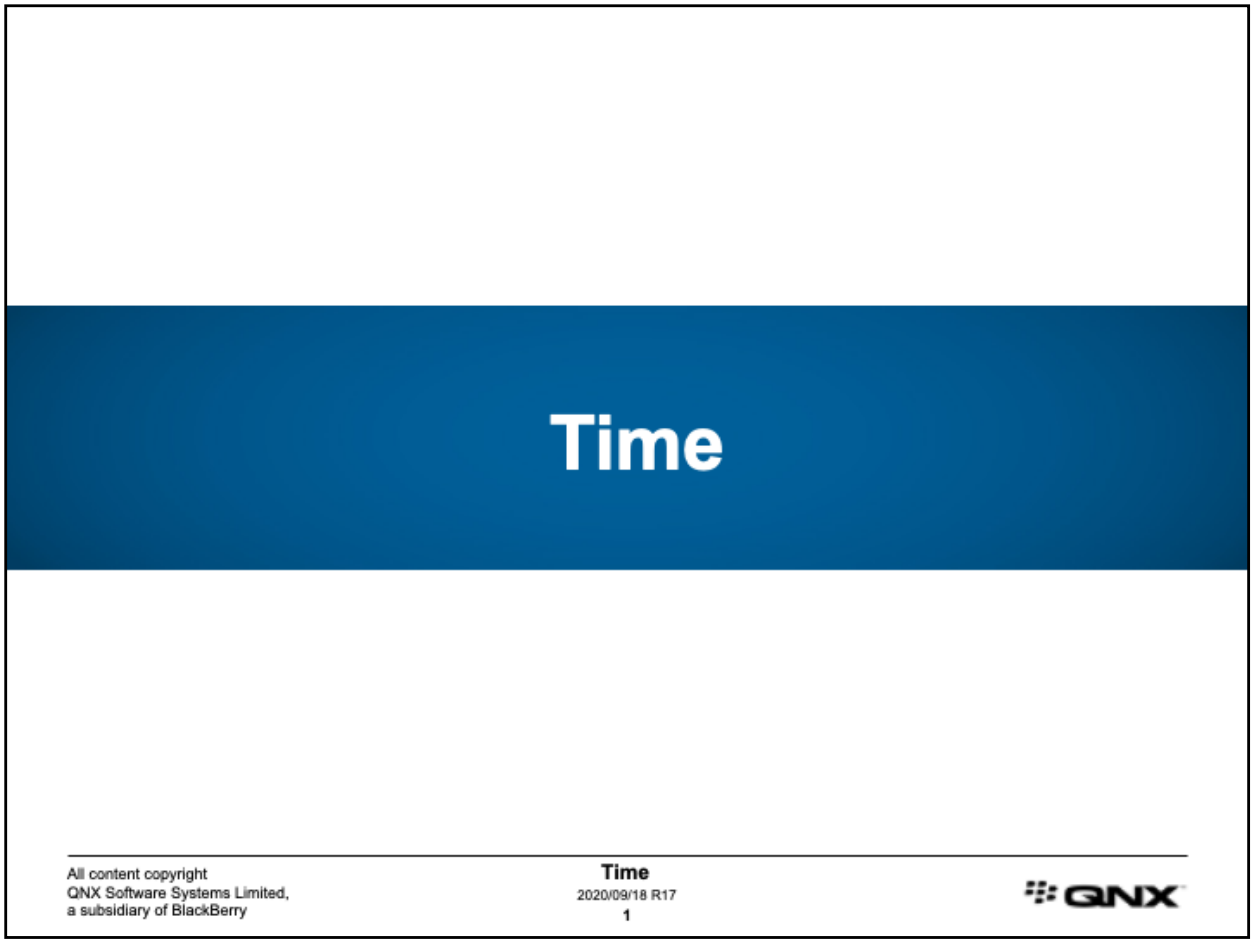


NOTES:

Introduction

You will learn how:

- QNX Neutrino handles time
- to read and update the system clock
- to use system timers and kernel timeouts

NOTES:

Time

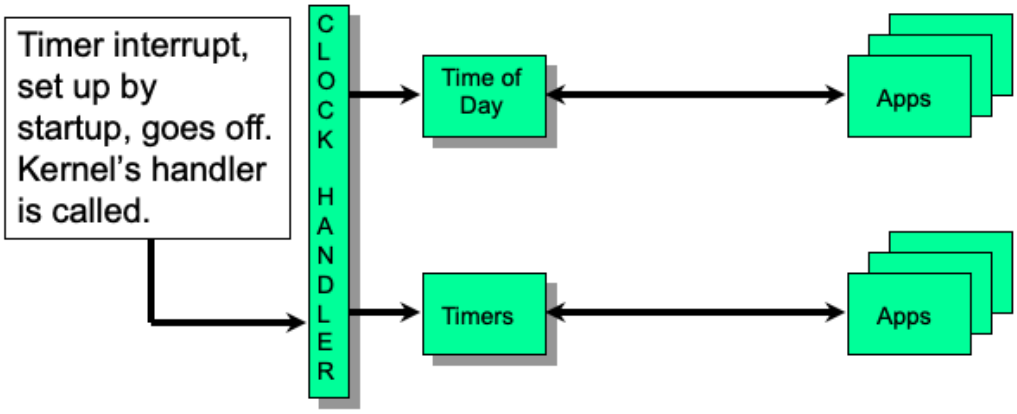
Topics:

- **Timing Architecture**
- **Getting and Setting the System Clock**
- **Timers**
- **Tolerant and High-Precision Timers**
- **Design Considerations**
- **Kernel Timeouts**
- **Conclusion**

