

# Towards Sound and Complete Analysis of Integrated Circuits at Transistor-Level

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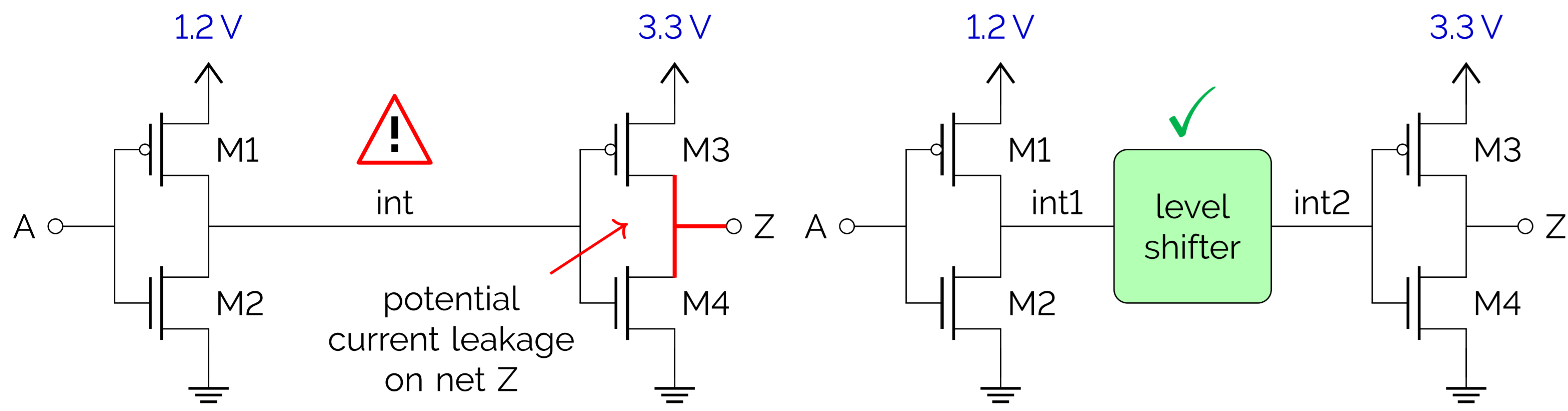
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## Transistor-level error verification

