How to Measure RTOS Performance

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Memory Footprint

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Introduction – Why?

Desktop computers

- Infinite CPU power
- Infinite memory
- Costs nothing

Embedded systems

- Enough CPU power – just
- Adequate memory – none to spare
- Power consumption an issue
- Cost normally critical

Introduction – Choosing an RTOS

- RTOS solutions
  - Proprietary [in-house; home brew]
  - Commercial
    - At least 200 product available
  - Open source
- Asking the right questions is important
- Understanding the answers is critical
  - Pitfalls with misinterpretation

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RTOS Metrics

- Three common categories:
  - Memory footprint
    - Program and data
  - Latency
    - Interrupt and scheduling
  - Services performance
- No real standardization
  - Embedded Microprocessor Benchmark Consortium (EEMBC) not widely adopted
    - Oriented towards CPU benchmarking

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Memory Footprint

- RAM and ROM requirements of RTOS
  - On a specific platform

- ROM size:
  - Kernel code
  - Read-only data
  - Runtime library code
  - Maybe in flash; possibly copied to RAM

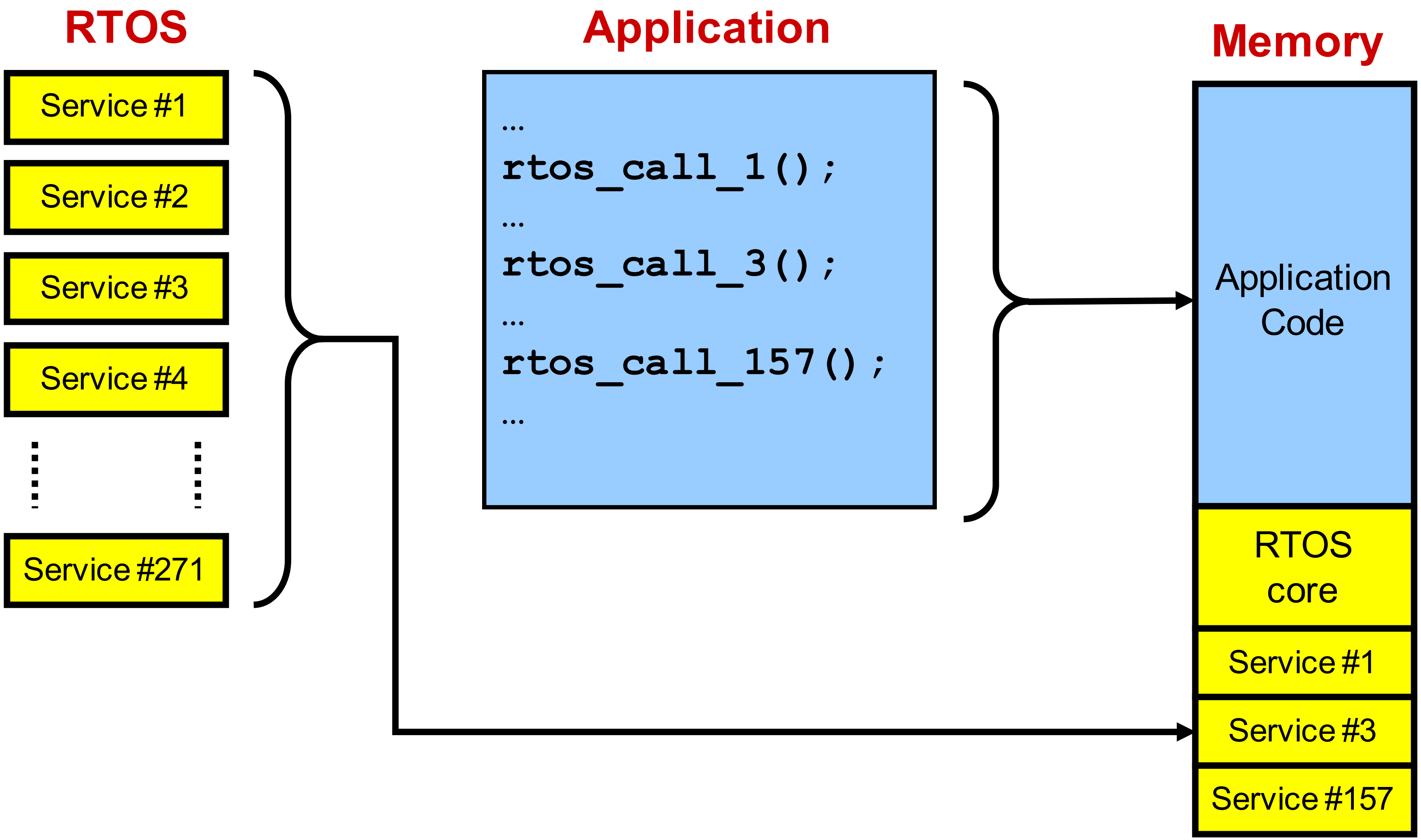
- RAM size:
  - Kernel data structures
  - Global variables
  - May need accommodate "ROM"

