Modeling I/O Buffers

(Part 2)

Dr. José Ernesto Rayas Sánchez

Outline

- Linear models for I/O buffers
- Quasi-linear models for I/O buffers
- Behavioral modeling
- IBIS models
- ANN-based behavioral models

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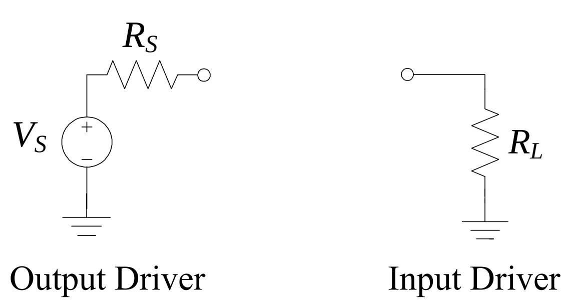
Types of Buffer Models for Digital Design

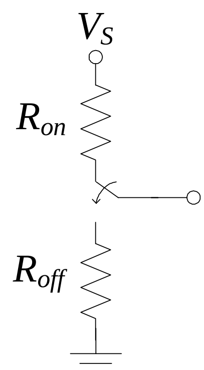
- Linear models
- Nonlinear behavioral models
- ✓ Detailed electrical models (transistor level)

Linear Models

- Linear models are the most basic approximation of I/O buffers
- They can be circuital or behavioral



Quasi-Linear Models for Output Drivers



Output Driver

Behavioral Models

- Behavioral models are mathematical expressions that reproduce an observed circuit's behavior
- The "observed" circuit's behavior can be obtained from measurements or from accurate simulations
- The mathematical expressions interpolate the actual performance of the circuit
- Typical mathematical expressions (interpolants) used:
  - Look-up tables
  - Logarithmic, exponential and power function
  - Polynomial expansions and rational functions
  - Artificial neural networks

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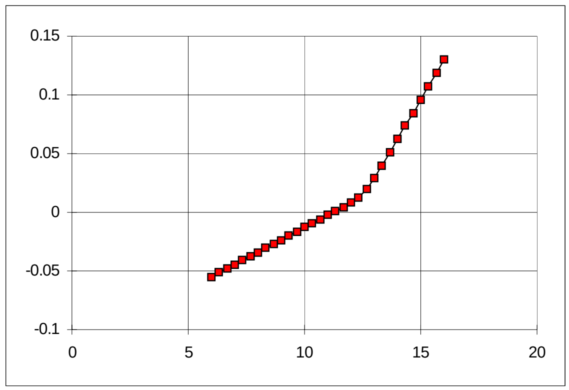
Curve Fitting in Behavioral Modeling

X	Y
6	-0.055
6.333333	-0.0515
6.666667	-0.048
7	-0.0445
7.333333	-0.041
7.666667	-0.0375
8	-0.034
8.333333	-0.0305
8.666667	-0.027
9	-0.0235
9.333333	-0.02
9.666667	-0.0165
10	-0.013
10.33333	-0.0095
10.66667	-0.005999
11	-0.002496
11.33333	0.001017
11.66667	0.004577
12	0.008349
12.33333	0.01295
12.66667	0.01972
13	0.029127
13.33333	0.039894
13.66667	0.051059
14	0.062315
14.33333	0.073591
14.66667	0.084872
15	0.096154
15.33333	0.107436
15.66667	0.118718
16	0.13

Curve Fit Equation

$$y = -0.118 + 0.0105\,x + 0.0117\,\log\left[1 + 10^{\frac{(x - 12.573)}{0.5}}\right]$$



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(T. R. Turlington, 2000)

