

# Modeling and Analysis: Measuring

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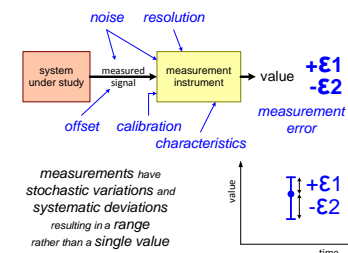
## Abstract

This presentation addresses the fundamentals of measuring: What and how to measure, impact of context and experiment on measurement, measurement errors, validation of the result against expectations, and analysis of variation and credibility.

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October 20, 2017  
status: preliminary  
draft  
version: 1.2



## *content*

What and How to measure

Impact of experiment and context on measurement

Validation of results, a.o. by comparing with expectation

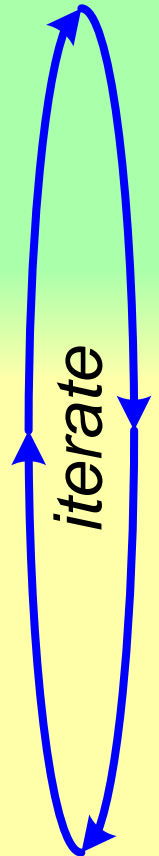
Consolidation of measurement data

Analysis of variation and analysis of credibility

# Measuring Approach: What and How

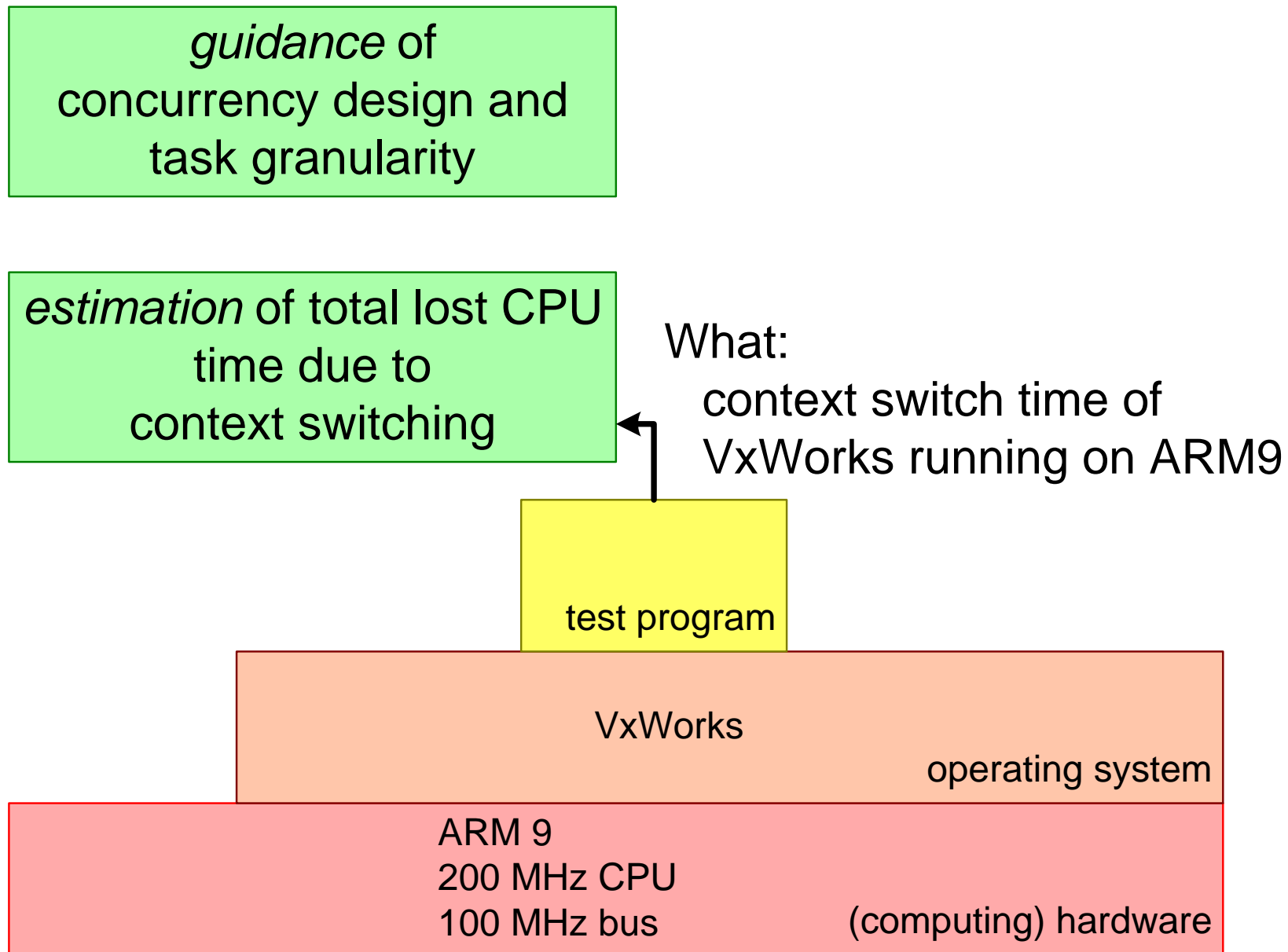
## *what*

1. What do we need to know?	
2. Define quantity to be measured.	initial model
3. Define required accuracy	purpose
4A. Define the measurement circumstances	fe.g. by use cases
4B. Determine expectation	historic data or estimation
4C. Define measurement set-up	
5. Determine actual accuracy	uncertainties, measurement error
6. Start measuring	
7. Perform sanity check	expectation versus actual outcome