### Missing level-shifter detection

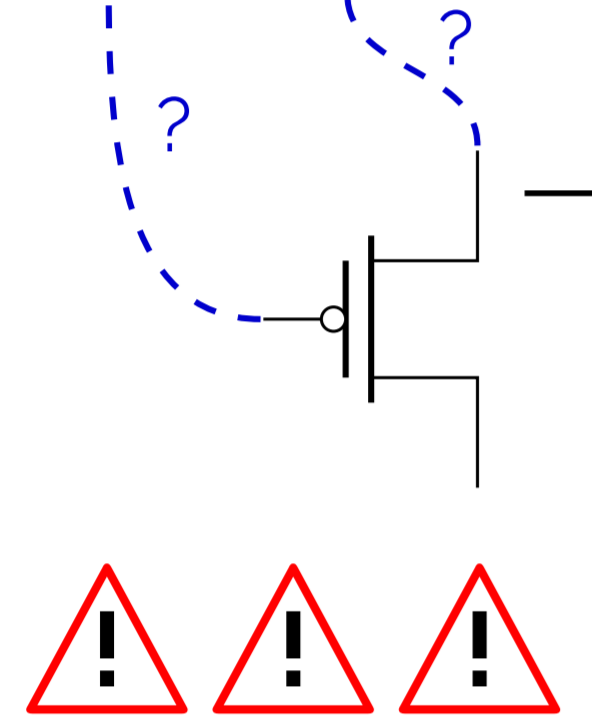


## Error analysis

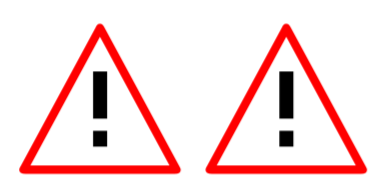
### Classical analysis techniques

Search for potential