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A Unified Environment for Modeling Very Deep Submicron MOS Transistors

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Why are different simulation models still in use ?

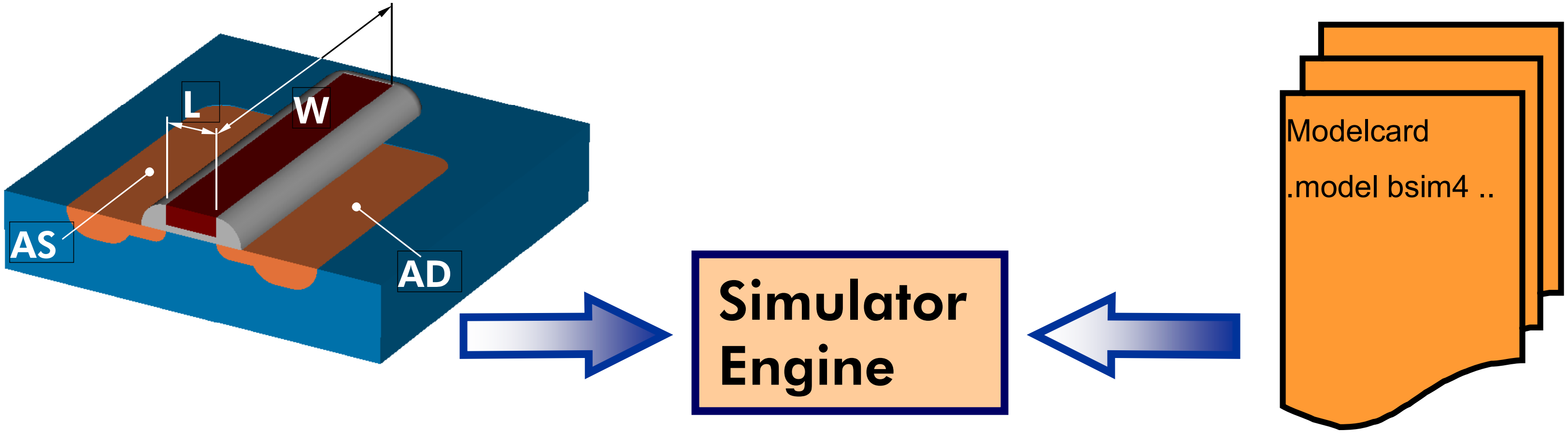
The Compact Model Council established the BSIM3v3 model as the first standard MOS model in semiconductor industry. Normally it could be assumed, that anyone uses this model as a base for MOS circuit design. However, it could be identified, that not all users of MOS simulation models will or can follow this recommendation due to the following reasons:

- Models for RF applications require special extensions than models for “normal” transistors.
- Companies are still developing and using internal models beside the public domain models.
- Some models are dedicated for special applications, like low voltage and low power devices or high power transistors.
- Not all relevant physical effects of very modern processes can be covered by the standard models.
- Due to simulator issues, more than one model must be provided to the end users.

⇒ **A unified environment was developed to enable the generation of several MOS model types based on a common data base of measured data.**

Scalable MOS models

Scalability means, the MOS model for a certain transistor is called inside the simulator together with some information about the dimensions of the device.

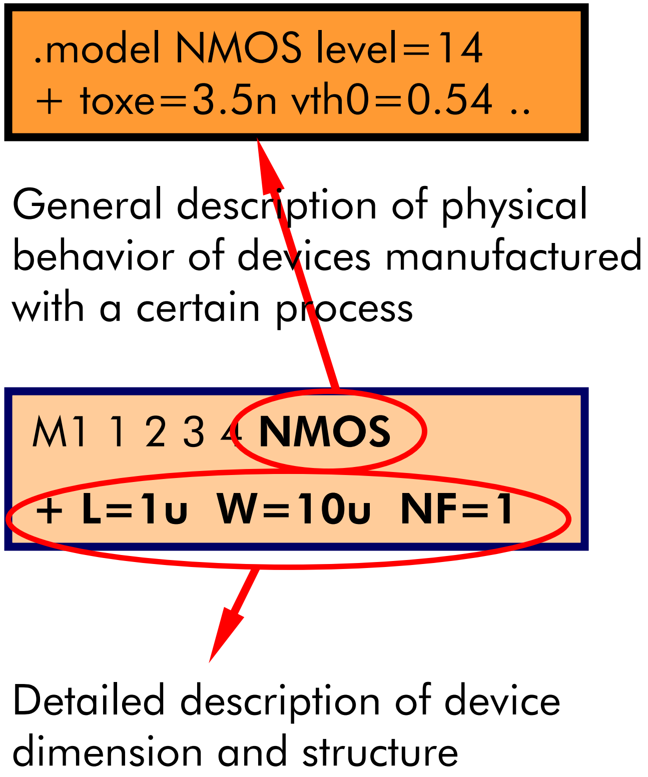


Simulator Engine

This strategy is very unique compared to other models (bipolar transistors, primitive devices without geometry information).