## *how*

# 1. What do We Need? Example Context Switching

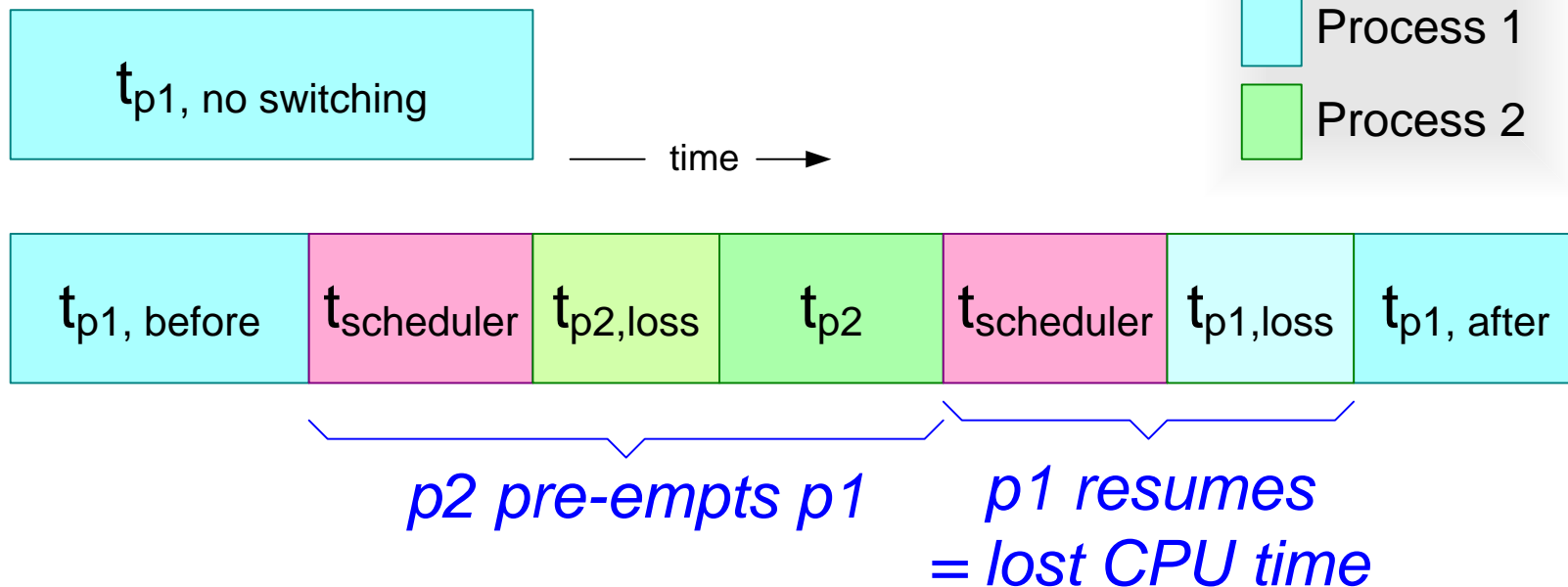


## 2. Define Quantity by Initial Model

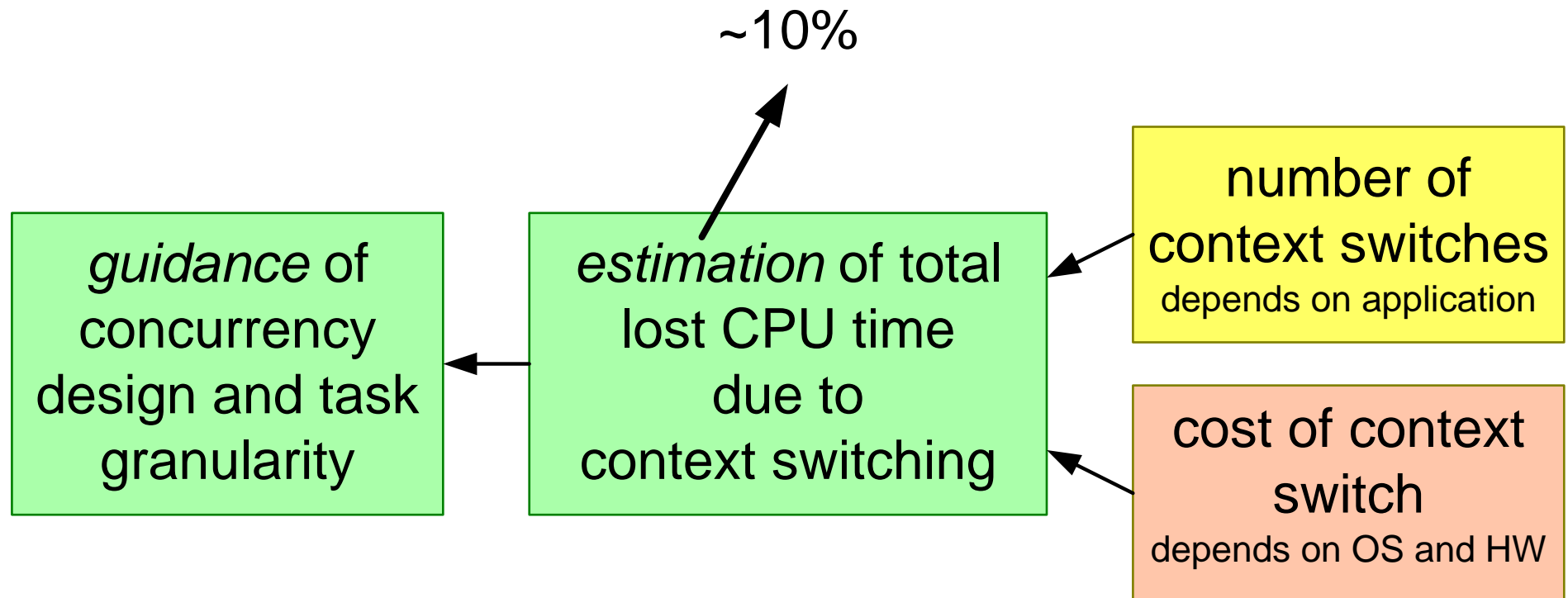
What (original):  
context switch time of  
VxWorks running on ARM9

