A Universal SPICE Modeling Approach with Artificial Neural Network

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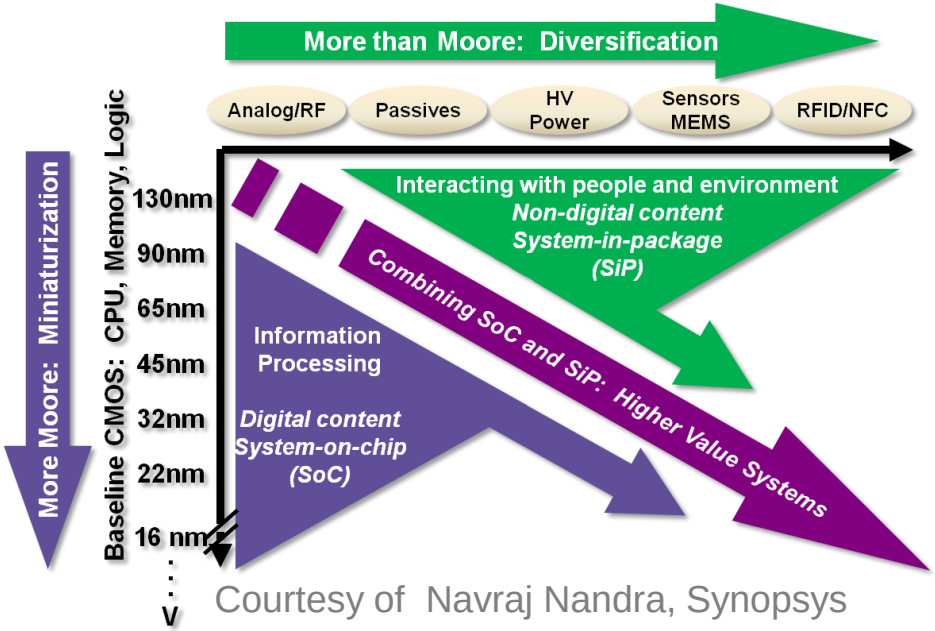
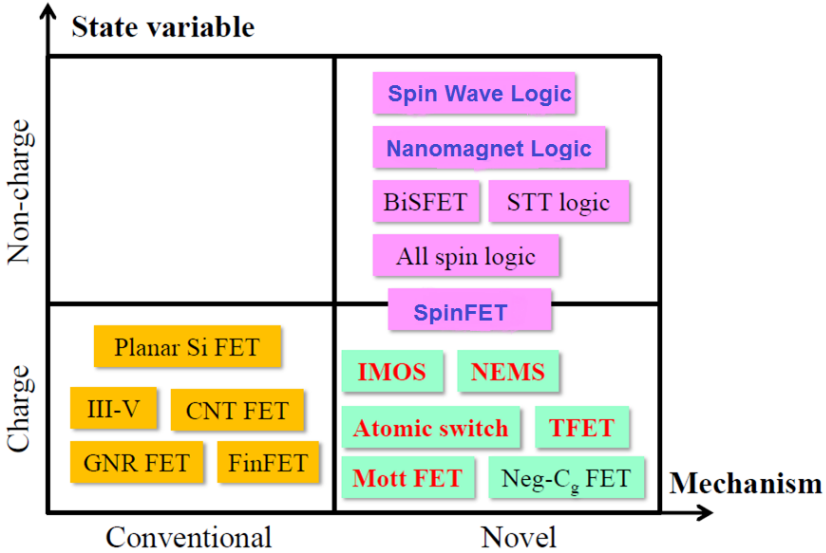
Quite Many Devices Emerging



