RTOS VxWorks 6.x

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Topics

- VxWorks 6.x kernel – components, properties
- Kernel customization to a specific application
- Configuration of development workplace, basic conceptions

VxWorks 6.x – basic properties I.

- UNIX type real-time operating system
- Proprietary, WindRiver (owned by Intel)

- Unlimited number of tasks
- Preemptive scheduling
  - Priority-Based
  - Round-Robin
- 256 priority levels
- Fast and flexible interprocess communication

VxWorks 6.x – basic properties II.

- Binary, counting and mutex semaphores
- Supports priority inheritance
- Message queues
- Signals
- Pipes
- Sockets
- Shared memory

VxWorks 6.x – basic properties III.

- Asynchronous I/O
- SCSI
- MSDOS (FAT16) file system
- „raw“ file system
- TrueFFS (for flash memories)
- ISO9660 (CDROM)
- PCMCIA support

VxWorks 6.x – supported CPUs

- PowerPC
- ARM
- Intel x86
- Intel XScale
- MIPS
- SuperH
- ColdFire

VxWorks 6.x – Wind API

- C language
  - Why? C is a portable assembler.
- Basic API OS VxWorks
- Is not POSIX compatible
- Less complicated
- Usually solves drawbacks of POSIX specification
- Using this API produces less portable code

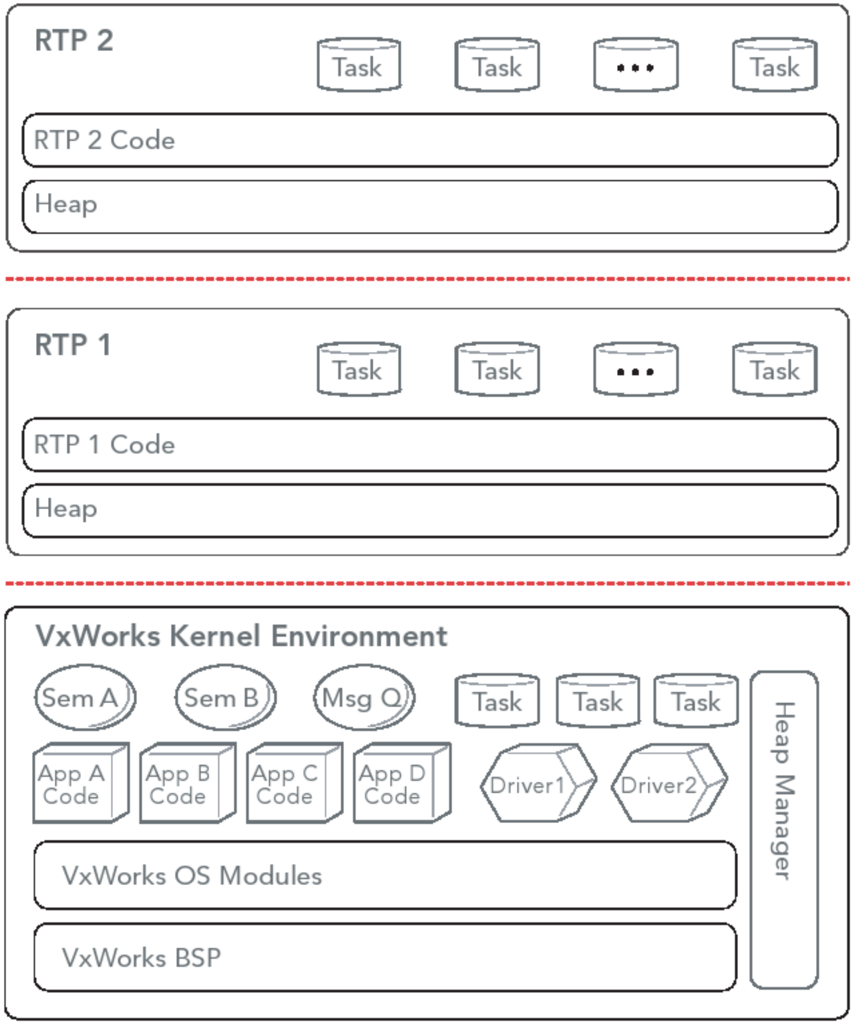
VxWorks 6.x – POSIX API

- Standard API compatible with POSIX 1003.1b specification for
  - Asynchronous I/O
  - Semaphores
  - Message queues
  - Memory management
  - Signals
  - Scheduler
  - Timers

Applications types

- Downloadable kernel module (DKM)
  - No memory protection
  - Direct access to HW
- Real-time process (RTP)
  - New in VxWorks 6.x
  - Employs memory protection
  - No direct access to HW
- DKM is similar to Linux kernel modules (drivers)
- WindRiver tries to provide same (similar) APIs for both DKM and RTP.

Overall VxWorks OS Structure



Task Management I.

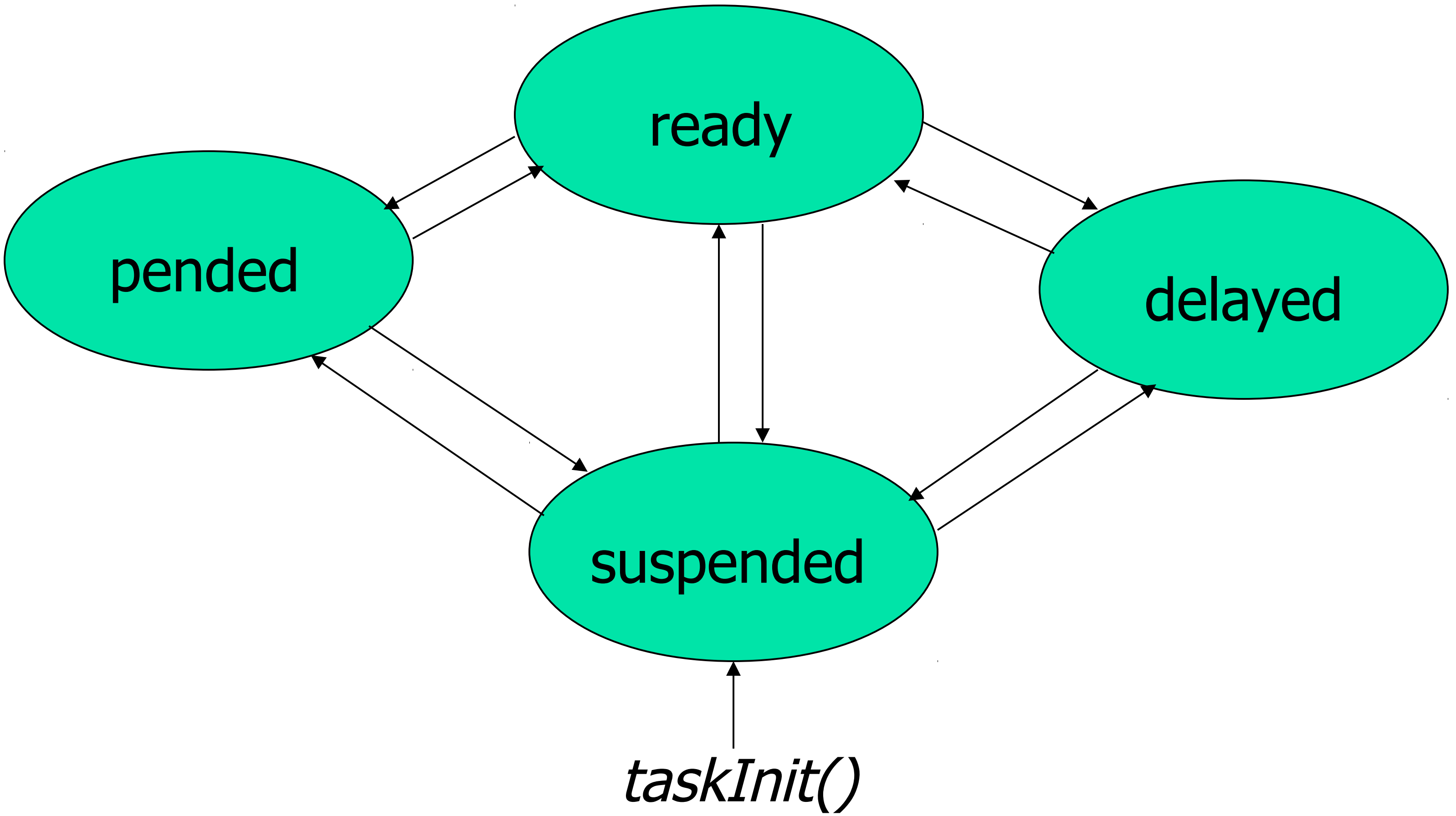
Task context a.k.a. task_struct (Linux)

