Embedded Systems, Memory Systems, and Embedded Memory Systems

Prof. Bruce Jacob
Electrical & Computer Engineering
University of Maryland at College Park
USA

Yesterday's high-performance technologies
are today's embedded technologies,
but yesterday's embedded-systems ***issues***
are today's high-performance ***issues***

Ankush Varma, U. Maryland PhD 2007 (Intel)

Four-Day Overview

1. Embedded Systems

2. Memory Systems

3. Memory Systems, cont'd
   (DRAM Systems detail if time)

4. Embedded Memory Systems

Part I. Embedded Systems

Today's Story

- **What are embedded systems?**
  (more than just processor and/or software)

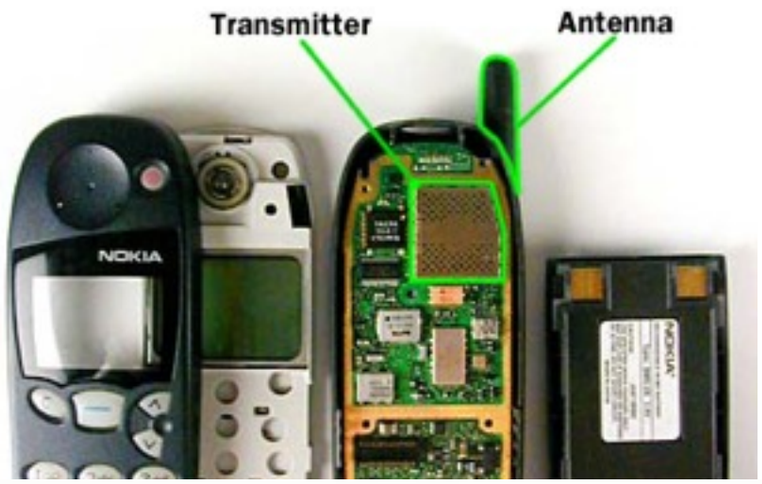
- **What is the main problem?**
  (difficult to verify that they work correctly)

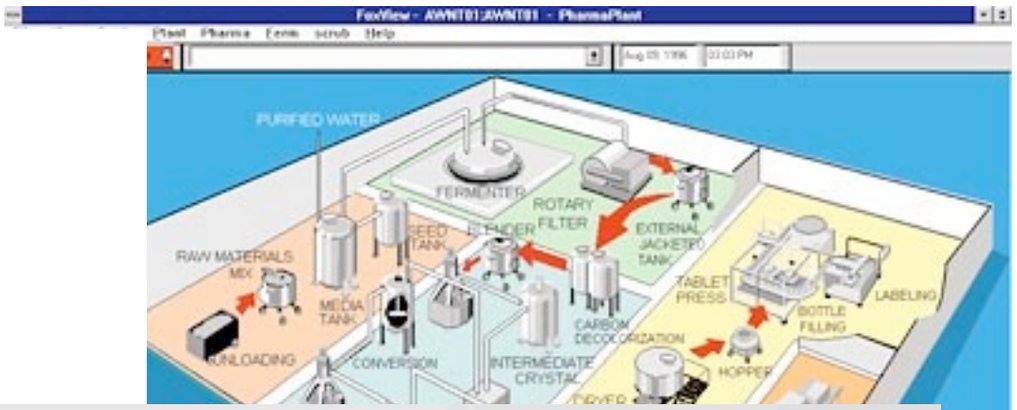
- **Why has it become a problem?**
  (now in the era of non-classical systems)

- **What is/are the solution/s? :)**

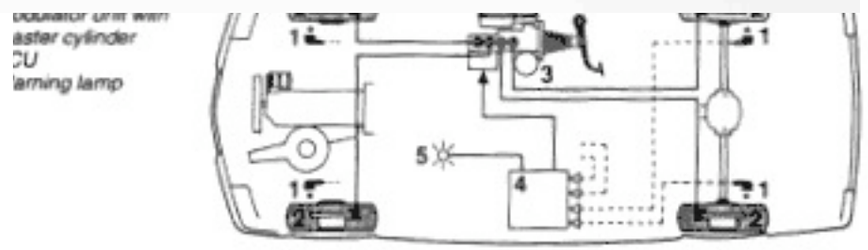
Perspective

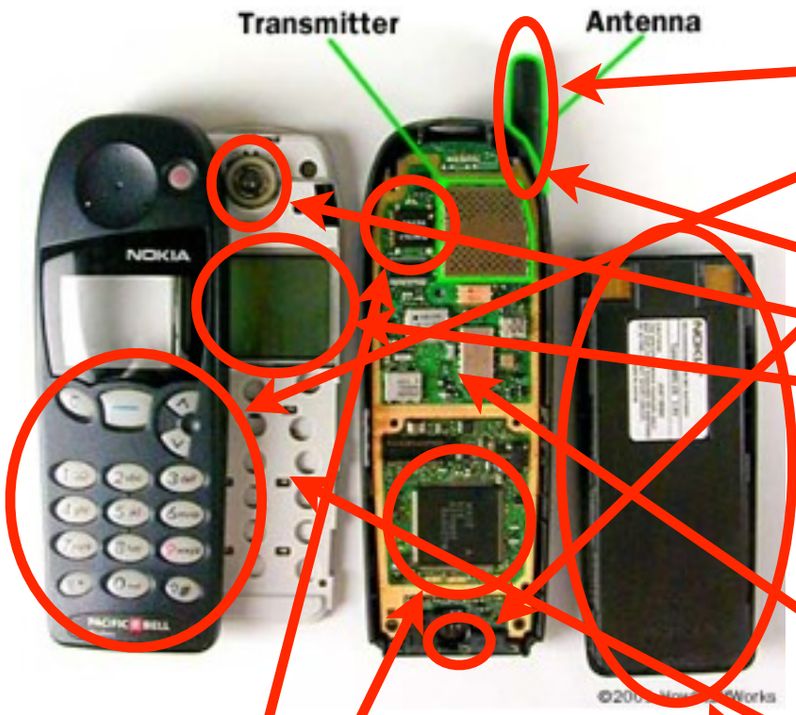
- High-Performance Design Space (yesterday): Performance
- High-Performance Design Space (today): Performance and Power
- Embedded-System Design Space:
  Correctness of design,
  Predictability,
  Reliability,
  Power Dissipation,
  Size,
  Cost,
  …
  Performance





EMBEDDED SYSTEMS





Sensor/s
(Multi-Mode)

Actuator/s
(Multi-Mode)

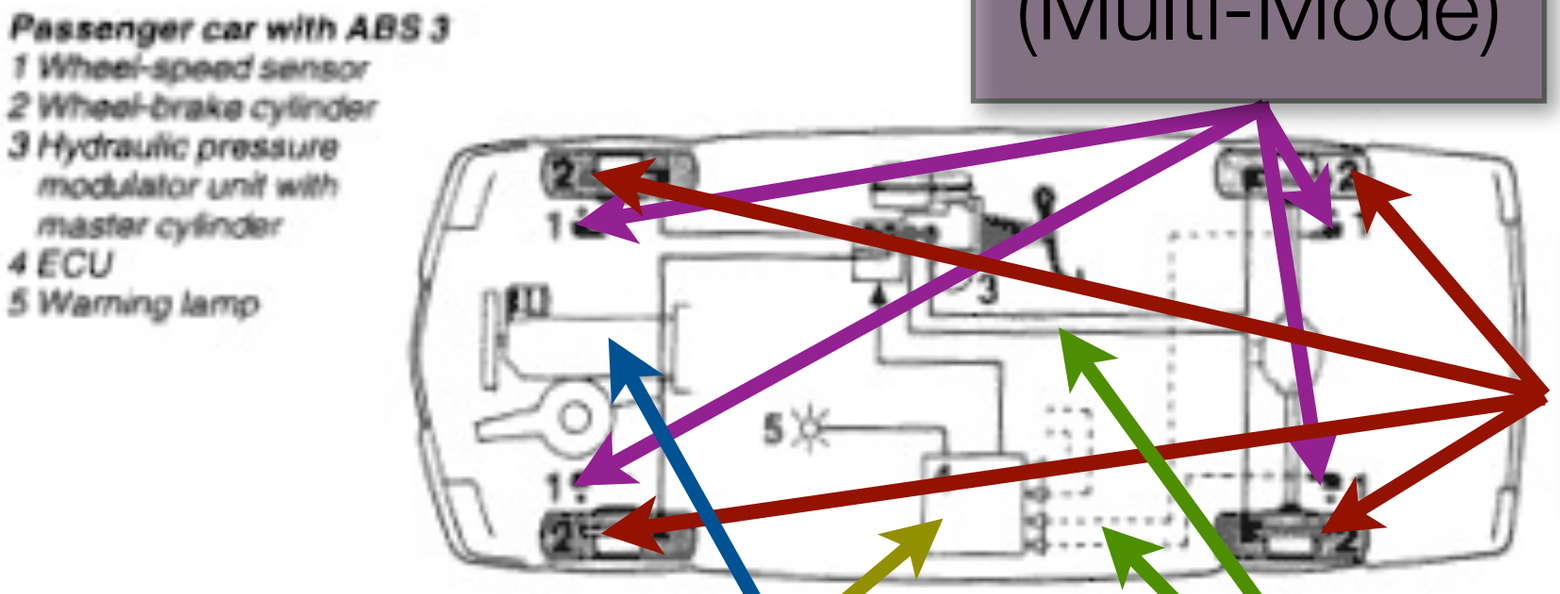
A DISSECTION

Microprocessor/s
and dedicated
software

Power Supply
(Self-Sufficient)

Communication
Network/s
(Multi-Mode)

Sensor/s
(Multi-Mode)



Actuator/s
(Multi-Mode)

A DISSECTION

Microprocessor/s
and dedicated
software

Power Supply
(Self-Sufficient)

Communication
Network/s
(Multi-Mode)

Characteristics

- Dedicated function (not general-purpose)
- Interact with environment (real-time)
- Resource-constrained (power, space, cost)
- Safety-critical (loss of life, property, etc.)
- Increasing pressure on time-to-market

THIS IS A BAD MIX

Examples Abound …

REUTERS NEWS AND FINANCIAL INTELLIGENCE FROM THE WORLD LEADER

TOP NEWS

Official Trapped in Car After Computer Fails

Mon May 12, 2003 09:44 AM ET

BANGKOK (Reuters) - Security guards smashed their way into an official limousine with sledgehammers on Monday to rescue Thailand's finance minister after his car's computer failed.

Suchart Jaovisidha and his driver were trapped inside the BMW for more than 10 minutes before guards broke a window. All doors and windows had locked automatically when the computer crashed, and the air-conditioning stopped, officials said.

'We could hardly breathe for over 10 minutes,' Suchart told reporters. 'It took my guard a long time to realize that we really wanted the window smashed so that we could crawl out. It was a harrowing experience.'

Examples Abound ...

Microsoft

PressPass · Information for Journalists

Microsoft Technology Hits the Road in BMW 7 Series

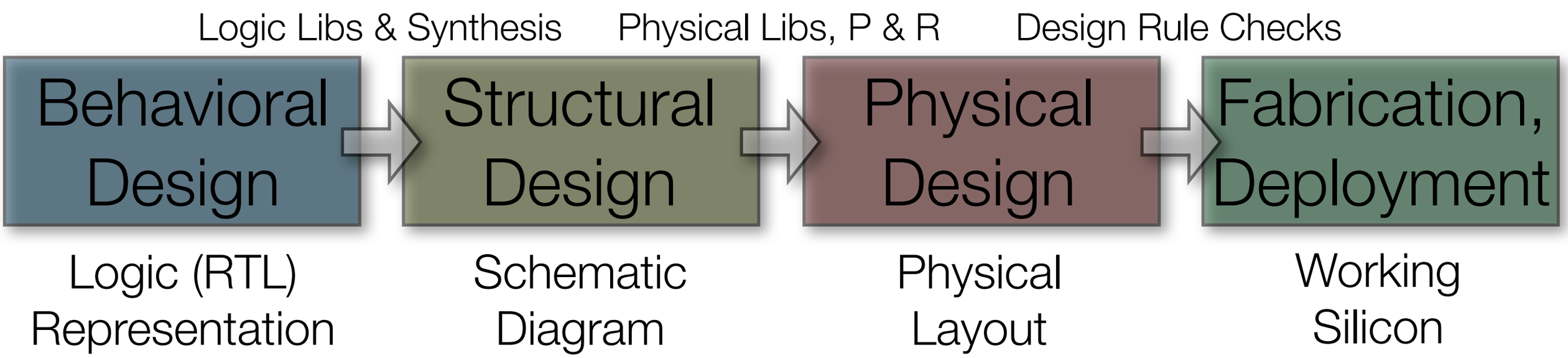
Microsoft Navigates the Automotive Industry, Enhances the Driver Experience

REDMOND, Wash. -- March 4, 2002

THE PROBLEM

COMPONENTS MAY BE VERIFIABLE,
BUT THE SYSTEM IS NOT

A Tale of Two Design Flows



VLSI Design Flow:
characterized by strict design rules, verifiable physical design

A Tale of Two Design Flows

Logic Libs & Synthesis

Physical Libs, P & R

Design Rule Checks

Behavioral Design

Structural Design

Physical Design

Fabrication, Deployment

Logic (RTL) Representation

```
module fibonacci(clk2, rst_l, out_w);

input clk2, rst_l;
output  [7:0] out_w;

reg     [7:0] src1, out;
wire    [7:0] out_w = out;

always @(posedge clk2)
begin
        if(!rst_l)

        begin
                src1 <= 1'd0;
                  out <= 1'd1;
        end
        else
        begin
                src1 <= out_w;
                out <= src1 + out_w;
        end
end

endmodule
```

A Tale of Two Design Flows

Logic Libs & Synthesis

Physical Libs, P & R

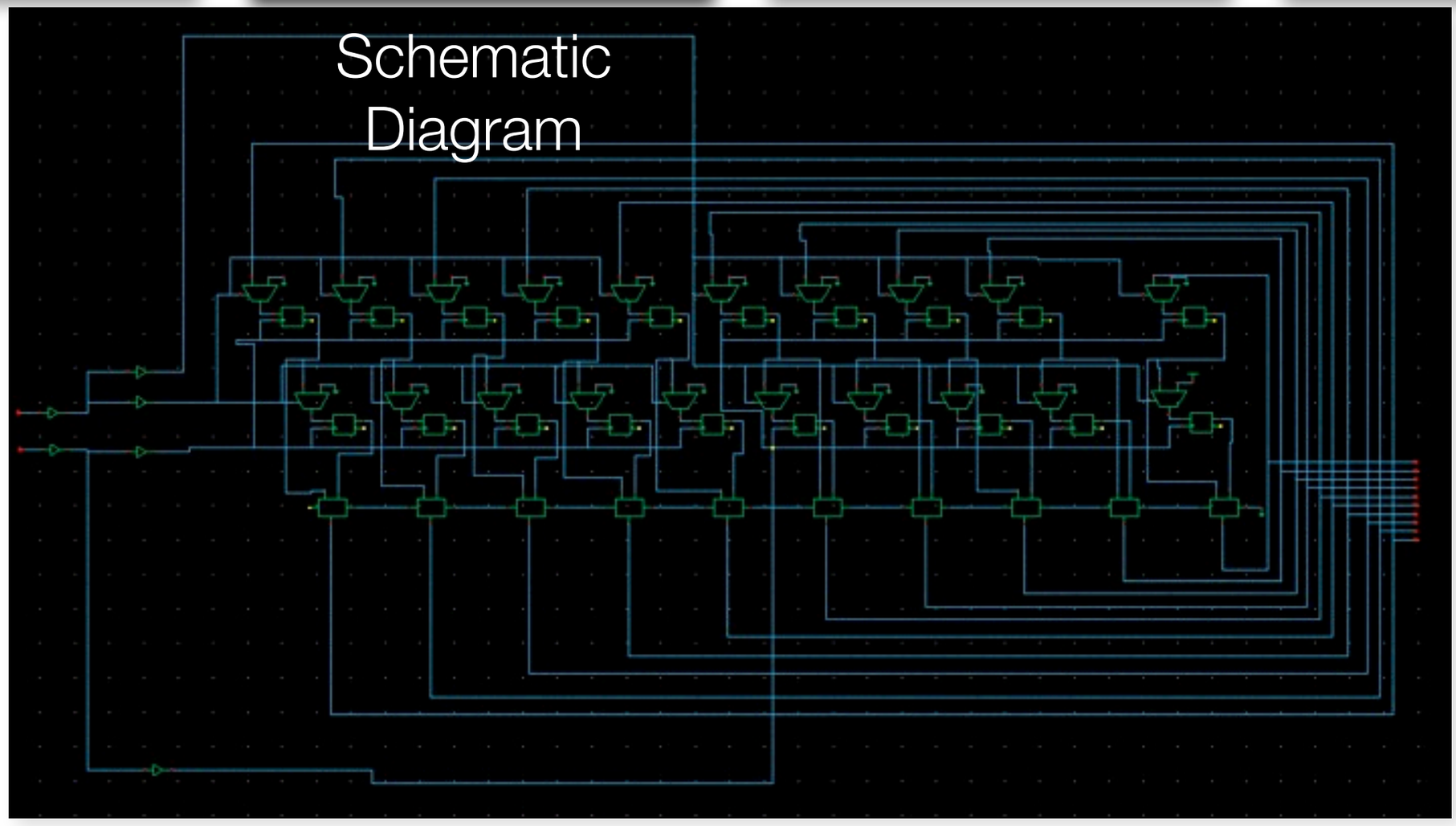
Design Rule Checks

Behavioral Design

Structural Design

Physical Design

Fabrication, Deployment



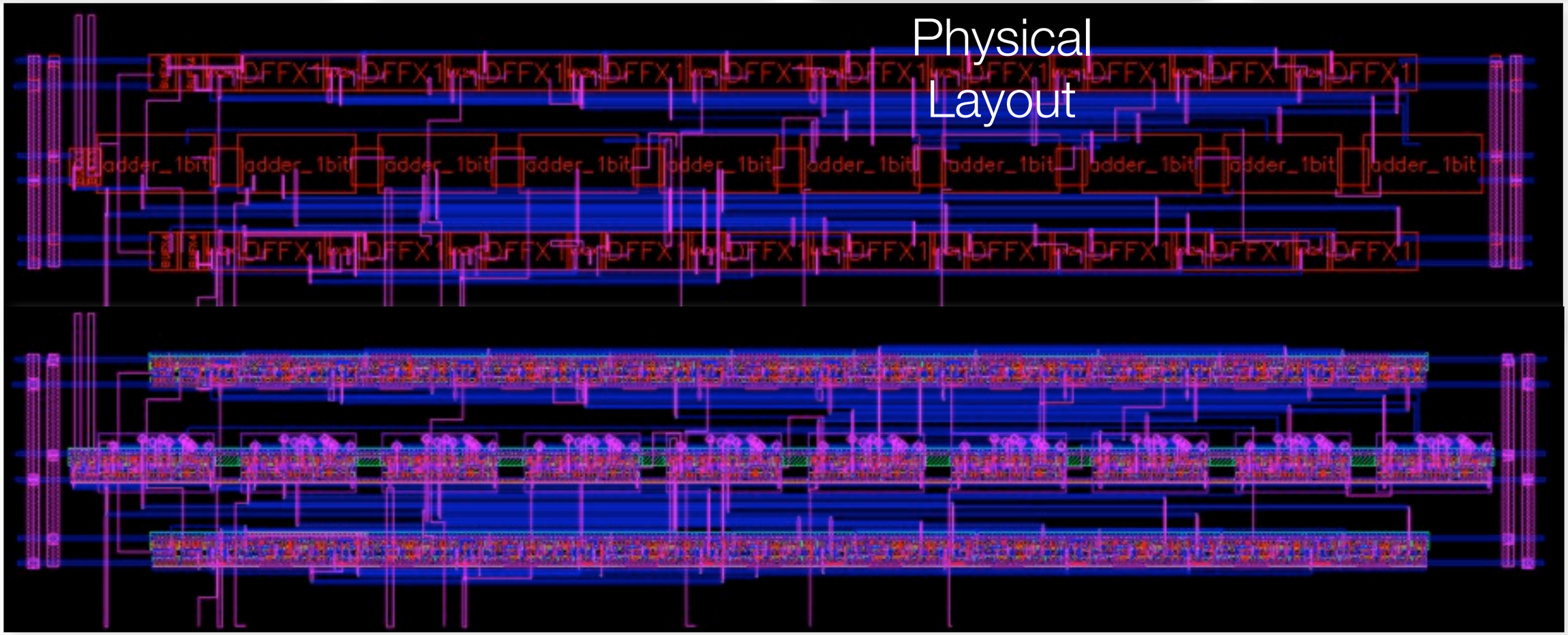
A Tale of Two Design Flows

Logic Libs & Synthesis

Physical Libs, P & R

Design Rule Checks

Behavioral Design → Structural Design → **Physical Design** → Fabrication, Deployment



A Tale of Two Design Flows

Logic Libs & Synthesis

Physical Libs, P & R

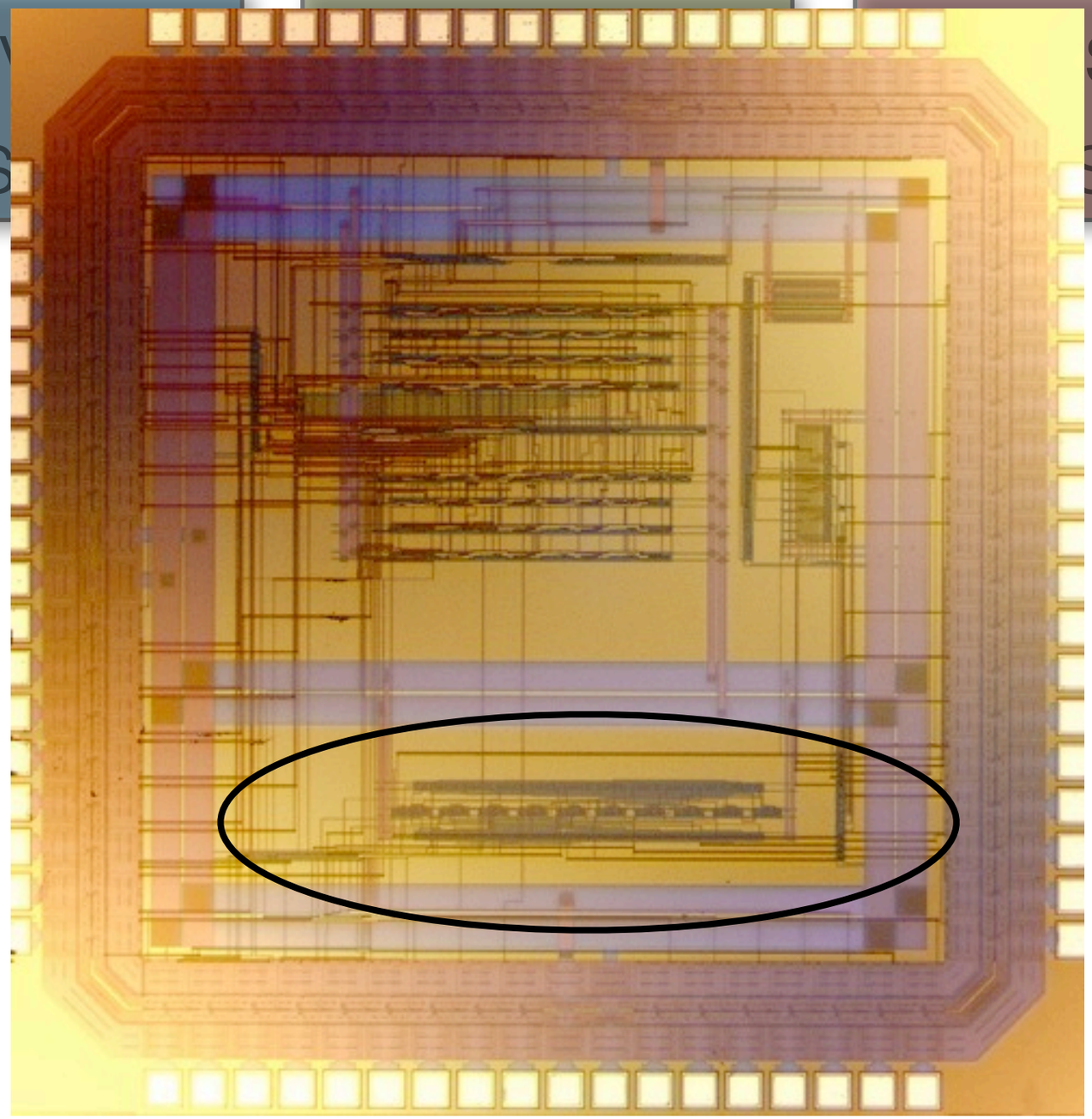
Design Rule Checks

Behav

Des

sical

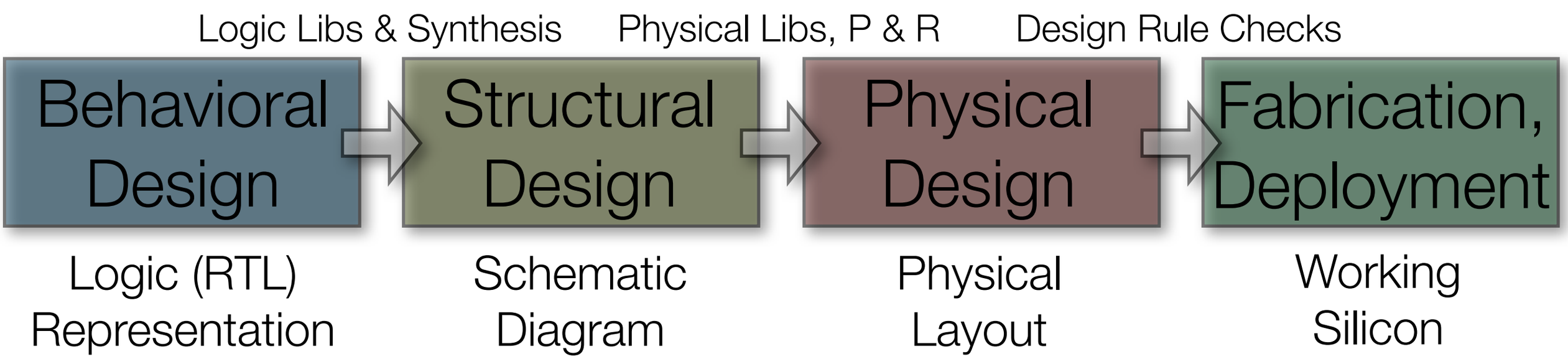
sign



Fabrication, Deployment

Working Silicon

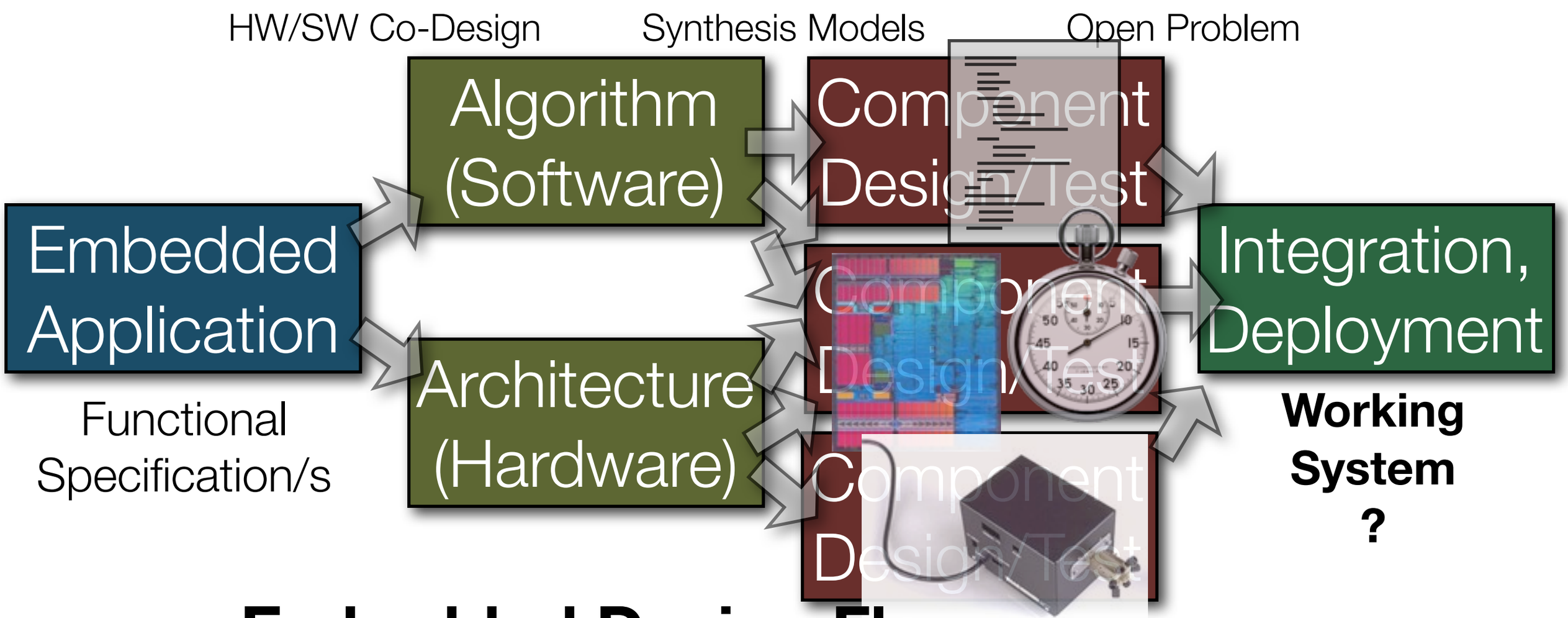
A Tale of Two Design Flows



VLSI Limitation:
you can build *WIRES* or *TRANSISTORS*

VLSI Design Flow:
characterized by strict design rules, verifiable physical design

A Tale of Two Design Flows



Embedded Design Flow:
characterized by nonexistent design rules,
ad hoc methods for system-level verification

Examples Abound ...

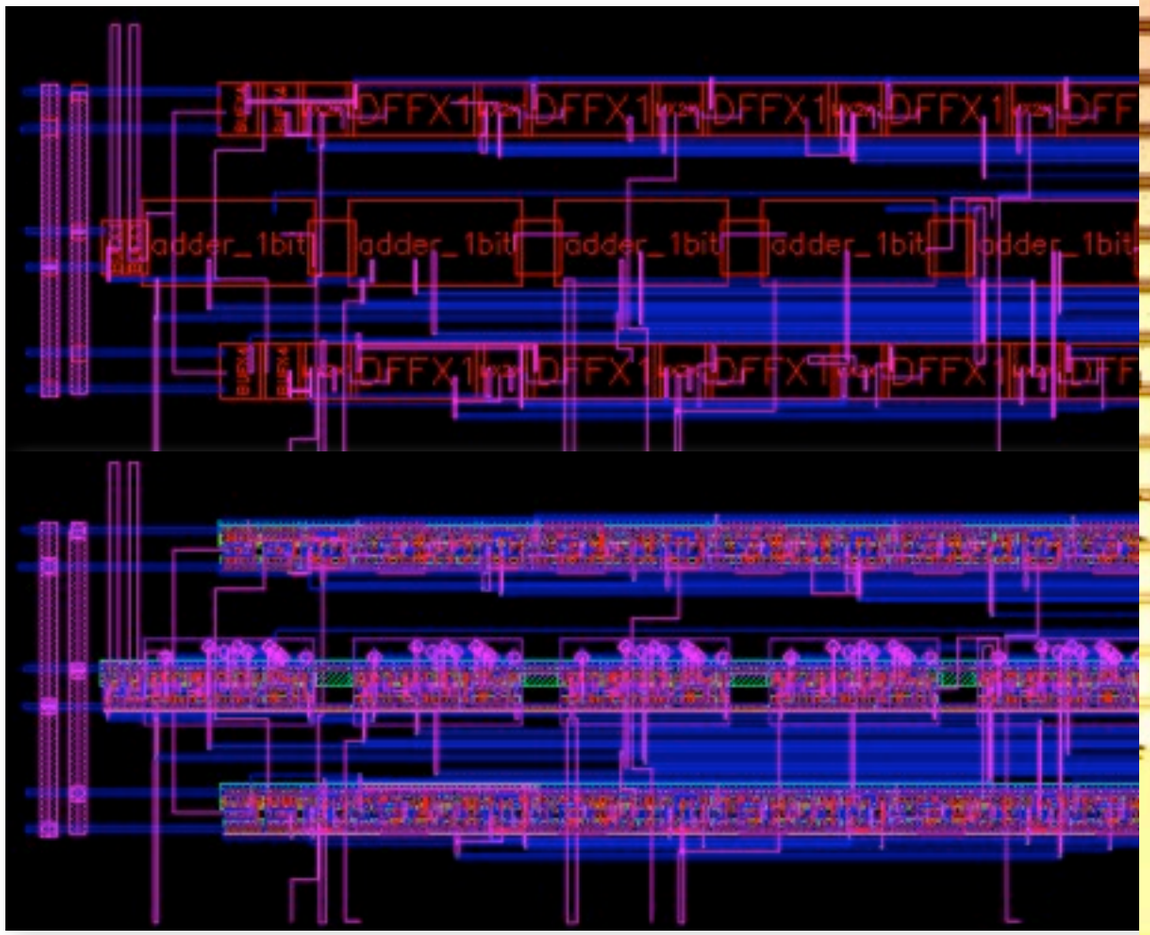
"System Level EMC Testing of Spacecraft," Narvaez, *EMC* 2003.

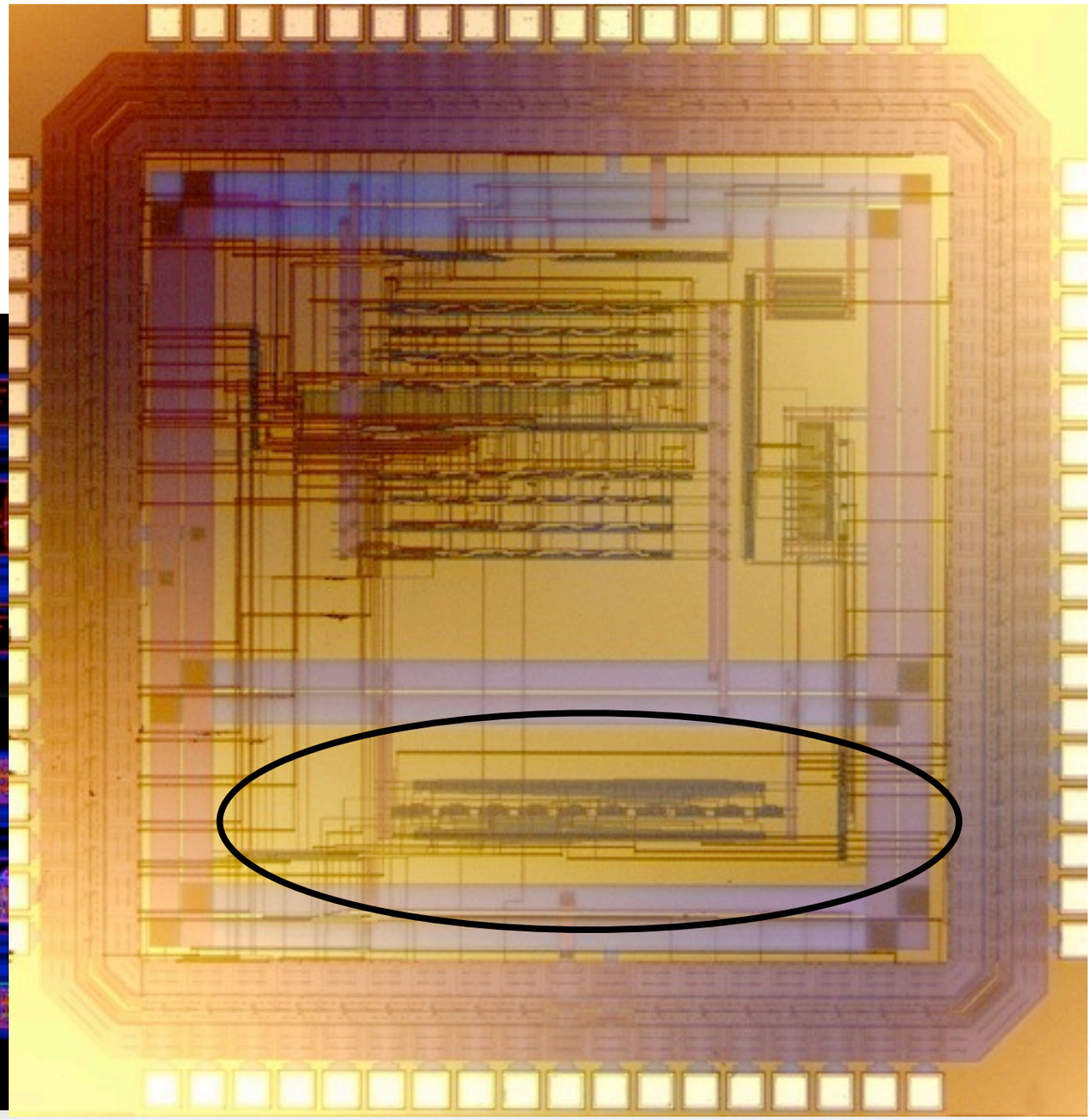
Jet Propulsion Laboratory, California Institute of Technology

NON-CLASSICAL SYSTEMS

Classical Systems

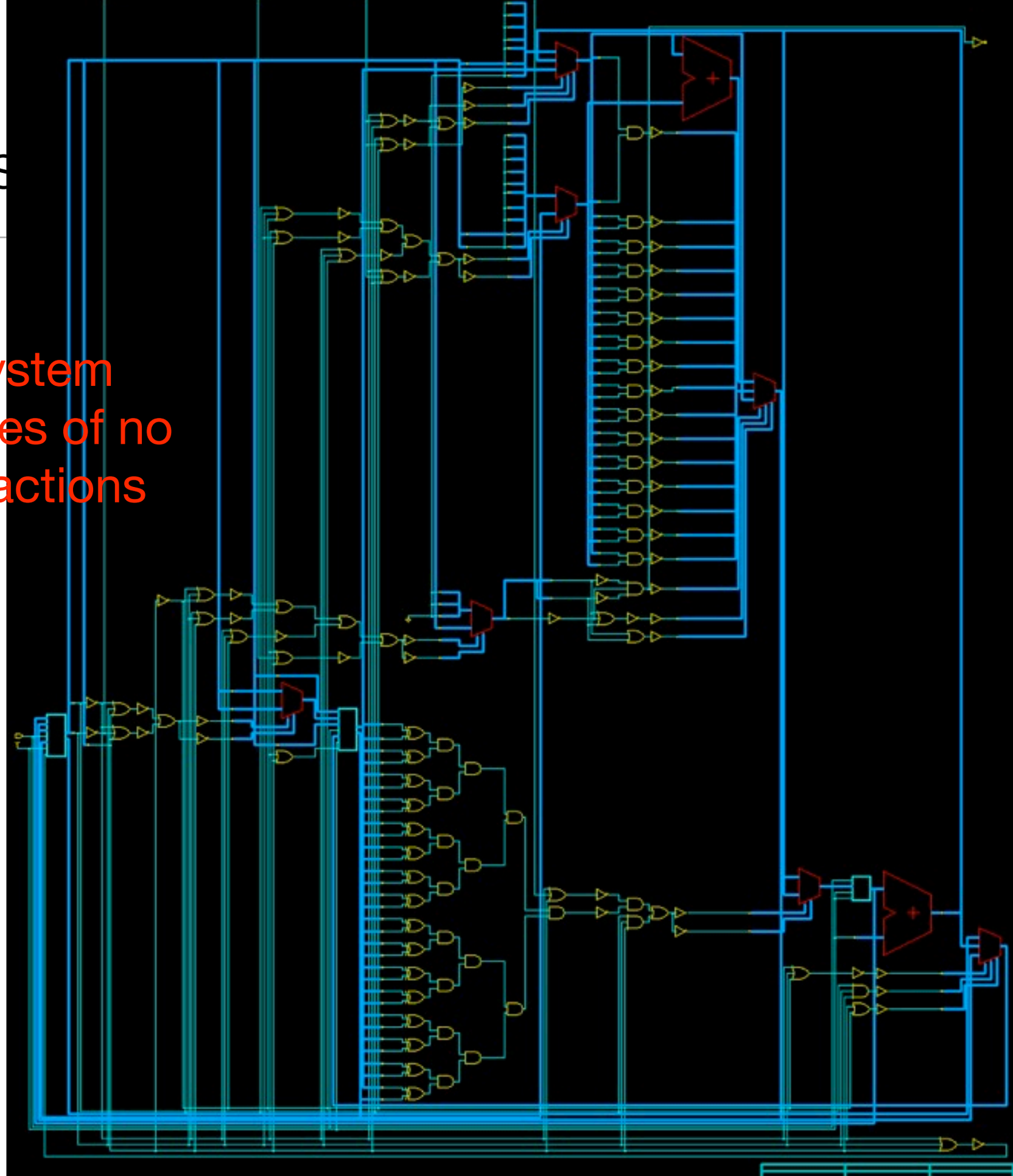
Analysis of this system requires guarantees of no out-of-band interactions





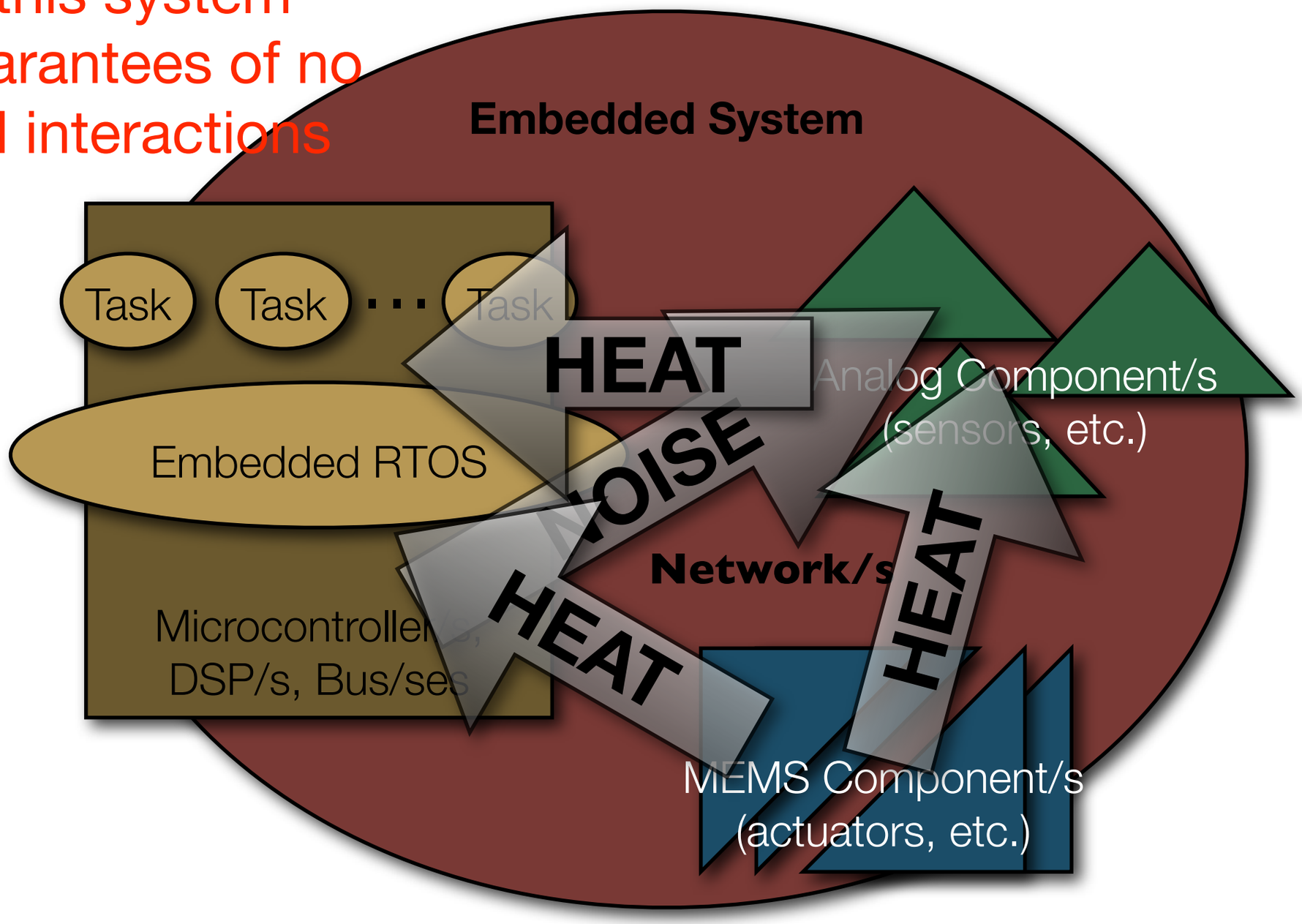
Classical Systems

Analysis of this system requires guarantees of no out-of-band interactions



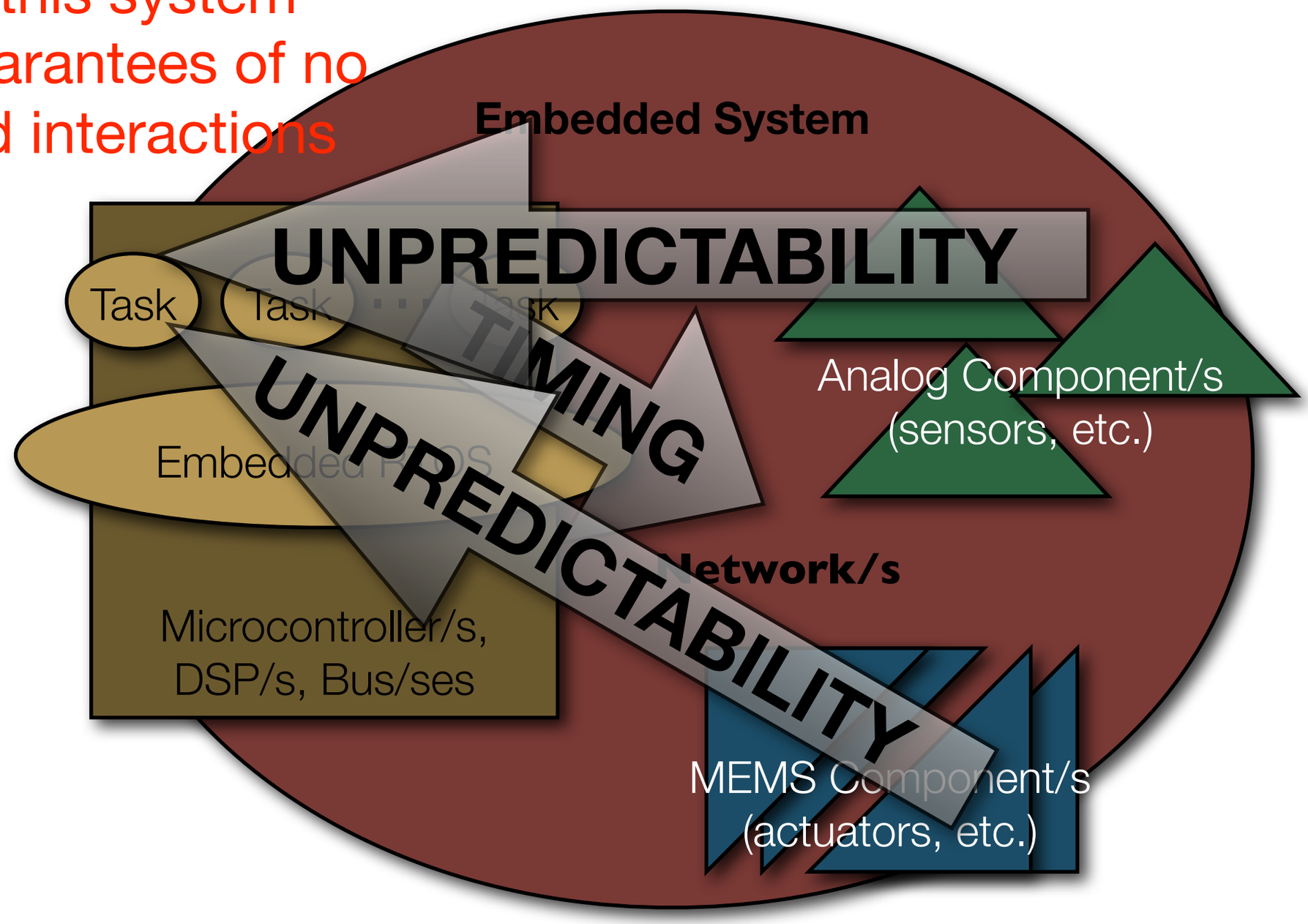
A Classical System?

Analysis of this system requires guarantees of no out-of-band interactions



A Classical System?

Analysis of this system requires guarantees of no out-of-band interactions

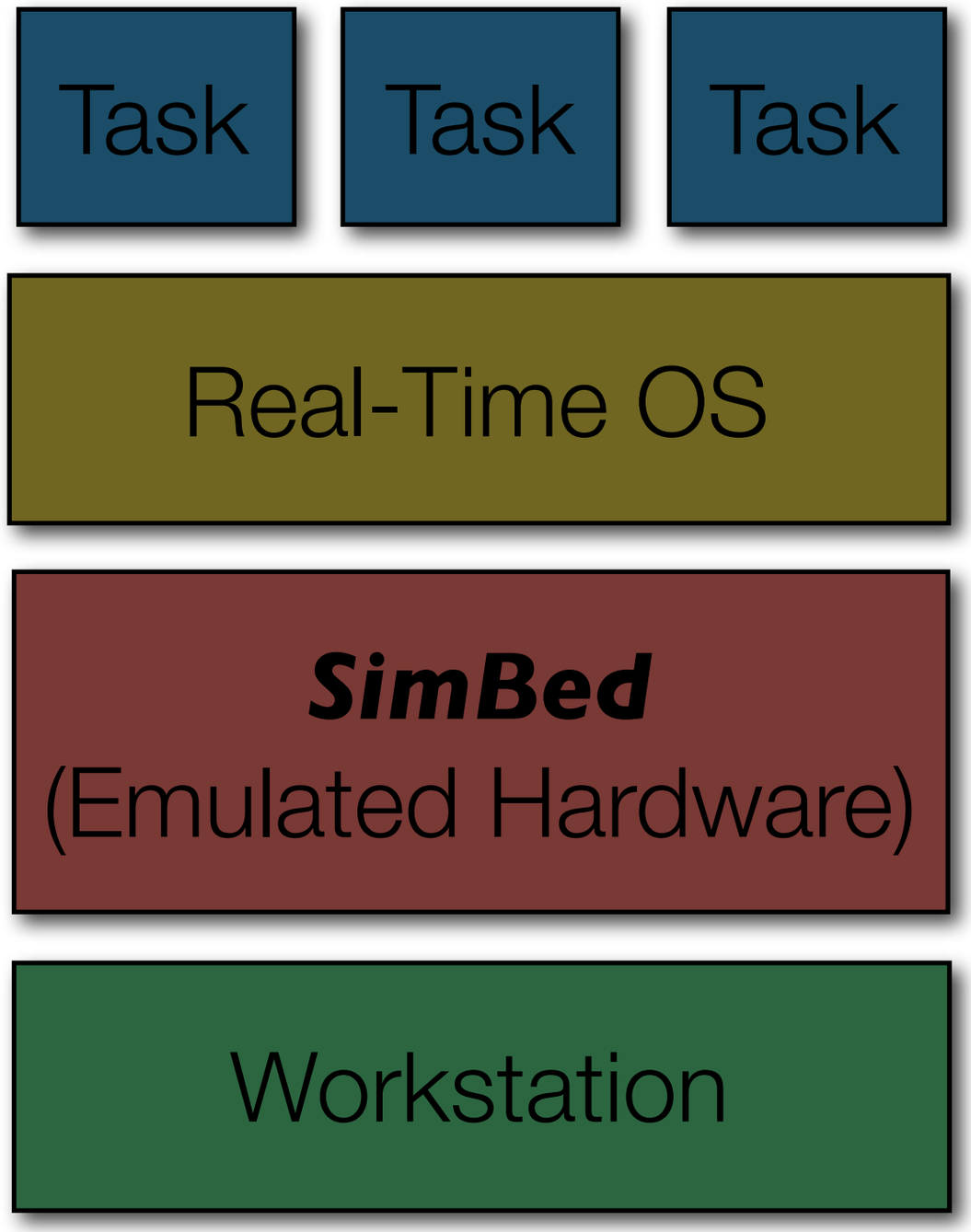


THE SOLUTION

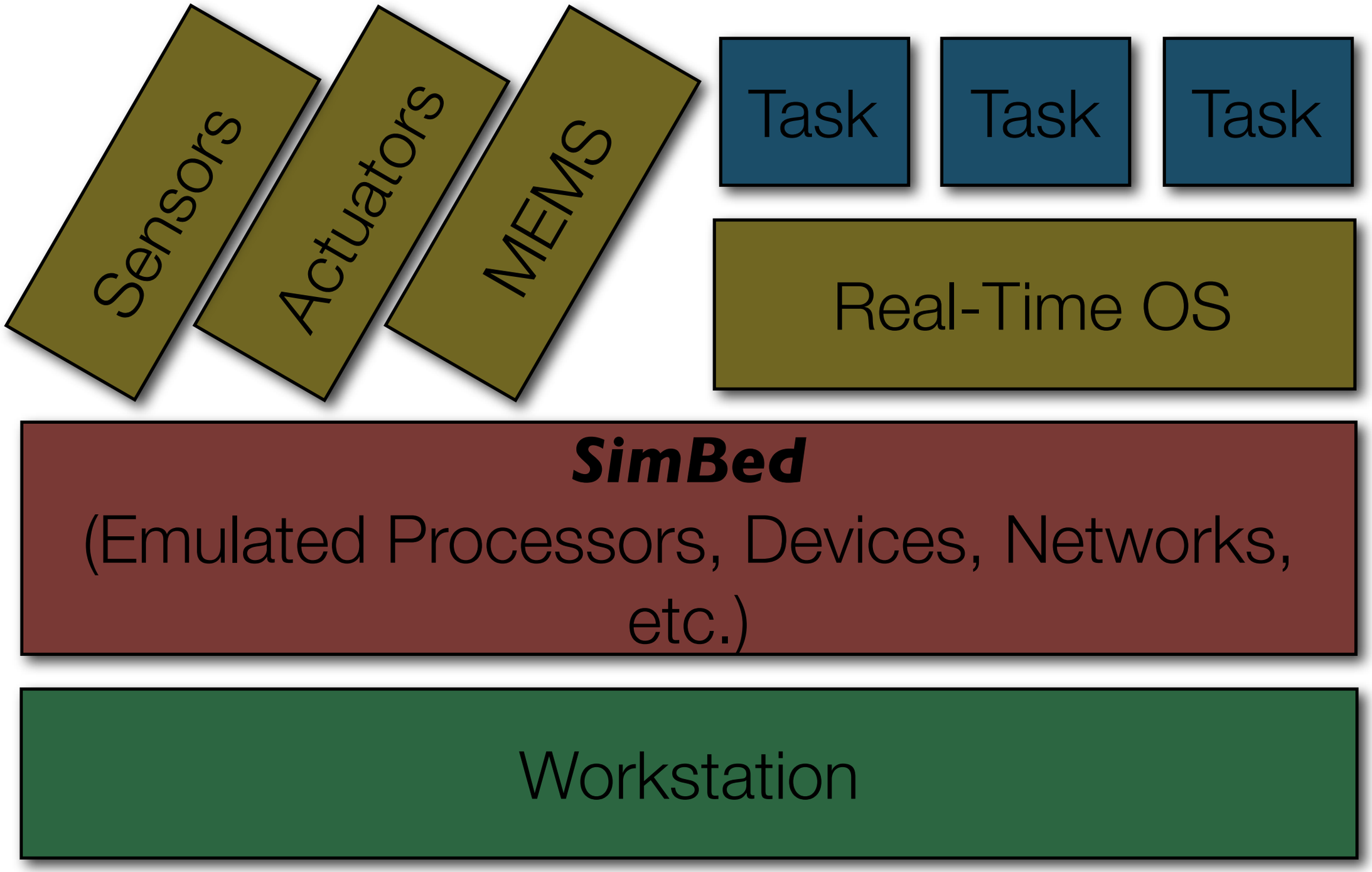
EXTREMELY ACCURATE MODELS

Existing: SimBed

- Extremely accurate software model of embedded hardware
- Runs unmodified RTOS and application binaries
- Models performance and energy consumption
- Allows arbitrary probing & debugging of system



… Expanded


Sensors
Actuators
MEMS
Task
Task
Task
Real-Time OS
SimBed
(Emulated Processors, Devices, Networks, etc.)
Workstation

But Wait, There's More

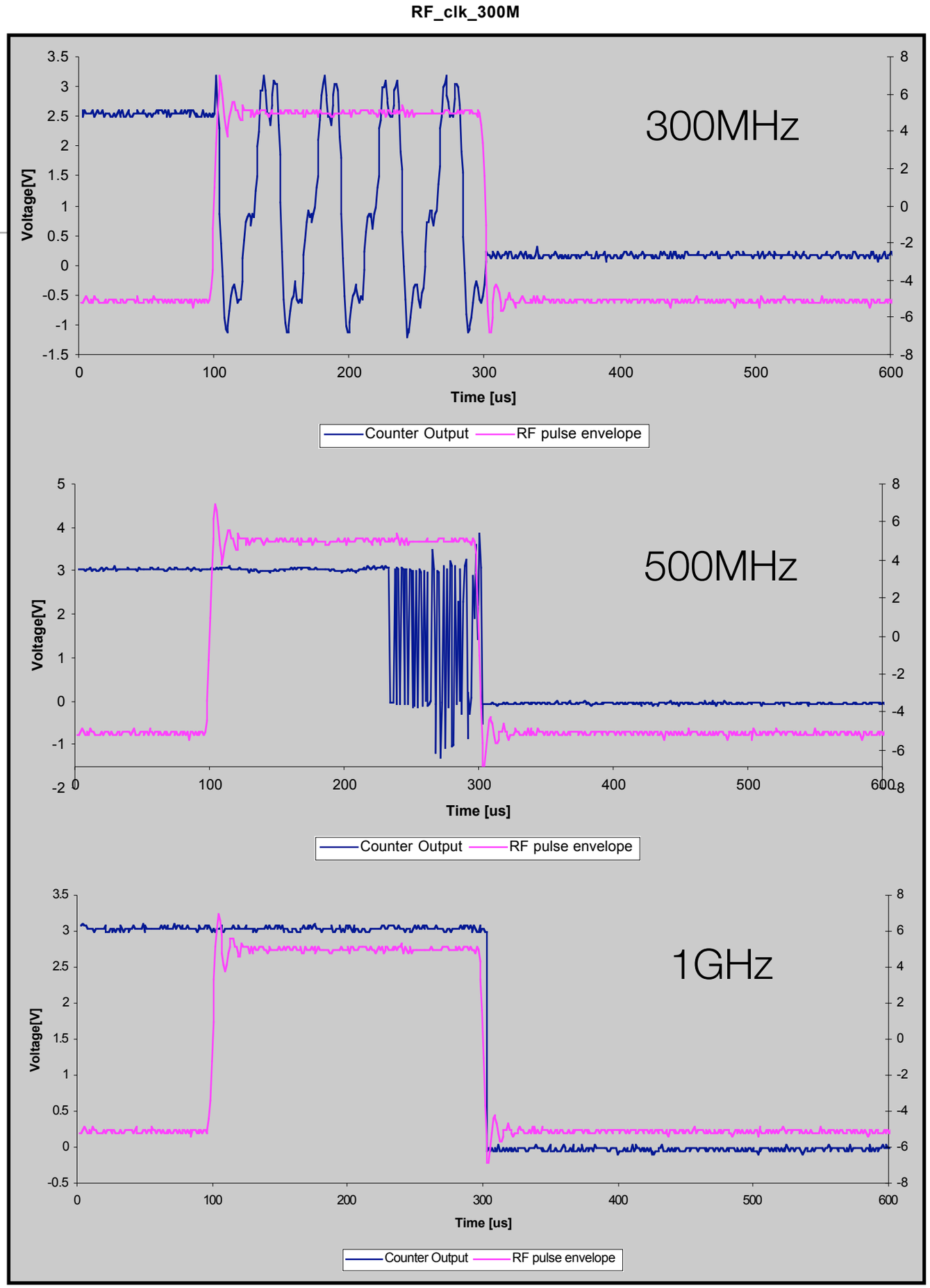
OUT-OF-BAND EFFECTS:

- Electromagnetic Interference
- Thermal Interference
- Mechanical Interference
- etc. …

But Wait, There's More

OUT-OF-BAND EFFECTS:

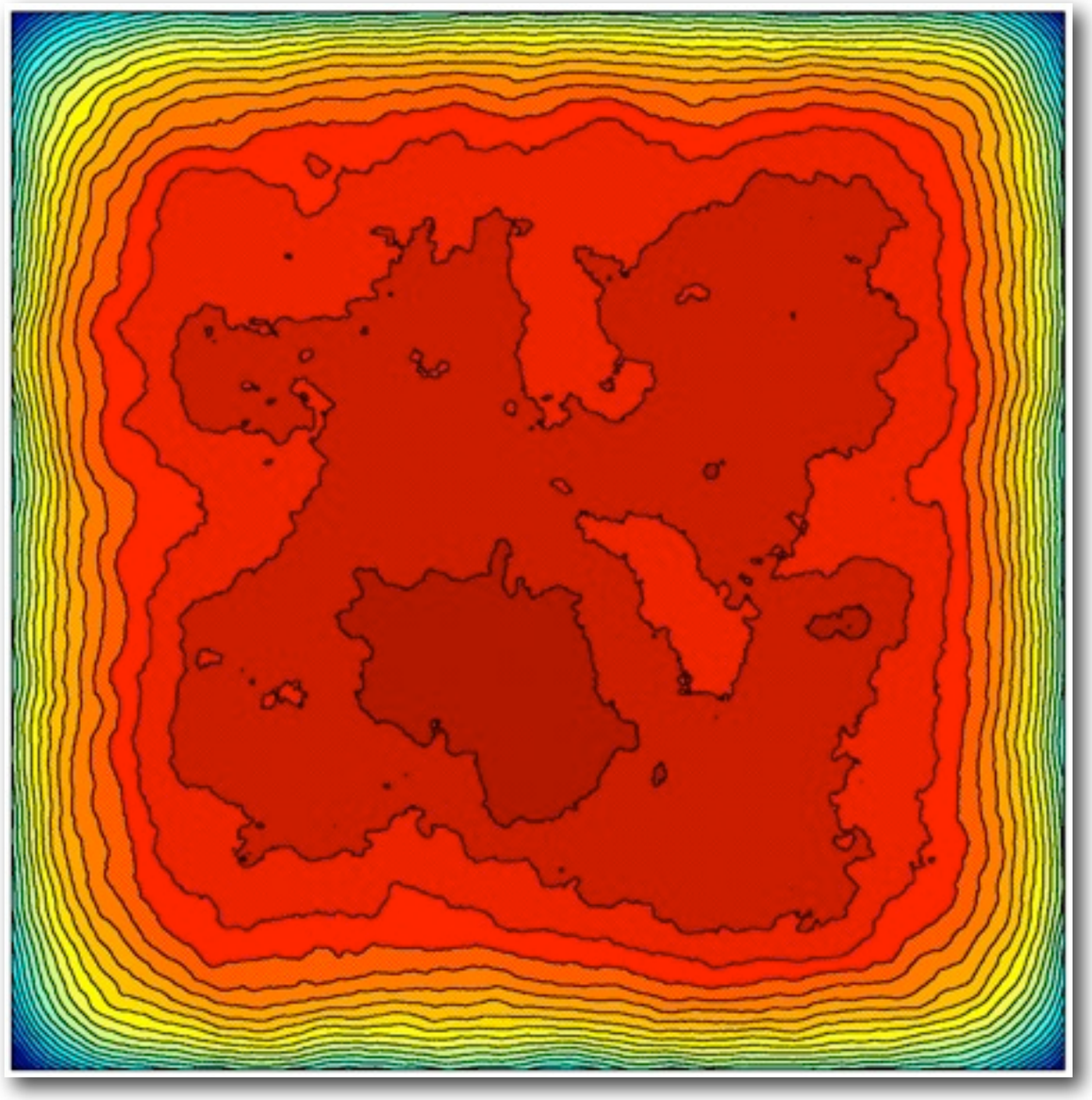
- Electromagnetic Interference
- Thermal Interference
- Mechanical Interference
- etc. …



But Wait, There's More

OUT-OF-BAND EFFECTS:

- Electromagnetic Interference
- Thermal Interference
- Mechanical Interference
- etc. …



But Wait, There's More

OUT-OF-BAND EFFECTS:

- Electromagnetic Interference
- Thermal Interference
- Mechanical Interference
- etc. …

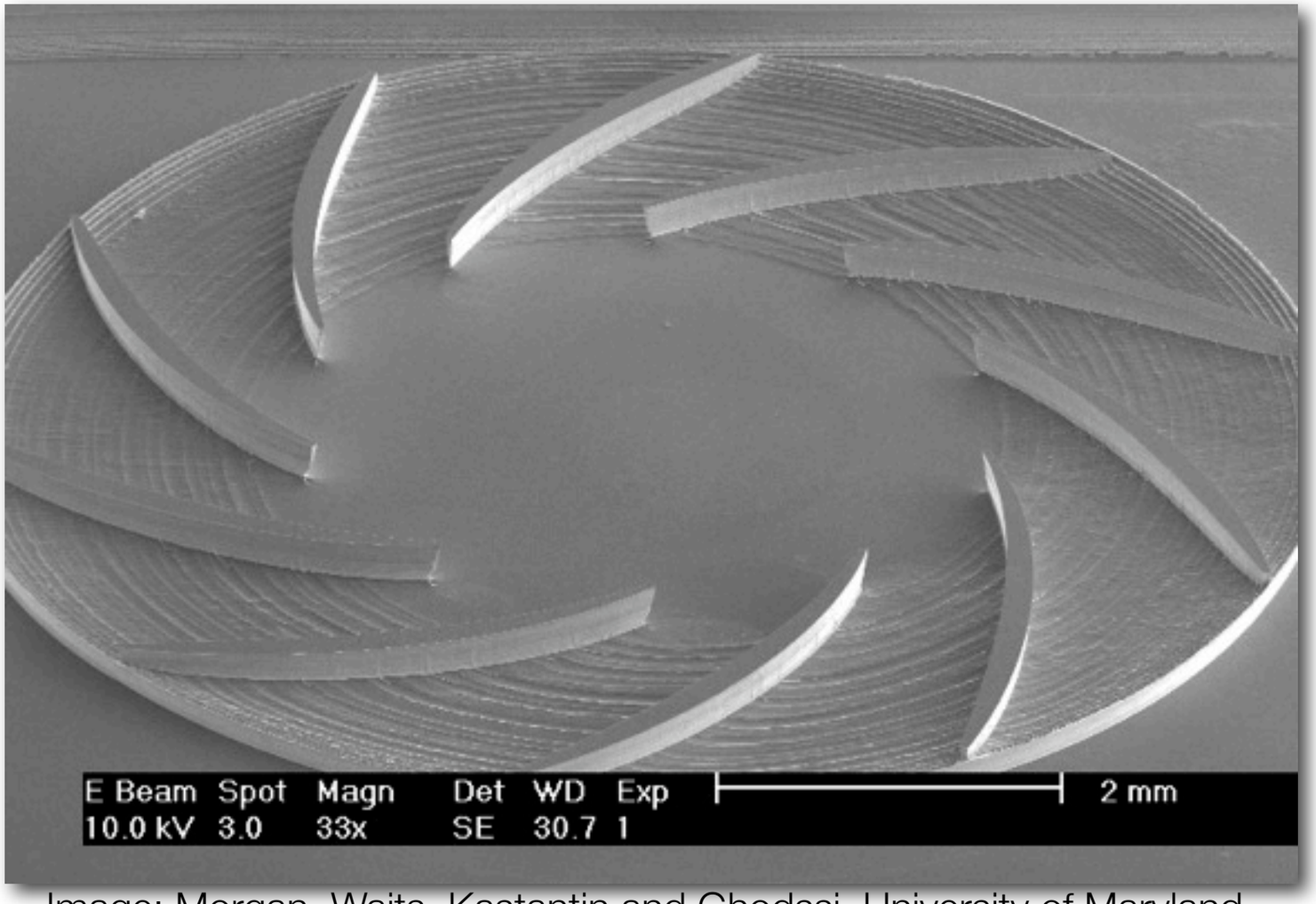
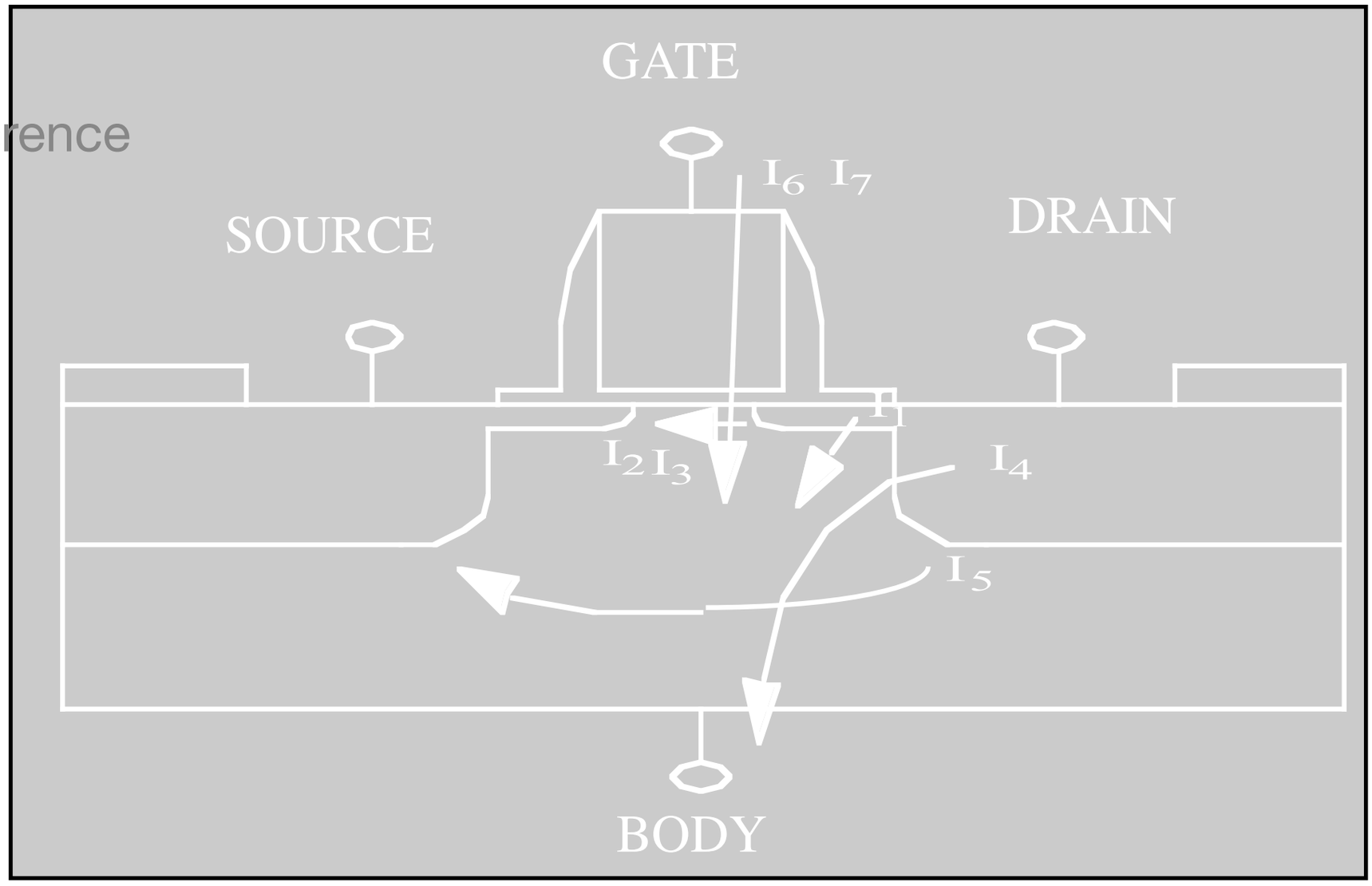


Image: Morgan, Waits, Kastantin and Ghodssi, University of Maryland, Feb. 2003

But Wait, There's More

OUT-OF-BAND EFFECTS:

- Electromagnetic Interference
- Thermal Interference
- Mechanical Interference
- etc. …



Device Physics?

What is Required?

- Expertise in design: VLSI, PCB, system
- Expertise in tools: CAD, codesign, compiler
- Expertise in digital, mixed-mode, MEMS, …
- Expertise in controls, networks
- Expertise in real-time systems software
- Proven ability to make things that work

What is Required?

- *(most importantly)* Foresee all possibilities

THE SOLUTION

Come up with a totally new understanding

Perspective, Revisited

- Embedded systems care about correctness of design

- Embedded systems are becoming increasingly complex, involving many heterogeneous components

- The embedded-systems community has SOLVED (or at least ADDRESSED more-or-less successfully) issues of correctness, power/space, etc. … in particular the very issues that now confront the general-purpose community (granted, issues have been addressed rel. to older technology, but still …)

- (next time) The memory system has become the dominant concern in performance, and it is rapidly becoming a/the dominant concern in power.

- Time to take a page from the embedded-systems community …