connectivity to different power supplies

1.2V 3.3V

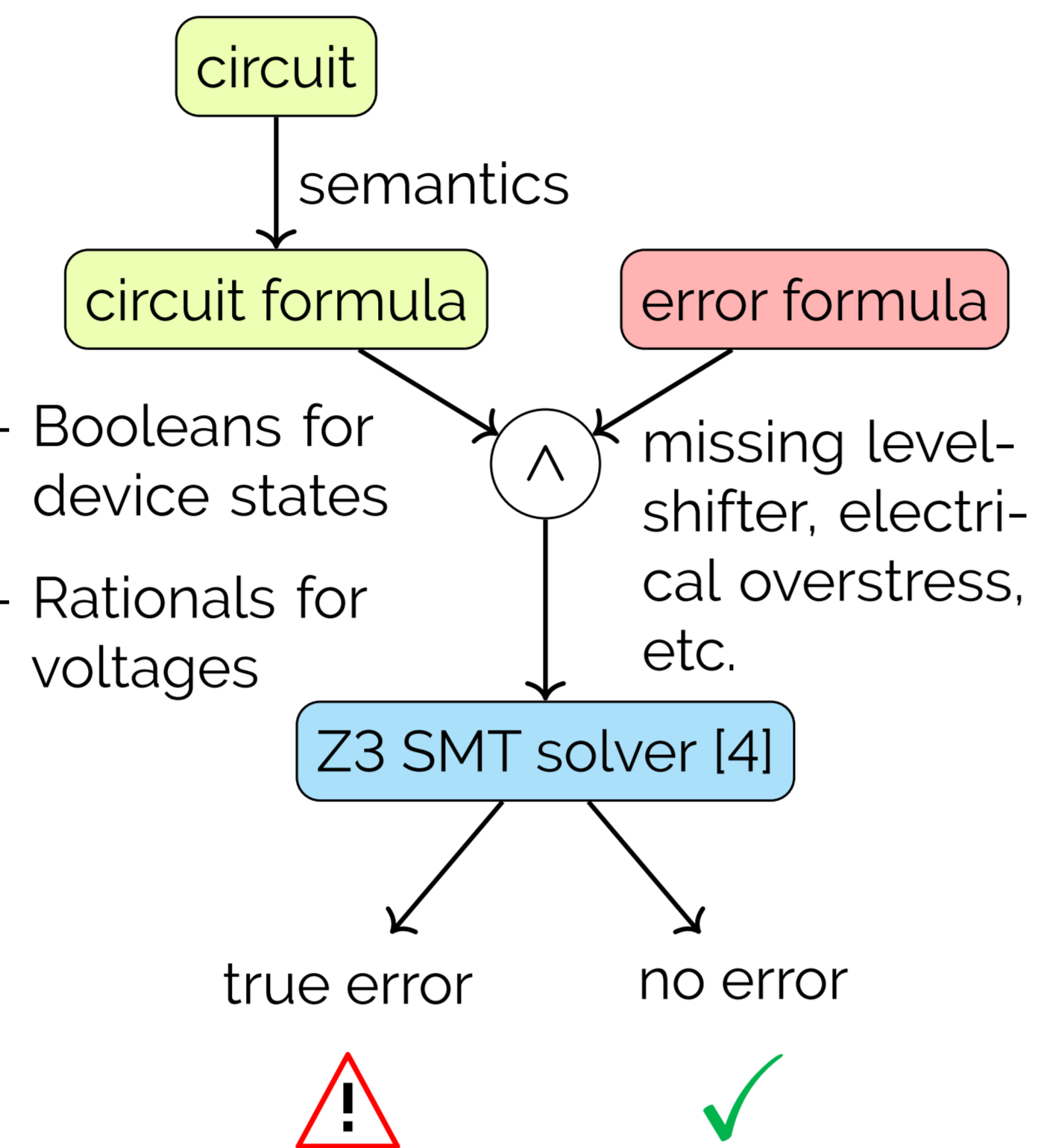


Pattern matching for false alarm reduction



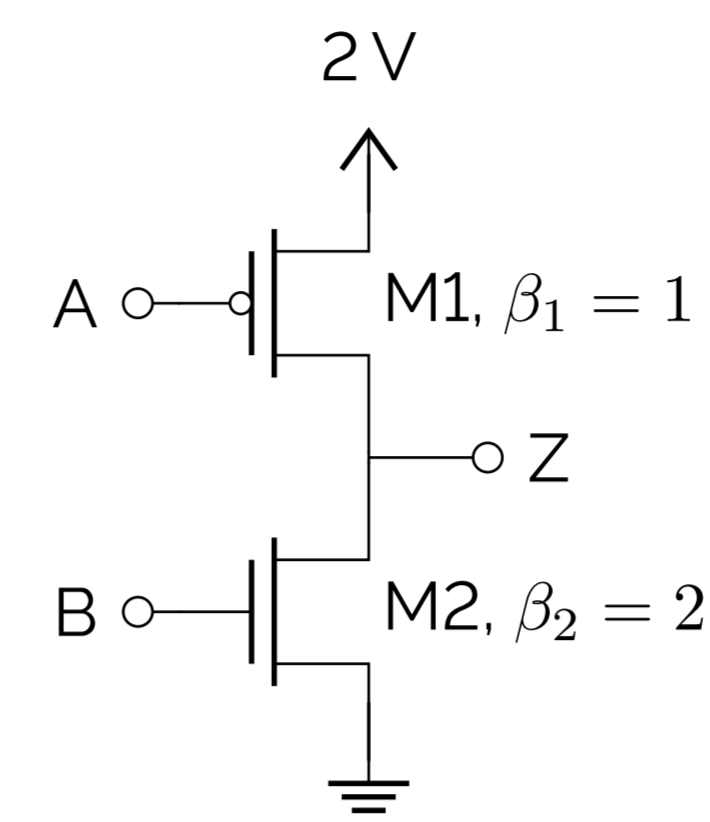
vs.

