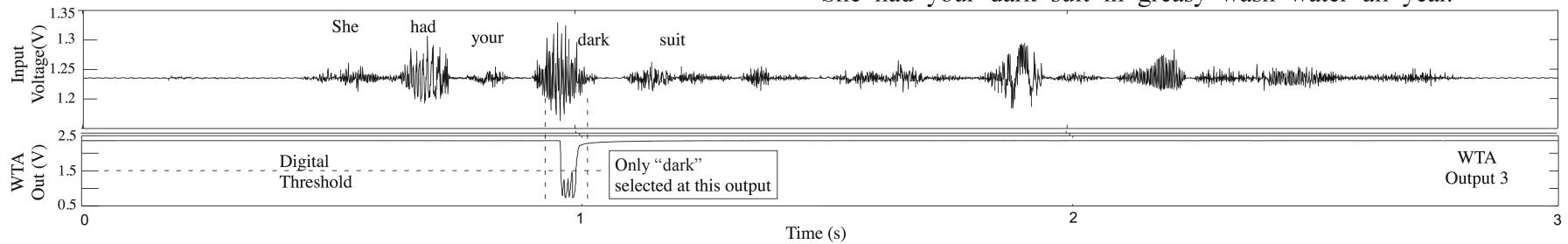
# Measured XOR Classifier: Different CABs



# SoC FPAAC: Computing



“She had your dark suit in greasy wash water all year.”



# Experiment Session

Perform the 2-input VMM + WTA block for the XOR problem

When you start your classifier, the weights might not be quite right. You should change these weights until you get the resulting function and take note of these differences