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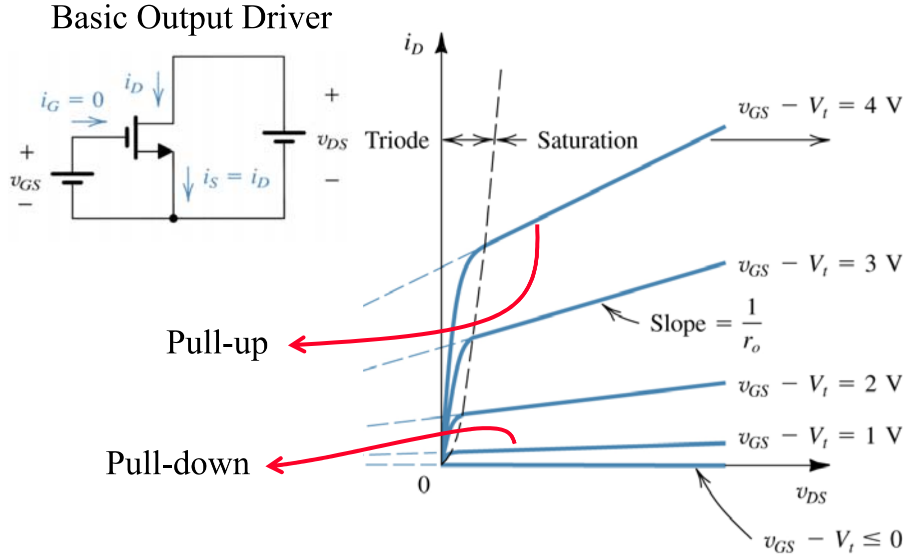
Developing Behavioral Models – Example

Basic Output Driver



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IBIS Models

Industry standard for behavioral description of buffers

IBIS

(I/O Buffer Information Specification)

Version 4.1

Ratified January 30, 2004

IBIS Models (cont)

```
|==============================================================================
|==============================================================================
| I/O Buffer Information Specification (IBIS) Version 4.1 (January 30, 2004)
|
| IBIS is a standard for electronic behavioral specifications of integrated
| circuit input/output analog characteristics.
|==============================================================================
|==============================================================================
|
|                   T A B L E    O F    C O N T E N T S
|
|==============================================================================
|==============================================================================
|
```

IBIS Models (cont)

EIA-656-A

EIA STANDARD

I/O Buffer Information Specification (IBIS) Version 3.2

EIA-656-A
(Revision of EIA-656)

SEPTEMBER 1999

ELECTRONIC INDUSTRIES ALLIANCE
ENGINEERING DEPARTMENT

Electronic Industries Alliance

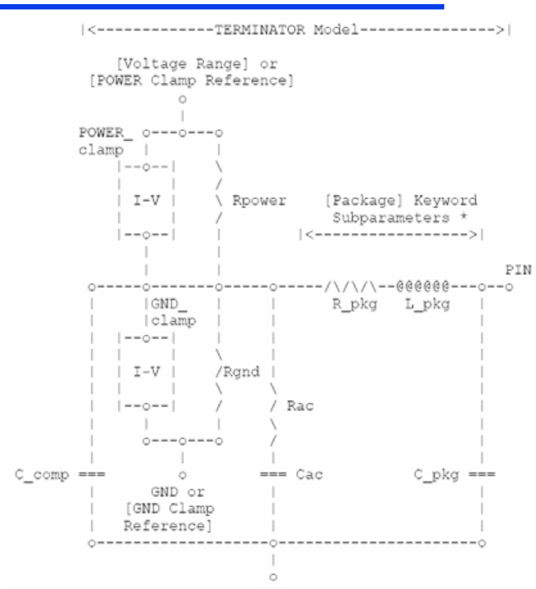
IBIS Models (cont)

[POWER Clamp]

Voltage	I(typ)	I(min)	I(max)
-5.0V	4450.0m	NA	NA
-0.7V	95.0m	NA	NA
-0.6V	23.0m	NA	NA
-0.5V	2.4m	NA	NA
-0.4V	0.0m	NA	NA
0.0V	0.0m	NA	NA

[GND Clamp]

Voltage	I(typ)	I(min)	I(max)
-5.0V	-3900.0m	-3800.0m	-4000.0m
-0.7V	-80.0m	-75.0m	-85.0m
-0.6V	-22.0m	-20.0m	-25.0m
-0.5V	-2.4m	-2.0m	-2.9m
-0.4V	0.0m	0.0m	0.0m
5.0V	0.0m	0.0m	0.0m



