PennOS

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Chapter 1

Class Index

1.1 Class List

Here are the classes, structs, unions and interfaces with brief descriptions:

Chapter 2

File Index

2.1 File List

Here is a list of all files with brief descriptions:

Chapter 3

Class Documentation

3.1 dir_entry_t Struct Reference

Directory entry structure for files in the filesystem.

```
#include <fat_routines.h>
```

Public Attributes

- char name [32]
- uint32_t size
- uint16_t firstBlock
- uint8_t type
- uint8_t perm
- time_t mtime
- char reserved [16]

3.1.1 Detailed Description

Directory entry structure for files in the filesystem.

Definition at line 47 of file fat_routines.h.

3.1.2 Member Data Documentation

3.1.2.1 firstBlock

```
uint16_t dir_entry_t::firstBlock
```

Definition at line 50 of file fat_routines.h.

3.1.2.2 mtime

```
time_t dir_entry_t::mtime
```

Definition at line 53 of file fat_routines.h.

3.1.2.3 name

```
char dir_entry_t::name[32]
```

Definition at line 48 of file fat_routines.h.

3.1.2.4 perm

```
uint8_t dir_entry_t::perm
```

Definition at line 52 of file fat_routines.h.

3.1.2.5 reserved

```
char dir_entry_t::reserved[16]
```

Definition at line 54 of file fat_routines.h.

3.1.2.6 size

```
uint32_t dir_entry_t::size
```

Definition at line 49 of file fat_routines.h.

3.1.2.7 type

```
uint8_t dir_entry_t::type
```

Definition at line 51 of file fat_routines.h.

The documentation for this struct was generated from the following file:

- SRC/fs/fat_routines.h

3.2 fd_entry_t Struct Reference

File descriptor entry structure for open files.

```
#include <fat_routines.h>
```

Public Attributes

- int in_use
- int ref_count
- char filename [32]
- uint32_t size
- uint16_t first_block
- uint32_t position
- uint8_t mode

3.2.1 Detailed Description

File descriptor entry structure for open files.

Definition at line 60 of file fat_routines.h.

3.2.2 Member Data Documentation

3.2.2.1 filename

```
char fd_entry_t::filename[32]
```

Definition at line 63 of file fat_routines.h.

3.2.2.2 first_block

```
uint16_t fd_entry_t::first_block
```

Definition at line 65 of file fat_routines.h.

3.2.2.3 in_use

```
int fd_entry_t::in_use
```

Definition at line 61 of file fat_routines.h.

3.2.2.4 mode

`uint8_t fd_entry_t::mode`

Definition at line 67 of file fat_routines.h.

3.2.2.5 position

`uint32_t fd_entry_t::position`

Definition at line 66 of file fat_routines.h.

3.2.2.6 ref_count

`int fd_entry_t::ref_count`

Definition at line 62 of file fat_routines.h.

3.2.2.7 size

`uint32_t fd_entry_t::size`

Definition at line 64 of file fat_routines.h.

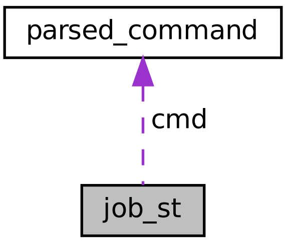
The documentation for this struct was generated from the following file:

- SRC/fs/fat_routines.h

3.3 job_st Struct Reference

`#include <Job.h>`

Collaboration diagram for job_st:



Public Attributes

- jid_t id
- struct parsed_command * cmd
- pid_t * pids
- job_state_t state
- size_t num_pids
- pid_t pgid
- size_t finished_count

3.3.1 Detailed Description

Definition at line 16 of file Job.h.

3.3.2 Member Data Documentation

3.3.2.1 cmd

```
struct parsed_command* job_st::cmd
```

Definition at line 18 of file Job.h.

3.3.2.2 finished_count

```
size_t job_st::finished_count
```

Definition at line 23 of file Job.h.

3.3.2.3 id

```
jid_t job_st::id
```

Definition at line 17 of file Job.h.

3.3.2.4 num_pids

```
size_t job_st::num_pids
```

Definition at line 21 of file Job.h.

3.3.2.5 pgid

```
pid_t job_st::pgid
```

Definition at line 22 of file Job.h.

3.3.2.6 pids

```
pid_t* job_st::pids
```

Definition at line 19 of file Job.h.

3.3.2.7 state

```
job_state_t job_st::state
```

Definition at line 20 of file Job.h.

The documentation for this struct was generated from the following file:

- SRC/shell/Job.h

3.4 parsed_command Struct Reference

```
#include <parser.h>
```

Public Attributes

- bool is_background
- bool is_file_append
- const char * stdin_file
- const char * stdout_file
- size_t num_commands
- char ** commands []

3.4.1 Detailed Description

struct parsed_command stored all necessary information needed for penn-shell.

Definition at line 36 of file parser.h.

3.4.2 Member Data Documentation

3.4.2.1 commands

```
char** parsed_command::commands[]
```

Definition at line 56 of file parser.h.

3.4.2.2 is_background

```
bool parsed_command::is_background
```

Definition at line 39 of file parser.h.

3.4.2.3 is_file_append

```
bool parsed_command::is_file_append
```

Definition at line 43 of file parser.h.

3.4.2.4 num_commands

```
size_t parsed_command::num_commands
```

Definition at line 52 of file parser.h.

3.4.2.5 stdin_file

```
const char* parsed_command::stdin_file
```

Definition at line 46 of file parser.h.

3.4.2.6 stdout_file

```
const char* parsed_command::stdout_file
```

Definition at line 49 of file parser.h.

The documentation for this struct was generated from the following file:

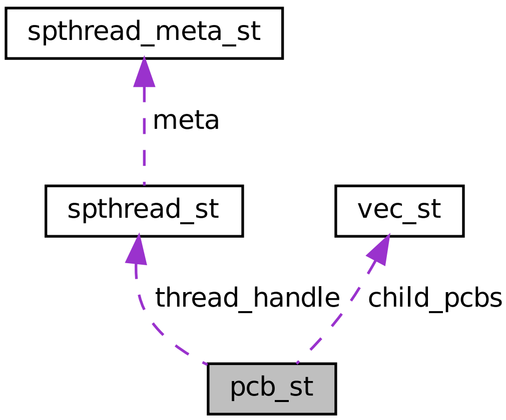
- SRC/shell/parser.h

3.5 pcb_st Struct Reference

The PCB structure, which contains all the information about a process. Notably, it contains the thread handle, pid, parent pid, child pcbs, priority level, process state, command string, signals to be sent, input and output file descriptors, process status, sleeping status, and time to wake.

```
#include <kern_pcb.h>
```

Collaboration diagram for pcb_st:



Public Attributes

- spthread_t thread_handle
- pid_t pid
- pid_t par_pid
- Vec child_pcbs
- int priority
- char process_state
- char * cmd_str
- bool signals [3]
- int input_fd
- int output_fd
- int process_status
- bool is_sleeping
- int time_to_wake
- int fd_table [FILE_DESCRIPTOR_TABLE_SIZE]

3.5.1 Detailed Description

The PCB structure, which contains all the information about a process. Notably, it contains the thread handle, pid, parent pid, child pcbs, priority level, process state, command string, signals to be sent, input and output file descriptors, process status, sleeping status, and time to wake.

Definition at line 29 of file kern_pcb.h.

3.5.2 Member Data Documentation

3.5.2.1 child_pcbs

```
Vec pcb_st::child_pcbs
```

Definition at line 35 of file kern_pcb.h.

3.5.2.2 cmd_str

```
char* pcb_st::cmd_str
```

Definition at line 41 of file kern_pcb.h.

3.5.2.3 fd_table

```
int pcb_st::fd_table[FILE_DESCRIPTOR_TABLE_SIZE]
```

Definition at line 60 of file kern_pcb.h.

3.5.2.4 input_fd

```
int pcb_st::input_fd
```

Definition at line 47 of file kern_pcb.h.

3.5.2.5 is_sleeping

```
bool pcb_st::is_sleeping
```

Definition at line 57 of file kern_pcb.h.

3.5.2.6 output_fd

```
int pcb_st::output_fd
```

Definition at line 48 of file kern_pcb.h.

3.5.2.7 par_pid

```
pid_t pcb_st::par_pid
```

Definition at line 33 of file kern_pcb.h.

3.5.2.8 pid

```
pid_t pcb_st::pid
```

Definition at line 32 of file kern_pcb.h.

3.5.2.9 priority

```
int pcb_st::priority
```

Definition at line 37 of file kern_pcb.h.

3.5.2.10 process_state

```
char pcb_st::process_state
```

Definition at line 38 of file kern_pcb.h.

3.5.2.11 process_status

```
int pcb_st::process_status
```

Definition at line 50 of file kern_pcb.h.

3.5.2.12 signals

```
bool pcb_st::signals[3]
```

Definition at line 43 of file kern_pcb.h.

3.5.2.13 thread_handle

```
spthread_t pcb_st::thread_handle
```

Definition at line 30 of file kern_pcb.h.

3.5.2.14 time_to_wake

```
int pcb_st::time_to_wake
```

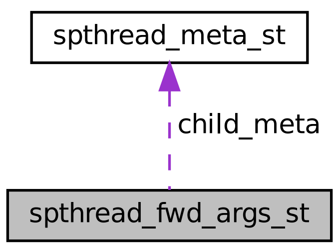
Definition at line 58 of file kern_pcb.h.

The documentation for this struct was generated from the following file:

- SRC/kernel/kern_pcb.h

3.6 spthread_fwd_args_st Struct Reference

Collaboration diagram for spthread_fwd_args_st:



Public Attributes

- pthread_fn actual_routine
- void * actual_arg
- bool setup_done
- pthread_mutex_t setup_mutex
- pthread_cond_t setup_cond
- spthread_meta_t * child_meta

3.6.1 Detailed Description

Definition at line 22 of file spthread.c.

3.6.2 Member Data Documentation

3.6.2.1 actual_arg

```
void* spthread_fwd_args_st::actual_arg
```

Definition at line 27 of file spthread.c.

3.6.2.2 actual_routine

```
pthread_fn spthread_fwd_args_st::actual_routine
```

Definition at line 26 of file spthread.c.

3.6.2.3 child_meta

```
spthread_meta_t* spthread_fwd_args_st::child_meta
```

Definition at line 40 of file spthread.c.

3.6.2.4 setup_cond

```
pthread_cond_t spthread_fwd_args_st::setup_cond
```

Definition at line 37 of file spthread.c.

3.6.2.5 setup_done

```
bool spthread_fwd_args_st::setup_done
```

Definition at line 35 of file spthread.c.

3.6.2.6 setup_mutex

```
pthread_mutex_t spthread_fwd_args_st::setup_mutex
```

Definition at line 36 of file spthread.c.

The documentation for this struct was generated from the following file:

- SRC/lib/spthread.c

3.7 spthread_meta_st Struct Reference

Public Attributes

- sigset_t suspend_set
- volatile sig_atomic_t state
- pthread_mutex_t meta_mutex

3.7.1 Detailed Description

Definition at line 57 of file spthread.c.

3.7.2 Member Data Documentation

3.7.2.1 meta_mutex

```
pthread_mutex_t spthread_meta_st::meta_mutex
```

Definition at line 71 of file spthread.c.

3.7.2.2 state

```
volatile sig_atomic_t spthread_meta_st::state
```

Definition at line 68 of file spthread.c.

3.7.2.3 suspend_set

```
sigset_t spthread_meta_st::suspend_set
```

Definition at line 59 of file spthread.c.

The documentation for this struct was generated from the following file:

- SRC/lib/spthread.c

3.8 spthread_signal_args_st Struct Reference

Public Attributes

- const int signal
- volatile sig_atomic_t ack
- pthread_mutex_t shutup_mutex

3.8.1 Detailed Description

Definition at line 46 of file spthread.c.

3.8.2 Member Data Documentation

3.8.2.1 ack

```
volatile sig_atomic_t spthread_signal_args_st::ack
```

Definition at line 48 of file spthread.c.

3.8.2.2 shutup_mutex

```
pthread_mutex_t spthread_signal_args_st::shutup_mutex
```

Definition at line 49 of file spthread.c.

3.8.2.3 signal

```
const int spthread_signal_args_st::signal
```

Definition at line 47 of file spthread.c.

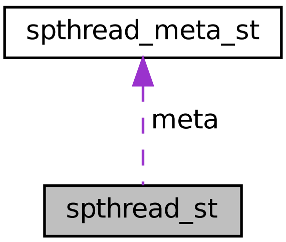
The documentation for this struct was generated from the following file:

- SRC/lib/spthread.c

3.9 spthread_st Struct Reference

```
#include <spthread.h>
```

Collaboration diagram for spthread_st:



Public Attributes

- pthread_t thread
- spthread_meta_t * meta

3.9.1 Detailed Description

Definition at line 28 of file spthread.h.

3.9.2 Member Data Documentation

3.9.2.1 meta

`spthread_meta_t* spthread_st::meta`

Definition at line 30 of file spthread.h.

3.9.2.2 thread

`pthread_t spthread_st::thread`

Definition at line 29 of file spthread.h.

The documentation for this struct was generated from the following file:

- SRC/lib/spthread.h

3.10 vec_st Struct Reference

`#include <Vec.h>`

Public Attributes

- ptr_t * data
- size_t length
- size_t capacity
- ptr_dtor_fn ele_dtor_fn

3.10.1 Detailed Description

Definition at line 10 of file Vec.h.

3.10.2 Member Data Documentation

3.10.2.1 capacity

```
size_t vec_st::capacity
```

Definition at line 13 of file Vec.h.

3.10.2.2 data

```
ptr_t* vec_st::data
```

Definition at line 11 of file Vec.h.

3.10.2.3 ele_dtor_fn

```
ptr_dtor_fn vec_st::ele_dtor_fn
```

Definition at line 14 of file Vec.h.

3.10.2.4 length

```
size_t vec_st::length
```

Definition at line 12 of file Vec.h.

The documentation for this struct was generated from the following file:

- SRC/lib/Vec.h

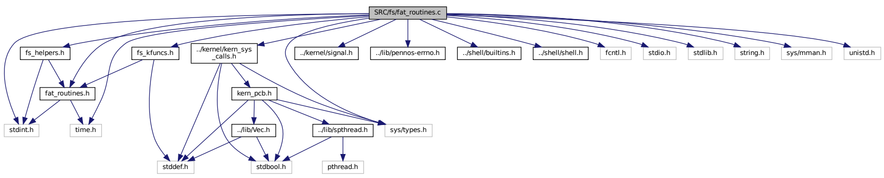
Chapter 4

File Documentation

4.1 SRC/fs/fat_routines.c File Reference

```
#include "fat_routines.h"
#include "../kernel/kern_sys_calls.h"
#include "../kernel/signal.h"
#include "../lib/pennos-errno.h"
#include "../shell/builtins.h"
#include "../shell/shell.h"
#include "fs_helpers.h"
#include "fs_kfuncs.h"
#include <fcntl.h>
#include <stdint.h>
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <sys/mman.h>
#include <sys/types.h>
#include <time.h>
#include <unistd.h>
```

Include dependency graph for fat_routines.c:



Functions

- int mkfs (const char ∗fs_name, int num_blocks, int blk_size)

  Creates a PennFAT filesystem in the file named fs_name at the OS-level.
- int mount (const char ∗fs_name)

  Mounts a filesystem with name fs_name by loading its FAT into memory.
- int unmount ()

Unmounts the current filesystem and reset variables.
- void * cat (void *arg)

  Concatenates and displays files.
- void * ls (void *arg)

  Searches root directory and lists all files in the directory.
- void * touch (void *arg)

  Creates files or updates timestamps.
- void * mv (void *arg)

  Renames files.
- void * cp (void *arg)

  Copies the source file to the destination.
- void * rm (void *arg)

  Removes files.
- void * chmod (void *arg)

  Changes the permissions of a file.
- void * cmpctdir (void *arg)

  Implements compaction of root directory.

Variables

- pcb_t * current_running_pcb

4.1.1 Function Documentation

4.1.1.1 cat()

```
void* cat (
            void * arg )
```

Concatenates and displays files.

This function reads the content of files and writes it to stdout or to another file. It supports reading from stdin when no input files are specified.

Usage formats:

- cat FILE ... (displays content to stdout)
- cat FILE ... -w OUTPUT_FILE (writes content to OUTPUT_FILE, overwriting)
- cat FILE ... -a OUTPUT_FILE (appends content to OUTPUT_FILE)
- cat -w OUTPUT_FILE (reads from stdin, writes to OUTPUT_FILE)
- cat -a OUTPUT_FILE (reads from stdin, appends to OUTPUT_FILE)

Parameters

arg	Arguments array (command line arguments)

Returns

void pointer (unused)

