Modeling and Analysis: Measuring

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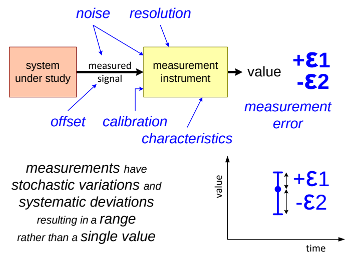
Abstract

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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Presentation Content

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

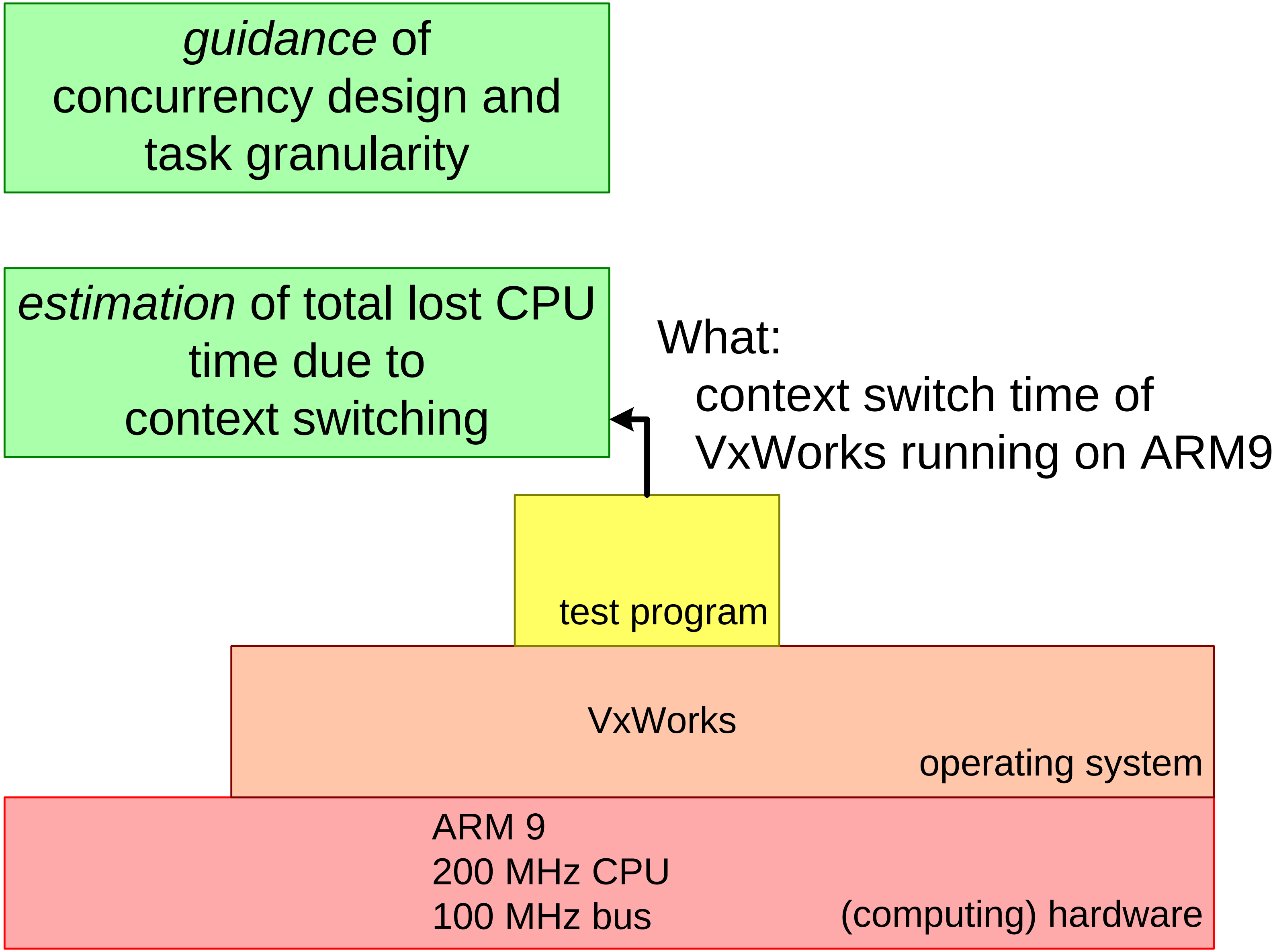
what

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

iterate

how

1. What do We Need? Example Context Switching

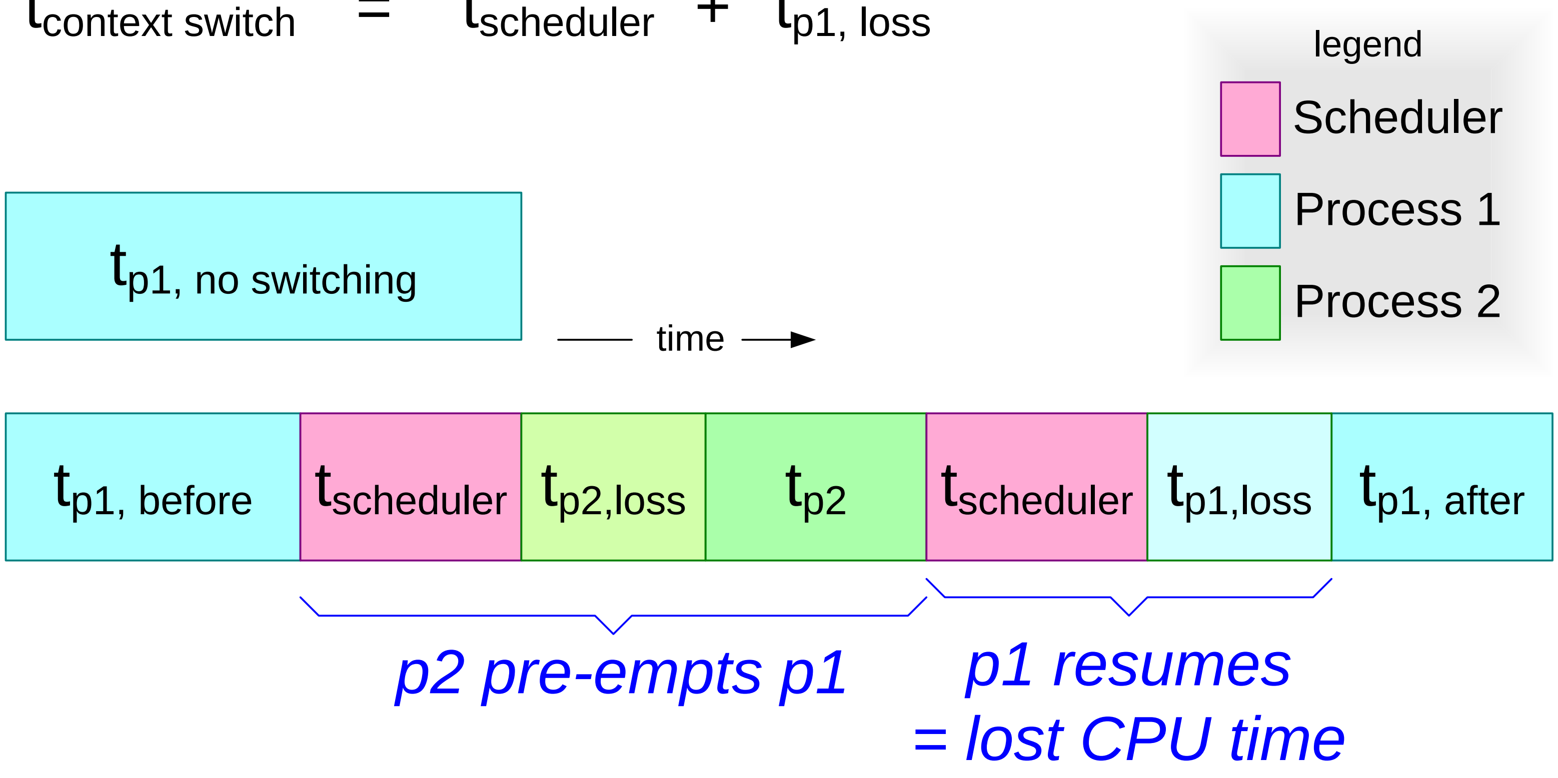


2. Define Quantity by Initial Model

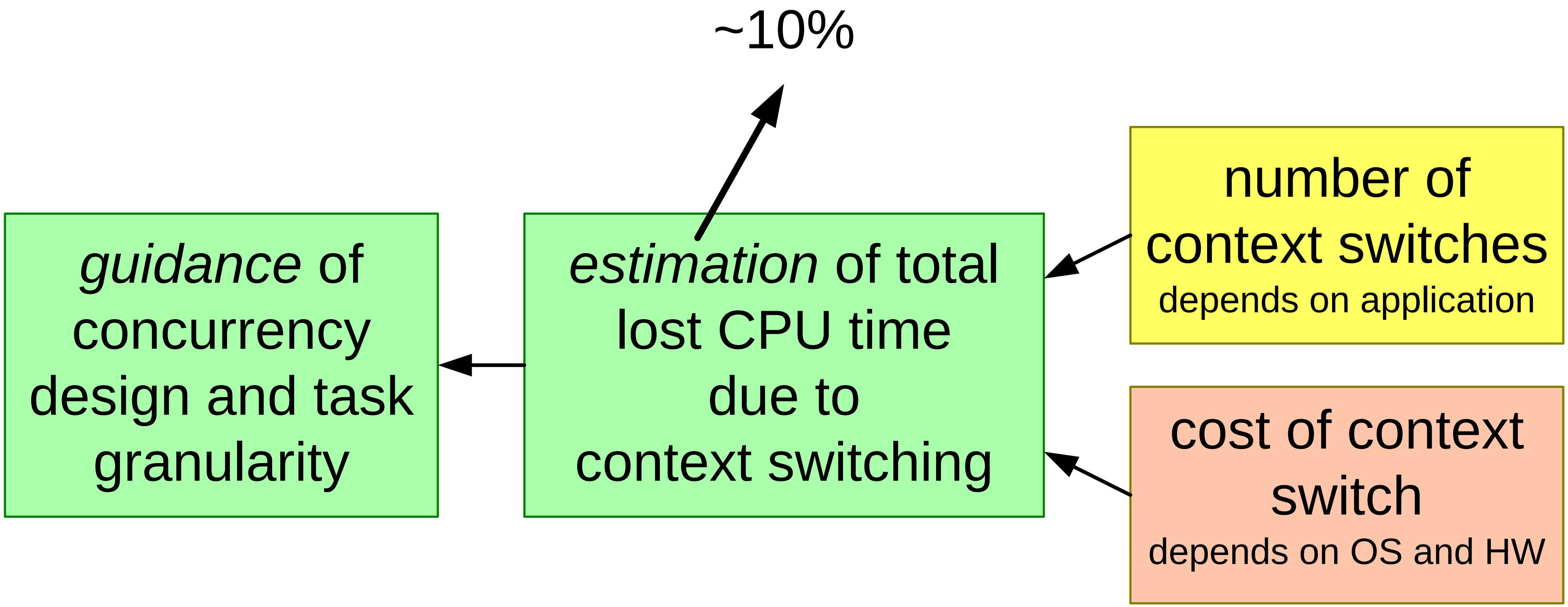
What (original):
context switch time of
VxWorks running on ARM9