- Program counter
- Content of CPU registers
- Stack
- Assignment of standard I/O
- Timer for function *delay*
- Timeslice timer
- Kernel control structures
- Signal handlers
- Debugging a monitoring variables

Task management II.

- All tasks run in one common address space (either kernel or RTP)
  - + Fast context switch
  - − Zero protection
- Besides other things, RTP implements protection mechanisms (if CPU has MMU)

Task state



READY state

- The task is ready to run
- Doesn't wait for any resources except for CPU
- VxWorks doesn't distinguish whether the task is running (has assigned CPU) or not.

PEND state

- Task is blocked, waits for some resource to be assigned to it.
- Typical examples are waiting for a semaphore, reading from an empty message queue etc.
- Most of the time caused by calling ***semTake***, ***msgQReceive*** etc.

DELAY state

- The task waits for some time interval to elapse
- Caused by calling taskDelay() or nanosleep()
- Warning! This is different from elapsing of timeout in some calls.

SUSPEND state

- The execution of the task is forbidden
- Typically used when the task is debugged
- Doesn't forbid change of task state, only its execution
- This state can be set by calling ***taskSuspend***

STOP state

- also used by debugger
- signalizes the task was stopped by a breakpoint

Task State – Combinations I.

- DELAY+S
  Simultaneously delayed and suspended, e.g. call to ***taskDelay*** during debugging
- PEND+S
  Simultaneously pended and suspended e.g. waiting for a semaphore (***semTake***) during debugging

Tasks state – combinations II.

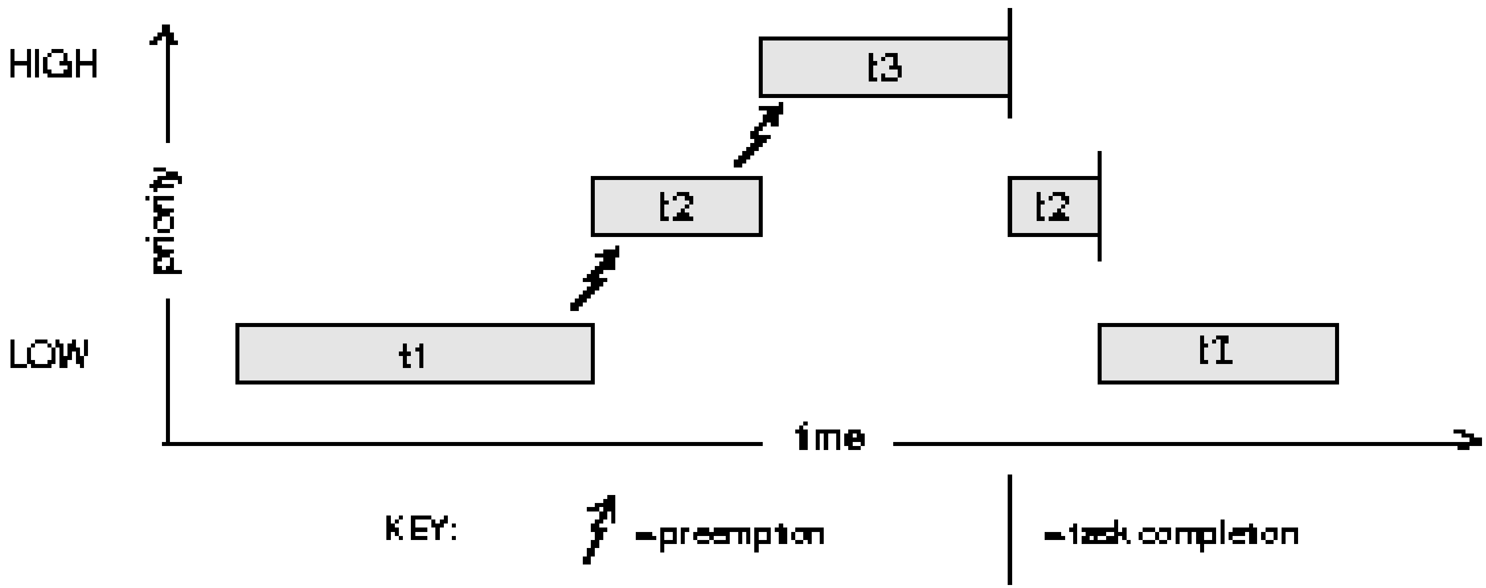
- PEND+T
  waiting for a resource with timeout
- PEND+T+S
  same as PEND+T, but suspend because of debugging
- State+I
  arbitrary state, priority inheritance mechanism is active

Task priorities

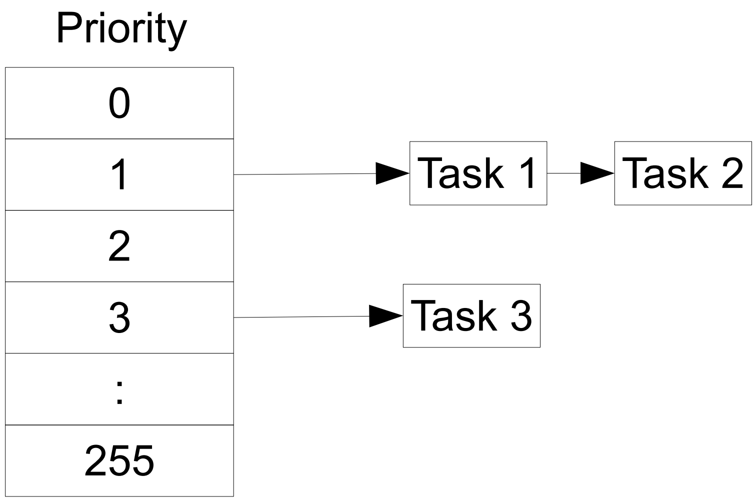
- Tasks have priorities in range 0 (highest) through 255 (lowest)
- Priority can be read or set at runtime (***taskPriorityGet***, ***taskPrioritySet***)
- When creating the task manually (debugger, shell) the priority is set to the default value 100
- Recommended priority ranges:
  - Applications: 100 – 255
  - Drivers: 51 – 99
  - Network handling (tNet0): 50

Preemptive fixed-priority scheduling

- Default scheduler
- Reflects only task priorities
- How does scheduler work and when it is invoked?