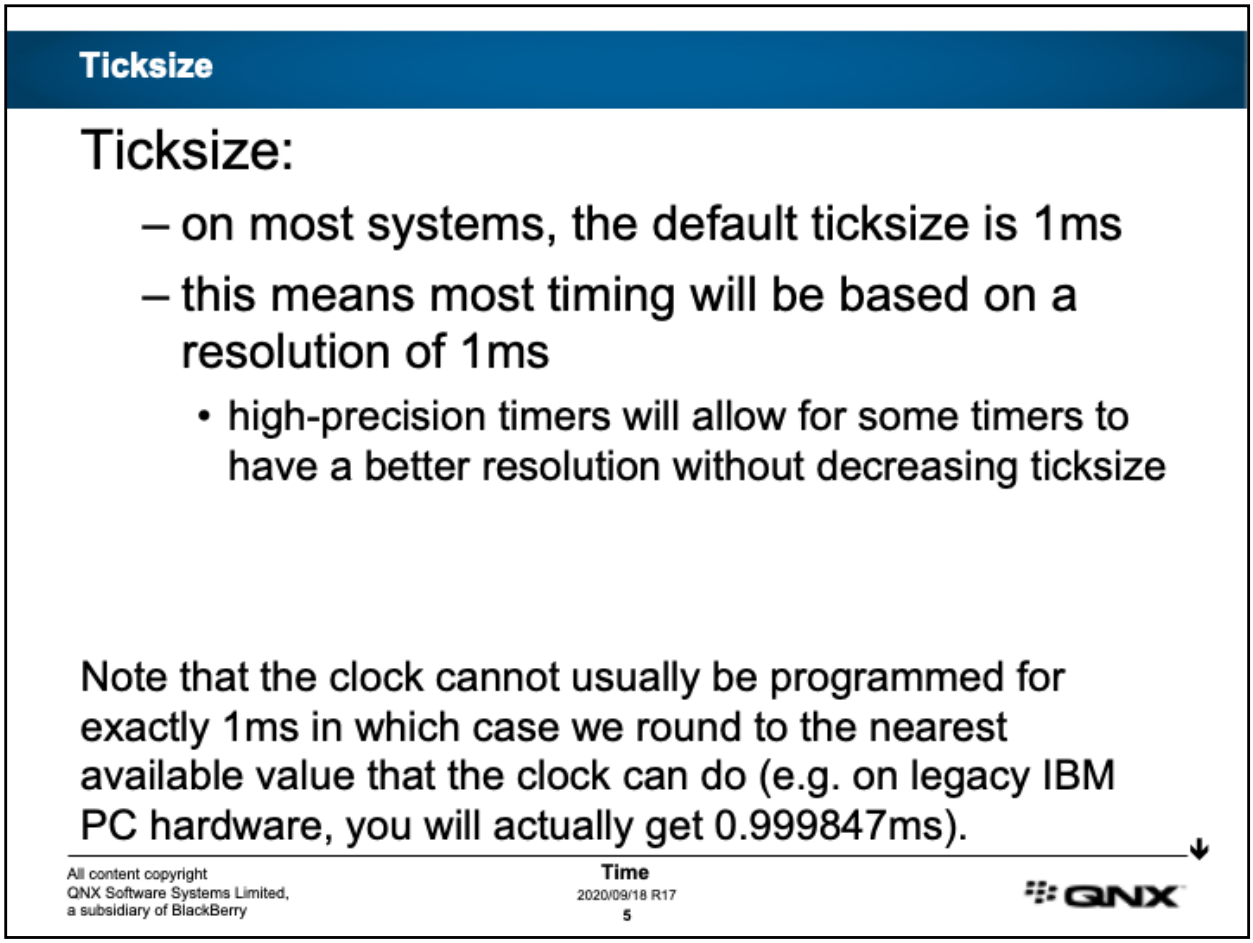
NOTES:

Concepts

QNX® Neutrino®'s Concept of Time:



NOTES:



NOTES:

Ticksize has a variety of names -- it can also be referred to as timebase, clockperiod, clock resolution and others.

The kernel will most likely not provide exactly the nominal value because the rate is derived from the crystal oscillator, and is divided by an INTEGER divisor.

On very slow systems (if your processor is < 40MHz) then the default ticksize is 10ms.

Time Slice

The time slice:

- is 4 times the ticksize so it defaults to 4ms
- the multiplier, 4, cannot be changed. If you change the ticksize then the time slice will also change

NOTES:

The timeslice affects two things, round robin scheduling and SMP global rescheduling. The size of the timeslice is usually not an issue, as threads don't usually run for their entire time slice before blocking.

The QNX timer used to use the 8254 as the hardware timer on x86. Currently on x86, we look for a LAPIC, then HPET, and then for an 8254. See the –z option for **`startup-*`** to control this.

Timing Examples

Let's examine how timing works by looking at some examples:

- we'll have two threads, t1 and t2, both READY at priority 10, both doing round-robin
- t2 will go to sleep for 10.5ms (a relative time)
- when t2 goes to sleep, the kernel figures out when to wake it up using this formula:

```
wake_up_time = now + requested_time + 1 tick
```

(where **now** is really the time as of the last tick)

NOTES:

Why does the kernel add 1 tick extra? Because according to POSIX you cannot sleep for less time than you ask for. The kernel has no idea what the time is in between ticks. In the formula above, **now** is actually the time as of the last tick. If we didn't add an extra tick then you could end up sleeping for less time than you asked for.

Timing Example 1

Keep in mind the following:

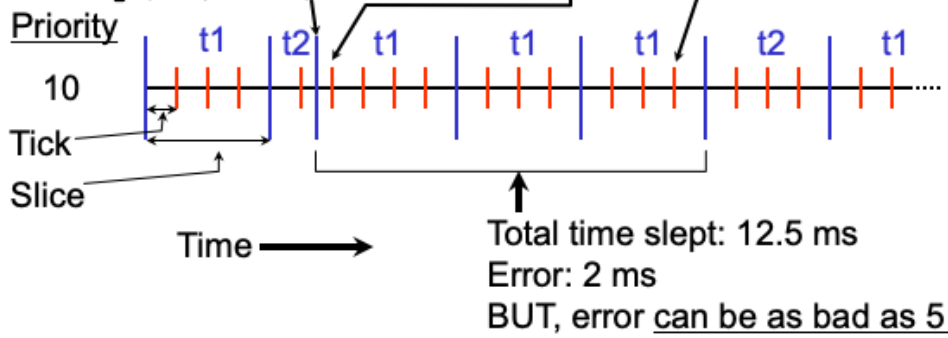
1. At every tick the kernel checks for expired timers.
2. If a thread's timer has expired then the kernel puts that thread at the end of the READY queue for that thread's priority.

For the expiry time, the kernel adds 10.5 ms to whatever time it will be here

t2's timer has expired. t2 is put at the end of priority 10's READY queue, BUT t1 still runs

t2 does:

```
t.tv_nsec = 10500000;
nanosleep(&t,NULL);
```



Total time slept: 12.5 ms
Error: 2 ms
BUT, error can be as bad as 5 ms!

