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# Fundamental Differences Between Analog and Digital Design Problems

## An Introduction

Jürgen Scheible

# The Digital Transformation

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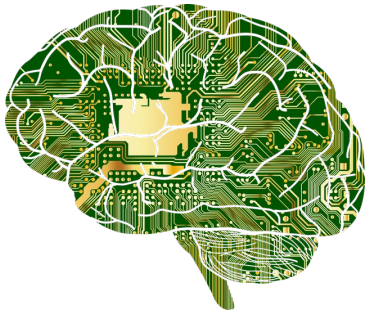

1960 1970 1980 1990 2000 2010 2020 2030

# The Digital Transformation

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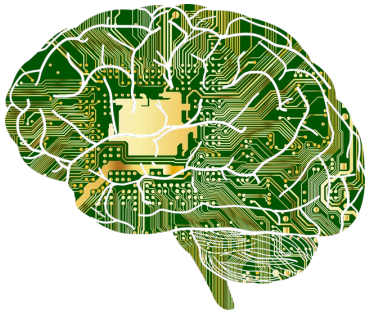

1960 1970 1980 1990 2000 2010 2020 2030

# The Digital Transformation

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**Real World**

Sensors:
- Sound
- Position
- Light
- Pressure
- Temperature
- Humidity
- …

Analog

A/D

**„Digital“ World**

DC/DC AC/DC

Powe ment

Analog

D/A

**Real World**

Actuators:
- Speaker
- Display
- Lamp
- Heater
- …

Analog

# System on Chip (SOC)

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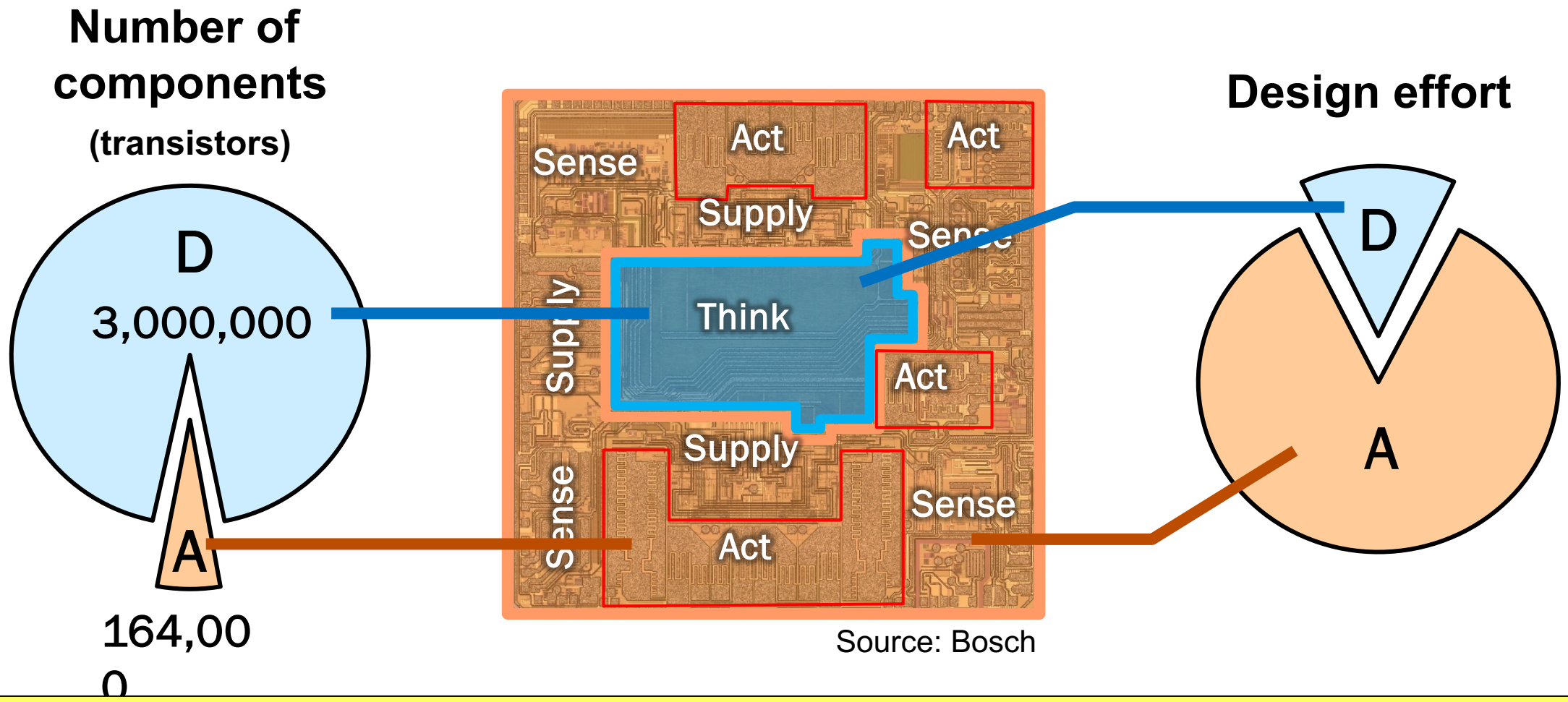


