EE2026 Digital Design

MODULE INTRODUCTION

Chua Dingjuan elechuad@nus.edu.sg

Slides credit to Prof Massimo Alioto and Prof YP Xu

Course Description

First course on digital systems

- Introduces fundamental digital logic, digital circuits, and programmable devices
- The course also provides an overview of computer systems
- This course provides students with an understanding of the building blocks of modern digital systems and methods of designing, simulating and realizing such systems
- The emphasis of this module is on understanding the fundamentals of **digital design across different levels of abstraction** using Hardware Description Languages
- Developing valuable design skills for the design of digital systems through FPGAs and state-of-the-art CAD tools, as required by the job market (**exciting projects**)

Module Team

Lecturer : Dr. Chua Dingjuan

Lab Instructors :

Mr. Christopher Moy (B01, B03)
Dr. Goh Shu Ting (B02)

Tutors :

Dr. Chua Dingjuan, Mr. Christopher Moy, Dr. Goh Shu Ting, Mr. Yu Juezhao

Lab Officers:

Mr. Ho Fook Mun, Ms. Chia Meow Hwa and Mdm. Goh Kah Seok

Module Lecture Structure

Contents

Part 1 (Combinational Logic)

- Number systems + Verilog
- Boolean Algebra and logic gates + Verilog
- Gate-level design and minimization + Verilog
- Combinational logic blocks and design + Verilog

Part 2 (Sequential Logic)

- Basic Sequential Logic Blocks - Flip-flops + Verilog
- Counters + Verilog
- Combining combinational/sequential building blocks + Verilog
- Finite State Machines + Verilog

Module Organization (Refer Canvas)

Week	Lab	Lecture	Tutorial
WK 1		✓	
WK 2	(CDE Day, no classes on WED PM)	✓	Tutorial – 1
WK 3	Lab 1	✓	Tutorial – 2
WK 4	Lab 2	✓	Tutorial – 3
WK 5	Lab 3 (Wed AM and Wed PM)	✓ No Lecture on Monday due to LNY PH	Tutorial – 4
WK 6	Lab 3 (Mon AM)	✓ **Mid-Term Quiz**	
Recess Week			

Module Organization (Refer Canvas)

Week	**Lab**	**Lecture**	**Tutorial**
WK 7	Project 1	✓	Tutorial – 5
WK 8	Project 2	✓	Tutorial – 6
WK 9	Project 3	✓	Tutorial – 7
WK 10	Verilog Evaluation	✓	Tutorial – 8
WK 11			Tutorial – 9
WK 12	Project 4 - Assessment and Demo		
WK 13		Final Quiz	

No final exam ☺

Module Assessment

Component	Assessment Weight
Quizzes	**Total 40%**
○ Mid-Term Quiz	20%
○ Part 2 Weekly Canvas Quizzes	5%
○ Part 2 Final Quiz	15%
Labs	**Total 30%**
○ Lab Assignment 1	3%
○ Lab Assignment 2	6%
○ Lab Assignment 3	10%
○ Verilog Evaluation	11%
Design Project – Team Work	**Total 30%**
○ Project basic features (specified) ○ Enhanced features (open-ended)	30%

No final exam ☺

Expected Learning Outcomes

Expected learning outcome **(Part 1)**

- *Be able to perform conversion* between binary, octal, hexadecimal and decimal number systems, and *solve simple problems;*
- *Understand* Boolean Algebra, and *manipulate and simplify* Boolean functions using theorems and postulates;
- *Be able to design simple combinational logic circuits* based on Truth table and Karnaugh Map
- *Be able to design complex combinational logic circuits* using Hardware Description Languages (Verilog) and/or combinational building blocks
- *Be able to simulate complex combinational blocks* and verify their proper functionality through behavioural simulation
- *Be able to design combinational logic circuits* for practical problems / applications

Expected Learning Outcomes

Expected learning outcome (Part-2)