QNX

NOTES:

The *nanosleep()* function puts a thread to sleep for some number of milliseconds:

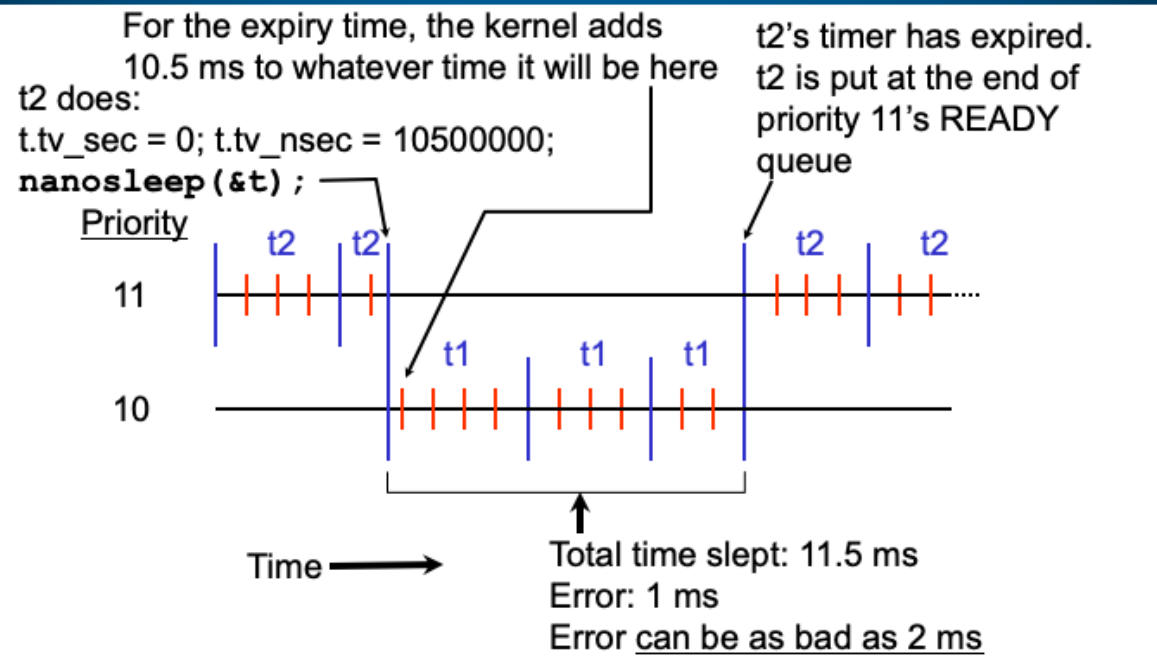
```
nanosleep( struct timespec *requestedtime,
           struct timespec *timeremaining);
```

Notice that in the example above, we asked to sleep for 10,500,000 nsecs which is 10.5 msecs.

Note that the above is an idealized diagram. On an IBM PC, a 1ms tick would really be 0.999847ms.

If a timer expires and makes a thread ready and a time slice is expiring, the thread is made ready by the timer first, then the time slice expiry is applied.

Timing Example 2



Don't forget. A higher priority thread can preempt all of this and interrupt handlers can preempt even those.

NOTES:

To improve the timing further, you could make the ticksize smaller. Keep in mind though that the tick really represents the kernel's interrupt handler for the timer interrupt. By decreasing the ticksize you are increasing the frequency of this interrupt and therefore increase interrupt and scheduling latencies and system overhead.

Ticksize

From code we can change the ticksize

– Let's change it to 100 us (.1 ms):

```
struct _clockperiod newval, oldval;

newval.nsec = 100*1000;       // 1e5 ns = .1 ms
newval.fract = 0;             // reserved, must be 0
ClockPeriod (CLOCK_REALTIME, &newval, &oldval, 0);
```

– the **oldval** parameter allows you to query the ticksize

☞ You must have **PROCMGR_AID_CLOCKPERIOD** to change the ticksize as it is a system wide setting.

NOTES:

Again, the kernel will most likely not be able to provide exactly .1 ms timing; it will round to the nearest available clock period. To find out what actual ticksize you got, call `ClockPeriod( CLOCK_REALTIME, NULL, &curval, 0);` after making your change.

The ticksize is a system wide configuration. You would normally set it once as part of your system initialization to whatever you have chosen.

Time

Topics:

- Timing Architecture
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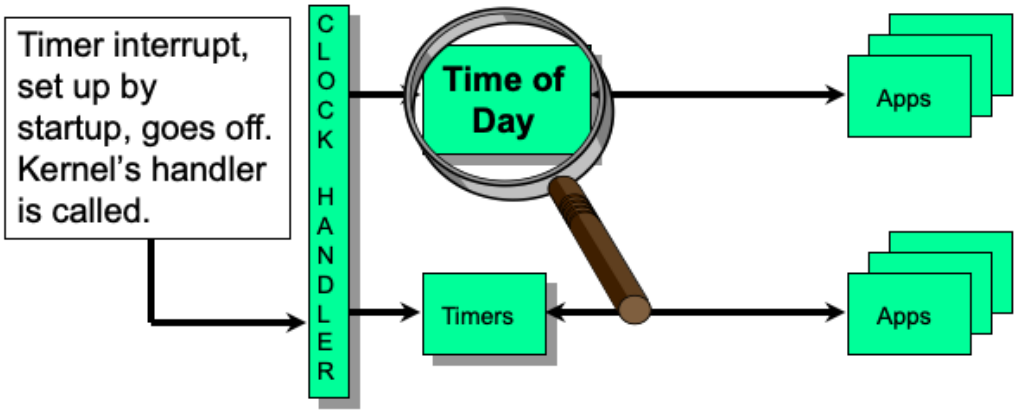
NOTES:

Clock Concepts

Let's look at the time of day functions:



NOTES:

The system clock is often referred to as the "time of day" clock.

Time Representation

QNX Neutrino time representation:

- internally stores time as 64-bit nanoseconds since 1970
  - this is actually stored as two 64-bit nanosecond values:
    - nanoseconds since boot
    - boot time since Jan 1, 1970
- POSIX functions uses a struct timespec
  - specified as seconds since Jan 1, 1970 and nanoseconds since last second
  - in 32-bit, QNX defines seconds as **`_Uint32t`**
  - in 64-bit, QNX defines seconds as **`_Int64t`**

NOTES:

When do these expire? (That is, when do the values wrap to 0/negative).

