Hardware Modeling [VU] (191.011) – WS25 –

Introduction to Hardware Design

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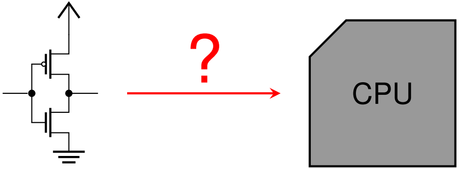
Motivation

- How to go from simple circuits to complex ones?
  - Up to **billions** of transistors
  - Complexity continuously increasing (*Moore's Law*)

⇒ Hardware Modeling

  - Tools and techniques to bridge the gap



Why bother?

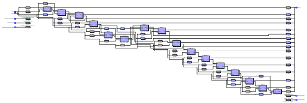
- Why should you care about designing hardware?

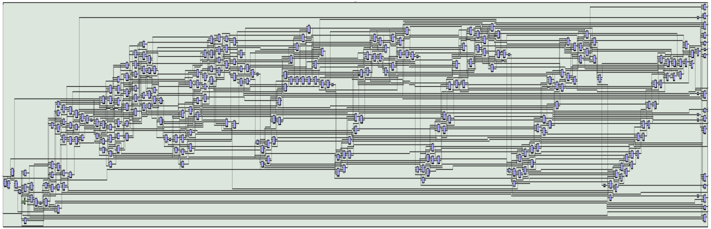
⇒ Same as for software

  - Custom requirements ⇒ custom solution
  - Required for niche applications
  - Reduce overhead

Why bother? (Cont'd)

- Become a better programmer
  - Understand hardware limits
  - Know which knobs to turn
  - New way of thinking
- Example: addition and division in same technology





Differences to Software Design

- Software
  - Typically sequential
  - Concurrency possible but takes care
  - Asymptotic behavior (mostly)
  - Easy to update
- Hardware
  - Typically concurrent
  - Sequential possible but takes care
  - Details matter
  - First-time-right paradigm

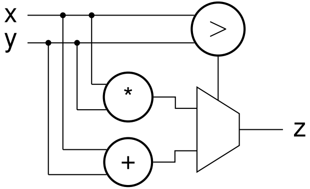
Takeaway

This duality makes hardware design hard but also rewarding

Comparison to Software Design (Cont’d)

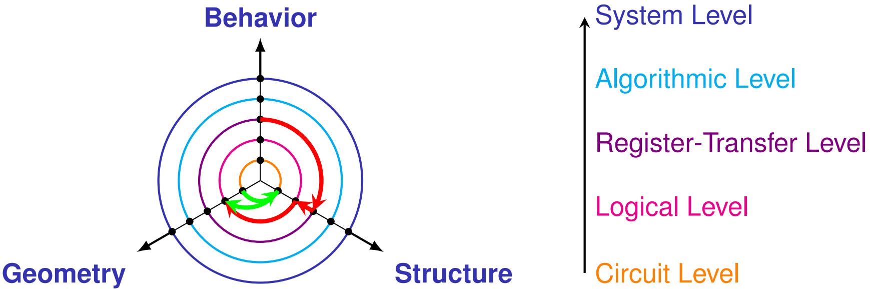
- Software
  - Sequential execution
  - Either multiplication or addition
- Hardware
  - Computations done concurrently
  - All operations always active

```
if (x > y)
  z = x * y;
else
  z = x + y;
return z;
```



Gajski Y-Chart

- Abstraction is key
  - Start on high abstraction and (automatically) move inwards
  - Catch: Increasing abstraction ⇒ decreased optimization potential
- All points of view describe same circuit
  - Translate between them as beneficial
  - Harnessed by tools



Behavior

Geometry

Structure

System Level

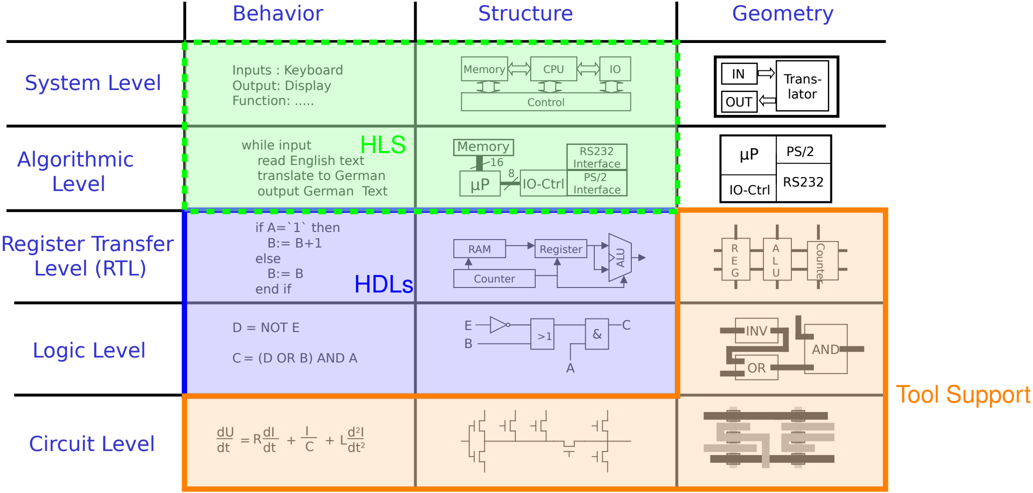
Algorithmic Level

Register-Transfer Level

Logical Level

Circuit Level

Y-Table



	Behavior	Structure	Geometry
System Level	Inputs : Keyboard Output: Display Function:	Memory CPU IO Control	IN OUT Trans-lator
Algorithmic Level	while input read English text translate to German output German Text	Memory 16 8 µP IO-Ctrl RS232 Interface PS/2 Interface	µP PS/2 IO-Ctrl RS232

Register Transfer Level (RTL)	if A=`1` then
	B:= B+1
	else
	B:= B
	end if
		RAM
		Register
		Counter
		ALU
			REG
			ALU
			Counter

Logic Level	D = NOT E
	C = (D OR B) AND A
		E
		B
		>1
		&
		C
		A
			INV
			AND
			OR

Circuit Level	$\frac{dU}{dt} = R\frac{dI}{dt} + \frac{I}{C} + L\frac{d^2I}{dt^2}$		

HLS

HDLs

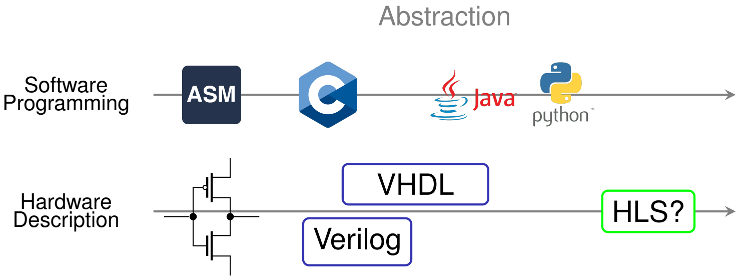
Tool Support

Hardware Description Languages

- Drawing circuits does not scale
  - Require more abstract method

⇒ *Hardware Description Languages* (HDLs)

  - Most popular: VHDL, (System)Verilog



Abstraction

Software Programming

ASM

Java

python™

Hardware Description

VHDL

Verilog

HLS?

We will use VHDL! But why?

- Verbose code
- Strongly typed
  - Harder to make subtle mistakes
- Highly structured and modular
- Different from what you know

VHDL Standard

- The latest VHDL standard (2019) can be found here
  - Download through the TU network (e.g., via eduroam or VPN connection)
- Watch out for VHDL standard and implementation references

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Lecture Complete!