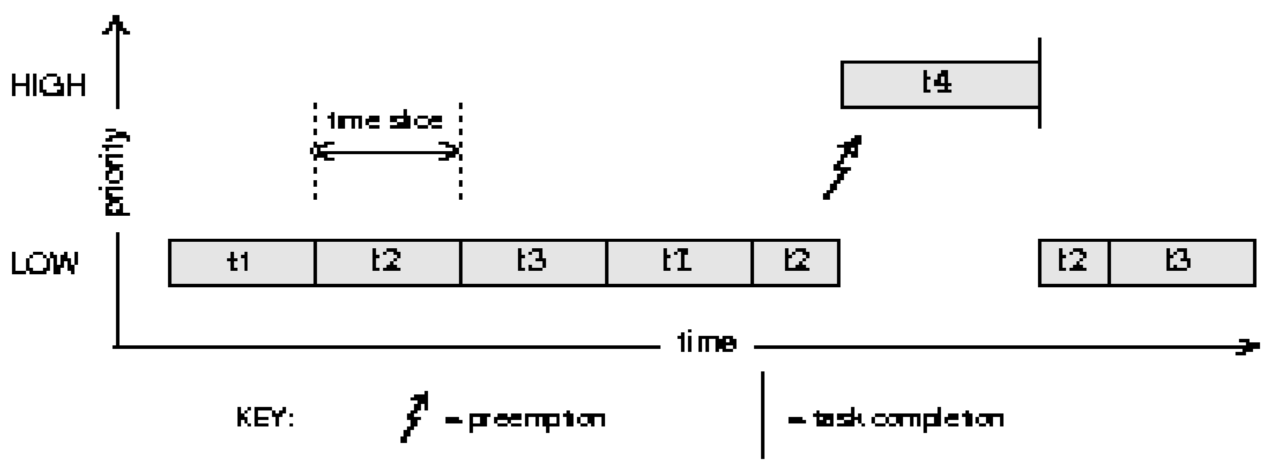


Run queue



Round-Robin Scheduling

- Limits time (*timeslice*), when the CPU is assigned to one task, then rescheduling to different one is forced.
- *Timeslice* can be set by system call ***kernelTimeSlice()***
- Task priority remains the main criterion .



Disabling of Scheduling

- Every task can disable/enable rescheduling to other task using ***taskLock***/***taskUnlock*** *calls*
- In locked state, rescheduling is possible only if the task is blocked (PEND state) or suspended
- Interrupts are not blocked at all

- What is it good for?
- What is better for real-time? Using taskLock() or mutexes?

Task creation

- ***taskInit*** – create a task
- ***taskActivate*** – run a task
- ***taskSpawn*** = ***taskInit*** + ***taskActivate***
  Creates and runs the task according to the parameters:
  - Task name
  - Stack size
  - Code (entry function)
  - Entry function parameters

Task Creation Options

- **VX_FP_TASK** – must be specified when the task uses floating-point operations. Why?
- VX_NO_STACK_PROTECT – Create without stack overflow or underflow guard zones.
- VX_TASK_NOACTIVATE – Used with taskOpen( ) so that the task is not activated.
- VX_NO_STACK_FILL – Does not fill the stack with 0xEE.
  - Filling stacks is useful during development for debugging with the checkStack( ) routine.

Task termination

- Task is terminated when either
  - The entry function returns or
  - ***taskDelete(taskId)*** *is called*
- Enabling/disablig task deletion – ***taskSafe***/***taskUnsafe*** *calls*
- If the task is in Safe state, other tasks calling ***taskDelete*** on the task are blocked.
- Beware: deleted task does not release held locks (mutexes)

Tasks in POSIX = Threads

- pthread library
- pthread_create() – no two phase initialization
- pthread_cancel()
- Thread cancelation (see POSIX:2008 2.9.5)

Task control

- ***taskSuspend***/***taskResume*** – suspends/resumes task
- ***taskRestart*** – recreates the task with the original creation arguments
- ***taskDelay*** – delays the execution for specified time. Time is measured in ticks of system timer (default frequency is 60 Hz, can be changed/read by ***sysClkRateSet***/***sysClkRateGet***)
- POSIX
  - ***nanosleep*** – delay, time in nanoseconds

Scheduler – POSIX API

- POSIX priority numbering is inverse to VxWorks
- POSIX allows setting the scheduling algorithm independently for each task
- Lowest and higher priority level is not defined
- VxWorks supports only one algorithm for all tasks in the system

Scheduler – POSIX API (1)

```
/* Header file */
#include <sched.h>

/* Constants */
```

- `SCHED_FIFO` – Preemtive priority-based scheduling
- `SCHED_RR` – Round-robin scheduling
- `SCHED_OTHER` – Other, implementation dependent scheduling
- `SCHED_SPORADIC` – Sporadic server scheduling

```
/* Get/set scheduling algorithm */
int sched_getscheduler(pid_t pid);
int sched_setscheduler(pid_t pid, int policy,
   struct sched_param *params);
```

Scheduler – API (2)

```
/* Get and set scheduling parameters */
int sched_getparam(pid_t pid, struct sched_param
   *params);
int sched_setparam(pid_t pid, struct sched_param
   *params);
int sched_rr_getinterval(pid_t pid, struct
   timespec *t);
/* Explicitly execute rescheduling */
int sched_yield(void);
/* Get minimal and maximal priority applicable to
   a given scheduler */
int sched_get_priority_min(int policy);
int sched_get_priority_max(int policy);
```

Scheduler invocation

- When is scheduler executed?
  - After every interrupt – there might be new work to do
    - Timer (system tick)
    - I/O device
  - As a part of some system calls
    - taskDelay
    - semTake, semGive
    - ... and many more
- What exactly is the context switch?

Shared code, reentrancy

- Every part of the code can be called from any task within the current address space (RTP, kernel)
- Almost all system functions are reentrant (exceptions have two variants with and without **_r** suffix).
- Global variables are problematic – it is possible to use so called *task variables*

Task variable

- global variable, there is a copy for each task
- ***taskVarAdd(int *ptr)*** – global variable of the length 4 bytes is added to the task context.
  - Each task, which called this function have its own copy of this variable.

Inter-task/Inter-process Communication (IPC)

- shared memory
- semaphores
- message queues and pipes
- sockets
- signals
- events

Shared memory

- All tasks (threads) in a multi-threaded program share memory.
- Tasks can communicate by writing and reading to the memory.
- Shared memory is the fastest IPC mechanism – there is no software-induced overhead.
- It might not be as easy to use as it seems...

Memory consistency

- When data are accessed/modified from multiple places (e.g. tasks), extra care has to be taken.
- We don’t want tasks to randomly overwrite data used by other tasks.
  - This type of programming error is known as a “race condition”
  - Race conditions are very hard to debug!
  - Race conditions are not deterministic – typically they happen only from time to time, e.g. once per week
- Solution: synchronize the tasks somehow

Maintaining data consistency

- If shared data is accessed from:
  - multiple tasks => **mutexes**
  - Tasks and interrupts => **disable interrupts**
  - Interrupts on multiple processors (SMP) => **spinlock**
- Other methods (scalable in SMP)
  - Non-blocking synchronization (atomic instructions)
  - Per-CPU variables
  - Read-Copy-Update (RCU, SMP)
    - Details are out of scope of this lecture

Semaphores

- Basic synchronization mechanism
- Internal variable has the value 0 or 1 (binary, mutex semafor) or arbitrary non-negative integer (counting semaphore)
- Two primitives for accessing semaphore
  - **semTake** – takes the semaphore (internal variable is decremented), if the semaphore is not available (variable = 0), calling task is blocked (PEND state)
  - **semGive** – „returns“ the semaphore (increments the internal variable and optionally wakes a waiting task up)

Simple semaphore implementation (on uniprocessor)

```
struct Sem {
  int count;
  struct task *queue;
};
```

```
semTake(sem) {
  if (sem->count > 0) {
    sem->count--;
    return;
  }
  current->state = PEND;
  runq_del(curent)
  listAppend(sem->queue, current);
  schedule();
}
```

```
semGive(sem) {
  waiting = listRemoveFirst(sem->queue);
  if (waiting) {
    waiting->state = READY;
    runq_add(waiting);
    schedule();
  } else {
    sem->count++;
  }
}
```

Simple semaphore implementation (on uniprocessor)

```
struct Sem {
  int count;
  struct task *queue;
};
```

```
semTake(sem) {
  intLock();
  if (sem->count > 0) {
    sem->count--;
    intUnlock();
    return;
  }
  current->state = PEND;
  runq_del(curent)
  listAppend(sem->queue, current);
  intUnlock();
  schedule();
}
```

```
semGive(sem) {
  intLock();
  waiting = listRemoveFirst(sem->queue);
  if (waiting) {
    waiting->state = READY;
    runq_add(waiting);
    intUnlock();
    schedule();
  } else {
    sem->count++;
    intUnlock();
  }
}
```

Semaphores – API I.

Semaphore Creation

semBCreate(int options, SEM_B_STATE initialState)
semCCreate(int options, int initialCount)
semMCreate(int options)

initialState: SEM_FULL (1), SEM_EMPTY (0)
initialCount: initial value of the internal variable

options: specifies how the tasks waiting for the semaphore are queued i.e. who will get the semaphore first after the semaphore is returned.

- **SEM_Q_FIFO** – according to the order in which tasks asked for the semaphore
- **SEM_Q_PRIORITY** – first according to the priority, then according to the order

Semaphores – API II.

Asking for (Locking) the Semaphore

```
STATUS semTake(SEM_ID semId,/*semafore to take*/
               int timeout /*timeout in ticks*/)
timeout:       WAIT_NOWAIT (0) don't wait
               WAIT_FOREVER (-1)
               timeout v system clock ticks
```

Returning (Unlocking) the Semaphore

```
STATUS semGive ( SEM_ID semId)
```

Deleting the Semaphore

```
STATUS semDelete ( SEM_ID semId)
```

Use of Semaphores

- Mutual exclusion
  - The semaphore (called mutex) is initialized as full
  - A task wanting to access the resource takes it, uses the resource and gives the mutex back
  - The code in between is called **critical section**
  - Mutex has a concept of **owner**
- Synchronization (producer-consumer)
  - The semaphore is initialized as empty
  - A task trying to wait for an event tries to take the semaphore and gets blocked
  - Whenever the event (e.g. IRQ) occurs, the semaphore is "given" by semGive (e.g. in an interrupt handler)

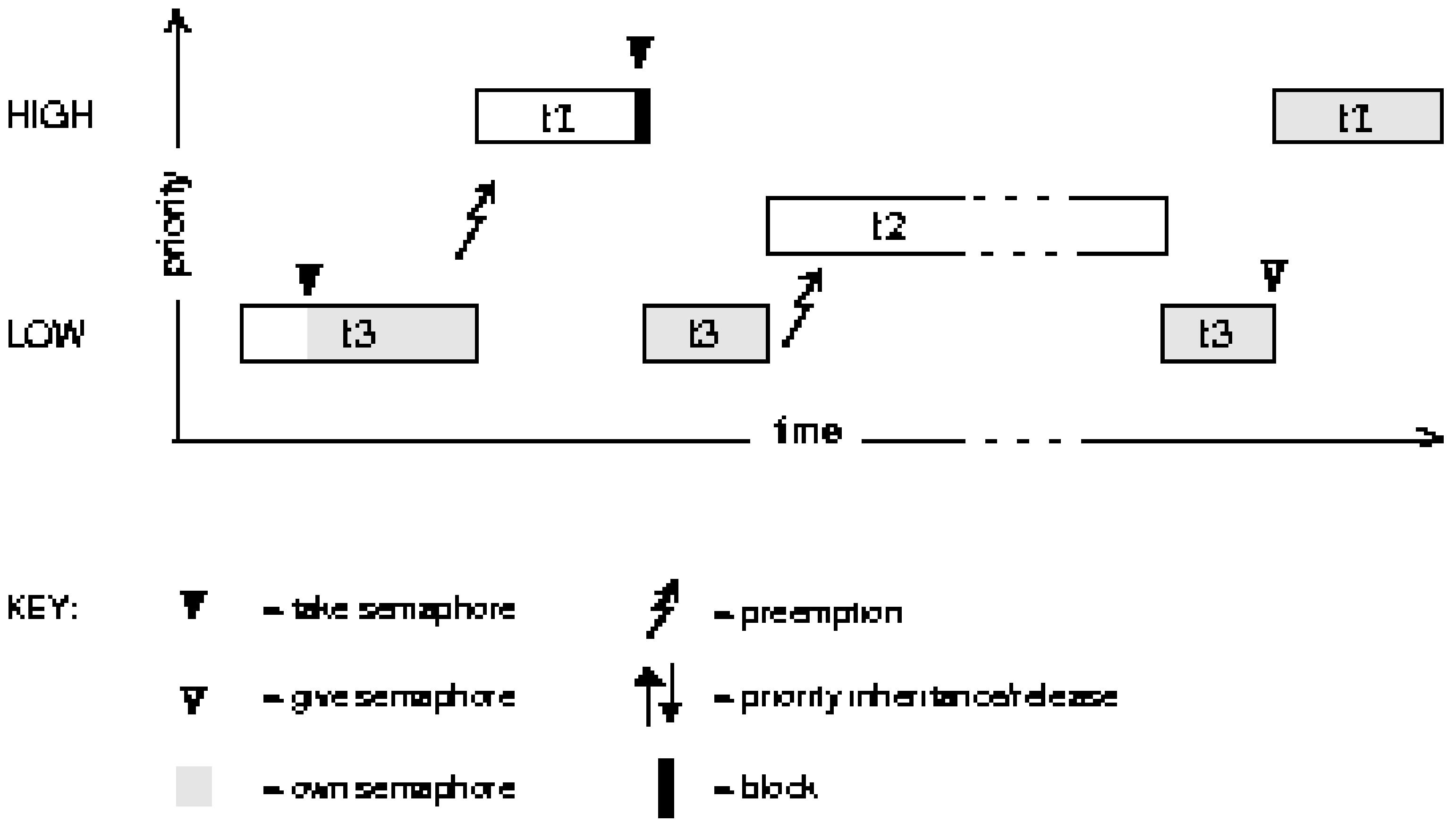
How does mutex protect things?

- Mutex can “protect” many things, e.g.
  - data structure
  - hardware device
- Association between the mutex and the thing it protects is just an **software abstraction**
  - Other tasks can access the data (without mutex) even if another task has locked the mutex
  - It is often necessary to add comments about what the mutex protects
  - Higher-level languages make this easier: monitors, synchronized methods in Java
  - Fine-grained locking

Options – mutex semafor

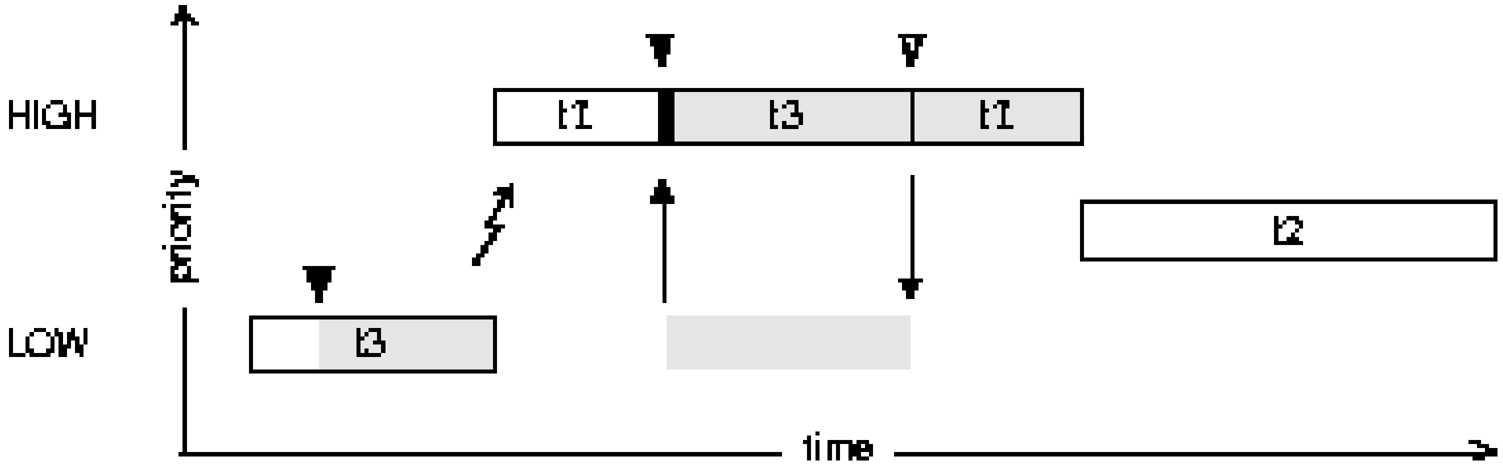
- **SEM_INVERSION_SAFE** – activates priority inheritance mechanism (priority inversion avoidance)
- **SEM_DELETE_SAFE** – it is not possible to delete the task owning this semaphore (corresponds to **taskSafe**)
- **SEM_INTERRUPTIBLE** – waiting for the semaphore can be interrupted by a signal.

Priority Inversion Problem



Possible Solution – Priority Inheritance

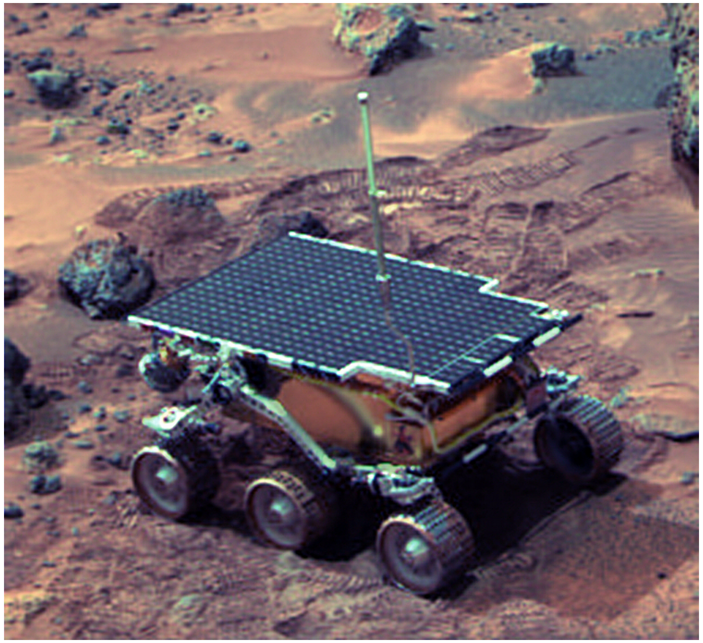
- The priority of tasks having “locked” some resource is temporarily increased to the highest priority among tasks waiting for that resource.



- TODO Draw locking chain

Mars Pathfinder & priority inversion

- Mars Pathfinder began experiencing total system resets
- One task missed a deadline and safety software caused the reset.
- A mutex without priority inheritance enabled was used inside the select() system call.
- It was sufficient to enable the priority inheritance by default.



- http://research.microsoft.com/~mbj/Mars_Pathfinder/

Recursive Use of Mutex Semaphore

- One task can lock the mutex repeatedly even if it is already locked by the same task.
- What is it good for?
- The number of semTake calls has to be the same as the number of semGive calls
- Mutex semaphore can be only returned by the task, which has locked the mutex.

Semaphores – POSIX API I.

- POSIX semaphore is always counting
- Can have a name (for sharing between processes/address spaces)

Semaphores – API (1)

```
/* Header file */
#include <semaphore.h>
```

```
/* Useful constants */
```

- `SEM_VALUE_MAX` – maximal available value of a semaphore (>= 32767)

```
/* Useful constants, named variant */
```

- `O_RDONLY, O_WRONLY, O_RDWR` – see. message queues
- `O_CREAT, O_EXCL` – see. message queues

Semaphores – API (2)

```
/* Create/destroy memory-based (unnamed)
   semaphore*/
int sem_init(sem_t *sema, int pshared, unsigned
   int initial_value);
int sem_destroy(sem_t *sema);

/* Connect to/open, close, delete named semaphore
   */
sem_t sem_open(const char *sem_name, int oflag,
   mode_t creat_mode, unsigned int init_val);
int sem_close(sem_t *sema);
int sem_unlink(const char *sem_name);
```

Semaphores – API (3)

```
/* Semaphore operations common to named and
   unnamed variants */

/* Enter critical section - blocking/nonblocking
   variant */
int sem_wait(sem_t *sema);
int sem_trywait(sem_t *sema);
/* Leave critical section */
int sem_post(sem_t *sema);
/* Read the value of semaphore */
int sem_getvalue(sem_t *sema, int *value);
/* wait with an absolute timeout (only
   CLOCK_REALTIME) */
int sem_timedwait(sem_t *sem, const struct
   timespec *abs_timeout);
```

Real-Time processes (RTP) I.

- Similar to processes in different OSes (Unix)
- Optimized for RT
- Each RTP contains one or more tasks (sometimes called threads in other OSes)
- RTP can be thought as an organizing unit that groups several tasks. RTP alone is not scheduled, only the tasks within RTP are scheduled.
- Each RTP has its own address space
- User application can also be run as a kernel module. In that case its tasks are not part of any RTP.

Real-Time processes (RTP)II.

(optimizations for real-time)

- Two memory models
  - Flat (default) – each process uses distinct area of virtual address space – faster. Why?
  - Overlapped – same as common OSes
- Entire process is always loaded in memory (no swapping/page faults)
- New RTP is spawn in two phases.
  - 1^{st} phase runs with the priority of the calling process
  - 2^{nd} phase (load) is executed with the priority of the new process, i.e. lower-priority processes do not influence the task that created them.