POSIX 32-bit seconds, if interpreted as a signed value (historically common case), wraps to negative in 2038.

POSIX 32-bit unsigned seconds wraps in 2106.

QNX unsigned 64-bit nanosecond value is valid past 2500.

The fact that the **`time_t`** (seconds) changes from an unsigned 32-bit value in 32-bit compilation to a signed 64-bit value in 64-bit compilation makes *printf()* format for time values tricky to get correct, and may require **`#if`** or **`#ifdef`** in code.

Keeping Track of Time

At bootup time:

- the kernel is given the current date and time from somewhere (battery backed up clock as on a PC, GPS, NTP, some atomic clock, ...)
- from then on, every tick, the kernel adds the ticksize to the current time
  - e.g. for a 1ms tick, every 1ms the kernel adds 1ms to the current time

NOTES:

Actually, the kernel adds the real (nanosecond) value of the ticksize on each tick, not the "rounded" 1ms value that might have been requested.

NTP stands for Network Time Protocol and is a way of getting time over a network (often from an atomic clock).

Read and/or Set the System Clock:

```
struct timespec tval;

clock_gettime( CLOCK_REALTIME, &tval );
tval.tv_sec += (60*60)*24L; /* add one day */
tval.tv_nsec = 0;
clock_settime( CLOCK_REALTIME, &tval );
```

- You must have **PROCMGR_AID_CLOCKSET** to change the system time.

NOTES:

Clocks

We can adjust the time:

– Bring it forward by one second:

```
struct _clockadjust new, old;

new.tick_nsec_inc = 10000; // 1e4 ns == 10 µs
new.tick_count = 100000;   // 100k * 10µs = 1s
ClockAdjust (CLOCK_REALTIME, &new, &old);
```

– Bring it backward by one second:

```
new.tick_nsec_inc = -10000;// 1e4 ns == 10 µs
new.tick_count = 100000;   // 100k * 10µs = 1s
ClockAdjust (CLOCK_REALTIME, &new, &old);
```

In both above examples the total adjustment will usually take 100 seconds (100k ticks (for a 1 msec tick size) = 100 seconds).

☞ As this changes the system time, it also requires **PROCMGR_AID_CLOCKSET**.

NOTES:

Rule of thumb:

Do not adjust the clock by more than 1% of the tick size, otherwise distortion from the “real” world would be too great. Definitely don’t adjust more than the ticksize, especially in the negative direction as this would result in time going backwards.

Miscellaneous

QNX provides a free running counter:

```
uint64_t count;
count = ClockCycles ();
```

- It returns increments of the **cycles_per_sec** available from the system page (see below).
- On a system with supporting hardware we use it
  - e.g. **rdtsc** op code on x86 machines
  - these often increment at processor clock speed, e.g on a 500 MHz processor it returns increments of 2 ns (1/2 ns on 2 GHz, etc.)
- On a processor that does not have a free running counter, we fake it
  - these mostly don't get used anymore (e.g. 80486)

To find out how many cycles per second this clock is running at:

```
#include <sys/syspage.h>
uint64_t  cycles_per_sec;
cycles_per_sec = SYSPAGE_ENTRY(qtime)->cycles_per_sec;
```


NOTES:

While a 64-bit value incremented at 2 GHz would take approximately 272 years to wrap, on other processors there may only be a 32-bit counter available, in which case wrapping is a possibility. This may need to be taken into account.

Accessing the system page is discouraged except in cases where the information cannot be found anywhere else.

EXERCISE

Exercise:

- in your **`time`** project
- look at **`calctime1.c`**, and run it
  - what do the first set of delta values represent?
  - what would you do to figure out how long each iteration of the second **`for`** loop takes in microseconds?
- modify **`calctime2.c`** to adjust the ticksize to be ½ millisecond (500 us)

NOTES:

Time

Topics:

- Timing Architecture
- Getting and Setting the System Clock
- → Timers
- Tolerant and High-Precision Timers
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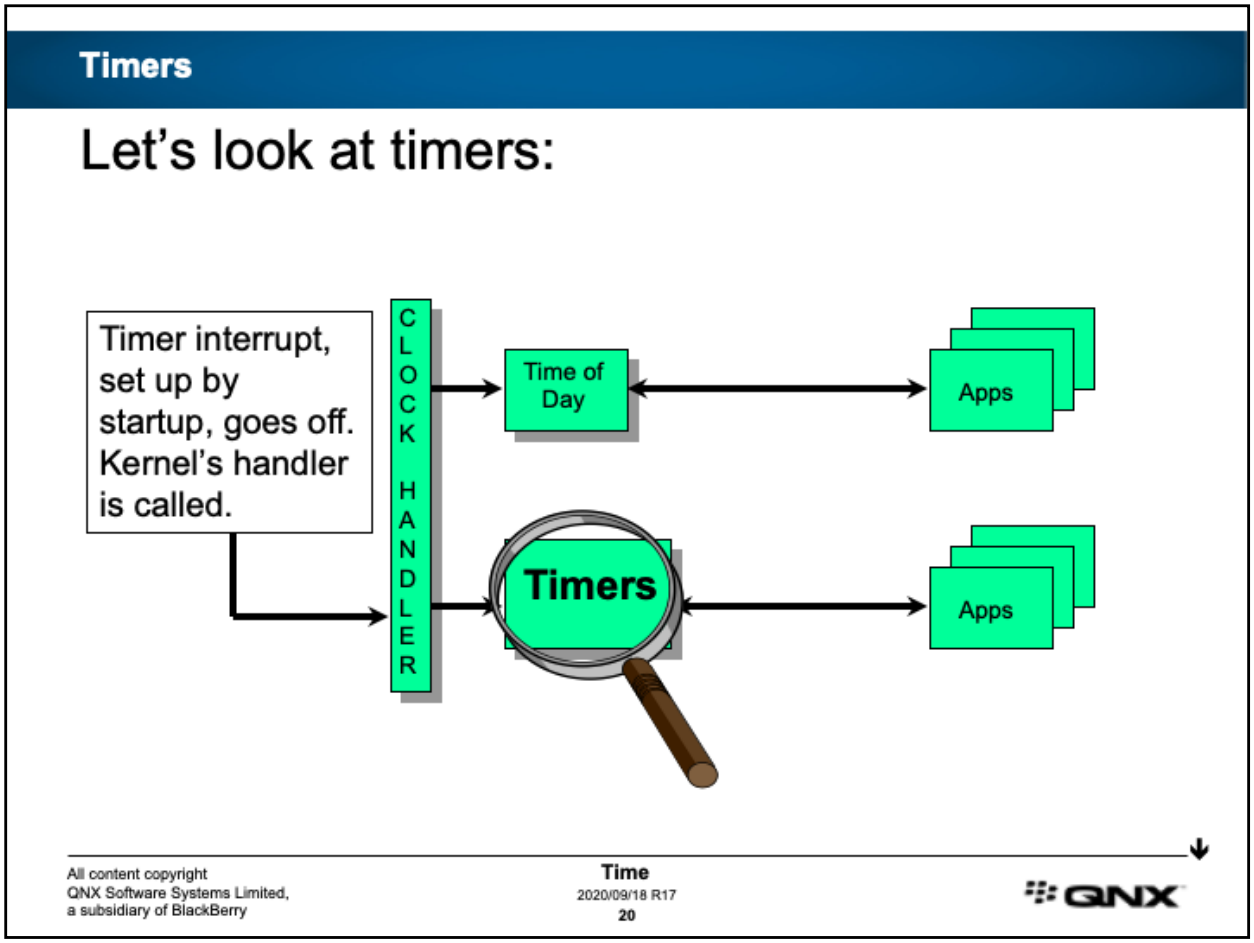
NOTES:



NOTES:

The kernel keeps the list of timers sorted. The timer to expire soonest is at the head of the list. If that timer has not expired then none of the other timers have. So if you have many timers, unless they are all expiring during the same tick, you will not increase the length of time spent by the kernel in its timer interrupt handler.

Setting a Timer

To set a timer, the process chooses:

- what kind of timer
  - periodic
  - one shot
- timer anchor
  - absolute
  - relative
- event to deliver upon trigger
  - fill in an EVENT structure

NOTES:

Using Timers

POSIX timer functions:

- administration

```
timer_create (clockID, &event, &timerID);
timer_delete (timerID);
```

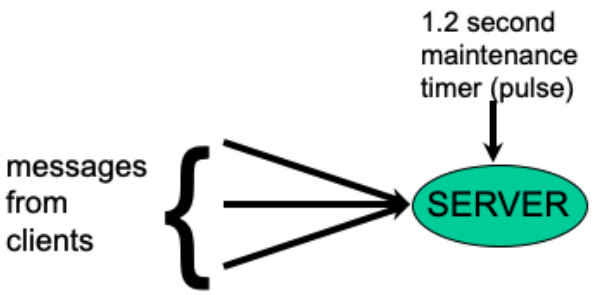
- configuration

```
timer_settime (timerID, flags, &newtime, &oldtime);
```


NOTES:

Setting a Timer and Receiving Timer Pulses

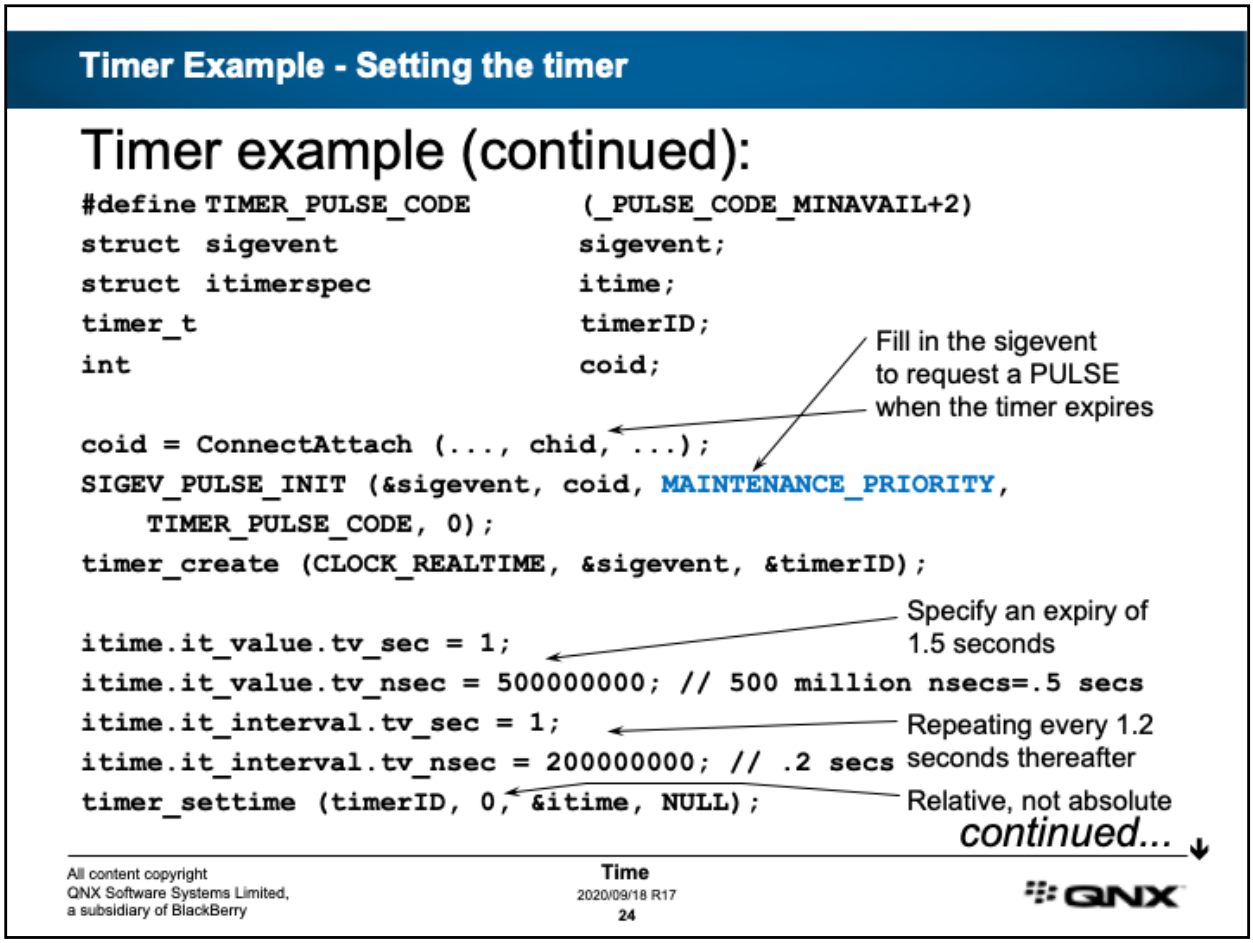
Timer example:



We want to have the server receive maintenance timer messages every 1.2 seconds, so that it can go out and perform housekeeping duties / integrity checks, etcetera.

continued...