Definition at line 214 of file fat_routines.c.

```
214                          {
215   char** args = (char**)arg;
216
217   // verify that the file system is mounted
218   if (!is_mounted) {
219     P_ERRNO = P_EFS_NOT_MOUNTED;
220     u_perror("cat");
221     return NULL;
222   }
223
224   // early return if there is nothing after cat
225   if (args[1] == NULL) {
226     // if none of the above conditions, then check if we need to redirect stdin
227     if (current_running_pcb) {
228       // open new stdin
229       int in_fd = current_running_pcb->input_fd;
230       int out_fd = current_running_pcb->output_fd;
231       char* file_1 = fd_table[in_fd].filename;
232       char* file_2 = fd_table[out_fd].filename;
233
234       // edge case when input and output have the same file name and we're
235       // appending
236       if ((strcmp(file_1, file_2) == 0) && is_append) {
237         P_ERRNO = P_EREDIR;
238         u_perror("cat");
239         return NULL;
240       }
241
242       // edge case when input and output files names are the same but we're not
243       // appending truncates the file
244       if ((strcmp(file_1, file_2) == 0)) {
245         return NULL;
246       }
247
248       // get the size of stdin file
249       off_t in_fd_size = k_lseek(in_fd, 0, SEEK_END);
250       if (in_fd_size == -1) {
251         k_close(in_fd);
252         u_perror("cat");
253         return NULL;
254       }
255       if (k_lseek(in_fd, 0, SEEK_SET) == -1) {
256         k_close(in_fd);
257         u_perror("cat");
258         return NULL;
259       }
260
261       char* buffer = (char*)malloc(block_size);
262       if (buffer == NULL) {
263         P_ERRNO = P_EMALLOC;
264         k_close(in_fd);
265         u_perror("cat");
266         return NULL;
267       }
268
269       int bytes_read;
270       ssize_t bytes_remaining = in_fd_size;
271
272       while (bytes_remaining > 0) {
273         ssize_t bytes_to_read =
274             bytes_remaining < block_size ? bytes_remaining : block_size;
275         bytes_read = k_read(in_fd, buffer, bytes_to_read);
276
277         if (bytes_read <= 0) {
278           break;
279         }
280
281         if (k_write(out_fd, buffer, bytes_read) != bytes_read) {
282           free(buffer);
283           k_close(in_fd);
284           u_perror("cat");
```

```
          break;
        }

        bytes_remaining -= bytes_read;
      }

      // read error
      if (bytes_read < 0) {
        free(buffer);
        k_close(in_fd);
        u_perror("cat");
        return NULL;
      }

      k_close(in_fd);
      if (out_fd != STDOUT_FILENO) {
        k_close(out_fd);
      }
      free(buffer);
      return NULL;
    }
    P_ERRNO = P_EINVAL;
    u_perror("cat");
    return NULL;
  }

  // check for output file with -w or -a flag
  int out_fd = -1;
  int out_mode = 0;

  // scan arguments and determine output fd and output mode
  int i;
  for (i = 1; args[i] != NULL; i++) {
    if (strcmp(args[i], "-w") == 0 && args[i + 1] != NULL) {
      out_mode = F_WRITE;
      out_fd = k_open(args[i + 1], F_WRITE);
      if (out_fd < 0) {
        u_perror("cat");
        return NULL;
      }
      break;
    } else if (strcmp(args[i], "-a") == 0 && args[i + 1] != NULL) {
      out_mode = F_APPEND;
      out_fd = k_open(args[i + 1], F_APPEND);
      if (out_fd < 0) {
        u_perror("cat");
        return NULL;
      }
      break;
    }
  }

  // if no output redirection found, use STDOUT
  if (out_fd < 0) {
    if (current_running_pcb) {
      out_fd = current_running_pcb->output_fd;
    } else {
      out_fd = STDOUT_FILENO;
    }
  }

  // handle small case: cat -w OUTPUT_FILE or cat -a OUTPUT_FILE (read from
  // stdin)
  if ((strcmp(args[1], "-w") == 0 || strcmp(args[1], "-a") == 0) &&
      args[2] != NULL && args[3] == NULL) {
    char buffer[1024];

    while (1) {
      ssize_t bytes_read = k_read(STDIN_FILENO, buffer, sizeof(buffer));

      if (bytes_read < 0) {
        u_perror("cat");
        if (out_fd != STDOUT_FILENO) {
          k_close(out_fd);
        }
        return NULL;
      }

      if (bytes_read == 0) {
        break;
      }

      if (k_write(out_fd, buffer, bytes_read) != bytes_read) {
        u_perror("cat");
        if (out_fd != STDOUT_FILENO) {
          k_close(out_fd);
        }
```

```
        return NULL;
      }
    }

    if (out_fd != STDOUT_FILENO) {
      k_close(out_fd);
    }
    return NULL;
  }

  // handle concatenating one or more files: cat FILE ... [-w/-a OUTPUT_FILE]
  int start = 1;
  int end = i - 1;

  if (out_mode != 0) {
    end = i - 1;  // skip the output redirection arguments
  }

  // process each input file
  for (i = start; i <= end; i++) {
    // skip the redirection flags and their arguments
    if (strcmp(args[i], "-w") == 0 || strcmp(args[i], "-a") == 0) {
      i++;
      continue;
    }

    // open the current input file
    int in_fd = k_open(args[i], F_READ);
    if (in_fd < 0) {
      u_perror("cat");
      continue;
    }

    // use lseek to get the size of in_fd
    off_t in_fd_size = k_lseek(in_fd, 0, SEEK_END);
    if (in_fd_size == -1) {
      k_close(in_fd);
      u_perror("cat");
      continue;
    }

    // use lseek to reset position to 0 for reading
    if (k_lseek(in_fd, 0, SEEK_SET) == -1) {
      k_close(in_fd);
      u_perror("cat");
      continue;
    }

    // copy file content to output
    char* buffer = (char*)malloc(block_size);
    if (buffer == NULL) {
      P_ERRNO = P_EMALLOC;
      k_close(in_fd);
      u_perror("cat");
      continue;
    }

    int bytes_read;
    ssize_t bytes_remaining = in_fd_size;

    while (bytes_remaining > 0) {
      ssize_t bytes_to_read =
          bytes_remaining < block_size ? bytes_remaining : block_size;
      bytes_read = k_read(in_fd, buffer, bytes_to_read);

      if (bytes_read <= 0) {
        break;
      }

      if (k_write(out_fd, buffer, bytes_read) != bytes_read) {
        free(buffer);
        k_close(in_fd);
        u_perror("cat");
        break;
      }

      bytes_remaining -= bytes_read;
    }

    // read error
    if (bytes_read < 0) {
      free(buffer);
      k_close(in_fd);
      u_perror("cat");
      continue;
    }

```

```
    k_close(in_fd);
    free(buffer);
  }

  // close output file if not stdout
  if (out_fd != STDOUT_FILENO) {
    k_close(out_fd);
  }

  return NULL;
}
```

4.1.1.2 chmod()

```
void* chmod (
            void * arg )
```

Changes the permissions of a file.

Changes file permissions.

- chmod +x FILE (adds executable permission)
- chmod +rw FILE (adds read and write permissions)
- chmod -wx FILE (removes write and executable permissions)

Definition at line 770 of file fat_routines.c.

```
770                           {
771   char** args = (char**)arg;
772   if (!args || !args[0] || !args[1] || !args[2]) {
773     P_ERRNO = P_EINVAL;
774     return NULL;
775   }
776
777   // Parse permission string
778   const char* perm_str = args[1];
779   if (perm_str[0] != '+' && perm_str[0] != '-') {
780     P_ERRNO = P_EINVAL;
781     return NULL;
782   }
783
784   // Find the file and get its current directory entry
785   dir_entry_t dir_entry;
786   int entry_offset = find_file(args[2], &dir_entry);
787   if (entry_offset < 0) {
788     P_ERRNO = P_ENOENT;
789     return NULL;
790   }
791
792   // Calculate new permissions
793   uint8_t new_perm = dir_entry.perm;
794   int i = 1;  // Start after + or -
795   while (perm_str[i] != '\0') {
796     switch (perm_str[i]) {
797       case 'r':
798         if (perm_str[0] == '+') {
799           new_perm |= PERM_READ;
800         } else {
801           new_perm &= ~PERM_READ;
802         }
803         break;
804       case 'w':
805         if (perm_str[0] == '+') {
806           new_perm |= PERM_WRITE;
807         } else {
808           new_perm &= ~PERM_WRITE;
809         }
810         break;
811       case 'x':
812         if (perm_str[0] == '+') {
813           new_perm |= PERM_EXEC;
```

```
        } else {
          new_perm &= ~PERM_EXEC;
        }
        break;
      default:
        P_ERRNO = P_EINVAL;
        return NULL;
    }
    i++;
  }

  // Update the directory entry
  dir_entry.perm = new_perm;
  dir_entry.mtime = time(NULL);

  // Seek to the entry's position
  if (lseek(fs_fd, entry_offset, SEEK_SET) == -1) {
    P_ERRNO = P_ELSEEK;
    return NULL;
  }

  // Write the updated entry back
  if (write(fs_fd, &dir_entry, sizeof(dir_entry)) != sizeof(dir_entry)) {
    P_ERRNO = P_EWRITE;
    return NULL;
  }

  return NULL;
}
```

4.1.1.3 cmpctdir()

```
void* cmpctdir (
            void * arg )
```

Implements compaction of root directory.

Compacts the root directory by removing all deleted entries.

Definition at line 851 of file fat_routines.c.

```
851                         {
852   if (!is_mounted) {
853     P_ERRNO = P_EFS_NOT_MOUNTED;
854     u_perror("cmpctdir");
855     return NULL;
856   }
857
858   if (compact_directory() != 0) {
859     u_perror("cmpctdir");
860   }
861
862   return NULL;
863 }
```

4.1.1.4 cp()

```
void* cp (
            void * arg )
```

Copies the source file to the destination.

Copies files.

Definition at line 640 of file fat_routines.c.

```
640                    {
```

```
  char** args = (char**)arg;

  // check that we have enough arguments
  if (args[1] == NULL || args[2] == NULL) {
    P_ERRNO = P_EINVAL;
    u_perror("cp");
    return NULL;
  }

  // cp -h SOURCE DEST
  if (strcmp(args[1], "-h") == 0) {
    if (args[2] == NULL || args[3] == NULL) {
      P_ERRNO = P_EINVAL;
      u_perror("cp");
      return NULL;
    }

    if (copy_host_to_pennfat(args[2], args[3]) != 0) {
      u_perror("cp");
      return NULL;
    }
    return NULL;
  }

  // cp SOURCE -h DEST
  if (args[2] != NULL && strcmp(args[2], "-h") == 0) {
    if (args[3] == NULL) {
      P_ERRNO = P_EINVAL;
      u_perror("cp");
      return NULL;
    }

    if (copy_pennfat_to_host(args[1], args[3]) != 0) {
      u_perror("cp");
      return NULL;
    }
    return NULL;
  }

  // cp SOURCE DEST
  if ((args[1] != NULL && strcmp(args[1], "-h") != 0) &&
      (args[2] != NULL && strcmp(args[2], "-h") != 0) && args[3] == NULL) {
    if (copy_source_to_dest(args[1], args[2]) != 0) {
      u_perror("cp");
      return NULL;
    }
    return NULL;
  }

  P_ERRNO = P_EUNKNOWN;
  u_perror("cp");
  return NULL;
}
```

4.1.1.5 ls()

```
void* ls (
            void * arg )
```

Searches root directory and lists all files in the directory.

Lists files in the current directory.

This function is a wrapper for k_ls, which is a kernel-level function.

Definition at line 476 of file fat_routines.c.

```
476                     {
477   // Note: we already check if fs is mounted in k_ls
478
479   char** args = (char**)arg;
480   if (args[1] != NULL) {
481     if (k_ls(args[1]) == -1) {
482       u_perror("ls");
483       return NULL;
484     }
```

```
  } else {
    if (k_ls(NULL) == -1) {
      u_perror("ls");
      return NULL;
    }
  }

  return NULL;
}
```

4.1.1.6 mkfs()

```
int mkfs (
            const char * fs_name,
            int num_blocks,
            int blk_size )
```

Creates a PennFAT filesystem in the file named fs_name at the OS-level.

Creates a PennFAT filesystem in the file named fs_name.

Definition at line 34 of file fat_routines.c.

```
34                                                              {
35   // validate arguments
36   if (num_blocks < 1 || num_blocks > 32) {
37     P_ERRNO = P_EINVAL;
38     return -1;
39   }
40   if (blk_size < 0 || blk_size > 4) {
41     P_ERRNO = P_EINVAL;
42     return -1;
43   }
44
45   // determine the file system size
46   int block_sizes[] = {256, 512, 1024, 2048, 4096};
47   int actual_block_size = block_sizes[blk_size];
48   int fat_size = num_blocks * actual_block_size;
49   int fat_entries = fat_size / 2;
50   int num_data_blocks =
51       (num_blocks == 32)
52           ? fat_entries - 2
53           : fat_entries - 1;  // note: first entry is reserved for metadata!
54   size_t filesystem_size = fat_size + (actual_block_size * num_data_blocks);
55
56   // create the file for the filesystem
57   int fd = open(fs_name, O_RDWR | O_CREAT | O_TRUNC, 0644);
58   if (fd == -1) {
59     P_ERRNO = P_EOPEN;
60     return -1;
61   }
62
63   // extend the file to the required size
64   if (ftruncate(fd, filesystem_size) == -1) {
65     P_ERRNO = P_EFUNC;
66     close(fd);
67     return -1;
68   }
69
70   // allocate the FAT
71   uint16_t* temp_fat = (uint16_t*)calloc(fat_entries, sizeof(uint16_t));
72   if (!temp_fat) {
73     P_ERRNO = P_EMALLOC;
74     close(fd);
75     return -1;
76   }
77
78   // initialize FAT entries to their correct values
79   temp_fat[0] = (num_blocks « 8) | blk_size;
80   temp_fat[1] = FAT_EOF;
81   for (int i = 2; i < fat_entries; i++) {
82     temp_fat[i] = FAT_FREE;
83   }
84
85   // write the FAT to the file
86   if (write(fd, temp_fat, fat_size) != fat_size) {
```

```c
    P_ERRNO = P_EWRITE;
    free(temp_fat);
    close(fd);
    return -1;
  }

  // initialize the root directory + write to memory
  uint8_t* root_dir = (uint8_t*)calloc(actual_block_size, 1);
  if (lseek(fd, fat_size, SEEK_SET) == -1) {
    P_ERRNO = P_ELSEEK;
    free(temp_fat);
    free(root_dir);
    close(fd);
    return -1;
  }
  if (write(fd, root_dir, actual_block_size) != actual_block_size) {
    P_ERRNO = P_EWRITE;
    free(temp_fat);
    free(root_dir);
    close(fd);
    return -1;
  }

  // clean up
  free(temp_fat);
  free(root_dir);
  close(fd);
  return 0;
}
```

4.1.1.7 mount()

```c
int mount (
        const char * fs_name )
```

Mounts a filesystem with name fs_name by loading its FAT into memory.

Mounts the filesystem named fs_name by loading its FAT into memory.

Definition at line 120 of file fat_routines.c.

```c
120                               {
121   // check if a filesystem is already mounted
122   if (is_mounted) {
123     P_ERRNO = P_EBUSY;
124     return -1;
125   }
126 
127   // open the file with fs_name + set the global fs_fd
128   fs_fd = open(fs_name, O_RDWR);
129   if (fs_fd == -1) {
130     P_ERRNO = P_ENOENT;
131     return -1;
132   }
133 
134   // read the first two bytes to get size configuration
135   uint16_t config;
136   if (read(fs_fd, &config, sizeof(config)) != sizeof(config)) {
137     P_ERRNO = P_EREAD;
138     close(fs_fd);
139     fs_fd = -1;
140     return -1;
141   }
142 
143   // extract FAT region size information
144   num_fat_blocks = (config >> 8) & 0xFF;  // MSB
145   int block_size_config = config & 0xFF;  // LSB
146   int block_sizes[] = {256, 512, 1024, 2048, 4096};
147   block_size = block_sizes[block_size_config];
148   fat_size = num_fat_blocks * block_size;
149 
150   // map the FAT region into memory
151   if (lseek(fs_fd, 0, SEEK_SET) == -1) {
152     P_ERRNO = P_ELSEEK;
153     close(fs_fd);
154     fs_fd = -1;
155     return -1;
```

```
156   }
157
158   fat = mmap(NULL, fat_size, PROT_READ | PROT_WRITE, MAP_SHARED, fs_fd, 0);
159   if (fat == MAP_FAILED) {
160     P_ERRNO = P_EMAP;
161     close(fs_fd);
162     fs_fd = -1;
163     return -1;
164   }
165
166   init_fd_table(fd_table);  // initialize the file descriptor table
167   is_mounted = true;
168   return 0;
169 }
```

4.1.1.8 mv()

```
void* mv (
            void * arg )
```

Renames files.

Renames the source file to the destination name. If the destination file already exists, it will be overwritten.

Usage: mv SOURCE DEST

Parameters

arg	Arguments array (command line arguments)

Returns

void pointer (unused)

Definition at line 561 of file fat_routines.c.

```
561                     {
562   char** args = (char**)arg;
563
564   // verify that the file system is mounted
565   if (!is_mounted) {
566     P_ERRNO = P_EFS_NOT_MOUNTED;
567     u_perror("mv");
568     return NULL;
569   }
570
571   // check if we have both source and destination arguments
572   if (args[1] == NULL || args[2] == NULL) {
573     P_ERRNO = P_EINVAL;
574     u_perror("mv");
575     return NULL;
576   }
577
578   char* source = args[1];
579   char* dest = args[2];
580
581   // check if they're trying to rename to the same name
582   if (strcmp(source, dest) == 0) {
583     return NULL;
584   }
585
586   // check if source file exists
587   dir_entry_t source_entry;
588   int source_offset = find_file(source, &source_entry);
589   if (source_offset < 0) {
590     u_perror("mv");
591     return NULL;
592   }
```

```c

  // check if the destination file already exists
  dir_entry_t dest_entry;
  int dest_offset = find_file(dest, &dest_entry);

  // destination file exists
  if (dest_offset >= 0) {
    // check if the destination file is currently open by any process
    for (int i = 0; i < MAX_FDS; i++) {
      if (fd_table[i].in_use && strcmp(fd_table[i].filename, dest) == 0) {
        P_ERRNO = P_EBUSY;
        u_perror("mv");
        return NULL;
      }
    }

    // if destination file exists, delete it
    if (mark_entry_as_deleted(&dest_entry, dest_offset) != 0) {
      u_perror("mv");
      return NULL;
    }
  }

  // rename file
  strncpy(source_entry.name, dest, sizeof(source_entry.name) - 1);
  source_entry.name[sizeof(source_entry.name) - 1] = '\0';

  // write the updated entry back to disk
  if (lseek(fs_fd, source_offset, SEEK_SET) == -1) {
    P_ERRNO = P_ELSEEK;
    u_perror("mv");
    return NULL;
  }

  if (write(fs_fd, &source_entry, sizeof(source_entry)) !=
      sizeof(source_entry)) {
    P_ERRNO = P_EWRITE;
    u_perror("mv");
    return NULL;
  }

  return NULL;
}
```

4.1.1.9 rm()

```
void* rm (
            void * arg )
```

Removes files.

Deletes one or more files from the filesystem. Each file is processed as a separate transaction.

Parameters

arg	Arguments array (command line arguments)

Returns

void pointer (unused)

Definition at line 698 of file fat_routines.c.

```c
698                    {
699   char** args = (char**)arg;
700
701   // verify that the file system is mounted
702   if (!is_mounted) {
703     P_ERRNO = P_EFS_NOT_MOUNTED;
```

```
    u_perror("rm");
    return NULL;
  }

  // check if we have any arguments
  if (args[1] == NULL) {
    P_ERRNO = P_EINVAL;
    u_perror("rm");
    return NULL;
  }

  // process each file argument
  for (int i = 1; args[i] != NULL; i++) {
    // find the file in the directory
    dir_entry_t entry;
    int entry_offset = find_file(args[i], &entry);

    if (entry_offset < 0) {
      // file doesn't exist
      P_ERRNO = P_ENOENT;
      u_perror("rm");
      continue;
    }

    // check if file is currently open
    for (int j = 0; j < MAX_FDS; j++) {
      if (fd_table[j].in_use && strcmp(fd_table[j].filename, args[i]) == 0) {
        P_ERRNO = P_EBUSY;
        u_perror("rm");
        continue;
      }
    }

    // mark the directory entry as deleted
    if (lseek(fs_fd, entry_offset, SEEK_SET) == -1) {
      P_ERRNO = P_ELSEEK;
      u_perror("rm");
      continue;
    }

    char deleted = 1;  // mark as deleted
    if (write(fs_fd, &deleted, sizeof(deleted)) != sizeof(deleted)) {
      P_ERRNO = P_EWRITE;
      u_perror("rm");
      continue;
    }

    // free the FAT chain for this file
    uint16_t block = entry.firstBlock;
    while (block != FAT_FREE && block != FAT_EOF) {
      uint16_t next_block = fat[block];
      fat[block] = FAT_FREE;
      block = next_block;
    }
  }

  return NULL;
}
```

4.1.1.10 touch()

```
void* touch (
            void * arg )
```

Creates files or updates timestamps.

Creates empty files or updates timestamps.

For each file argument, creates the file if it doesn't exist, or updates its timestamp if it already exists.

Definition at line 501 of file fat_routines.c.

```
501                           {
502   char** args = (char**)arg;
503
504   // verify that the file system is mounted
```

```
  if (!is_mounted) {
    P_ERRNO = P_EFS_NOT_MOUNTED;
    u_perror("touch");
    return NULL;
  }

  // check if we have any arguments
  if (args[1] == NULL) {
    P_ERRNO = P_EINVAL;
    u_perror("touch");
    return NULL;
  }

  // process each file argument
  for (int i = 1; args[i] != NULL; i++) {
    dir_entry_t entry;
    int entry_offset = find_file(args[i], &entry);

    // file exists
    if (entry_offset >= 0) {
      entry.mtime = time(NULL);

      // write the updated entry back to the directory
      if (lseek(fs_fd, entry_offset, SEEK_SET) == -1) {
        P_ERRNO = P_ELSEEK;
        u_perror("touch");
        continue;
      }
      if (write(fs_fd, &entry, sizeof(entry)) != sizeof(entry)) {
        P_ERRNO = P_EWRITE;
        u_perror("touch");
        continue;
      }
    } else {
      // file doesn't exist, create a new empty file

      // check if the fat is full
      if (P_ERRNO == P_EFULL) {
        u_perror("touch");
        return NULL;
      }

      // add the file entry to root directory
      if (add_file_entry(args[i], 0, 0, TYPE_REGULAR, PERM_READ_WRITE) == -1) {
        u_perror("touch");
        continue;
      }
    }
  }

  return NULL;
}
```

4.1.1.11 unmount()

```
int unmount ( )
```

Unmounts the current filesystem and reset variables.

Unmounts the currently mounted filesystem.