Scalable MOS models (2)

BSIM4: fully scalable



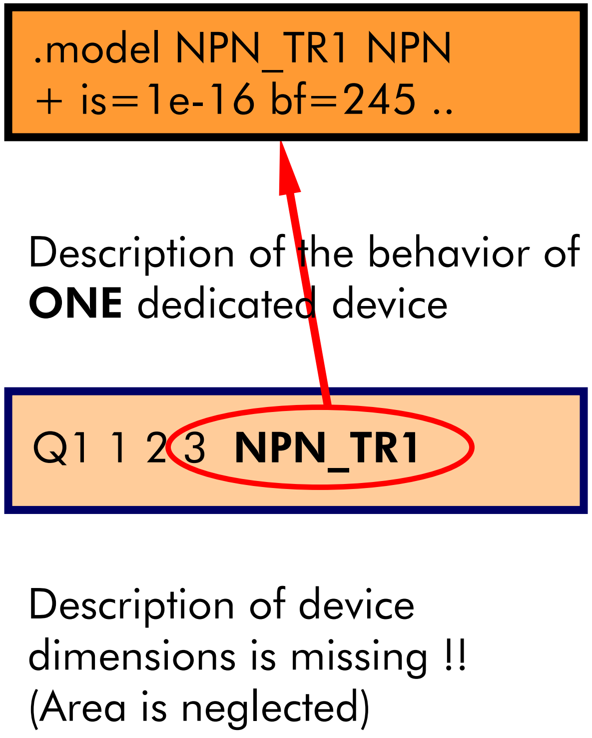
```
.model NMOS level=14
+ toxe=3.5n vth0=0.54 ..
```

General description of physical behavior of devices manufactured with a certain process

```
M1 1 2 3 4 NMOS
+ L=1u  W=10u  NF=1
```

Detailed description of device dimension and structure

BJT GP: practically not scalable



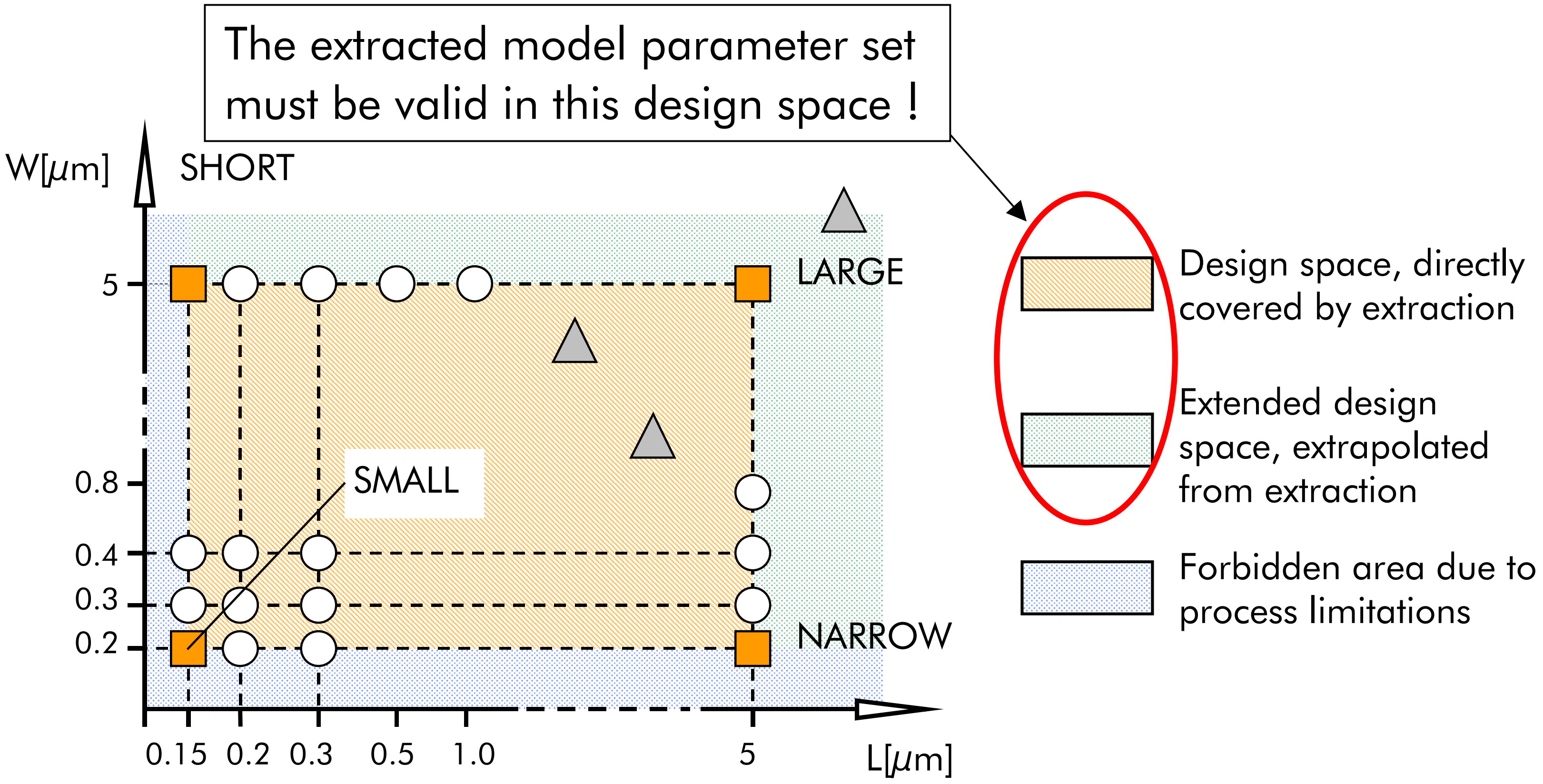
```
.model NPN_TR1 NPN
+ is=1e-16 bf=245 ..
```

Description of the behavior of **ONE** dedicated device

```
Q1 1 2 3  NPN_TR1
```

Description of device dimensions is missing !!
(Area is neglected)

Test devices for scalable MOS models



The extracted model parameter set must be valid in this design space !