What (more explicit):  
The amount of lost CPU time,  
due to context switching on  
VxWorks running on ARM9  
on a heavy loaded CPU

$$t_{\text{context switch}} = t_{\text{scheduler}} + t_{p1, \text{loss}}$$



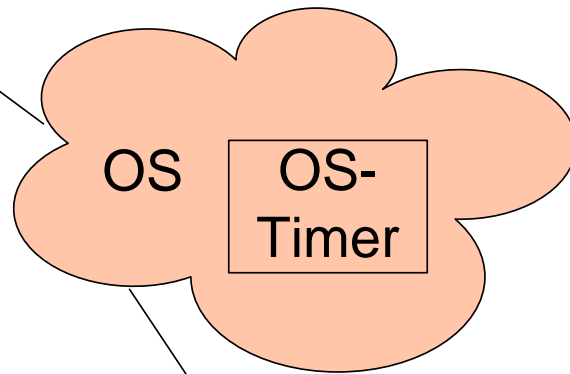
### 3. Define Required Accuracy



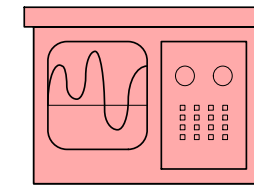
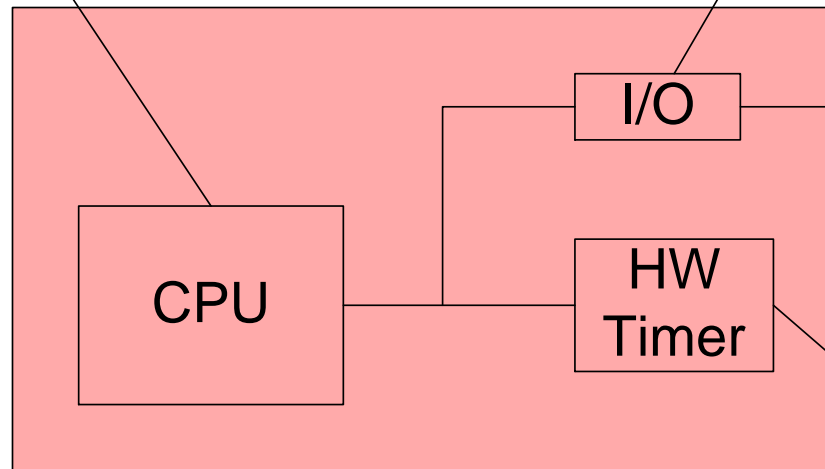
*purpose drives required accuracy*