NOTES:



NOTES:

For an absolute time put **`TIMER_ABSTIME`** in the second parameter to *timer_settime()*. **`itime.it_value.tv_sec`** would then be the time at which the timer should go off (e.g. 5:00pm Friday.) The time would be given as the number of seconds since Jan 1 1970 00:00 GMT (see *mktime()* for one way of getting this.) **`itime.it_interval`** can still contain a repetition interval.

As we are getting this event from the kernel, not a server, we don't need to register our event.

Timer Example - Receiving the timer pulses

Timer example (continued):

```
typedef union {
   struct _pulse   pulse;
   // other message types you will receive
} myMessage_t;

myMessage_t   msg;
    ... // the setup code from the previous page goes here
    while (1) {
      rcvid = MsgReceive (chid, &msg, sizeof(msg), NULL);
      if (rcvid == 0) {
        // it's a pulse, check what type...
        switch (msg.pulse.code) {
          case  TIMER_PULSE_CODE:
                periodic_maintenance();
                break;
        }
      }
    }
```


NOTES:

Cancelling a Timer

You can cancel a timer without destroying it:

- useful if you will frequently be cancelling then restarting it
  - e.g. going into/coming out of low-power modes
- to cancel a timer:

```
struct itimerspec itime;
itime.it_value.tv_sec = 0;
itime.it_value.tv_nsec = 0;
timer_settime (timeID, 0, &itime, NULL);
```

- to restart it simply fill in the timing and call *timer_settime()* again

NOTES:

This does mean you can't start a repeating timer "right now" by giving it a 0 **`it_value`** field. The soonest you can do it is **`tv_sec = 0`**, **`tv_nsec = 1`**.

EXERCISE

Exercise:

- in you **`time`** project is a file called **`reptimer.c`**
- when finished, it will wake up 5 seconds from the time it runs and then every 1500 milliseconds after that
  - it will wake up by receiving a pulse.
- all of the code is in *main()* for setting up the pulse event structure and for receiving the pulse
- however, the code for creating the timer and starting it ticking is missing
  - add it
- to test it do:

  `reptimer`
- you should see a message displayed to the screen 5 seconds from the time you ran it, and then every 1500 milliseconds (1.5 seconds) after

NOTES:

Time

Topics:

- Timing Architecture
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NOTES:

Tickless Operation

The kernel may operate in “tickless” mode:

- this is intended to help with managing power consumption
- to enter “tickless” mode:
  - it must be enabled by the **`-Z`** option to **`startup-*`**
  - no clock adjustment may be in process (*ClockAdjust()*)
  - all CPU cores must be idle
- in tickless mode, the kernel:
  - reprograms the timer chip to generate an interrupt when the next timer should expire
  - sets some internal flags
  - resets to regular mode as soon as any non-idle thread is scheduled

NOTES:

Tolerant Timers

To help enable the kernel to enter “tickless” mode, or other low-power modes:

- a timer may have a tolerance value associated with it
- only affects the timer in “tickless” mode
- the tolerance is added to the regular expiry time to determine when the timer actually needs to next expire
- a **`CLOCK_SOFTTIME`** timer is the equivalent of a tolerant timer with an infinite tolerance

NOTES:

A tolerance value will never cause a timer to fire earlier, or more often than configured.

Tolerant Timers

To set the tolerance on a timer:

- make an **additional** call to *timer_settime()* or *TimerSettime()*
- pass **`TIMER_TOLERANCE`** in the flags field
- specify the tolerance in the **`itimerspec.it_value`** or **`_itimer.nsec`** fields, respectively
  - the tolerance value must be greater than the current ticksize
- if using *TimerSettime()*, an infinite tolerance may be specified by passing **`~0ULL`** in the **`nsec`** field
- a default tolerance for the timers in a process may be set with *procmgr_timer_tolerance()*

NOTES:

Timer Tolerance

Tolerant Timer example:

```
struct  sigevent                sigevent;
struct  itimerspec              itime;
struct _itimer                  ker_itime;
timer_t                         timerID;
coid = ConnectAttach (..., chid, ...);
...
timer_create (CLOCK_REALTIME, &sigevent, &timerID);

itime.it_value.tv_sec = 1;
itime.it_value.tv_nsec = 500000000; // 500 million nsecs=.5 secs
itime.it_interval.tv_sec = 1;
itime.it_interval.tv_nsec = 200000000; // .2 secs
timer_settime (timerID, 0, &itime, NULL);// set timer

ker_itime.nsec = 10 * 1000 * 1000 * 1000; // 10 second tolerance
TimerSettime( timerID, TIMER_TOLERANCE, &ker_itime, NULL );
```


NOTES:

High-Precision Timers

To make a timer high-precision:

- first make a call to *timer_settime()* or *TimerSettime()* with **`TIMER_TOLERANCE`** in the flags field
  - for high precision timers, set the timer tolerance prior to starting your timer
  - specify the resolution in the **`it_value.tv_nsec`** field
    - the value must fall between 0 and the ticksize
  - the kernel will adjust the hardware timer appropriately
    - doesn't change ticksize
    - extra calculations during the last timer interrupt before expiry

  ☞ will add jitter to all regular timers in the system
- then set the timer as per usual

☞ this is a privileged operation, requires **`PROCMGR_AID_HIGH_RESOLUTION_TIMER`** ability

NOTES:

High-Precision Timer example:

- want a timer that fires in 5.4ms, accurate to 20 usec

```
struct itimerspec     timerTol, itime;
...
timer_create (CLOCK_REALTIME, &sigevent, &timerID);

memset( &timerTol, 0, sizeof timerTol );
timerTol.it_value.tv_nsec = 20 * 1000; // 20 usec resolution
timer_settime( timerID, TIMER_TOLERANCE, &timerTol, NULL );
  // Kernel will adjust HW timer as needed to give 20000 nsec
  // resolution for this timer

memset( &itime, 0, sizeof itime );
itime.it_value.tv_nsec = 5400 * 1000;
timer_settime ( timerID, 0, &itime, NULL ); // set timer
```