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

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

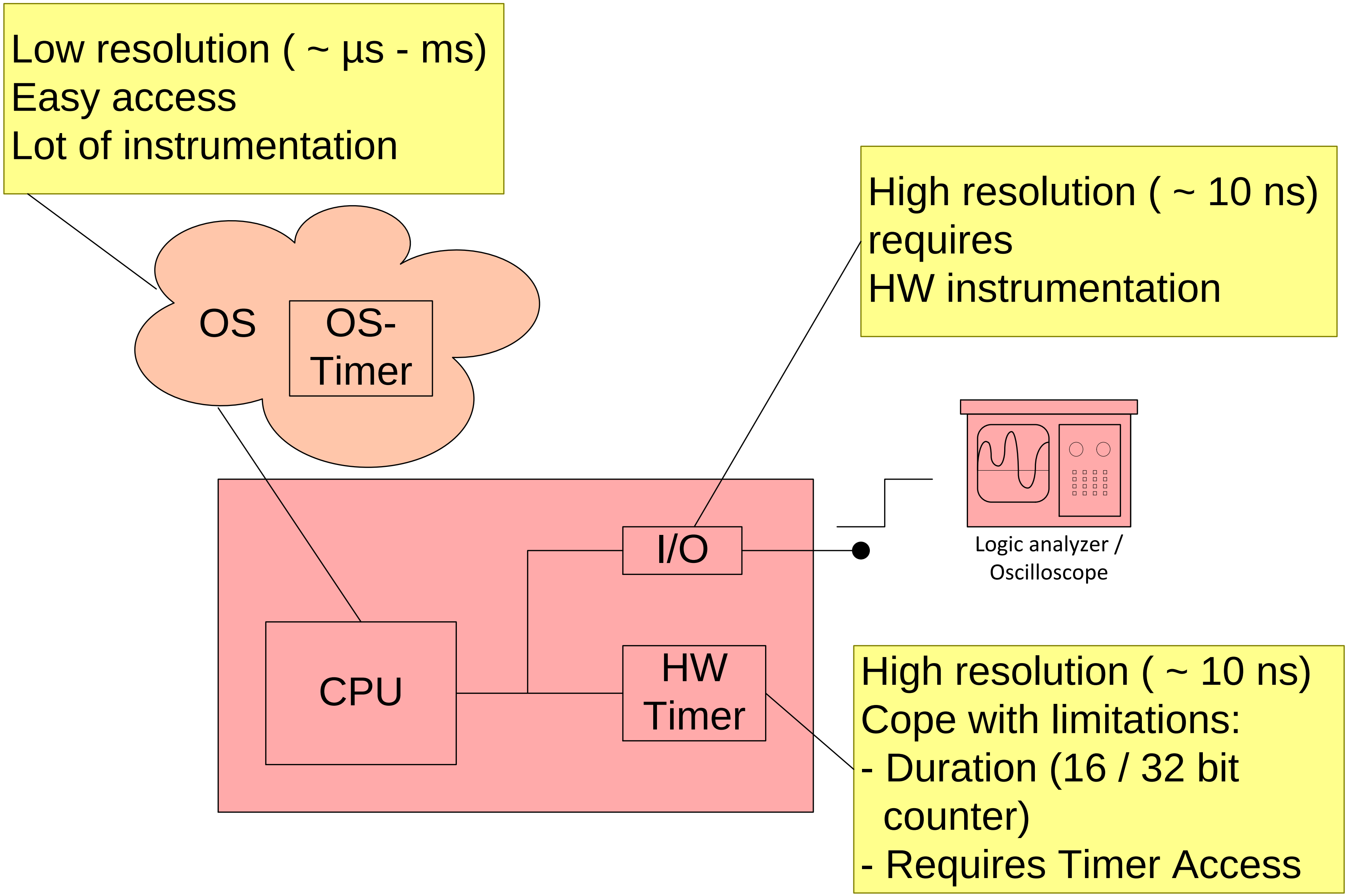


