Lecture
0_4.2

Systems: Taxonomies

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Goal

- The lecture aims at introducing the concept of System from a hierarchical perspective
- The concept of Processing Element (PE) is then introduced
- Each PE is then presented in terms of DataPath & Control Unit
- An extensive presentation of the most widely used taxonomies for digital systems concludes the lecture.

Prerequisites

- Lecture 0_4.1 Systems Definitions

Homework

- None

Further readings

- **Students interested in making a reference to a text book on the arguments covered in this lecture can refer, for instance, to:**
  - ***G. Conte, A. Mazzeo, N. Mazzocca, P. Prinetto*: "Architettura dei calcolatori", *Città Studi, 2015* (Chapter 1: Classificazioni e Concetti base) (In Italian)**

Outline

- System Taxonomies
- Different view points

Outline

- – System Taxonomies
- – Different view points

System Taxonomies

A plenty of possible taxonomies:

- *Information coding*
- *Behavior of output signals w.r.t. timing signals*
- *Behavior of operations w.r.t. timing signals*
- *Architectural model*
- *Functionality*
- *Implementation*
- *Physical Dimensions & Market target.*

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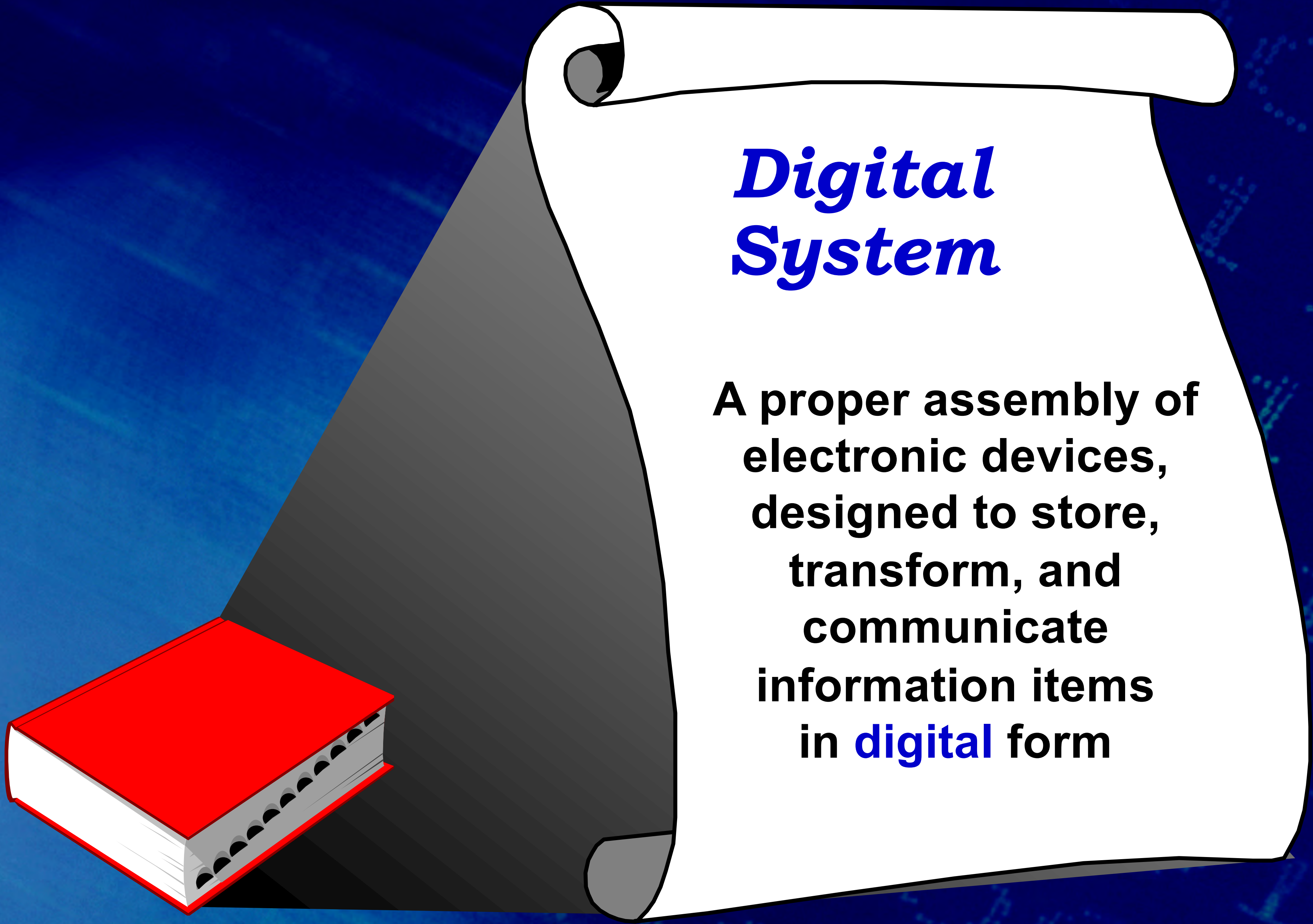
Information coding

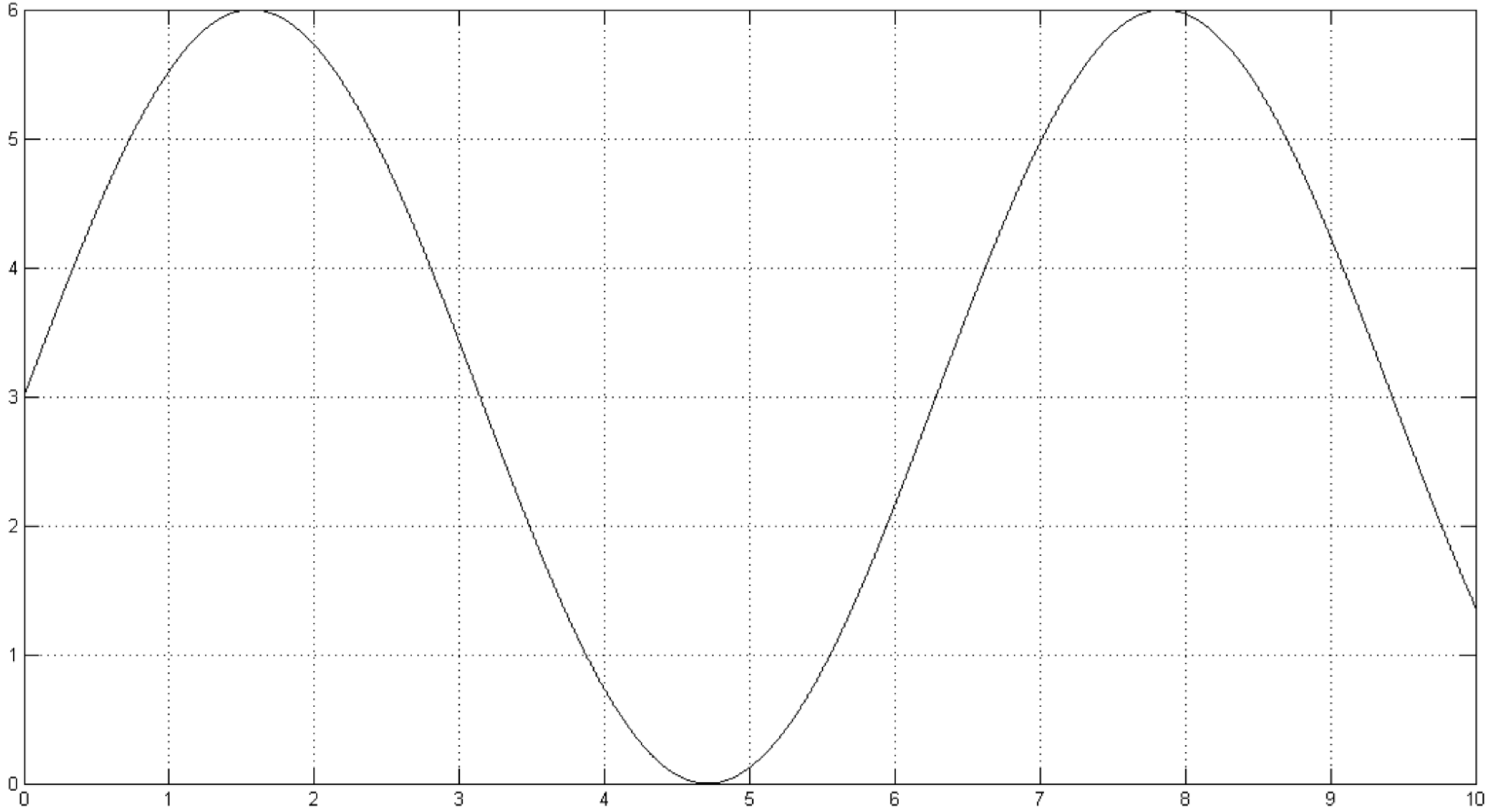
- *Digital System*
- *Analog System*

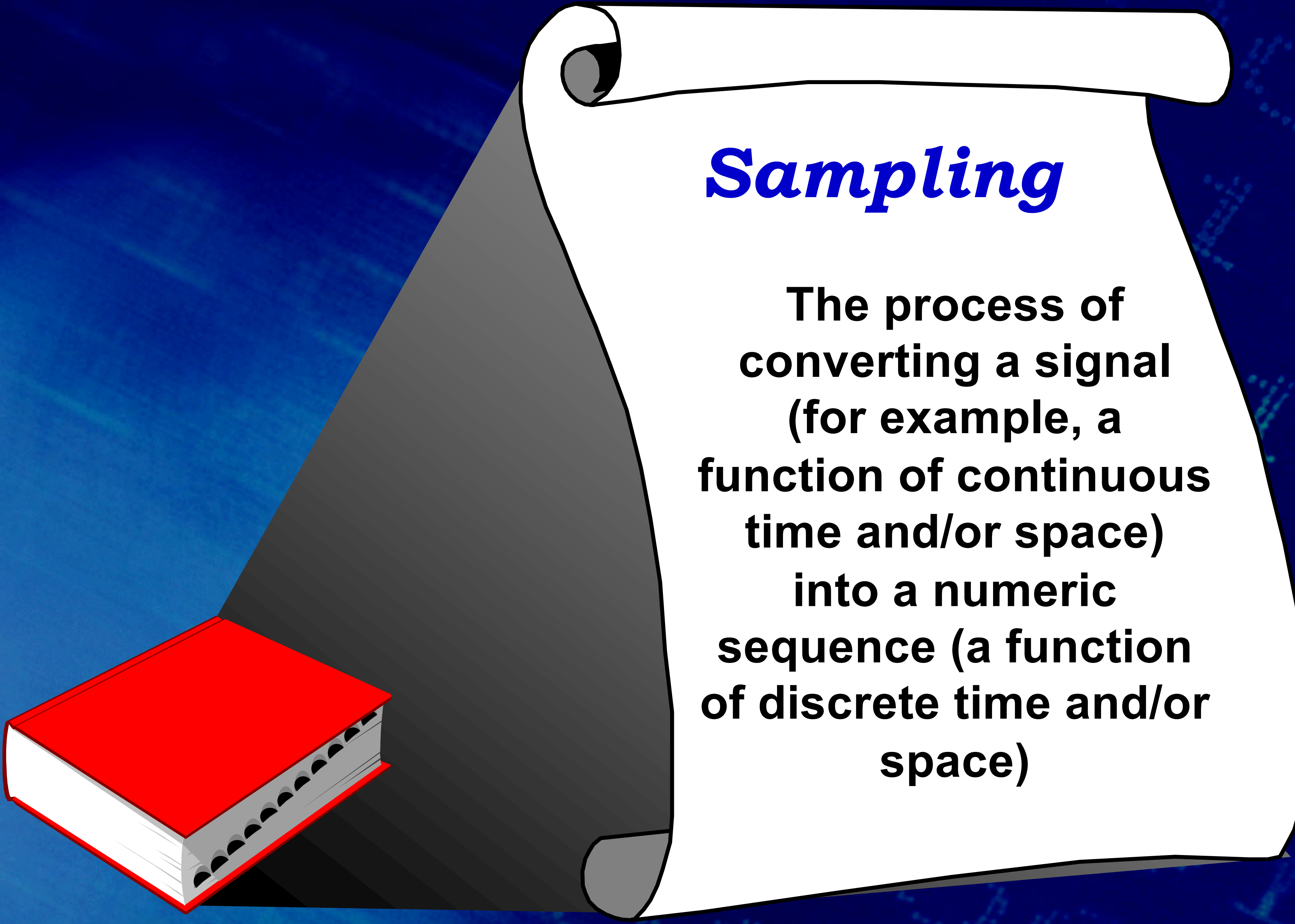


Digital System

A proper assembly of electronic devices, designed to store, transform, and communicate information items in digital form

Analog





Sampling

The process of converting a signal (for example, a function of continuous time and/or space) into a numeric sequence (a function of discrete time and/or space)

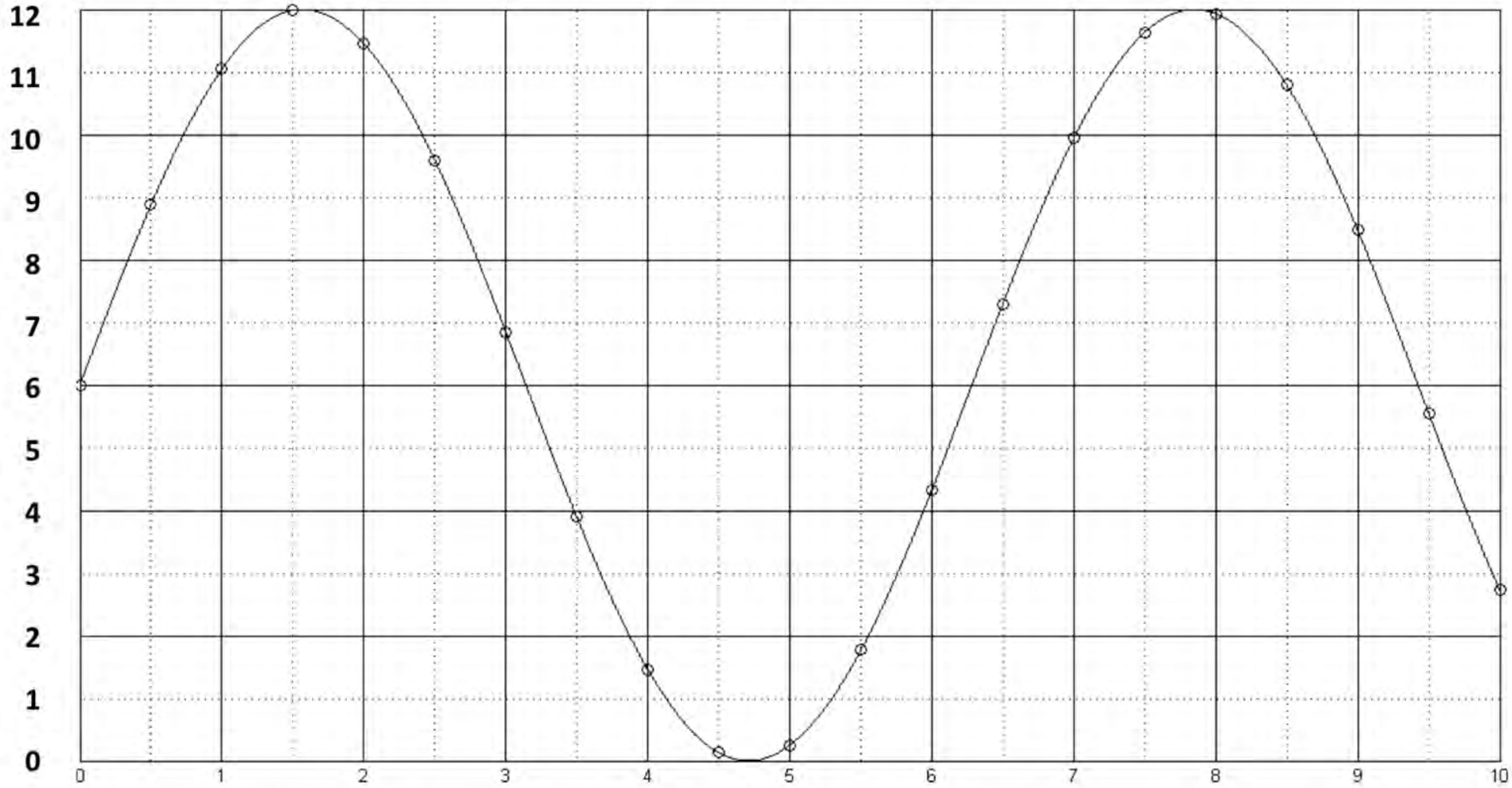
Nyquist–Shannon sampling theorem

- If a function x(t) contains no frequencies higher than B Hz, it is completely determined by giving its ordinates at a series of points spaced 1/(2B) seconds apart

Nyquist–Shannon sampling theorem

- If a function x(t) contains no frequencies higher than B Hz, it is completely determined by giving its ordinates at a series of points spaced 1/(2B) seconds apart
- A sufficient sample-rate is therefore 2B samples/s, or anything larger
- Equivalently, for a given sample rate fs, perfect reconstruction is guaranteed possible for a bandlimit B < fs/2.

Sampled & Digitalized



0110	1001	1011	1100	1100	1010	0111	0100	0010	0000	0000	0010	0100	0111	1010	1100	1100	1011	1001	0110	0011

System Taxonomies

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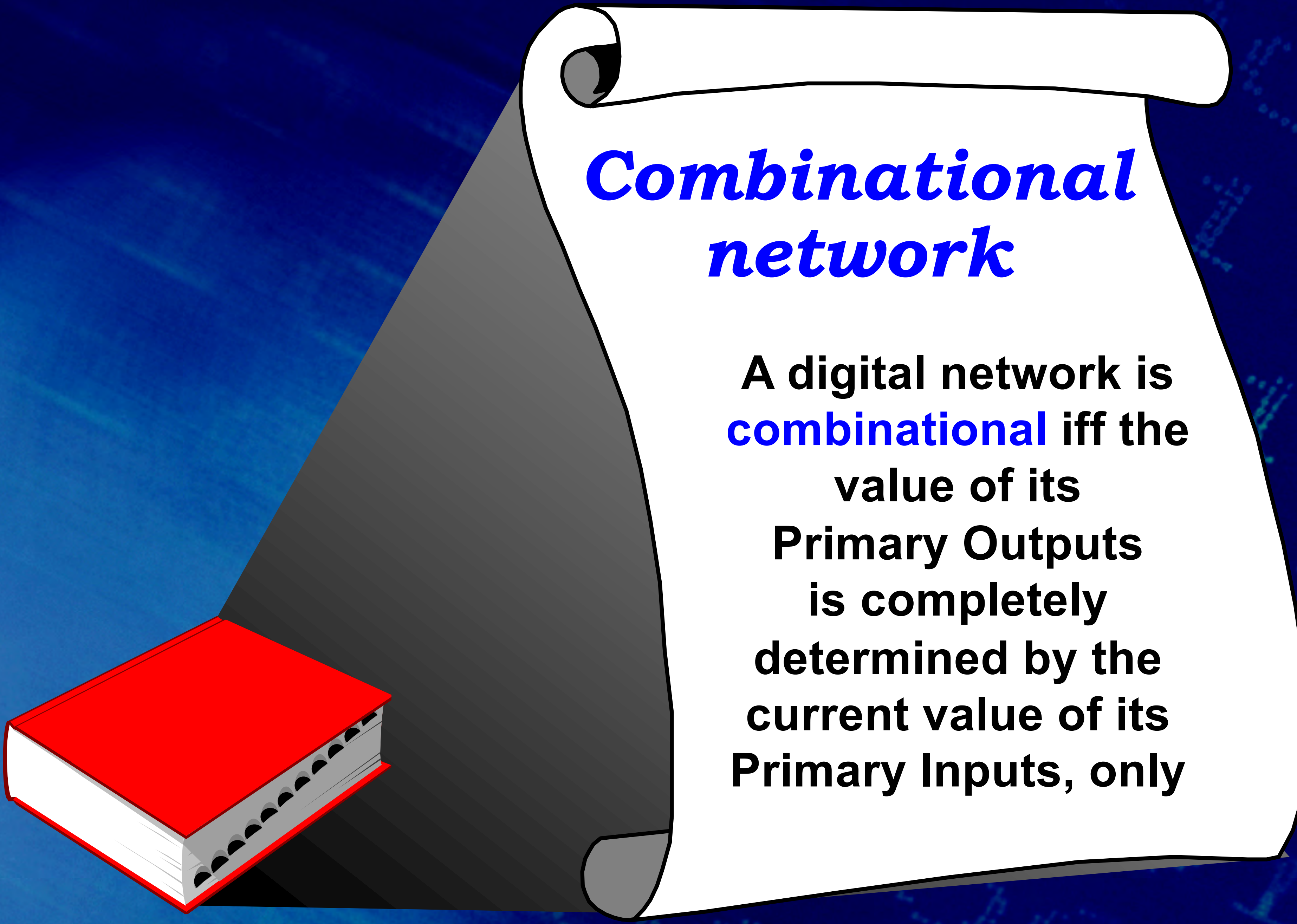
Behavior of output signals w.r.t. timing signals

- ***Combinational***
- ***Sequential***



Combinational network

A digital network is combinational iff the value of its Primary Outputs is completely determined by the current value of its Primary Inputs, only

Sequential network

A digital network is **sequential** if the value of its Primary Outputs is a function of past as well as current values of its Primary Inputs

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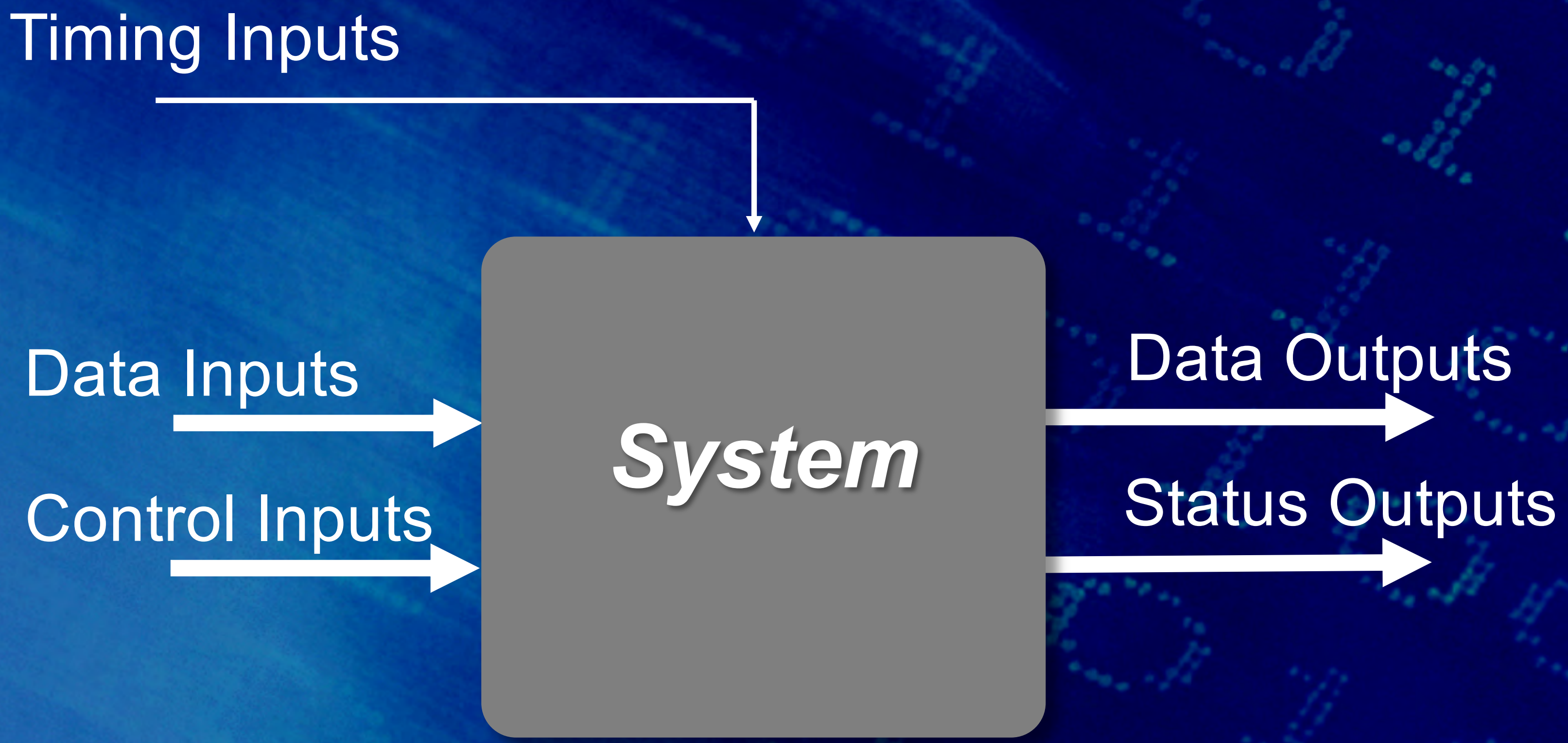
Behavior of operations w.r.t. timing signals



Timing Inputs

Data Inputs

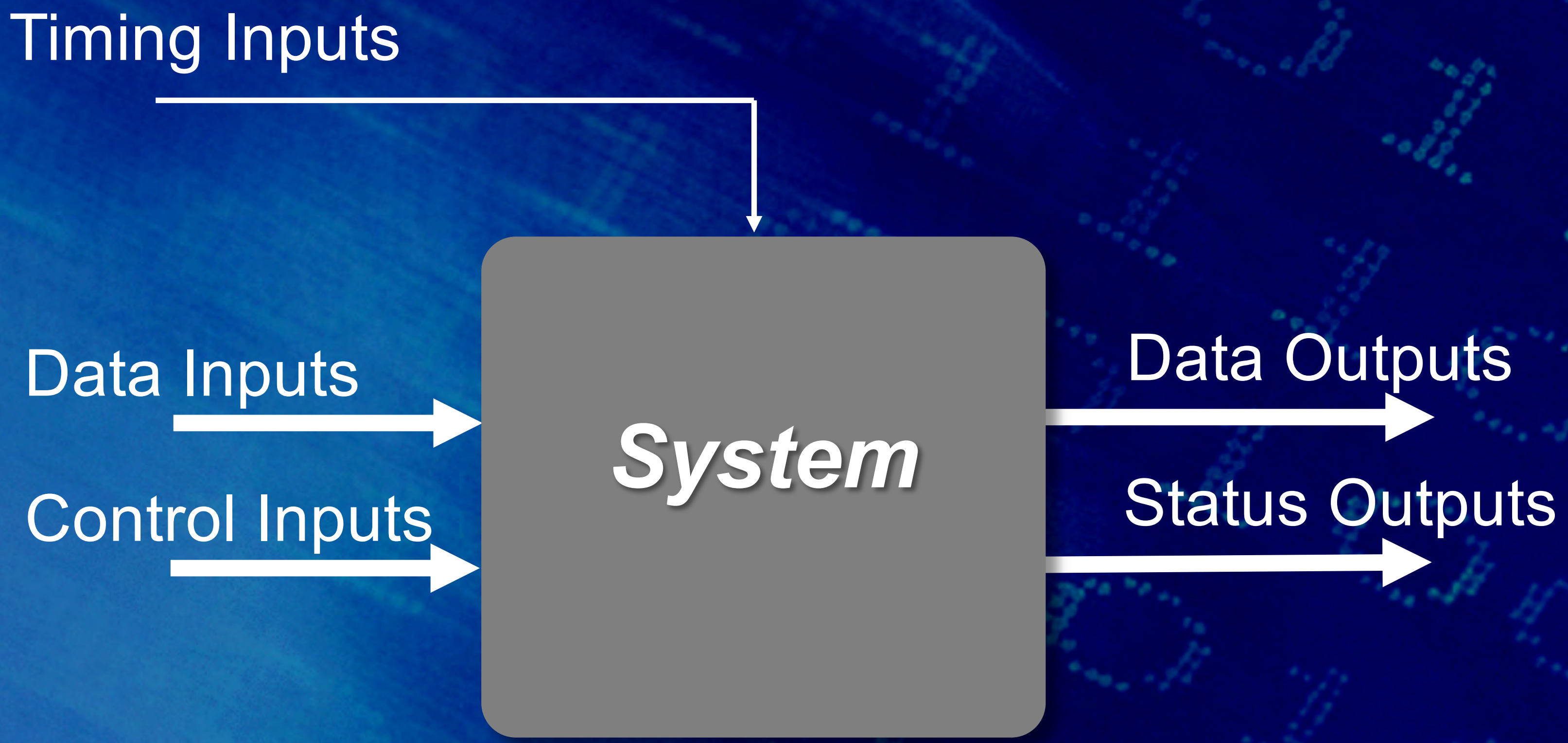
Control Inputs

System

Data Outputs

Status Outputs

Behavior of operations w.r.t. timing signals


Timing Inputs

Data Inputs

Control Inputs

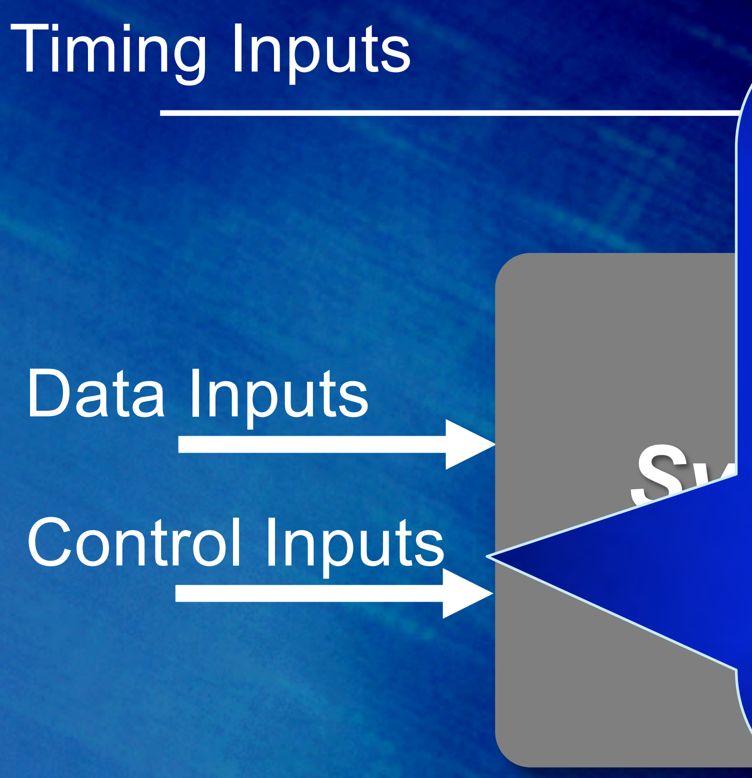
System

Data Outputs

Status Outputs

At any instant t, the system can perform, concurrently, K operations (K ≥1)

Behavior of operations w.r.t. timing signals



Timing Inputs

Data Inputs

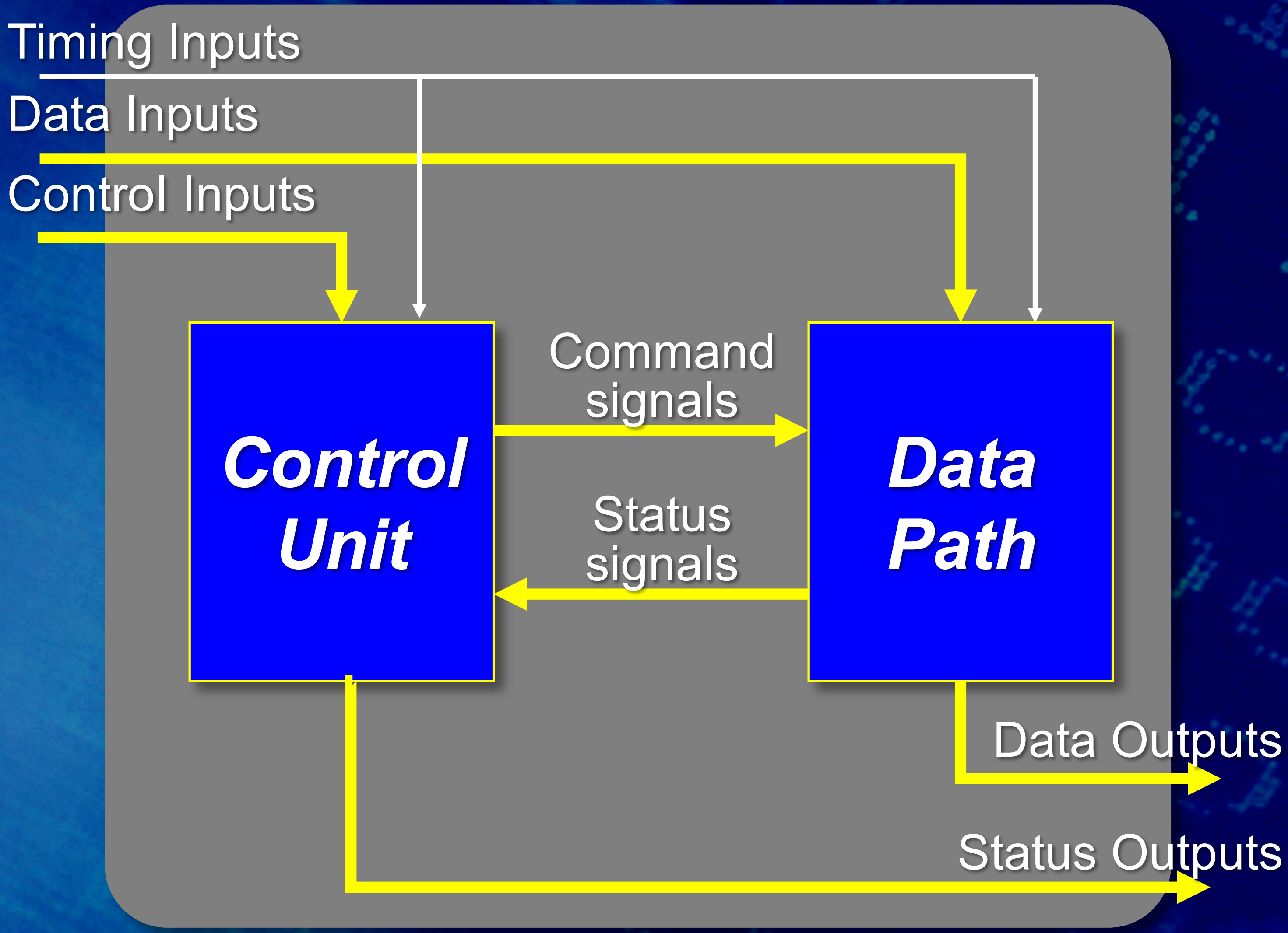
Control Inputs

At any instant t, the set of operations to be performed may depend:

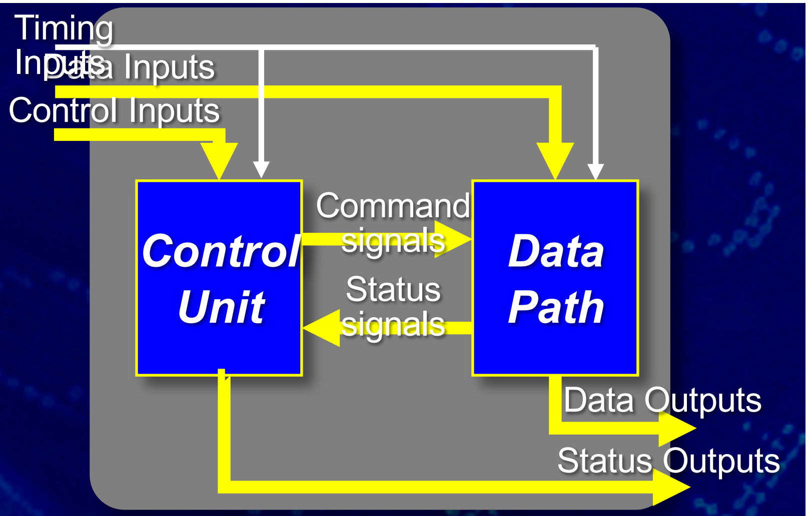
- **On the current values of *Control Inputs*, only**
- **On the current values as well as on the past values of the *Control Inputs***

At any instant t, the system can perform, concurrently, K operations (K ≥1)

Behavior of operations w.r.t. timing signals



Behavior of operations w.r.t. timing signals



Control Unit

	Combinational	Sequential
Sequential	***Finite State Machines (FMS)***	***Complex Sequential Circuits***
Combinational	***Combinational Circuits***	***RT level basic blocks***

Data Path

System Taxonomies

A plenty of possible taxonomies:

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- ***Architectural model***
- *Functionality*
- *Implementation*
- *Physical Dimensions & Market target.*

Architectural models

Flynn taxonomy

Instruction Stream		
Multiple	***MISD*** ***(Multiple Instruction, Single Data)***	***MIMD*** ***(Multiple Instruction, Multiple Data)***
Single	***SISD*** ***(Single Instruction, Single Data)***	***SIMD*** ***(Single Instruction, Multiple Data)***
	Single	**Multiple**
		Data Stream

MIMD Architectures

- ***Multi-computers***

  Several interacting computers, each with its own memory

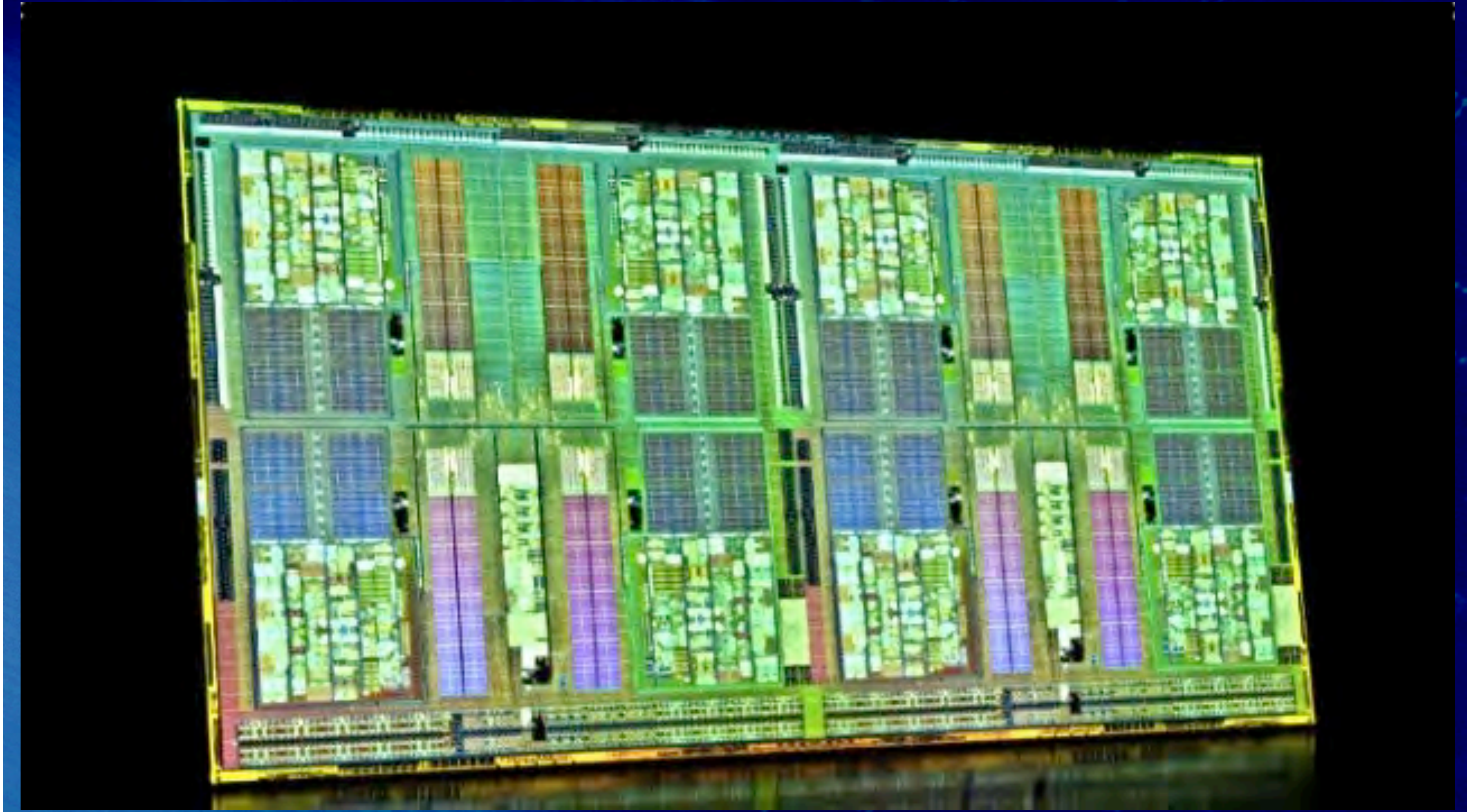
- ***Multi-processors***

  Several interacting computers sharing memories

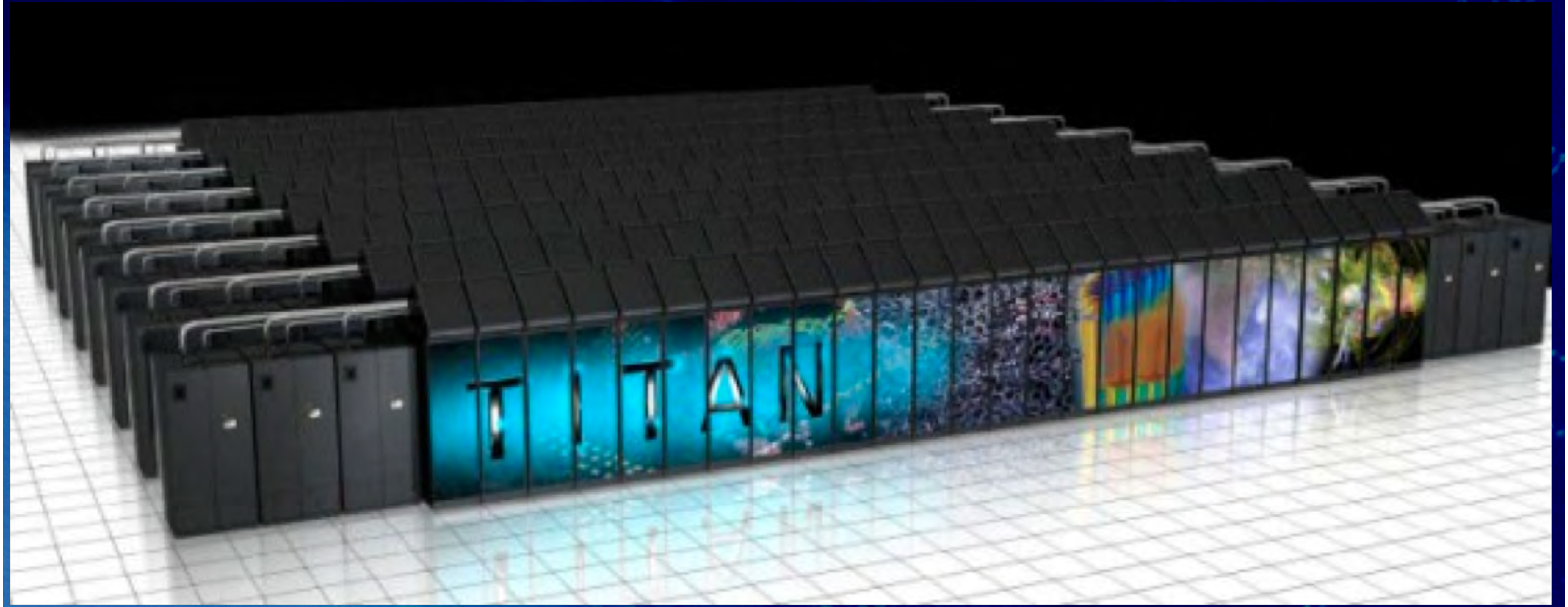
Today Multiprocessors

- **Multiprocessor SoC Architecture (MPSoC);**
  - ***Multi-core*: on a same chip, more instances of a same processor (e.g., Dual-core, Quad-core, etc)**
  - ***Many-core*: on a same chip, more instances of different processors**

CPU AMD Opteron including 16 cores x86 at 2.6 GHz

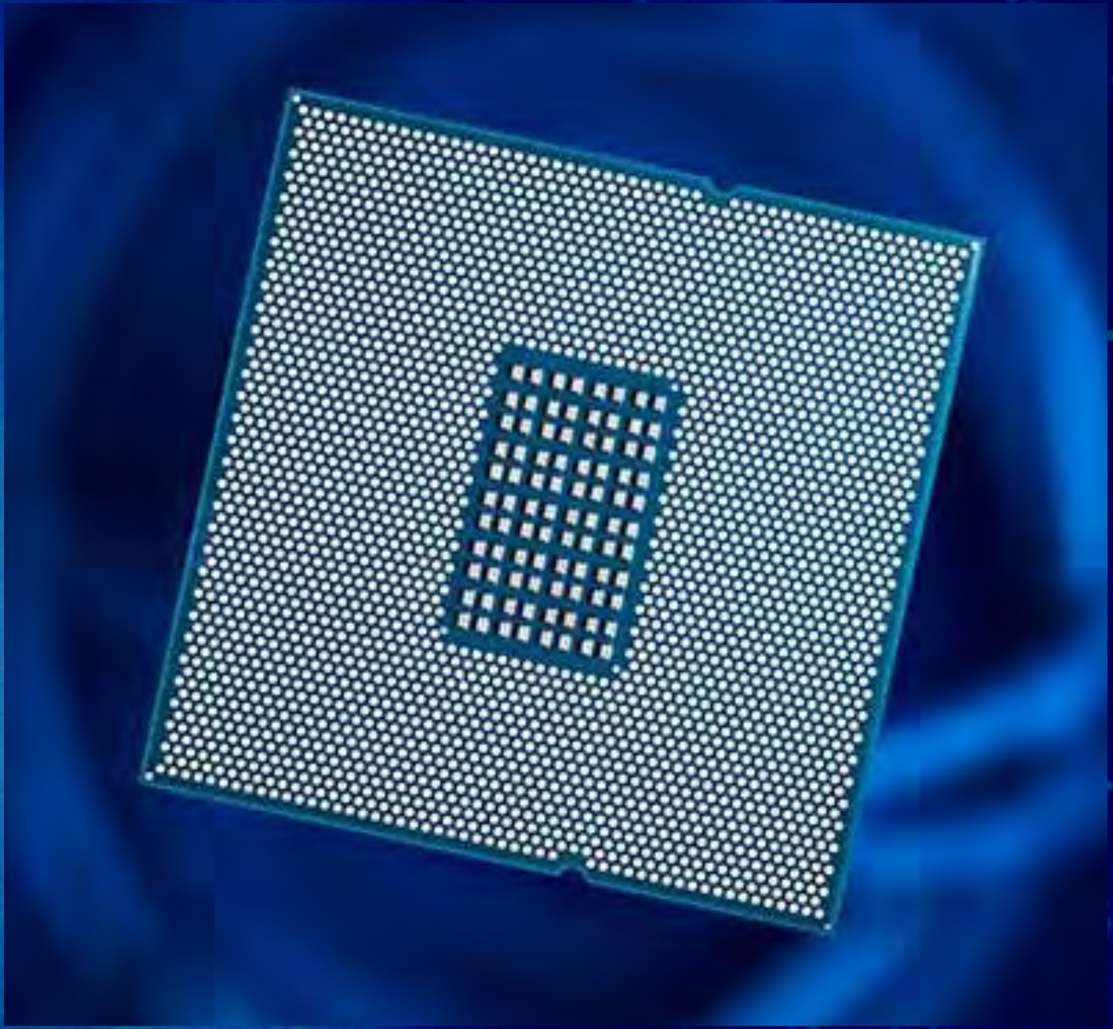


Titan Cray XK7



- 17.59 PFlop/s (10^{15} Flop/s)
- 18,688 CPU AMD Opteron + 18,688 CGPU Nvidia Tesla, for a total of 560,640 processor core
- Consumes 8.2 MW
- Total memory of 700 TB

Qualcomm Centriq 2400 series: 48-cores built on 10nm FinFET process technology



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Functionality

- *General purpose processors*
- *Special purpose processors*
- *DSP (Digital Signal Processor)*
- *GPU (Graphics Processing Unit)*

Functionality

- ***General purpose processors***
  Can execute any kind of program

Functionality

- ***Special purpose processors***

  Can efficiently execute just special purpose programs

Functionality

- ***DSP (Digital Signal Processor)***

  Design to efficiently perform signal processing oriented operations (FFT, DFFT, filters, convolutions, ...)

Functionality

- ***GPU (Graphics Processing Unit)***

  Design to efficiently perform graphic oriented operations

System Taxonomies

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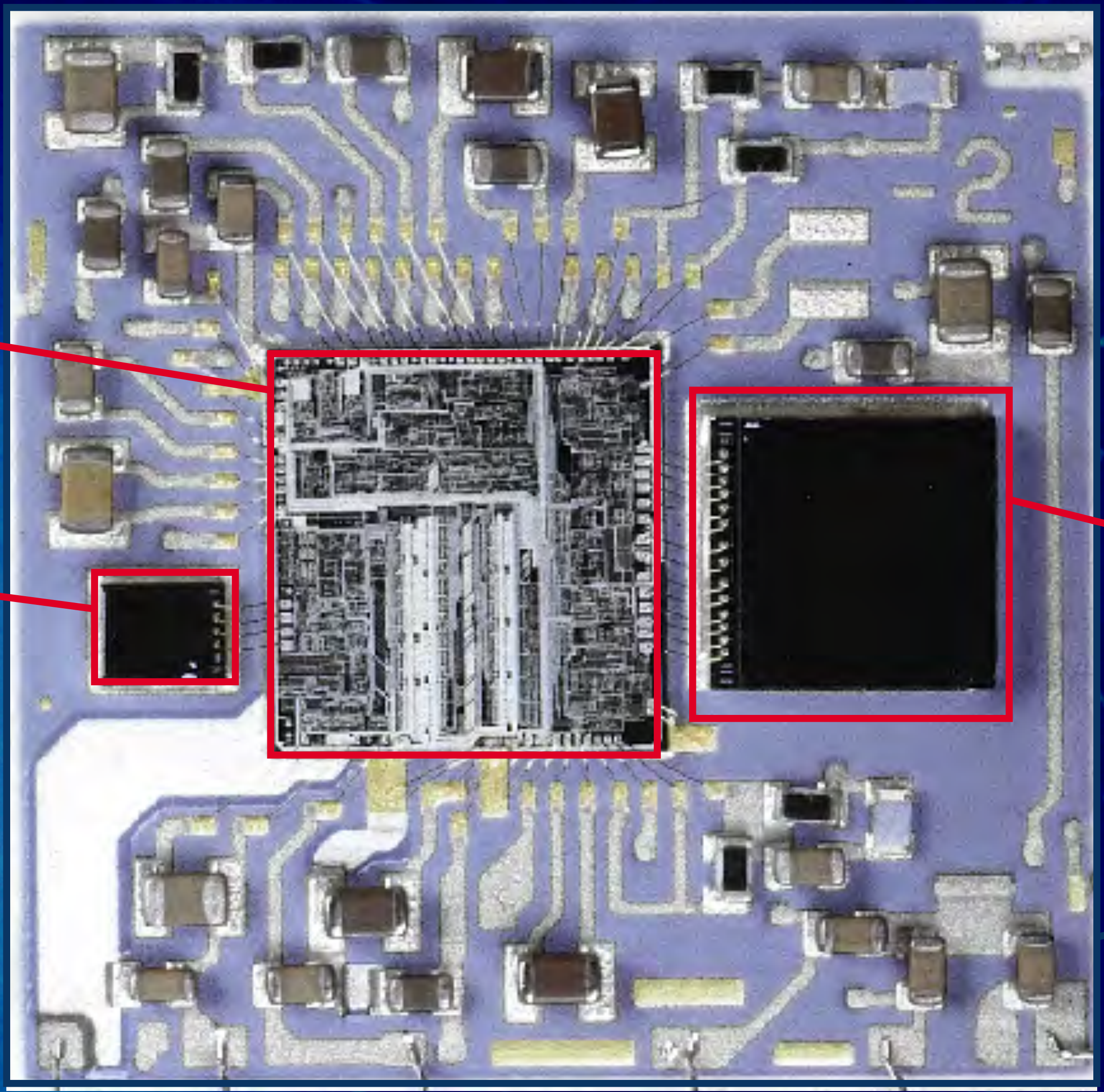
Implementation

- *System-On-Rack*
- *System-On-Board*
- *System-In-Package (SIP)*
- *System-On-Chip (SoC)*
- *System-On-Programmable Devices*

System-On-Rack

System-On-Board

System-In-Package (SIP)



ASIC (Signal Processing, Bus Control)

Micromechanical Acceleration Sensor

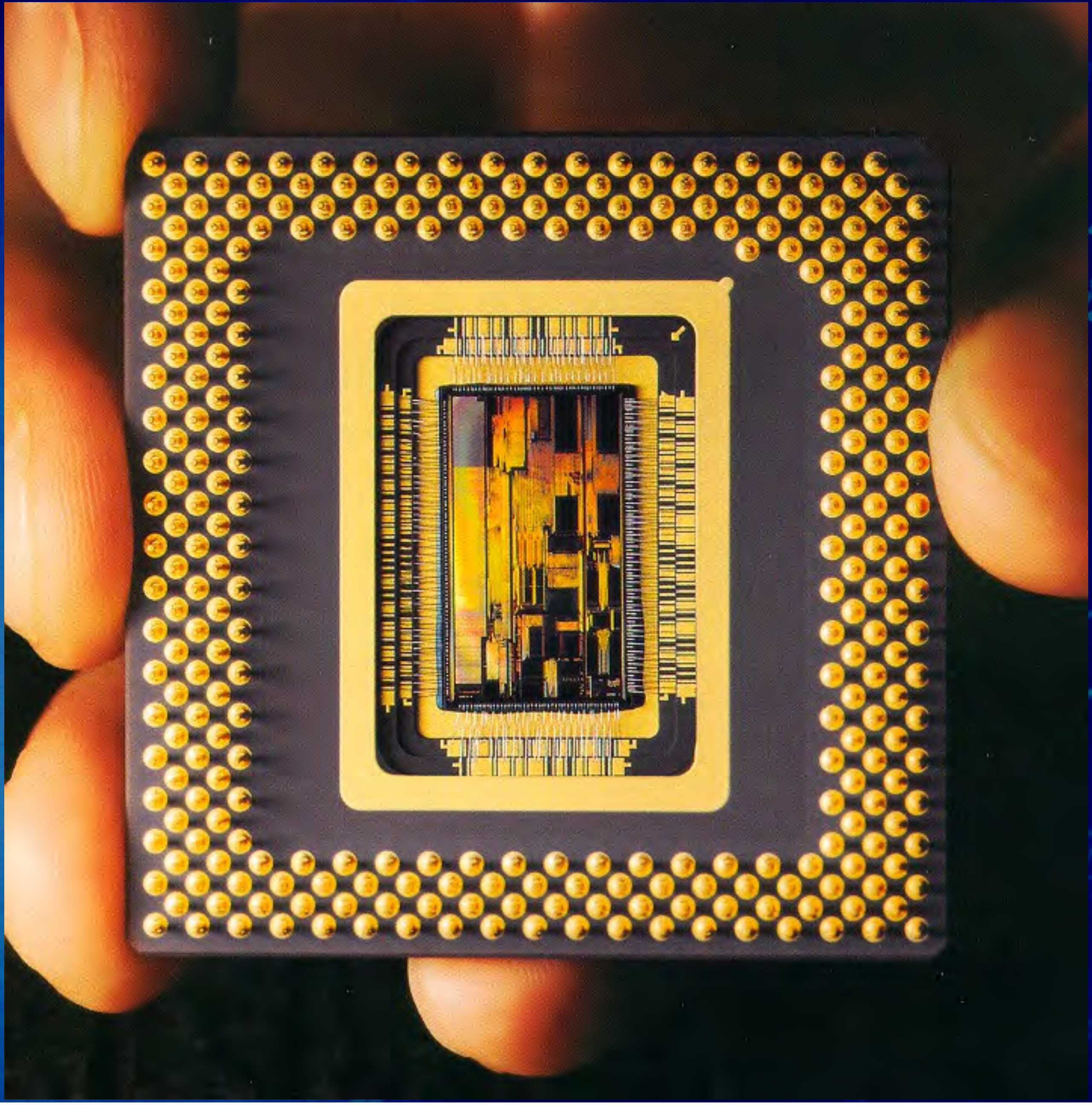
Micromech. Yaw Rate Sensor

Micro hybrid Carrier

ESP-Module

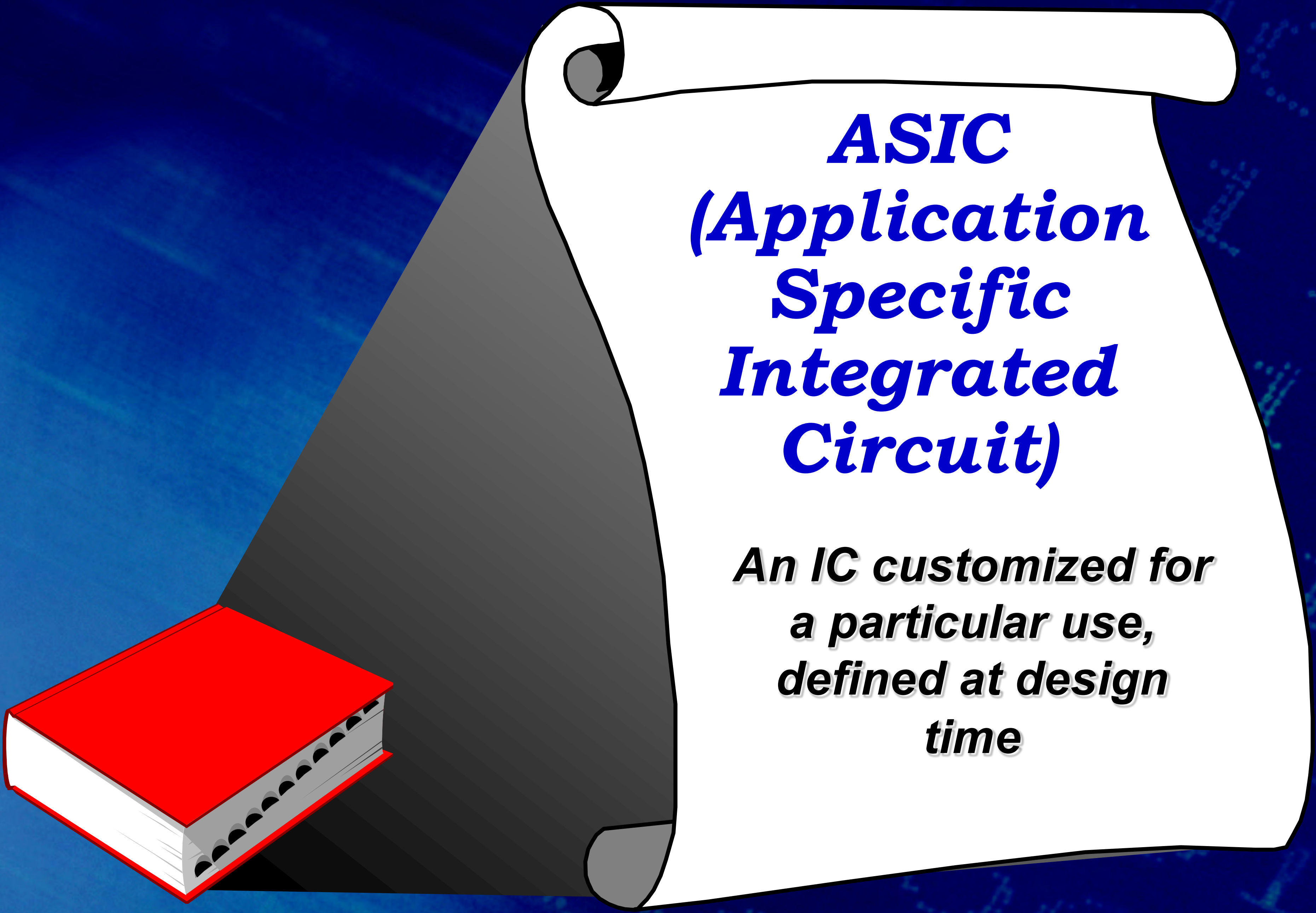
BOSCH

System-On-Chip (SoC)



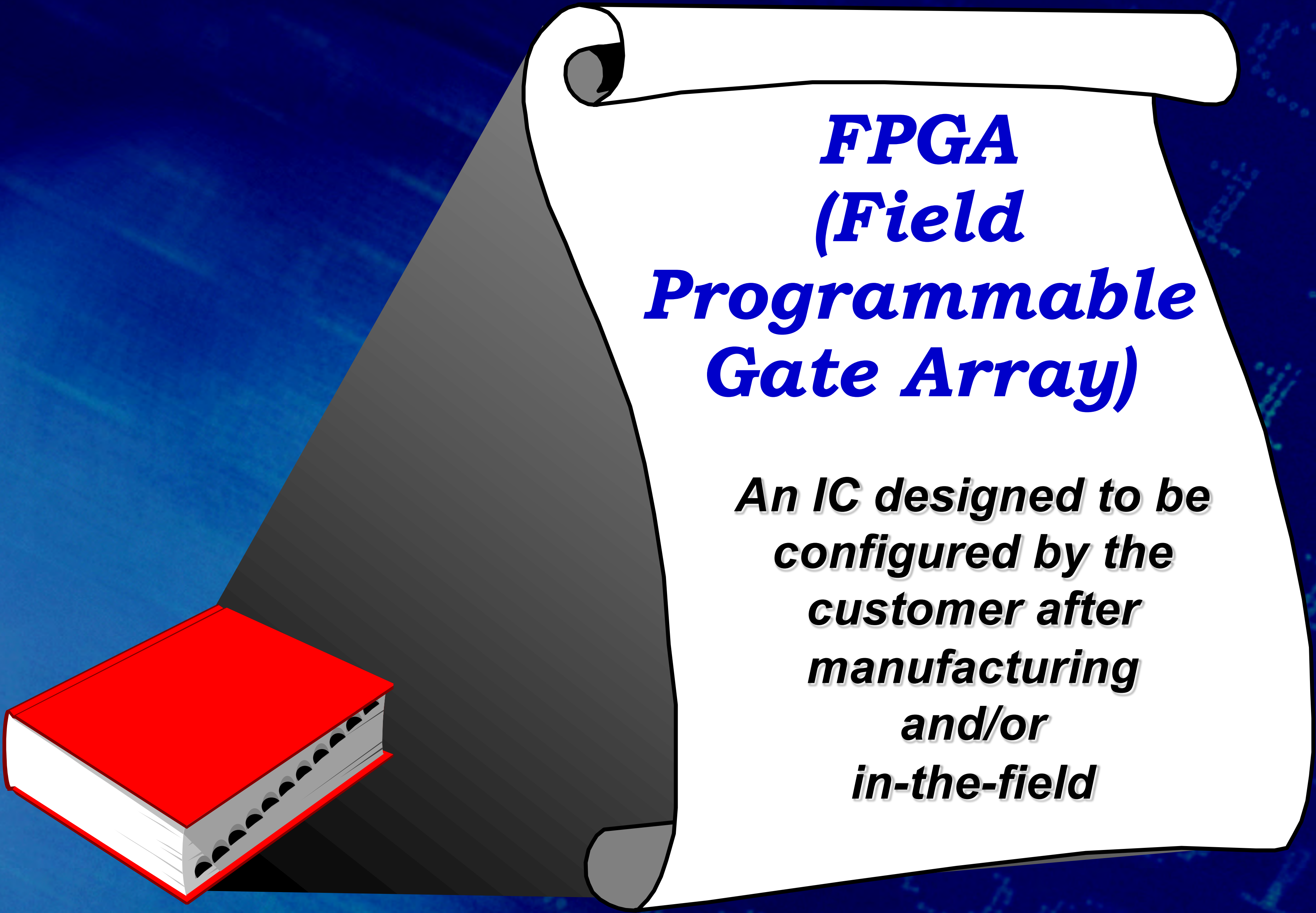
System-On-Programmable Devices

- **FPGA-based**



ASIC (Application Specific Integrated Circuit)

An IC customized for a particular use, defined at design time

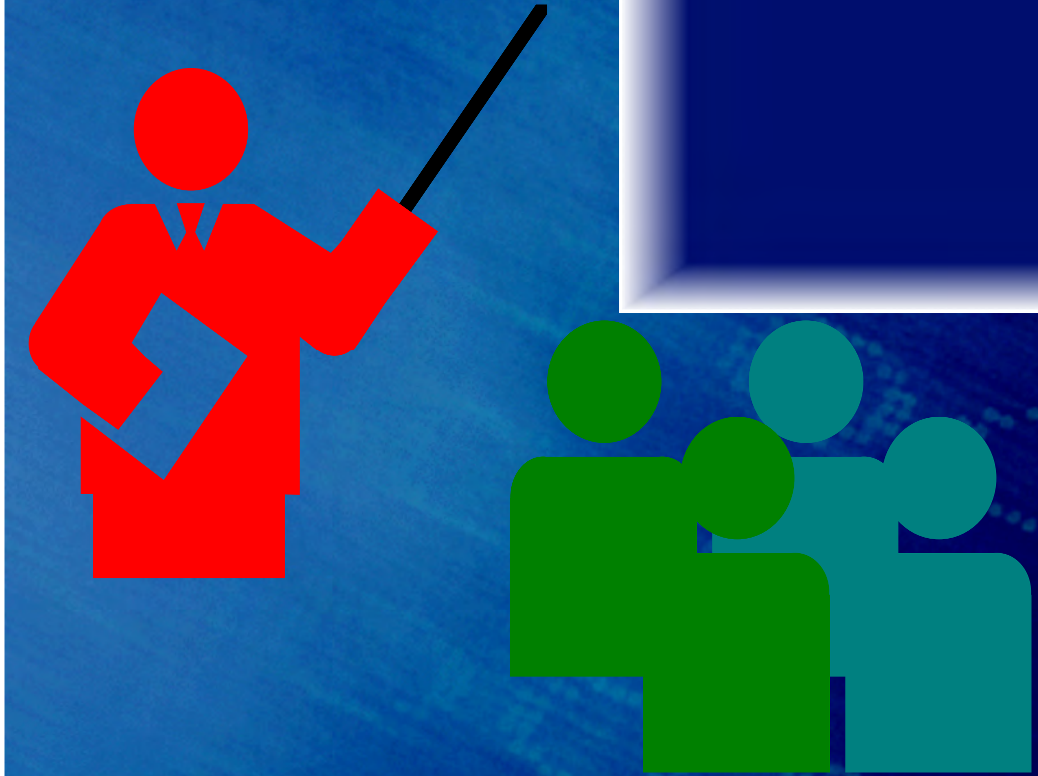


FPGA (Field Programmable Gate Array)

An IC designed to be configured by the customer after manufacturing and/or in-the-field

FPGA

They include logic gates,
RAM blocks, and DSPs
to implement any
complex digital computations



ASIC vs. FPGA

ASIC:

- High NRE costs
- No Flexibility
+ Very High speed
+ Low power

FPGA

+ Low NRE costs
+ In-field reconfigurable
- Up to 1 GHz
- Moderate power cons.

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Physical Dimensions & Market target

- *Supercomputer*
- *Server*
- *Desktop*
- *Mobile Systems*
- *Embedded Systems*

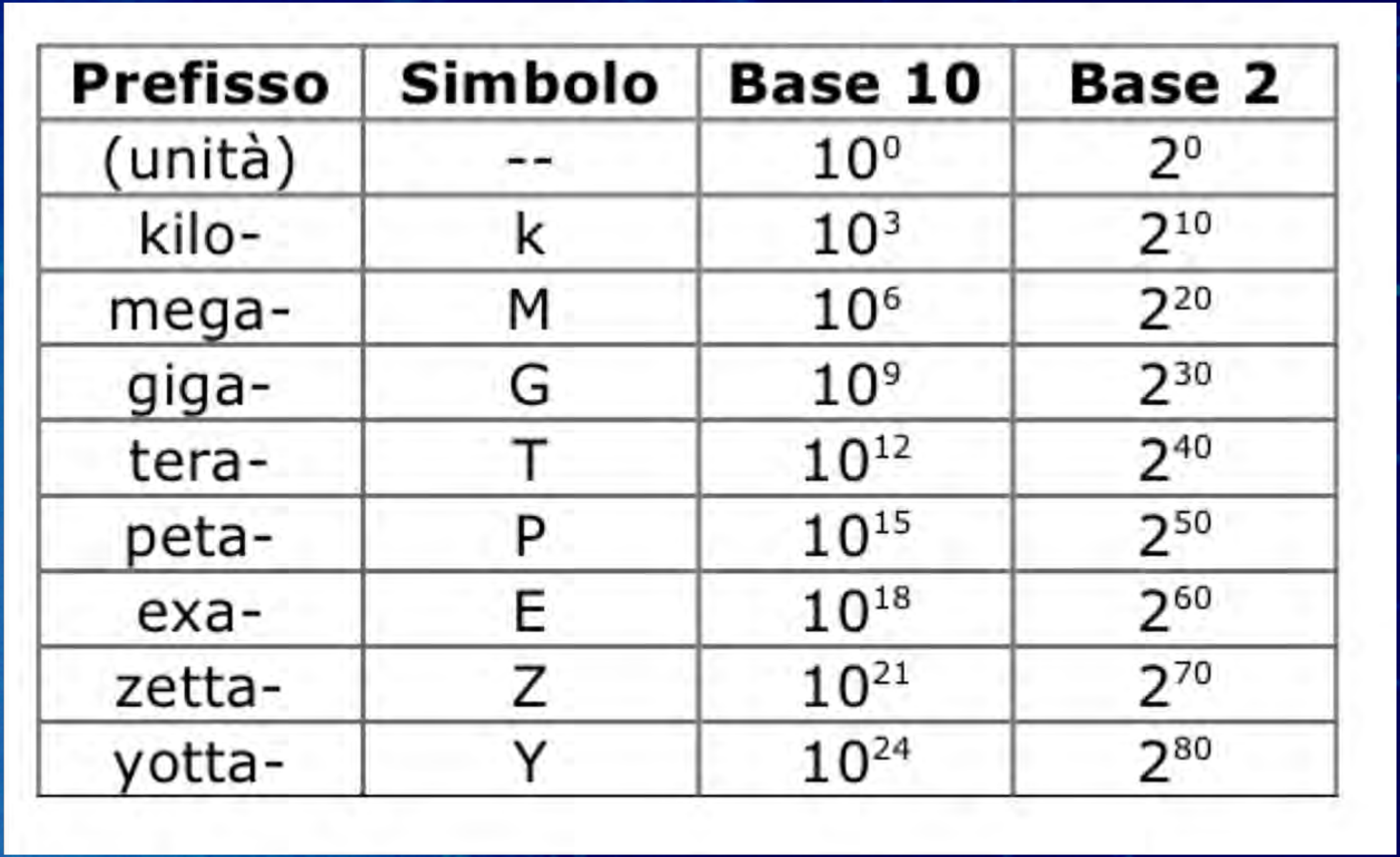
Supercomputers

– **High Performance Computing HPC**

Performances:

- **measured in terms of *Flop/s* (Floating Point Operations Per Second)**
- **Pflop/s (*Titan Cray XK7* & IBM Blue-Gene).**

Measuring Units



Prefisso	Simbolo	Base 10	Base 2
(unità)	--	10^0	2^0
kilo-	k	10^3	2^{10}
mega-	M	10^6	2^{20}
giga-	G	10^9	2^{30}
tera-	T	10^{12}	2^{40}
peta-	P	10^{15}	2^{50}
exa-	E	10^{18}	2^{60}
zetta-	Z	10^{21}	2^{70}
yotta-	Y	10^{24}	2^{80}

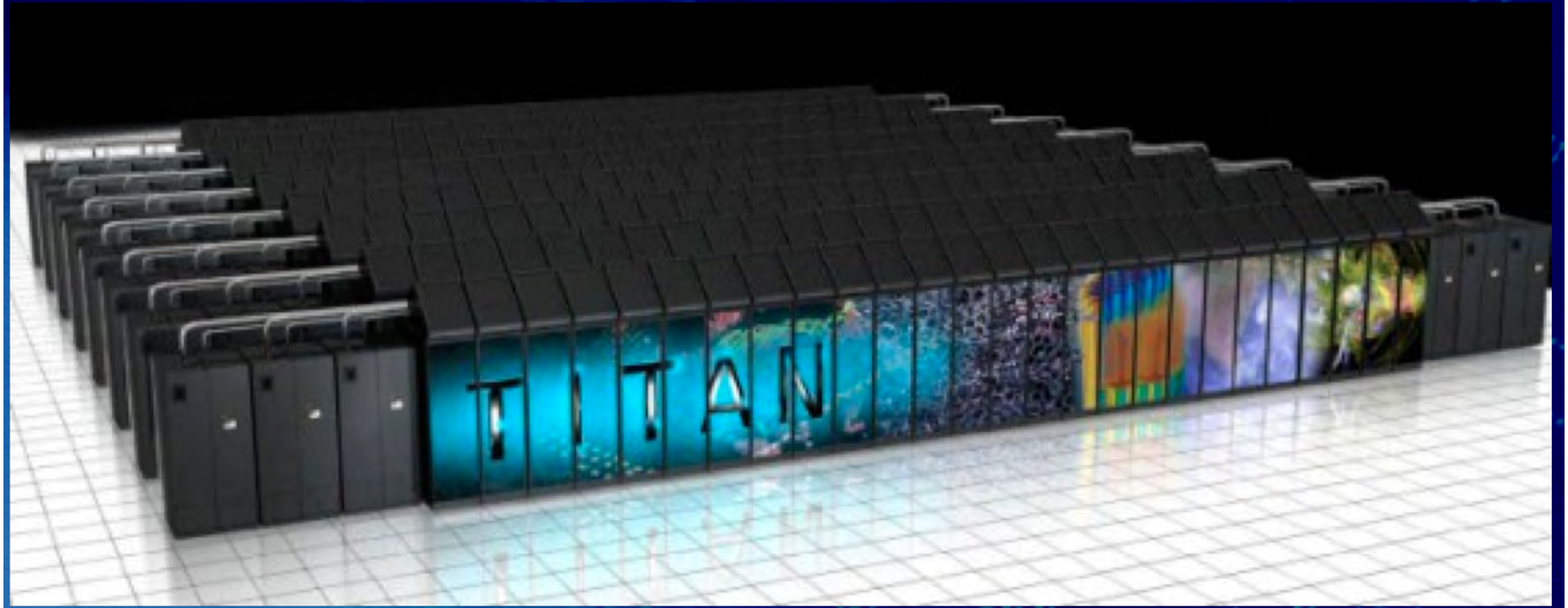
Tianhe-2 (MilkyWay-2)

Source: http://www.top500.org

Tianhe-2 (MilkyWay-2)

- **Developed by NUDT**
- **Installed at National Super Computer Center in Guangzhou (China)**
- **33.862 PFlop/s**
- **3,120,000 core**
- **Consumes 17.8 MW**
- **Total memory 1 PB**

Titan Cray XK7



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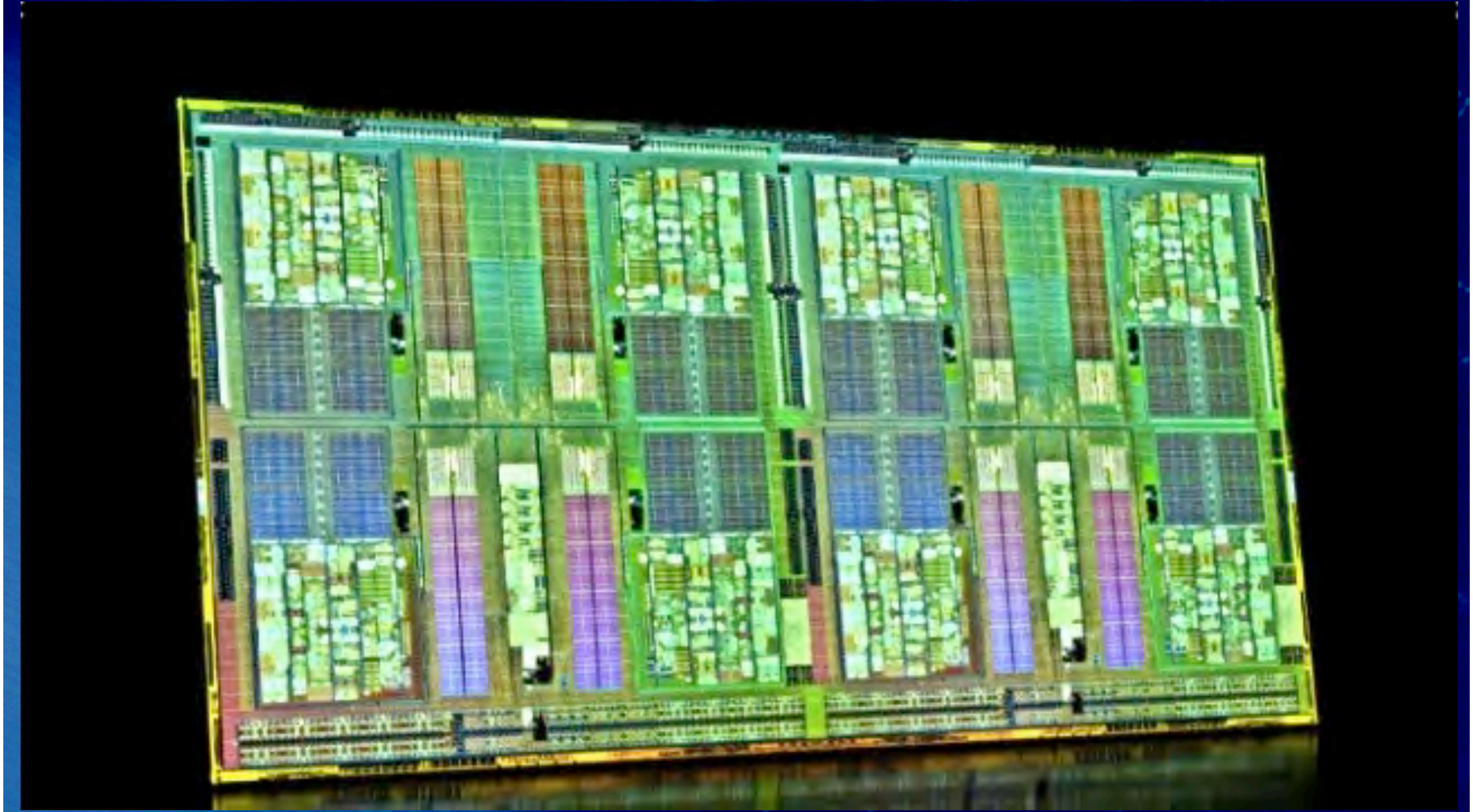


IBM Blue-Gene

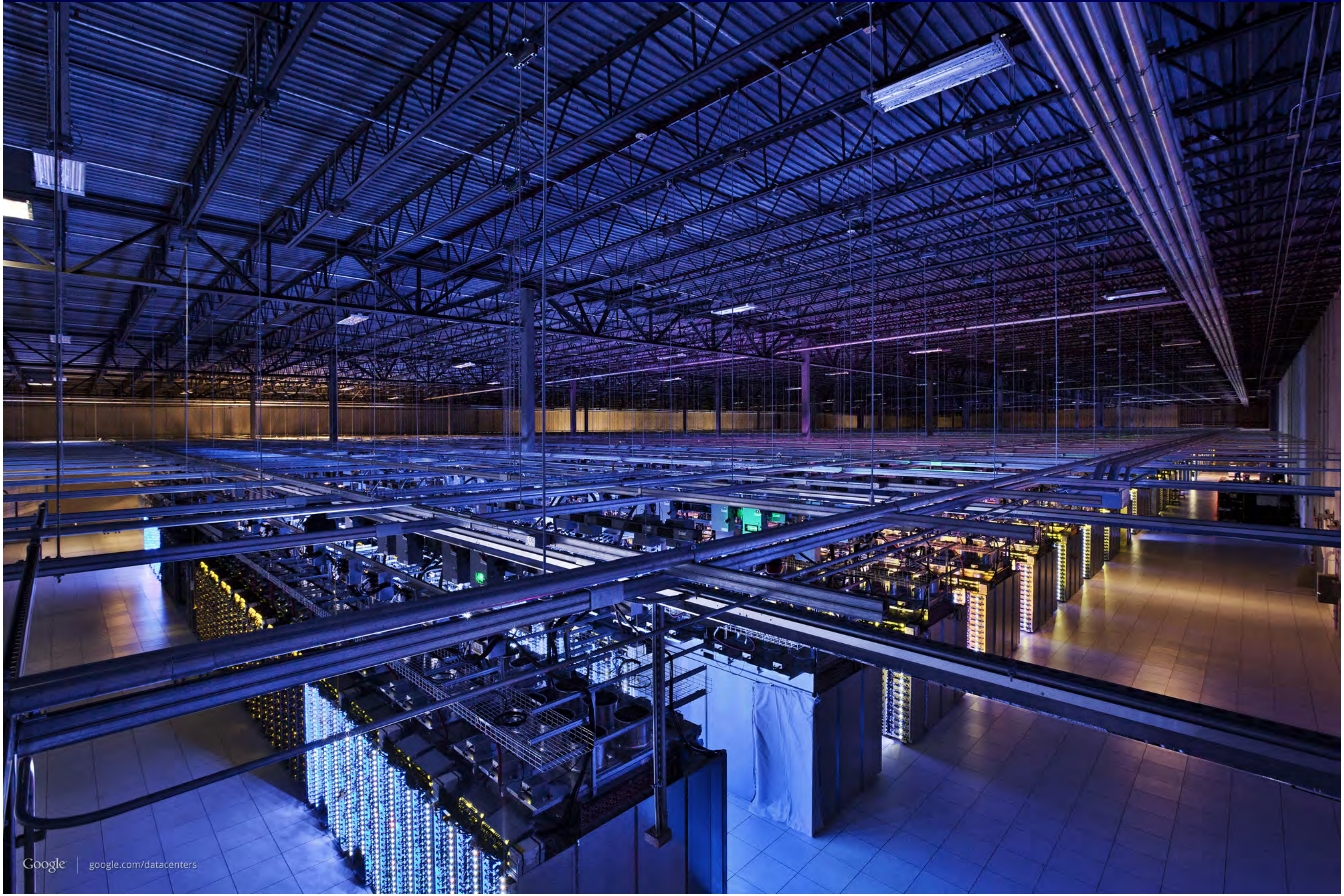
Physical Dimensions & Market target

- Supercomputer
- Server
- Desktop
- Mobile Systems
- Embedded Systems

Servers

Server Room

Google Data Center



Google | google.com/datacenters

Dropbox Diskotech

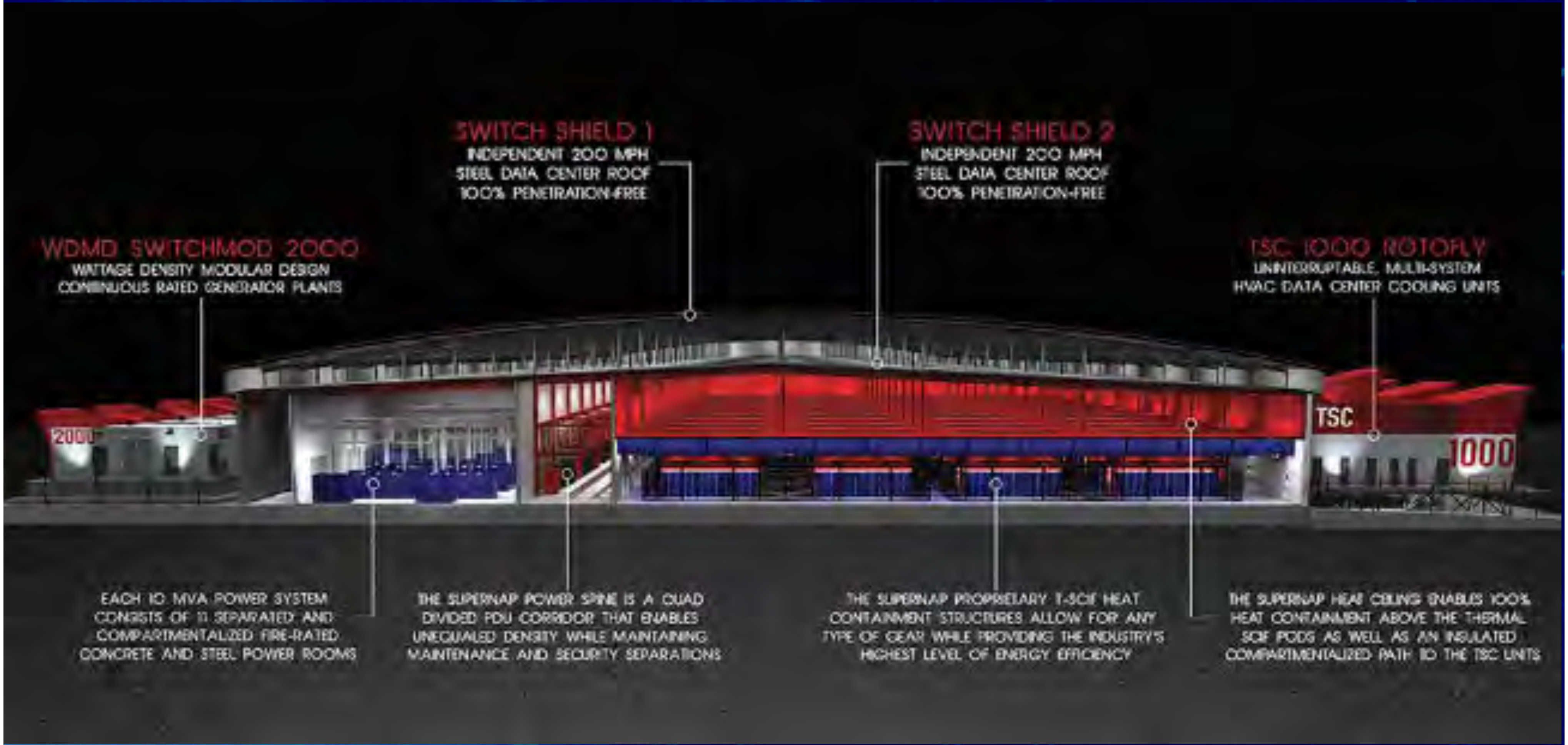
Dropbox Diskotech

- Measuring only 1.5 x 3.5 feet by 6 inches, each Diskotech box holds as much as a petabyte of data, or a million gigabytes
- Just 50 of these machines could store everything human beings have ever written.

Supernap.com

Supernap.com

Supernap.com



SWITCH SHIELD 1
INDEPENDENT 200 MPH
STEEL DATA CENTER ROOF
100% PENETRATION-FREE

SWITCH SHIELD 2
INDEPENDENT 200 MPH
STEEL DATA CENTER ROOF
100% PENETRATION-FREE

WDMD SWITCHMOD 2000
WATTAGE DENSITY MODULAR DESIGN
CONTINUOUS RATED GENERATOR PLANTS

TSC 1000 ROTOFLY
UNINTERRUPTABLE, MULTI-SYSTEM
HVAC DATA CENTER COOLING UNITS

EACH 10 MVA POWER SYSTEM CONSISTS OF 11 SEPARATED AND COMPARTMENTALIZED FIRE-RATED CONCRETE AND STEEL POWER ROOMS

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THE SUPERNAP PROPRIETARY T-SCIF HEAT CONTAINMENT STRUCTURES ALLOW FOR ANY TYPE OF GEAR WHILE PROVIDING THE INDUSTRY'S HIGHEST LEVEL OF ENERGY EFFICIENCY

THE SUPERNAP HEAT CEILING ENABLES 100% HEAT CONTAINMENT ABOVE THE THERMAL SCIF PODS AS WELL AS AN INSULATED COMPARTMENTALIZED PATH TO THE TSC UNITS

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Physical Dimensions & Market target

- *Supercomputer*
- *Server*
- ***Desktop***
- *Mobile Systems*
- *Embedded Systems*

Desktop

Physical Dimensions & Market target

- *Supercomputer*
- *Server*
- *Desktop*
- *Mobile Systems*
- *Embedded Systems*

Mobile Systems

Osborne 1 è un business computer così personal che vi segue dovunque. In ufficio, a casa e anche in aereo.

Quando l'uomo che ha scritto più di chiunque altro sui computer fa un personal computer, potete stare tranquilli che sarà una bomba. Prendete infatti Osborne, il primo personal business computer, si vede subito che ha qualcosa in più.

Per esempio ha molto peso in meno, funziona anche a batterie ed è veramente portatile, vale a dire che sta sotto il sedile in aereo. Ma vi dà una CPU Z80A, 64 Kbytes di memoria RAM ed ulteriore spazio per il software su ROM. Ci sono poi due drives per floppy disk da 5¼" per un totale di 204mila caratteri pari a 110 cartelle dattiloscritte (è disponibile anche la versione a doppia densità). I dischetti possono essere trasportati in uno speciale alloggiamento che ne può contenere fino a 24.

Osborne 1 comprende già un video da 5" ma può essere collegato con uno da 12" opzionale, l'interfacciamento è già predisposto, come è predisposto per ogni modello di stampante presente sul mercato e per il bus standard di strumentazione IEEE 488. Se lavorate con le parole, Osborne 1 è fornito con il programma Wordstar, che farà improvvisamente apparire ogni macchina da scrivere obsoleta, e con MailMerge potrete gestire anche l'archivio indirizzi. Se invece lavorate con i numeri, Supercalc è il programma, fornito gratuitamente, che vi permette di lavorare bene con le più complesse proiezioni ed i modelli di simulazione.

In tutto quello che fa, Osborne 1 è professionale. Usa il sistema operativo CP/M e due potenti linguaggi Basic Standard (MBASIC e CBASIC). Può essere usato con migliaia di software diversi e collegato a un grosso computer per avere accesso alle banche dati. E quando diciamo che Osborne 1 è leggero non ci riferiamo solo al peso, ma anche al prezzo: solo £. 3.490.350 (IVA esclusa) tutto, ma veramente tutto compreso.

OSBORNE 1

£. 3.490.350*
tutto compreso.
Proprio tutto.
Incluso £. 1.350.000
di software.

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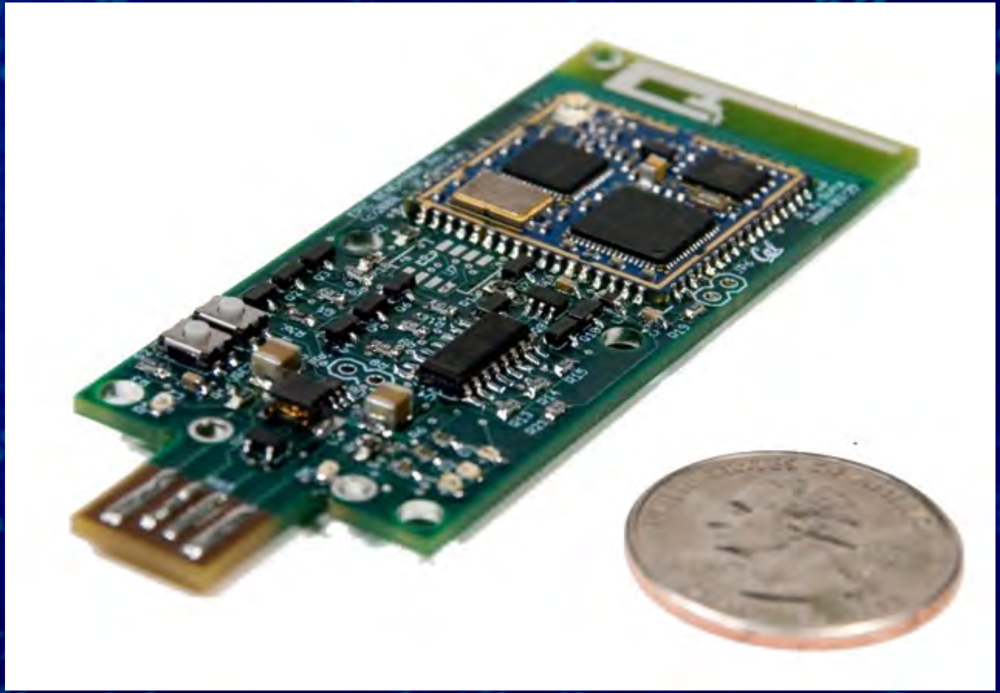
Mobile Systems

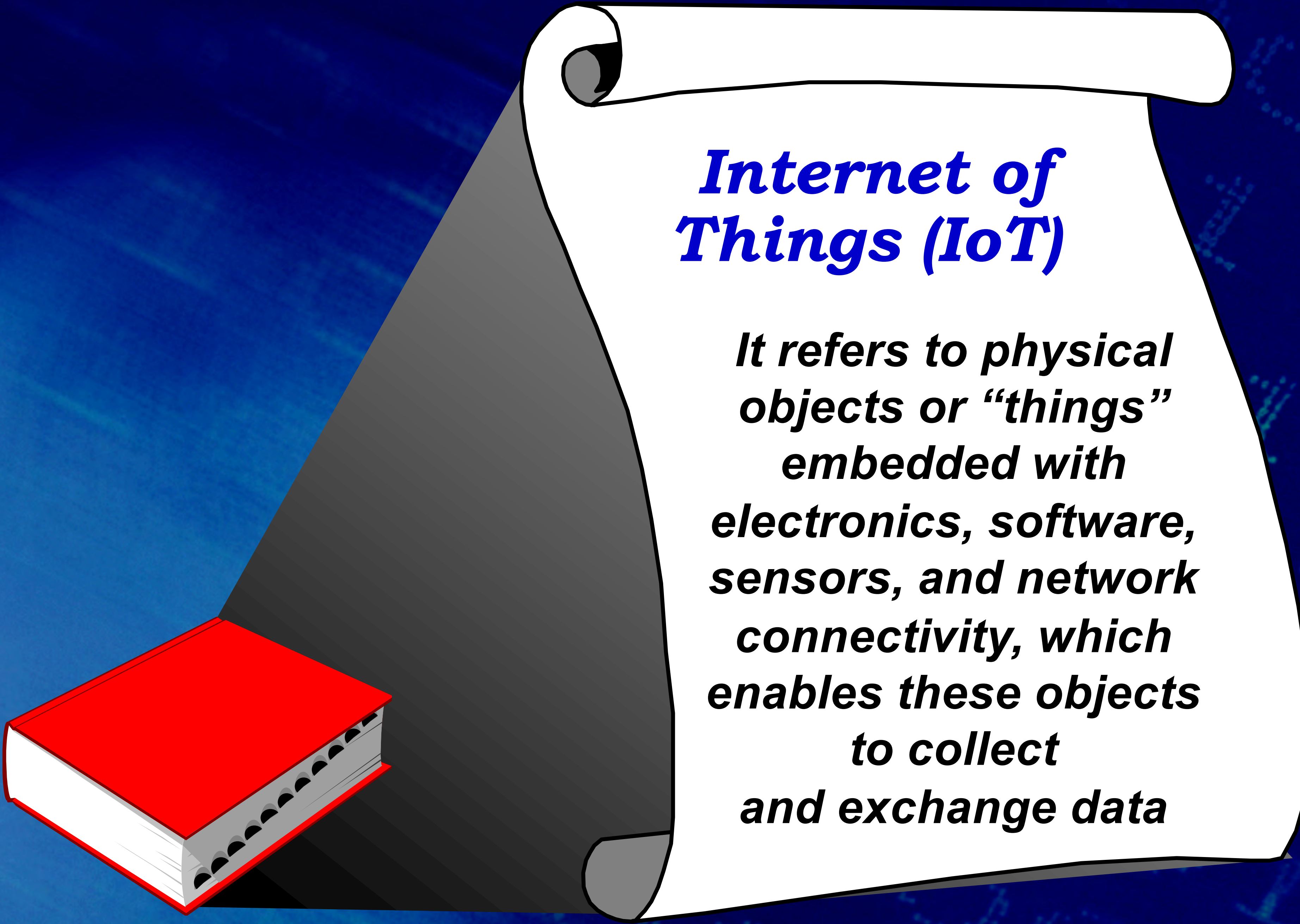
Physical Dimensions & Market target

- Supercomputer
- Server
- Desktop
- Mobile Systems
- **Embedded Systems**

Embedded Systems

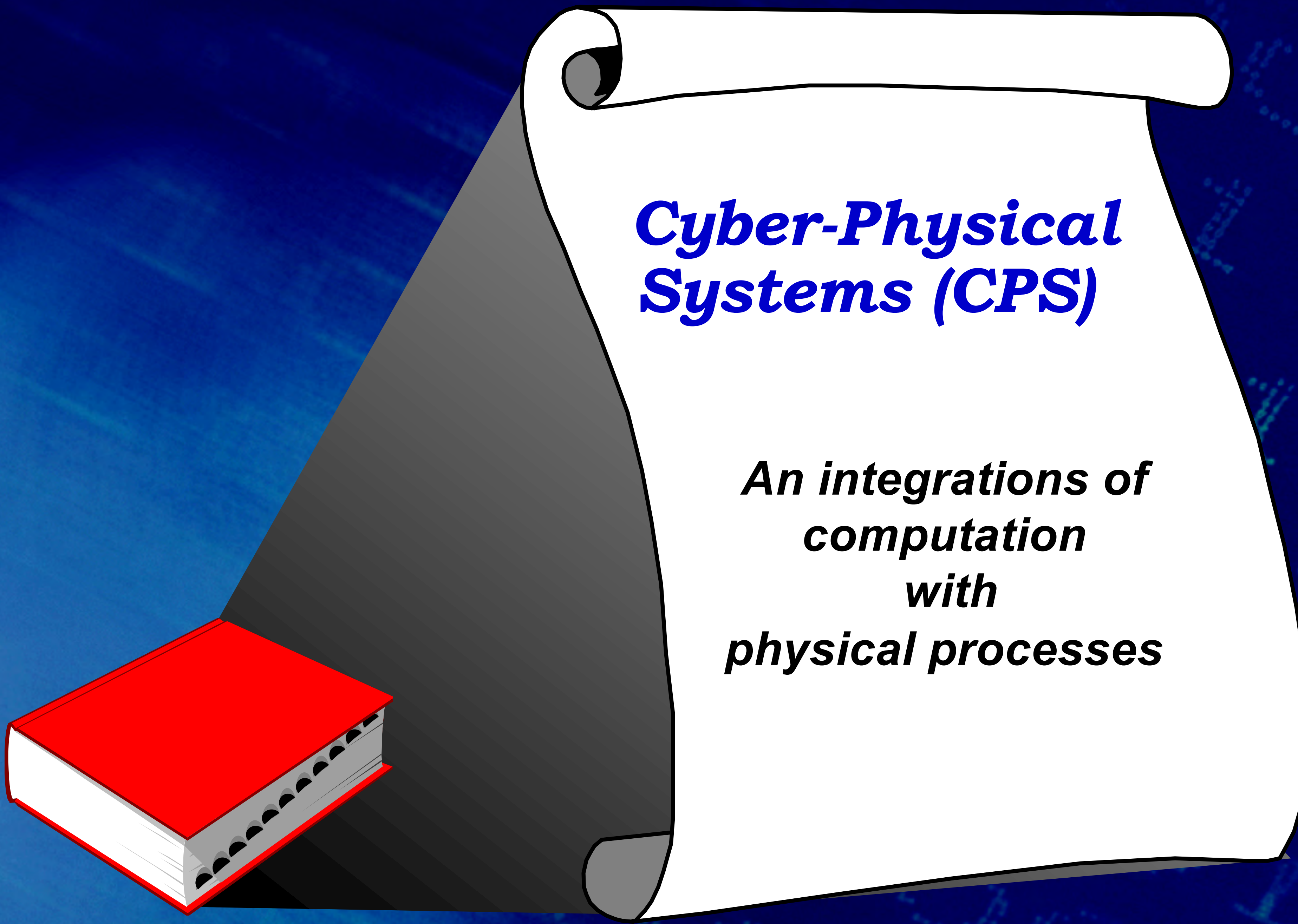
- System *Embedded* (hidden) into other systems, devices, machines, tools
- Not perceived as processors by the end-users





Internet of Things (IoT)

It refers to physical objects or “things” embedded with electronics, software, sensors, and network connectivity, which enables these objects to collect and exchange data



Cyber-Physical Systems (CPS)

An integrations of computation with physical processes

Water supply systems

Cyber Physical System

Water supply systems

Real-time monitoring and control, addition of fewer chemicals, accident prevention, faster response to contamination or other events, better leak detection to minimize losses, safer and more secure water that costs less

Water supply systems

SCADA

Supervisory Control And Data Acquisition

Aqueduct

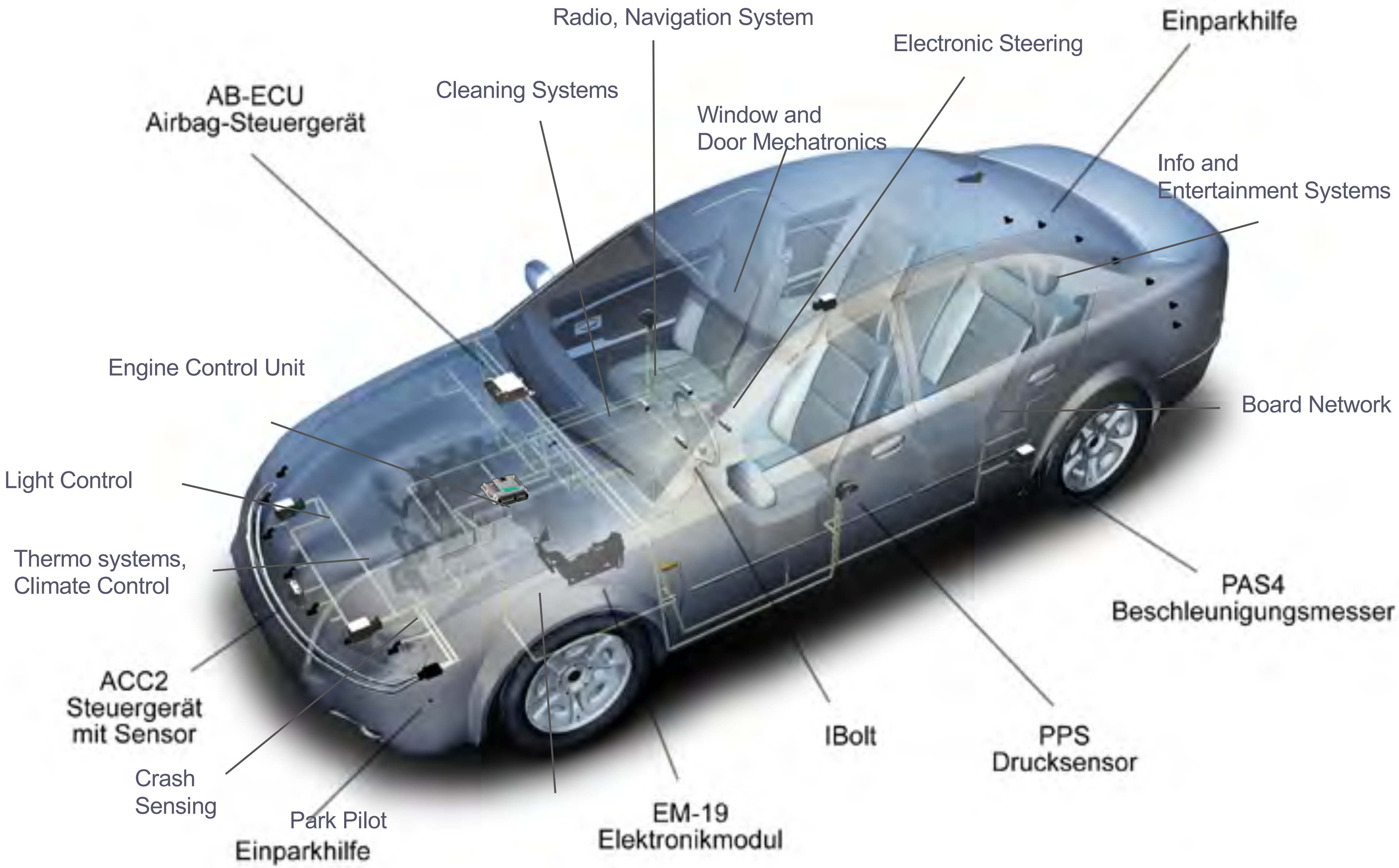
Water Treatment Facility

Pump Station-Distribution

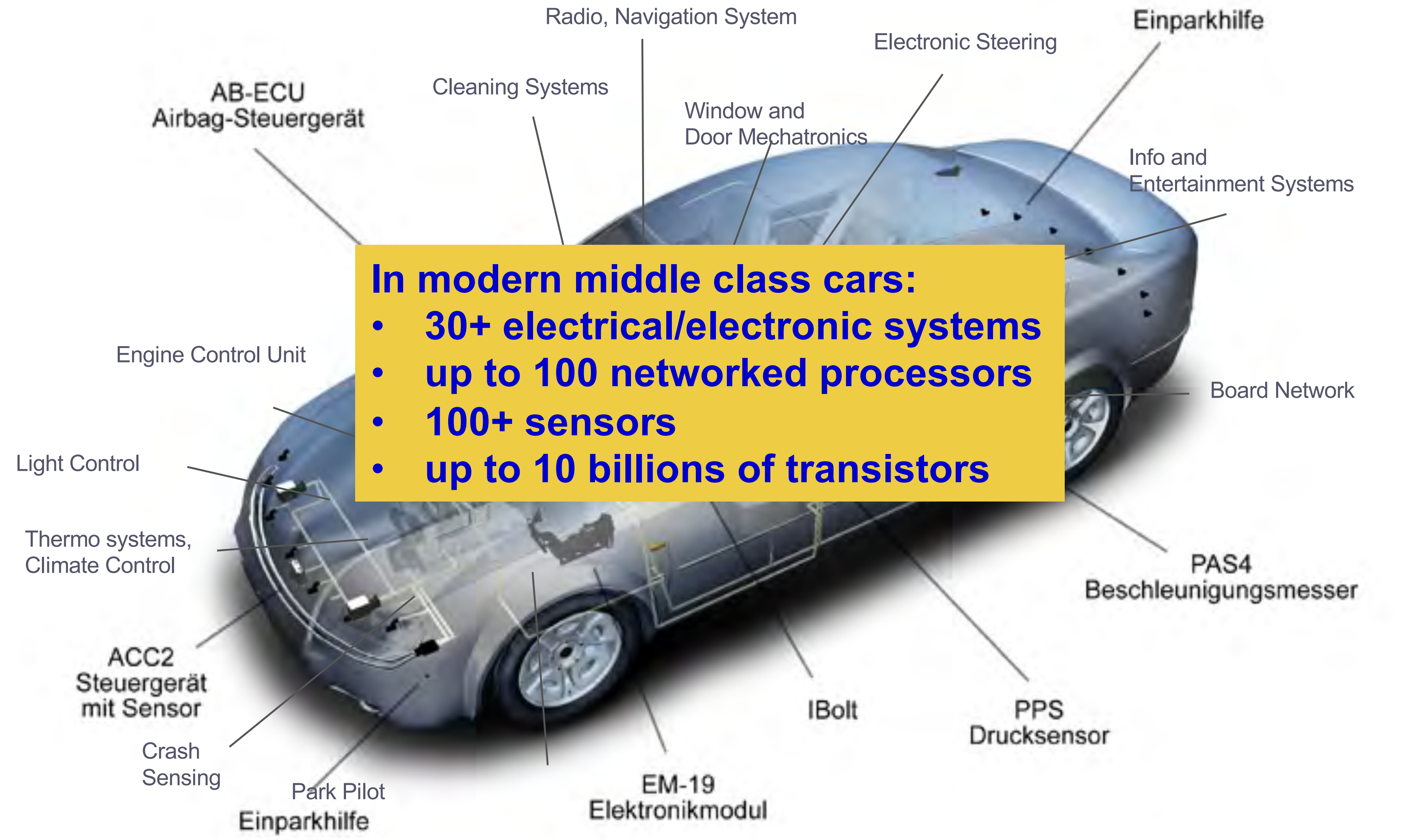
Water Distribution

Result

Real-time monitoring and control, addition of fewer chemicals, accident prevention, faster response to contamination or other events, better leak detection to minimize losses, safer and more secure water that costs less



Automotive Electronics



In modern middle class cars:

- **30+ electrical/electronic systems**
- **up to 100 networked processors**
- **100+ sensors**
- **up to 10 billions of transistors**

Outline

- System Taxonomies
- **Different view points**

Different view points

- System Designer
- Hardware Designer
- Assembler level programmer
- High level language programmer
- Computer user
- End user

Different view points

- ***System Designer:***

  Looks at the system as an interconnection of Sub-Systems

Different view points

- ***Hardware Designer:***

  Looks at the system as an interconnection of Components

Different view points

- *Assembler level programmer:*

  Looks at the system as an interconnection functional units, capable of executing the machine instructions defined by the Instruction Set Architecture (ISA)

Different view points

- *High level language programmer:*

  Looks at the system as a Virtual machine, capable of executing the instructions defined by the adopted programming language

Different view points

– *Computer user:*

  Looks at the system as:

  - **a *Service Provider* (e.g. the ones provided the application she/he is using)**
  - **a *Command Interpreter* (e.g., the ones provided the Operating System she/he is interacting with)**

Different view points

- *End user:*

  Even doesn’t realize she/he is interacting with a Processing Element (e.g., all the Embedded Systems Users)

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