➜ The proper design of appropriate test structures is the ultimate pre-requisite for accurate model generation !

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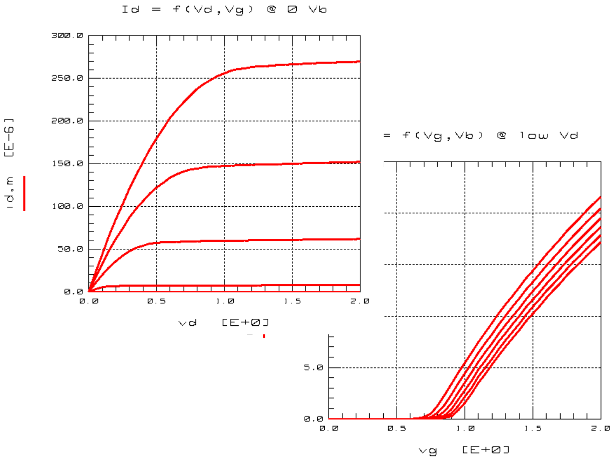
Conventional data representation

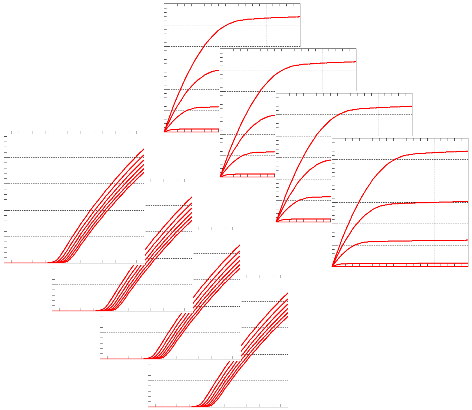
The conventional method is based on **single device** modeling.



I-V-curves are used to:

- extract parameters
- compare measurements versus simulations

This method was mapped to scalable models like BSIM3, MM9 . . .



. . . and resulted in a huge amount of I-V curves to:

optimize scalable effects on different devices

verify simulation over devices with different dimensions

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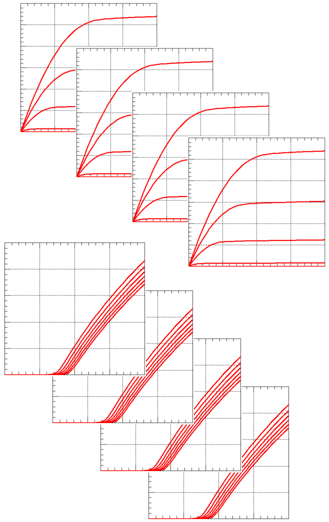
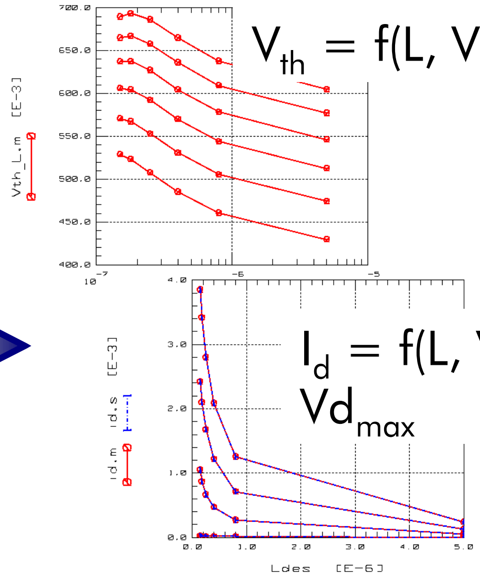
Advanced data representation concept

Collect data of up to 30 test structures during measurement phase of:



I-V, C-V curves etc.

Generate condensed data arrays for e.g.:

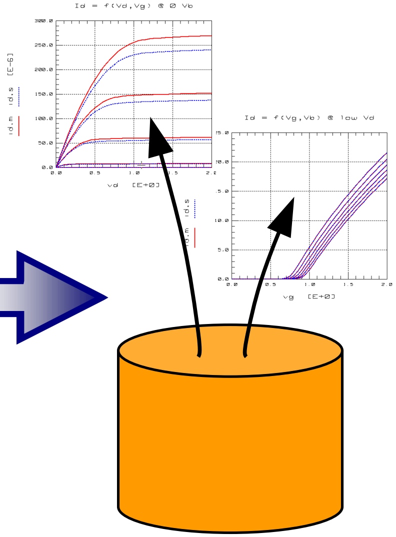


$V_{th} = f(L, V_{bs})$

$I_d = f(L, V_{gs}), Vd_{max}$

- Extraction of geometry dependant effects and parameters
- meaningful data representation