Definition at line 174 of file fat_routines.c.

```
174                 {
175   // first check that a file system is actually mounted
176   if (!is_mounted) {
177     P_ERRNO = P_EFS_NOT_MOUNTED;
178     return -1;
179   }
180
181   // unmap the FAT
182   if (fat != NULL) {
183     if (munmap(fat, fat_size) == -1) {
184       P_ERRNO = P_EMAP;
185       return -1;
186     }
187     fat = NULL;
188   }
```

```

  // close fs_fd
  if (fs_fd != -1) {
    if (close(fs_fd) == -1) {
      P_ERRNO = P_ECLOSE;
      return -1;
    }
    fs_fd = -1;
  }

  // reset the other globals
  num_fat_blocks = 0;
  block_size = 0;
  fat_size = 0;
  is_mounted = false;
  return 0;
}
```

4.1.2 Variable Documentation

4.1.2.1 current_running_pcb

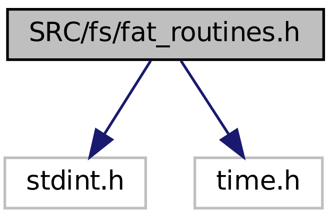
```
pcb_t* current_running_pcb [extern]
```

Definition at line 38 of file scheduler.c.

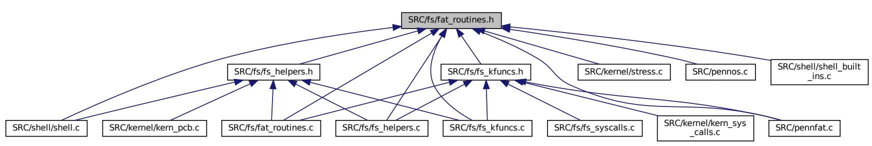
4.2 SRC/fs/fat_routines.h File Reference

```
#include <stdint.h>
#include <time.h>
```

Include dependency graph for fat_routines.h:



This graph shows which files directly or indirectly include this file:



Classes

- struct dir_entry_t

    Directory entry structure for files in the filesystem.
- struct fd_entry_t

    File descriptor entry structure for open files.

Macros

- #define FAT_EOF 0xFFFF
- #define FAT_FREE 0x0000
- #define TYPE_UNKNOWN 0
- #define TYPE_REGULAR 1
- #define TYPE_DIRECTORY 2
- #define TYPE_SYMLINK 4
- #define PERM_NONE 0
- #define PERM_WRITE 1
- #define PERM_READ 2
- #define PERM_EXEC 4
- #define PERM_READ_WRITE (PERM_READ | PERM_WRITE)
- #define PERM_READ_EXEC (PERM_READ | PERM_EXEC)
- #define PERM_READ_WRITE_EXEC (PERM_READ | PERM_WRITE | PERM_EXEC)
- #define F_READ 0x01
- #define F_WRITE 0x02
- #define F_APPEND 0x04

Functions

- int mkfs (const char *fs_name, int num_blocks, int block_size)

    Creates a PennFAT filesystem in the file named fs_name.
- int mount (const char *fs_name)

    Mounts the filesystem named fs_name by loading its FAT into memory.
- int unmount ()

    Unmounts the currently mounted filesystem.
- void * cat (void *arg)

    Concatenates and displays files.
- void * ls (void *arg)

    Lists files in the current directory.
- void * touch (void *arg)

    Creates empty files or updates timestamps.
- void * mv (void *arg)

    Renames files.
- void * cp (void *arg)

    Copies files.
- void * rm (void *arg)

    Removes files.
- void * chmod (void *arg)

    Changes file permissions.
- void * cmpctdir (void *arg)

    Compacts the root directory by removing all deleted entries.

4.2.1 Macro Definition Documentation

4.2.1.1 F_APPEND

```
#define F_APPEND 0x04
```

Definition at line 38 of file fat_routines.h.

4.2.1.2 F_READ

```
#define F_READ 0x01
```

Definition at line 36 of file fat_routines.h.

4.2.1.3 F_WRITE

```
#define F_WRITE 0x02
```

Definition at line 37 of file fat_routines.h.

4.2.1.4 FAT_EOF

```
#define FAT_EOF 0xFFFF
```

Definition at line 17 of file fat_routines.h.

4.2.1.5 FAT_FREE

```
#define FAT_FREE 0x0000
```

Definition at line 18 of file fat_routines.h.

4.2.1.6 PERM_EXEC

```
#define PERM_EXEC 4
```

Definition at line 30 of file fat_routines.h.

4.2.1.7 PERM_NONE

```
#define PERM_NONE 0
```

Definition at line 27 of file fat_routines.h.

4.2.1.8 PERM_READ

```
#define PERM_READ 2
```

Definition at line 29 of file fat_routines.h.

4.2.1.9 PERM_READ_EXEC

```
#define PERM_READ_EXEC (PERM_READ | PERM_EXEC)
```

Definition at line 32 of file fat_routines.h.

4.2.1.10 PERM_READ_WRITE

```
#define PERM_READ_WRITE (PERM_READ | PERM_WRITE)
```

Definition at line 31 of file fat_routines.h.

4.2.1.11 PERM_READ_WRITE_EXEC

```
#define PERM_READ_WRITE_EXEC (PERM_READ | PERM_WRITE | PERM_EXEC)
```

Definition at line 33 of file fat_routines.h.

4.2.1.12 PERM_WRITE

```
#define PERM_WRITE 1
```

Definition at line 28 of file fat_routines.h.

4.2.1.13 TYPE_DIRECTORY

```
#define TYPE_DIRECTORY 2
```

Definition at line 23 of file fat_routines.h.

4.2.1.14 TYPE_REGULAR

```
#define TYPE_REGULAR 1
```

Definition at line 22 of file fat_routines.h.

4.2.1.15 TYPE_SYMLINK

```
#define TYPE_SYMLINK 4
```

Definition at line 24 of file fat_routines.h.

4.2.1.16 TYPE_UNKNOWN

```
#define TYPE_UNKNOWN 0
```

Definition at line 21 of file fat_routines.h.

4.2.2 Function Documentation

4.2.2.1 cat()

```
void* cat (
            void * arg )
```

Concatenates and displays files.

This function reads the content of files and writes it to stdout or to another file. It supports reading from stdin when no input files are specified.

Usage formats:

- cat FILE ... (displays content to stdout)
- cat FILE ... -w OUTPUT_FILE (writes content to OUTPUT_FILE, overwriting)
- cat FILE ... -a OUTPUT_FILE (appends content to OUTPUT_FILE)
- cat -w OUTPUT_FILE (reads from stdin, writes to OUTPUT_FILE)
- cat -a OUTPUT_FILE (reads from stdin, appends to OUTPUT_FILE)

Parameters

arg	Arguments array (command line arguments)

Returns

void pointer (unused)

Definition at line 214 of file fat_routines.c.

```
214                         {
215   char** args = (char**)arg;
216 
217   // verify that the file system is mounted
218   if (!is_mounted) {
219     P_ERRNO = P_EFS_NOT_MOUNTED;
220     u_perror("cat");
221     return NULL;
222   }
223 
224   // early return if there is nothing after cat
225   if (args[1] == NULL) {
226     // if none of the above conditions, then check if we need to redirect stdin
227     if (current_running_pcb) {
228       // open new stdin
229       int in_fd = current_running_pcb->input_fd;
230       int out_fd = current_running_pcb->output_fd;
231       char* file_1 = fd_table[in_fd].filename;
232       char* file_2 = fd_table[out_fd].filename;
233 
234       // edge case when input and output have the same file name and we're
235       // appending
236       if ((strcmp(file_1, file_2) == 0) && is_append) {
237         P_ERRNO = P_EREDIR;
238         u_perror("cat");
239         return NULL;
240       }
241 
242       // edge case when input and output files names are the same but we're not
243       // appending truncates the file
244       if ((strcmp(file_1, file_2) == 0)) {
245         return NULL;
246       }
247 
248       // get the size of stdin file
249       off_t in_fd_size = k_lseek(in_fd, 0, SEEK_END);
250       if (in_fd_size == -1) {
251         k_close(in_fd);
252         u_perror("cat");
253         return NULL;
254       }
255       if (k_lseek(in_fd, 0, SEEK_SET) == -1) {
256         k_close(in_fd);
257         u_perror("cat");
258         return NULL;
259       }
260 
261       char* buffer = (char*)malloc(block_size);
262       if (buffer == NULL) {
263         P_ERRNO = P_EMALLOC;
264         k_close(in_fd);
265         u_perror("cat");
266         return NULL;
267       }
268 
269       int bytes_read;
270       ssize_t bytes_remaining = in_fd_size;
271 
272       while (bytes_remaining > 0) {
273         ssize_t bytes_to_read =
274             bytes_remaining < block_size ? bytes_remaining : block_size;
275         bytes_read = k_read(in_fd, buffer, bytes_to_read);
276 
277         if (bytes_read <= 0) {
278           break;
279         }
280 
281         if (k_write(out_fd, buffer, bytes_read) != bytes_read) {
282           free(buffer);
283           k_close(in_fd);
284           u_perror("cat");
```

```
          break;
        }

        bytes_remaining -= bytes_read;
      }

      // read error
      if (bytes_read < 0) {
        free(buffer);
        k_close(in_fd);
        u_perror("cat");
        return NULL;
      }

      k_close(in_fd);
      if (out_fd != STDOUT_FILENO) {
        k_close(out_fd);
      }
      free(buffer);
      return NULL;
    }
    P_ERRNO = P_EINVAL;
    u_perror("cat");
    return NULL;
  }

  // check for output file with -w or -a flag
  int out_fd = -1;
  int out_mode = 0;

  // scan arguments and determine output fd and output mode
  int i;
  for (i = 1; args[i] != NULL; i++) {
    if (strcmp(args[i], "-w") == 0 && args[i + 1] != NULL) {
      out_mode = F_WRITE;
      out_fd = k_open(args[i + 1], F_WRITE);
      if (out_fd < 0) {
        u_perror("cat");
        return NULL;
      }
      break;
    } else if (strcmp(args[i], "-a") == 0 && args[i + 1] != NULL) {
      out_mode = F_APPEND;
      out_fd = k_open(args[i + 1], F_APPEND);
      if (out_fd < 0) {
        u_perror("cat");
        return NULL;
      }
      break;
    }
  }

  // if no output redirection found, use STDOUT
  if (out_fd < 0) {
    if (current_running_pcb) {
      out_fd = current_running_pcb->output_fd;
    } else {
      out_fd = STDOUT_FILENO;
    }
  }

  // handle small case: cat -w OUTPUT_FILE or cat -a OUTPUT_FILE (read from
  // stdin)
  if ((strcmp(args[1], "-w") == 0 || strcmp(args[1], "-a") == 0) &&
      args[2] != NULL && args[3] == NULL) {
    char buffer[1024];

    while (1) {
      ssize_t bytes_read = k_read(STDIN_FILENO, buffer, sizeof(buffer));

      if (bytes_read < 0) {
        u_perror("cat");
        if (out_fd != STDOUT_FILENO) {
          k_close(out_fd);
        }
        return NULL;
      }

      if (bytes_read == 0) {
        break;
      }

      if (k_write(out_fd, buffer, bytes_read) != bytes_read) {
        u_perror("cat");
        if (out_fd != STDOUT_FILENO) {
          k_close(out_fd);
        }
```

```
      return NULL;
    }
  }

  if (out_fd != STDOUT_FILENO) {
    k_close(out_fd);
  }
  return NULL;
}

// handle concatenating one or more files: cat FILE ... [-w/-a OUTPUT_FILE]
int start = 1;
int end = i - 1;

if (out_mode != 0) {
  end = i - 1;  // skip the output redirection arguments
}

// process each input file
for (i = start; i <= end; i++) {
  // skip the redirection flags and their arguments
  if (strcmp(args[i], "-w") == 0 || strcmp(args[i], "-a") == 0) {
    i++;
    continue;
  }

  // open the current input file
  int in_fd = k_open(args[i], F_READ);
  if (in_fd < 0) {
    u_perror("cat");
    continue;
  }

  // use lseek to get the size of in_fd
  off_t in_fd_size = k_lseek(in_fd, 0, SEEK_END);
  if (in_fd_size == -1) {
    k_close(in_fd);
    u_perror("cat");
    continue;
  }

  // use lseek to reset position to 0 for reading
  if (k_lseek(in_fd, 0, SEEK_SET) == -1) {
    k_close(in_fd);
    u_perror("cat");
    continue;
  }

  // copy file content to output
  char* buffer = (char*)malloc(block_size);
  if (buffer == NULL) {
    P_ERRNO = P_EMALLOC;
    k_close(in_fd);
    u_perror("cat");
    continue;
  }

  int bytes_read;
  ssize_t bytes_remaining = in_fd_size;

  while (bytes_remaining > 0) {
    ssize_t bytes_to_read =
        bytes_remaining < block_size ? bytes_remaining : block_size;
    bytes_read = k_read(in_fd, buffer, bytes_to_read);

    if (bytes_read <= 0) {
      break;
    }

    if (k_write(out_fd, buffer, bytes_read) != bytes_read) {
      free(buffer);
      k_close(in_fd);
      u_perror("cat");
      break;
    }

    bytes_remaining -= bytes_read;
  }

  // read error
  if (bytes_read < 0) {
    free(buffer);
    k_close(in_fd);
    u_perror("cat");
    continue;
  }

```

```
    k_close(in_fd);
    free(buffer);
  }

  // close output file if not stdout
  if (out_fd != STDOUT_FILENO) {
    k_close(out_fd);
  }

  return NULL;
}
```

4.2.2.2 chmod()

```
void* chmod (
              void * arg )
```

Changes file permissions.

Modifies the permissions of the specified file.

Usage formats:

- chmod +x FILE (adds executable permission)
- chmod +rw FILE (adds read and write permissions)
- chmod -wx FILE (removes write and executable permissions)

Parameters

arg	Arguments array (command line arguments)

Returns

void pointer (unused)

Changes file permissions.

- chmod +x FILE (adds executable permission)
- chmod +rw FILE (adds read and write permissions)
- chmod -wx FILE (removes write and executable permissions)

Definition at line 770 of file fat_routines.c.

```
770                          {
771   char** args = (char**)arg;
772   if (!args || !args[0] || !args[1] || !args[2]) {
773     P_ERRNO = P_EINVAL;
774     return NULL;
775   }
776
777   // Parse permission string
778   const char* perm_str = args[1];
779   if (perm_str[0] != '+' && perm_str[0] != '-') {
780     P_ERRNO = P_EINVAL;
781     return NULL;
```

```
  }

  // Find the file and get its current directory entry
  dir_entry_t dir_entry;
  int entry_offset = find_file(args[2], &dir_entry);
  if (entry_offset < 0) {
    P_ERRNO = P_ENOENT;
    return NULL;
  }

  // Calculate new permissions
  uint8_t new_perm = dir_entry.perm;
  int i = 1;  // Start after + or -
  while (perm_str[i] != '\0') {
    switch (perm_str[i]) {
      case 'r':
        if (perm_str[0] == '+') {
          new_perm |= PERM_READ;
        } else {
          new_perm &= ~PERM_READ;
        }
        break;
      case 'w':
        if (perm_str[0] == '+') {
          new_perm |= PERM_WRITE;
        } else {
          new_perm &= ~PERM_WRITE;
        }
        break;
      case 'x':
        if (perm_str[0] == '+') {
          new_perm |= PERM_EXEC;
        } else {
          new_perm &= ~PERM_EXEC;
        }
        break;
      default:
        P_ERRNO = P_EINVAL;
        return NULL;
    }
    i++;
  }

  // Update the directory entry
  dir_entry.perm = new_perm;
  dir_entry.mtime = time(NULL);

  // Seek to the entry's position
  if (lseek(fs_fd, entry_offset, SEEK_SET) == -1) {
    P_ERRNO = P_ELSEEK;
    return NULL;
  }

  // Write the updated entry back
  if (write(fs_fd, &dir_entry, sizeof(dir_entry)) != sizeof(dir_entry)) {
    P_ERRNO = P_EWRITE;
    return NULL;
  }

  return NULL;
}
```

4.2.2.3 cmpctdir()

```
void* cmpctdir (
          void * arg )
```

Compacts the root directory by removing all deleted entries.

Parameters

arg	Arguments array (command line arguments)

Returns

void pointer (unused)

Compacts the root directory by removing all deleted entries.

Definition at line 851 of file fat_routines.c.

```
                              {
  if (!is_mounted) {
    P_ERRNO = P_EFS_NOT_MOUNTED;
    u_perror("cmpctdir");
    return NULL;
  }

  if (compact_directory() != 0) {
    u_perror("cmpctdir");
  }

  return NULL;
}
```

4.2.2.4 cp()

```
void* cp (
            void * arg )
```

Copies files.

Copies the source file to the destination. If the destination file already exists, it will be overwritten.

Usage formats:

- cp SOURCE DEST (copies within PennFAT)
- cp -h SOURCE DEST (copies from host OS to PennFAT)
- cp SOURCE -h DEST (copies from PennFAT to host OS)

Parameters

arg	Arguments array (command line arguments)

Returns

return 0 on success, -1 on error

Copies files.

Definition at line 640 of file fat_routines.c.

```
                        {
  char** args = (char**)arg;

  // check that we have enough arguments
  if (args[1] == NULL || args[2] == NULL) {
    P_ERRNO = P_EINVAL;
    u_perror("cp");
    return NULL;
  }

```

```
  // cp -h SOURCE DEST
  if (strcmp(args[1], "-h") == 0) {
    if (args[2] == NULL || args[3] == NULL) {
      P_ERRNO = P_EINVAL;
      u_perror("cp");
      return NULL;
    }

    if (copy_host_to_pennfat(args[2], args[3]) != 0) {
      u_perror("cp");
      return NULL;
    }
    return NULL;
  }

  // cp SOURCE -h DEST
  if (args[2] != NULL && strcmp(args[2], "-h") == 0) {
    if (args[3] == NULL) {
      P_ERRNO = P_EINVAL;
      u_perror("cp");
      return NULL;
    }

    if (copy_pennfat_to_host(args[1], args[3]) != 0) {
      u_perror("cp");
      return NULL;
    }
    return NULL;
  }

  // cp SOURCE DEST
  if ((args[1] != NULL && strcmp(args[1], "-h") != 0) &&
      (args[2] != NULL && strcmp(args[2], "-h") != 0) && args[3] == NULL) {
    if (copy_source_to_dest(args[1], args[2]) != 0) {
      u_perror("cp");
      return NULL;
    }
    return NULL;
  }

  P_ERRNO = P_EUNKNOWN;
  u_perror("cp");
  return NULL;
}
```

4.2.2.5 ls()

```
void* ls (
            void * arg )
```

Lists files in the current directory.

This function displays information about files in the current directory, including block number, permissions, size, and name.

Parameters

arg	Arguments array (command line arguments)

Returns

0 on success, -1 on error

Lists files in the current directory.

This function is a wrapper for k_ls, which is a kernel-level function.

Definition at line 476 of file fat_routines.c.

```
476                  {
477   // Note: we already check if fs is mounted in k_ls
478 
479   char** args = (char**)arg;
480   if (args[1] != NULL) {
481     if (k_ls(args[1]) == -1) {
482       u_perror("ls");
483       return NULL;
484     }
485   } else {
486     if (k_ls(NULL) == -1) {
487       u_perror("ls");
488       return NULL;
489     }
490   }
491 
492   return NULL;
493 }
```

4.2.2.6 mkfs()

```
int mkfs (
        const char * fs_name,
        int num_blocks,
        int blk_size )
```

Creates a PennFAT filesystem in the file named fs_name.

This function initializes a new PennFAT filesystem with the specified parameters. The number of blocks in the FAT ranges from 1 through 32, and the block size is determined by block_size (0=256B, 1=512B, 2=1024B, 3=2048B, 4=4096B).

Parameters

fs_name	The name of the file to create the filesystem in.
num_blocks	The number of blocks in the FAT region (1-32).
block_size	The block size configuration (0-4).

Creates a PennFAT filesystem in the file named fs_name.

Definition at line 34 of file fat_routines.c.

```
34                                                              {
35   // validate arguments
36   if (num_blocks < 1 || num_blocks > 32) {
37     P_ERRNO = P_EINVAL;
38     return -1;
39   }
40   if (blk_size < 0 || blk_size > 4) {
41     P_ERRNO = P_EINVAL;
42     return -1;
43   }
44 
45   // determine the file system size
46   int block_sizes[] = {256, 512, 1024, 2048, 4096};
47   int actual_block_size = block_sizes[blk_size];
48   int fat_size = num_blocks * actual_block_size;
49   int fat_entries = fat_size / 2;
50   int num_data_blocks =
51       (num_blocks == 32)
52           ? fat_entries - 2
53           : fat_entries - 1;  // note: first entry is reserved for metadata!
54   size_t filesystem_size = fat_size + (actual_block_size * num_data_blocks);
55 
56   // create the file for the filesystem
57   int fd = open(fs_name, O_RDWR | O_CREAT | O_TRUNC, 0644);
58   if (fd == -1) {
```

```
    P_ERRNO = P_EOPEN;
    return -1;
  }

  // extend the file to the required size
  if (ftruncate(fd, filesystem_size) == -1) {
    P_ERRNO = P_EFUNC;
    close(fd);
    return -1;
  }

  // allocate the FAT
  uint16_t* temp_fat = (uint16_t*)calloc(fat_entries, sizeof(uint16_t));
  if (!temp_fat) {
    P_ERRNO = P_EMALLOC;
    close(fd);
    return -1;
  }

  // initialize FAT entries to their correct values
  temp_fat[0] = (num_blocks « 8) | blk_size;
  temp_fat[1] = FAT_EOF;
  for (int i = 2; i < fat_entries; i++) {
    temp_fat[i] = FAT_FREE;
  }

  // write the FAT to the file
  if (write(fd, temp_fat, fat_size) != fat_size) {
    P_ERRNO = P_EWRITE;
    free(temp_fat);
    close(fd);
    return -1;
  }

  // initialize the root directory + write to memory
  uint8_t* root_dir = (uint8_t*)calloc(actual_block_size, 1);
  if (lseek(fd, fat_size, SEEK_SET) == -1) {
    P_ERRNO = P_ELSEEK;
    free(temp_fat);
    free(root_dir);
    close(fd);
    return -1;
  }
  if (write(fd, root_dir, actual_block_size) != actual_block_size) {
    P_ERRNO = P_EWRITE;
    free(temp_fat);
    free(root_dir);
    close(fd);
    return -1;
  }

  // clean up
  free(temp_fat);
  free(root_dir);
  close(fd);
  return 0;
}
```

4.2.2.7 mount()

```
int mount (
            const char * fs_name )
```

Mounts the filesystem named fs_name by loading its FAT into memory.

This function loads the filesystem's FAT into memory for subsequent operations. Only one filesystem can be mounted at a time.

Parameters

fs_name	The name of the filesystem file to mount.

Returns

0 on success, -1 on failure with P_ERRNO set.

Mounts the filesystem named fs_name by loading its FAT into memory.

Definition at line 120 of file fat_routines.c.

```
120                                {
121   // check if a filesystem is already mounted
122   if (is_mounted) {
123     P_ERRNO = P_EBUSY;
124     return -1;
125   }
126
127   // open the file with fs_name + set the global fs_fd
128   fs_fd = open(fs_name, O_RDWR);
129   if (fs_fd == -1) {
130     P_ERRNO = P_ENOENT;
131     return -1;
132   }
133
134   // read the first two bytes to get size configuration
135   uint16_t config;
136   if (read(fs_fd, &config, sizeof(config)) != sizeof(config)) {
137     P_ERRNO = P_EREAD;
138     close(fs_fd);
139     fs_fd = -1;
140     return -1;
141   }
142
143   // extract FAT region size information
144   num_fat_blocks = (config >> 8) & 0xFF;  // MSB
145   int block_size_config = config & 0xFF;  // LSB
146   int block_sizes[] = {256, 512, 1024, 2048, 4096};
147   block_size = block_sizes[block_size_config];
148   fat_size = num_fat_blocks * block_size;
149
150   // map the FAT region into memory
151   if (lseek(fs_fd, 0, SEEK_SET) == -1) {
152     P_ERRNO = P_ELSEEK;
153     close(fs_fd);
154     fs_fd = -1;
155     return -1;
156   }
157
158   fat = mmap(NULL, fat_size, PROT_READ | PROT_WRITE, MAP_SHARED, fs_fd, 0);
159   if (fat == MAP_FAILED) {
160     P_ERRNO = P_EMAP;
161     close(fs_fd);
162     fs_fd = -1;
163     return -1;
164   }
165
166   init_fd_table(fd_table);  // initialize the file descriptor table
167   is_mounted = true;
168   return 0;
169 }
```

4.2.2.8 mv()

```
void* mv (
            void * arg )
```

Renames files.

Renames the source file to the destination name. If the destination file already exists, it will be overwritten.

Usage: mv SOURCE DEST

Parameters

arg	Arguments array (command line arguments)

Returns

void pointer (unused)

Definition at line 561 of file fat_routines.c.

```
561                         {
562   char** args = (char**)arg;
563 
564   // verify that the file system is mounted
565   if (!is_mounted) {
566     P_ERRNO = P_EFS_NOT_MOUNTED;
567     u_perror("mv");
568     return NULL;
569   }
570 
571   // check if we have both source and destination arguments
572   if (args[1] == NULL || args[2] == NULL) {
573     P_ERRNO = P_EINVAL;
574     u_perror("mv");
575     return NULL;
576   }
577 
578   char* source = args[1];
579   char* dest = args[2];
580 
581   // check if they're trying to rename to the same name
582   if (strcmp(source, dest) == 0) {
583     return NULL;
584   }
585 
586   // check if source file exists
587   dir_entry_t source_entry;
588   int source_offset = find_file(source, &source_entry);
589   if (source_offset < 0) {
590     u_perror("mv");
591     return NULL;
592   }
593 
594   // check if the destination file already exists
595   dir_entry_t dest_entry;
596   int dest_offset = find_file(dest, &dest_entry);
597 
598   // destination file exists
599   if (dest_offset >= 0) {
600     // check if the destination file is currently open by any process
601     for (int i = 0; i < MAX_FDS; i++) {
602       if (fd_table[i].in_use && strcmp(fd_table[i].filename, dest) == 0) {
603         P_ERRNO = P_EBUSY;
604         u_perror("mv");
605         return NULL;
606       }
607     }
608 
609     // if destination file exists, delete it
610     if (mark_entry_as_deleted(&dest_entry, dest_offset) != 0) {
611       u_perror("mv");
612       return NULL;
613     }
614   }
615 
616   // rename file
617   strncpy(source_entry.name, dest, sizeof(source_entry.name) - 1);
618   source_entry.name[sizeof(source_entry.name) - 1] = '\0';
619 
620   // write the updated entry back to disk
621   if (lseek(fs_fd, source_offset, SEEK_SET) == -1) {
622     P_ERRNO = P_ELSEEK;
623     u_perror("mv");
624     return NULL;
625   }
626 
627   if (write(fs_fd, &source_entry, sizeof(source_entry)) !=
628       sizeof(source_entry)) {
629     P_ERRNO = P_EWRITE;
630     u_perror("mv");
631     return NULL;
```

```
  }

  return NULL;
}
```

4.2.2.9 rm()

```
void* rm (
            void * arg )
```

Removes files.

Deletes one or more files from the filesystem. Each file is processed as a separate transaction.

Parameters

arg	Arguments array (command line arguments)

Returns

void pointer (unused)

Definition at line 698 of file fat_routines.c.

```
698                  {
699   char** args = (char**)arg;
700 
701   // verify that the file system is mounted
702   if (!is_mounted) {
703     P_ERRNO = P_EFS_NOT_MOUNTED;
704     u_perror("rm");
705     return NULL;
706   }
707 
708   // check if we have any arguments
709   if (args[1] == NULL) {
710     P_ERRNO = P_EINVAL;
711     u_perror("rm");
712     return NULL;
713   }
714 
715   // process each file argument
716   for (int i = 1; args[i] != NULL; i++) {
717     // find the file in the directory
718     dir_entry_t entry;
719     int entry_offset = find_file(args[i], &entry);
720 
721     if (entry_offset < 0) {
722       // file doesn't exist
723       P_ERRNO = P_ENOENT;
724       u_perror("rm");
725       continue;
726     }
727 
728     // check if file is currently open
729     for (int j = 0; j < MAX_FDS; j++) {
730       if (fd_table[j].in_use && strcmp(fd_table[j].filename, args[i]) == 0) {
731         P_ERRNO = P_EBUSY;
732         u_perror("rm");
733         continue;
734       }
735     }
736 
737     // mark the directory entry as deleted
738     if (lseek(fs_fd, entry_offset, SEEK_SET) == -1) {
739       P_ERRNO = P_ELSEEK;
740       u_perror("rm");
741       continue;
742     }
```

```
    char deleted = 1;  // mark as deleted
    if (write(fs_fd, &deleted, sizeof(deleted)) != sizeof(deleted)) {
      P_ERRNO = P_EWRITE;
      u_perror("rm");
      continue;
    }

    // free the FAT chain for this file
    uint16_t block = entry.firstBlock;
    while (block != FAT_FREE && block != FAT_EOF) {
      uint16_t next_block = fat[block];
      fat[block] = FAT_FREE;
      block = next_block;
    }
  }

  return NULL;
}
```

4.2.2.10 touch()

```
void* touch (
            void * arg )
```

Creates empty files or updates timestamps.

For each file argument, creates the file if it doesn't exist, or updates its timestamp if it already exists.

Parameters

arg	Arguments array (command line arguments)

Returns

void pointer (unused)

Creates empty files or updates timestamps.

For each file argument, creates the file if it doesn't exist, or updates its timestamp if it already exists.

Definition at line 501 of file fat_routines.c.

```
                            {
  char** args = (char**)arg;

  // verify that the file system is mounted
  if (!is_mounted) {
    P_ERRNO = P_EFS_NOT_MOUNTED;
    u_perror("touch");
    return NULL;
  }

  // check if we have any arguments
  if (args[1] == NULL) {
    P_ERRNO = P_EINVAL;
    u_perror("touch");
    return NULL;
  }

  // process each file argument
  for (int i = 1; args[i] != NULL; i++) {
    dir_entry_t entry;
    int entry_offset = find_file(args[i], &entry);

    // file exists
    if (entry_offset >= 0) {
      entry.mtime = time(NULL);
```

```

      // write the updated entry back to the directory
      if (lseek(fs_fd, entry_offset, SEEK_SET) == -1) {
        P_ERRNO = P_ELSEEK;
        u_perror("touch");
        continue;
      }
      if (write(fs_fd, &entry, sizeof(entry)) != sizeof(entry)) {
        P_ERRNO = P_EWRITE;
        u_perror("touch");
        continue;
      }
    } else {
      // file doesn't exist, create a new empty file

      // check if the fat is full
      if (P_ERRNO == P_EFULL) {
        u_perror("touch");
        return NULL;
      }

      // add the file entry to root directory
      if (add_file_entry(args[i], 0, 0, TYPE_REGULAR, PERM_READ_WRITE) == -1) {
        u_perror("touch");
        continue;
      }
    }
  }

  return NULL;
}
```

4.2.2.11 unmount()

`int unmount ( )`

Unmounts the currently mounted filesystem.

This function flushes any pending changes and unmounts the filesystem.

Returns

0 on success, -1 on failure with P_ERRNO set.

Unmounts the currently mounted filesystem.

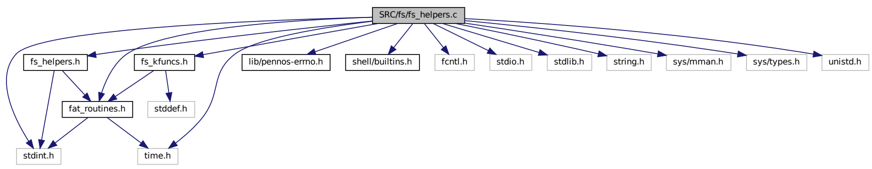
Definition at line 174 of file fat_routines.c.

```
174               {
175   // first check that a file system is actually mounted
176   if (!is_mounted) {
177     P_ERRNO = P_EFS_NOT_MOUNTED;
178     return -1;
179   }
180
181   // unmap the FAT
182   if (fat != NULL) {
183     if (munmap(fat, fat_size) == -1) {
184       P_ERRNO = P_EMAP;
185       return -1;
186     }
187     fat = NULL;
188   }
189
190   // close fs_fd
191   if (fs_fd != -1) {
192     if (close(fs_fd) == -1) {
193       P_ERRNO = P_ECLOSE;
194       return -1;
195     }
196     fs_fd = -1;
197   }
198
199   // reset the other globals
200   num_fat_blocks = 0;
201   block_size = 0;
202   fat_size = 0;
203   is_mounted = false;
204   return 0;
205 }
```

4.3 SRC/fs/fs_helpers.c File Reference

```
#include "fs_helpers.h"
#include "fat_routines.h"
#include "fs_kfuncs.h"
#include "lib/pennos-errno.h"
#include "shell/builtins.h"
#include <fcntl.h>
#include <stdint.h>
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <sys/mman.h>
#include <sys/types.h>
#include <time.h>
#include <unistd.h>
```

Include dependency graph for fs_helpers.c:



Functions

- void init_fd_table (fd_entry_t ∗fd_table)

  Initializes the global kernel-level file descriptor table.
- int get_free_fd (fd_entry_t ∗fd_table)

  Gets a free file descriptor.
- int increment_fd_ref_count (int fd)

  Increments the reference count of a file descriptor.
- int decrement_fd_ref_count (int fd)

  Decrements the reference count of a file descriptor.
- int has_executable_permission (int fd)

  Checks if a file has executable permissions.
- uint16_t allocate_block ()

  Allocates a block.
- int find_file (const char ∗filename, dir_entry_t ∗entry)

  Searches for a file in the root directory.
- int add_file_entry (const char ∗filename, uint32_t size, uint16_t first_block, uint8_t type, uint8_t perm)

  Adds a file to the root directory.
- int mark_entry_as_deleted (dir_entry_t ∗entry, int absolute_offset)

  Marks a file entry as deleted and frees its blocks.
- int copy_host_to_pennfat (const char ∗host_filename, const char ∗pennfat_filename)

  Copies data from host OS file to the PennFAT file.
- int copy_pennfat_to_host (const char ∗pennfat_filename, const char ∗host_filename)

  Copies data from PennFAT file to host OS file.
- int copy_source_to_dest (const char ∗source_filename, const char ∗dest_filename)

  Copies data from source file to destination file.
- int compact_directory ()

  Compacts a directory.

Variables

- int fs_fd = -1
- int block_size = 0
- int num_fat_blocks = 0
- int fat_size = 0
- uint16_t * fat = NULL
- bool is_mounted = false
- int MAX_FDS = 100
- fd_entry_t fd_table [100]

4.3.1 Function Documentation

4.3.1.1 add_file_entry()

```
int add_file_entry (
            const char * filename,
            uint32_t size,
            uint16_t first_block,
            uint8_t type,
            uint8_t perm )
```

Adds a file to the root directory.

Adds a new file entry to the root directory.

Definition at line 267 of file fs_helpers.c.

```
271                                     {
272   if (!is_mounted) {
273     P_ERRNO = P_EFS_NOT_MOUNTED;
274     return -1;
275   }
276
277   // check if file already exists
278   dir_entry_t existing;
279   if (find_file(filename, &existing) >= 0) {
280     P_ERRNO = P_EEXIST;
281     return -1;
282   }
283
284   // start with root directory block (block 1)
285   uint16_t current_block = 1;
286   int offset = 0;
287   dir_entry_t dir_entry;
288
289   while (1) {
290     // position at the start of current block of the root directory
291     if (lseek(fs_fd, fat_size + (current_block - 1) * block_size, SEEK_SET) ==
292         -1) {
293       P_ERRNO = P_ELSEEK;
294       return -1;
295     }
296
297     // reset offset for new block
298     offset = 0;
299
300     // search current block for free slot
301     while (offset < block_size) {
302       if (read(fs_fd, &dir_entry, sizeof(dir_entry)) != sizeof(dir_entry)) {
303         P_ERRNO = P_EREAD;
304         return -1;
305       }
306
307       // found a free slot
308       if (dir_entry.name[0] == 0 || dir_entry.name[0] == 1) {
```

```
        // initialize the new entry
        memset(&dir_entry, 0, sizeof(dir_entry));
        strncpy(dir_entry.name, filename, 31);
        dir_entry.size = size;
        dir_entry.firstBlock = first_block;
        dir_entry.type = type;
        dir_entry.perm = perm;
        dir_entry.mtime = time(NULL);

        // write the entry
        if (lseek(fs_fd, fat_size + (current_block - 1) * block_size + offset,
                  SEEK_SET) == -1) {
          P_ERRNO = P_ELSEEK;
          return -1;
        }
        if (write(fs_fd, &dir_entry, sizeof(dir_entry)) != sizeof(dir_entry)) {
          P_ERRNO = P_EWRITE;
          return -1;
        }

        return offset;
      }

      offset += sizeof(dir_entry);
    }

    // current block is full, check if there's a next block
    if (fat[current_block] != FAT_EOF) {
      current_block = fat[current_block];
      continue;
    }

    // allocate a new block for the root directory
    uint16_t new_block = allocate_block();
    if (new_block == 0) {
      P_ERRNO = P_EFULL;
      return -1;
    }

    // chain the new block
    fat[current_block] = new_block;
    fat[new_block] = FAT_EOF;

    // initialize new block
    uint8_t* zero_block = calloc(block_size, 1);
    if (!zero_block) {
      P_ERRNO = P_EINVAL;
      return -1;
    }

    // write this new block to the file system
    if (lseek(fs_fd, fat_size + (new_block - 1) * block_size, SEEK_SET) == -1) {
      P_ERRNO = P_ELSEEK;
      free(zero_block);
      return -1;
    }
    if (write(fs_fd, zero_block, block_size) != block_size) {
      P_ERRNO = P_EWRITE;
      free(zero_block);
      return -1;
    }

    free(zero_block);

    // initialize the new entry
    memset(&dir_entry, 0, sizeof(dir_entry));
    strncpy(dir_entry.name, filename, 31);
    dir_entry.size = size;
    dir_entry.firstBlock = first_block;
    dir_entry.type = type;
    dir_entry.perm = perm;
    dir_entry.mtime = time(NULL);

    // write the new entry at the start of the new block in the file system
    if (lseek(fs_fd, fat_size + (new_block - 1) * block_size, SEEK_SET) == -1) {
      P_ERRNO = P_ELSEEK;
      return -1;
    }
    if (write(fs_fd, &dir_entry, sizeof(dir_entry)) != sizeof(dir_entry)) {
      P_ERRNO = P_EWRITE;
      return -1;
    }

    return 0;
  }
}
```

4.3.1.2 allocate_block()

```
uint16_t allocate_block ( )
```

Allocates a block.

Allocates a free block in the FAT.

If no block found, we try compacting the directory.

Definition at line 166 of file fs_helpers.c.

```
166                              {
167   for (int i = 2; i < fat_size / 2; i++) {
168     if (fat[i] == FAT_FREE) {
169       fat[i] = FAT_EOF;
170       return i;
171     }
172   }
173 
174   if (compact_directory() == 0) {
175     for (int i = 2; i < fat_size / 2; i++) {
176       if (fat[i] == FAT_FREE) {
177         fat[i] = FAT_EOF;
178         return i;
179       }
180     }
181   }
182 
183   return 0;
184 }
```

4.3.1.3 compact_directory()

```
int compact_directory ( )
```

Compacts a directory.

Compacts the root directory by removing all deleted entries.

Definition at line 699 of file fs_helpers.c.

```
699                            {
700   if (!is_mounted) {
701     P_ERRNO = P_EFS_NOT_MOUNTED;
702     return -1;
703   }
704 
705   // buffer for temp storage of a block
706   uint8_t* dir_buffer = malloc(block_size);
707   if (!dir_buffer) {
708     P_ERRNO = P_EMALLOC;
709     return -1;
710   }
711 
712   // start at root directory
713   uint16_t current_block = 1;
714   int dir_entries_count = 0;
715   int deleted_entries_count = 0;
716 
717   // calculate number of entries and deleted entries in the root directory
718   while (current_block != FAT_EOF) {
719     if (lseek(fs_fd, fat_size + (current_block - 1) * block_size, SEEK_SET) ==
720         -1) {
721       P_ERRNO = P_ELSEEK;
722       free(dir_buffer);
723       return -1;
724     }
```

```
    if (read(fs_fd, dir_buffer, block_size) != block_size) {
      P_ERRNO = P_EREAD;
      free(dir_buffer);
      return -1;
    }

    // count entries and deleted entries in this block
    for (int offset = 0; offset < block_size; offset += sizeof(dir_entry_t)) {
      dir_entry_t* entry = (dir_entry_t*)(dir_buffer + offset);

      // check if we've reached the end of directory
      if (entry->name[0] == 0) {
        break;
      }

      dir_entries_count++;

      // check if it's a deleted entry
      if (entry->name[0] == 1) {
        deleted_entries_count++;
      }
    }

    // move onto next block, if there is one
    if (fat[current_block] != FAT_EOF) {
      current_block = fat[current_block];
    } else {
      break;
    }
  }

  // if no deleted entries, no compaction needed
  if (deleted_entries_count == 0) {
    free(dir_buffer);
    return 0;
  }

  // allocate space for all valid entries
  dir_entry_t* all_entries = malloc(dir_entries_count * sizeof(dir_entry_t));
  if (!all_entries) {
    P_ERRNO = P_EMALLOC;
    free(dir_buffer);
    return -1;
  }

  // read all entries into the buffer, skipping deleted ones
  current_block = 1;
  int valid_entry_idx = 0;

  while (current_block != FAT_EOF) {
    if (lseek(fs_fd, fat_size + (current_block - 1) * block_size, SEEK_SET) ==
        -1) {
      P_ERRNO = P_ELSEEK;
      free(dir_buffer);
      free(all_entries);
      return -1;
    }

    if (read(fs_fd, dir_buffer, block_size) != block_size) {
      P_ERRNO = P_EREAD;
      free(dir_buffer);
      free(all_entries);
      return -1;
    }

    // process entries in this block
    for (int offset = 0; offset < block_size; offset += sizeof(dir_entry_t)) {
      dir_entry_t* entry = (dir_entry_t*)(dir_buffer + offset);

      // check if we've reached the end of directory
      if (entry->name[0] == 0) {
        break;
      }

      // skip deleted entries
      if (entry->name[0] == 1) {
        continue;
      }

      // copy valid entry to our array
      memcpy(&all_entries[valid_entry_idx++], entry, sizeof(dir_entry_t));
    }

    // move to the next block
    if (fat[current_block] != FAT_EOF) {
      current_block = fat[current_block];
```

```
    } else {
      break;
    }
  }

  // rewrite the directory with only valid entries
  current_block = 1;
  int entries_per_block = block_size / sizeof(dir_entry_t);
  int blocks_needed =
      (valid_entry_idx + entries_per_block - 1) / entries_per_block;

  // clean up any excess directory blocks in the FAT chain
  uint16_t next_block = fat[current_block];
  if (blocks_needed == 1) {
    // only need one block, free all others
    while (next_block != FAT_EOF) {
      uint16_t temp = fat[next_block];
      fat[next_block] = FAT_FREE;
      next_block = temp;
    }
    fat[current_block] = FAT_EOF;
  } else {
    // navigate through needed blocks
    int block_count = 1;
    uint16_t prev_block = current_block;

    while (block_count < blocks_needed) {
      if (next_block == FAT_EOF) {
        // need to allocate a new block
        uint16_t new_block = allocate_block();
        if (new_block == 0) {
          P_ERRNO = P_EFULL;
          free(dir_buffer);
          free(all_entries);
          return -1;
        }
        fat[prev_block] = new_block;
        next_block = new_block;
      }

      prev_block = next_block;
      next_block = fat[next_block];
      block_count++;
    }

    // free any excess blocks
    fat[prev_block] = FAT_EOF;
    while (next_block != FAT_EOF) {
      uint16_t temp = fat[next_block];
      fat[next_block] = FAT_FREE;
      next_block = temp;
    }
  }

  // write the valid entries back to the directory blocks
  current_block = 1;
  int entries_written = 0;

  while (entries_written < valid_entry_idx) {
    if (lseek(fs_fd, fat_size + (current_block - 1) * block_size, SEEK_SET) ==
        -1) {
      P_ERRNO = P_ELSEEK;
      free(dir_buffer);
      free(all_entries);
      return -1;
    }

    memset(dir_buffer, 0, block_size);

    // copy entries to the buffer
    int entries_in_this_block = 0;
    while (entries_written < valid_entry_idx &&
           entries_in_this_block < entries_per_block) {
      memcpy(dir_buffer + (entries_in_this_block * sizeof(dir_entry_t)),
             &all_entries[entries_written], sizeof(dir_entry_t));
      entries_written++;
      entries_in_this_block++;
    }

    // write the buffer to the file system
    if (write(fs_fd, dir_buffer, block_size) != block_size) {
      P_ERRNO = P_EINVAL;
      free(dir_buffer);
      free(all_entries);
      return -1;
    }

```

```
    // move to the next block if needed
    if (entries_written < valid_entry_idx) {
      current_block = fat[current_block];
    }
  }

  free(dir_buffer);
  free(all_entries);
  return 0;
}
```

4.3.1.4 copy_host_to_pennfat()

```
int copy_host_to_pennfat (
            const char * host_filename,
            const char * pennfat_filename )
```

Copies data from host OS file to the PennFAT file.

Copies a file from the host OS to the PennFAT filesystem.

Definition at line 438 of file fs_helpers.c.

```
                                                          {
  if (!is_mounted) {
    P_ERRNO = P_EFS_NOT_MOUNTED;
    return -1;
  }

  // open the host file
  int host_fd = open(host_filename, O_RDONLY);
  if (host_fd == -1) {
    P_ERRNO = P_EOPEN;
    return -1;
  }

  // determine file size by seeking to the end and getting position
  off_t host_file_size_in_bytes = lseek(host_fd, 0, SEEK_END);
  if (host_file_size_in_bytes == -1) {
    P_ERRNO = P_ELSEEK;
    close(host_fd);
    return -1;
  }

  // go back to beginning of file for reading
  if (lseek(host_fd, 0, SEEK_SET) == -1) {
    P_ERRNO = P_ELSEEK;
    close(host_fd);
    return -1;
  }

  // open the destination file in PennFAT
  int pennfat_fd = k_open(pennfat_filename, F_WRITE);
  if (pennfat_fd < 0) {
    close(host_fd);
    return -1;
  }

  // copy the data into this buffer
  uint8_t* buffer = (uint8_t*)malloc(block_size);
  if (!buffer) {
    P_ERRNO = P_EMALLOC;
    k_close(pennfat_fd);
    close(host_fd);
    return -1;
  }

  uint32_t bytes_remaining = host_file_size_in_bytes;
  ssize_t bytes_read;

  // read from host file
  while (bytes_remaining > 0) {
    // ensure bytes to read never exceeds the block size
    ssize_t bytes_to_read =
        bytes_remaining < block_size ? bytes_remaining : block_size;
    bytes_read = read(host_fd, buffer, bytes_to_read);

```

```
    if (bytes_read <= 0) {
      break;
    }

    // write to pennfat_fd using k_write
    if (k_write(pennfat_fd, (const char*)buffer, bytes_read) != bytes_read) {
      free(buffer);
      k_close(pennfat_fd);
      close(host_fd);
      return -1;
    }

    bytes_remaining -= bytes_read;
  }

  // check for read error
  if (bytes_read < 0) {
    P_ERRNO = P_EREAD;
    free(buffer);
    k_close(pennfat_fd);
    close(host_fd);
    return -1;
  }

  // otherwise, cleanup and return success
  free(buffer);
  k_close(pennfat_fd);
  close(host_fd);
  return 0;
}
```

4.3.1.5 copy_pennfat_to_host()

```
int copy_pennfat_to_host (
            const char * pennfat_filename,
            const char * host_filename )
```

Copies data from PennFAT file to host OS file.

Copies a file from the PennFAT filesystem to the host OS.

Definition at line 527 of file fs_helpers.c.

```
{
  if (!is_mounted) {
    P_ERRNO = P_EFS_NOT_MOUNTED;
    return -1;
  }

  // open the PennFAT file
  int pennfat_fd = k_open(pennfat_filename, F_READ);
  if (pennfat_fd < 0) {
    return -1;
  }

  // get the pennfat file size
  off_t pennfat_file_size_in_bytes = k_lseek(pennfat_fd, 0, SEEK_END);
  if (pennfat_file_size_in_bytes == -1) {
    k_close(pennfat_fd);
    return -1;
  }

  // go back to beginning of file for reading
  if (k_lseek(pennfat_fd, 0, SEEK_SET) == -1) {
    k_close(pennfat_fd);
    return -1;
  }

  // open the host file
  int host_fd = open(host_filename, O_WRONLY | O_CREAT | O_TRUNC, 0644);
  if (host_fd == -1) {
    P_ERRNO = P_EOPEN;
    k_close(pennfat_fd);
    return -1;
  }

  // allocate buffer for data transfer
```

```
  char* buffer = (char*)malloc(block_size);
  if (!buffer) {
    P_ERRNO = P_EMALLOC;
    k_close(pennfat_fd);
    close(host_fd);
    return -1;
  }

  uint32_t bytes_remaining = pennfat_file_size_in_bytes;
  ssize_t bytes_read;

  // read from PennFAT file and write to host file
  while (bytes_remaining > 0) {
    // ensure bytes to read never exceeds the block size
    ssize_t bytes_to_read =
        bytes_remaining < block_size ? bytes_remaining : block_size;
    bytes_read = k_read(pennfat_fd, buffer, bytes_to_read);

    if (bytes_read <= 0) {
      break;
    }

    if (write(host_fd, buffer, bytes_read) != bytes_read) {
      P_ERRNO = P_EINVAL;
      free(buffer);
      close(host_fd);
      k_close(pennfat_fd);
      return -1;
    }

    bytes_remaining -= bytes_read;
  }

  // check for read error
  if (bytes_read < 0) {
    P_ERRNO = P_EREAD;
    free(buffer);
    close(host_fd);
    k_close(pennfat_fd);
    return -1;
  }

  // otherwise, cleanup and return success
  free(buffer);
  close(host_fd);
  k_close(pennfat_fd);
  return 0;
}
```

4.3.1.6 copy_source_to_dest()

```
int copy_source_to_dest (
              const char * source_filename,
              const char * dest_filename )
```

Copies data from source file to destination file.

Copies a file from a source file to a destination file.

Definition at line 614 of file fs_helpers.c.

```
                                                        {
  if (!is_mounted) {
    P_ERRNO = P_EFS_NOT_MOUNTED;
    return -1;
  }

  // open the source file
  int source_fd = k_open(source_filename, F_READ);
  if (source_fd < 0) {
    return -1;
  }

  // get the source file size
  off_t source_file_size_in_bytes = k_lseek(source_fd, 0, SEEK_END);
  if (source_file_size_in_bytes == -1) {
    k_close(source_fd);
```

```
    return -1;
  }

  // move to the beginning of the source file for reading
  if (k_lseek(source_fd, 0, SEEK_SET) < 0) {
    k_close(source_fd);
    return -1;
  }

  // open the destination file
  int dest_fd = k_open(dest_filename, F_WRITE);
  if (dest_fd < 0) {
    k_close(source_fd);
    return -1;
  }

  // read from source to destination
  char* buffer = (char*)malloc(block_size);
  if (!buffer) {
    P_ERRNO = P_EMALLOC;
    k_close(source_fd);
    k_close(dest_fd);
    return -1;
  }

  uint32_t bytes_remaining = source_file_size_in_bytes;
  ssize_t bytes_read;

  while (bytes_remaining > 0) {
    // make sure the bytes to read doesn't exceed block size
    ssize_t bytes_to_read =
        bytes_remaining < block_size ? bytes_remaining : block_size;
    bytes_read = k_read(source_fd, buffer, bytes_to_read);

    if (bytes_read <= 0) {
      break;
    }

    if (k_write(dest_fd, buffer, bytes_read) != bytes_read) {
      free(buffer);
      k_close(source_fd);
      k_close(dest_fd);
      return -1;
    }
  }

  // check for read error
  if (bytes_read < 0) {
    free(buffer);
    k_close(source_fd);
    k_close(dest_fd);
    return -1;
  }

  // otherwise, cleanup and return success
  free(buffer);
  k_close(source_fd);
  k_close(dest_fd);
  return 0;
}
```

4.3.1.7 decrement_fd_ref_count()

```
int decrement_fd_ref_count (
              int fd )
```

Decrements the reference count of a file descriptor.

If reference count reaches 0, flush field values.

Definition at line 107 of file fs_helpers.c.

```
107                                  {
108   if (fd < 0 || fd >= MAX_FDS) {
109     P_ERRNO = P_EBADF;
110     return -1;
111   }
```

```c

  if (!fd_table[fd].in_use) {
    P_ERRNO = P_EBADF;
    return -1;
  }

  fd_table[fd].ref_count--;
  if (fd_table[fd].ref_count == 0) {
    fd_table[fd].in_use = 0;
    memset(fd_table[fd].filename, 0, sizeof(fd_table[fd].filename));
    fd_table[fd].size = 0;
    fd_table[fd].first_block = 0;
    fd_table[fd].position = 0;
    fd_table[fd].mode = 0;
  }
  return fd_table[fd].ref_count;
}
```

4.3.1.8 find_file()

```c
int find_file (
            const char * filename,
            dir_entry_t * entry )
```

Searches for a file in the root directory.

Retrieves the file's absolute offset in the filesystem.

Definition at line 191 of file fs_helpers.c.

```c
191 {
192   if (!is_mounted) {
193     P_ERRNO = P_EFS_NOT_MOUNTED;
194     return -1;
195   }
196
197   // Start with root directory block (block 1)
198   uint16_t current_block = 1;
199   int offset_in_block = 0;
200   int absolute_offset = 0;
201   dir_entry_t dir_entry;
202
203   while (1) {
204     // Position at the start of current block
205     if (lseek(fs_fd, fat_size + (current_block - 1) * block_size, SEEK_SET) ==
206         -1) {
207       P_ERRNO = P_ELSEEK;
208       return -1;
209     }
210
211     // reset offset for new block
212     offset_in_block = 0;
213
214     // calculate the absolute offset
215     absolute_offset = fat_size + (current_block - 1) * block_size;
216
217     // search current block
218     while (offset_in_block < block_size) {
219       if (read(fs_fd, &dir_entry, sizeof(dir_entry)) != sizeof(dir_entry)) {
220         P_ERRNO = P_EREAD;
221         return -1;
222       }
223
224       // check if we've reached the end of directory
225       if (dir_entry.name[0] == 0) {
226         break;
227       }
228
229       // check if this is a deleted entry
230       if (dir_entry.name[0] == 1 || dir_entry.name[0] == 2) {
231         offset_in_block += sizeof(dir_entry);
232         absolute_offset += sizeof(dir_entry);
233         continue;
234       }
235
236       // check if we found the file
237       if (strcmp(dir_entry.name, filename) == 0) {
```

```
        if (entry) {
          memcpy(entry, &dir_entry, sizeof(dir_entry));
        }
        return absolute_offset;  // return the absolute file offset
      }

      offset_in_block += sizeof(dir_entry);
      absolute_offset += sizeof(dir_entry);
    }

    // if we've reached the end of the current block, check if there's a next
    // block
    if (fat[current_block] != FAT_EOF) {
      current_block = fat[current_block];
      continue;
    }

    // no more blocks to search
    break;
  }

  // file not found
  P_ERRNO = P_ENOENT;
  return -1;
}
```

4.3.1.9 get_free_fd()

```
int get_free_fd (
            fd_entry_t * fd_table )
```

Gets a free file descriptor.

Finds the first available file descriptor in the table.

Definition at line 77 of file fs_helpers.c.

```
77                                          {
78   for (int i = 3; i < MAX_FDS; i++) {
79     if (!fd_table[i].in_use) {
80       return i;
81     }
82   }
83   return -1;
84 }
```

4.3.1.10 has_executable_permission()

```
int has_executable_permission (
            int fd )
```

Checks if a file has executable permissions.

Checks if a file has executable permissions in the PennFAT filesystem.

Definition at line 133 of file fs_helpers.c.

```
133                                          {
134   // check if fs is mounted
135   if (!is_mounted) {
136     P_ERRNO = P_EFS_NOT_MOUNTED;
137     return -1;
138   }
139
140   // validate fd argument
141   if (fd < 0 || fd >= MAX_FDS) {
142     P_ERRNO = P_EINVAL;
```

```
    return -1;
  }

  // determine whether the file exists
  dir_entry_t entry;
  int entry_offset = find_file(fd_table[fd].filename, &entry);
  if (entry_offset < 0) {
    return -1;
  }

  // if it exists, get its permission
  if (entry.perm & PERM_EXEC) {
    return 1;
  }

  return 0;
}
```

4.3.1.11 increment_fd_ref_count()

```
int increment_fd_ref_count (
            int fd )
```

Increments the reference count of a file descriptor.

Parameters

fd	file descriptor to increment

Returns

new reference count, or -1 on error

Definition at line 89 of file fs_helpers.c.

```
89                                     {
90   if (fd < 0 || fd >= MAX_FDS) {
91     P_ERRNO = P_EBADF;
92     return -1;
93   }
94   if (!fd_table[fd].in_use) {
95     P_ERRNO = P_EBADF;
96     return -1;
97   }
98   fd_table[fd].ref_count++;
99   return fd_table[fd].ref_count;
100 }
```

4.3.1.12 init_fd_table()

```
void init_fd_table (
            fd_entry_t * fd_table )
```

Initializes the global kernel-level file descriptor table.

Initializes all entries in the file descriptor table to not in use.

Definition at line 43 of file fs_helpers.c.

```
43                                           {
44   // STDIN (fd 0)
```

```
  fd_table[0].in_use = 1;
  fd_table[0].ref_count = 1;
  strncpy(fd_table[0].filename, "<stdin>", 31);
  fd_table[0].mode = F_READ;

  // STDOUT (fd 1)
  fd_table[1].in_use = 1;
  strncpy(fd_table[1].filename, "<stdout>", 31);
  fd_table[1].mode = F_WRITE;  // write-only
  fd_table[1].ref_count = 1;

  // STDERR (fd 2)
  fd_table[2].in_use = 1;
  strncpy(fd_table[2].filename, "<stderr>", 31);
  fd_table[2].mode = F_WRITE;  // write-only
  fd_table[2].ref_count = 1;

  // other file descriptors (fd 3 and above)
  for (int i = 3; i < MAX_FDS; i++) {
    fd_table[i].in_use = 0;
    fd_table[i].ref_count = 0;
    memset(fd_table[i].filename, 0, sizeof(fd_table[i].filename));
    fd_table[i].size = 0;
    fd_table[i].first_block = 0;
    fd_table[i].position = 0;
    fd_table[i].mode = 0;
  }
}
```

4.3.1.13 mark_entry_as_deleted()

```
int mark_entry_as_deleted (
            dir_entry_t * entry,
            int absolute_offset )
```

Marks a file entry as deleted and frees its blocks.

Marks a file entry as deleted and frees its blocks in the FAT.

Definition at line 399 of file fs_helpers.c.

```
399                                                                   {
400   if (!is_mounted || entry == NULL || absolute_offset < 0) {
401     P_ERRNO = P_EINVAL;
402     return -1;
403   }
404
405   // free the blocks
406   uint16_t current_block = entry->firstBlock;
407   while (current_block != FAT_FREE && current_block != FAT_EOF) {
408     uint16_t next_block = fat[current_block];
409     fat[current_block] = FAT_FREE;
410     current_block = next_block;
411   }
412
413   // mark the entry as deleted in the root directory
414   dir_entry_t deleted_entry = *entry;
415   deleted_entry.name[0] = 1;
416   if (lseek(fs_fd, absolute_offset, SEEK_SET) == -1) {
417     P_ERRNO = P_ELSEEK;
418     return -1;
419   }
420   if (write(fs_fd, &deleted_entry, sizeof(deleted_entry)) !=
421       sizeof(deleted_entry)) {
422     P_ERRNO = P_EINVAL;
423     return -1;
424   }
425
426   // mark the passed entry as deleted
427   entry->name[0] = 1;
428   return 0;
429 }
```

4.3.2 Variable Documentation

4.3.2.1 block_size

```
int block_size = 0
```

Definition at line 28 of file fs_helpers.c.

4.3.2.2 fat

```
uint16_t* fat = NULL
```

Definition at line 31 of file fs_helpers.c.

4.3.2.3 fat_size

```
int fat_size = 0
```

Definition at line 30 of file fs_helpers.c.

4.3.2.4 fd_table

```
fd_entry_t fd_table[100]
```

Definition at line 34 of file fs_helpers.c.

4.3.2.5 fs_fd

```
int fs_fd = -1
```

Definition at line 27 of file fs_helpers.c.

4.3.2.6 is_mounted

```
bool is_mounted = false
```

Definition at line 32 of file fs_helpers.c.

4.3.2.7 MAX_FDS

```
int MAX_FDS = 100
```

Definition at line 33 of file fs_helpers.c.

4.3.2.8 num_fat_blocks

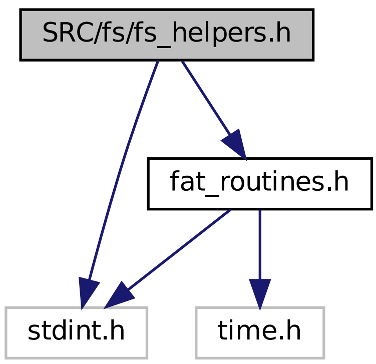
```
int num_fat_blocks = 0
```

Definition at line 29 of file fs_helpers.c.

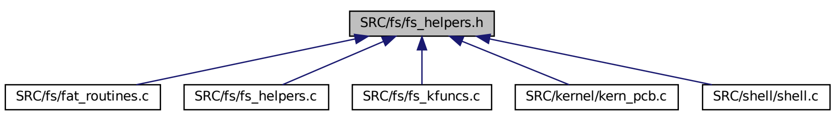
4.4 SRC/fs/fs_helpers.h File Reference

```
#include <stdint.h>
#include "fat_routines.h"
```

Include dependency graph for fs_helpers.h:



This graph shows which files directly or indirectly include this file:



Functions

- void init_fd_table (fd_entry_t ∗fd_table)

    Initializes all entries in the file descriptor table to not in use.
- int get_free_fd (fd_entry_t ∗fd_table)

    Finds the first available file descriptor in the table.
- int increment_fd_ref_count (int fd)

    Increments the reference count of a file descriptor.
- int decrement_fd_ref_count (int fd)

    Decrements the reference count of a file descriptor.
- int has_executable_permission (int fd)

    Checks if a file has executable permissions in the PennFAT filesystem.
- uint16_t allocate_block ()

    Allocates a free block in the FAT.
- int find_file (const char ∗filename, dir_entry_t ∗entry)

    Searches for a file in the root directory.
- int add_file_entry (const char ∗filename, uint32_t size, uint16_t first_block, uint8_t type, uint8_t perm)

    Adds a new file entry to the root directory.
- int mark_entry_as_deleted (dir_entry_t ∗entry, int offset)

    Marks a file entry as deleted and frees its blocks in the FAT.
- int copy_host_to_pennfat (const char ∗host_filename, const char ∗pennfat_filename)

    Copies a file from the host OS to the PennFAT filesystem.
- int copy_pennfat_to_host (const char ∗pennfat_filename, const char ∗host_filename)

    Copies a file from the PennFAT filesystem to the host OS.
- int copy_source_to_dest (const char ∗source_filename, const char ∗dest_filename)

    Copies a file from a source file to a destination file.
- int compact_directory ()

    Compacts the root directory by removing all deleted entries.

Variables

- int fs_fd
- int block_size
- int num_fat_blocks
- int fat_size
- uint16_t ∗ fat
- bool is_mounted
- int MAX_FDS
- fd_entry_t fd_table [100]

4.4.1 Function Documentation

4.4.1.1 add_file_entry()

```
int add_file_entry (
            const char * filename,
            uint32_t size,
            uint16_t first_block,
            uint8_t type,
            uint8_t perm )
```

Adds a new file entry to the root directory.

Parameters

filename	name of the file to add
size	size of the file in bytes
first_block	block number of the first block of the file
type	file type (regular, directory, etc.)
perm	file permissions

Returns

offset of the new entry in the directory if successful, -1 on error

Adds a new file entry to the root directory.

Definition at line 267 of file fs_helpers.c.

```
                                      {
  if (!is_mounted) {
    P_ERRNO = P_EFS_NOT_MOUNTED;
    return -1;
  }

  // check if file already exists
  dir_entry_t existing;
  if (find_file(filename, &existing) >= 0) {
    P_ERRNO = P_EEXIST;
    return -1;
  }

  // start with root directory block (block 1)
  uint16_t current_block = 1;
  int offset = 0;
  dir_entry_t dir_entry;

  while (1) {
    // position at the start of current block of the root directory
    if (lseek(fs_fd, fat_size + (current_block - 1) * block_size, SEEK_SET) ==
        -1) {
      P_ERRNO = P_ELSEEK;
      return -1;
    }

    // reset offset for new block
    offset = 0;

    // search current block for free slot
    while (offset < block_size) {
      if (read(fs_fd, &dir_entry, sizeof(dir_entry)) != sizeof(dir_entry)) {
        P_ERRNO = P_EREAD;
        return -1;
      }

      // found a free slot
      if (dir_entry.name[0] == 0 || dir_entry.name[0] == 1) {
        // initialize the new entry
        memset(&dir_entry, 0, sizeof(dir_entry));
        strncpy(dir_entry.name, filename, 31);
        dir_entry.size = size;
        dir_entry.firstBlock = first_block;
        dir_entry.type = type;
        dir_entry.perm = perm;
        dir_entry.mtime = time(NULL);

        // write the entry
        if (lseek(fs_fd, fat_size + (current_block - 1) * block_size + offset,
                  SEEK_SET) == -1) {
          P_ERRNO = P_ELSEEK;
          return -1;
        }
        if (write(fs_fd, &dir_entry, sizeof(dir_entry)) != sizeof(dir_entry)) {
          P_ERRNO = P_EWRITE;
          return -1;
        }

        return offset;
      }

```

```
      offset += sizeof(dir_entry);
    }

    // current block is full, check if there's a next block
    if (fat[current_block] != FAT_EOF) {
      current_block = fat[current_block];
      continue;
    }

    // allocate a new block for the root directory
    uint16_t new_block = allocate_block();
    if (new_block == 0) {
      P_ERRNO = P_EFULL;
      return -1;
    }

    // chain the new block
    fat[current_block] = new_block;
    fat[new_block] = FAT_EOF;

    // initialize new block
    uint8_t* zero_block = calloc(block_size, 1);
    if (!zero_block) {
      P_ERRNO = P_EINVAL;
      return -1;
    }

    // write this new block to the file system
    if (lseek(fs_fd, fat_size + (new_block - 1) * block_size, SEEK_SET) == -1) {
      P_ERRNO = P_ELSEEK;
      free(zero_block);
      return -1;
    }
    if (write(fs_fd, zero_block, block_size) != block_size) {
      P_ERRNO = P_EWRITE;
      free(zero_block);
      return -1;
    }

    free(zero_block);

    // initialize the new entry
    memset(&dir_entry, 0, sizeof(dir_entry));
    strncpy(dir_entry.name, filename, 31);
    dir_entry.size = size;
    dir_entry.firstBlock = first_block;
    dir_entry.type = type;
    dir_entry.perm = perm;
    dir_entry.mtime = time(NULL);

    // write the new entry at the start of the new block in the file system
    if (lseek(fs_fd, fat_size + (new_block - 1) * block_size, SEEK_SET) == -1) {
      P_ERRNO = P_ELSEEK;
      return -1;
    }
    if (write(fs_fd, &dir_entry, sizeof(dir_entry)) != sizeof(dir_entry)) {
      P_ERRNO = P_EWRITE;
      return -1;
    }

    return 0;
  }
}
```

4.4.1.2 allocate_block()

```
uint16_t allocate_block ( )
```

Allocates a free block in the FAT.

Returns

block number of the allocated block, or 0 if no free blocks available

Allocates a free block in the FAT.

If no block found, we try compacting the directory.

Definition at line 166 of file fs_helpers.c.

```
{
  for (int i = 2; i < fat_size / 2; i++) {
    if (fat[i] == FAT_FREE) {
      fat[i] = FAT_EOF;
      return i;
    }
  }

  if (compact_directory() == 0) {
    for (int i = 2; i < fat_size / 2; i++) {
      if (fat[i] == FAT_FREE) {
        fat[i] = FAT_EOF;
        return i;
      }
    }
  }

  return 0;
}
```

4.4.1.3 compact_directory()

`int compact_directory ( )`

Compacts the root directory by removing all deleted entries.

Returns

0 on success, -1 on error

Compacts the root directory by removing all deleted entries.

Definition at line 699 of file fs_helpers.c.

```
{
  if (!is_mounted) {
    P_ERRNO = P_EFS_NOT_MOUNTED;
    return -1;
  }

  // buffer for temp storage of a block
  uint8_t* dir_buffer = malloc(block_size);
  if (!dir_buffer) {
    P_ERRNO = P_EMALLOC;
    return -1;
  }

  // start at root directory
  uint16_t current_block = 1;
  int dir_entries_count = 0;
  int deleted_entries_count = 0;

  // calculate number of entries and deleted entries in the root directory
  while (current_block != FAT_EOF) {
    if (lseek(fs_fd, fat_size + (current_block - 1) * block_size, SEEK_SET) ==
        -1) {
      P_ERRNO = P_ELSEEK;
      free(dir_buffer);
      return -1;
    }

    if (read(fs_fd, dir_buffer, block_size) != block_size) {
```

```
      P_ERRNO = P_EREAD;
      free(dir_buffer);
      return -1;
    }

    // count entries and deleted entries in this block
    for (int offset = 0; offset < block_size; offset += sizeof(dir_entry_t)) {
      dir_entry_t* entry = (dir_entry_t*)(dir_buffer + offset);

      // check if we've reached the end of directory
      if (entry->name[0] == 0) {
        break;
      }

      dir_entries_count++;

      // check if it's a deleted entry
      if (entry->name[0] == 1) {
        deleted_entries_count++;
      }
    }

    // move onto next block, if there is one
    if (fat[current_block] != FAT_EOF) {
      current_block = fat[current_block];
    } else {
      break;
    }
  }

  // if no deleted entries, no compaction needed
  if (deleted_entries_count == 0) {
    free(dir_buffer);
    return 0;
  }

  // allocate space for all valid entries
  dir_entry_t* all_entries = malloc(dir_entries_count * sizeof(dir_entry_t));
  if (!all_entries) {
    P_ERRNO = P_EMALLOC;
    free(dir_buffer);
    return -1;
  }

  // read all entries into the buffer, skipping deleted ones
  current_block = 1;
  int valid_entry_idx = 0;

  while (current_block != FAT_EOF) {
    if (lseek(fs_fd, fat_size + (current_block - 1) * block_size, SEEK_SET) ==
        -1) {
      P_ERRNO = P_ELSEEK;
      free(dir_buffer);
      free(all_entries);
      return -1;
    }

    if (read(fs_fd, dir_buffer, block_size) != block_size) {
      P_ERRNO = P_EREAD;
      free(dir_buffer);
      free(all_entries);
      return -1;
    }

    // process entries in this block
    for (int offset = 0; offset < block_size; offset += sizeof(dir_entry_t)) {
      dir_entry_t* entry = (dir_entry_t*)(dir_buffer + offset);

      // check if we've reached the end of directory
      if (entry->name[0] == 0) {
        break;
      }

      // skip deleted entries
      if (entry->name[0] == 1) {
        continue;
      }

      // copy valid entry to our array
      memcpy(&all_entries[valid_entry_idx++], entry, sizeof(dir_entry_t));
    }

    // move to the next block
    if (fat[current_block] != FAT_EOF) {
      current_block = fat[current_block];
    } else {
      break;
```

```
    }
  }

  // rewrite the directory with only valid entries
  current_block = 1;
  int entries_per_block = block_size / sizeof(dir_entry_t);
  int blocks_needed =
      (valid_entry_idx + entries_per_block - 1) / entries_per_block;

  // clean up any excess directory blocks in the FAT chain
  uint16_t next_block = fat[current_block];
  if (blocks_needed == 1) {
    // only need one block, free all others
    while (next_block != FAT_EOF) {
      uint16_t temp = fat[next_block];
      fat[next_block] = FAT_FREE;
      next_block = temp;
    }
    fat[current_block] = FAT_EOF;
  } else {
    // navigate through needed blocks
    int block_count = 1;
    uint16_t prev_block = current_block;

    while (block_count < blocks_needed) {
      if (next_block == FAT_EOF) {
        // need to allocate a new block
        uint16_t new_block = allocate_block();
        if (new_block == 0) {
          P_ERRNO = P_EFULL;
          free(dir_buffer);
          free(all_entries);
          return -1;
        }
        fat[prev_block] = new_block;
        next_block = new_block;
      }

      prev_block = next_block;
      next_block = fat[next_block];
      block_count++;
    }

    // free any excess blocks
    fat[prev_block] = FAT_EOF;
    while (next_block != FAT_EOF) {
      uint16_t temp = fat[next_block];
      fat[next_block] = FAT_FREE;
      next_block = temp;
    }
  }

  // write the valid entries back to the directory blocks
  current_block = 1;
  int entries_written = 0;

  while (entries_written < valid_entry_idx) {
    if (lseek(fs_fd, fat_size + (current_block - 1) * block_size, SEEK_SET) ==
        -1) {
      P_ERRNO = P_ELSEEK;
      free(dir_buffer);
      free(all_entries);
      return -1;
    }

    memset(dir_buffer, 0, block_size);

    // copy entries to the buffer
    int entries_in_this_block = 0;
    while (entries_written < valid_entry_idx &&
           entries_in_this_block < entries_per_block) {
      memcpy(dir_buffer + (entries_in_this_block * sizeof(dir_entry_t)),
             &all_entries[entries_written], sizeof(dir_entry_t));
      entries_written++;
      entries_in_this_block++;
    }

    // write the buffer to the file system
    if (write(fs_fd, dir_buffer, block_size) != block_size) {
      P_ERRNO = P_EINVAL;
      free(dir_buffer);
      free(all_entries);
      return -1;
    }

    // move to the next block if needed
    if (entries_written < valid_entry_idx) {
```

```
      current_block = fat[current_block];
    }
  }

  free(dir_buffer);
  free(all_entries);
  return 0;
}
```

4.4.1.4 copy_host_to_pennfat()

```
int copy_host_to_pennfat (
            const char * host_filename,
            const char * pennfat_filename )
```

Copies a file from the host OS to the PennFAT filesystem.

Parameters

host_filename	path to the file on the host OS
pennfat_filename	name to give the file in PennFAT

Returns

0 on success, -1 on error

Copies a file from the host OS to the PennFAT filesystem.

Definition at line 438 of file fs_helpers.c.

```
                                                        {
  if (!is_mounted) {
    P_ERRNO = P_EFS_NOT_MOUNTED;
    return -1;
  }

  // open the host file
  int host_fd = open(host_filename, O_RDONLY);
  if (host_fd == -1) {
    P_ERRNO = P_EOPEN;
    return -1;
  }

  // determine file size by seeking to the end and getting position
  off_t host_file_size_in_bytes = lseek(host_fd, 0, SEEK_END);
  if (host_file_size_in_bytes == -1) {
    P_ERRNO = P_ELSEEK;
    close(host_fd);
    return -1;
  }

  // go back to beginning of file for reading
  if (lseek(host_fd, 0, SEEK_SET) == -1) {
    P_ERRNO = P_ELSEEK;
    close(host_fd);
    return -1;
  }

  // open the destination file in PennFAT
  int pennfat_fd = k_open(pennfat_filename, F_WRITE);
  if (pennfat_fd < 0) {
    close(host_fd);
    return -1;
  }

  // copy the data into this buffer
  uint8_t* buffer = (uint8_t*)malloc(block_size);
  if (!buffer) {
```

```
    P_ERRNO = P_EMALLOC;
    k_close(pennfat_fd);
    close(host_fd);
    return -1;
  }

  uint32_t bytes_remaining = host_file_size_in_bytes;
  ssize_t bytes_read;

  // read from host file
  while (bytes_remaining > 0) {
    // ensure bytes to read never exceeds the block size
    ssize_t bytes_to_read =
        bytes_remaining < block_size ? bytes_remaining : block_size;
    bytes_read = read(host_fd, buffer, bytes_to_read);

    if (bytes_read <= 0) {
      break;
    }

    // write to pennfat_fd using k_write
    if (k_write(pennfat_fd, (const char*)buffer, bytes_read) != bytes_read) {
      free(buffer);
      k_close(pennfat_fd);
      close(host_fd);
      return -1;
    }

    bytes_remaining -= bytes_read;
  }

  // check for read error
  if (bytes_read < 0) {
    P_ERRNO = P_EREAD;
    free(buffer);
    k_close(pennfat_fd);
    close(host_fd);
    return -1;
  }

  // otherwise, cleanup and return success
  free(buffer);
  k_close(pennfat_fd);
  close(host_fd);
  return 0;
}
```

4.4.1.5 copy_pennfat_to_host()

```
int copy_pennfat_to_host (
              const char * pennfat_filename,
              const char * host_filename )
```

Copies a file from the PennFAT filesystem to the host OS.

Parameters

pennfat_filename	name of the file in PennFAT
host_filename	path to save the file on the host OS

Returns

0 on success, -1 on error

Copies a file from the PennFAT filesystem to the host OS.

Definition at line 527 of file fs_helpers.c.

```
                                                         {
  if (!is_mounted) {
    P_ERRNO = P_EFS_NOT_MOUNTED;
    return -1;
  }

  // open the PennFAT file
  int pennfat_fd = k_open(pennfat_filename, F_READ);
  if (pennfat_fd < 0) {
    return -1;
  }

  // get the pennfat file size
  off_t pennfat_file_size_in_bytes = k_lseek(pennfat_fd, 0, SEEK_END);
  if (pennfat_file_size_in_bytes == -1) {
    k_close(pennfat_fd);
    return -1;
  }

  // go back to beginning of file for reading
  if (k_lseek(pennfat_fd, 0, SEEK_SET) == -1) {
    k_close(pennfat_fd);
    return -1;
  }

  // open the host file
  int host_fd = open(host_filename, O_WRONLY | O_CREAT | O_TRUNC, 0644);
  if (host_fd == -1) {
    P_ERRNO = P_EOPEN;
    k_close(pennfat_fd);
    return -1;
  }

  // allocate buffer for data transfer
  char* buffer = (char*)malloc(block_size);
  if (!buffer) {
    P_ERRNO = P_EMALLOC;
    k_close(pennfat_fd);
    close(host_fd);
    return -1;
  }

  uint32_t bytes_remaining = pennfat_file_size_in_bytes;
  ssize_t bytes_read;

  // read from PennFAT file and write to host file
  while (bytes_remaining > 0) {
    // ensure bytes to read never exceeds the block size
    ssize_t bytes_to_read =
        bytes_remaining < block_size ? bytes_remaining : block_size;
    bytes_read = k_read(pennfat_fd, buffer, bytes_to_read);

    if (bytes_read <= 0) {
      break;
    }

    if (write(host_fd, buffer, bytes_read) != bytes_read) {
      P_ERRNO = P_EINVAL;
      free(buffer);
      close(host_fd);
      k_close(pennfat_fd);
      return -1;
    }

    bytes_remaining -= bytes_read;
  }

  // check for read error
  if (bytes_read < 0) {
    P_ERRNO = P_EREAD;
    free(buffer);
    close(host_fd);
    k_close(pennfat_fd);
    return -1;
  }

  // otherwise, cleanup and return success
  free(buffer);
  close(host_fd);
  k_close(pennfat_fd);
  return 0;
}
```

4.4.1.6 copy_source_to_dest()

```
int copy_source_to_dest (
            const char * source_filename,
            const char * dest_filename )
```

Copies a file from a source file to a destination file.

Parameters

source_filename	name of the source filename
dest_filename	name of the destination filename

Returns

0 on success, -1 on error

Copies a file from a source file to a destination file.

Definition at line 614 of file fs_helpers.c.

```
                                                  {
  if (!is_mounted) {
    P_ERRNO = P_EFS_NOT_MOUNTED;
    return -1;
  }

  // open the source file
  int source_fd = k_open(source_filename, F_READ);
  if (source_fd < 0) {
    return -1;
  }

  // get the source file size
  off_t source_file_size_in_bytes = k_lseek(source_fd, 0, SEEK_END);
  if (source_file_size_in_bytes == -1) {
    k_close(source_fd);
    return -1;
  }

  // move to the beginning of the source file for reading
  if (k_lseek(source_fd, 0, SEEK_SET) < 0) {
    k_close(source_fd);
    return -1;
  }

  // open the destination file
  int dest_fd = k_open(dest_filename, F_WRITE);
  if (dest_fd < 0) {
    k_close(source_fd);
    return -1;
  }

  // read from source to destination
  char* buffer = (char*)malloc(block_size);
  if (!buffer) {
    P_ERRNO = P_EMALLOC;
    k_close(source_fd);
    k_close(dest_fd);
    return -1;
  }

  uint32_t bytes_remaining = source_file_size_in_bytes;
  ssize_t bytes_read;

  while (bytes_remaining > 0) {
    // make sure the bytes to read doesn't exceed block size
    ssize_t bytes_to_read =
        bytes_remaining < block_size ? bytes_remaining : block_size;
    bytes_read = k_read(source_fd, buffer, bytes_to_read);

    if (bytes_read <= 0) {
      break;
    }

```

```
    if (k_write(dest_fd, buffer, bytes_read) != bytes_read) {
      free(buffer);
      k_close(source_fd);
      k_close(dest_fd);
      return -1;
    }
  }

  // check for read error
  if (bytes_read < 0) {
    free(buffer);
    k_close(source_fd);
    k_close(dest_fd);
    return -1;
  }

  // otherwise, cleanup and return success
  free(buffer);
  k_close(source_fd);
  k_close(dest_fd);
  return 0;
}
```

4.4.1.7 decrement_fd_ref_count()

```
int decrement_fd_ref_count (
        int fd )
```

Decrements the reference count of a file descriptor.

Parameters

fd	file descriptor to decrement

Returns

new reference count, or -1 on error

If reference count reaches 0, flush field values.

Definition at line 107 of file fs_helpers.c.

```
107                                      {
108   if (fd < 0 || fd >= MAX_FDS) {
109     P_ERRNO = P_EBADF;
110     return -1;
111   }
112
113   if (!fd_table[fd].in_use) {
114     P_ERRNO = P_EBADF;
115     return -1;
116   }
117
118   fd_table[fd].ref_count--;
119   if (fd_table[fd].ref_count == 0) {
120     fd_table[fd].in_use = 0;
121     memset(fd_table[fd].filename, 0, sizeof(fd_table[fd].filename));
122     fd_table[fd].size = 0;
123     fd_table[fd].first_block = 0;
124     fd_table[fd].position = 0;
125     fd_table[fd].mode = 0;
126   }
127   return fd_table[fd].ref_count;
128 }
```

4.4.1.8 find_file()

```
int find_file (
            const char * filename,
            dir_entry_t * entry )
```

Searches for a file in the root directory.

Parameters

filename	name of the file to find
entry	pointer to store the directory entry if found

Returns

offset of the entry in the directory if found, -1 if not found

Retrieves the file's absolute offset in the filesystem.

Definition at line 191 of file fs_helpers.c.

```
191                                                             {
192   if (!is_mounted) {
193     P_ERRNO = P_EFS_NOT_MOUNTED;
194     return -1;
195   }
196
197   // Start with root directory block (block 1)
198   uint16_t current_block = 1;
199   int offset_in_block = 0;
200   int absolute_offset = 0;
201   dir_entry_t dir_entry;
202
203   while (1) {
204     // Position at the start of current block
205     if (lseek(fs_fd, fat_size + (current_block - 1) * block_size, SEEK_SET) ==
206         -1) {
207       P_ERRNO = P_ELSEEK;
208       return -1;
209     }
210
211     // reset offset for new block
212     offset_in_block = 0;
213
214     // calculate the absolute offset
215     absolute_offset = fat_size + (current_block - 1) * block_size;
216
217     // search current block
218     while (offset_in_block < block_size) {
219       if (read(fs_fd, &dir_entry, sizeof(dir_entry)) != sizeof(dir_entry)) {
220         P_ERRNO = P_EREAD;
221         return -1;
222       }
223
224       // check if we've reached the end of directory
225       if (dir_entry.name[0] == 0) {
226         break;
227       }
228
229       // check if this is a deleted entry
230       if (dir_entry.name[0] == 1 || dir_entry.name[0] == 2) {
231         offset_in_block += sizeof(dir_entry);
232         absolute_offset += sizeof(dir_entry);
233         continue;
234       }
235
236       // check if we found the file
237       if (strcmp(dir_entry.name, filename) == 0) {
238         if (entry) {
239           memcpy(entry, &dir_entry, sizeof(dir_entry));
240         }
241         return absolute_offset;  // return the absolute file offset
242       }
243
244       offset_in_block += sizeof(dir_entry);
```

```
      absolute_offset += sizeof(dir_entry);
    }

    // if we've reached the end of the current block, check if there's a next
    // block
    if (fat[current_block] != FAT_EOF) {
      current_block = fat[current_block];
      continue;
    }

    // no more blocks to search
    break;
  }

  // file not found
  P_ERRNO = P_ENOENT;
  return -1;
}
```

4.4.1.9 get_free_fd()

```
int get_free_fd (
              fd_entry_t * fd_table )
```

Finds the first available file descriptor in the table.

Parameters

fd_table	pointer to the file descriptor table to search

Returns

index of the first free file descriptor, or -1 if none available

Finds the first available file descriptor in the table.

Definition at line 77 of file fs_helpers.c.

```
77                                        {
78   for (int i = 3; i < MAX_FDS; i++) {
79     if (!fd_table[i].in_use) {
80       return i;
81     }
82   }
83   return -1;
84 }
```

4.4.1.10 has_executable_permission()

```
int has_executable_permission (
              int fd )
```

Checks if a file has executable permissions in the PennFAT filesystem.

Parameters

fd	The fd of the file to check.

Returns

1 if the file has executable permissions, 0 if it doesn't, -1 if an error occurred.

Checks if a file has executable permissions in the PennFAT filesystem.

Definition at line 133 of file fs_helpers.c.

```
133                                        {
134   // check if fs is mounted
135   if (!is_mounted) {
136     P_ERRNO = P_EFS_NOT_MOUNTED;
137     return -1;
138   }
139
140   // validate fd argument
141   if (fd < 0 || fd >= MAX_FDS) {
142     P_ERRNO = P_EINVAL;
143     return -1;
144   }
145
146   // determine whether the file exists
147   dir_entry_t entry;
148   int entry_offset = find_file(fd_table[fd].filename, &entry);
149   if (entry_offset < 0) {
150     return -1;
151   }
152
153   // if it exists, get its permission
154   if (entry.perm & PERM_EXEC) {
155     return 1;
156   }
157
158   return 0;
159 }
```

4.4.1.11 increment_fd_ref_count()

```
int increment_fd_ref_count (
              int fd )
```

Increments the reference count of a file descriptor.

Parameters

fd	file descriptor to increment

Returns

new reference count, or -1 on error

Definition at line 89 of file fs_helpers.c.

```
89                                        {
90   if (fd < 0 || fd >= MAX_FDS) {
91     P_ERRNO = P_EBADF;
92     return -1;
93   }
94   if (!fd_table[fd].in_use) {
95     P_ERRNO = P_EBADF;
96     return -1;
97   }
98   fd_table[fd].ref_count++;
99   return fd_table[fd].ref_count;
100 }
```

4.4.1.12 init_fd_table()

```
void init_fd_table (
            fd_entry_t * fd_table )
```

Initializes all entries in the file descriptor table to not in use.

Parameters

fd_table	pointer to the file descriptor table to initialize

Initializes all entries in the file descriptor table to not in use.

Definition at line 43 of file fs_helpers.c.

```
43                                            {
44    // STDIN (fd 0)
45    fd_table[0].in_use = 1;
46    fd_table[0].ref_count = 1;
47    strncpy(fd_table[0].filename, "<stdin>", 31);
48    fd_table[0].mode = F_READ;
49
50    // STDOUT (fd 1)
51    fd_table[1].in_use = 1;
52    strncpy(fd_table[1].filename, "<stdout>", 31);
53    fd_table[1].mode = F_WRITE;  // write-only
54    fd_table[1].ref_count = 1;
55
56    // STDERR (fd 2)
57    fd_table[2].in_use = 1;
58    strncpy(fd_table[2].filename, "<stderr>", 31);
59    fd_table[2].mode = F_WRITE;  // write-only
60    fd_table[2].ref_count = 1;
61
62    // other file descriptors (fd 3 and above)
63    for (int i = 3; i < MAX_FDS; i++) {
64      fd_table[i].in_use = 0;
65      fd_table[i].ref_count = 0;
66      memset(fd_table[i].filename, 0, sizeof(fd_table[i].filename));
67      fd_table[i].size = 0;
68      fd_table[i].first_block = 0;
69      fd_table[i].position = 0;
70      fd_table[i].mode = 0;
71    }
72 }
```

4.4.1.13 mark_entry_as_deleted()

```
int mark_entry_as_deleted (
            dir_entry_t * entry,
            int absolute_offset )
```

Marks a file entry as deleted and frees its blocks in the FAT.

This function takes a directory entry and its offset in the directory, marks it as deleted in the directory, and frees all blocks in its FAT chain.

Parameters

entry	the entry struct of the file to mark as deleted.
offset	the offset of the entry in the directory

Returns

0 on success, -1 on error

Marks a file entry as deleted and frees its blocks in the FAT.

Definition at line 399 of file fs_helpers.c.

```
399                                                                          {
400   if (!is_mounted || entry == NULL || absolute_offset < 0) {
401     P_ERRNO = P_EINVAL;
402     return -1;
403   }
404 
405   // free the blocks
406   uint16_t current_block = entry->firstBlock;
407   while (current_block != FAT_FREE && current_block != FAT_EOF) {
408     uint16_t next_block = fat[current_block];
409     fat[current_block] = FAT_FREE;
410     current_block = next_block;
411   }
412 
413   // mark the entry as deleted in the root directory
414   dir_entry_t deleted_entry = *entry;
415   deleted_entry.name[0] = 1;
416   if (lseek(fs_fd, absolute_offset, SEEK_SET) == -1) {
417     P_ERRNO = P_ELSEEK;
418     return -1;
419   }
420   if (write(fs_fd, &deleted_entry, sizeof(deleted_entry)) !=
421       sizeof(deleted_entry)) {
422     P_ERRNO = P_EINVAL;
423     return -1;
424   }
425 
426   // mark the passed entry as deleted
427   entry->name[0] = 1;
428   return 0;
429 }
```

4.4.2 Variable Documentation

4.4.2.1 block_size

```
int block_size [extern]
```

Definition at line 28 of file fs_helpers.c.

4.4.2.2 fat

```
uint16_t* fat [extern]
```

Definition at line 31 of file fs_helpers.c.

4.4.2.3 fat_size

```
int fat_size [extern]
```

Definition at line 30 of file fs_helpers.c.

4.4.2.4 fd_table

```
fd_entry_t fd_table[100] [extern]
```

Definition at line 34 of file fs_helpers.c.

4.4.2.5 fs_fd

```
int fs_fd [extern]
```

Definition at line 27 of file fs_helpers.c.

4.4.2.6 is_mounted

```
bool is_mounted [extern]
```

Definition at line 32 of file fs_helpers.c.

4.4.2.7 MAX_FDS

```
int MAX_FDS [extern]
```

Definition at line 33 of file fs_helpers.c.

4.4.2.8 num_fat_blocks

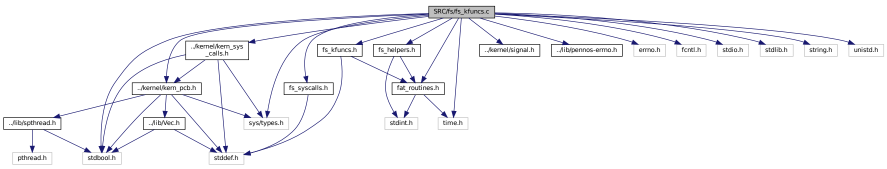
```
int num_fat_blocks [extern]
```

Definition at line 29 of file fs_helpers.c.

4.5 SRC/fs/fs_kfuncs.c File Reference

```
#include "fs_kfuncs.h"
#include "../kernel/kern_pcb.h"
#include "../kernel/kern_sys_calls.h"
#include "../kernel/signal.h"
#include "../lib/pennos-errno.h"
#include "fat_routines.h"
#include "fs_helpers.h"
#include "fs_syscalls.h"
#include <errno.h>
#include <fcntl.h>
#include <stdbool.h>
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <sys/types.h>
#include <time.h>
#include <unistd.h>
```

Include dependency graph for fs_kfuncs.c:



Functions

- int k_open (const char ∗fname, int mode)

  Kernel-level call to open a file.
- int k_read (int fd, char ∗buf, int n)

  Kernel-level call to read a file.
- int k_write (int fd, const char ∗str, int n)

  Kernel-level call to write to a file.
- int k_close (int fd)

  Kernel-level call to close a file.
- int k_unlink (const char ∗fname)

  Kernel-level call to remove a file.
- int k_lseek (int fd, int offset, int whence)

  Kernel-level call to re-position a file offset.
- int k_ls (const char ∗filename)

  Kernel-level call to list files.

Variables

- pcb_t ∗ current_running_pcb
- pid_t current_fg_pid

4.5.1 Function Documentation

4.5.1.1 k_close()

```
int k_close (
        int fd )
```

Kernel-level call to close a file.

Closes an open file.

Definition at line 526 of file fs_kfuncs.c.

```
526                          {
527   // validate the file descriptor
528   if (fd < 0 || fd >= MAX_FDS) {
529     P_ERRNO = P_EBADF;
530     return -1;
531   }
532
533   // ensure any pending changes are written to disk
534   // update the directory entry with the current file size
535   dir_entry_t entry;
536   int file_offset = find_file(fd_table[fd].filename, &entry);
537
538   if (file_offset >= 0) {
539     // update file size if it changed
540     if (entry.size != fd_table[fd].size) {
541       entry.size = fd_table[fd].size;
542       entry.mtime = time(NULL);
543
544       if (lseek(fs_fd, file_offset, SEEK_SET) == -1) {
545         P_ERRNO = P_ELSEEK;
546         return -1;
547       }
548       if (write(fs_fd, &entry, sizeof(entry)) != sizeof(entry)) {
549         P_ERRNO = P_EWRITE;
550         return -1;
551       }
552     }
553   }
554
555   // decrement the reference count
556   decrement_fd_ref_count(fd);
557
558   return 0;
559 }
```

4.5.1.2 k_ls()

```
int k_ls (
        const char * filename )
```

Kernel-level call to list files.

Lists files or file information.

Definition at line 666 of file fs_kfuncs.c.

```
666                                     {
667   if (!is_mounted) {
668     P_ERRNO = P_EFS_NOT_MOUNTED;
669     return -1;
670   }
671
672   // start with root directory block
673   uint16_t current_block = 1;
```

```
    dir_entry_t dir_entry;
    uint32_t offset = 0;

    // if filename is null, list all files in the current directory
    if (filename == NULL) {
      while (1) {
        // adjust pointer to beginning of current block
        if (lseek(fs_fd, fat_size + (current_block - 1) * block_size, SEEK_SET) ==
            -1) {
          P_ERRNO = P_ELSEEK;
          return -1;
        }

        offset = 0;

        // search current block
        while (offset < block_size) {
          if (read(fs_fd, &dir_entry, sizeof(dir_entry)) != sizeof(dir_entry)) {
            P_ERRNO = P_EREAD;
            return -1;
          }

          // check if we've reached the end of directory
          if (dir_entry.name[0] == 0) {
            break;
          }

          // skip deleted entries
          if (dir_entry.name[0] == 1 || dir_entry.name[0] == 2) {
            offset += sizeof(dir_entry);
            continue;
          }

          // format permission string
          char perm_str[4] = "---";
          if (dir_entry.perm & PERM_READ)
            perm_str[0] = 'r';
          if (dir_entry.perm & PERM_WRITE)
            perm_str[1] = 'w';
          if (dir_entry.perm & PERM_EXEC)
            perm_str[2] = 'x';

          // format time
          struct tm* tm_info = localtime(&dir_entry.mtime);
          char time_str[50];
          strftime(time_str, sizeof(time_str), "%b %d %H:%M:%S %Y", tm_info);

          // print entry details
          char buffer[128];
          int len;
          if (dir_entry.firstBlock == 0) {
            len = snprintf(buffer, sizeof(buffer), "   -%s- %6d %s %s\n",
                           perm_str, dir_entry.size, time_str, dir_entry.name);
          } else {
            len = snprintf(buffer, sizeof(buffer), "%2d -%s- %6d %s %s\n",
                           dir_entry.firstBlock, perm_str, dir_entry.size,
                           time_str, dir_entry.name);
          }

          if (len < 0 || len >= (int)sizeof(buffer)) {
            P_ERRNO = P_EUNKNOWN;
            return -1;
          }

          if (k_write(STDOUT_FILENO, buffer, len) != len) {
            P_ERRNO = P_EWRITE;
            return -1;
          }

          offset += sizeof(dir_entry);
        }

        // move to the next block if there is one
        if (fat[current_block] != FAT_EOF) {
          current_block = fat[current_block];
          continue;
        }

        // no more blocks to search
        break;
      }
    } else {
      // find and display specific file
      int file_offset = find_file(filename, &dir_entry);
      if (file_offset < 0) {
        P_ERRNO = P_ENOENT;
        return -1;
```

```
    }

    if (dir_entry.name[0] == 0) {
      P_ERRNO = P_ENOENT;
      return -1;
    }

    // skip deleted entries
    if (dir_entry.name[0] == 1 || dir_entry.name[0] == 2) {
      P_ERRNO = P_ENOENT;
      return -1;
    }

    // format permission string
    char perm_str[4] = "---";
    if (dir_entry.perm & PERM_READ)
      perm_str[0] = 'r';
    if (dir_entry.perm & PERM_WRITE)
      perm_str[1] = 'w';
    if (dir_entry.perm & PERM_EXEC)
      perm_str[2] = 'x';

    // format time
    struct tm* tm_info = localtime(&dir_entry.mtime);
    char time_str[50];
    strftime(time_str, sizeof(time_str), "%b %d %H:%M:%S %Y", tm_info);

    // print entry details
    char buffer[128];
    int len;
    if (dir_entry.firstBlock == 0) {
      len = snprintf(buffer, sizeof(buffer), "   -%s- %6d %s %s\n", perm_str,
                     dir_entry.size, time_str, dir_entry.name);
    } else {
      len = snprintf(buffer, sizeof(buffer), "%2d -%s- %6d %s %s\n",
                     dir_entry.firstBlock, perm_str, dir_entry.size, time_str,
                     dir_entry.name);
    }

    if (len < 0 || len >= (int)sizeof(buffer)) {
      P_ERRNO = P_EUNKNOWN;
      return -1;
    }

    if (k_write(STDOUT_FILENO, buffer, len) != len) {
      P_ERRNO = P_EWRITE;
      return -1;
    }
  }

  return 0;
}
```

4.5.1.3 k_lseek()

```
int k_lseek (
        int fd,
        int offset,
        int whence )
```

Kernel-level call to re-position a file offset.