RTP creation

- ***rtpSpawn** call*
  - *filename on filesystem*
  - *Initial task is created*
  - *Starts with main() function*

RTP Termination

- *main() function returns*
- When last task exits
- If any task in process calls ***exit()***
- *By calling* ***rtpDelete***

Shared memory between RTPs

- Part of the address space is shared between multiple processes (not within a single VxWorks RTP)
- Mostly implemented in HW (memory management unit)
  - OS only sets up page tables
- To maintain data consistency, exclusive access must be ensured by some means, e.g.:
  - disabling interrupts (***intLock***/***intUnlock***) – it works (only on one CPU), but is not good with respect to real-time behavior
  - disabling of rescheduling (*taskLock*/*taskUnlock*) – better, but still not good
  - binary or mutex semaphore – the best approach is most cases

Shared Memory – API (1)

```
/* Header file */
#include <sys/mman.h>

/* Useful constants */
```

- `O_RDONLY, O_RDWR, O_CREAT, O_EXCL` – see message queues
- `O_TRUNC` – truncate file to zero bytes (default)
- `PROT_NONE, PROT_READ, PROT_WRITE, PROT_EXEC` – enable none / read / write / code execution in shared memory
- `MAP_FIXED, MAP_SHARED, MAP_PRIVATE` - map shared memory block to a given address / writes are visible by others / non-visible for others (copy on write – COW)

Shared Memory – API (2)

```
/* Create(open), close, delete named mapped
   memory */
int shm_open(char *name, int oflag, mode_t mode);
int close(int fd);
int shm_unlink(const char *name);

/* Set shared memory size */
int ftruncate(int fd, off_t total_size);

/* Map a file to the address space */
void * mmap(void *where_i_want_it, size_t length,
   int mem_protection, int map_flags,
   int fd, off_t offset_within_shared_mem);
```

Shared Memory – API (3)

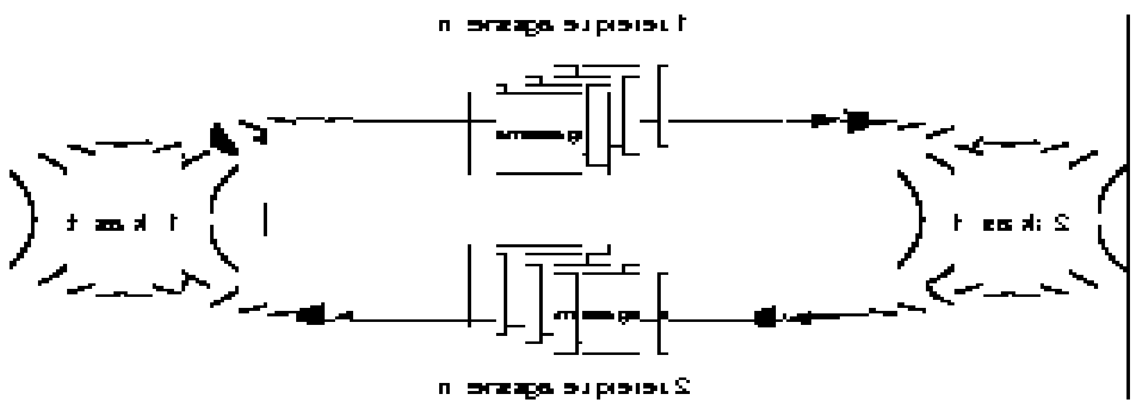
```
/* Unmap the memory from the process address
   space */
int munmap(void *begin, size_t length);

/* Extension: change memory protection for a
   mapped memory (whole or only a portion) */
int mprotect(void *begin, size_t length, int
   mem_protecion);

/* Extension: synchronize the memory with mapped
   file (only for mmaped files) */
int msync(void *begin, size_t length, int flags);
```

Message Queues

- Transfer of messages of arbitrary length
  - The maximal length must by specified in advance
- FIFO
- One queue = one direction, for both directions two queues must be used



Message Queues – API

- ***msgQCreate*** – creation
- ***msgQSend*** – insert a message to the queue
- ***msgQRecv*** – get a message from the queue
- ***msgQDelete*** – delete queue and free used memory
- ***msgQNumMsgs*** – find out the number of messages in the queue

Message Queues – API II.

MSG_Q_ID ***msgQCreate***(int maxMsgs,
int maxLen,
int options)

maxMsgs – max number of msg. in the queue

maxLen – max length of one message (Bytes)

options – MSG_Q_FIFO, MSG_Q_PRIORITY

how are ordered waiting tasks

Message Queues – API III.

STATUS ***msgQSend*** (MSG_Q_ID msgQId,
char *buffer,
UINT nBytes,
int timeout,
int priority)

buffer, nBytes – data and its length

timeout – how long to wait for freeing the queue if it is full

priority – message priority (MSG_PRI_NORMAL, MSG_PRI_URGENT)

Message Queues – API IV.

```
int msgQReceive(MSG_Q_ID msgQId,
                char *buffer,
                UINT maxNBytes,
                int timeout)
```

buffer, maxNBytes – where to store received data. Longer messages will be truncated

timeout – how long to wait for getting something from an empty queue

Returns the length of the received message

Message Queues – POSIX API

mq_open – open named queue

mq_close – close it

mq_unlink – delete it

mq_send – insert message to the queue

mq_receive – get the message from the queue

mq_notify – ask for sending a signal when a message is inserted to the empty queue

mq_setattr/***mq_getattr*** – setting/getting of queue parameters

Message Queues – Wind/POSIX API Comparison

	Wind	POSIX
Number of priority levels	2	32
Ordering of waiting tasks	FIFO of priority	priority
Timeout waiting	yes	no
Notification by a signal	no	yes (one proces)

Pipes

- Message queue that looks like a file
- Created by calling ***pipeDevCreate***
- Then standard I/O operation (read, write) can be used
- Unlike msg. queue, pipe can be used in ***select*** call (waiting for multiple I/O events)

Signals

- Asynchronous events with respect to task execution
- Very similar to interrupts (generated by HW)
- Signals are generated by SW (OS or apps)
- When a signal is delivered, task execution is stopped and a signal handler is executed
- Bit-field in task_struct
- Two possible APIs:
  - UNIX-BSD
  - POSIX 1003.1 including queued signal extensions POSIX 1003.1b

Signals – BSD/POSIX API Comparison

POSIX	**BSD**	**funkce**
signal	*signal*	handler assignment
kill	*kill*	send signal to given process
raise	---	send signal to self
sigaction	*sigvec*	get/set handler
sigsuspend	*pause*	suspend process until a signal is delivered
sigpending	---	find out delivered signals blocked by mask
sigemptyset, sigfillset, sigaddset, sigismember, sigdelset, sigprocmask	*sigsetmask, sigblock*	signal mask manipulation

Signals – which ones to use

- The number of signals differs across platforms
- Some signals are used by the OS
- Availability and meaning of signals is different across platforms, see manual, *sigLib* library
- There are 7 signals starting with SIGRTMIN, for user application

Signals – multiple reception I.

- Handler executes with the priority of receiving task
- Problem: what happens when another signal is delivered before executing the handler of the same previously delivered signal?
- In that case the handler is executed **only once** (each signal is represented by one bit)
- Solution – queued signal extensions (POSIX 1003.1b)

Signals – multiple reception II.

- Signal is sent by calling ***sigqueue***
- Sent signals are queued
- For each signal instance, the handler is executed
- It is possible to wait for signal (synchronous reception) without installing a handler – ***sigwaitinfo, sigtimedwait*** *calls*
- Queued signals can carry additional value specified by the user. The type of the value is pointer. Type casting can be used for other simple types.

POSIX 1003.1b realtime signals – API

```
/* Send a signal */
int sigqueue(pid_t victim_id, int sig, union
   sigval extra_info);

/* Wait for one or more signals */
int sigwaitinfo(const sigset_t *mask, siginfo_t
   *extra_info);
int sigtimedwait(... , const struct timespec
   *timeout);
```

Usage of Signals for Handling of Error States

```
struct jmp_buf jbuf;

int f( int *x )
{
    /* Set signal handler */
    sigaction( SIGBUS, &sighnd, NULL );

    /* Place of safe return */
    if ( 0 != setjmp( &jbuf ) )
        return ERROR;

    /* Access to VME bus */
    *x = *((int *) BUSERR_ADDR);

    return OK;
}
```

```
void sighnd()
{
    longjmp(jbuf, 1);
}
```

return value = 1

- It is not possible to just set a global variable in the handler as the CPU would retry the bus access.

VxWorks Events

- Lightweight task-to-task and ISR-to-task synchronization
- Notifications from message queues or semaphores
- Similar to signals – sent asynchronously, but received only synchronously
- 32 different events (25-32 are reserved to VxWorks)

Events API

- `eventSend(int taskId, UINT32 events)`
- ```
  eventReceive(UINT32 events, UINT8 options, int timeout,
               UINT32 *pEventsReceived)
  ```
- `semEvStart(MSG_Q_ID msgQId, UINT32 events, UINT8 options)`
- `semEvStop()`
- `msgQEvStart()`
- `msgQEvStop()`
  ```

Interrupts

- Handling interrupts is only possible in kernel tasks, not in RTPs
- Interrupt handler is set up by calling ***intConnect***
- There is a separate task context for all the interrupt handlers
- Handlers use a separate stack
- Interrupts can be globally disabled/enabled by calling ***intLock***/***intUnlock***
- Interrupt mask can be set by ***intLevelSet***

Interrupt Handlers
(Interrupt Service Routines – ISR)

- Should be as short as possible to minimize interrupt latency (why?)
- Cannot call functions that can cause blocking e.g.
  - *semTake* (but can call *semGive*), no mutex semaphores
  - *msgQReceive* (be aware of *msgQSend*! If the queue is full, the message is thrown away.)
  - *taskDelay*
  - *taskSuspend*
  - the full list can be found in the documentation
- Cannot use floating point functions
- Debugging: **logMsg()**

Minimizing Work Performed Within an ISR

1. Program the interrupting device to **stop interrupting** the CPU
2. Prepare and **queue** a data structure describing what needs to be done later with the device (status register, ...)
3. Use a semaphore to **unblock a task** (with appropriate priority) that will perform the necessary work later (when the ISR completes and the task is scheduled).
4. **Return** from the ISR. The OS runs the scheduler and the just unblocked task will run if not higher priority task is ready.

- isrDeferLib simplifies this: isrDeferJobAdd()

Signals vs. interrupts

- In both handlers it is not allowed to call services which **block**
- Maintaining data consistency (we can't use mutexes)
  - Signal mask in OS vs. interrupt masking in CPU
- Signal delivery interrupts some system calls
  - taskDelay etc.; see also SEM_INTERRUPTIBLE flag
  - Interrupts don't influence system calls but a signal can be sent from an interrupt handler

Static Instantiation of Kernel Objects

- Creation of kernel objects (tasks, semaphores, ...) requires memory allocation – slow, not always succeeds, ...
- It is possible to allocate the memory statically (required by many safety standards)

```
VX_TASK(myTask,4096);
int myTaskId;

STATUS initializeFunction (void)
{
myTaskId = VX_TASK_INITIALIZE(myTask, 100, 0, 4096, pEntry, \
                              0,1,2,3,4,5,6,7,8,9)
```

Timing

- taskDelay
- nanosleep
- POSIX timers
- watchdog timers

TaskDelay

- Task execution is stopped for given number of system timer ticks
- taskDelay(0) only puts the task at the end of ready queue.
- Waiting is terminated when a signal is delivered to the delayed task
- System clock frequency can be changed during runtime (***sysClkRateSet***/***Get***)
- When setting the system clock, return value must be checked. Too high frequency gives an error.
- Default frequency is 60 Hz.

nanosleep

- Task execution is delayed for a given amount of time
- Time is specified in seconds and nonoseconds
  - ```
    struct timespec
    (
        time_t tv_sec;   /* seconds */
        long   tv_nsec;  /* nanoseconds */
     )
    ```
- Delivery of a signal terminates waiting
    ```

POSIX timers

- After the desired time interval elapses, the signal (SIGALRM by default) is delivered to the task
- Input parameters are:
  - Time to the first tick
  - The period of the other ticks
  - These can differ
  - time resolution in nanoseconds

POSIX timer – API

- ***timer_create*** – creates timer
- ***timer_settime*** – starts timer
- ***timer_gettime*** – find out remaining time
- (non POSIX) ***timer_connect*** – handler initialization (calls *sigaction*)
- (non POSIX) ***timer_cancel*** – stops the timer (calls *timer_settime* with zero interval)

Watchdog timer

- Timer that calls a specified function upon elapsing of the time interval
- Not available for RTP
- Executed as a part of timer interrupt
- API:
  - ***wdCreate*** – creates wdtimer
  - ***wdStart*** – runs wdtimer
  - ***wdCancel*** – cancels the timer
  - ***wdDelete*** – deletes wdtimer

Networking

- Wide range of supported protocols, IPv4/IPv6
- standard API – BSD sokets
- for high throughput applications: zbuf sockets
- supported booting from Ethernet (BOOTP+TFTP/FTP/RSH)

Supported protokols

- SLIP, CSLIP, PPP
- IP, UDP, TCP, ARP, DNS
- DHCP, BOOTP
- OSPF, RIP, NDP
- RPC, RSH
- FTP, TFTP
- NFS
- telnet

Network API – sockets

- standard API for BSD sockets
- Additional libraries: hostLib, ifLib, ftpLib, ...
- more detailed description in VxWorks Network Programmer's Guide

Alternative API – zbuf sockets I.

- Kernel tasks only, not in RTP
- BSD sockets use different buffers in applications and in the kernel – data must be copied between them
- zbuf sockets API enables to share the same buffer between all the layers – no need for copying
- almost all functions from BSD sockets API have corresponding coutnerparts in zbuf sockets API

Alternative API – zbuf sockets II.

- ***zbufSockSend*** – send zbuffer (TCP)
- ***zbufSockSendTo*** – dtto, UDP
- ***zbufSockBufSend*** – send data from user buffer (TCP)
- ***zbufSockBufSendTo*** – dtto, UDP
- ***zbufSockRecv*** – read data (TCP)
- ***zbufSockRecvfrom*** – dtto, UDP

BSP – board support package

- Enables VxWorks to run on the specific hardware (board)
- Provides
  - initialization of hardware and special device drivers
  - detection of size and type of memory
  - preparation of interrupt systems
  - preparation of timers
- Usually provided by hardware vendors
- BSP for PCs can be found at
  - WindRiver/vxworks-6.1/target/config/pcPentium4
  - WindRiver/vxworks-6.1/target/src (other VxW parts, drivers, ...)

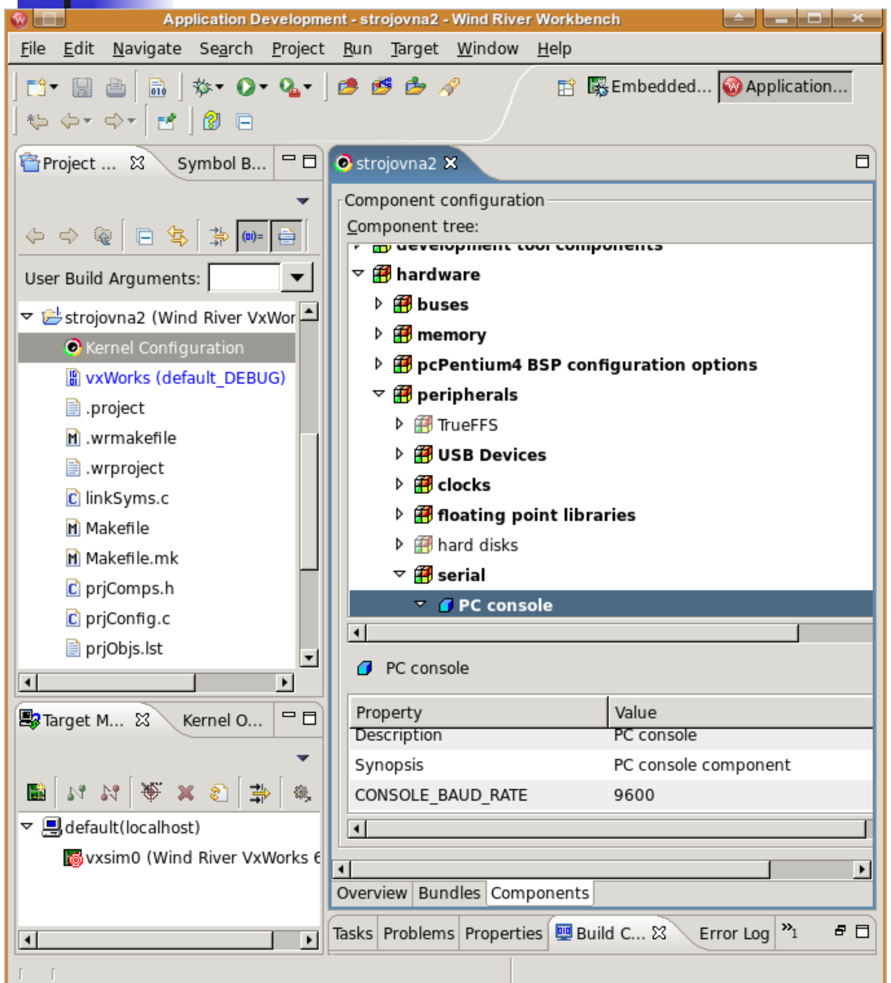
Writing own BSP – boot sequence (similar for all "embedded" systmes)

- Kernel image is located in FLASH/ROM memory or is loaded from network/disk by a bootloader to RAM.
- Initialize processor for running C (_romInit)
  - in assembler
  - initialize memory and a temporary stack
  - disable interrupts
- romStart is called (*installDir*/vxworks-6.x/target/config/all/bootInit.c)
  - copy (and decompress) data sections from ROM to RAM
- _sysInit() is called
  - initialize cache, vector table; perform board specific initialization
  - start multi-tasking and user-booting task

VxWorks boot loader

- Loads a VxWorks image onto a target (from disk or network)
- Stripped down VxWorks kernel with boot loader shell
- Separate project type in WR Workbench
- VxWorks supports also self-booting image which does not need any boot loader

Preparing a Custom VxWorks Kernel



- VxWorks Image Project
- Choose which components to include and their settings
- Run “build”
  - Most components are available as binary only objects
  - => linking

Multiprocessor systems

- SMP – Symmetric Multi-Processing
  - All CPUs share the whole memory
  - A task can run on arbitrary CPU
  - Need for different synchronization primitives
    - Spinlocks, memory barriers, cache coherency...
- AMP – Asymmetric Multi-Processing
  - Supported only on multicore systems
  - Each CPU runs independent VxWorks OS copy
  - Ability to send messages between CPUs

Differences between SMP and AMP

Figure 17-2 :SMP System

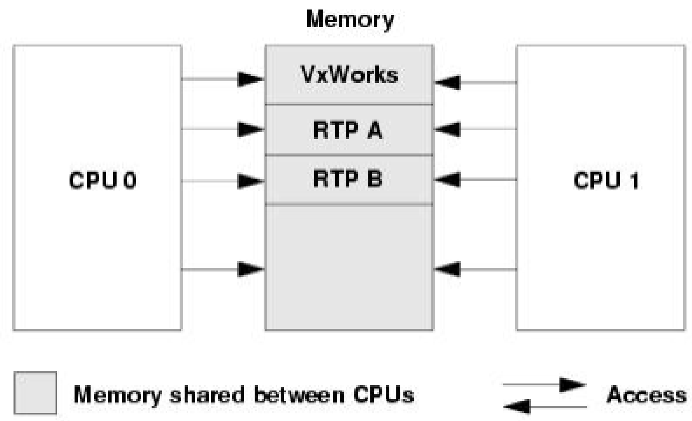
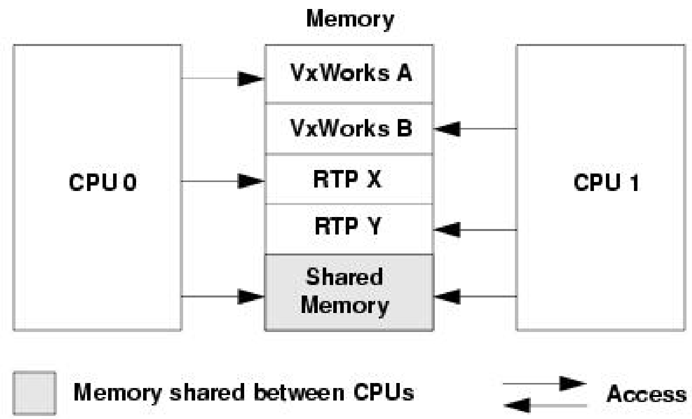


Figure 17-3 :AMP System

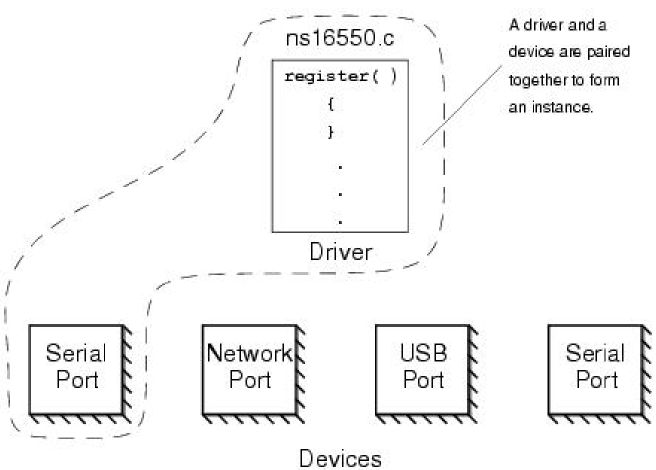


VxWorks Device Drivers

- Means of communication between VxWorks and hardware devices.
- Two types:
  - VxBus-enabled device drivers
    - Every driver is a plugable component
  - Legacy device drivers (versions 5.x and early 6.x)
    - Enabling/disabling a driver requires significant knowledge of BSP

VxBus

- Infrastructure for support of device drivers in VxWorks, with minimal BSP support.
- Terminology: *device* + *driver* = *instance*
- Drivers publishes *methods* (entry points)
- vxbDevMethodGet(): query which instance supports the given method (e.g. {vxbTimerFuncGet}() for timer instance)
- Driver classes:
  Serial, storage, network, ...
- Every class defines mandatory methods



Driver files

- Source code
- Component description file – integration with development tools
- *driverName*.**dc** file – provides the prototype for the driver registration routine
- *driverName*.**dr** file – provides a fragment of C code to call the driver registration routine
- README
- Makefile

Driver Source Code

- Table of initialization functions
- List of driver methods
- Driver's registration information structure
- Registration function (registers the driver with VxBus)

- See vxworks-6.7/target/src/hwif/*.c

Linux vs. VxWorks

- Price and license
- VxWorks is much simpler than Linux
  - Less overhead (sometimes)
  - Smaller memory footprint
- VxWorks has not so wide HW support
- VxWorks is certified for “almost everything”
- Linux real-time support is already quite good (rt_preempt)