# Intermezzo: How to Measure CPU Time?

Low resolution ( ~  $\mu\text{s}$  - ms)  
Easy access  
Lot of instrumentation



High resolution ( ~ 10 ns)  
requires  
HW instrumentation

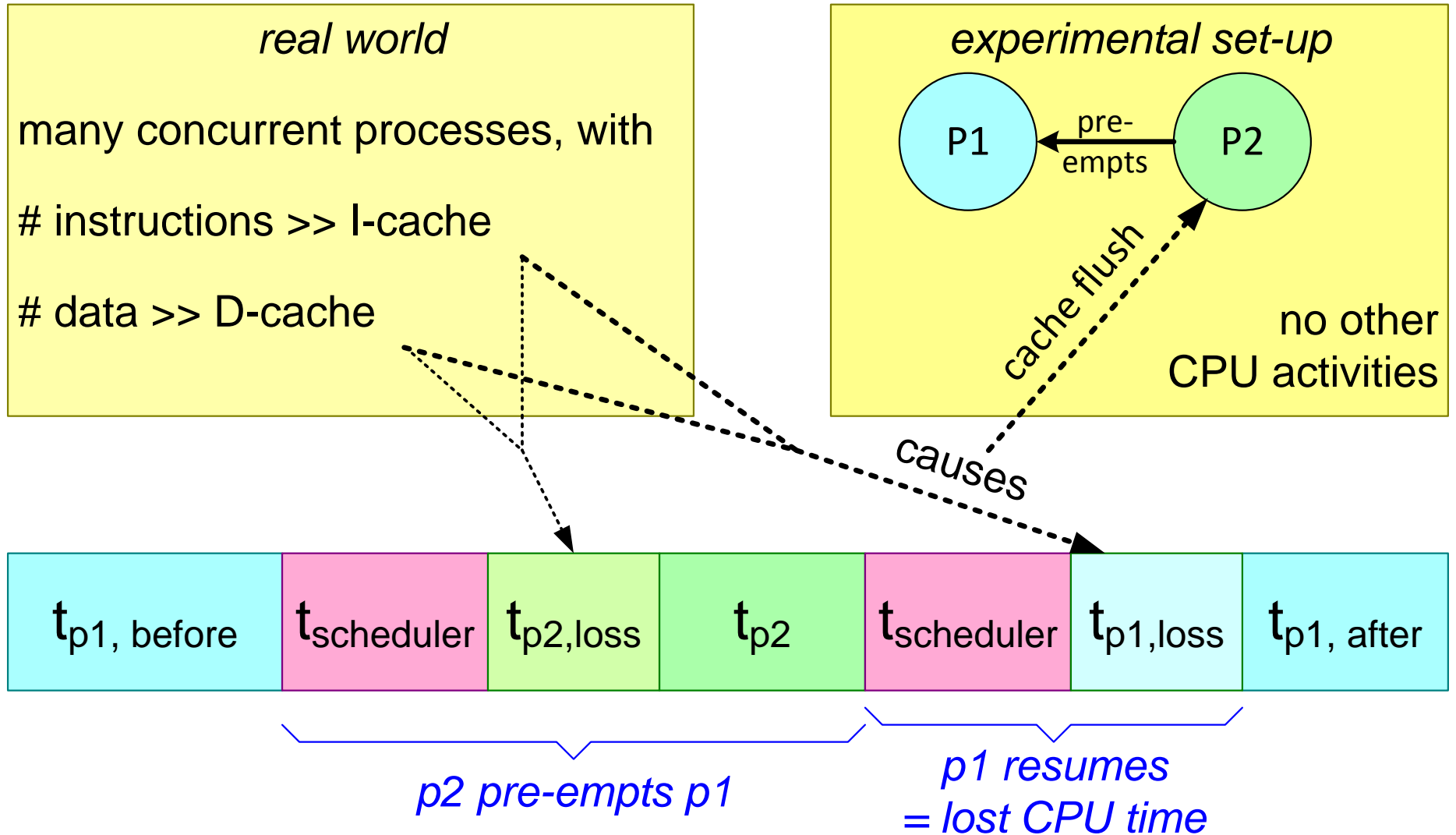


Logic analyzer /  
Oscilloscope

High resolution ( ~ 10 ns)  
Cope with limitations:  
- Duration (16 / 32 bit  
counter)  
- Requires Timer Access