- *Be able to describe simple sequential logic circuits* based on functional descriptions
- *Be able to describe simple sequential logic circuits* based on state transition diagrams
- *Be able to design complex logic circuits* using Hardware Description Languages (Verilog) and/or sequential/combinational building blocks/IPs
- *Be able to simulate complex blocks* and verify their proper functionality through behavioural simulation
- *Be able to design complex logic circuits* for practical problems / applications

LAB / PROJECT REMINDER

- EE2026 is a hands-on module → significant lab and project time / components
- Software : Xilinx Vivado 2018.2
- **Unfortunately, this software is not supported on Mac operating systems (only windows / linux)**
- Referring to installation instructions provided on Canvas, please install the software by end of Week 2
- If you have difficulties accessing a windows-based system, please check in with us.

Module information

Course materials

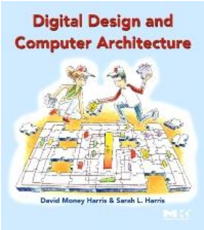
- Canvas (everything about the course)

Need Help?

- Tutors (tutorial questions)
- TAs and GAs (labs and projects)
  - During lab sessions
- Face-to-face consultation with lecturer:
  - by appointment

Reference book (download from NUS library)

- D. Harris, S. Harris, Digital Design and Computer Architecture (1st ed.), Morgan Kaufmann, 2007



Why study this module?

The module is about the fundamentals of digital systems, which is important if you are interested in the design of digital circuits and systems, especially if you plan to specialize in the following areas:

- Integrated circuit design (very important)
- Digital integrated circuits (very important)
- Embedded systems and Computer Architecture (very important)

It's the first module about Hardware Description Language (HDL), which is widely used for digital system design and modeling

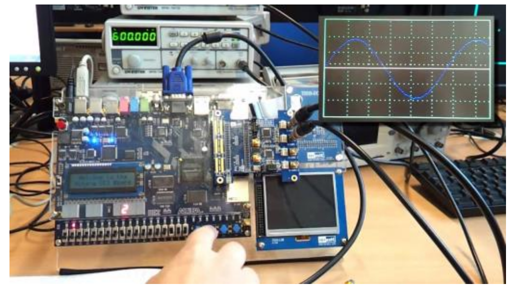
You will also learn analytical and problem solving skills through the projects (practical design problems)

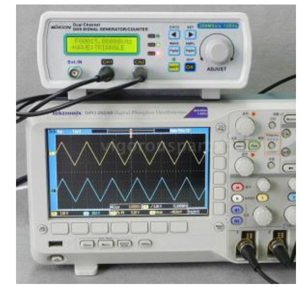
It also serves as prerequisite for other modules at senior levels.

EE2026: Not Just Another Module…

Think & do: strong foundations, real-world design

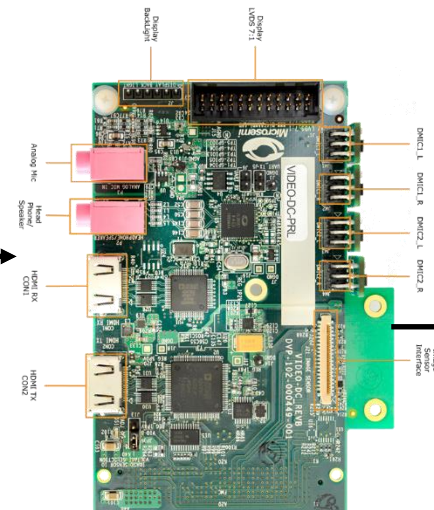
- Industry-relevant project



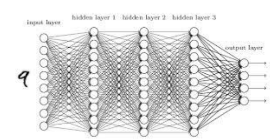


  – This year: machine learning and human-machine interfaces

handwritten input



your design on FPGA board



text output (classification)

