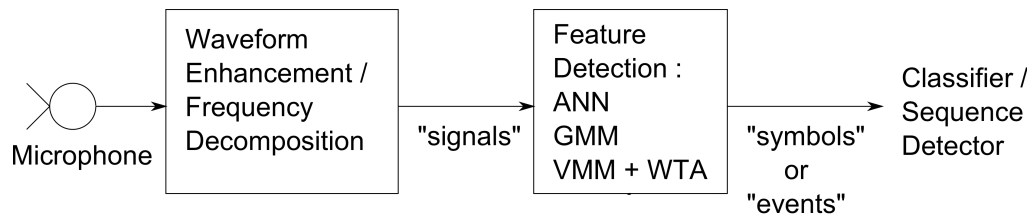


Classifiers for Sensory Data



Key Signal to Symbol Refinement

Two layers: (VMM + nonlinear functions)

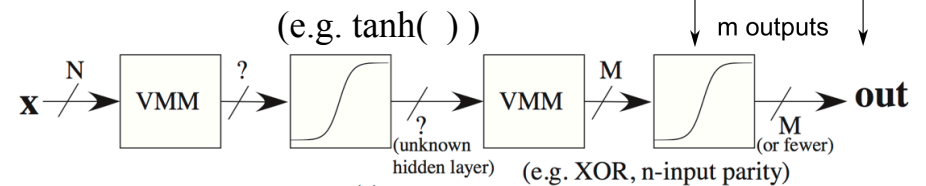
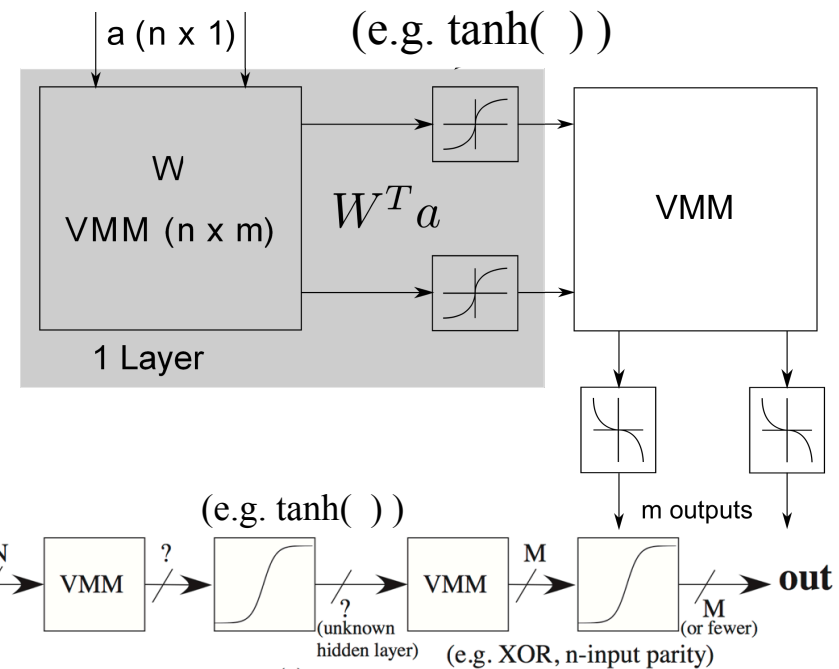
Required for Universal Approximator
= arbitrary function approximation with
infinite (countable) neurons