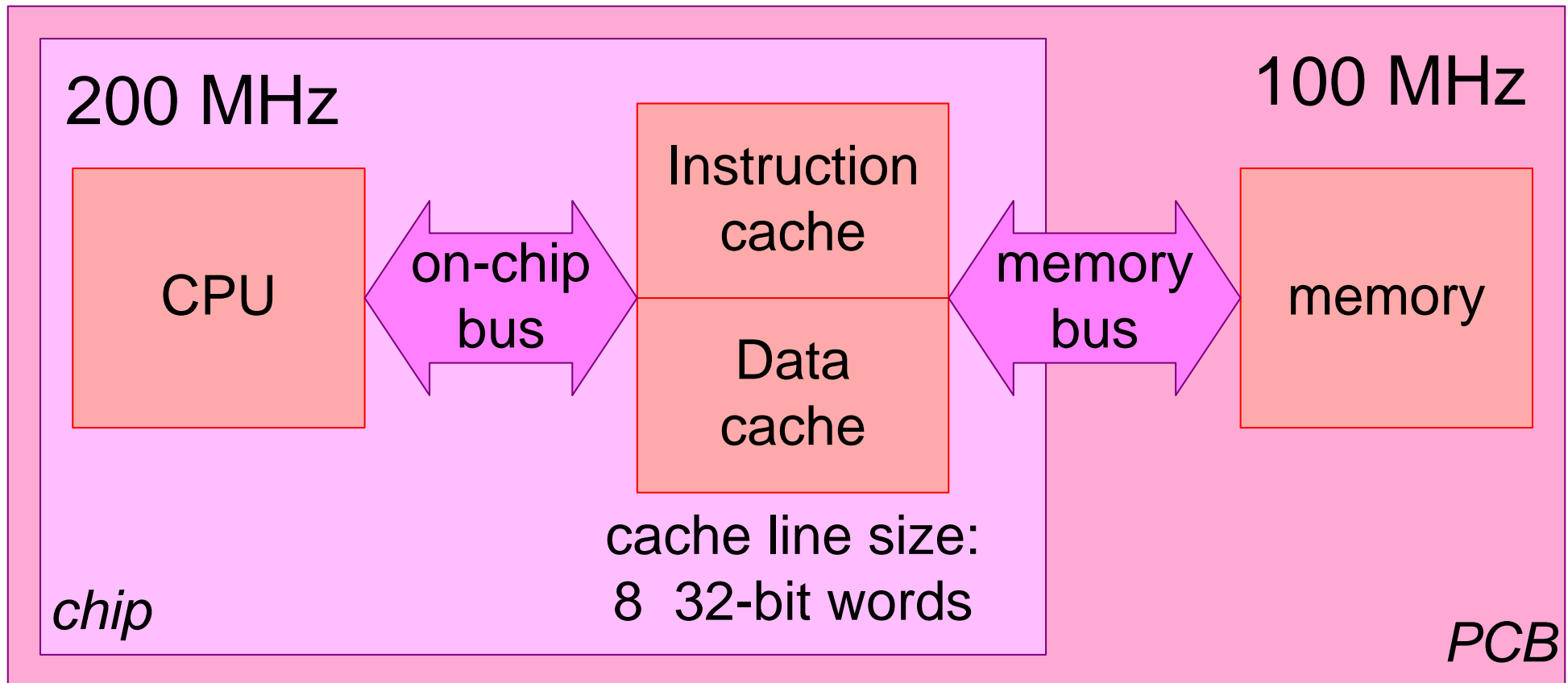
# 4A. Define the Measurement Set-up

*Mimick relevant real world characteristics*

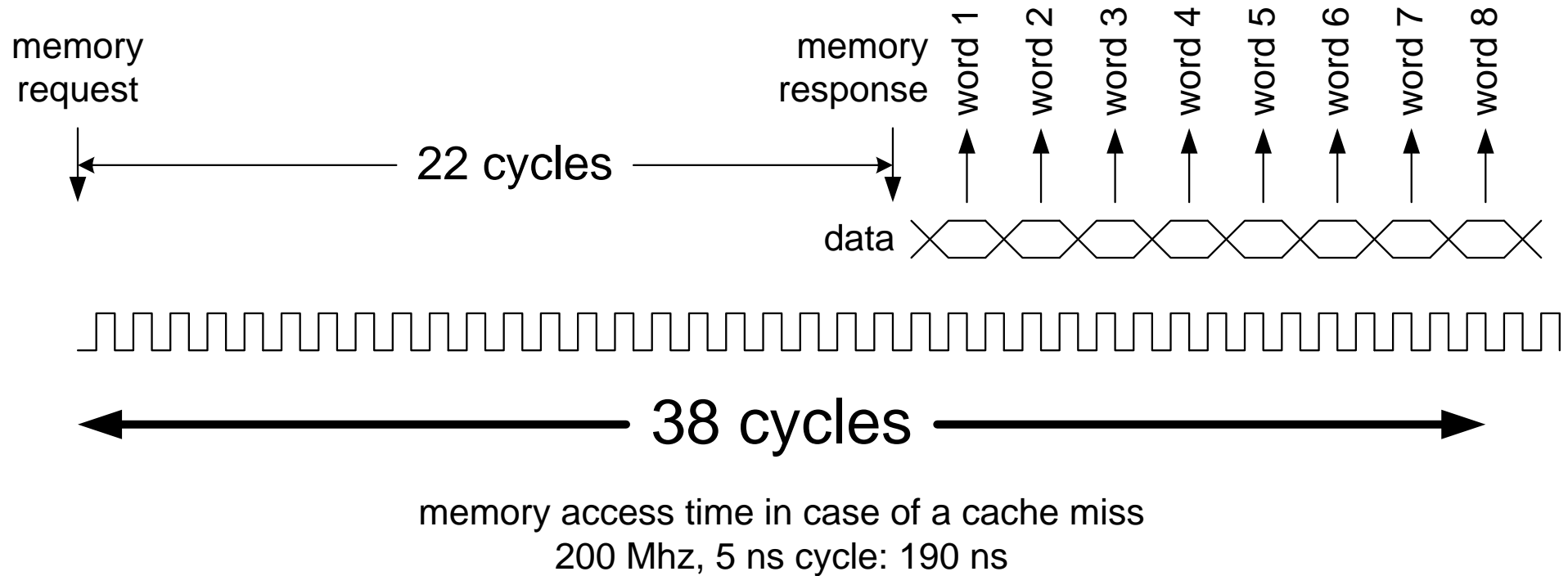




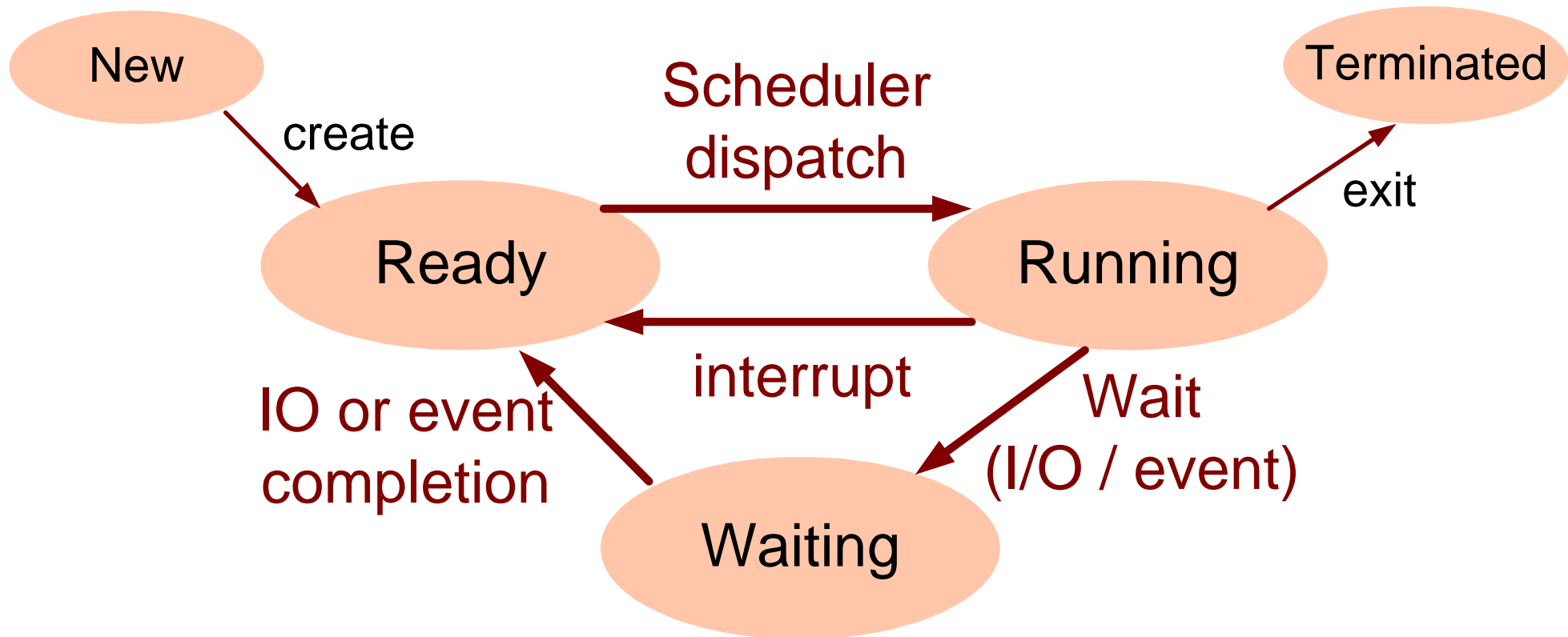
## 4B. Case: ARM9 Hardware Block Diagram



# Key Hardware Performance Aspect



# OS Process Scheduling Concepts



# Determine Expectation

simple SW model of context switch:

save state P1

determine next runnable task

update scheduler administration

load state P2

run P2

input data HW:

$t_{\text{ARM instruction}} = 5 \text{ ns}$

$t_{\text{memory access}} = 190 \text{ ns}$

Estimate how many  
instructions and memory accesses  
are needed per context switch

Calculate the estimated time  
needed per context switch

# Determine Expectation Quantified

instructions  
memory  
accesses

10	1	simple SW model of context switch: save state P1 determine next runnable task update scheduler administration load state P2 run P2
50	2	
20	1	
10	1	
10	1	
<hr/>		
100	6	

Estimate how many instructions and memory accesses are needed per context switch

500 ns	input data HW: $t_{\text{ARM instruction}} = 5 \text{ ns}$ $t_{\text{memory access}} = 190 \text{ ns}$
1140 ns	
<hr/>	
1640 ns	