### SMT based analysis flow

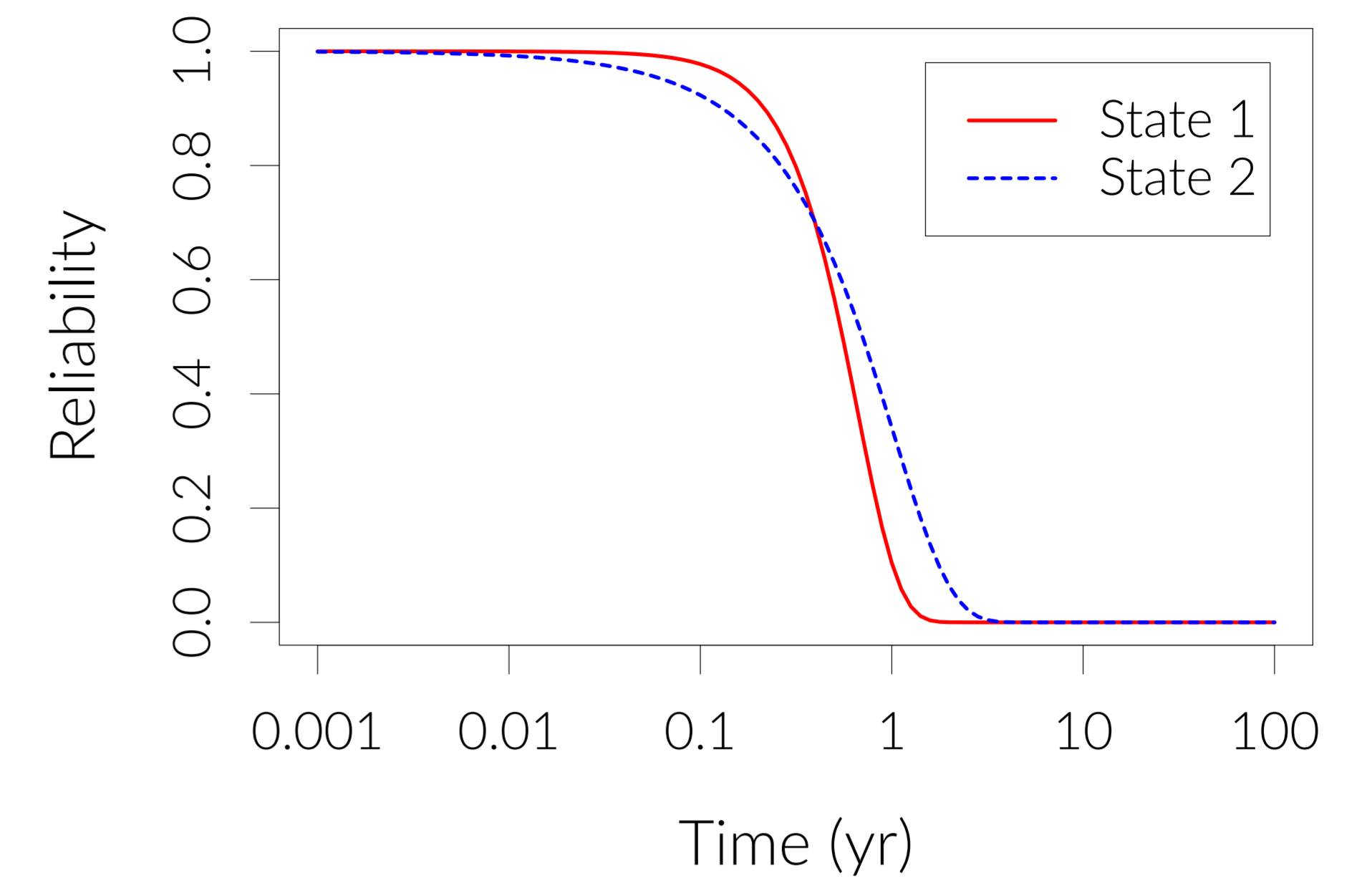


## Circuit reliability analysis

### Time-dependent dielectric breakdown



	State 1	State 2
$V(A)$	0V	-8V
$V(B)$	2V	0V



$$\mathcal{R}_{CIRC}(t) = \prod_{x \in \text{devices}} \mathcal{R}_{MOS}(v_x, t)$$

(Circuit reliability)

$$\mathcal{R}_{MOS}(v, t) = \exp\left(-\frac{t^\beta}{\alpha(v)}\right)$$

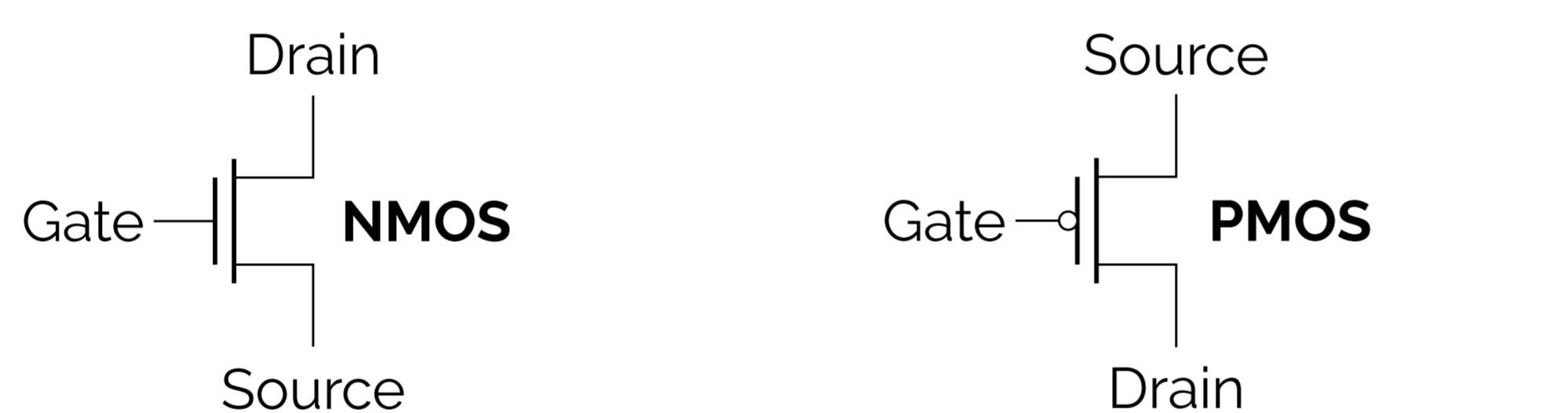
(Device reliability)

$$\alpha(v) = A_0 \cdot \exp\left(\frac{E_{aa}}{K \cdot T}\right) \cdot \exp(-\gamma \cdot v)$$