NOTES:

Time

Topics:

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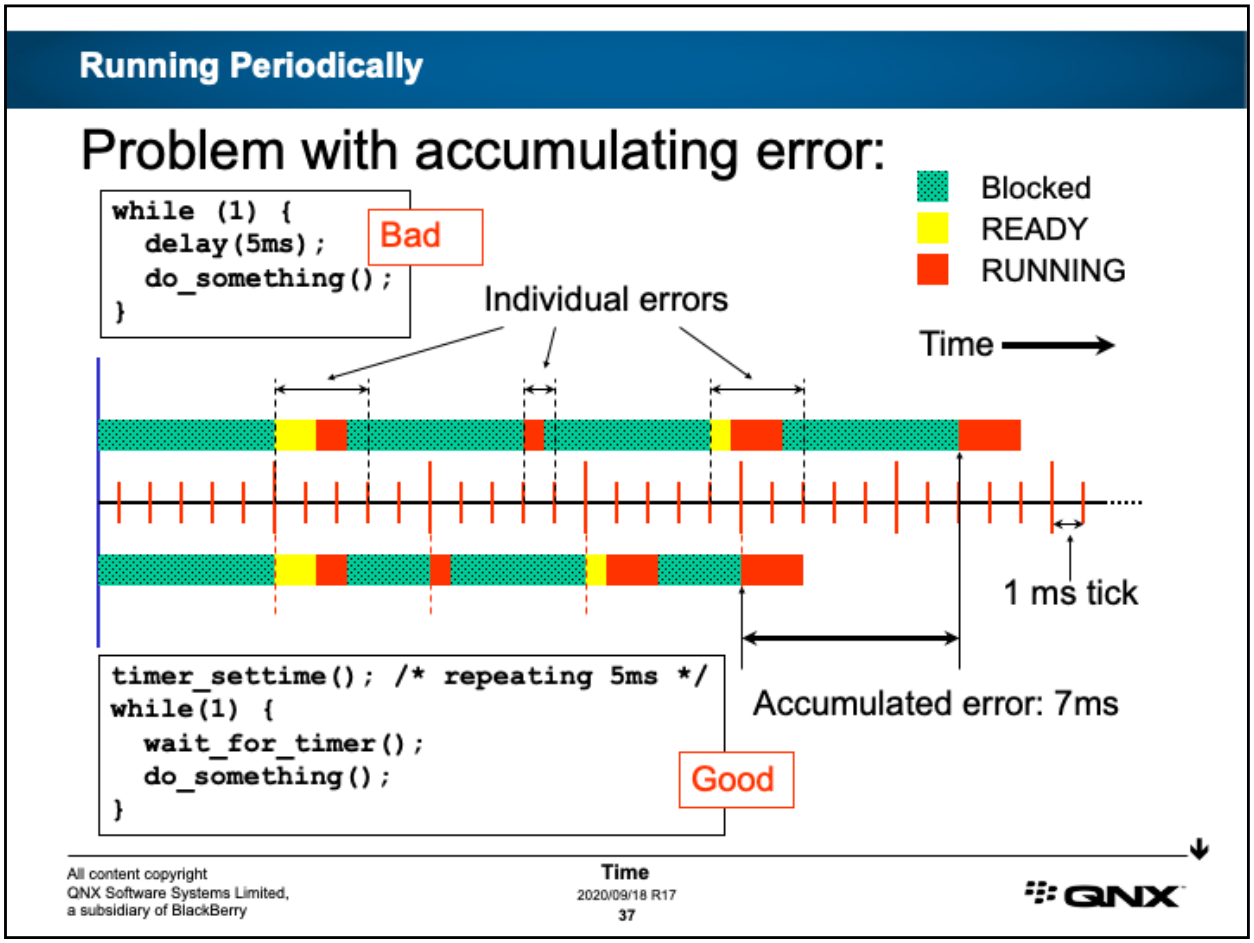
NOTES:

Design Considerations

Two timing design issues:

- how to run periodically without accumulating error
- timer frequency issues which can make timer expiry erratic

NOTES:



NOTES:

For both of these approaches we have the same initial error for the first 5 ms delay, and the same errors due to being made READY by our timer expiring and some other thread at our priority or a higher priority preventing us from running.

In the *delay()* case, though, we start a new 5 ms interval after we complete our work, so we get cumulative error from:

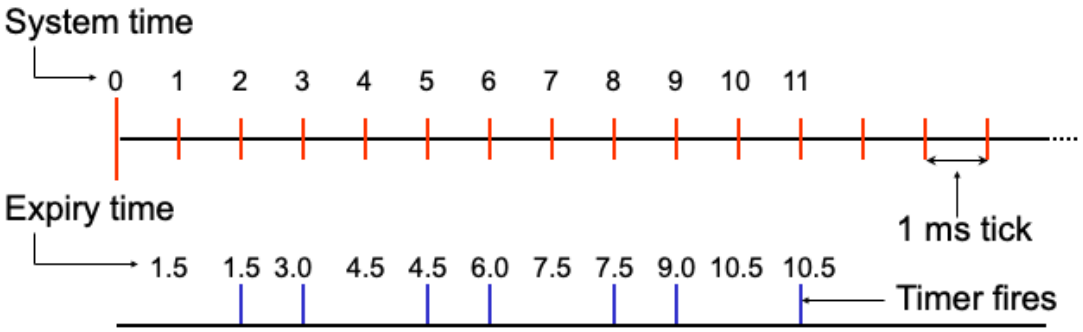
- any time READY but not RUNNING
- time spent doing the work
- timer initiatilizaton error do to ticksize round up

While in the repeating timer case, we have the same startup error, and the same errors from not getting scheduled immediately, the 5ms intervals are always measured from the startup of the timer, so we don't accumulate any error.

In this example, which is reasonably typical, when using the *delay()* loop, we've accumulated 7ms of error over 4 iterations.

Timer Frequency Issues

What happens if we ask for a repeating 1.5ms timer?



- we see an actual expiry pattern of : 2ms, 1ms, 2ms,1ms, 2ms,…
- the average is correct, and is the best our clock granularity can give.