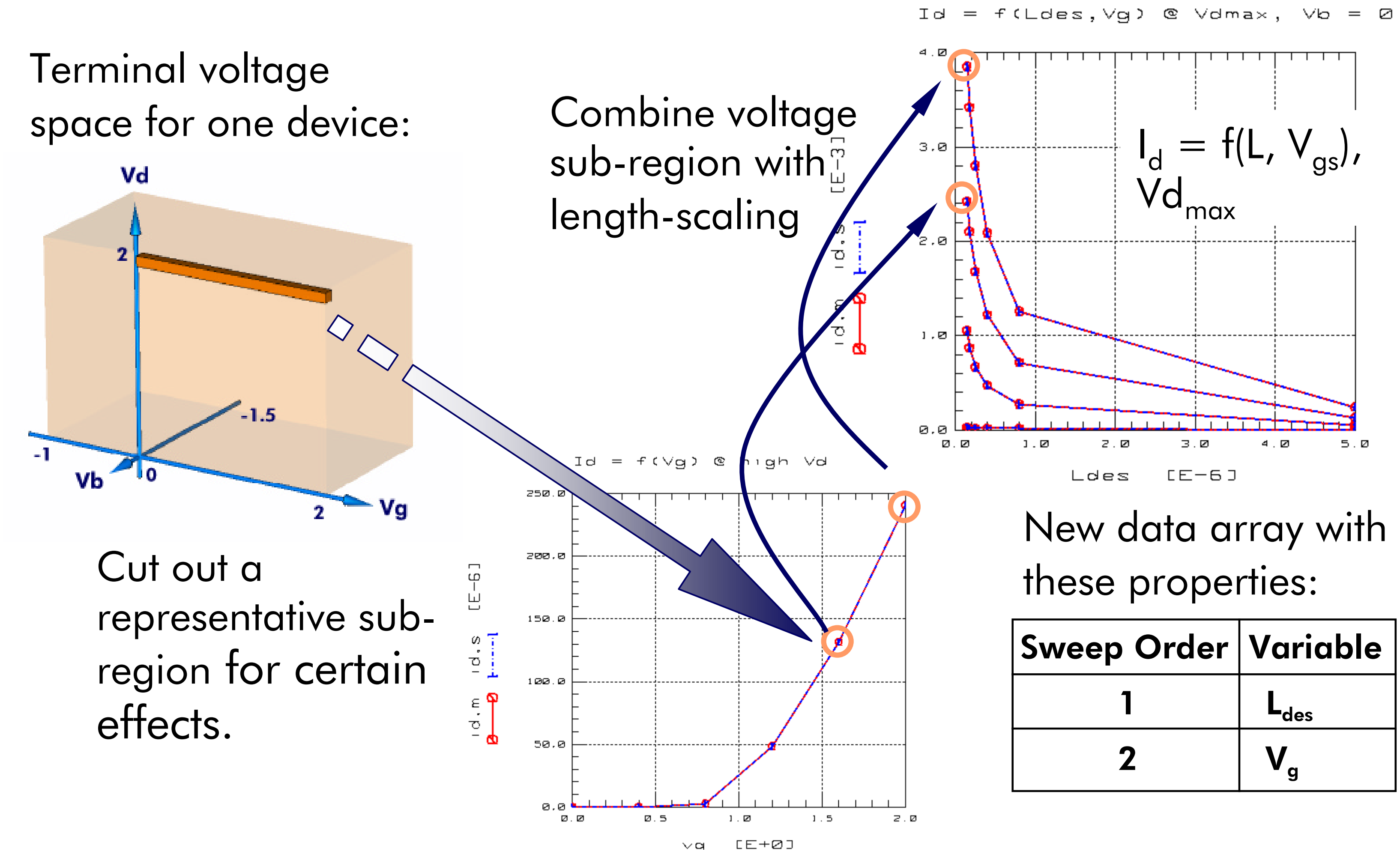
Individual device data display:



Load curves from a database if necessary.

Advanced data representation concept

Terminal voltage space for one device:



Cut out a representative sub-region for certain effects.

Combine voltage sub-region with length-scaling

$I_d = f(L, V_{gs})$, Vd_{max}

New data array with these properties:

Sweep Order	Variable
1	L_{des}
2	V_g

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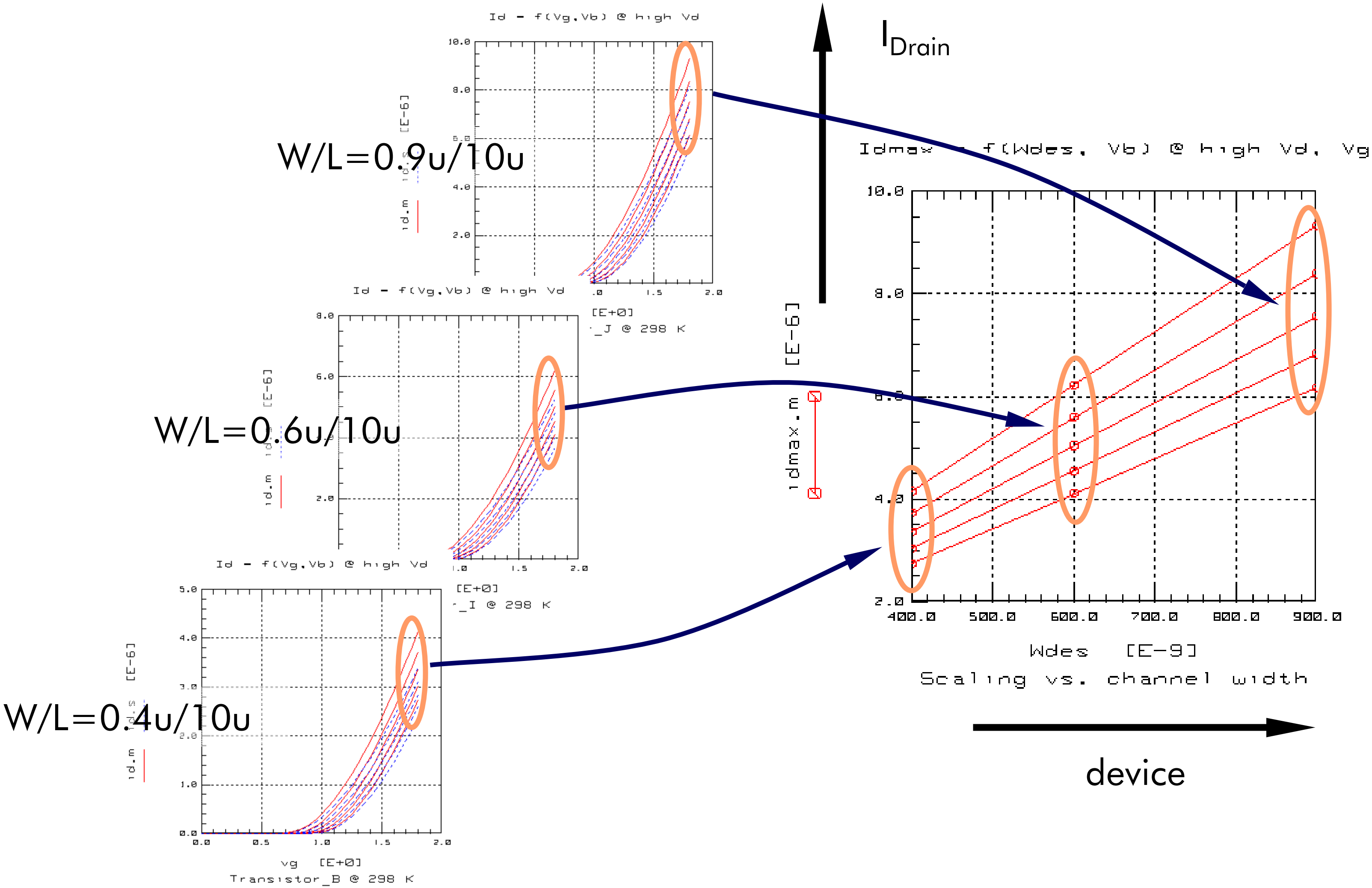
Example: width dependant bulk charge effect (BSIM4)



W/L=0.9u/10u

W/L=0.6u/10u

W/L=0.4u/10u

I_{Drain}

device

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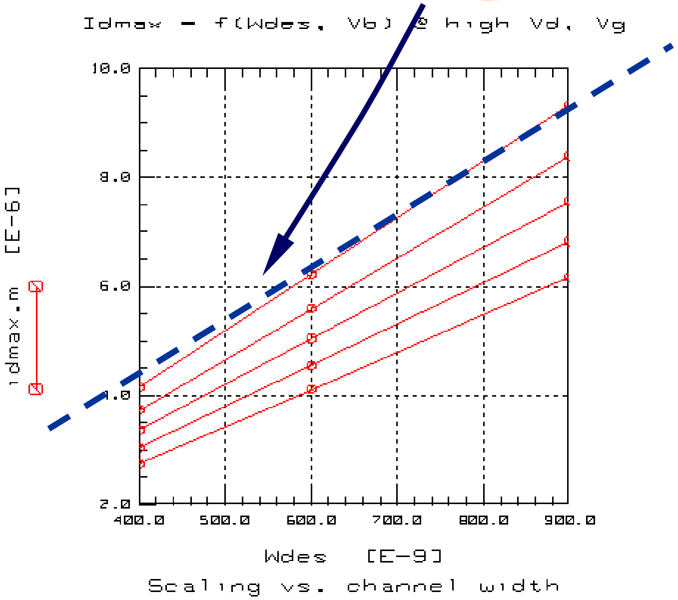
Example: width dependant bulk charge effect (BSIM4)

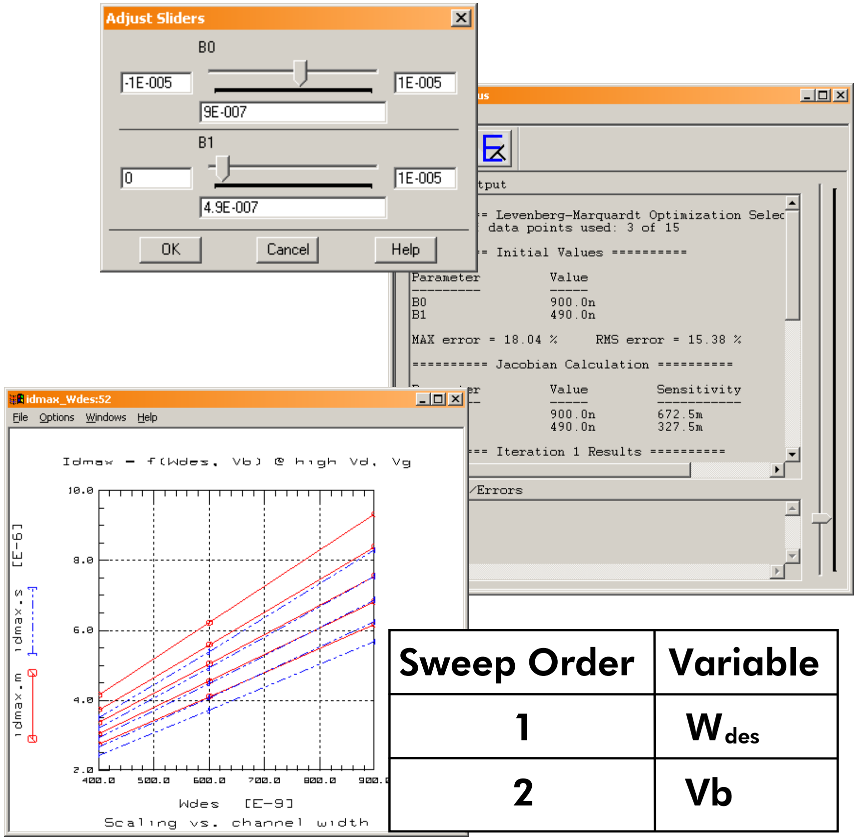
Direct parameter extraction through regression techniques

$$I_{DS} = f(W, A_{bulk})$$

$$A_{bulk} = const \cdot \frac{B0}{B1 + W_{eff}}$$



Manual fine tuning and optimization



```
== Levenberg-Marquardt Optimization Selec
 data points used: 3 of 15

== Initial Values ==========

Parameter          Value
---------          -----
B0                 900.0n
B1                 490.0n

MAX error = 18.04 %     RMS error = 15.38 %

========== Jacobian Calculation ==========

P      er          Value          Sensitivity
--       --        -----          -----------
                   900.0n         672.5m
                   490.0n         327.5m

=== Iteration 1 Results ==========
```

Sweep Order	Variable
1	W_{des}
2	Vb

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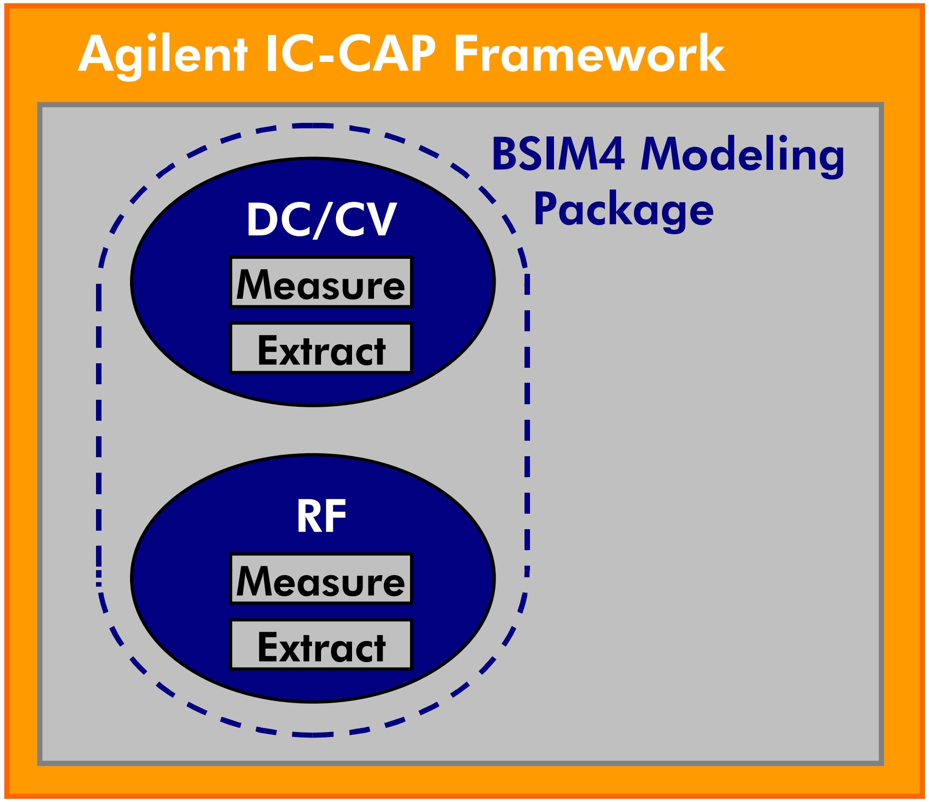
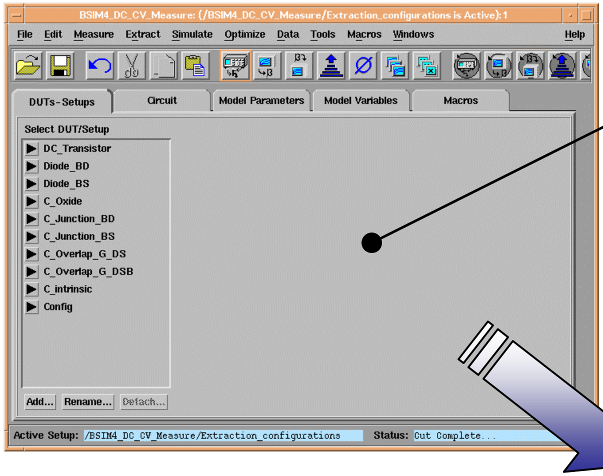
Database Architecture



- Modular structure using the IC-CAP framework concept with modules for DC/CV, RF modeling
- One software module to perform all measurement task and another one to extract the model parameters

Data management


BSIM4_DC_CV_Measure: (/BSIM4_DC_CV_Measure/Extraction_configurations is Active):1

Active Setup: /BSIM4_DC_CV_Measure/Extraction_configurations

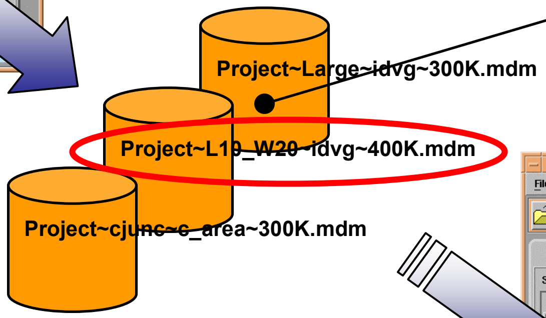
Status: Cut Complete...

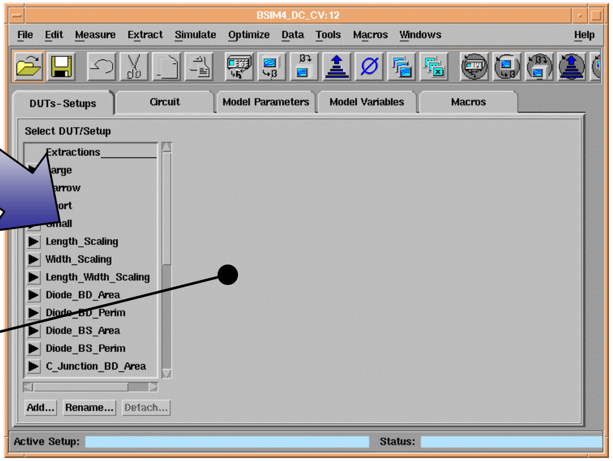
DC/CV Measurement module:

- different DUT/setup templates
- measurement control code
- Test and measurement setup GUI

.mdm files:

- measured curves
- device information
- organized in projects

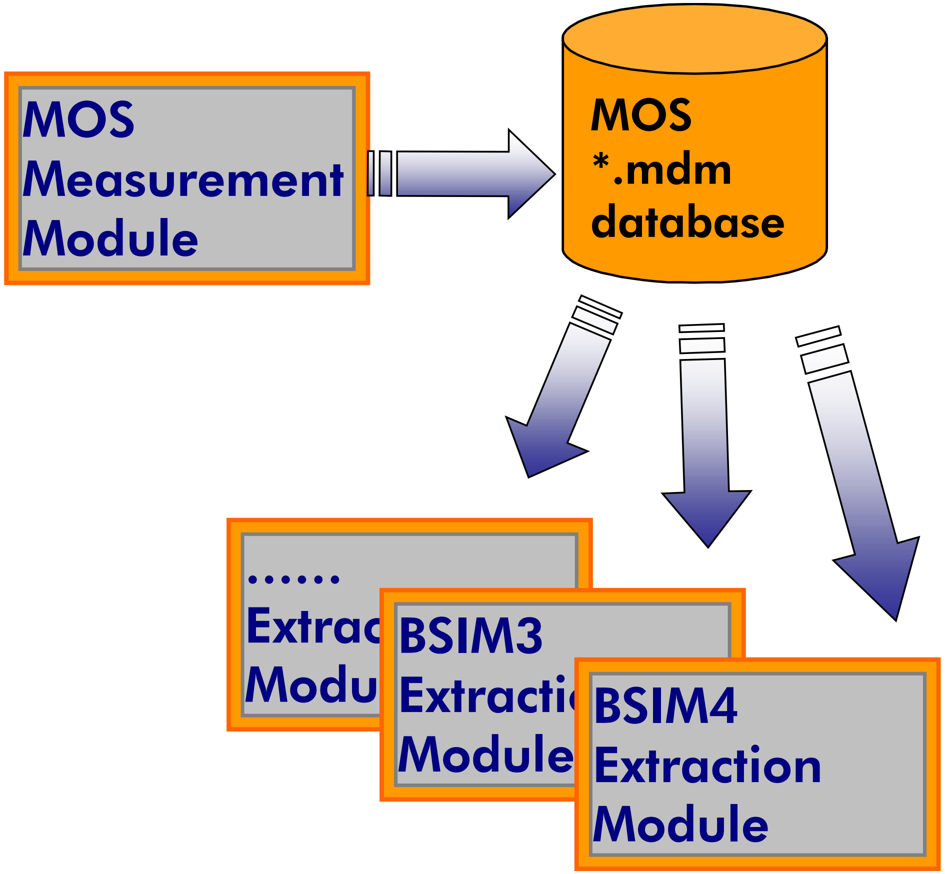



BSIM4_DC_CV:12

DC/CV Extraction module:

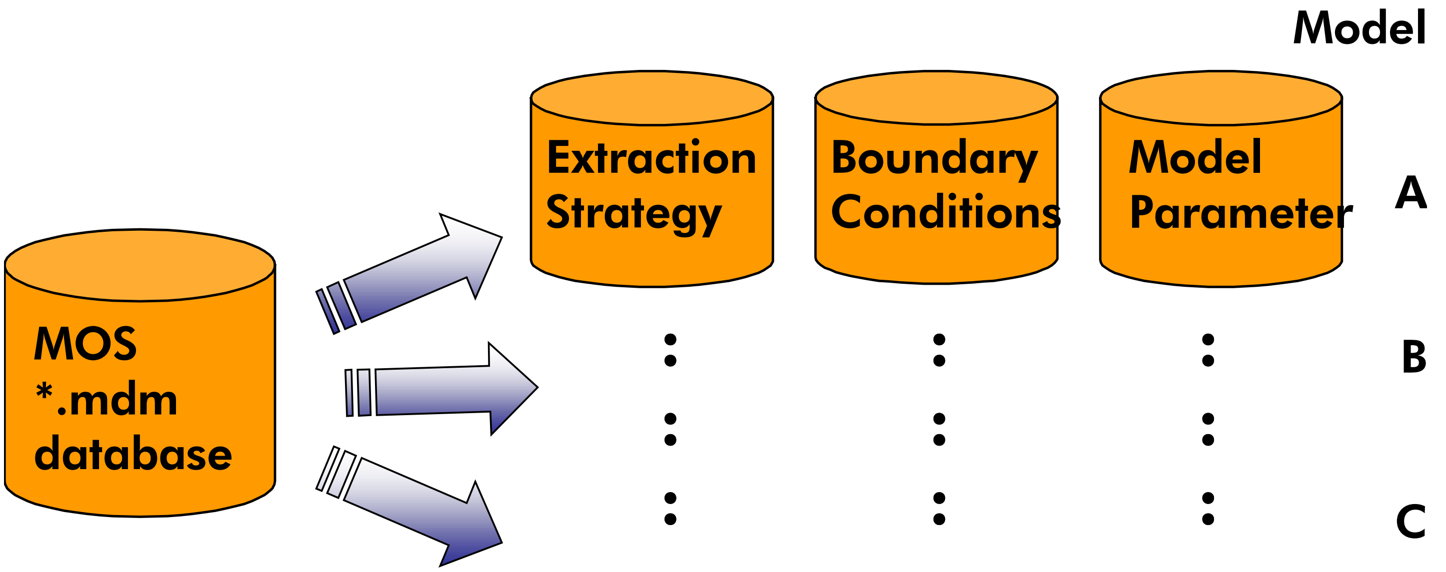
- Extraction routines
- Data import/export
- Documentation features etc.

Data Flow



- One single measurement module collects all data and stores it into the database
- The setup of these measurements are in the first step independent from the simulation model for which the parameters should be extracted.
- The only requirement is, that all diagrams in the later extraction modules are subsets of the measured data base.

Final Database Layout



- Finally, the data is organized in such a way, that for each generated model the model parameter set is stored together with the extraction strategy.
- That means not only the final result (model parameter) but also the way to achieve this result (extraction strategy) is stored in the data base. This makes all parameter extractions repeatable and self consistent.

Conclusion

- The need for an advanced data base concept to handle an emerging amount of measured data for MOS devices for modeling purposes could be demonstrated. This development is driven by two main factors: scalability and the need to generate different models from the same base of measured data.
- A concept to generate data representations in both, simulation setups and diagrams, which cannot be measured directly but are combined from measured data of different devices is presented.
- Finally, this method ends in a suggestion for an effective and flexible software structure.
- We have already implemented this strategy to generate BSIM4 and BSIM3 models. Other models, like EKV2.6, HiSIM1.1 will be available end of march.

Literature

[1] T. Gneiting, ‘BSIM4, BSIM3v3 and BSIMSOI RF MOS Modeling’, RF Modeling and Measurement Workshop, European Microwave Week, Paris 2000

[2] T. Gneiting, ‚BSIM4 Modeling’, Arbeitskreis MOS Modelle, München, 2001

[3] R. Friedrich, T. Gneiting, ‘BSIM4 Model Parameter Extraction’, IC-CAP Nonlinear Device Model Manual, Agilent Technologies., 2001

[4] "Characterisation System for Submicron CMOS Technologies," JESSI Reports AC41 94-1 through 94-6, 1994

[5] J. Deen, T. Fjeldly, T. Gneiting, F. Sischka, „CMOS RF Modeling, Characterization and Applications – RF MOS Measurements“, World Scientific, ISBN 981-02-4905-5