3. Define Required Accuracy



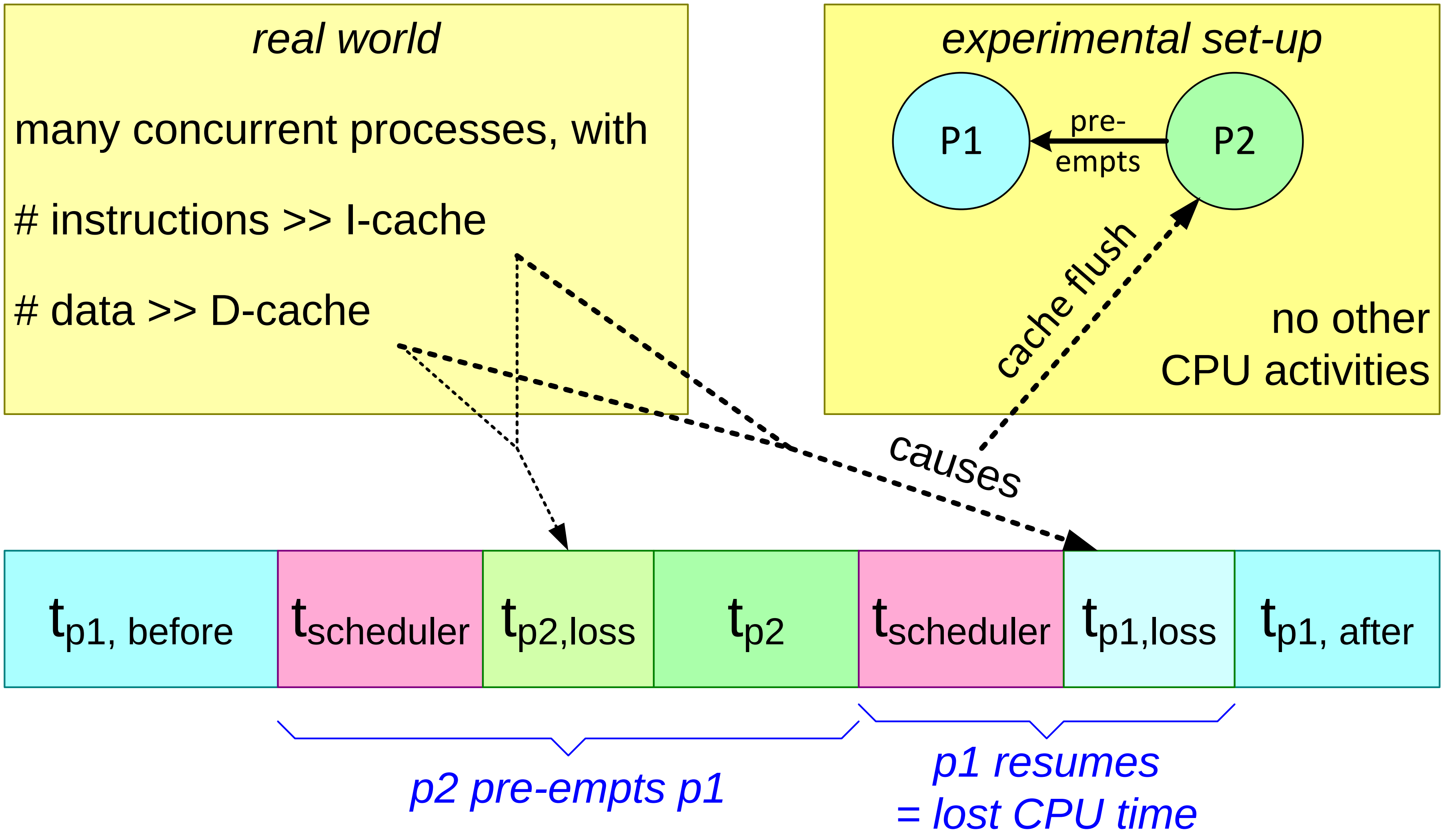
purpose drives required accuracy

Intermezzo: How to Measure CPU Time?