VMM = Vector Matrix Multiplication

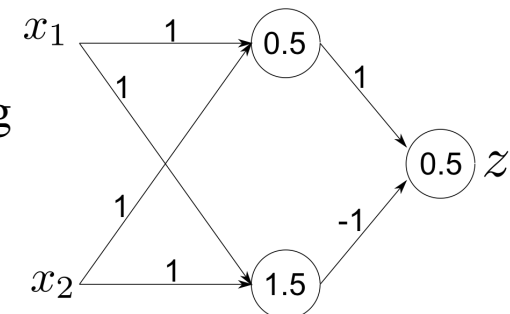
$$\mathbf{y} = \mathbf{W} \mathbf{x}$$

VMM often implemented in FPAA

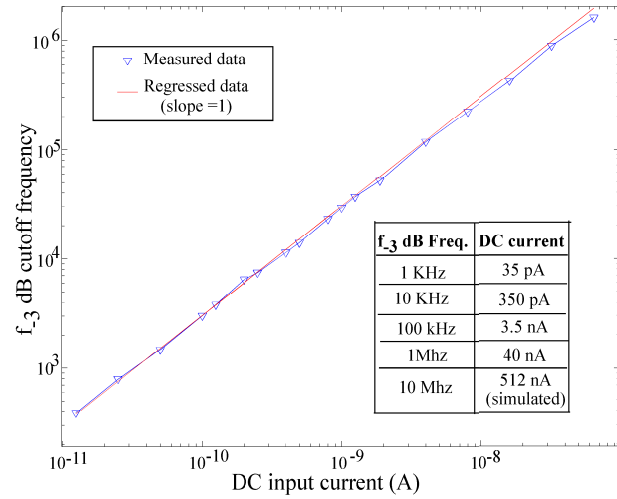
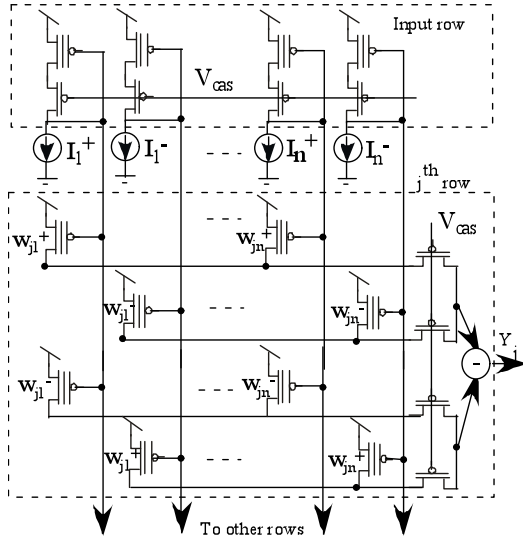
Nonlinear function (e.g. $\tanh$) allows
for decisions and nonlinear function
approximation



XOR: Classic
function showing
two layers
required to
fully implement

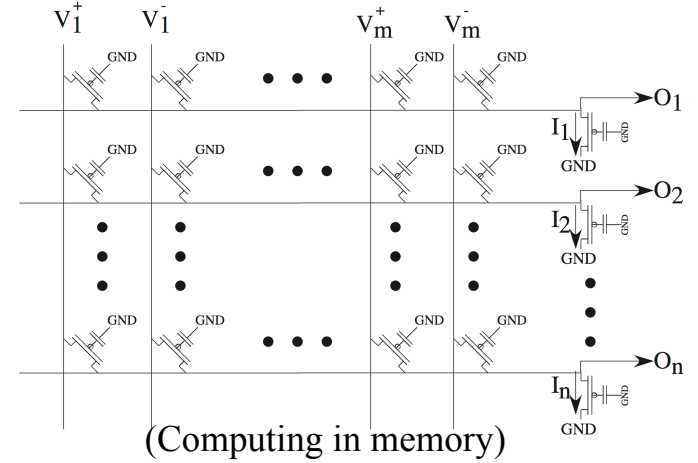


FG VMM



[Chawla, et. al, CICC 2004]

VMM in FPA Routing Fabric

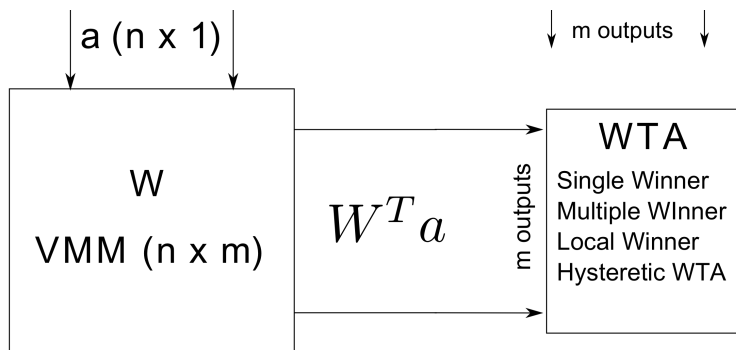


Analog (VMM): ~10-20MMAC/μW ~50-100 fJ / MAC Digital ~ 10MMAC/mW @ yield

SUMMARY OF PERFORMANCE PARAMETERS A SOURCE-DRIVEN VMM DEVICE. N = 8, M = 8. V_{dd} = 1V.