Source: Bosch

**Analog** design productivity lags behind **digital** design productivity by **orders of magnitude**!

# Differences between Analog and Digital

## Structural View

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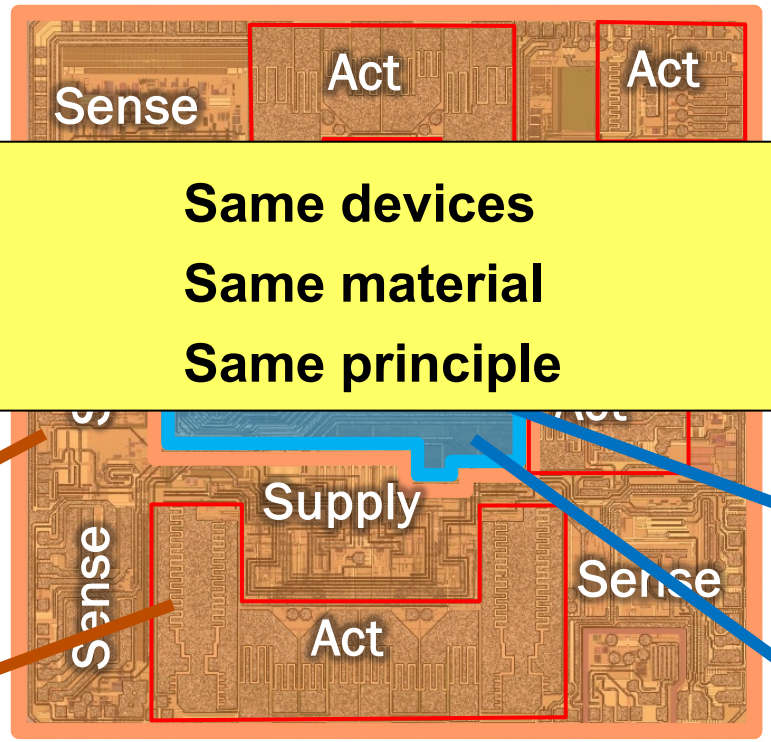
**Analog**

- Transistors
- made of silicon
- connected to circuits
- Many devices and nets ($10^4$ – $10^5$)




Source: Bosch

**Same devices**
**Same material**
**Same principle**

**Different number of elements**

**Digital**

- Transistors
- made of silicon
- connected to circuits
- Many more devices and nets (> $10^6$)

# Differences between Analog and Digital

## Functional View

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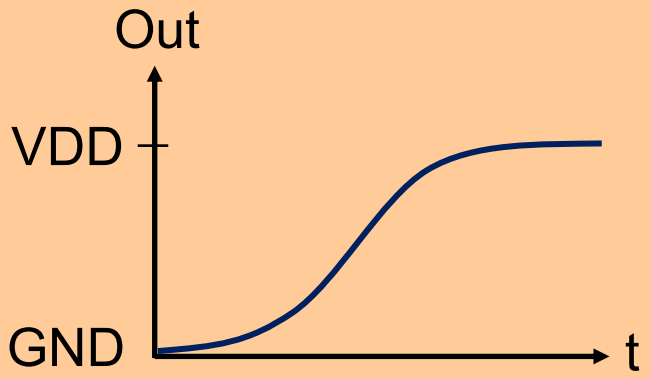
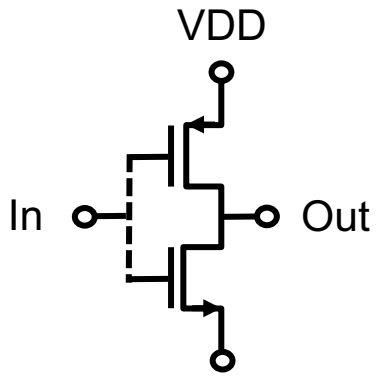
**Abstraction**

### Analog

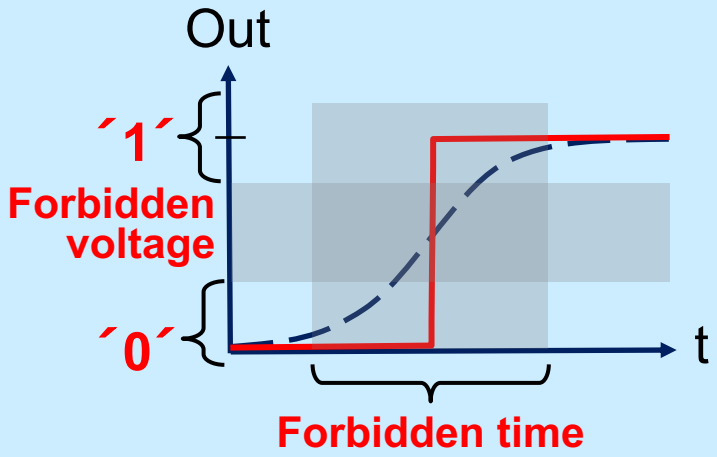



Continuous-value and continuous-time signals




**Diversity of influences**

### Digital




Synchronized circuit by clockrate
→ Value- and time-discrete signal

# Differences between Analog and Digital

## Functional View

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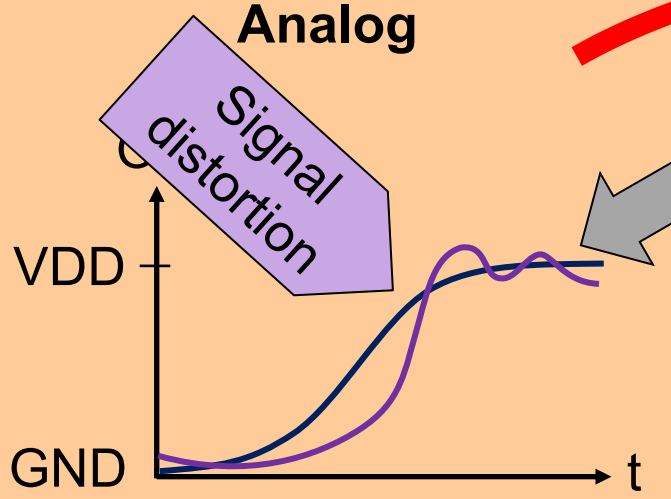
**Abstraction**