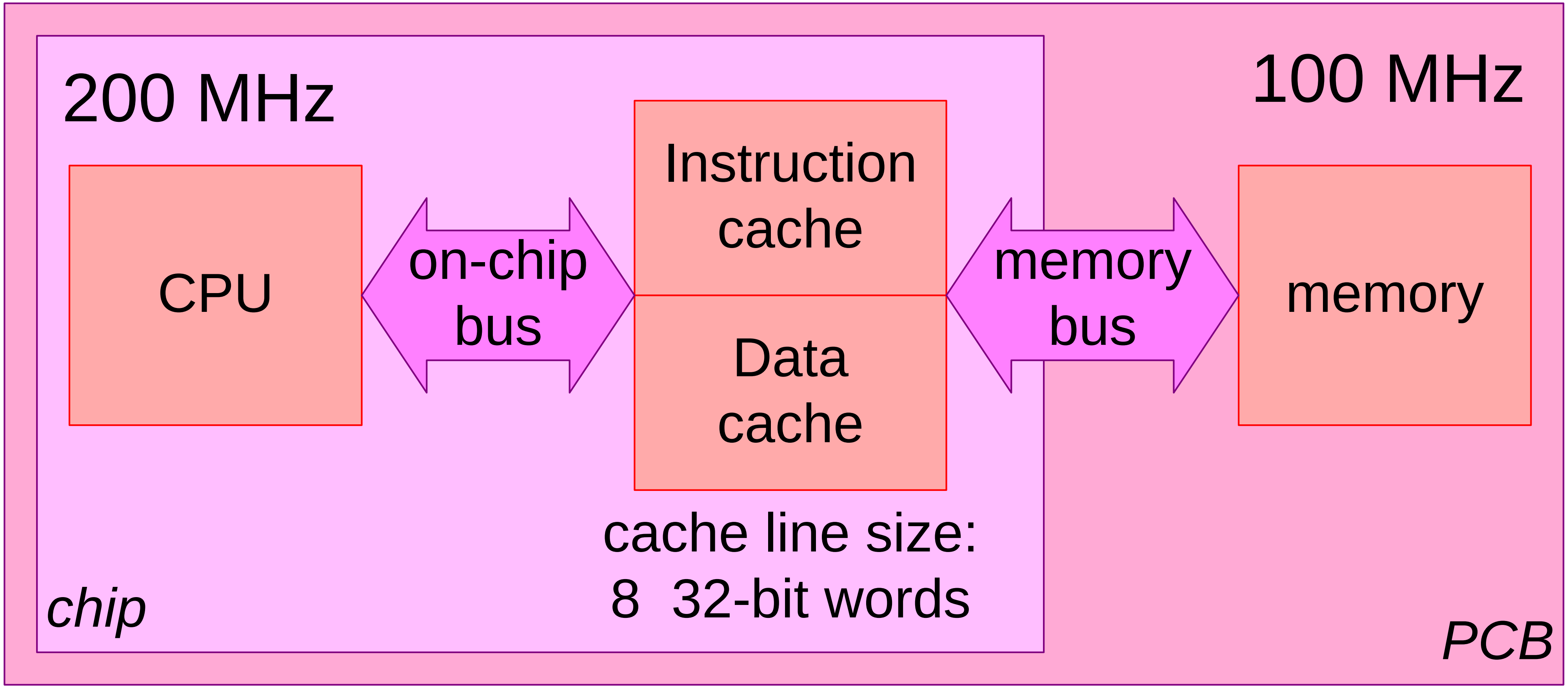


4A. Define the Measurement Set-up

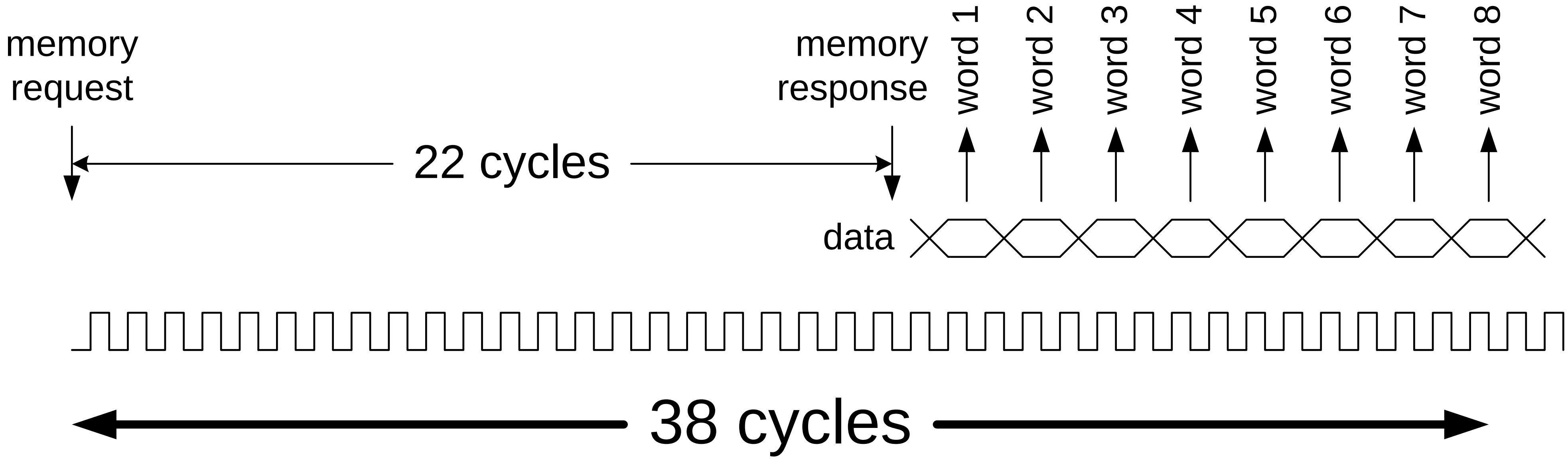
Mimick relevant real world characteristics



4B. Case: ARM9 Hardware Block Diagram

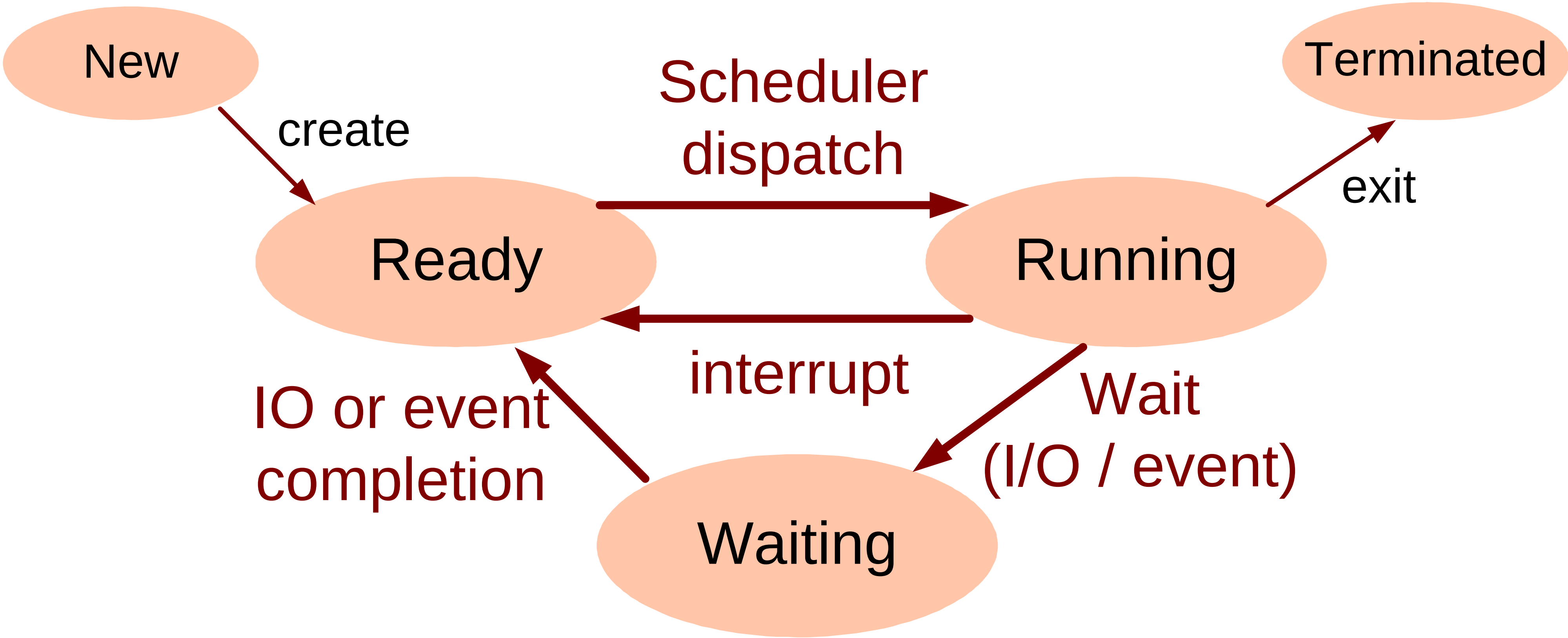


Key Hardware Performance Aspect



memory access time in case of a cache miss
200 Mhz, 5 ns cycle: 190 ns

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

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

input data HW:

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

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

Calculate the **estimated time** needed per **context switch**

Determine Expectation Quantified

instructions	memory accesses	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
100	6	

input data HW:

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

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

500 ns
1140 ns +
1640 ns

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

Calculate the estimated time needed per context switch

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

4C. Code to Measure Context Switch

Task 1

Time Stamp End
Cache Flush
Time Stamp Begin
Context Switch

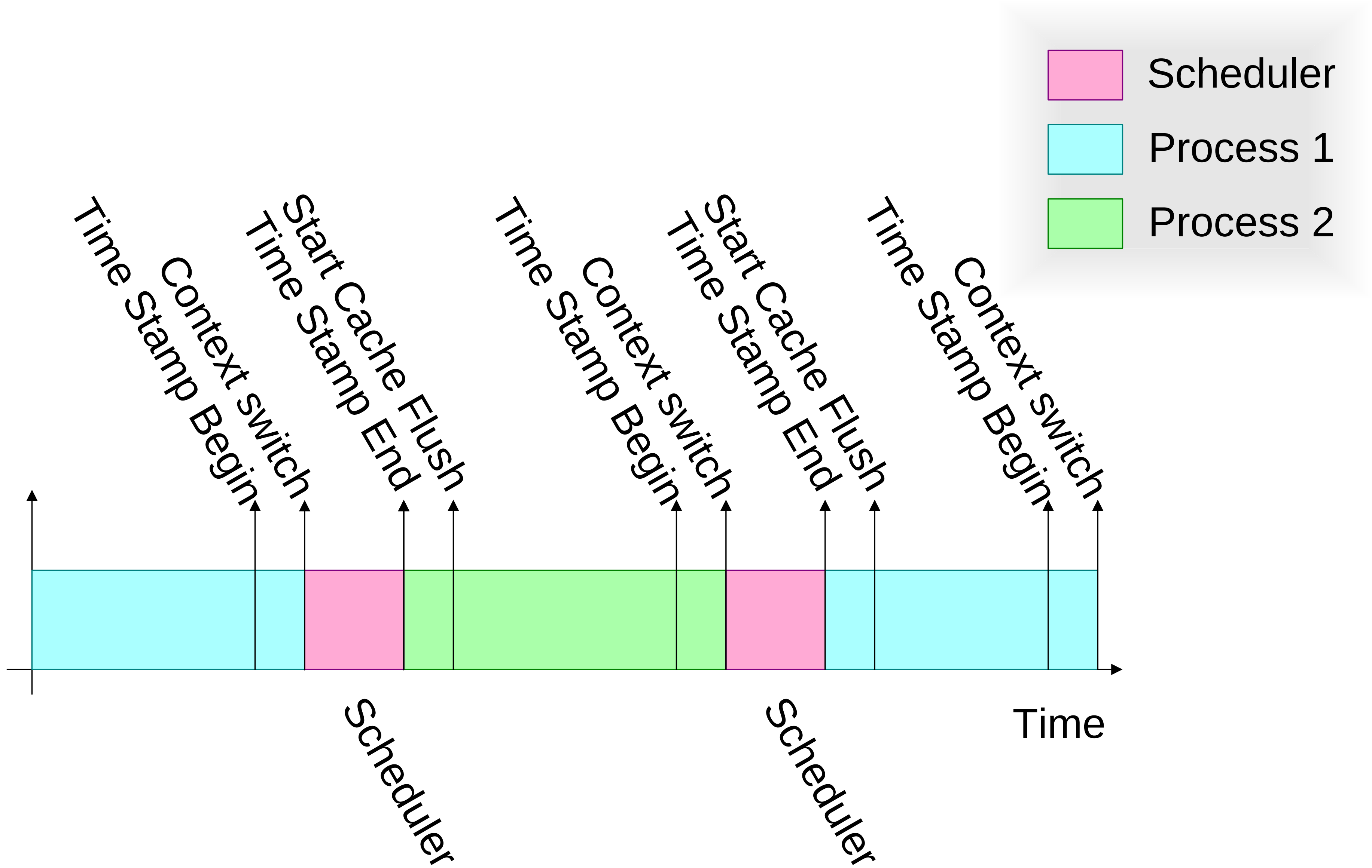
Time Stamp End
Cache Flush
Time Stamp Begin
Context Switch

Task 2

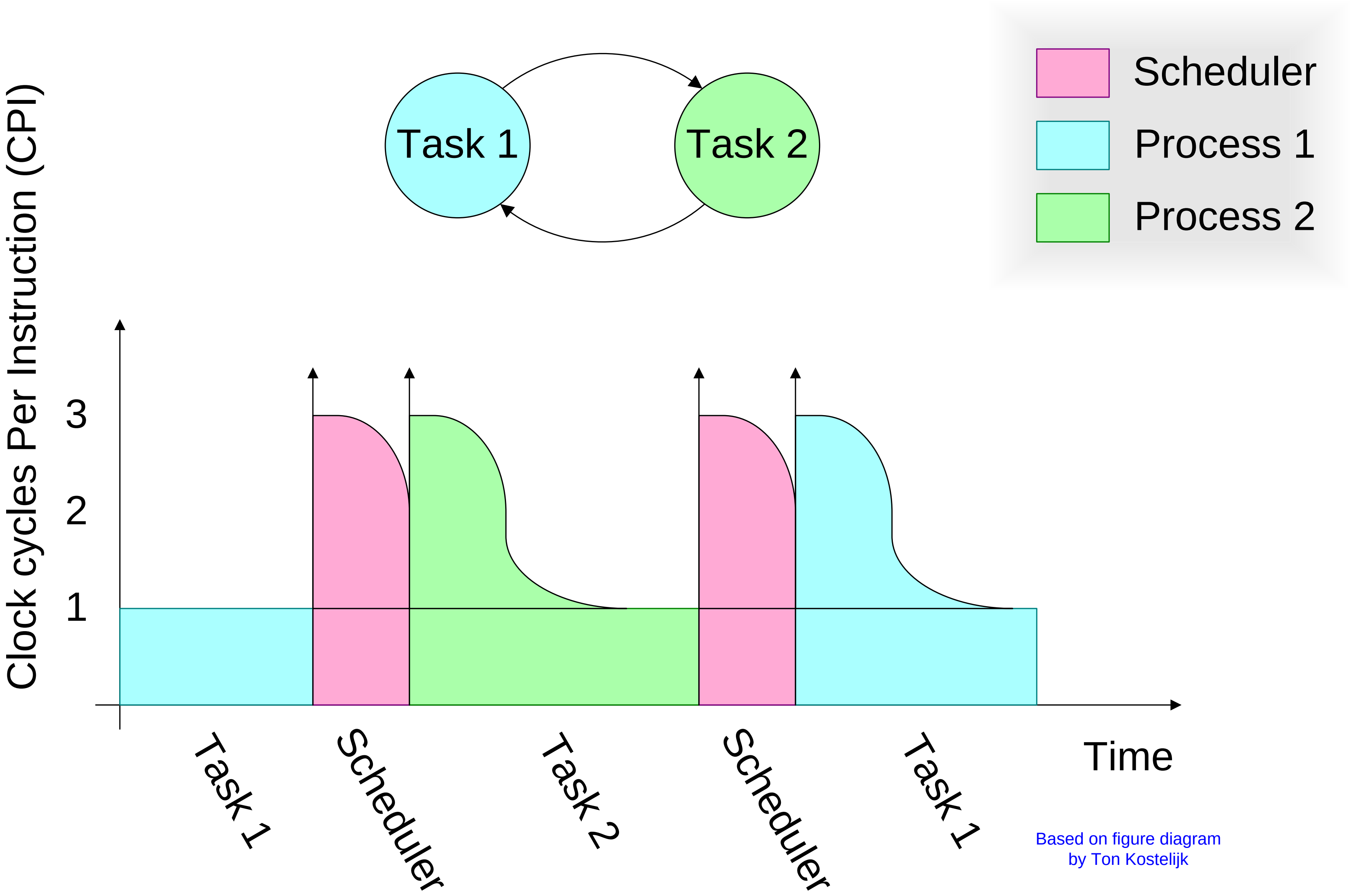
Time Stamp End
Cache Flush
Time Stamp Begin
Context Switch

Time Stamp End
Cache Flush
Time Stamp Begin
Context Switch

Measuring Task Switch Time

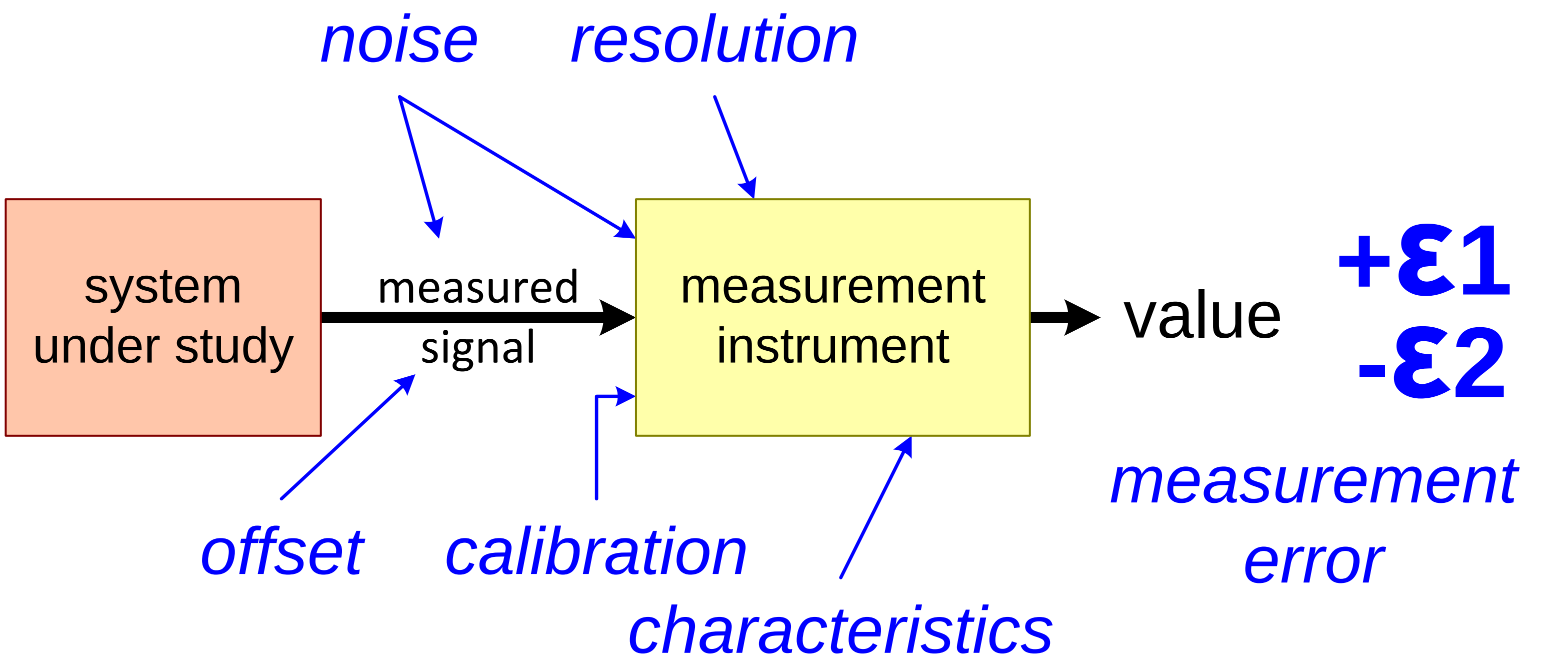


Understanding: Impact of Context Switch

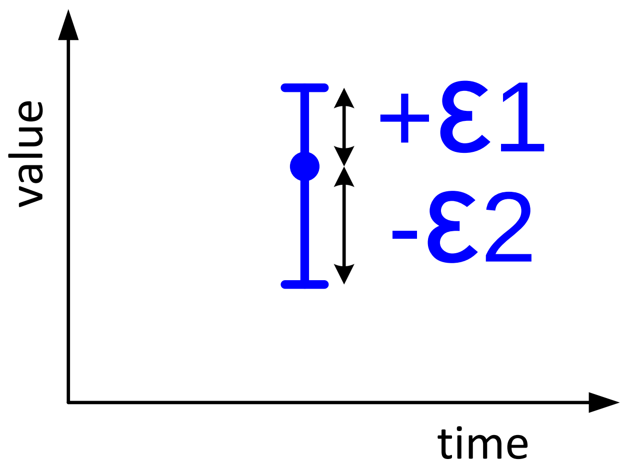


Based on figure diagram
by Ton Kostelijk

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

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

$$t_{start} = 10 \text{ +/- } 2\ \mu s$$

$$t_{end} = 14 \text{ +/- } 2\ \mu s$$

$$t_{duration} = 4 \text{ +/- } ?\ \mu s$$

systematic errors: add linear

stochastic errors: add quadratic

Intermezzo Modeling Accuracy

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.

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

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

7. Expectation versus Measurement

expected	$t_{\text{context switch}} = 2\ \mu s$
measured	$t_{\text{context switch}} = 10\ \mu s$

How to explain?

instructions	memory accesses	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
100	6	

input data HW:

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

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

500 ns

1140 ns +

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

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

$n_{context\ switch}$ (s^{-1})	$t_{context\ switch} = 10\mu s$		$t_{context\ switch} = 2\mu s$	
	$t_{overhead}$	CPU load overhead	$t_{overhead}$	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

Summary Measuring Approach

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

Colophon

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.