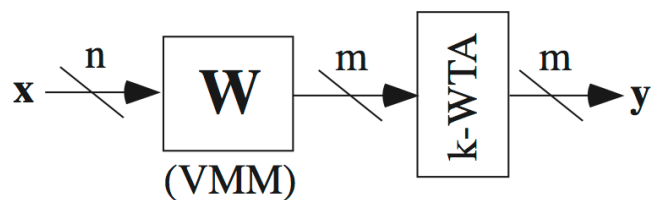
Property	Expression	25pA	2.5nA	250nA	25μA*
Bandwidth (f)	$\frac{I_{so}}{4\pi C_d U_T}$	3.86kHz	386kHz	38.6MHz	3.86GHz
Computation	2 N M f	500kMAC(/s)	50MMAC(/s)	5GMAC(/s)	500GMAC(/s)
Power (P)	$2NM I_{so} V_{dd}$	3.2nW	320nW	32μW	3.2mW
MMAC/μW	$\frac{1}{8\pi C_d U_T V_{dd}}$	33MMAC/μW	33MMAC/μW	33MMAC/μW	33MMAC/μW
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

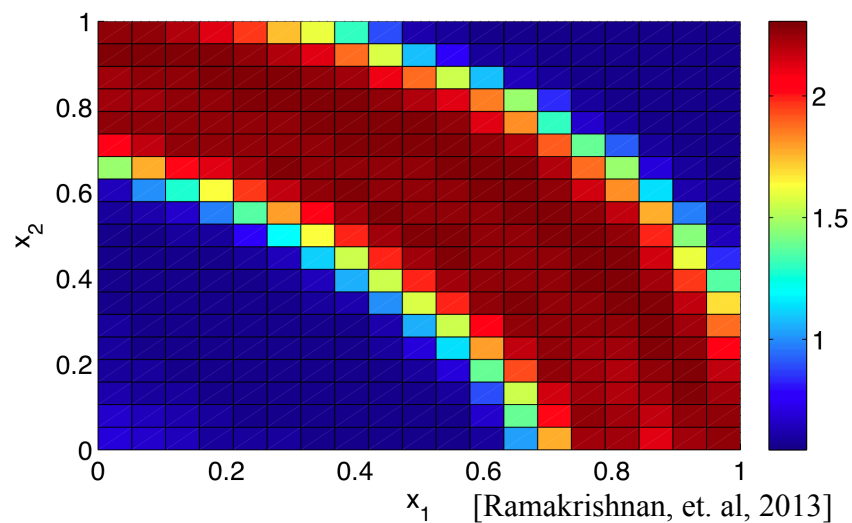


1 single VMM + n-WTA layer =
universal approximator
[Maass, et. al, 2000]

VMM+WTA Classifier

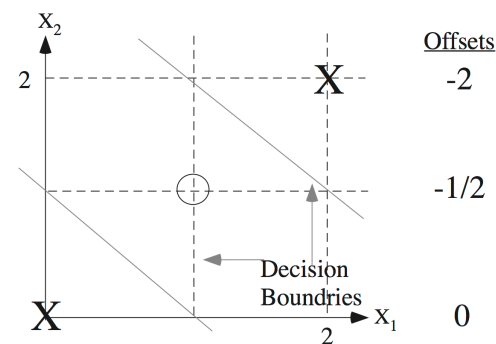
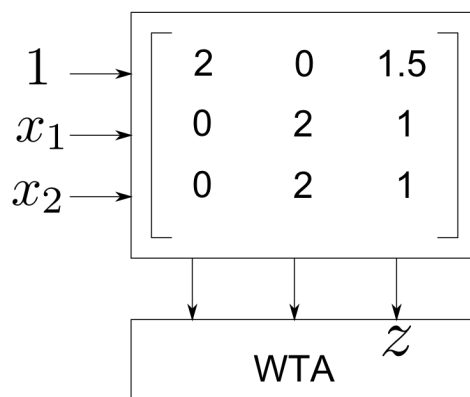


WTA: biologically inspired,
good framework for
further bio-inspired computing



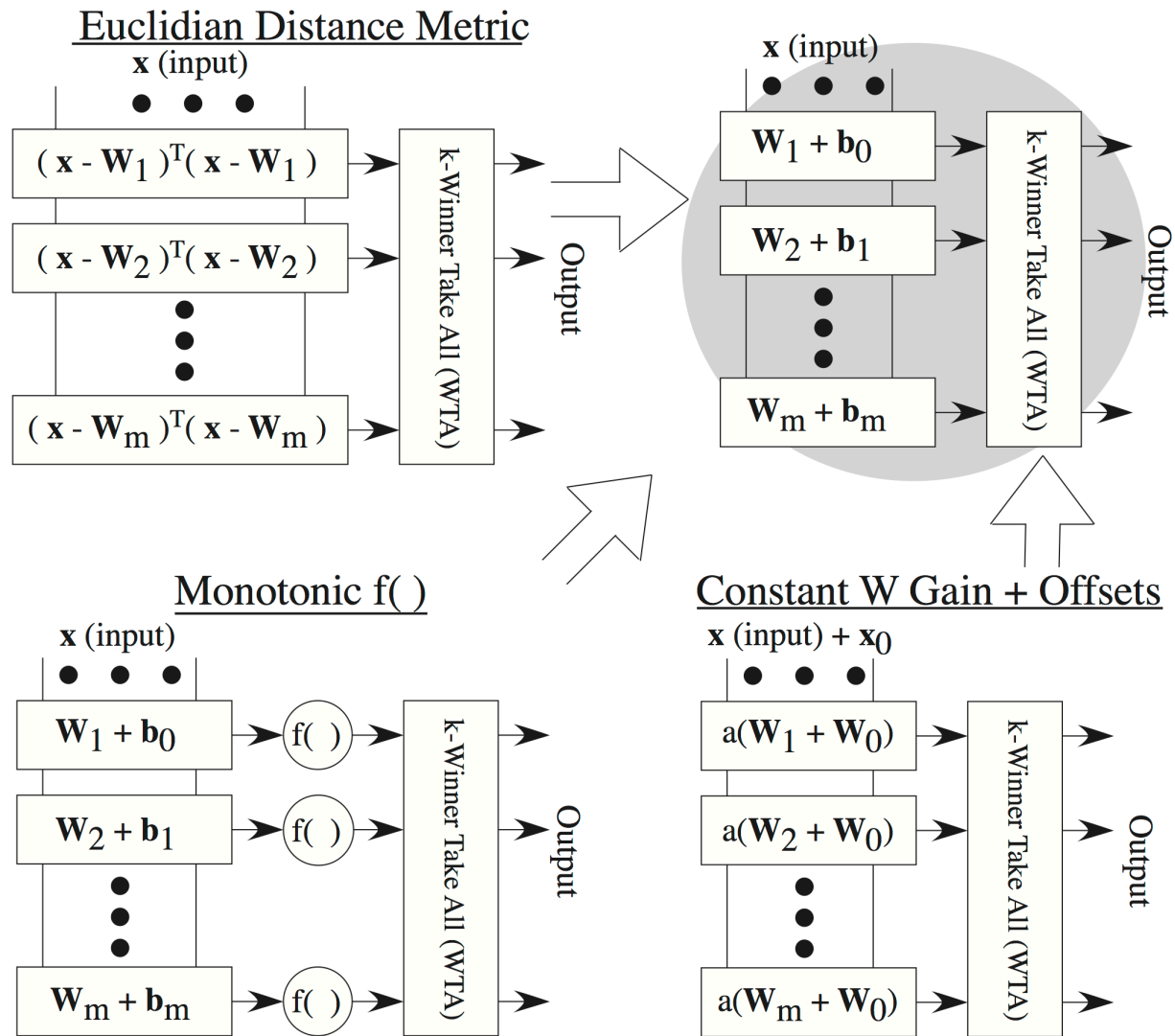
Measured XOR Scatter Plot

3 x 3 VMM



Offsets

Classifiers Equivalences with VMM+WTA



Invariance:

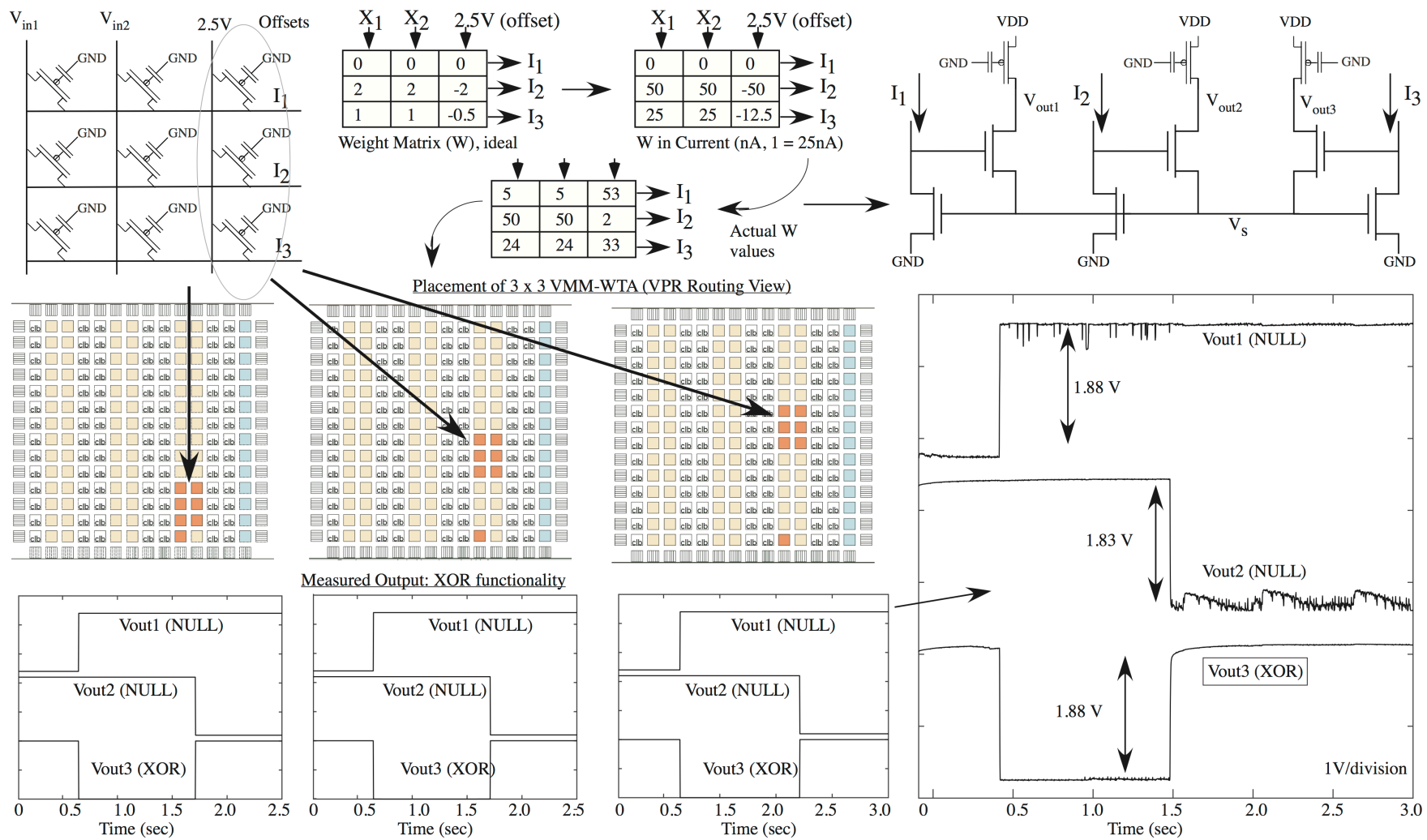
- Constant Weight Offsets
- Constant Weight Scaling
- Constant Input Offsets

→ Only requires 1 quadrant mult

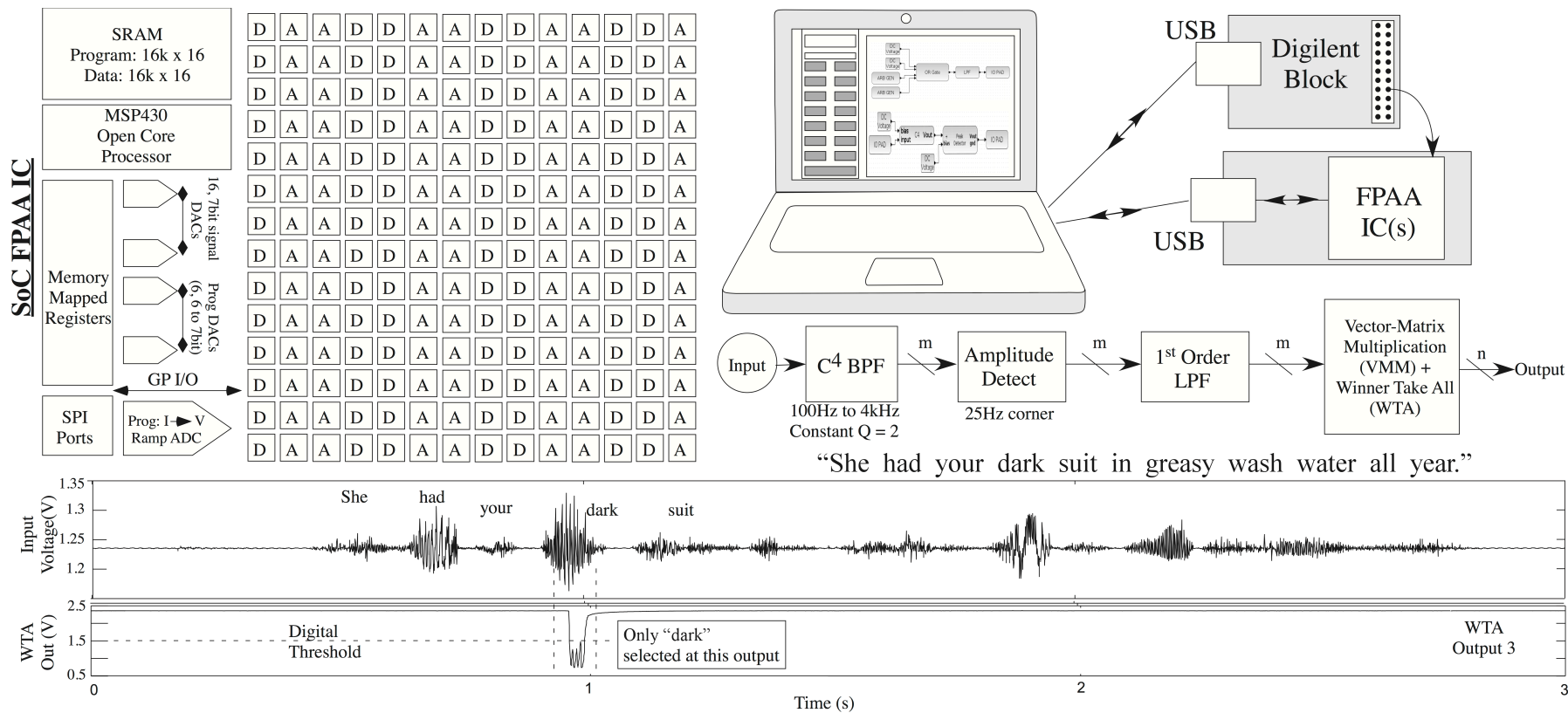
Equivalence:

- VQ
- SOM
- GMM

Measured XOR Classifier: Different CABs



SoC FPAA: Computing



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