EE2026: Quite Unique…

Design skills in very high demand

- FPGA designer (**startups,** SMEs, MNCs)
- Semiconductor industry

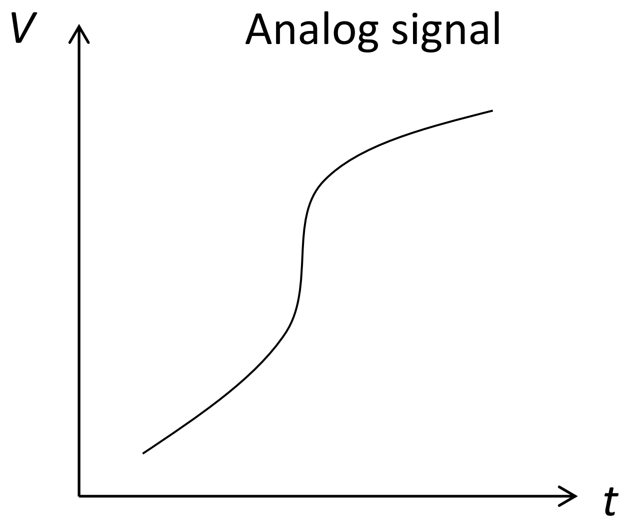
AND SO ON AND SO FORTH…

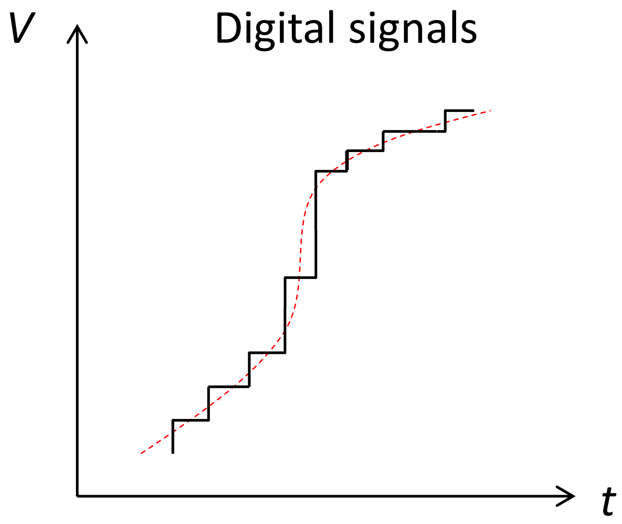
- Not capital intensive: create YOUR OWN technology/company

INTRODUCTION

Analog vs. Digital Circuit

- Analog circuit deals with continuous signals
- Digital circuit deals with signals having discrete levels





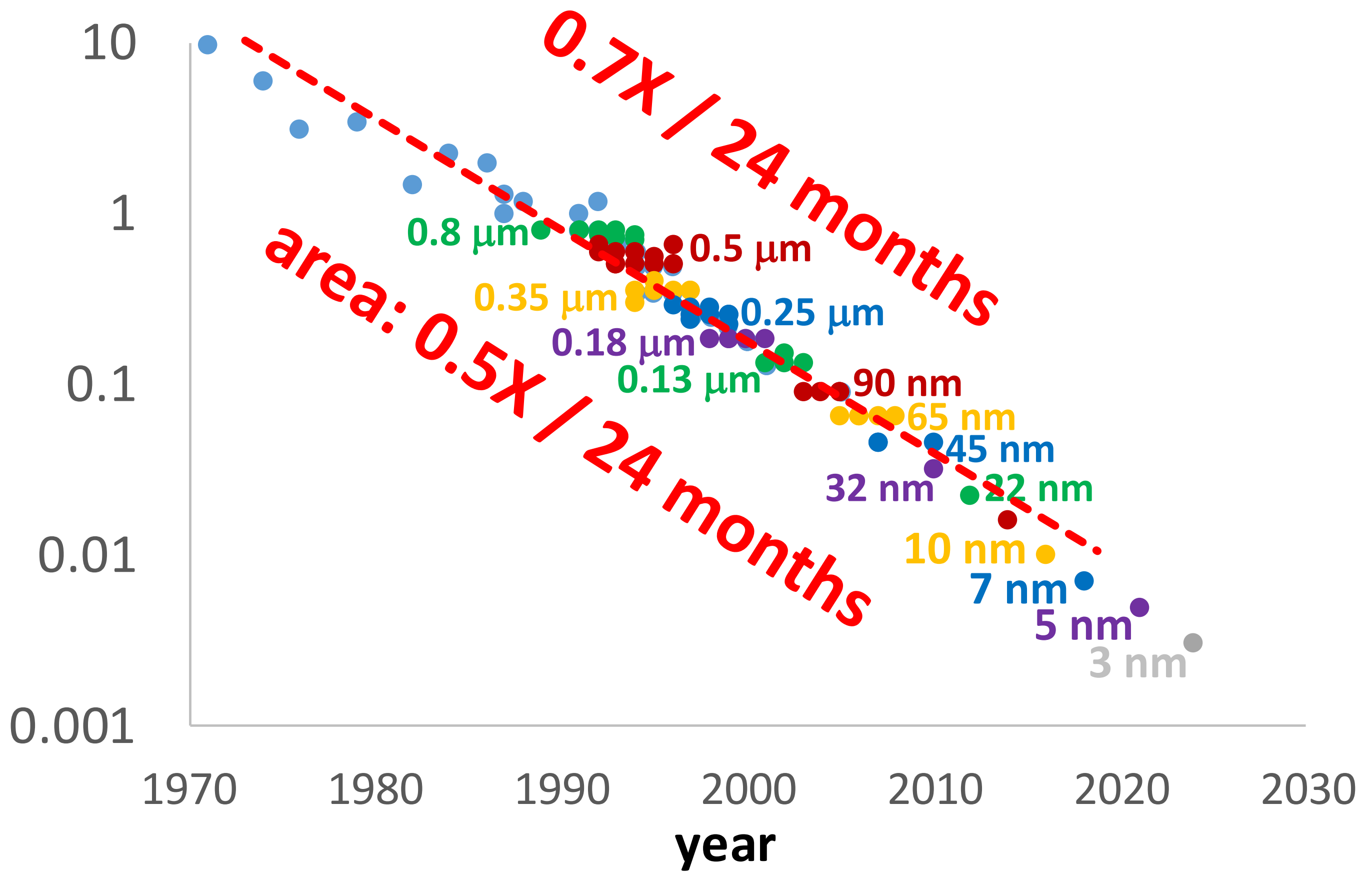
- ➢ Analog circuit is more susceptible to noise
- ➢ Digital circuit is a binary system which is much more robust

Why digital?

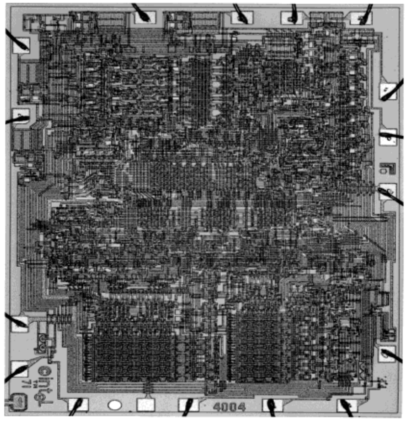
- Robustness (reliability)
- Programmability
- Scalability (in integrated circuit technology)
- Cost

Technology Scaling

Transistors got smaller over time (at a relentless pace)

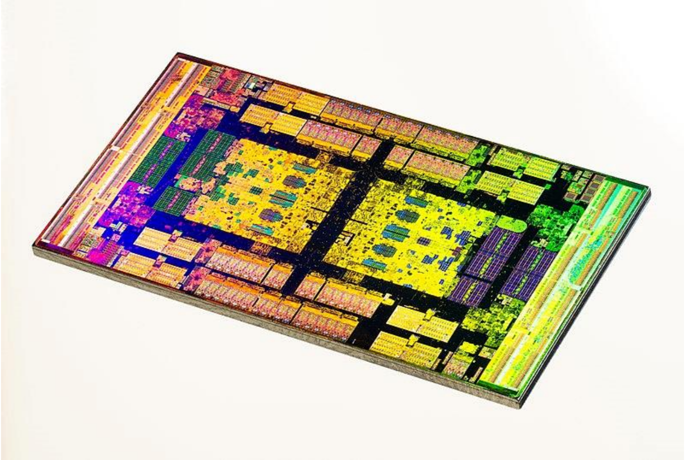


Technology Scaling (cont.)



1971:

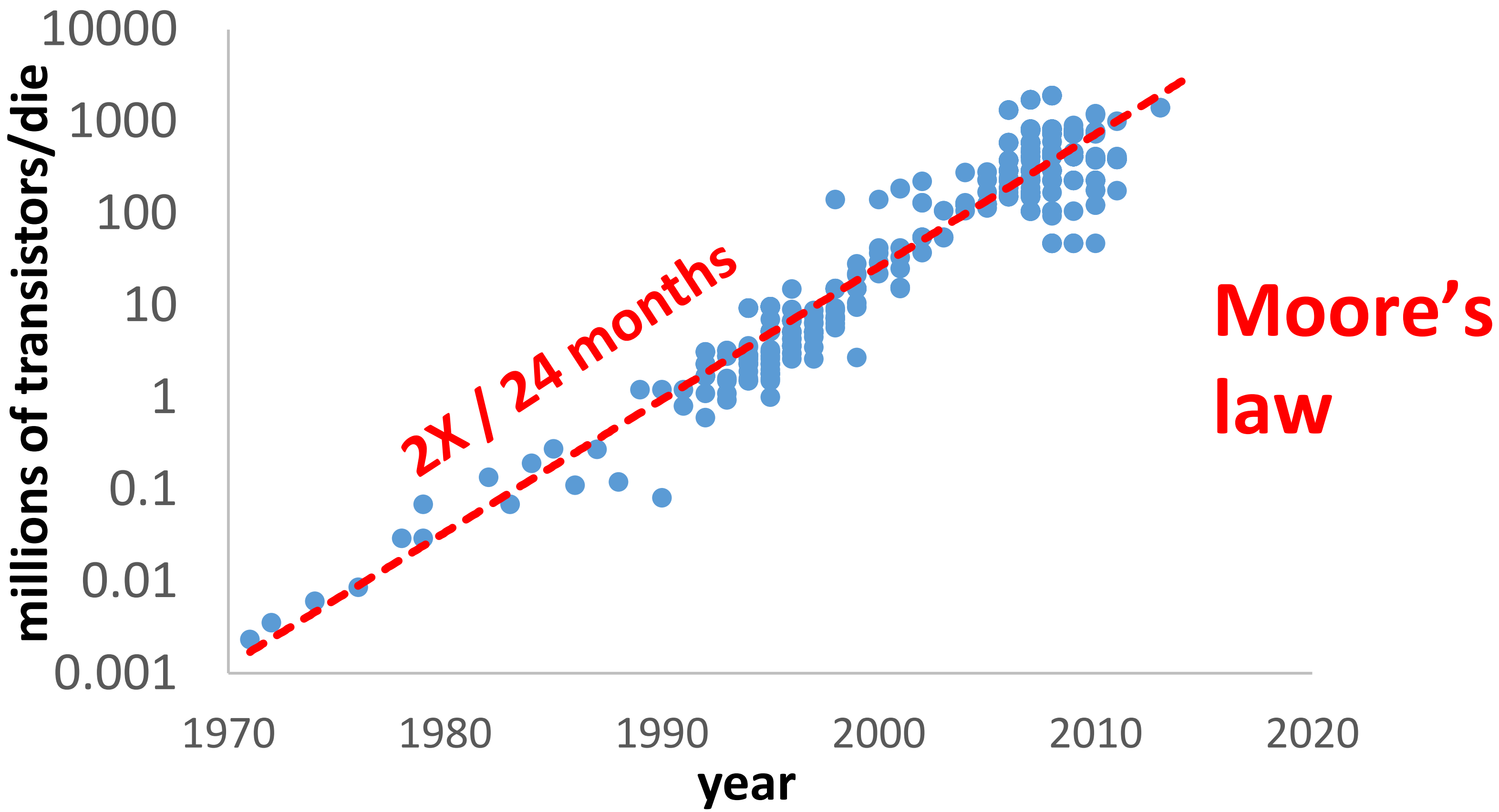
- Intel 4-bit processor in 10 μm PMOS process with 2300 transistors
- Initial clock speed of 108 kHz
- 10μm pMOS technology



2020:

- AMD Epyc Rome 7 nm processor (64 cores, 256MB L3, Zen 2 arch.) 40B transistors
- IBM z15 5.2 GHz clock freq., 12 cores in 14 nm FinFET, 9.2B transistors
- Intel Xeon Platinum 8180 in 14nm CMOS (28 cores), 3.6 GHz, 205 W, 8B transistors
- nVIDIA Ampere, 7nm FinFET, 5 PFLOPS, 54B transistors

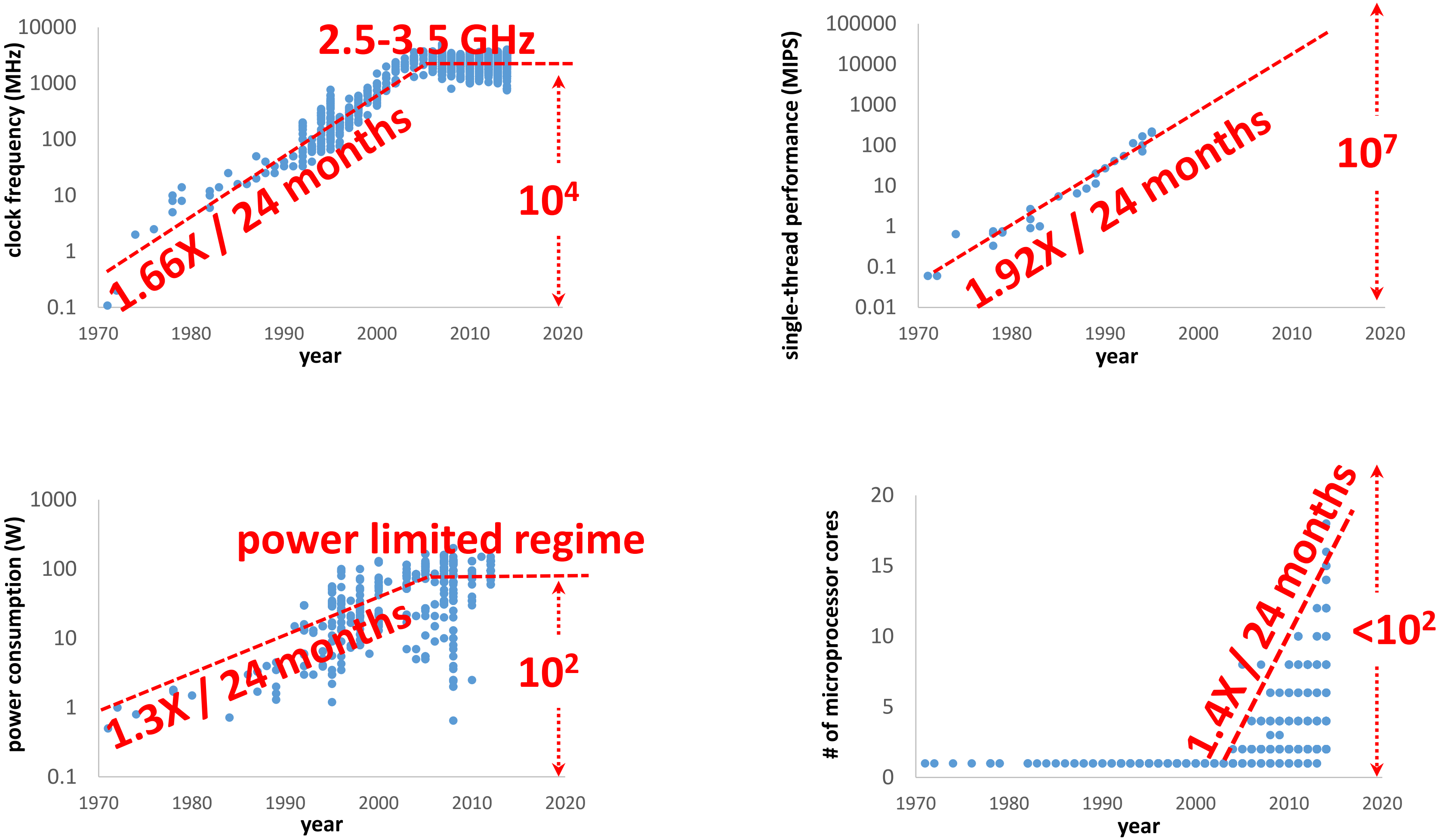
Technology Scaling (cont.)



As more and more transistors can be integrated on a single chip,

- functionality is increased
- for the same functionality: lower chip area, lower cost per transistor

Technology Scaling (cont.)



Digital Revolution & Information Age

1947 – Invention of transistor

1971 – First microprocessor

***Rapid development of digital computing and communication technology brought about the digital revolution and information age**

1980s – Personal computers

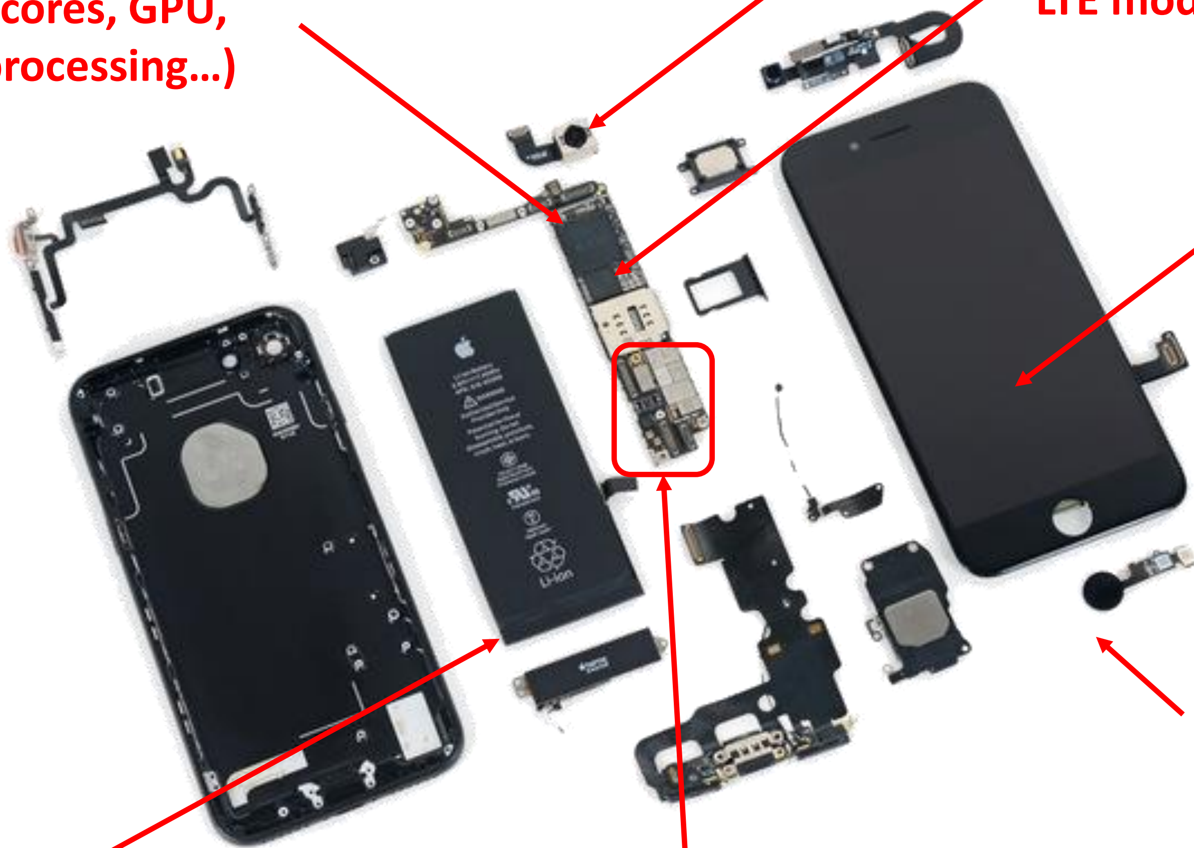
1990s – World Wide Web, digital cameras

2000s – Mobile phones, digital TVs, ipod

2010 – Smart phones, xPad, cloud computing (accessible everywhere), social networking (constantly connected)

2020 – Cloud computing, Internet of things, ultra-low power high-performance mobile computing, ubiquitous computing, immersive computing/augmented reality, gesture recognition...

Example in Your Pocket (Today)

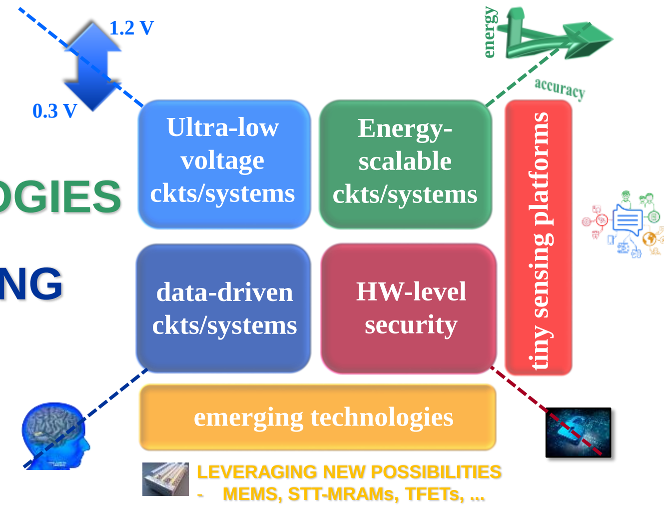


Example Available Everywhere (Tomorrow) from GREEN IC Group

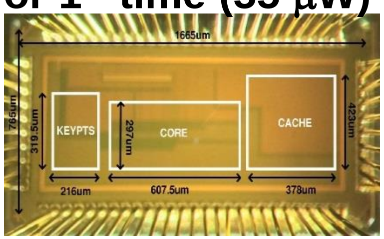
http://www.green-ic.org

CORE TECHNOLOGIES

CONNECTING THE DOTS

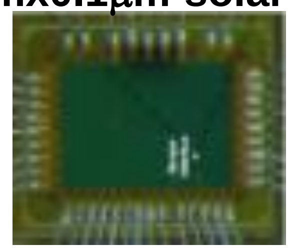


computer vision in IoT for 1st time (55 μW)

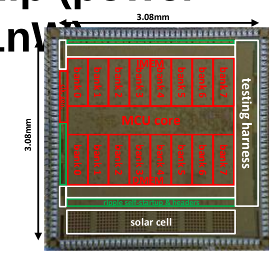


most (cyber)secure "silicon fingerprint"

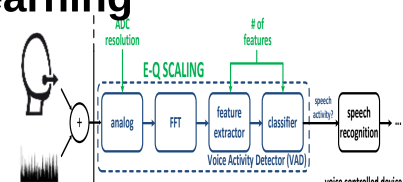
AES in 100 nW (0.1μmx0.1μm solar cell)



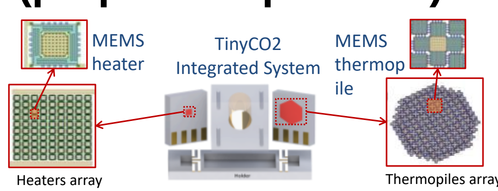
1st lunar-powered chip (power ~1nW)



sub-μW machine learning

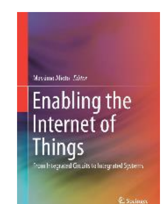


1st mm-scale CO2 sensor (perpetual operation)



PRESS

PCWorld ECN HOT CHIPS PHYS.ORG



1st book on chip design for IoT