Calculate the estimated time needed per context switch

round up (as margin) gives expected  $t_{\text{context switch}} = 2 \mu\text{s}$

# 4C. Code to Measure Context Switch

## *Task 1*

Time Stamp End  
Cache Flush  
Time Stamp Begin  
Context Switch

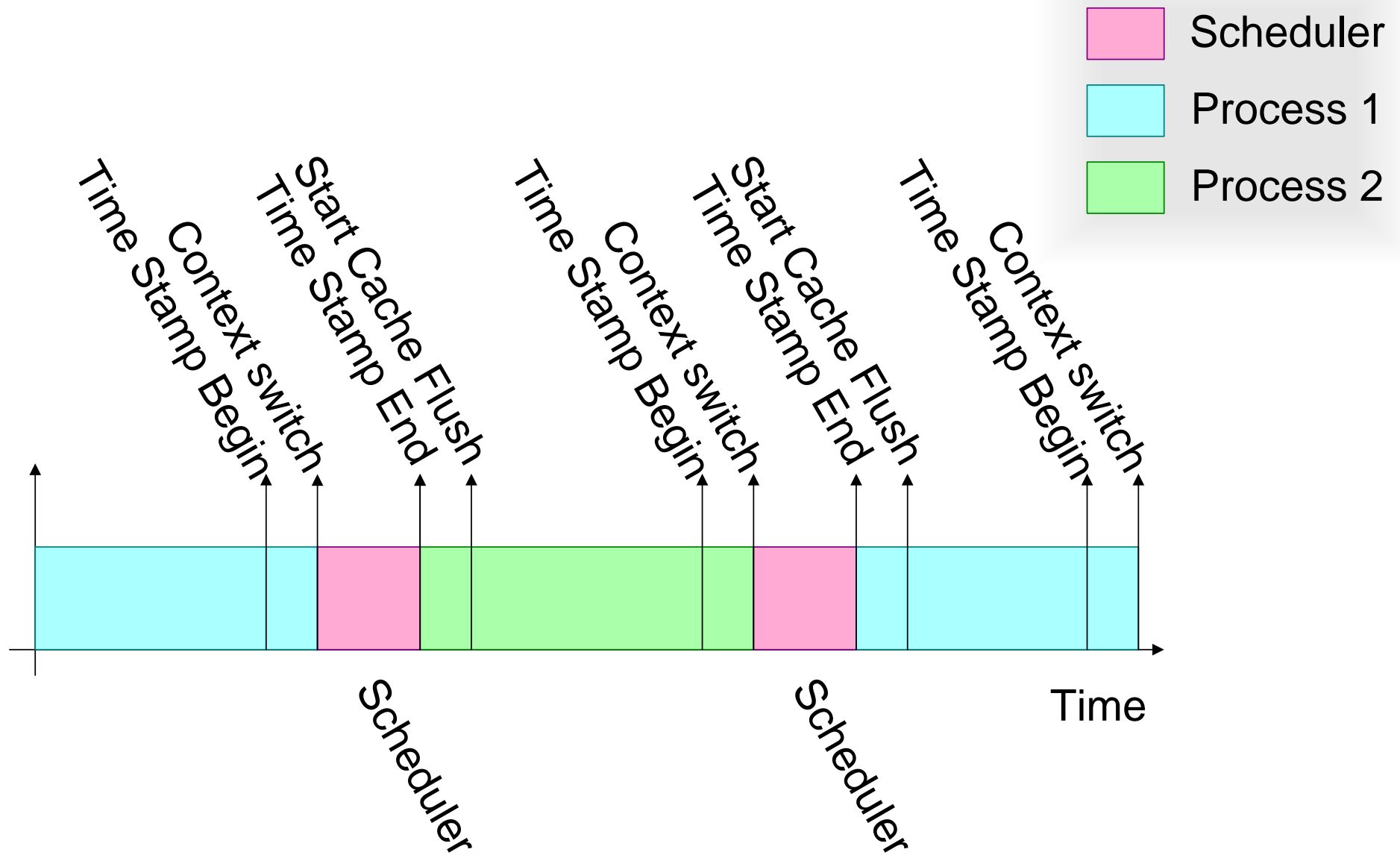
Time Stamp End  
Cache Flush  
Time Stamp Begin  
Context Switch

## *Task 2*

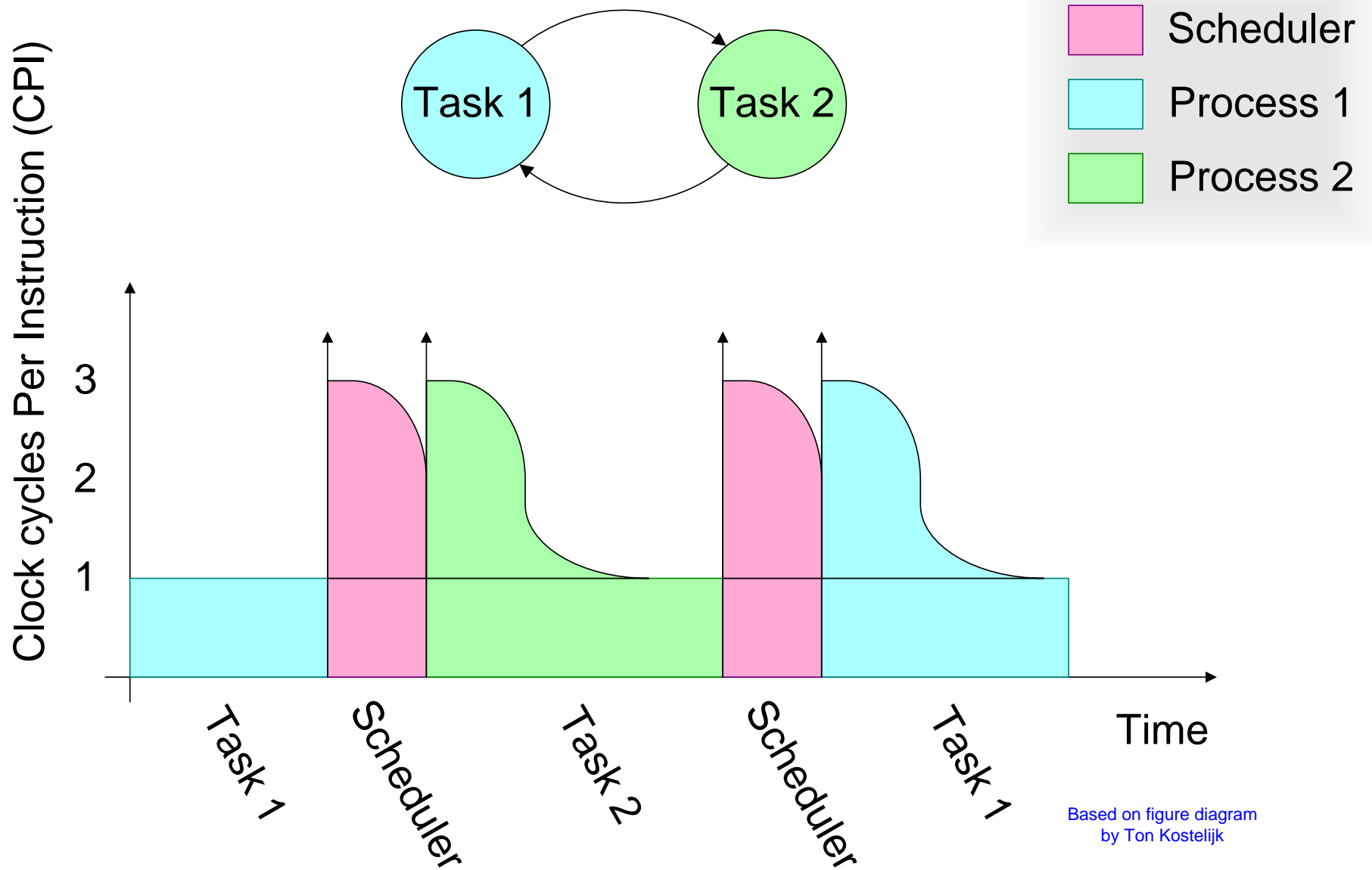
Time Stamp End  
Cache Flush  
Time Stamp Begin  
Context Switch

Time Stamp End  
Cache Flush  
Time Stamp Begin  
Context Switch

# Measuring Task Switch Time

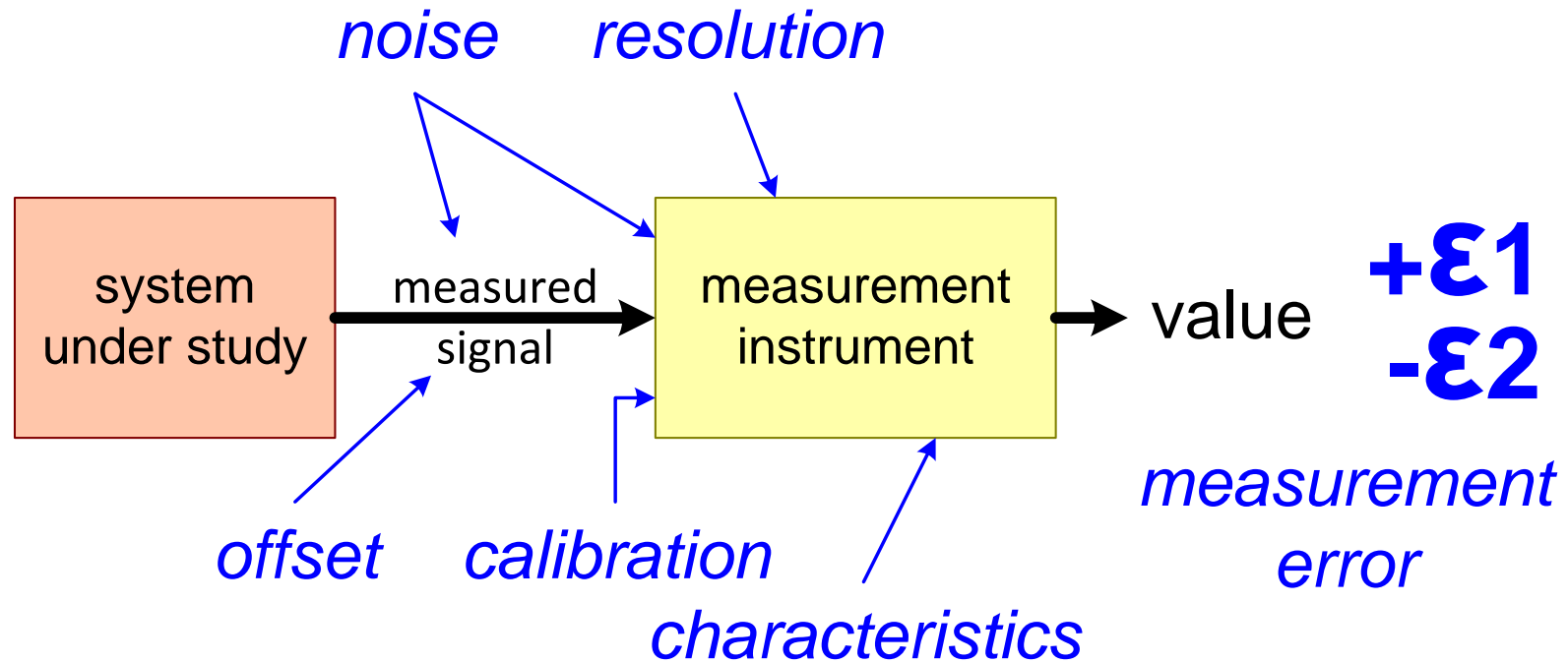


# Understanding: Impact of Context Switch

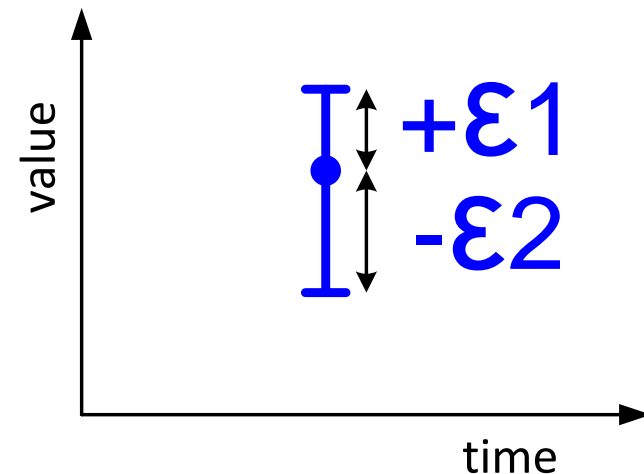




# 5. Accuracy: Measurement Error



*measurements have stochastic variations and systematic deviations resulting in a range rather than a single value*



# Accuracy 2: Be Aware of Error Propagation

$$t_{\text{duration}} = t_{\text{end}} - t_{\text{start}}$$

$$t_{\text{start}} = 10 \pm 2 \mu\text{s}$$

$$t_{\text{end}} = 14 \pm 2 \mu\text{s}$$

$$t_{\text{duration}} = 4 \pm ? \mu\text{s}$$

systematic errors: add linear

stochastic errors: add quadratic

*Measurements have*

*stochastic variations and systematic deviations*

*resulting in a range rather than a single value.*

The inputs of modeling,

"facts", assumptions, and measurement results,

also have stochastic variations and systematic deviations.

Stochastic variations and systematic deviations

propagate (add, amplify or cancel) through the model

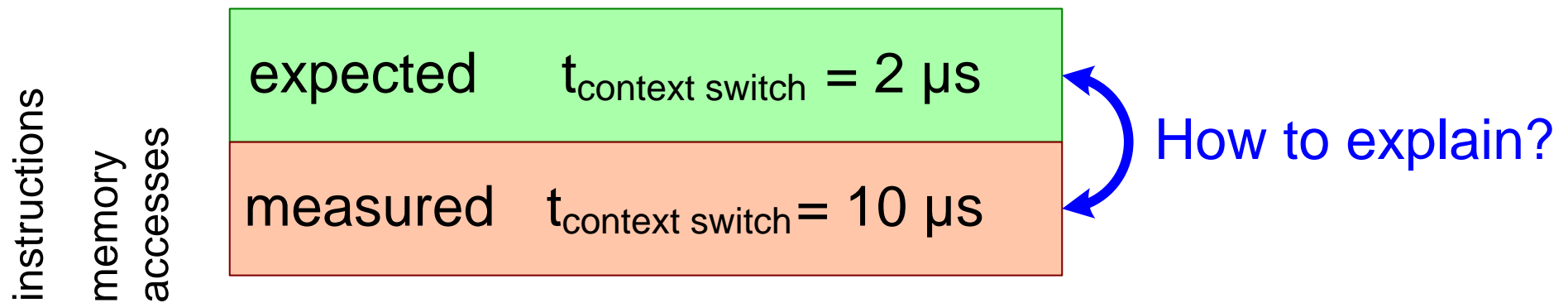
resulting in an output range.

## 6. Actual ARM Figures

ARM9 200 MHz  $t_{\text{context switch}}$   
as function of cache use

cache setting	$t_{\text{context switch}}$
From cache	2 $\mu\text{s}$
After cache flush	10 $\mu\text{s}$
Cache disabled	50 $\mu\text{s}$

# 7. Expectation versus Measurement



simple SW model of context switch:

10	1	save state P1
50	2	determine next runnable task
20	1	update scheduler administration
10	1	load state P2
10	1	run P2
<hr/>		
100	6	

input data HW:

500 ns	$t_{\text{ARM instruction}} = 5 \text{ ns}$
1140 ns	$t_{\text{memory access}} = 190 \text{ ns}$
<hr/>	
1640 ns	

*potentially missing in expectation:*

- memory accesses due to instructions  
~10 instruction memory accesses ~ = 2 μs
- memory management (MMU context)
- complex process model (parents, permissions)
- bookkeeping, e.g performance data
- layering (function calls, stack handling)
- the combination of above issues

*However, measurement seems to make sense*

# Conclusion Context Switch Overhead

$$t_{\text{overhead}} = n_{\text{context switch}} * t_{\text{context switch}}$$

$n_{\text{context switch}}$ ( $s^{-1}$ )	$t_{\text{context switch}} = 10\mu s$		$t_{\text{context switch}} = 2\mu s$	
	$t_{\text{overhead}}$	CPU load overhead	$t_{\text{overhead}}$	CPU load overhead
500	5ms	0.5%	1ms	0.1%
5000	50ms	5%	10ms	1%
50000	500ms	50%	100ms	10%

# Summary Context Switching on ARM9

## *goal of measurement*

Guidance of concurrency design and task granularity

Estimation of context switching overhead

Cost of context switch on given platform

## *examples of measurement*

Needed: context switch overhead ~10% accurate

Measurement instrumentation: HW pin and small SW test program

Simple models of HW and SW layers

Measurement results for context switching on ARM9

## *Conclusions*

Measurements are an important source of factual data.

A measurement requires a well-designed experiment.

Measurement error, validation of the result determine the credibility.

Lots of consolidated data must be reduced to essential understanding.

## *Techniques, Models, Heuristics of this module*

experimentation

error analysis

estimating expectations



This work is derived from the EXARCH course at CTT developed by *Ton Kostelijk* (Philips) and *Gerrit Muller*.

The Boderc project contributed to the measurement approach. Especially the work of

*Peter van den Bosch* (Océ),

*Oana Florescu* (TU/e),

and *Marcel Verhoef* (Chess)

has been valuable.