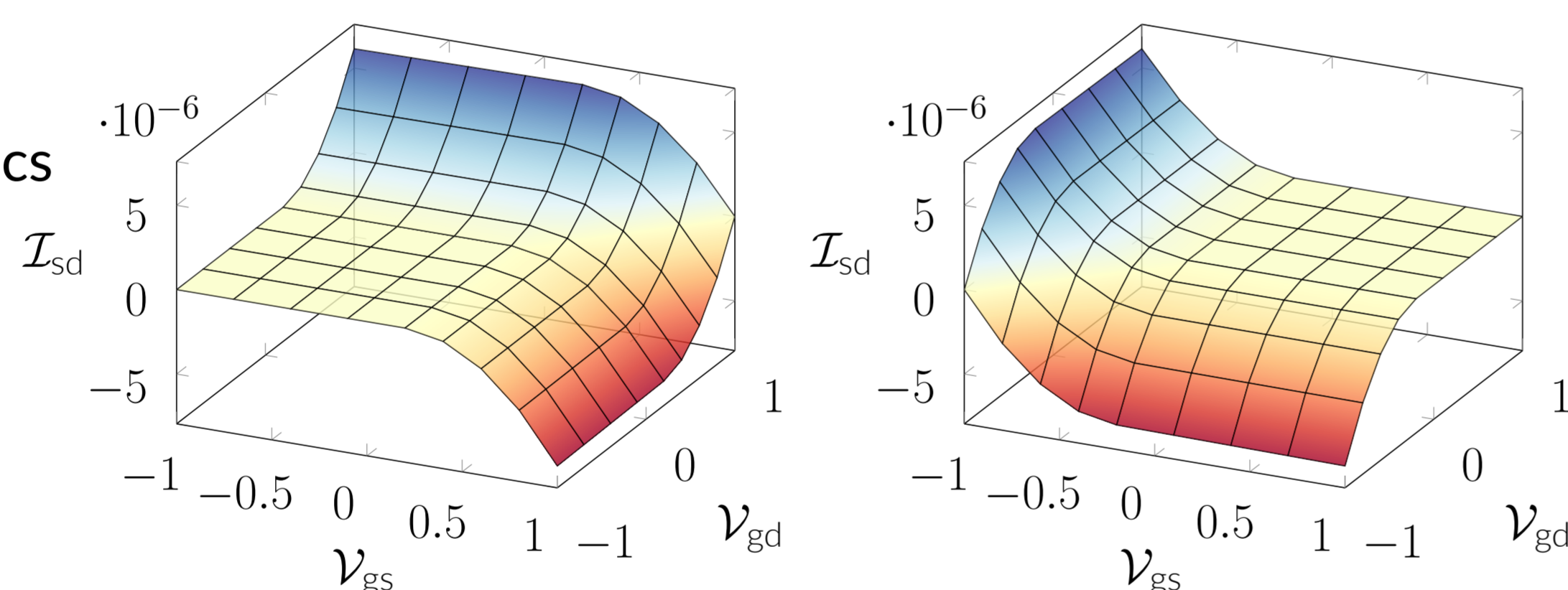
(JEDEC model [2])

## Device modeling

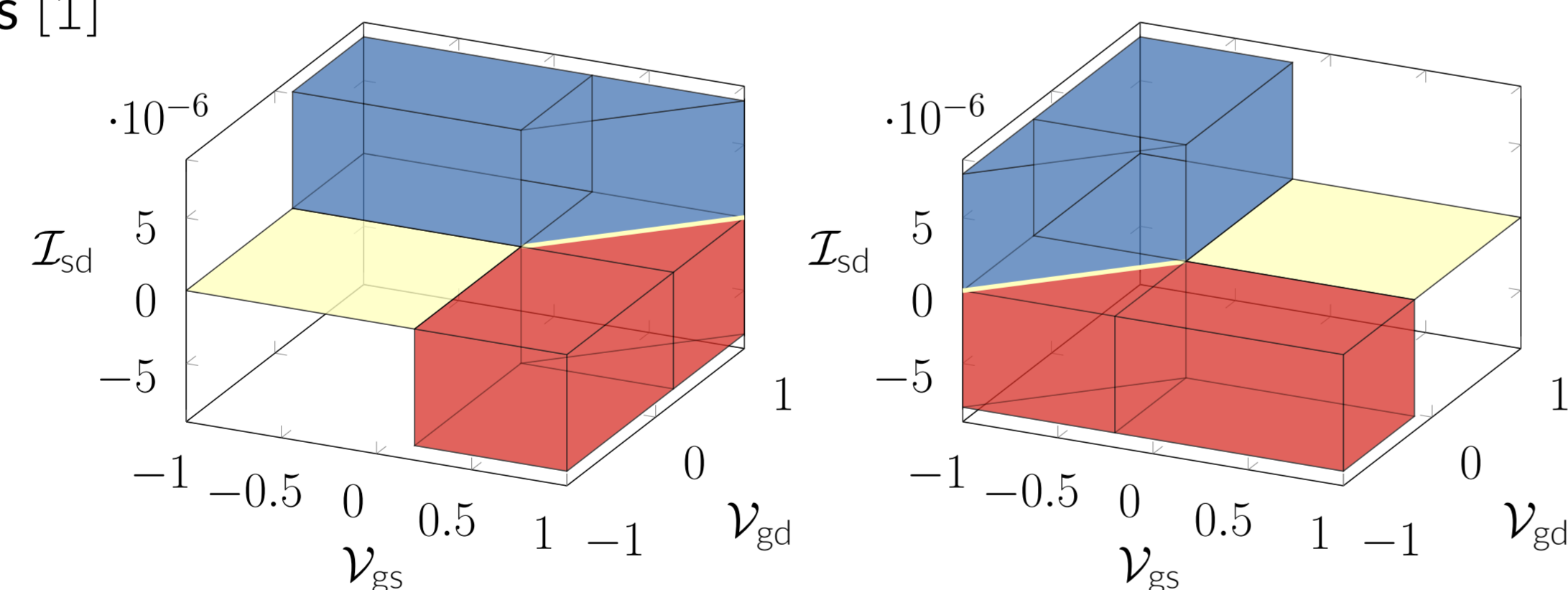
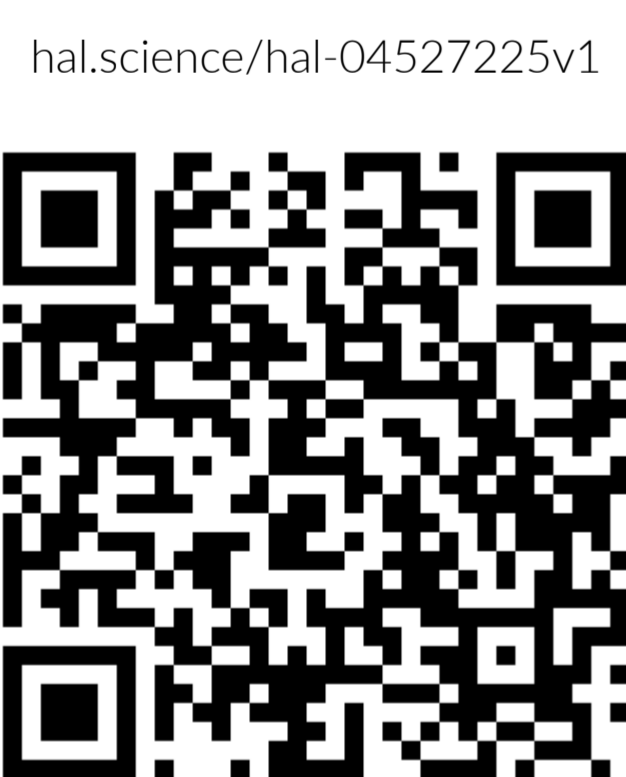
### MOSFET transistors



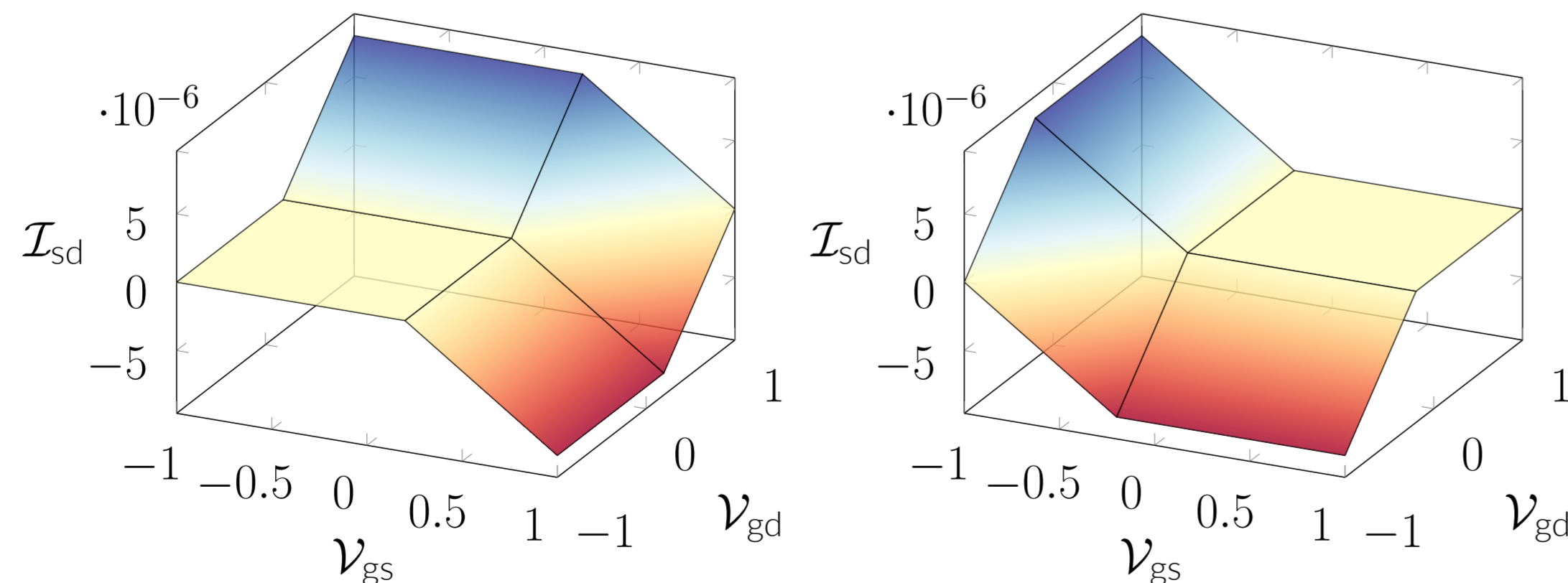
### Actual I-V characteristics



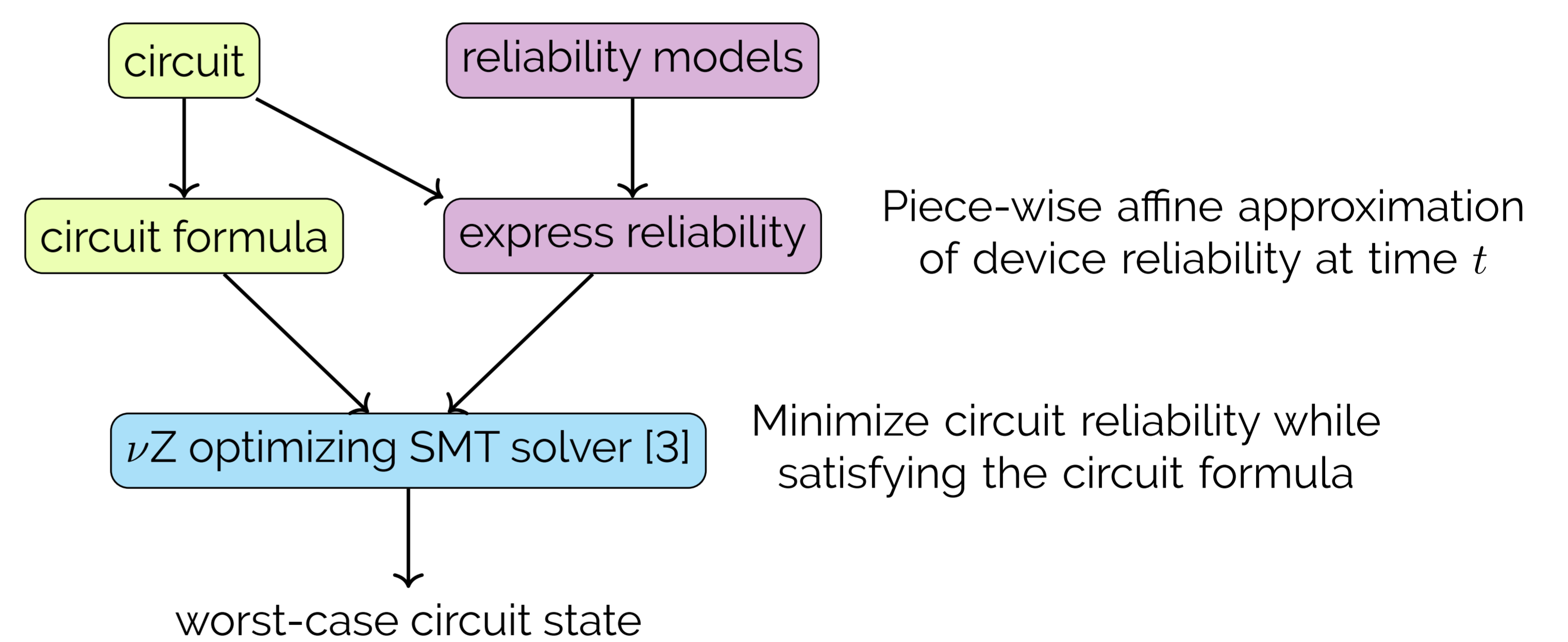
### Switch-based semantics [1]



### Quantitative semantics



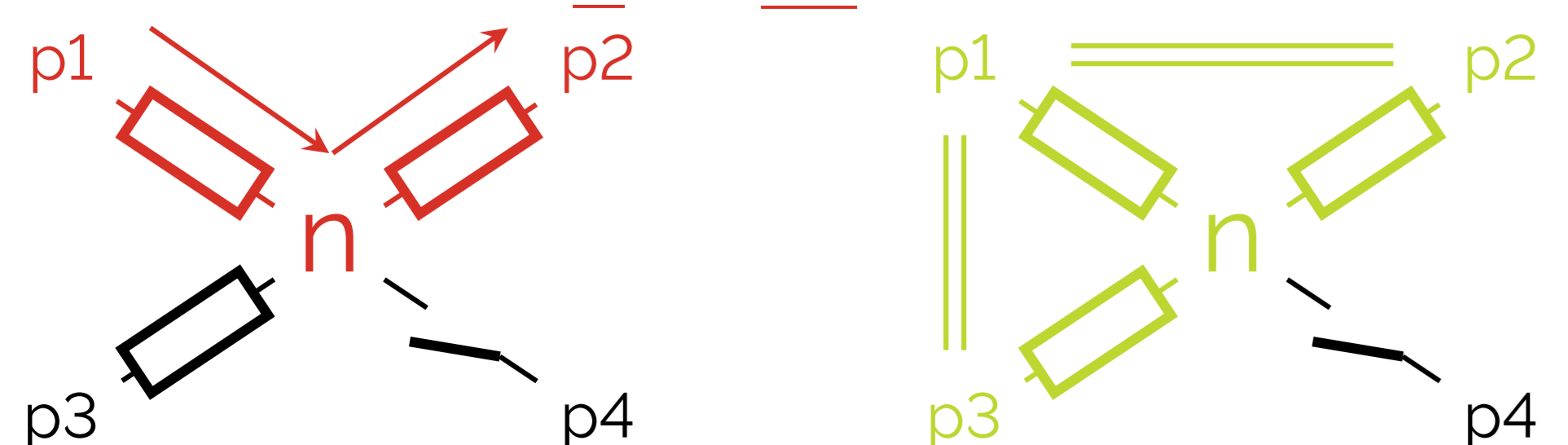
## Reliability analysis



## Composing devices: Net modeling

### Switch-based semantics

Either **current flows in and out** or **no current flows at all**



### Quantitative semantics

- Current  $I_{sd}$  constrained based on the operation region
- Kirchhoff's current law applied on each net

## References

- [1] O. Oulkaid, B. Ferres, M. Moy, P. Raymond, M. Khosravian, L. Henrio, and G. Radanne, "A Transistor Level Relational Semantics for Electrical Rule Checking by SMT Solving," in DATE, Valencia, Spain, Mar. 2024.
- [2] JEDEC Publication JEP122H, "Failure Mechanisms and Models for Semiconductor Devices," 2016.
- [3] N. S. Bjørner and A.-D. Phan, "vZ-Maximal Satisfaction with Z3." *Scss*, vol. 30, pp. 1–9, 2014.
- [4] L. De Moura and N. Bjørner, "Z3: An efficient SMT solver," in *International conference on Tools and Algorithms for the Construction and Analysis of Systems*. Springer, 2008, pp. 337–340.