### Analog




Continuous-value and continuous-time signals

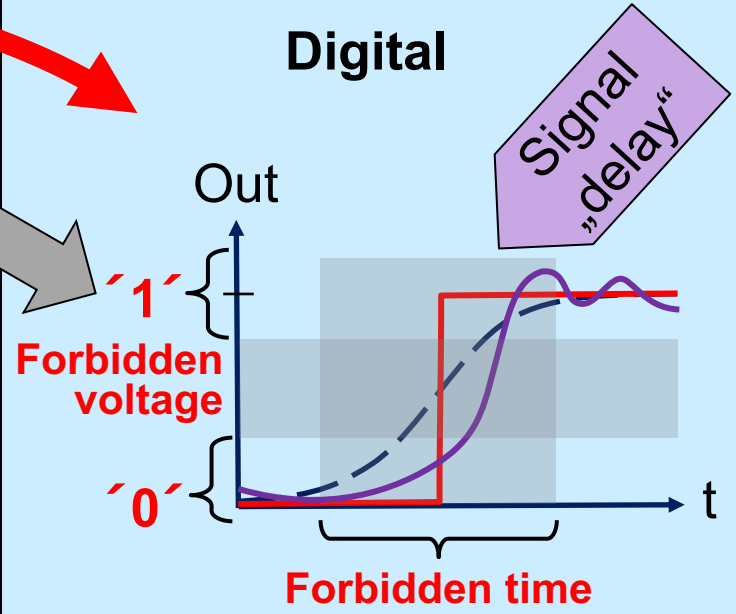
→ All effects have direct impact on signal quality

**All effects must be considered!**

### Diversity of influences

- **Fabrication tolerances**: variations of ±10% … ±50%
- **Temperature effects**: variations of R, $V_t$, $V_D$
- **Mechanic… …cts:** variations of … mobilities
- **Parasitic effec…**
  - R, C, L → IR-d…p, coupling, loss …
  - diodes, bips → substrate effects: carrier injection, latch up …
  - thick-field threshold → shorts
- **Additional sources of noise** …

### Digital




Synchronized circuit by clockrate

→ Value- and time-discrete signals

→ Design = „timing“ problem

**Effects can be faded out (mostly)**

# Differences between Analog and Digital

## Design flows

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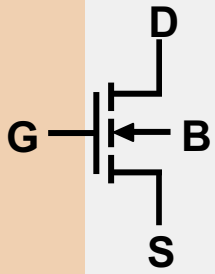
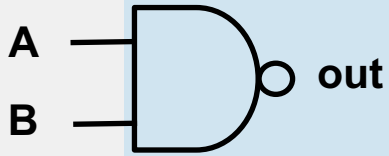
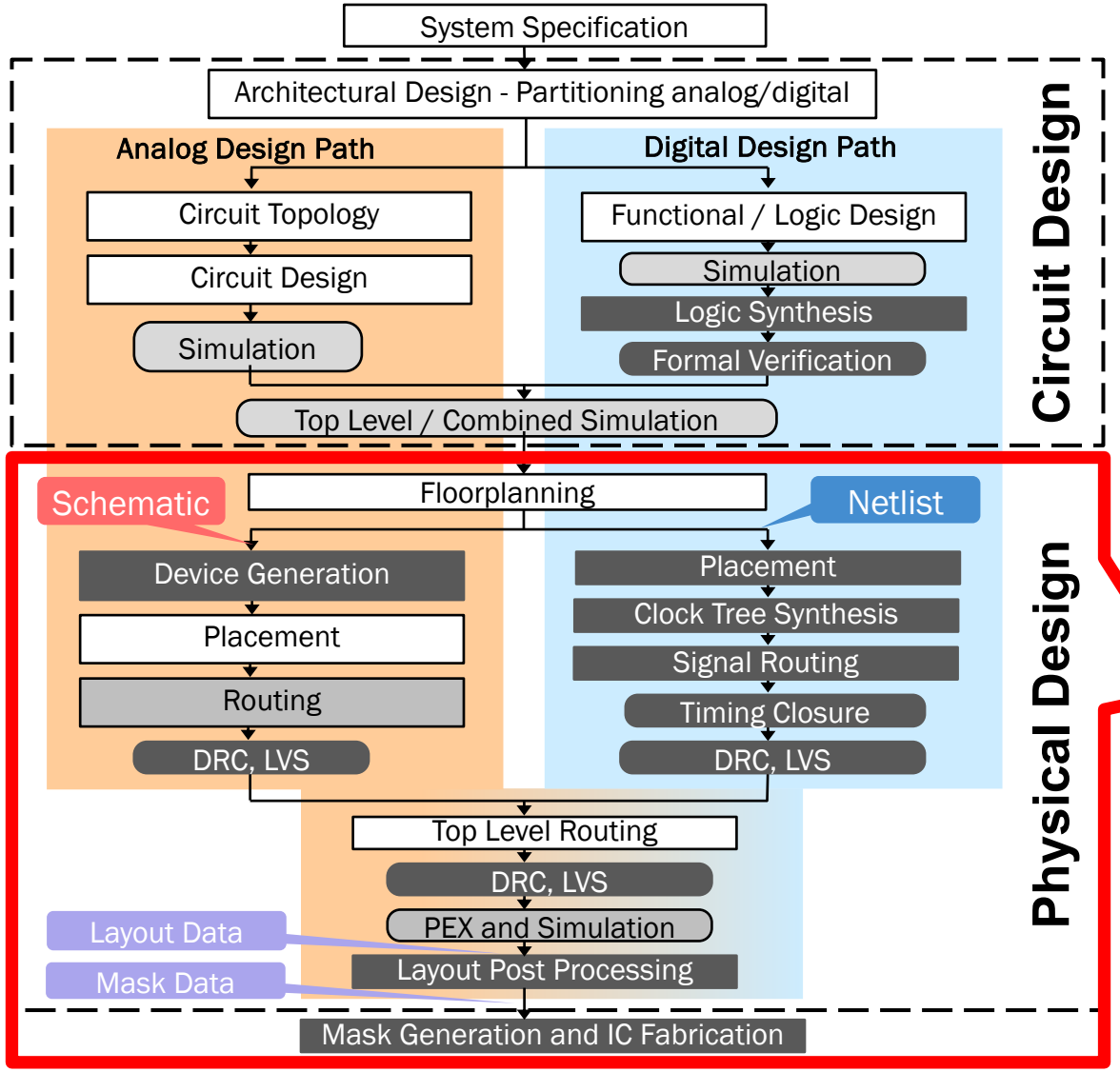
| Analog | | Digital |
|---|---|---|
| High qualitative complexity | **Problem type** | High quantitative complexity |
| **Transistors**<br>to be adapted individually:<br>• width<br>• length<br>• # gate fingers<br>• interleaving structures |  **Basic design entity** |  **Logic gates**<br>fixed elements:<br>• standard cells<br>• organized in libs<br>• „pick and place“ |
| • Transistor level<br>• manually with simulation in the loop<br>• experience-based<br>• bottom-up (mostly) |  **Design style** |  • Gate level and higher<br>• highly automated<br>• optimization-based<br>• top-down (mostly) |

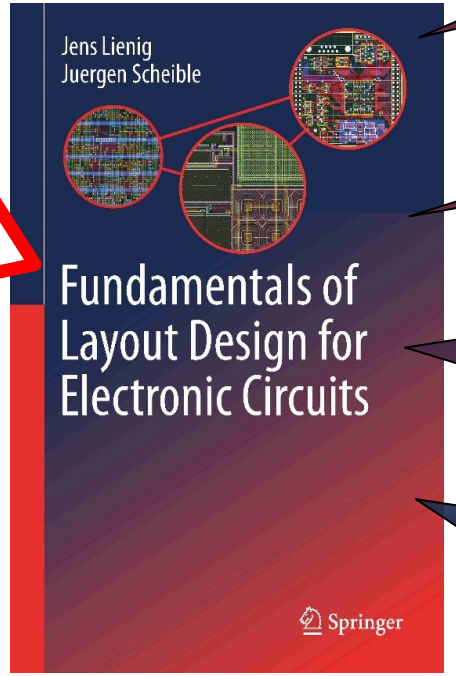
# Mixed-Signal Design Flow






**Level of automation:**

- none / low
- medium
- high




**Chap. 2**
Technology Knowhow: From Silicon to Devices

**Sect. 4.6**
Analog and Digital Design Flows

**Chap. 6**
Special Layout Techniques for Analog IC Design

**Chap. 7**
Addressing Reliability in Physical Design

Source: J. Lienig, J. Scheible: Fundamentals of Layout Design for Electronic Circuits, Springer 2020

# Further Reading

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## Related ISPD Papers

Juergen Scheible. 2022.

***Optimized is Not Always Optimal – The Dilemma of Analog Design Automation***.

ISPD '22. ACM, New York, NY, USA, 151–158.

https://doi.org/10.1145/3505170.3511042

Juergen Scheible and Jens Lienig. 2015.

***Automation of Analog IC Layout: Challenges and Solutions.***

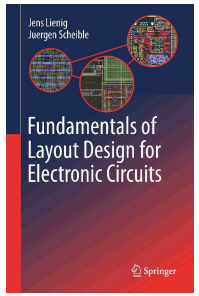
ISPD '15. ACM, New York, NY, USA, 33–40.

https://doi.org/10.1145/2717764.2717781

Why is analog and digital design so different?

Why is optimization-based automation not suitable for analog design problems?

How can analog design be successfully automated?




## Textbook

J. Lienig, J. Scheible.

***Fundamentals of Layout Design for Electronic Circuits***, Springer 2020

https://link.springer.com/10.1007/978-3-030-39284-0

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# Backup Slides

# Analog vs Digital: Design Gaps

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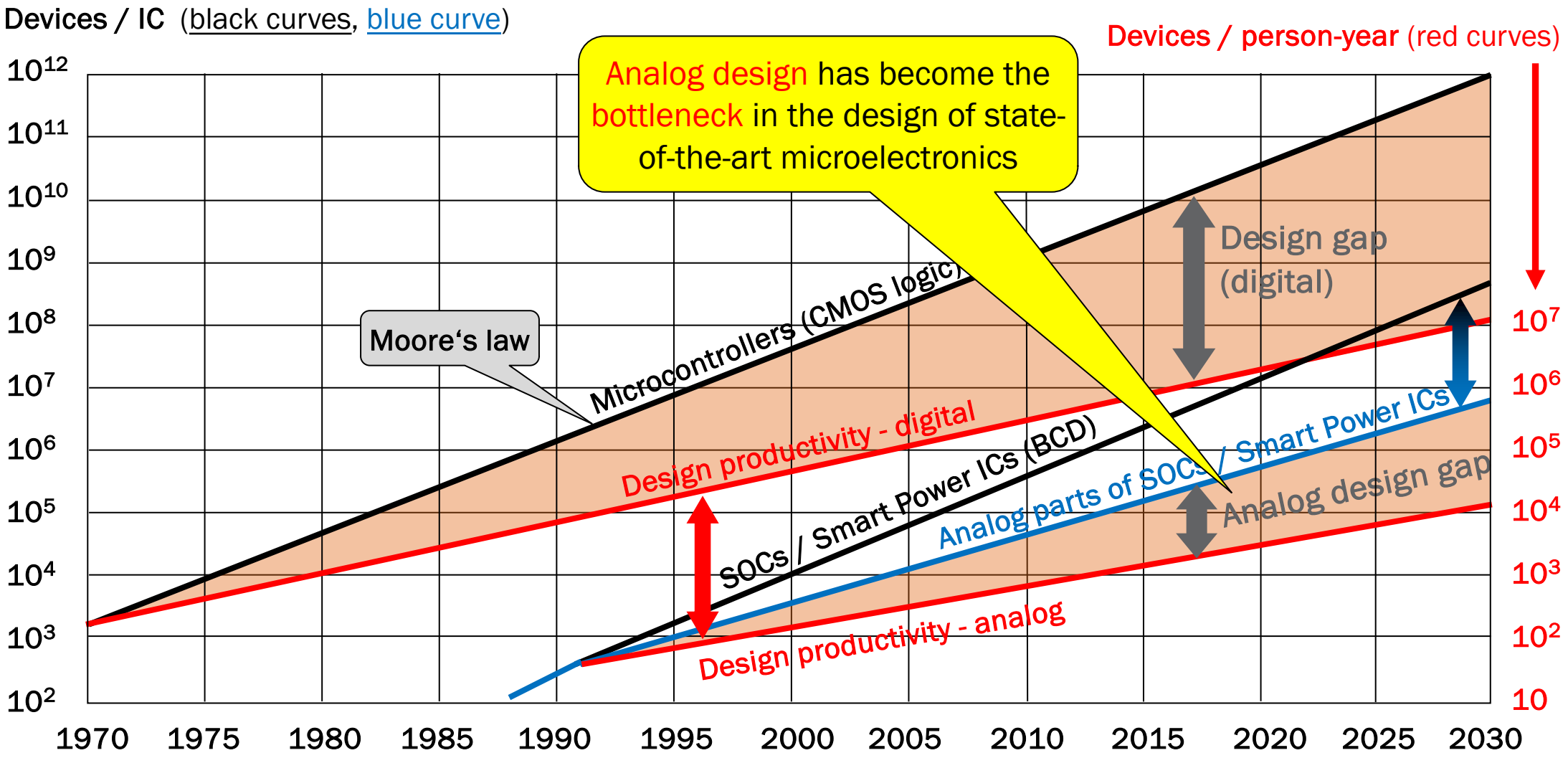
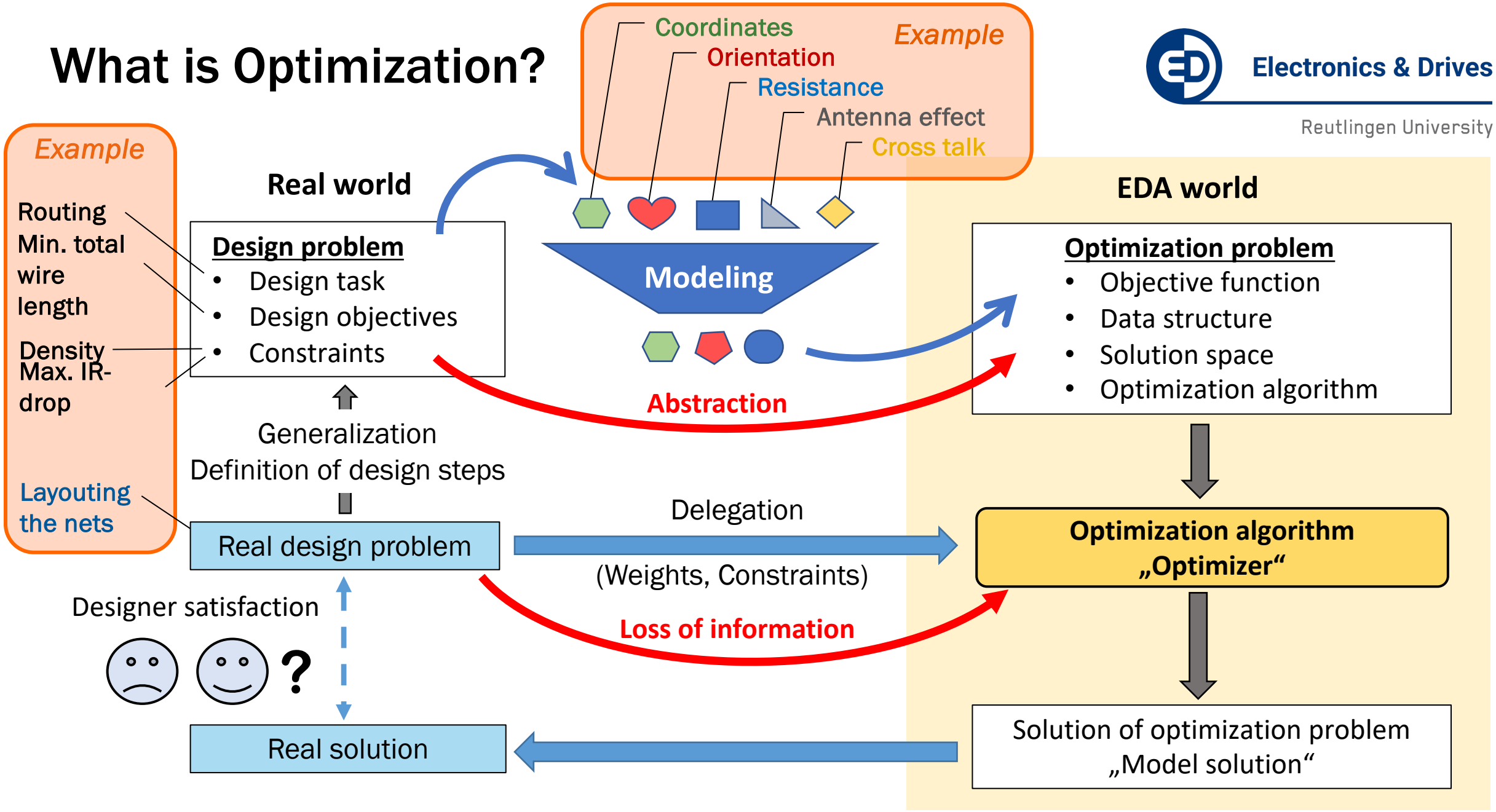


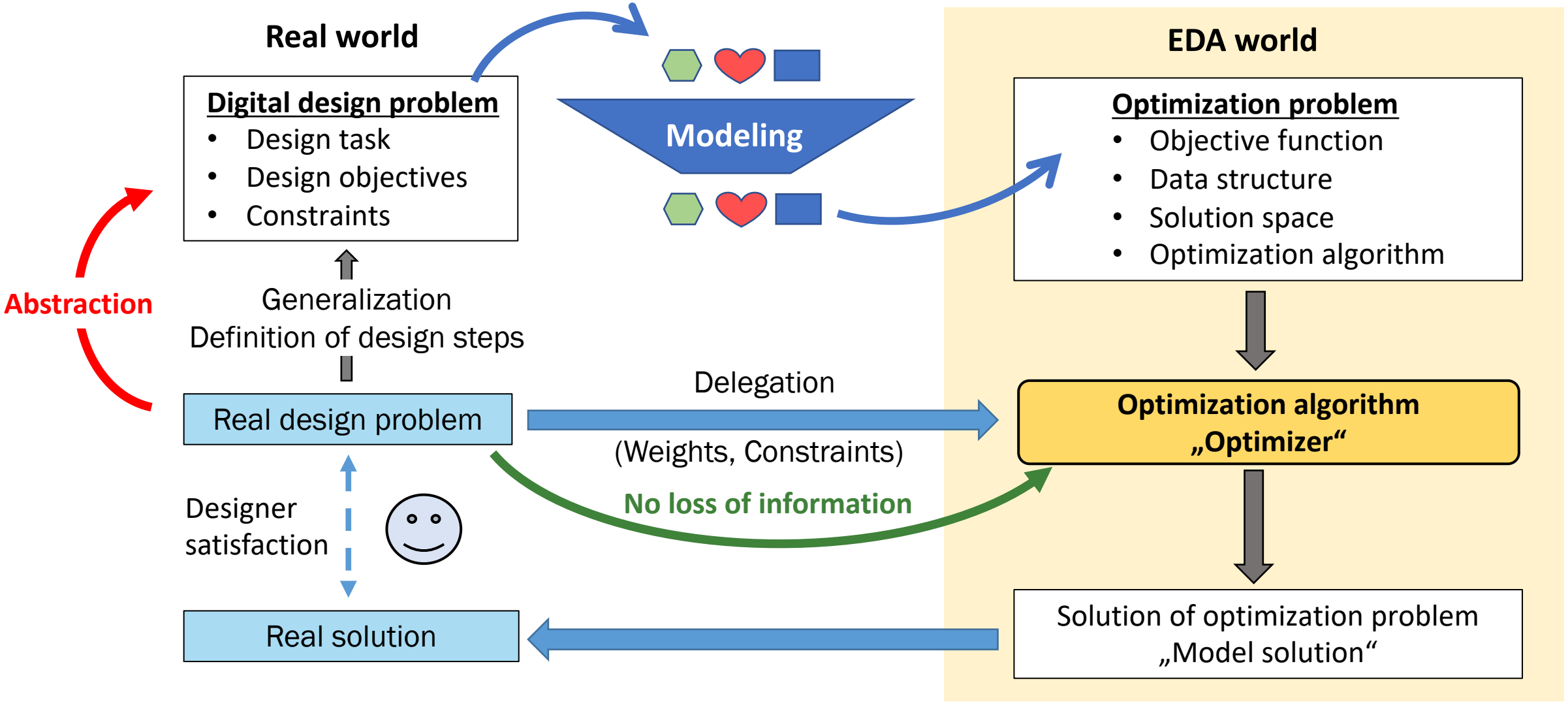
# What is Optimization?





# Optimization in digital design

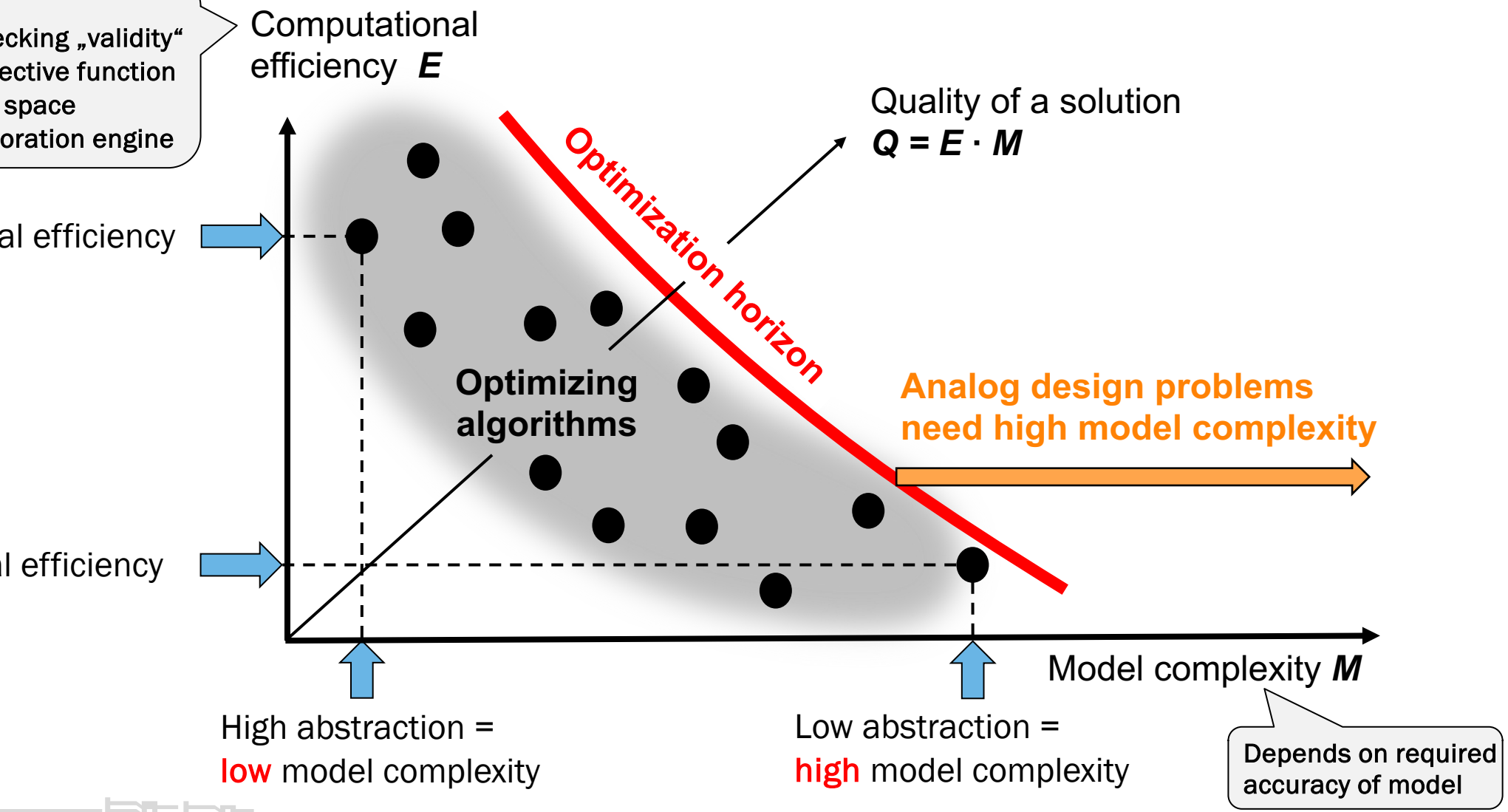




# Optimization Horizon → Dilemma of Optimizing

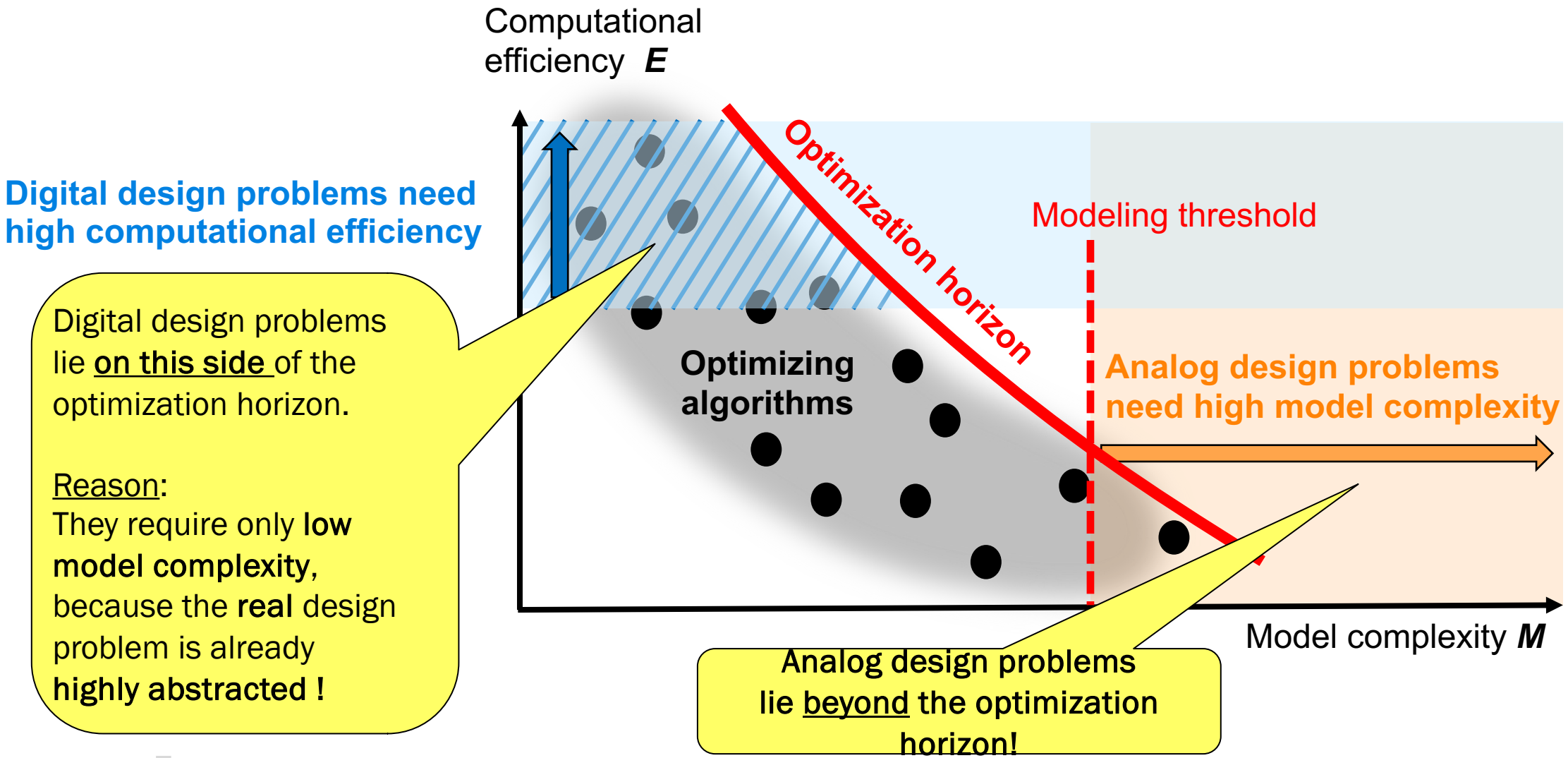


Depends on:
- Compute effort for checking „validity“
- Compute effort for objective function
- Complexity of solution space
- Search strategy of exporation engine



# Optimization Horizon → Dilemma of Optimizing





# An alternative approach: Generators



- A generator is basically a script that captures the design strategy for a specific design task.
- When executed it replicates the work of a designer in a straight-forward manner.
- Generators are parametrized to cover a certain range of applications.

| | Optimizer | Generator (Procedure) |
|---|---|---|
| Design flow | top-down | bottom-up |
| Handling of goals, constraints, problem aspects … | explicitly | implicitly |
| Solution / result | found by algorithm,<br>repeatedly „re-invented“ | conceived by human expert,<br>re-use of experience-based design strategy |
| „Real-world“ quality of solution | intrinsic quality loss<br>(due to optimization horizon) | full-custom (handmade) |
| Industrial acceptance for analog design | low | high |

# Today‘s design flows in the Y-model

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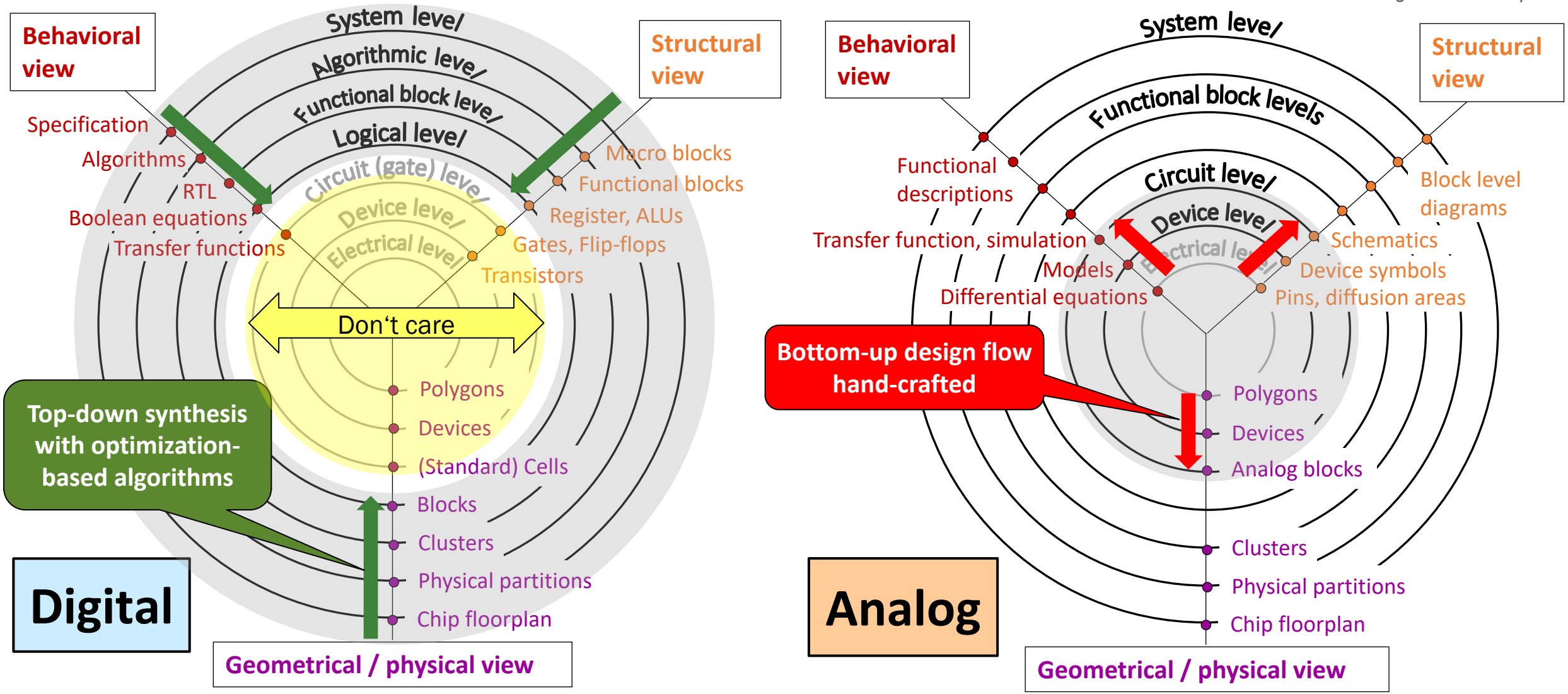

# Future design flows in the Y-model

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