But, what if we ask for a repeating 1.0 ms timer...

NOTES:

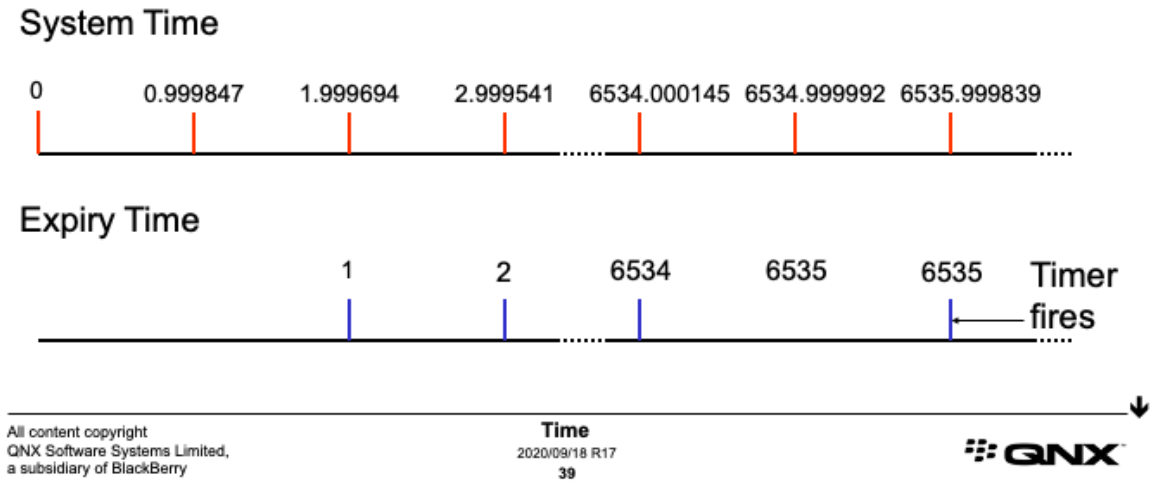
On each tick, QNX checks to see if the system time has exceeded the expiry time for the timer, and once it has, the timer will fire.

In the real world, the time values would not be counting from 0, but would be counting actual clock time.

Timer Hardware Issues

A 1 ms ticksize is really the highest value less than 1ms which the hardware can do:

- e.g. on a legacy x86 it would be .999847 ms
- how would this behave?



NOTES:

Because of the initialization error, we do miss the first tick -- this is expected. But, we will also, very occasionally, have a (almost) 2ms interval instead of our desired 1ms interval. This can often cause a problem.

Other hardware will have different values for the actual ticksize, but this same problem will occur, just at different intervals.

This issue will also add an additional error of almost 1ms to every iteration of the *delay()* based method of repeatedly running.

Timer Frequency Issues - What to do

So what do you do? There are some choices:

- use a high-precision timer
  - dangerous as it introduces jitter to everyone else
- make sure your tick size is quite a bit smaller than the smallest timer period you need
  - smaller ticksizes will impose more system overhead from the kernel handling the timer interrupt more frequently
- make your timer expiry an exact multiple of the actual tick size
  - use *ClockPeriod()* to get this value
  - use **`CLOCK_MONOTONIC`** so that time changes and *ClockAdjust()* don't affect your timing

NOTES:

Time

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NOTES:

Setting Timeouts

The kernel provides a timeout mechanism:

```
#define BILLION         1000000000LL
#define MILLION         1000000
struct sigevent         event;
uint64_t                timeout;

event.sigev_notify = SIGEV_UNBLOCK;

timeout = (2 * BILLION) + 500 * MILLION;

flags = _NTO_TIMEOUT_SEND | _NTO_TIMEOUT_REPLY;

TimerTimeout (CLOCK_REALTIME, flags, &event, &timeout, NULL);
MsgSend (…);    // will time out in 2.5 seconds
```

Specify the event

Length of time (2.5 seconds)

Which blocking states

NOTES:

Note that this timeout is done on a per-thread basis.

If you don't like working in 64-bit nanosecond values, *timer_timeout()* is a cover function that takes a **`struct itimerspec`** to specify the timeout instead.

Setting Timeouts

Some notes on timeouts:

- timeout is relative to when *TimerTimeout()* is called
- the timeout is automatically cancelled when the next kernel call returns
  - therefore you should not do anything else between the call to *TimerTimeout()* and the function that you are trying to timeout
  - but what if a signal handler is called? Might there be kernel calls made there? The same does not apply if the kernel call is made from within a signal handler that had preempted

NOTES:

Setting Timeouts

It can be used for checking/cleanup:

```
event.sigev_notify = SIGEV_UNBLOCK;
flags = _NTO_TIMEOUT_RECEIVE;
/* loop, receiving (cleaning up) all pulses in receive queue */
do {
    /* MsgReceivePulse() wont block, if there's a pulse it
     * will return 0, otherwise it will timeout immediately
    */
    TimerTimeout (CLOCK_REALTIME, flags, &event, NULL, NULL);
    rcvid = MsgReceivePulse (chid, &pulse, ...);
} while (rcvid != -1);
/* if errno is ETIMEDOUT, then we got all the pulses */
```

No time means "do not block"

This practice is not recommended for implementing polling since polling in general is wasteful of CPU. Usage like above is fine.

QNX

NOTES:

Using *TimerTimeout()* with **`NULL`** for the timeout parameter says, timeout immediately *if we are about to block*.

The above example is good if you've received one pulse at your main receive loop and expect that you might have gotten a burst of pulses. Rather than go back to the main receive loop and get each one, we sit in a loop cleaning them all out of our receive queue.

In the example above, if there is a pulse message waiting for us then *MsgReceivePulse()* is not about to block and will therefore not timeout. Instead it will just return with the pulse message. However, if there is no pulse message waiting then *MsgReceivePulse()* is about to block so it times out immediately and returns an error (`-1` and **`errno`** set to **`ETIMEDOUT`**).

Time

Topics:

- Timing Architecture
- Getting and Setting the System Clock
- Timers
- Tolerant and High-Precision Timers
- Design Considerations
- Kernel Timeouts
- → Conclusion

NOTES:

Conclusion

You learned:

- ticksize is the fundamental quantum of time
- how to set or gradually adjust the system time
- how to get periodic notification
- how to customize timers for power-management or higher accuracy
- how to timeout kernel calls

NOTES: