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- Threads may be associated with objects by the programmer (thereby facilitating object-oriented programming)

Models of Thread Use

Boss/Worker a single thread handles inputs, assigning tasks to worker threads

Example 1

```
while(1) {
..get input..
switch(request) {
        case 'a': pthread_create(...); break;
        case 'b': pthread_create(...); break;
        ...
        }
}
```

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Example 4

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while(1) {
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Peer Model each thread handles its own input

Example 5

```
server accepts client
pthread_create(...) // thread exclusively handles client
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Example 8

server accepts client

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Pipeline Model threads handle parts of tasks and pass results along

Example 9

Dynamics controller for robot

Thread 1 drives joint 1 to desired value. Computes joint velocity, acceleration.

Thread 2 drives joint 2 to desired value, accounting for motion of joint 1.

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- LWPs have their own signal stacks, alarms, timers, and scheduling priority.

Thread Creation

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#include <pthread.h>
void pthread_create(pthread_t *thread,const pthread_attr_t *attr,
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- Use pthread_create() to create new threads. A thread will use a light weight process when running.

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- One way to terminate the thread is to allow the start_routine() function to return.

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(See thrd1.c and thrd2.c)

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- If you don’t pthread_join() non-detached threads, you end up with **zombie threads**

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- A detached thread cannot be joined via `pthread_join()`
- When the process exits, detached threads will be terminated and all process and thread resources will be released

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  No mutexes. No condition variables. Etc.
- A thread may use the sem_post() call, however, to communicate with other threads. *link*

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- Recall sigprocmask() – that was for a process's mask; for threads, pthread_sigmask() is available.
- The signal sets may be built in the usual fashion using *sigsetops*: sigemptyset(), sigaddset(), sigdelset(), sigfillset(), and sigismember().

Threads: pthread_sigmask()

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#include <signal.h>
int pthread_sigmask(int how, const sigset_t *set, sigset_t *oldset);
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Threads: sigwait()

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- On success: sigwait() returns 0.
  On error: sigwait() returns a positive error number

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- Unlocks the semaphore pointed to by sem.
- This semaphore is *not* the same as the IPC semaphores presented earlier this semester.
- May be used to synchronize threads or processes (Posix semaphore)

Threads: sem_post()

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int sem_post(sem_t *sem);

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- More on Posix semaphores next week

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- Some signal dispositions will affect the entire process (stop, continue, terminate)

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  5. Destroy attribute (release resources); destroying attributes does not affect threads that have been initialized with them

Attributes: Initialization

```
#include <pthread.h>
pthread_attr_t attrib;
int pthread_attr_init(pthread_attr_t *attr);
int pthread_attr_destroy(pthread_attr_t *attr);
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- pthread_attr_init(): Initializes an attribute with default values.

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- pthread_attr_destroy(): Destroying an attribute has no effect on threads already created with the attribute

Attributes: Setting up a Thread's Stack

#include <pthread.h>
int pthread_attr_setstacksize(pthread_attr_t *attr, size_t stacksize);
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- pthread_attr_setstackaddr(): should point to a buffer of at least PTHREAD_STACK_MIN bytes that has been allocated by the caller.
  The pages of the allocated buffer should be both readable and writable.

(See thrdstacksize.c and thrdstack.c)

Attributes: Detached State

```
#include <pthread.h>
int pthread_detach(pthread_t thread);
int pthread_attr_setdetachstate(pthread_attr_t *attr, int detachstate);
int pthread_attr_getdetachstate(pthread_attr_t *attr, int *detachstate);
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- Caveat: once detached, one cannot "re-attach" it

see thrd_detached.c

Scheduling Scope

scheduling scope: which threads contend for processing

system scope Threads with system scope contend with all other threads with system scope, irrespective of which process to which they belong.
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process scope Threads with process scope contend only with other threads in the same process. These are lightweight process context switches, and may use the same or some small number of kernel entities (LWPs).
However, lower priority threads from other processes may run instead of your process' high priority thread.

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- An ASD defines the set of processors for which a thread may contend

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mpctl	apply processor affinity to applications

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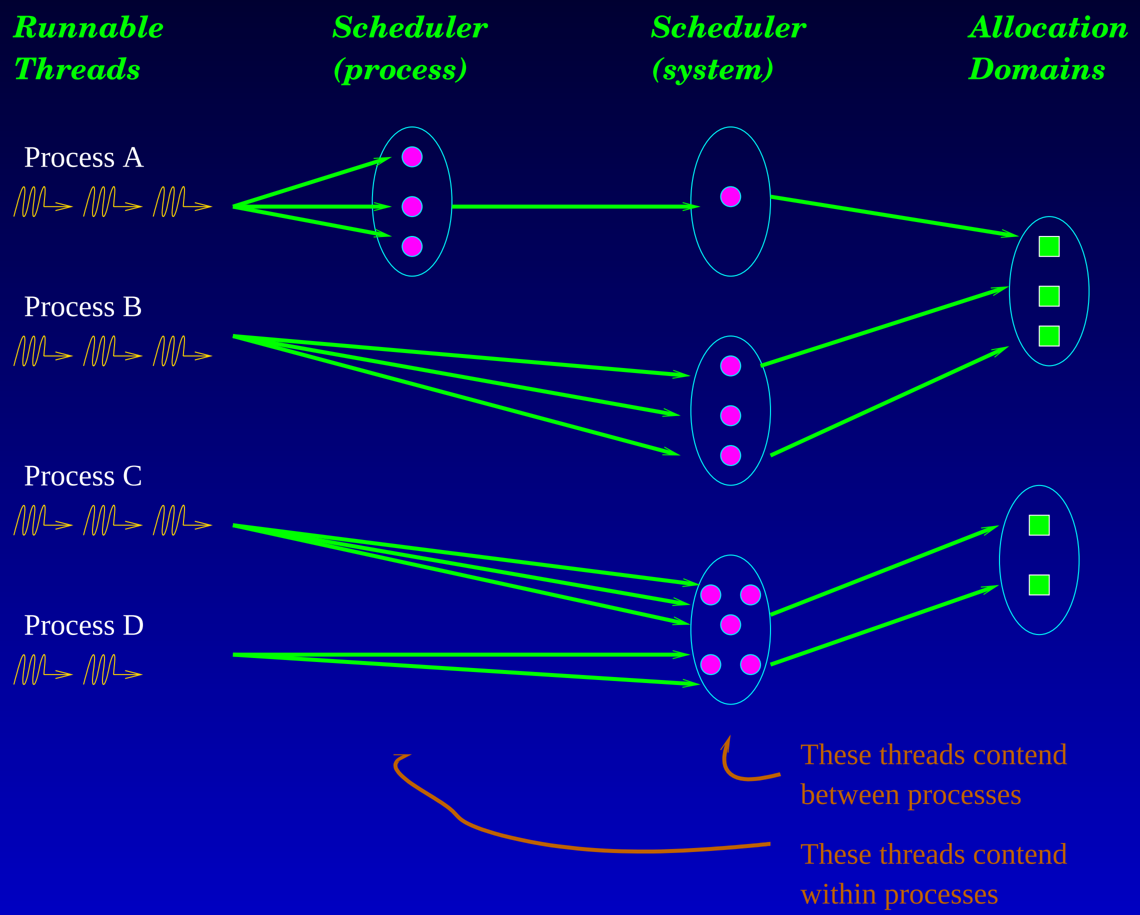
  - By default, the entire system is the scheduling allocation domain for an application.
  - One may group processors together for the exclusive use of specific applications
  - Threads in the same process may be bound to different processor sets

API	*Description*
pset_create	create a new PS
pset_destroy	destroy a PS
pset_assign	reassign a processor from one PS to another
pset_bind	rebind a process/thread from one PS to another
pset_setattr	change PS attribute values
pset_ctl	query PS configuration
pthread_pset_bind_np	change pset binding of a pthread
mpctl	apply processor affinity to applications within the app’s PS

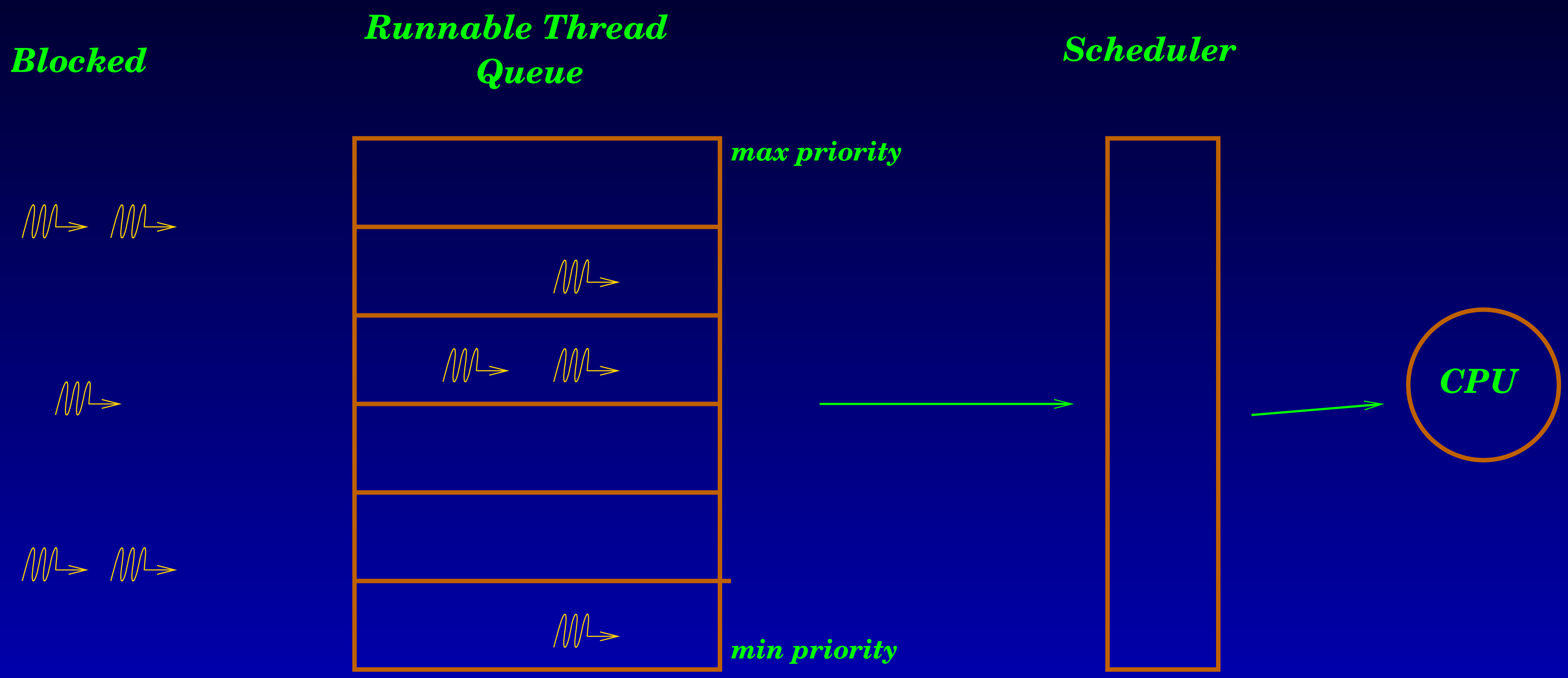
PS=processor set

Allocation Domains, con't.



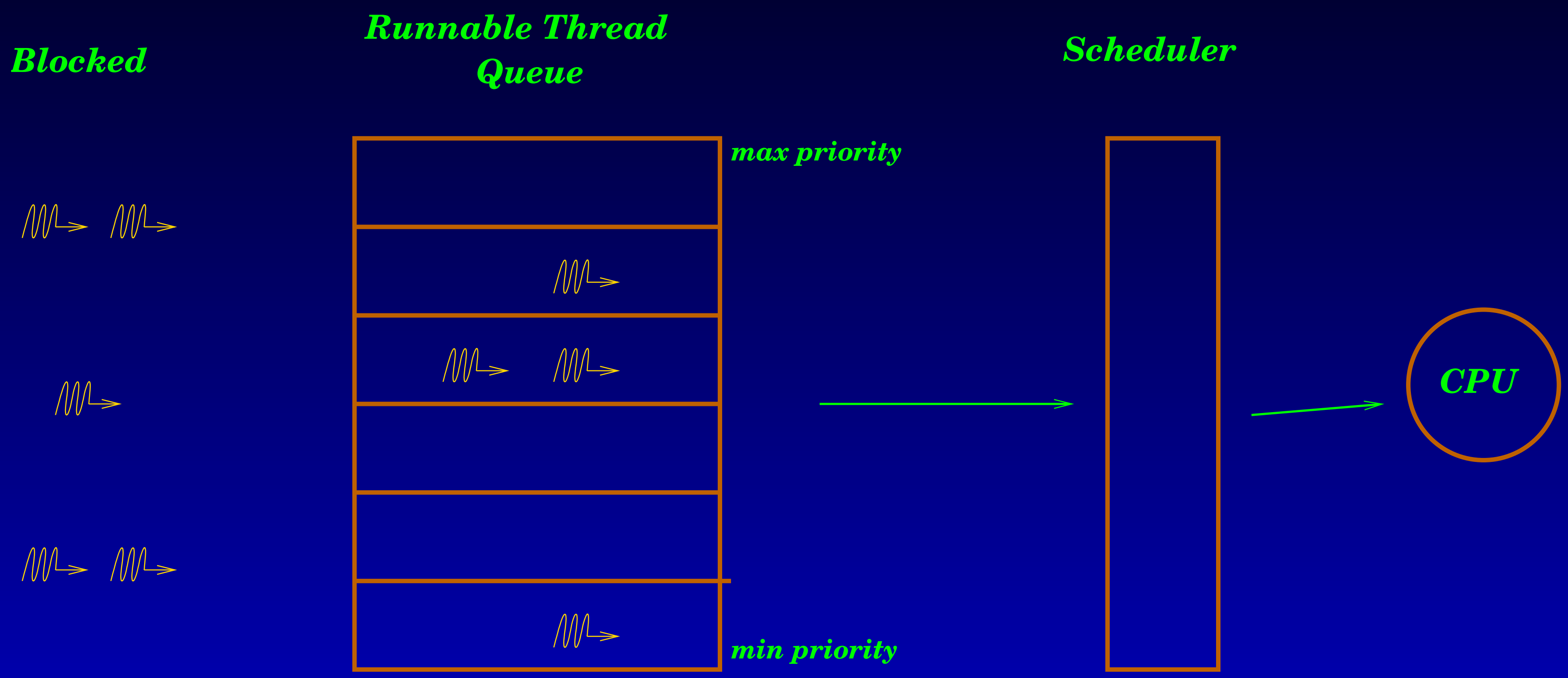
- With allocation domains, if threads are all blocked (say, C and D), then the CPUs in that domain may be idle even though the other domain's CPUs are running full bore with waiting threads

Scheduling Priority



- Threads are placed on priority queues

Scheduling Priority



- Threads are placed on priority queues
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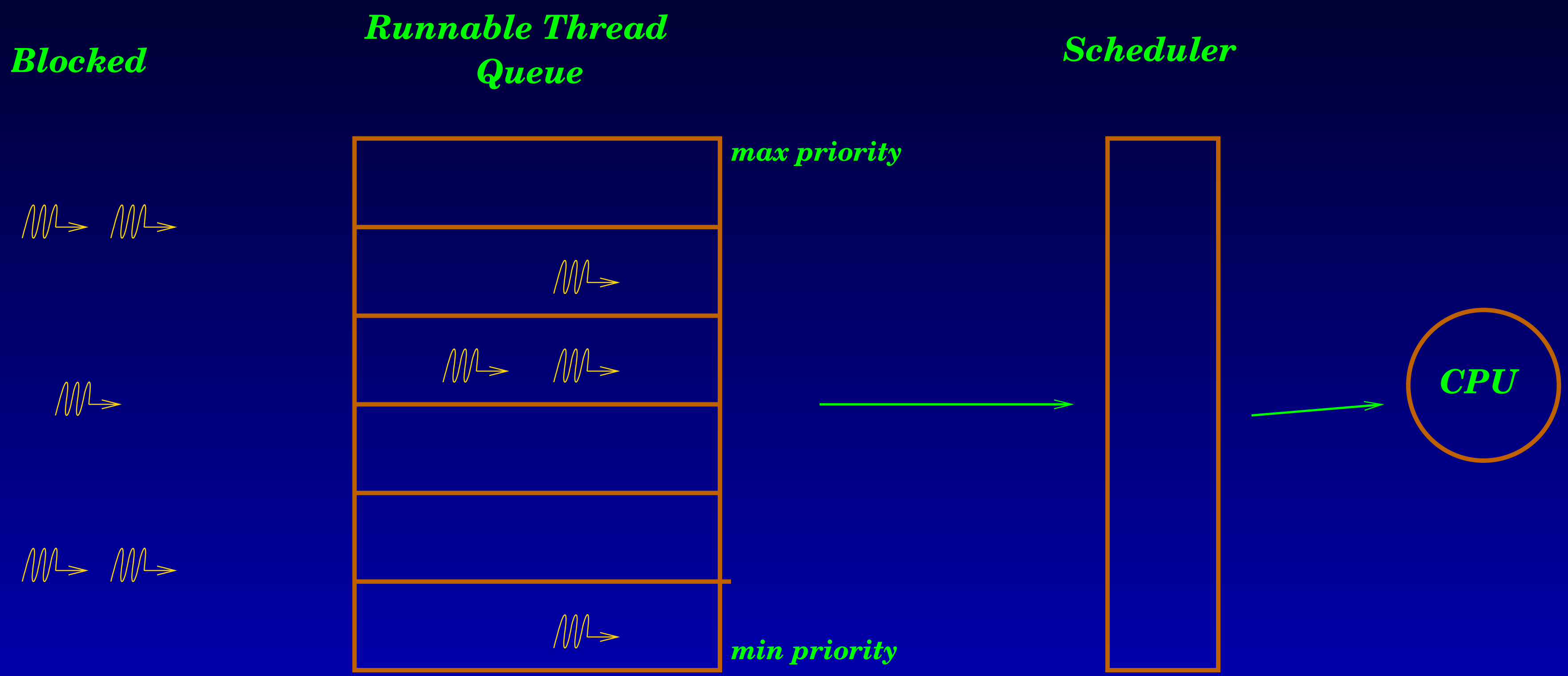
Scheduling Priority



- Threads are placed on priority queues
- The scheduler looks for the highest priority thread available to run
- Whenever a higher priority thread becomes runnable than the currently running thread's priority, the lower priority thread is interrupted and put at the end of its priority queue. This is known as an ***involuntary context switch***.

Scheduling Policy

Scheduling Policy: determines how long a thread runs after having been moved from a priority queue to a processing slot.

SCHED_FIFO : (first-in first-out) threads run until they block or exit. When a blocked thread again becomes runnable, it is placed at the back of its priority queue

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_POSIX_THREAD_PRIORITY_SCHEDULING

_POSIX_THREAD_ATTR_PRIORITY_SCHEDULING

Threads: Scope

```
#include <pthread.h>
int pthread_attr_setscope(pthread_attr_t *attr, int scope);
int pthread_attr_getscope(pthread_attr_t *attr, int *scope);
```

- The `pthread_attr_setscope()` function sets the thread's contention scope for the attribute object `attr`.

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(See thrdscope.c)

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(See thrdpolicy.c)

Threads: Priority Min/Max

```
#include <sched.h>
int sched_get_priority_max(int policy);
int sched_get_priority_min(int policy);
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- Processes with numerically higher priority values are scheduled before processes with numerically lower priority values

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(*See thrdprio.c*)

Threads: Setting Scheduling Parameters

#include <pthread.h>
int pthread_attr_setschedparam(pthread_attr_t *attr, const struct sched_param *param);
int pthread_attr_getschedparam(pthread_attr_t *attr, struct sched_param *param);

```
struct sched_param {
    int sched_priority; // only required member
}
```

1. Declare a sched_param structure object

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1. Declare a sched_param structure object
2. Pick a policy via pthread_attr_setsched()

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2. Pick a policy via pthread_attr_setsched()
3. Pick a priority within the policy's min/max bounds

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4. Assign it to ***.sched_priority

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3. Pick a priority within the policy's min/max bounds
4. Assign it to `***.sched_priority`
5. Use it with `pthread_attr_setschedparam()`

- This sets up a static priority attribute for use with `pthread_create()`.

Threads: Dynamic Priority

#include <pthread.h>
pthread_setschedparam(pthread_t thread, int policy, const struct sched_param *param);
pthread_getschedparam(pthread_t thread, int *policy, struct sched_param *param);

- The pthread_setschedparam() function sets the scheduling policy and parameters of the specified thread.

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- Set priority with `***.sched_priority` in a `sched_param` object.

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- Policies available are the usual three: SCHED_FIFO, SCHED_RR, and SCHED_OTHER.
- Set priority with ***.sched_priority in a sched_param object.
- You may set a thread's priority higher than the current thread's priority, causing the current thread to be *immediately pre-empted*.

Threads: Inheritance

```
#include <pthread.h>
int pthread_attr_setinheritsched(pthread_attr_t *attr,int inheritsched);
int pthread_attr_getinheritsched(pthread_attr_t *attr,int *inheritsched);
```

- You may have child threads inherit scheduling attributes from the parent thread instead of explicitly specifying it

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- pthread_attr_getinheritsched() returns the inherit scheduler attribute in *inheritsched

Threads: Cancelling Threads

```
#include <pthread.h>
int pthread_cancel(pthread_t thread);
int pthread_setcancelstate(int state, int *oldstate);
int pthread_setcanceltype(int type, int *oldtype);
```

- The `pthread_cancel()` function sends a cancellation request to the target `thread`.

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- The thread may control its cancelability state via pthread_setcancelstate().

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(See thrd_defines.c)

Threads: Controlled Cleanup

#include <pthread.h>

void pthread_cleanup_push(void (*routine)(void *), void *arg);

void pthread_cleanup_pop(int execute);

- The pthread_cleanup_push() function schedules a routine to be called when a thread is terminating

  (but not when its returning from its starting routine)

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- The thread cleanup function resembled atexit() (which pushes process-level cleanup function(s))

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  int pthread_once(pthread_once_t *once_control,void (*init_routine)(void));
  pthread_once_t once_control = PTHREAD_ONCE_INIT;
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  Allows one to specify a thread initialization routine.
  - One has multiple threads
  - Each thread has a call to pthread_once()
  - Only the first such call will succeeded in calling routine()

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- Use mutexes via pthread_mutex_lock() or pthread_mutex_trylock() (see later slide)

Sync: Initializing a Mutex

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#include <pthread.h>
pthread_mutex_t mutex = PTHREAD_MUTEX_INITIALIZER;
int pthread_mutex_init(pthread_mutex_t *restrict mutex, const pthread_mutexattr_t
*restrict attr);
int pthread_mutex_destroy(pthread_mutex_t *mutex);
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- Mutexes may themselves have attributes (see later slide)

Sync: Locking/Unlocking a Mutex

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(See thrdmutex.c)

Sync: Mutex Attributes

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#include <pthread.h>
int pthread_mutexattr_destroy(pthread_mutexattr_t *attr);
int pthread_mutexattr_init    (pthread_mutexattr_t *attr);
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PTHREAD_MUTEX_DEFAULT (default) results in *undefined behavior*. Attempting to unlock an unlocked mutex of this type also results in *undefined behavior*. An implementation may have PTHREAD_MUTEX_DEFAULT map to one of the other three types.

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- One way to prevent these deadlocks is to require that multiple locks must always be acquired in the same sequence by all threads
- Then, Process *b* would have tried to lock resource A first, and would have failed because *a* held the lock

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Mars Pathfinder's o/s had a mutex with a boolean parameter (attribute) supporting **priority inheritance**. It was off; when on, the process *C* would have inherited the priority of *A* when *A* blocked on the mutex. Simple fix; but painful to find.

Sync: Avoiding Priority Inversion

#include <pthread.h>
int pthread_mutexattr_getprotocol(const pthread_mutexattr_t * restrict attr, int *restrict protocol);
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(see thrdprioinherit.c)

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- In case of a broadcast, the desired condition may no longer hold due to some other c.v.-waiting thread's data modification(s)

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- Use the first method for a default c.v.

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- Don't use copies of cv in calls to pthread_cond_wait(), etc; use only the cv itself.

  (behavior is otherwise undefined)

Sync: Waiting for a Condition Variable

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(see thrdcond.c)

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- These two functions have no effect if no threads are blocked waiting for the c.v.

Sync: Reader/Writer Locks

int pthread_rwlock_destroy(pthread_rwlock_t *rwlock);
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- If a thread is blocked waiting for a read-write lock for reading, and it receives a signal, after its signal handler returns the thread will resume waiting.

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- If there are other threads holding a read lock on rwlock, then the object remains in the read locked state

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int pthread_rwlock_unlock(pthread_rwlock_t *rwlock);

- pthread_rwlock_unlock() releases any lock held on rwlock by the calling thread, whether it is a read or a write lock
- Unlocking a rwlock not held by the calling thread is undefined behavior.
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(see thrd_rdlock.c)

Sync: Reader/Writer Lock Attributes

int pthread_rwlockattr_getpshared(const pthread_rwlockattr_t * restrict attr, int *restrict pshared);

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- The SHARED feature is available only if the symbolic constant _POSIX_THREAD_PROCESS_SHARED is defined in unistd.h to be a value greater than zero.

Sync: Posix Semaphores

```
#include <semaphore.h>
int sem_init(sem_t *sem, int pshared, unsigned int value);
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- Using a destroyed semaphore produces undefined behavior (unless it has been re-initialized)

Sync: Using Posix Semaphores

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#include <semaphore.h>
int sem_wait(sem_t *sem);
int sem_trywait(sem_t *sem);
int sem_timedwait(sem_t *sem, const struct timespec *abs_timeout);
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- `sem_wait()` The thread/process will wait (block) until the semaphore's value becomes greater than or equal to one. It then atomically decrements the semaphore's value (ie. locks it) and unblocks.

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- Posix semaphores can be released *by any thread with access*.

see thrd_unnamedsem.c, thrd_timedwait.c

Sync: Posix Named Semaphores

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#include <fcntl.h>      // For O_* constants
#include <sys/stat.h> // For mode constants
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- If the semaphore with a given name already exists, both oflag and mode will simply be ignored.