Memory Footprint – Dependencies

- Key factors affect the footprint calculation

- CPU architecture
  - Huge effect on number of instructions
- Software configuration
  - Which kernel components are included
  - Scalability ...
- Compiler optimization
  - Reduces code size, but may adversely affect performance

Memory Footprint – Scalability



Memory Footprint – Measurement

- Making measurement need not be difficult
- Two key methods:
  - Memory MAP file
    - Generated by standard linkers
    - Quality and detail varies between tools
  - Specific tool
    - Shows footprint information for selected executable image
    - Example: objdump

Memory Footprint – Importance

- Limited memory availability
  - Small on-chip memory
  - No external memory option
  - Application code is priority
- Larger systems
  - Kernel performance a priority
  - Place in on-chip memory
  - Lock into cache
- Using a bootloader
  - Non-volatile memory and RAM space used

Memory Footprint – Pitfalls

- Vendor data can be readily misinterpreted

- Look at minimum configuration definition
  - It may be a tiny, impractical subset
- Runtime library functions are often not included
- RAM/ROM sizes should have a min/max range
  - RAM is likely to be application dependent
  - ROM driven by kernel configuration
    - Need minimum "useable" size
    - Also maximum measure with all services
  - Scalability variable – may be different kernel versions

Memory Footprint – Example

- Nucleus RTOS kernel is fully scalable
- Example: ARM Cortex A8 in ARM mode
- Built with Mentor Sourcery CodeBench toolchain
- Full optimization for size

- ROM = 12-30 Kbytes
- RAM = 500 bytes

Memory Footprint – Example

- Min has essential kernel services [dynamic memory, threads, semaphores, events, queues]
  - Runtime library excluded
- Max includes all kernel services

- Compiling for Thumb-2 mode reduces ROM by 35%
  - So Nucleus kernel can use 7.8 Kbytes on a Cortex-M based controller

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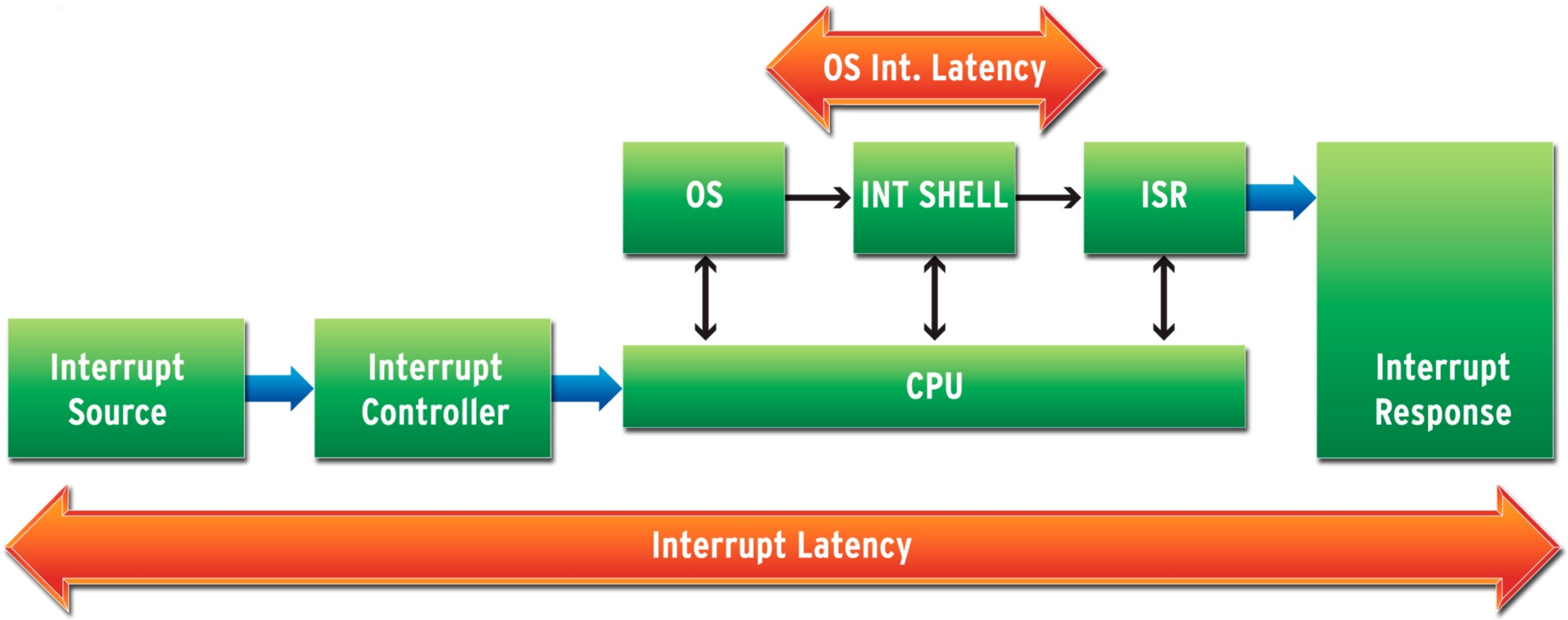
Interrupt Latency



Definitions of interrupt latency

Interrupt Latency – Definition

- Different definitions

- System: Time between interrupt assertion and the instant an observable response happens
- OS: Duration of when the CPU was interrupted until the start of the corresponding interrupt service routine (ISR)
  – This is really OS overhead
  – Many vendors refer to this as the latency
  – Hence often report zero latency

Interrupt Latency – Measurement

Interrupt response is the sum of two distinct times:

$$\tau_{IL} = \tau_{H} + \tau_{OS}$$

where:

τ_{H} is the hardware dependent time

- depends on the interrupt controller on the board as well as the type of the interrupt

τ_{OS} is the OS induced overhead

- Best and worst case scenarios
- Worst when kernel disables interrupts

Interrupt Latency – Measurement

- Best approach is to record time between interrupts source and response
  - Use an oscilloscope
  - For example:
    - One GPIO pin can generate an interrupt
    - Another pin toggled at the start of the ISR

Interrupt Latency – Importance

- Specific types of designs rely on this metric:
  - Time critical
  - Fault tolerant
- If high I/O bandwidth is needed, measure the latency of a particular interrupt
- Most systems can tolerate interrupt latency of tens of microseconds

Interrupt Latency – Pitfalls

- Main danger is interpretation of published figures

Hardware configuration

- Which platform?
- CPU speed?
- Cache configuration?
- Timer frequency?
- Interrupt controller type?

OS configuration

- Where is code running from? [Flash, SDRAM ...]
- Which interrupt used?
- Code optimized for speed?
- Is metric best or average case?

Interrupt Latency – Example

- Nucleus RTOS
  - ARM Cortex A8
  - 600MHz
  - Running from SRAM
- Average interrupt latency of less than 0.5 microseconds

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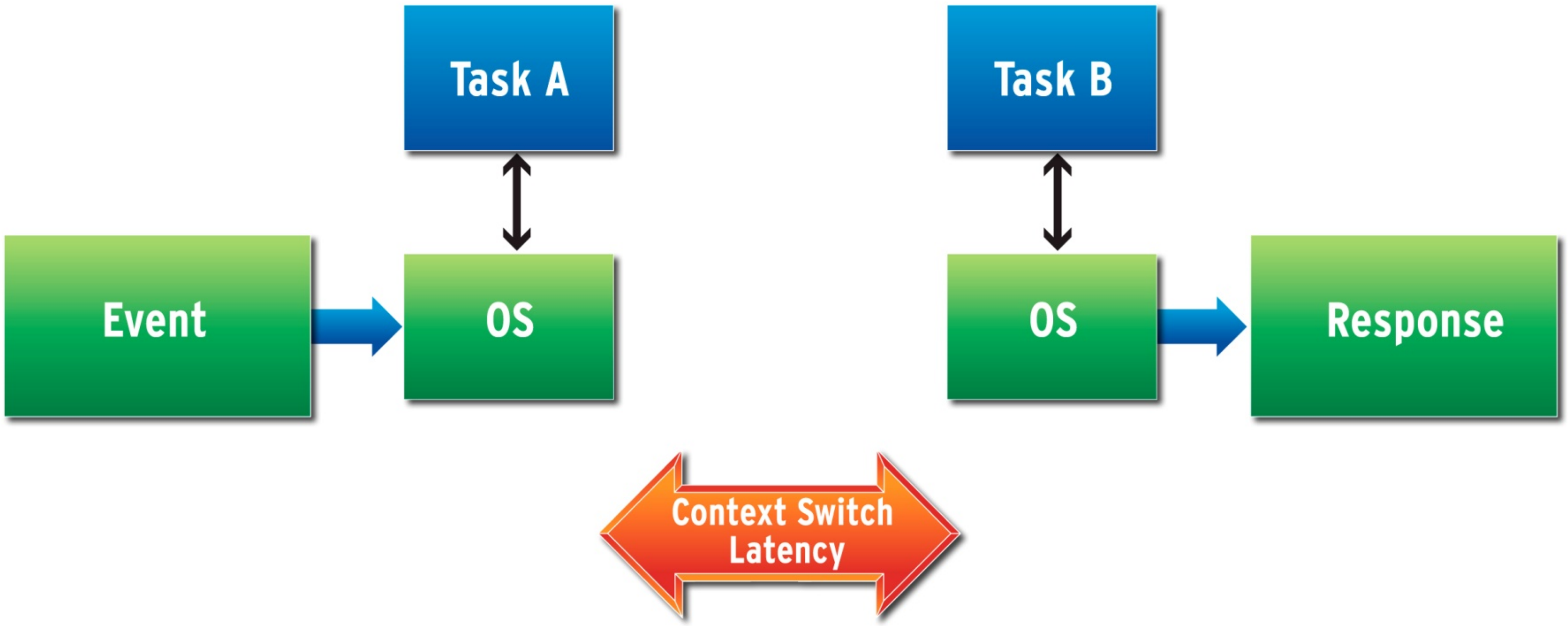
Scheduling Latency – Definition

- Performance of RTOS thread scheduler
- Very wide variation in measurement technique and interpretation
- Two distinct related quantities:
  - Context switch time
  - Scheduling overhead

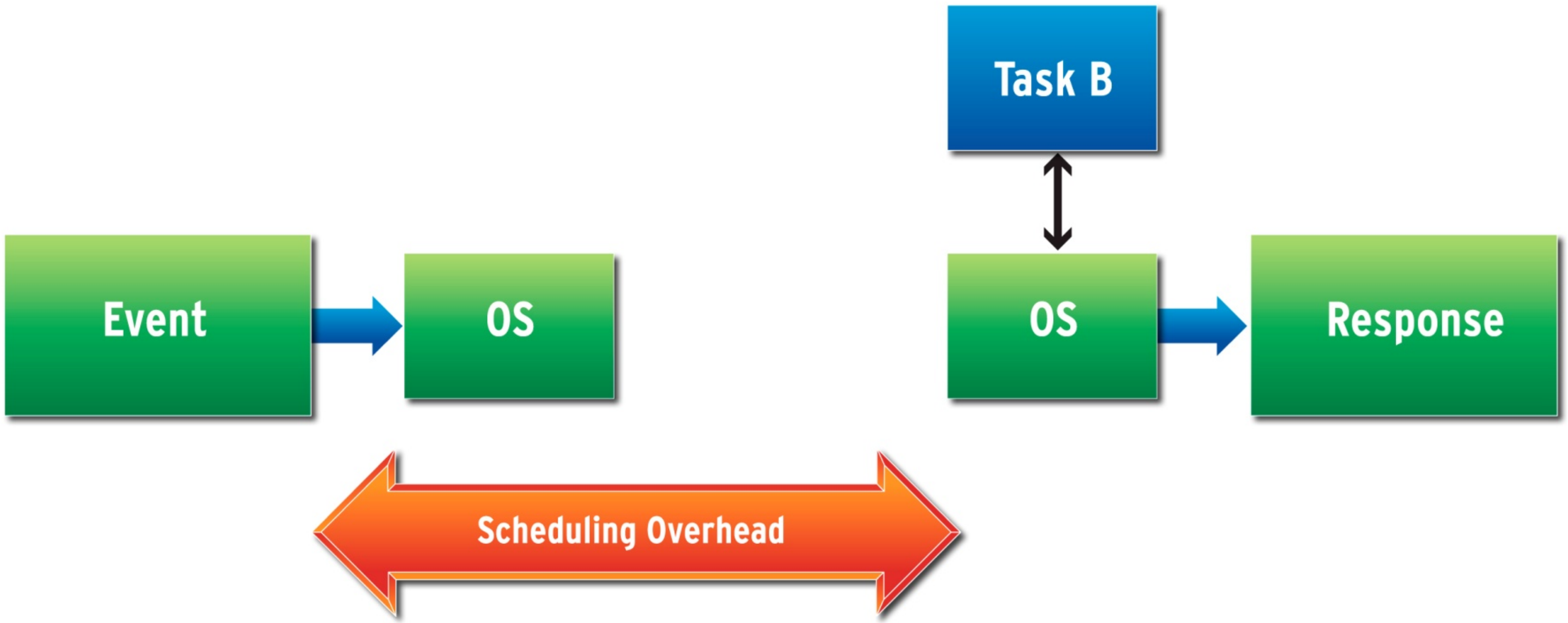
Scheduling Latency – Definition

Context switch time



Scheduling Latency – Definition

Scheduling overhead



Scheduling Latency – Measurement

Scheduling latency is the maximum of two times:

$$\tau_{SL} = MAX(\tau_{SO}, \tau_{CS})$$

where:

- τ_{SO} is the scheduling overhead
  - End of ISR to start of task schedule
- τ_{CS} is the time taken to save and restore thread context

Scheduling Latency – Importance

- Most systems that have stringent interrupt latency demands also need low scheduling latency
- Broadly, systems that are:
  - Time critical
  - Fault tolerant

Scheduling Latency – Pitfalls

- Ignoring initial system state
  - If system is idle, there is no time taken saving context

Hardware configuration

- Which platform?
- CPU speed?
- Cache configuration?
- Timer frequency?
- Interrupt controller type?

OS configuration

- Where is code running from? [Flash, SDRAM ...]
- Which interrupt used?
- Code optimized for speed?
- Is metric best or average case?

Scheduling Latency – Example

- Nucleus RTOS
  - ARM Cortex A8
  - 600MHz
  - Running from SRAM
- Scheduling latency is 1.3 microseconds

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Timing Kernel Services

- RTOS may have a great many API calls
- Timing of keys ones may be of interest
  - Focus on frequently used API calls
- Four key categories:
  - Threading services
  - Synchronization services
  - Inter-process communication services
  - Memory services

Timing Kernel Services

Threading Services

- Control of fundamental kernel functionality:
  - Create thread
  - Start thread
  - Resume thread
  - Stop thread
- Many multi-taking applications make heavy use of these calls

Timing Kernel Services

Synchronization Services

- Services to synchronize between contexts, like an ISR and a thread
- Also protection of critical code sections from concurrent access
  - e.g. Semaphore may be used by Ethernet ISR to write data into shared memory that is also used by a task
- Timing is important is the application has numerous shared resources or peripherals

Timing Kernel Services

Inter-process Communication Services

- Services to share data between multiple threads
- Examples:
  - FIFOs
  - Queues
  - Mailboxes
  - Event flags
- Many multi-taking applications make heavy use of this type of service

Timing Kernel Services

Memory Services

- In a multi-threaded context, kernel is used to manage dynamic memory
- Allocation and de-allocation times are important
  - Applications with large data throughput are particularly sensitive

Timing Kernel Services – Pitfalls

- Hardware configuration
  - Which platform?
  - CPU speed?
  - Cache configuration?
- OS configuration
  - Where is code running from? [Flash, SDRAM ...]
  - Code optimized for speed?
  - Is metric best or average case?
  - Is kernel configured for reduced error checking?

Timing Kernel Services – Example

Nucleus RTOS Kernel Service	Time in µS
Task resumption	0.3
Task suspension	0.3
Obtaining a semaphore	0.5
Set an event	0.4
Send message to queue	0.9
Allocate memory	0.2
De-allocate memory	0.7
Allocate partition	0.4

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Conclusions

- RTOS performance data provided by vendors can be useful
- It can also be misleading if it is misinterpreted
- Need a thorough understanding of:
  - Measurement techniques
  - Terminology
  - Trade-offs

  to conduct fair comparison
- Recommendation is to rely on holistic or application-oriented measurements

Thank you

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