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Executive Summary of the EvaluationReport of Windows CE 3.0 from Microsoft Corporation

Dedicated Systems Experts submitted Windows CE 3.0 to its recently expanded test suite. Aside from the standard real-time performance tests, the suite now includes stress tests that deal with nested interrupts, simultaneous interrupts, memory leaks, etc.

1 INTRODUCTION

Dedicated Systems Experts submitted Windows CE 3.0 to its recently expanded test suite. Aside from the standard real-time performance tests, the suite now includes stress tests that deal with nested interrupts, simultaneous interrupts, memory leaks, etc. A detailed description of the tests executed can be found in the document titled "report definition and test plan", which can be freely downloaded from the download center at http://www.dedicated-systems.com/encyc/.

2 ARCHITECTURE

Windows CE 3.0 is very scalable. The system is built from a set of discrete modules, each providing a specific functionality. Several of these modules are divided into components, which can be individually selected. (See Figure 1)

2.1 Tasks

Windows CE is a multi-process and multi-thread system. A thread represents a path of execution in a process. Every time the OS creates a process, it creates at least one thread for it. Every thread in a process shares all of the process's resources, including its address space. (See Table 1)

	Windows CE 3.0
Model	Processes and Threads
Priority levels	256 levels
Max. number of tasks	The maximum number of threads in a process is only limited by the amount of memory available. Windows CE can run a maximum of 32 processes simultaneously.
Scheduling policies	Round-robin with adjustable time-slice (quantum)When the quantum is set to zero, the thread runs to completion
Number of documented states	5 states (running, suspended, sleeping, blocked, and terminated).

Table 1. Windows CE 3.0 task handling properties.

All of the OS threads can be run in either kernel mode or user mode. While running threads in kernel mode will leave the entire system vulnerable, it also enables increased performance. This is because Windows CE bypasses security features that can prevent a thread from entering kernel mode. This may be acceptable in a closed environment, but in an open environment this can have dramatic effects that an OEM must consider.

2.2 Memory

In Windows CE 3.0, every process has its own virtual memory space. The address space is sliced up in 33 slots of 32MB, with slot 0 reserved for the currently running process. So the 32MB slice of virtual memory for the currently running process is in two places: in its slot among the 32 available slots and in slot 0 for the active process. If a process requires more than 32MB of memory, it can be allocated through memory-mapped files. (See Table 2)

	Windows CE 3.0
MMU	Yes
Physical page size	Either 1KB or 4KB, depending on the system
Paging/Swapping	Supported, but can be disabled to achieve real-time performance.
Virtual memory	Yes
Memory protection models	Full virtual memory protection. Each process runs in its own virtual memory space.

Table 2. Windows CE 3.0 Memory Management properties.

2.3 Interrupts

Windows CE uses a thread interrupt model to encourage most of the interrupt handling to be handled in the interrupt service thread (IST), instead of in the interrupt service routine (ISR).

The OEM can also use the ISR to perform a minimal amount of work. There is however no API to hook an ISR. The ISR can only be accessed by modifying the OAL (OEM Adaptation Layer). (See Table 3)

	Windows CE 3.0
Handling	Nested and prioritizedCE uses a thread interrupt model to encourage the use of threads to handle most of the interrupt service work. OEMs can access ISR also to perform a minimal amount of work.
Context	The ISR runs in a special context and uses virtual addresses statically mapped by the OEM.The IST is a normal application thread and has its own context.
Stack	The IST is a normal application thread and has its own stack.
Interrupt-to-task communication	Only an event can be used from within the ISR to signal the IST. No other API is accessible from within the ISR. OEM can create a shared memory region by statically mapping a memory region into the ISR's address space

Table 3. Windows CE 3.0 Interrupt handling properties.

3 API RICHNESS

To assess the API richness, we created a list of features for the most common system calls and compared it with the available system calls in Windows CE 3.0. Table 4 gives an overview of all the categories and the score (in percentage points) obtained. For a breakdown of the categories into individual features and system calls, the reader is referred to the evaluation report.

This table should not be misunderstood. Windows CE 3.0 uses a subset of the Win32 API. The Win32 includes a lot of system calls that pertain to features beyond the scope of this study, and are therefore not included in Table 4.

Mechanism	Richness
Thread Management	71%
Clock	86%
Interval Timer	67%
Fixed block size memory partition	0%
Non-fixed block size memory pool	69%
Interrupt Handling	38%
Counting Semaphore	80%
Binary Semaphore	0%
Mutex	67%
Conditional Variable	0%
Event Flags	75%
POSIX Signals	0%
Message Queue	69%
Mailbox	0%
AVERAGE PERCENTAGE	**44%**

Table 4. API Richness.

An average percentage of 44% was obtained. The average percentage does not include any weight factors. It is simply the average of each category's score.

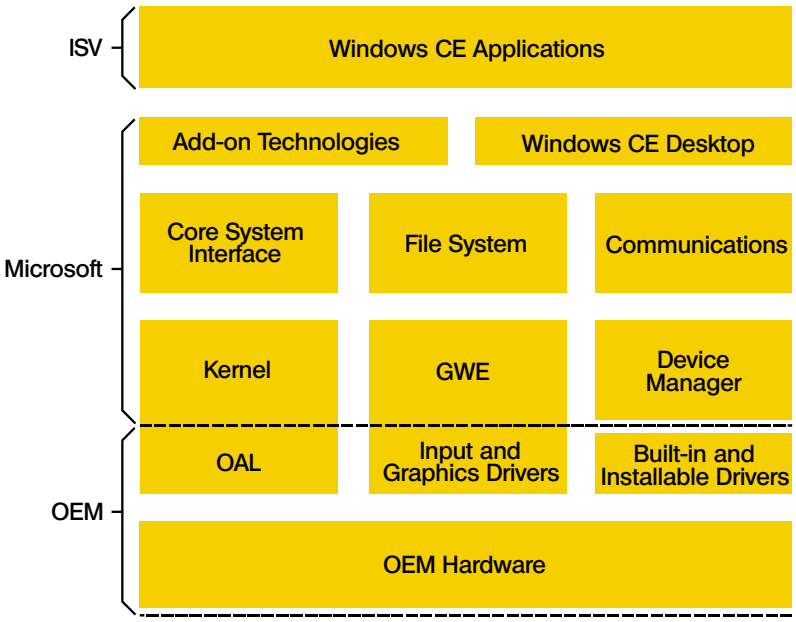

Figure 1. Windows CE architecture.

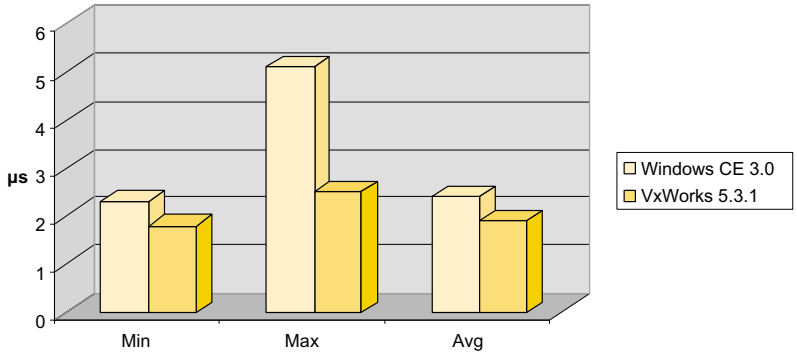

Figure 2. ISR Latency - Windows CE 3.0.

4 PERFORMANCE TESTS

4.1 Interrupt latencies

As was mentioned earlier, Windows CE uses a thread interrupt model i.e., the standard way to "hook" an interrupt by means of an API call results in an IST (Interrupt Service Thread) that responds to the interrupt. Naturally, an OEM can also use the ISR (Interrupt Service Routine) by modifying the OEM adaptation layer.

For this test, we measured the interrupt latency on both ISR and IST level. The interrupt latency is the time elapsed between the execution of the last instruction of the interrupted thread and the first instruction in the interrupt handler.

Figure 2 displays the result for the interrupt latency on ISR level, the ISR latency, and compares it with the ISR latency of VxWorks/x86 5.3.1 from WindRiver Systems, Inc.

Figure 3 displays the result for the IST latency, and compares it with the IST latency of RTX 4.2, a Windows NT real-time extension from Venturcom that also uses a thread interrupt model.

4.2 Priority inheritance

Windows CE 3.0 has a priority inheritance mechanism, which is essential for an RTOS. We tested this by creating a situation with 3 threads where the priority inversion problem occurs: a high priority thread wants to acquire a mutex that is owned by a low priority thread. A medium priority thread keeps the low priority thread from running and releasing the mutex so that the high priority thread can't acquire it.

For a detailed description and flow chart of the test, the reader is referred to the document "report definition and test plan", which can be downloaded from the visitor's center at (http://www.dedicated-systems.com/encyc).

In this test, we measured the time it takes for the highest priority thread to acquire the mutex. That time includes the time it takes to boost the priority of the lowest priority thread, have it release the mutex, and switch back to the highest priority thread so it can acquire the mutex. The results for the test are displayed in Figure 4. The results of VxWorks/x86 5.3.1 are included for the sake of comparison.

5 TOOLS & DEVELOPMENT METHOD

Platform builder is an integrated set of tools that lets OEMs create custom Windows CE platforms. Aside from this platform development tool, Microsoft also provides the Embedded Visual Tools for application development.

Platform builder includes support for a variety of hardware target platforms, like ARM, MIPS, PowerPC, SH or Intel x86 based platforms. Platform builder provides the most commonly used tools. Aside from the basic tools like compilers and debuggers, it includes a source code control system, various analysis tools and even tools to measure real-time performance.

The Platform Builder can be used to create a custom SDK (Software Development Kit) based on the Windows CE OS to allow developers to write applications that run on the target platform. An SDK is a set of

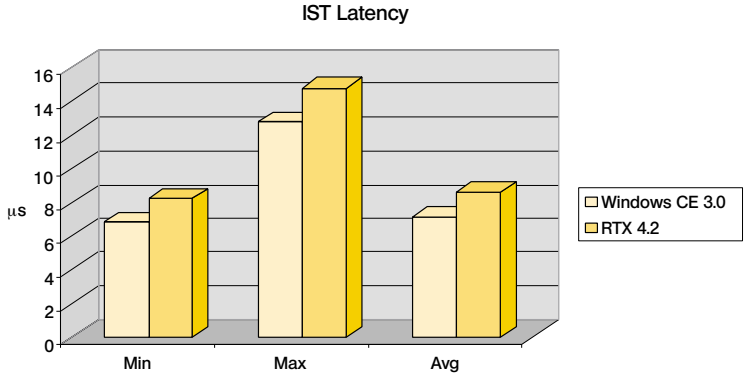

Figure 3. IST Latency - Windows CE 3.0.

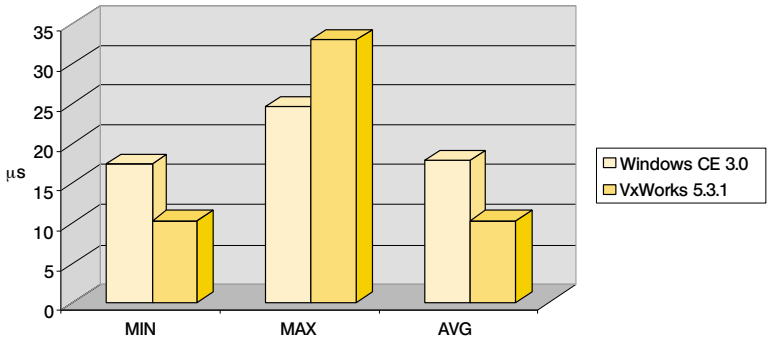

Figure 4. Priority Inheritance.

library, header, and Help files that developers use to write applications for a specific platform. The SDK is used in conjunction with the Embedded Visual Tools to create, debug and run custom applications.

6 Documentation & support

Windows CE comes with an online documentation set. This documentation contains a lot of information, but it is not presented in a very structured way. The documentation can easily be used as a reference, but is less appropriate as a tutorial. Newcomers will have a hard time acquiring an overview of the system if this is the only documentation they have at their disposal. It also lacks in-depth information about the inner workings of the system. Documenting the APIs and available features is not enough to provide the reader with a sufficient understanding of a complex system like Windows CE 3.0.

Microsoft provides an extensive knowledge base on its MSDN website, which can be freely consulted. Premier support for OEMs is available against payment.

7 CONCLUSION

Windows CE 3.0 exhibited true real-time behavior during most of the tests that were executed. The test suite also included stress tests, which were handled fine by CE 3.0. Readers who are interested in a detailed assessment of the real-time capabilities and robustness of Windows CE 3.0 are referred to the evaluation report.

8 OTHER PUBLICATIONS AND SERVICES

Dedicated Systems Experts has also evaluated VxWorks/x86 5.3.1, QNX 4.25 and pSOSystem/x86 2.2.6, as well as various real-time extensions to Windows NT 4.0.

The evaluation reports are intended for everyone who is in one way or another involved with dedicated systems technology. This obviously includes the system design engineers and application developers, who need to have a detailed understanding of how the product behaves in a real-time environment. However, the audience also includes managers and project leaders who need to make strategic decisions such as which RTOS to use, and how it will affect the overall execution of the project.

Finally, Dedicated Systems Experts also performs feasibility studies and product validations on customer demand. Please contact our offices for additional information ■

Bart Van Beneden has been with Dedicated Systems Experts since 1998 where he is involved in the RTOS evaluation program of Dedicated Systems Magazine as a project manager. He received his degree in computer science at the Free University of Brussels. Before joining Dedicated Systems Experts, he designed multimedia applications at LaserMedia Inc.