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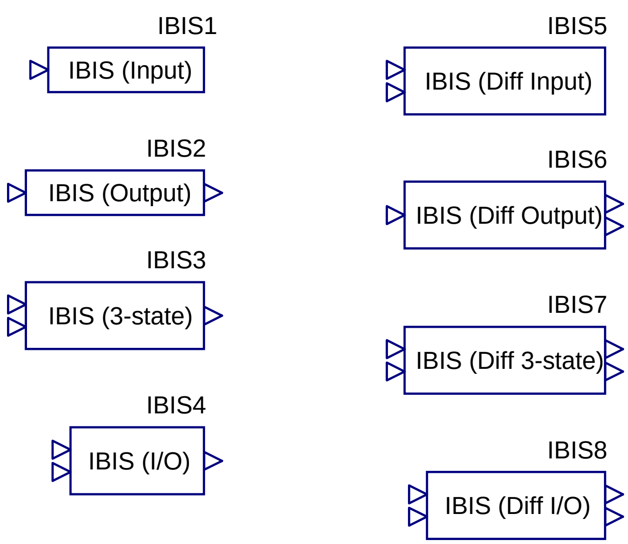
IBIS Models (cont)

```
|------------------------------------------------------------
| variable       R(typ)           R(min)           R(max)
[Rgnd]           330ohm           300ohm           360ohm
[Rpower]         220ohm           200ohm           NA
|
[Rac]            30ohm            NA               NA
|
| variable       C(typ)           C(min)           C(max)
[Cac]            50pF             NA               NA
|

|------------------------------------------------------------
[Package]
| variable       typ              min              max
R_pkg            250.0m           225.0m           275.0m
L_pkg            15.0nH           12.0nH           18.0nH
C_pkg            18.0pF           15.0pF           20.0pF
|
|============================================================
```


IBIS Models in APLAC

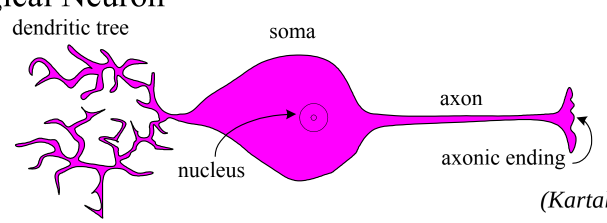


Behavioral ANN-based Approach

- Artificial Neural Networks (ANNs) can be used as effective interpolants to create behavioral models
- The ANN can be the model model itself, or it can be used as a preprocessing vehicle

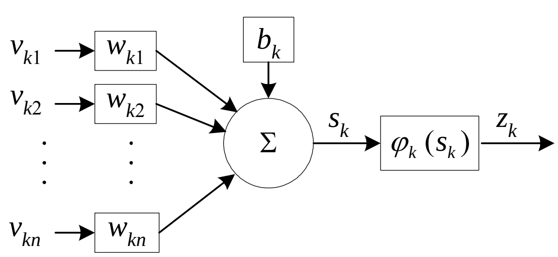
Artificial Neural Networks

- Biological Neuron



(Kartalopoulos, 1996)

- Artificial Neuron



$$s_k = b_k + \boldsymbol{v}_k^T \boldsymbol{w}_k$$

$$z_k = \varphi_k(s_k)$$

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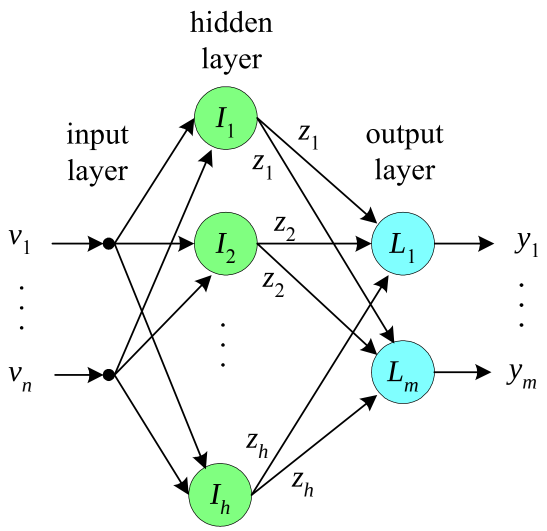
Most Common ANN: 3-Layer Perceptron



$$\boldsymbol{y} = \boldsymbol{b}^o + \boldsymbol{W}^o \boldsymbol{\Phi}(\boldsymbol{s})$$

$$\boldsymbol{s} = \boldsymbol{b}^h + \boldsymbol{W}^h \boldsymbol{v}$$

where

$$\boldsymbol{W}^o = [\boldsymbol{w}_1^{o\,T} \quad \cdots \quad \boldsymbol{w}_m^{o\,T}]^T$$

