POSIX and Real-Time POSIX

Portable Operating System Interface (for uniX)

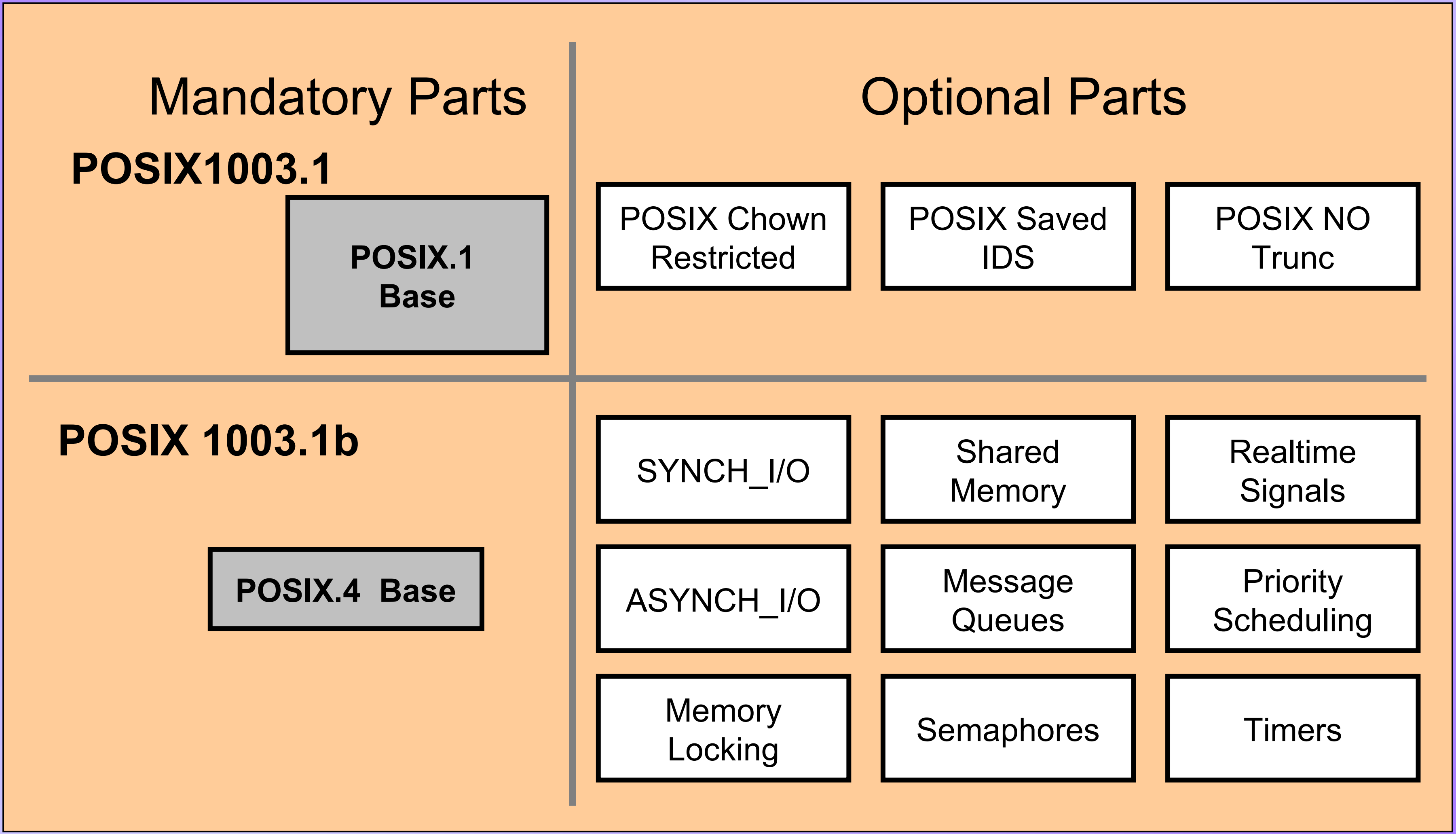
POSIX

- Goals:
  - To support application portability at **source-code level**
  - Interface, not implementation
  - The C language
  - Minimal changes to historical implementations
  - Minimal interface + extensions
- Standards:
  - Originally: POSIX = IEEE Std 1003.1-1988
  - Now:
    - POSIX = IEEE Std 1003.n and parts of ISO/IEC 9945
    - POSIX.1 = IEEE Std 1003.1-2004

Real-time POSIX

- IEEE Std 1003.1b-1993 Realtime Extension (formerly POSIX.4)
- IEEE Std 1003.1c-1995 Threads
- IEEE Std 1003.1d-1999 Additional Realtime Extensions
- IEEE Std 1003.1j-2000 Advanced Realtime Extensions
- IEEE Std 1003.1q-2000 Tracing

POSIX.1 and POSIX.4 mandatory and optional parts



POSIX 1003.1b – overview

- Coordination mechanisms
  - *Realtime* signals
  - General semaphores
  - Shared memory (and memory mapped files)
  - Message queues
- Scheduling

$\left.\right\}$ Covered in VxWorks lecture

- *Realtime* clocks and timers
- Memory locking
- Asynchronous and synchronous I/O

POSIX – What's in the box (1)

- Qualitative properties = what is implemented

  `#include <unistd.h>`

  - Constants with **`_POSIX_`**, prefix e.g. **`_POSIX_TIMERS, _POSIX_MEMLOCK, _POSIX_IPV6`**
- Quantitative properties = how many

  `#include <limits.h>`

  - **`_MAX`** constants e.g. **`OPEN_MAX, TIMER_MAX, AIO_MAX, RTSIG_MAX`**

POSIX – What's in the box (2)

- Run-time checking

```
#include <unistd.h>

/* Parameters valid for the whole OS */
long sysconf(int option);
e.g. sysconf(_SC_OPEN_MAX);
/* Parameters depending on directory/file */
long pathconf(char *pathname, int option);
long fpathconf(int fd, int option);

e.g. pathconf("/home", _PC_NAME_MAX);
```

POSIX – API conventions

- For `int` return type, `-1` represents error, `0` (or positive number) success
- In case of error, the global variable `errno` contains the error code (#include <errno.h>)
  - Each thread has its own value of `errno`.
- For pointer return types, NULL or -1 indicates an error
- If a special type is returned, it can often be typecasted to `int` and `-1` indicates an error

Example error handling

```
int fd = open("/etc/passwd", O_RDWR);
if (fd == -1) {
    perror("/etc/passwd");
    exit(1);
}
```

- perror prints string representation of `errno`
- e.g.: `if errno == EPERM` =>
  `/etc/passwd: Operation not permitted`

Tips & tricks

- Always start the names of named objects with „/“, then don't use this character again in the name
- In most times, the existence of named object at creation time indicates problems. Create named objects with `(O_CREAT|O_EXCL)` flags and in case of error check `errno` for detailed information.

Clocks & Timers

Clocks and timers

- Clocks are used to determine actual time
- Timers generate time intervals and periodic intervals of the same length
- Data type with nanosecond resolution
- Ability to determine resolution of each clock
- Notification by RT signal on timer expiration
- Timer overruns are detected

Clocks and timers – API (1)

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

```
/* Constants */
```

- `CLOCK_REALTIME` – System real-time clock
- `CLOCK_MONOTONIC` – Monotonic clock; cannot be set
- `CLOCK_PROCESS_CPUTIME_ID` – measures process CPU time
- `CLOCK_THREAD_CPUTIME_ID` – measures thread CPU time

```
/* POSIX.4 time data type */
struct timespec {
   time_t      tv_sec;   /* seconds (POSIX.1 type) */
   long tv_nsec;   /* nanoseconds */
}; /* Type for time, interval, time resolution */
```

Clocks – API (2)

```
/* Get clock resolution */
int clock_getres(clockid_t clock_id);

/* Get clock's actual time */
int clock_gettime(clockid_t clock_id, struct timespec *current_time);

/* Set clock's actual time */
int clock_settime(clockid_t clock_id, struct const timespec *new_time);


/* Delay the process execution */

int nanosleep(const struct timespec *interval, struct timespec
    *remaining_time);


/* high-resolution sleep with specifiable clock and absolute/relative
    timeout */
int clock_nanosleep(clockid_t clock_id, int flags, const struct timespec
    *request, struct timespec *remain);
```

Using clock_nanosleep to implement periodic task

```c
struct timespec timespec_add(struct timespec ts, unsigned long long ns)
{
		ts.tv_nsec += ns;
		while (ts.tv_nsec >= NSEC_PER_SEC) {
				ts.tv_nsec -= NSEC_PER_SEC;
				ts.tv_sec++;
		}
		return ts;
}


void periodic_task()
{
		struct timespec next;
		clock_gettime(CLOCK_MONOTONIC, &next);
		while (true) {
				do_something();
				/* Wait until next period */
				next = timespec_add(next, 100_000_000); /* period = 100 ms */
				clock_nanosleep(CLOCK_MONOTONIC, TIMER_ABSTIME, &next, NULL);
		}
}
```

Timers – API (3)

```
/* Create/delete timer */
int timer_create(clockid_t clock, struct sigevent
   *sigev, timer_t *created_timer);
int timer_delete(timer_t timer_to_delete);

/* Set/get timer interval */
int timer_settime(timer_t timer, int flags, const
   struct itimerspec *val,struct itimerspec *old);
int timer_gettime(timer_t timer, struct
   itimerspec *oldvalue);

/* Get number of timer overruns */
int timer_getoverrun(timer_t timerid);
```

Memory locking

Memory locking

- Prevents non-predictable delays caused by page faults (e.g. swapping memory to disk)
- This is not the same as “locking” a mutex!
- Useful for time critical processes
- Basic variant – lock all process memory
- Extended variant – lock a specified part of memory
- Use of extended variant depends on the compiler/linker

Memory locking – API (1)

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

/* Lock/unlock all process memory */
int mlockall(int flags);
int munlockall(void);

/* Lock/unlock memory area */
int mlock(void *address, size_t length);
int munlock(void *address, size_t length);
```

Synchronous and asynchronous I/O

Synchronous and asynchronous I/O

- When are data really stored to the disk?
  - *synchronized I/O* gives program control over it
- Why I have to wait for all I/O?
  - *asynchronous I/O* allows execution of I/O in parallel with the process execution
  - Solves the problem of waiting for multiple I/O operations

Synchronous I/O – API (1)

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

```
/* Constants */
```

- **F_GETFL –** determine the sync. file mode (POSIX.1)
- **F_SETFL –** change the sync. file mode (POSIX.1)
- **O_NONBLOCK** - read/write operations doesn't blocks the process (POSIX.1)
- **O_DSYNC** – synchronization during write
- **O_SYNC** – **O_DSYNC** + sync. Information stored in inodes
- **O_RSYNC** – synchronize inode information for reading (**O_SYNC** read equivalent)

Synchronous I/O – API (2)

```
/* Change file mode (POSIX.1) */
int fcntl(int fd, int oper, ...);

/* Write data and metadata (file size etc.) to
   the file */
int fsync(int fd);
/* Write only data (withou metadata) to the file
  (faster, possible problems after system crash.)
   */
int fdatasync(int fd);
```

Asynchronous I/O – API (1)

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

/* AIO control block */
struct aiocb {
   int     aio_fildes; /*I/O device/file FD */
   off_t aio_offset;  /* Offset in the file */
   volatile void *aio_buf; /* read/write buffer */
   struct sigevent aio_sigevent; /*notif. signal*/
   int    aio_lio_opcode; /* Requested operation */
   int    aio_rqprio;  /* AIO priority */
};
```

Asynchronous I/O – API (2)

```
/* Asynchronous input */
int aio_read(struct aiocb *read_aiocb);
/* Asynchronous output */
int aio_write(struct aiocb *write_aiocb);
/* Cancel asynchronous operation */
int aio_cancel(struct aiocb *cancel_aiocb);
/* Get (error) state of finished AIO operation */
ssize_t aio_return(struct aiocb *cancel_aiocb);
/* Get actual state of running/finished AIO
  operation, it can be called repeatedly */
int aio_error(struct aiocb *cancel_aiocb);
```

Asynchronous I/O – API (3)

```
/* Wait for completion of multiple AIO */
int aio_suspend(struct aiocb *laiocb[], int nent,
   const struct timespec *timeout);

/* Constants */
```

- `LIO_READ, LIO_WRITE, LIO_NOP` – typ operace
- `LIO_WAIT, LIO_NOWAIT` – blokující/neblokující chování

```
/* More AIO reads/writes in one call */
int aio_listio(int wait_or_not, struct aiocb *
   const laiocb[], int nent, struct sigevent
   *notification);
```

Threads

- pthread library
  - Run linker with `-lpthread`
  - pthread functions do not set errno but return error code
  - `#include <pthread.h>`
- **`pthread_create`**`(pthread_t*, pthread_attr_t*, *start_routine, *arg)`
- **`pthread_mutex_(init|lock|unlock)`**
- Thread-specific data (**`pthread_key_create()`**, **`pthread_getspecific()`**)
- Thread cancelation (see POSIX:2008 2.9.5)

Literature

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- Michael González Harbour: "REAL-TIME POSIX: AN OVERVIEW"
- http://www.opengroup.org/austin/papers/posix_faq.html
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