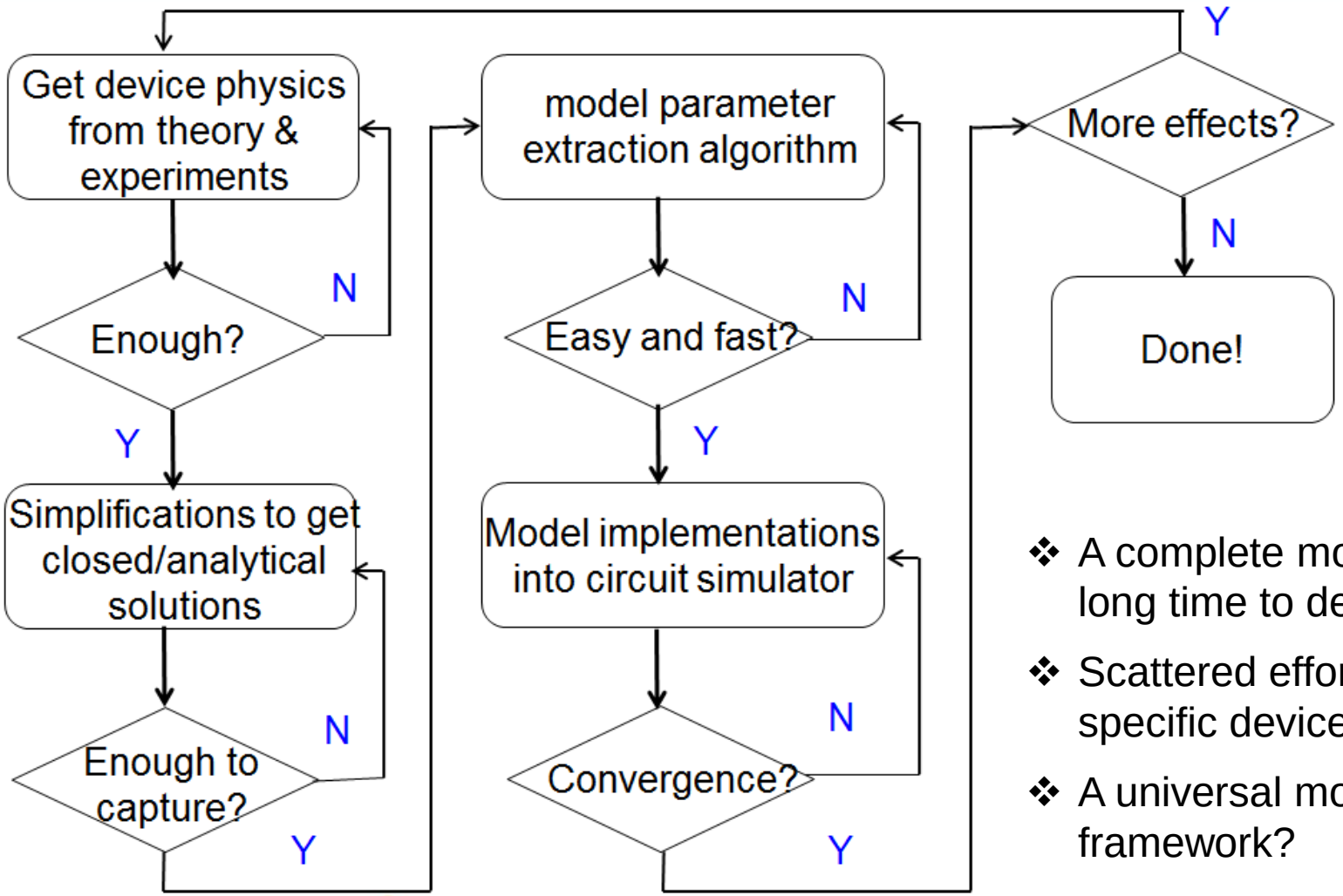
Courtesy of Navraj Nandra, Synopsys

- Continuous scaling pushes the More Moore devices
- Device innovations along the More than Moore direction
- System integrations

- Logic devices for scaling: many candidates
- Completely new device physics and mechanisms
- Modeling is a must

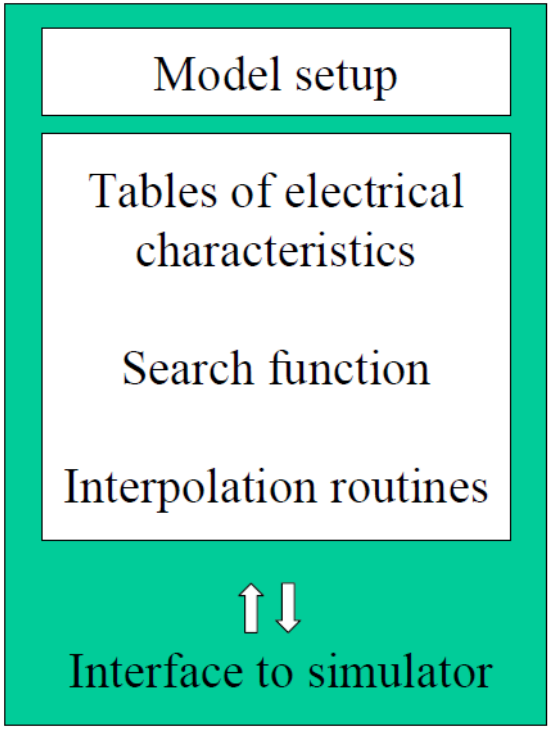


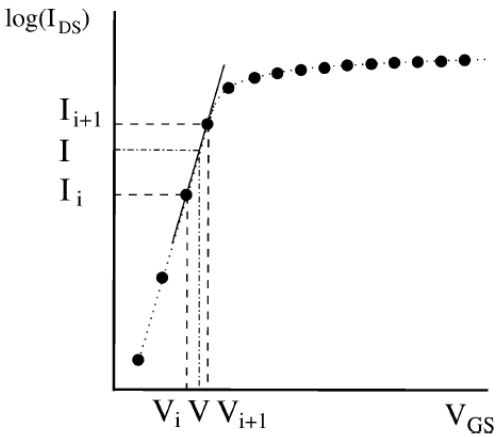
Traditional Compact Modeling



- A complete model takes long time to develop
- Scattered efforts for specific devices
- A universal model framework?

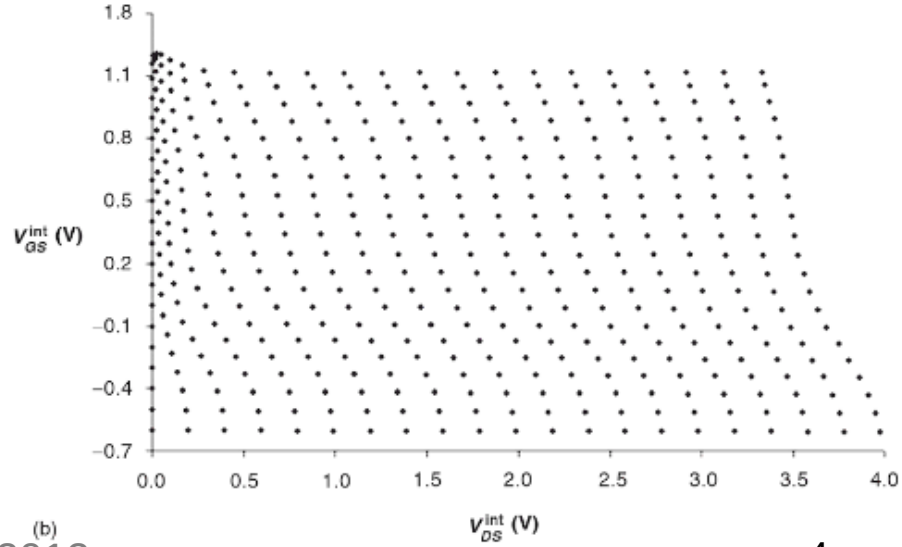
Data-Oriented Modeling: Table Model





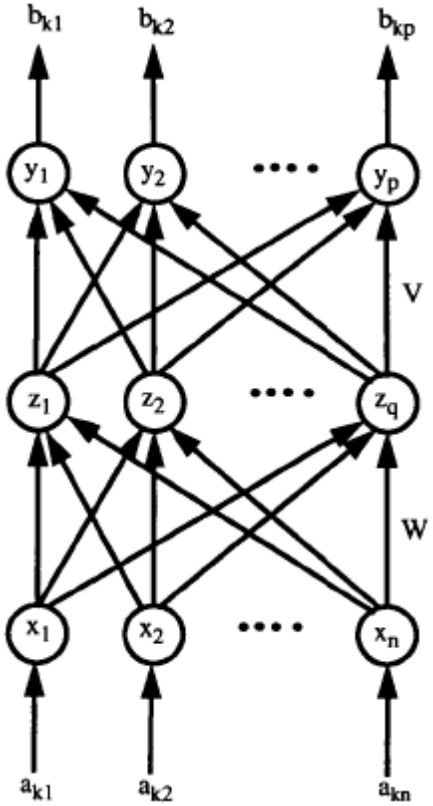
- Table look-up model is universal in some sense
- Interpolation techniques to enhance model FOM
- Loss of accuracy
- Standard options for fast spice

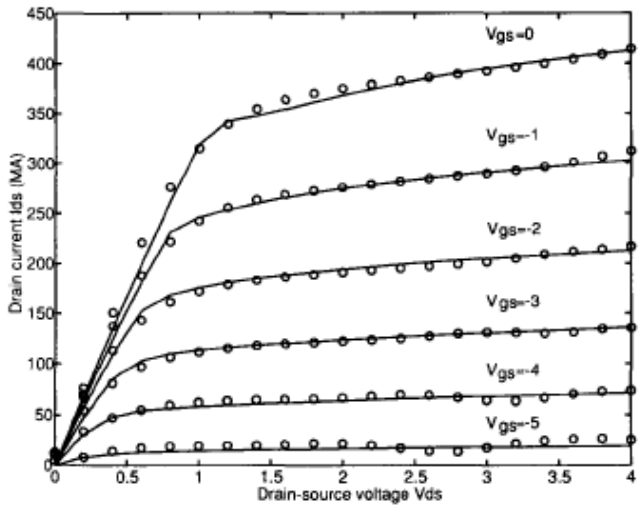
- Limited predictive capabilities
- Large storage issues and memory requirements
- Partial derivatives for small signal analysis



[1] V. Bourenkov, *et al*, 2005 [2] D. Root, *et al*, 2012

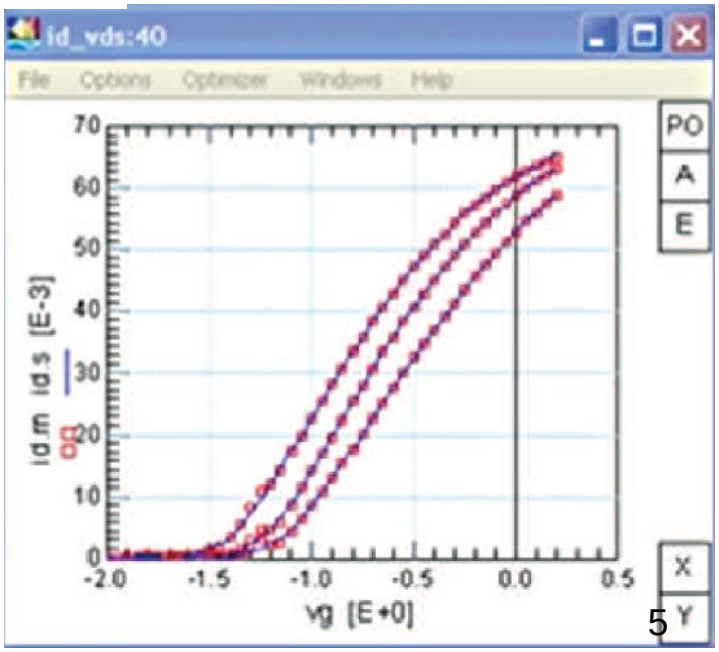
Data-Oriented Modeling: ANN Model





First demo [1]

NeuronFET [2]



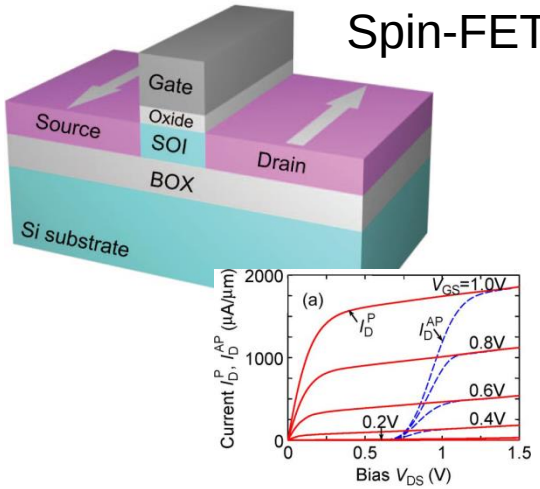
- Initiated quite some time ago for microwave device
- Features of ANN v.s. Requirements on SPICE model
- Foundry dependent device problem

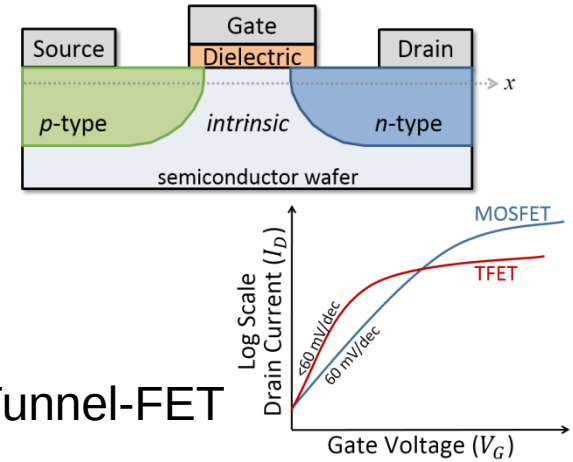
- Function approximation of the neural network
- Equivalency of model plus parameter extractions [back propagation]

[1] Q. Zhang, *et al*, 1995 [2] D. Root, 2012

ANN for A Universal SPICE Model?

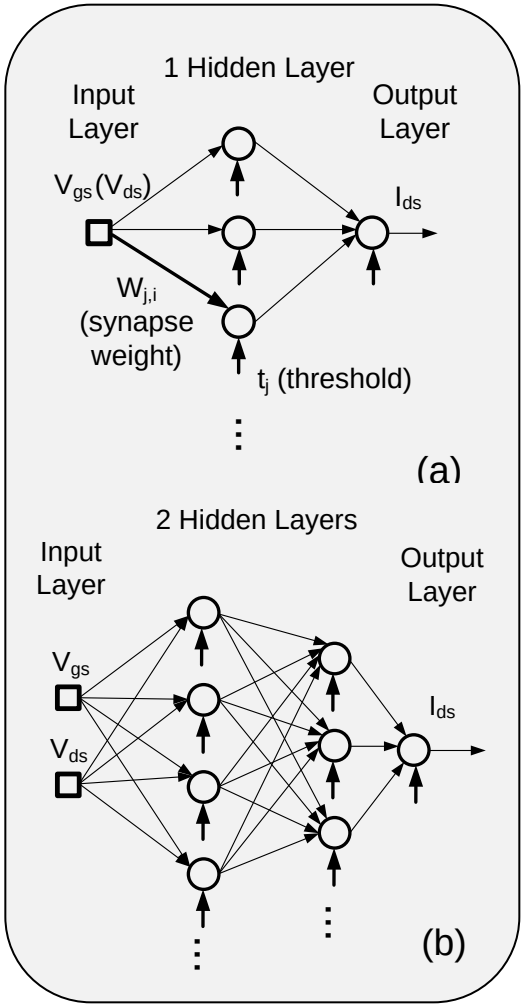
Spin-FET





Tunnel-FET

…other devices



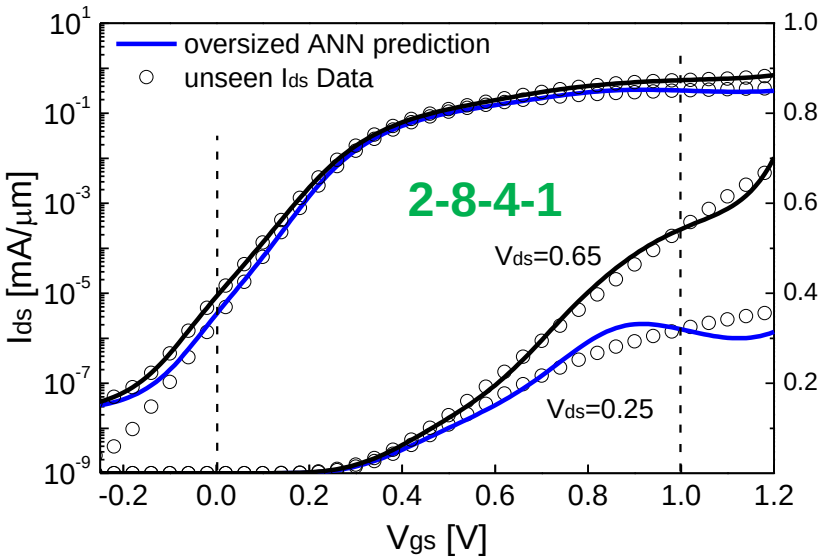
ANN model training

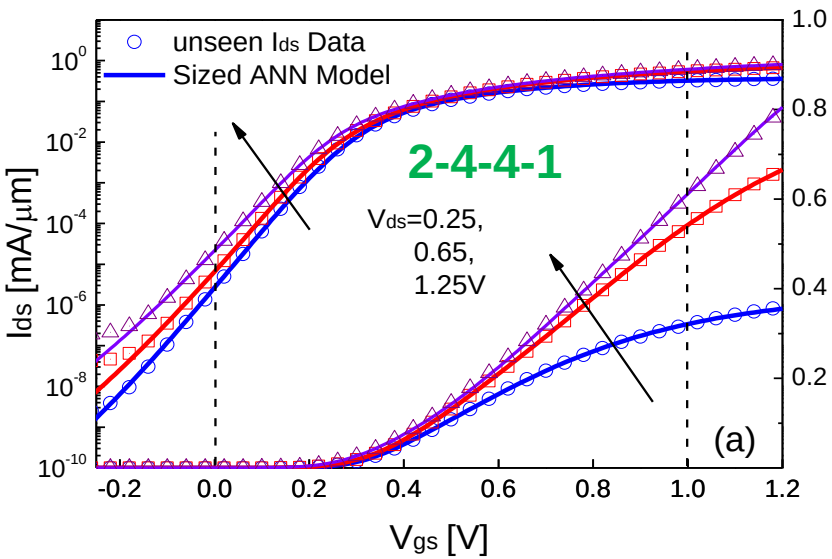
```
ann.c
annacld.c
annanalogfunction.c
annask.c
anndel.c
anndest.c
annguesstopology.c
anninit.c
annload.c
annmask.c
annmdel.c
annmpar.c
annnoise.c
annpar.c
annpzld.c
annsetup.c
anntemp.c
anntrunc.c
```

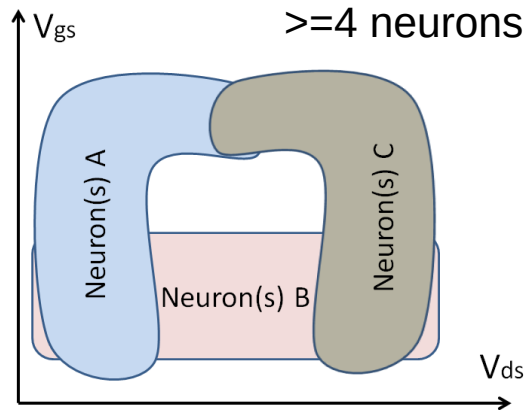
SPICE

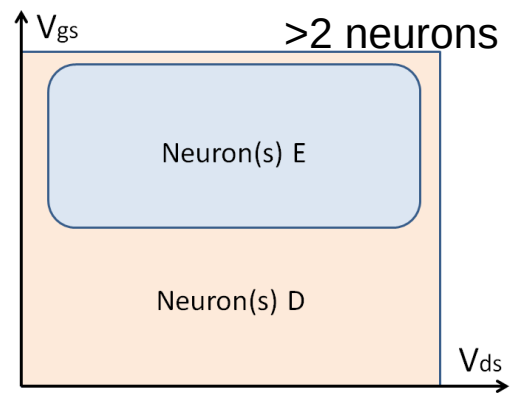
SPICE with a universal model

Accuracy of Generalizations



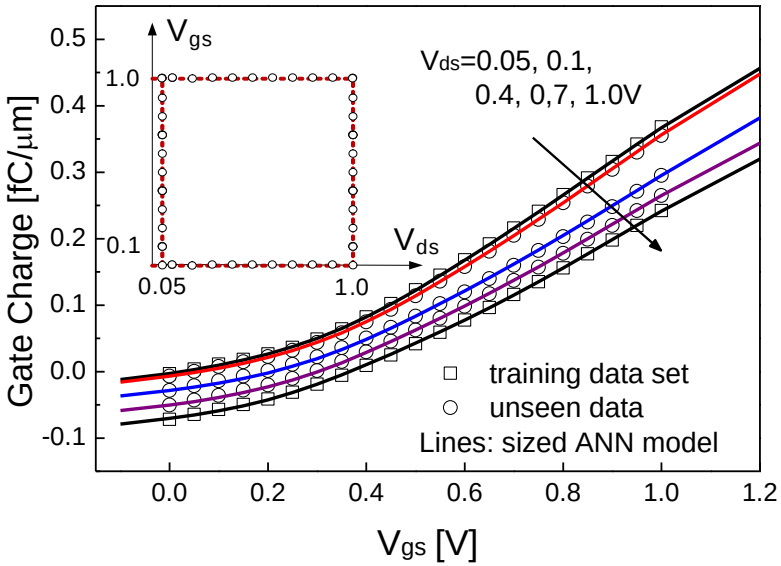


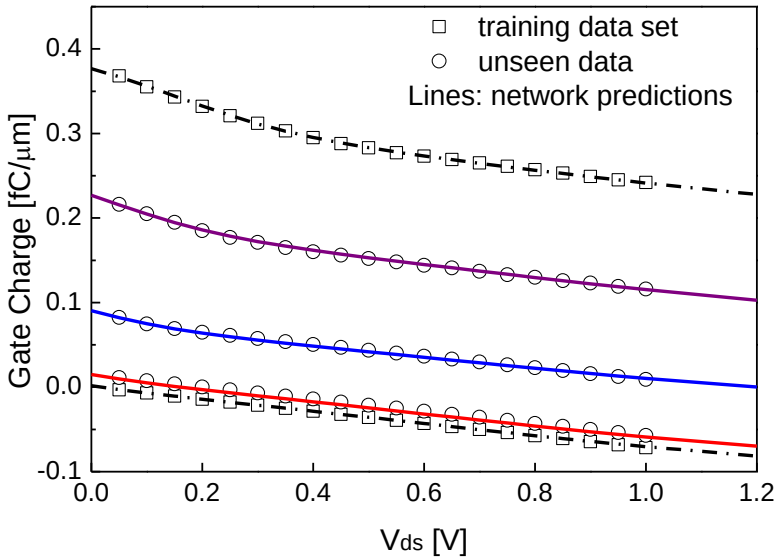




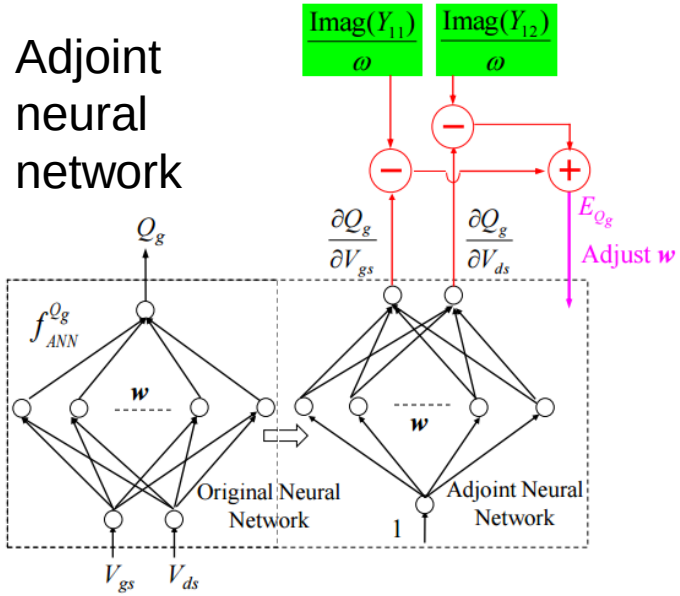
- ❖ Two hidden layers for universality
- ❖ Local and global features partition

Terminal Charge Modeling





Adjoint neural network

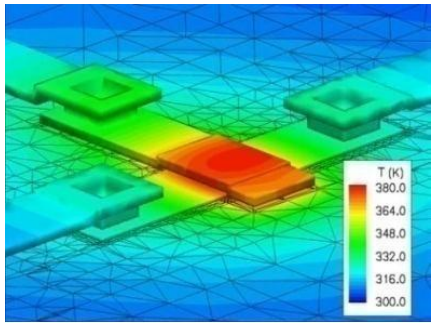


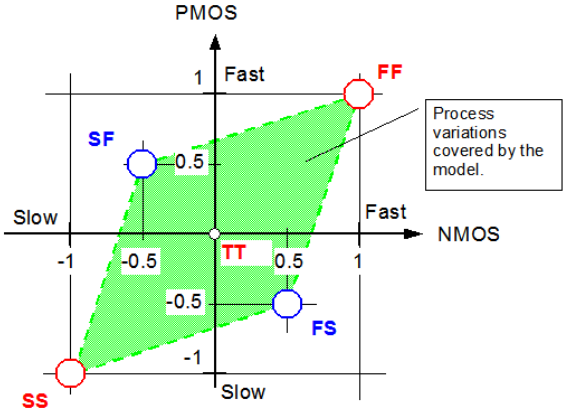
- Charge instead of capacitance
  --charge conservation
- Terminal charge (intri & extri)
  --integral functions
  --adjoint neural network
- Separated current and charge?
  -- intermediate electrostatics