$$\boldsymbol{W}^h = [\boldsymbol{w}_1^{h\,T} \quad \cdots \quad \boldsymbol{w}_h^{h\,T}]^T$$

$$\boldsymbol{\Phi}(\boldsymbol{s}) = [\varphi(s_1) \quad \cdots \quad \varphi(s_h)]^T$$

$$\boldsymbol{b}^h = [b_1^h \quad b_2^h \quad \cdots \quad b_h^h]^T$$

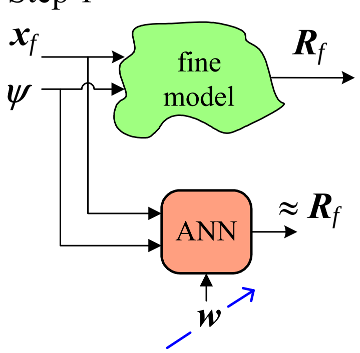
$$\boldsymbol{b}^o = [b_1^o \quad b_2^o \quad \cdots \quad b_m^o]^T$$

$$\boldsymbol{y}, \boldsymbol{b}^o \in \Re^m \quad \boldsymbol{s}, \boldsymbol{b}^h, \boldsymbol{\Phi} \in \Re^h \quad \boldsymbol{W}^o \in \Re^{m \times h} \quad \boldsymbol{W}^h \in \Re^{n \times h}$$

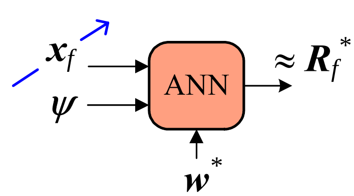
Behavioral ANN-based Approach (cont)

Using the ANN as the model itself

Step 1



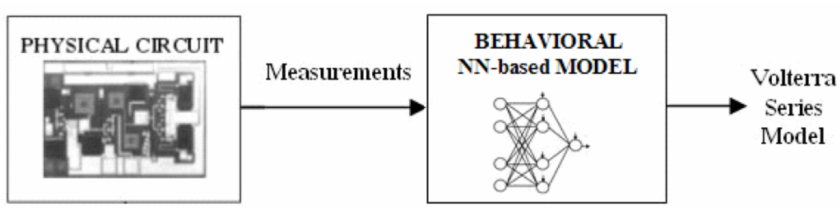
Step 2



(Many fine model simulations are needed)

Behavioral ANN-based Approach (cont)

Using the ANN as a pre-processing vehicle



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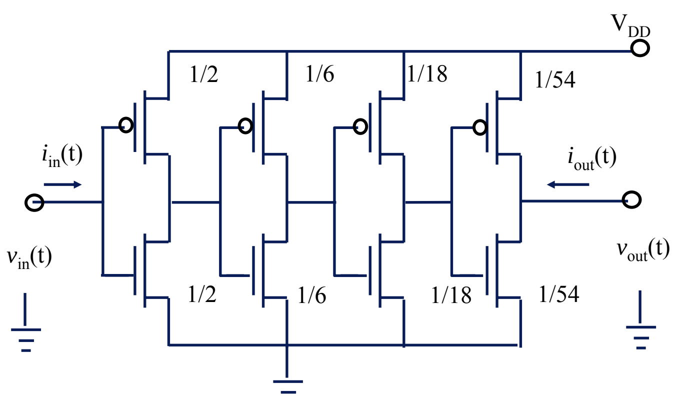
(G. Orengo, 2005) 19

Behavioral ANN-based Approach (cont)

Example: 4-Stage CMOS Driver



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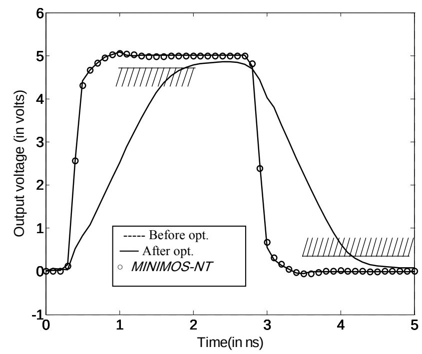
(Q.J. Zhang, 2005) 20

Behavioral ANN-based Approach (cont)

Example: 4-Stage CMOS Driver



	CPU Time for Optimization
ADNN-Based Optimization	8 seconds
Direct Optimization by Driving MINIMOS-NT	10.5 hours

(Q.J. Zhang, 2005)