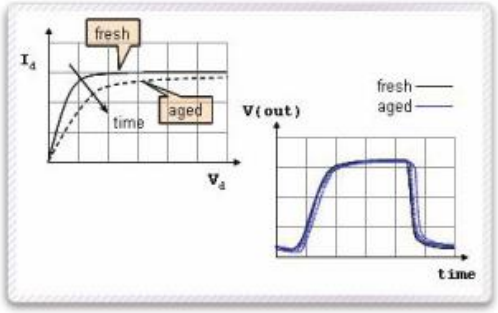
[1] J. Xu, et al, 2003

Pending Issues

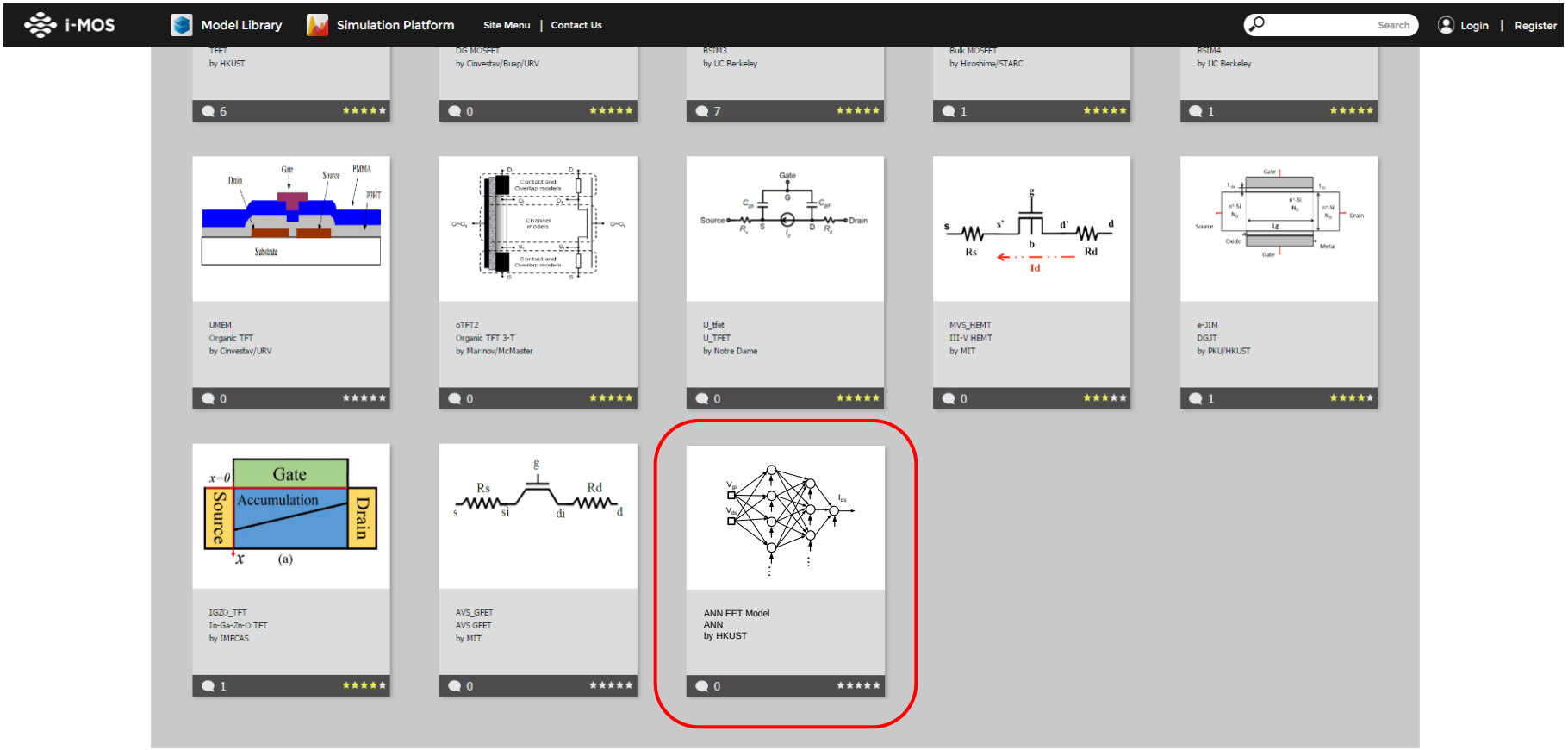
- Temperature effects and self-heating
- Corner modeling for device variations
- Device and circuit reliability simulations
- Noise modeling and integrations ?







Integration with *i*-MOS



- ANN model takes into formatted data and output the ‘modelcard’
- Integrated with the *i*-MOS framework including circuit simulations
- Alpha version coming soon https://i-mos.org

Wrap-up

- Artificial neural network for a universal compact modeling
- Techniques for accuracy control, sizing, and dataset
- ANN model benchmark and SPICE simulations

Acknowledgement

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