Repositions the file offset of an open file.

Definition at line 620 of file fs_kfuncs.c.

```
620                                             {
621   // standard file descriptors don't support lseek
622   if (fd == STDIN_FILENO || fd == STDOUT_FILENO || fd == STDERR_FILENO) {
623     P_ERRNO = P_EINVAL;
624     return -1;
625   }
626 
627   // validate the file descriptor
628   if (fd < 0 || fd >= MAX_FDS || !fd_table[fd].in_use) {
629     P_ERRNO = P_EBADF;
```

```
    return -1;
  }

  // calculate new position based on whence
  int32_t new_position;

  switch (whence) {
    case SEEK_SET:
      new_position = offset;
      break;
    case SEEK_CUR:
      new_position = fd_table[fd].position + offset;
      break;
    case SEEK_END:
      new_position = fd_table[fd].size + offset;
      break;
    default:
      P_ERRNO = P_EINVAL;
      return -1;
  }

  // check if new position is valid
  if (new_position < 0) {
    P_ERRNO = P_EINVAL;
    return -1;
  }

  // update file position
  fd_table[fd].position = new_position;

  return new_position;
}
```

4.5.1.4 k_open()

```
int k_open (
        const char * fname,
        int mode )
```

Kernel-level call to open a file.

Opens a file with the specified mode.

Definition at line 31 of file fs_kfuncs.c.

```
31                                              {
32   // validate arguments
33   if (fname == NULL || *fname == '\0') {
34     P_ERRNO = P_EINVAL;
35     return -1;
36   }
37   if ((mode & (F_READ | F_WRITE | F_APPEND)) == 0) {
38     P_ERRNO = P_EINVAL;
39     return -1;
40   }
41 
42   // check if the file system is mounted
43   if (!is_mounted) {
44     P_ERRNO = P_EFS_NOT_MOUNTED;
45     return -1;
46   }
47 
48   // get a free file descriptor
49   int fd = get_free_fd(fd_table);
50   if (fd < 0) {
51     P_ERRNO = P_EFULL;  // no free file descriptors
52     return -1;
53   }
54 
55   // check if the file exists
56   dir_entry_t entry;
57   int file_offset = find_file(fname, &entry);
58 
59   // file exists
60   if (file_offset >= 0) {
61     // check if the file is already open in write mode by another descriptor
62     if ((mode & (F_WRITE | F_APPEND)) != 0) {
```

```
     for (int i = 0; i < MAX_FDS; i++) {
       if (i != fd && fd_table[i].in_use &&
           strcmp(fd_table[i].filename, fname) == 0 &&
           (fd_table[i].mode & (F_WRITE | F_APPEND)) != 0) {
         P_ERRNO = P_EBUSY;  // file is already open for writing
         return -1;
       }
     }
   }

   // fill in the file descriptor entry
   fd_table[fd].in_use = 1;
   fd_table[fd].ref_count++;
   strncpy(fd_table[fd].filename, fname, 31);
   fd_table[fd].filename[31] = '\0';
   fd_table[fd].size = entry.size;
   fd_table[fd].first_block = entry.firstBlock;
   fd_table[fd].mode = mode;

   // set the initial position
   if (mode & F_APPEND) {
     fd_table[fd].position = entry.size;
   } else {
     fd_table[fd].position = 0;
   }

   // if mode includes F_WRITE and not F_APPEND, truncate the file
   if ((mode & F_WRITE) && !(mode & F_APPEND)) {
     // free all blocks except the first one
     uint16_t block = entry.firstBlock;
     uint16_t next_block;

     if (block != 0 && block != FAT_EOF) {
       next_block = fat[block];
       fat[block] = FAT_EOF;  // terminate the chain at the first block
       block = next_block;

        // free the rest of the chain
        while (block != 0 && block != FAT_EOF) {
          next_block = fat[block];
          fat[block] = FAT_FREE;
          block = next_block;
        }
      }

      // update file size to 0
      fd_table[fd].size = 0;
      entry.size = 0;
      entry.mtime = time(NULL);

      // update the file system with the truncated file
      if (lseek(fs_fd, file_offset, SEEK_SET) == -1) {
        P_ERRNO = P_ELSEEK;
        return -1;
      }
      if (write(fs_fd, &entry, sizeof(entry)) != sizeof(entry)) {
        P_ERRNO = P_EWRITE;
        return -1;
      }
    }
  } else {
    // file doesn't exist

    // we can only create it if we are reading the file
    if (!(mode & F_WRITE)) {
      P_ERRNO = P_ENOENT;
      return -1;
    }

    // allocate the first block
    uint16_t first_block = allocate_block();
    if (first_block == 0) {
      P_ERRNO = P_EFULL;
      return -1;
    }

    // create a new file entry
    if (add_file_entry(fname, 0, first_block, TYPE_REGULAR, PERM_READ_WRITE) ==
        -1) {
      // error code already set by add_file_entry
      fat[first_block] = FAT_FREE;
      return -1;
    }

    // fill in the file descriptor entry
    fd_table[fd].in_use = 1;
    fd_table[fd].ref_count++;
```

```
    strncpy(fd_table[fd].filename, fname, 31);
    fd_table[fd].filename[31] = '\0';
    fd_table[fd].size = 0;
    fd_table[fd].first_block = first_block;
    fd_table[fd].position = 0;
    fd_table[fd].mode = mode;
  }

  return fd;
}
```

4.5.1.5 k_read()

```
int k_read (
            int fd,
            char * buf,
            int n )
```

Kernel-level call to read a file.

Reads data from an open file.

Definition at line 164 of file fs_kfuncs.c.

```
164                                        {
165   // handle terminal control (if doesn't control, send a STOP signal)
166   if (fd == STDIN_FILENO && current_running_pcb != NULL) {
167     if (current_running_pcb->pid != current_fg_pid) {
168       s_kill(current_running_pcb->pid, P_SIGSTOP);
169     }
170   }
171
172   // handle standard input
173   if (fd == STDIN_FILENO) {
174     return read(STDIN_FILENO, buf, n);
175   }
176
177   // validate inputs
178   if (fd < 0 || fd >= MAX_FDS || !fd_table[fd].in_use) {
179     P_ERRNO = P_EBADF;
180     return -1;
181   }
182   if (buf == NULL || n < 0) {
183     P_ERRNO = P_EINVAL;
184     return -1;
185   }
186   if (n == 0) {
187     return 0;
188   }
189
190   // check if we're at EOF already
191   if (fd_table[fd].position >= fd_table[fd].size) {
192     return 0;
193   }
194
195   // determine how many bytes we can actually read
196   uint32_t bytes_to_read = n;
197   if (fd_table[fd].position + bytes_to_read > fd_table[fd].size) {
198     bytes_to_read = fd_table[fd].size - fd_table[fd].position;
199   }
200
201   // find the block containing the current position
202   uint16_t current_block = fd_table[fd].first_block;
203   uint32_t block_index = fd_table[fd].position / block_size;
204   uint32_t block_offset = fd_table[fd].position % block_size;
205
206   // navigate to the correct block in the chain
207   for (uint32_t i = 0; i < block_index; i++) {
208     if (current_block == 0 || current_block == FAT_EOF) {
209       // unexpected end of chain
210       P_ERRNO = P_EINVAL;
211       return -1;
212     }
213     current_block = fat[current_block];
214   }
215
```

```
  // now we're at the right block, start reading
  uint32_t bytes_read = 0;

  while (bytes_read < bytes_to_read) {
    // how much data can we read from the current block
    uint32_t bytes_left_in_block = block_size - block_offset;
    uint32_t bytes_to_read_now =
        (bytes_to_read - bytes_read) < bytes_left_in_block
            ? (bytes_to_read - bytes_read)
            : bytes_left_in_block;

    // seek to the right position in the file
    if (lseek(fs_fd, fat_size + (current_block - 1) * block_size + block_offset,
              SEEK_SET) == -1) {
      P_ERRNO = P_ELSEEK;
      if (bytes_read > 0) {
        fd_table[fd].position += bytes_read;
        return bytes_read;
      }
      return -1;
    }

    // read the data from the file
    ssize_t read_result = read(fs_fd, buf + bytes_read, bytes_to_read_now);
    if (read_result <= 0) {
      P_ERRNO = P_EREAD;
      // if we already read some data, return that count
      if (bytes_read > 0) {
        fd_table[fd].position += bytes_read;
        return bytes_read;
      }
      return -1;
    }

    bytes_read += read_result;
    block_offset += read_result;

    // if we've read all data from this block and still have more to read, go to
    // the next block
    if (block_offset == block_size && bytes_read < bytes_to_read) {
      if (current_block == FAT_EOF) {
        // unexpected end of chain
        break;
      }
      current_block = fat[current_block];
      block_offset = 0;
    }

    // if we read less than expected, we might have hit EOF
    if (read_result < bytes_to_read_now) {
      break;
    }
  }

  // update file position
  fd_table[fd].position += bytes_read;

  return bytes_read;
}
```

4.5.1.6 k_unlink()

```
int k_unlink (
            const char * fname )
```

Kernel-level call to remove a file.

Removes a file from the file system.

Definition at line 564 of file fs_kfuncs.c.

```
564                                     {
565   if (fname == NULL || *fname == '\0') {
566     P_ERRNO = P_EINVAL;
567     return -1;
568   }
569
```

```
  if (!is_mounted) {
    P_ERRNO = P_EFS_NOT_MOUNTED;
    return -1;
  }

  // check if file is currently open by any process
  for (int i = 0; i < MAX_FDS; i++) {
    if (fd_table[i].in_use && strcmp(fd_table[i].filename, fname) == 0) {
      P_ERRNO = P_EBUSY;
      return -1;
    }
  }

  // find the file in directory
  dir_entry_t entry;
  int file_offset = find_file(fname, &entry);
  if (file_offset < 0) {
    P_ERRNO = P_ENOENT;
    return -1;
  }

  // mark the directory entry as deleted (set first byte to 1)
  entry.name[0] = 1;

  // write the modified directory entry back
  if (lseek(fs_fd, file_offset, SEEK_SET) == -1) {
    P_ERRNO = P_ELSEEK;
    return -1;
  }
  if (write(fs_fd, &entry, sizeof(entry)) != sizeof(entry)) {
    P_ERRNO = P_EWRITE;
    return -1;
  }

  // free all blocks in the file chain
  uint16_t current_block = entry.firstBlock;
  uint16_t next_block;

  while (current_block != FAT_FREE && current_block != FAT_EOF) {
    next_block = fat[current_block];
    fat[current_block] = FAT_FREE;
    current_block = next_block;
  }

  return 0;
}
```

4.5.1.7 k_write()

```
int k_write (
        int fd,
        const char * str,
        int n )
```

Kernel-level call to write to a file.

Writes data to an open file.

Definition at line 279 of file fs_kfuncs.c.

```
279                                                 {
280   // handle standard output and error
281   if (fd == STDOUT_FILENO) {
282     return write(STDOUT_FILENO, str, n);
283   }
284   if (fd == STDERR_FILENO) {
285     return write(STDERR_FILENO, str, n);
286   }
287
288   // validate inputs
289   if (fd < 0 || fd >= MAX_FDS || !fd_table[fd].in_use) {
290     P_ERRNO = P_EBADF;
291     return -1;
292   }
293   if (str == NULL || n < 0) {
294     P_ERRNO = P_EINVAL;
```

```
    return -1;
  }
  if (n == 0) {
    return 0;
  }

  // check if filesystem is mounted and FAT is valid
  if (!is_mounted || fat == NULL) {
    P_ERRNO = P_EFS_NOT_MOUNTED;
    return -1;
  }

  // get file information
  uint16_t current_block = fd_table[fd].first_block;
  uint32_t current_position = fd_table[fd].position;

  // create a local buffer for block data
  char* block_buffer = (char*)malloc(block_size);
  if (block_buffer == NULL) {
    P_ERRNO = P_EMALLOC;
    return -1;
  }

  // calculate initial block position
  uint32_t block_index = current_position / block_size;
  uint32_t block_offset = current_position % block_size;

  // if the file doesn't have a first block yet, allocate one
  if (current_block == 0) {
    current_block = allocate_block();
    if (current_block == 0) {
      P_ERRNO = P_EFULL;
      free(block_buffer);
      return -1;
    }
    fd_table[fd].first_block = current_block;
  }

  // navigate to the appropriate block
  uint16_t prev_block = 0;
  for (uint32_t i = 0; i < block_index; i++) {
    if (current_block == 0 || current_block == FAT_EOF ||
        current_block >= fat_size / 2) {
      // reached the end of chain prematurely, need to allocate a new block
      uint16_t new_block = allocate_block();
      if (new_block == 0) {
        P_ERRNO = P_EFULL;
        free(block_buffer);
        return -1;
      }

      // update the chain
      if (prev_block != 0 && prev_block < fat_size / 2) {
        fat[prev_block] = new_block;
      } else {
        // if there's no previous block, this must be the first one
        fd_table[fd].first_block = new_block;
      }

      current_block = new_block;
    }

    prev_block = current_block;

    // validate the block number before accessing FAT
    if (current_block >= fat_size / 2) {
      P_ERRNO = P_EINVAL;
      free(block_buffer);
      return -1;
    }

    current_block = fat[current_block];
  }

  // if we ended up without a valid block, go back to the last valid one
  if (current_block == 0 || current_block == FAT_EOF ||
      current_block >= fat_size / 2) {
    if (prev_block != 0 && prev_block < fat_size / 2) {
      uint16_t new_block = allocate_block();
      if (new_block == 0) {
        P_ERRNO = P_EFULL;
        free(block_buffer);
        return -1;
      }

      fat[prev_block] = new_block;
      current_block = new_block;
```

```
    } else {
      P_ERRNO = P_EINVAL;
      free(block_buffer);
      return -1;
    }
  }

  // start writing data
  uint32_t bytes_written = 0;

  while (bytes_written < n) {
    // validate current block
    if (current_block == 0 || current_block == FAT_EOF ||
        current_block >= fat_size / 2) {
      P_ERRNO = P_EINVAL;
      break;
    }

    // how much can we write to this block
    uint32_t space_in_block = block_size - block_offset;
    uint32_t bytes_to_write = (n - bytes_written) < space_in_block
                                  ? (n - bytes_written)
                                  : space_in_block;

    // position in filesystem
    off_t block_position = fat_size + (current_block - 1) * block_size;

    // if we're not writing a full block or not starting at the beginning, we
    // need to read-modify-write
    if (bytes_to_write < block_size || block_offset > 0) {
      // read the current block
      if (lseek(fs_fd, block_position, SEEK_SET) == -1) {
        P_ERRNO = P_ELSEEK;
        break;
      }

      // read the current block data
      ssize_t read_result = read(fs_fd, block_buffer, block_size);
      if (read_result < 0) {
        P_ERRNO = P_EREAD;
        break;
      }

      // copy the new data into the block buffer
      memcpy(block_buffer + block_offset, str + bytes_written, bytes_to_write);

      // seek back to write the modified block
      if (lseek(fs_fd, block_position, SEEK_SET) == -1) {
        P_ERRNO = P_ELSEEK;
        break;
      }

      // write the full block back
      ssize_t write_result = write(fs_fd, block_buffer, block_size);
      if (write_result != block_size) {
        P_ERRNO = P_EWRITE;
        // we might have a partial write, but that's hard to handle correctly
        break;
      }
    } else {
      // we're writing a full block from the beginning
      if (lseek(fs_fd, block_position, SEEK_SET) == -1) {
        P_ERRNO = P_ELSEEK;
        break;
      }

      ssize_t write_result = write(fs_fd, str + bytes_written, bytes_to_write);
      if (write_result != bytes_to_write) {
        P_ERRNO = P_EWRITE;
        break;
      }
    }

    // update counters
    bytes_written += bytes_to_write;
    block_offset = (block_offset + bytes_to_write) % block_size;

    // if we've filled this block and still have more to write, go to the next
    // block
    if (block_offset == 0 && bytes_written < n) {
      // validate current block before accessing FAT
      if (current_block >= fat_size / 2) {
        P_ERRNO = P_EINVAL;
        break;
      }

      // check if there's a next block
```

```
      if (fat[current_block] == FAT_EOF) {
        // allocate a new block
        uint16_t new_block = allocate_block();
        if (new_block == 0) {
          P_ERRNO = P_EFULL;
          break;
        }

        // Update the FAT safely
        if (current_block < fat_size / 2) {
          fat[current_block] = new_block;
        } else {
          P_ERRNO = P_EINVAL;
          break;
        }

        current_block = new_block;
      } else {
        current_block = fat[current_block];
      }
    }
  }

  // free the block buffer
  free(block_buffer);

  // update file position
  fd_table[fd].position += bytes_written;

  // update file size if needed
  if (fd_table[fd].position > fd_table[fd].size) {
    fd_table[fd].size = fd_table[fd].position;

    // update the directory entry
    dir_entry_t entry;
    int dir_offset = find_file(fd_table[fd].filename, &entry);
    if (dir_offset >= 0) {
      entry.size = fd_table[fd].size;
      entry.mtime = time(NULL);

      if (lseek(fs_fd, dir_offset, SEEK_SET) == -1) {
        P_ERRNO = P_ELSEEK;
        return -1;
      }
      if (write(fs_fd, &entry, sizeof(entry)) != sizeof(entry)) {
        P_ERRNO = P_EWRITE;
        return -1;
      }
    }
  }

  return bytes_written;
}
```

4.5.2 Variable Documentation

4.5.2.1 current_fg_pid

```
pid_t current_fg_pid [extern]
```

Definition at line 31 of file kern_sys_calls.c.

4.5.2.2 current_running_pcb

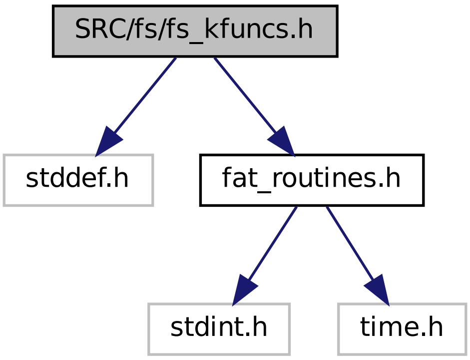
```
pcb_t* current_running_pcb [extern]
```

Definition at line 38 of file scheduler.c.

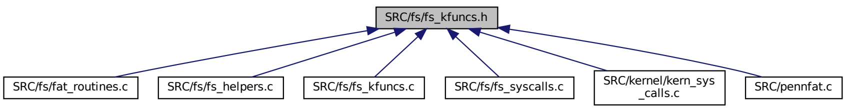
4.6 SRC/fs/fs_kfuncs.h File Reference

```
#include <stddef.h>
#include "fat_routines.h"
```

Include dependency graph for fs_kfuncs.h:



This graph shows which files directly or indirectly include this file:



Macros

- #define SEEK_SET 0
- #define SEEK_CUR 1
- #define SEEK_END 2

Functions

- int k_open (const char ∗fname, int mode)

  Opens a file with the specified mode.
- int k_read (int fd, char ∗buf, int n)

  Reads data from an open file.
- int k_write (int fd, const char ∗str, int n)

  Writes data to an open file.
- int k_close (int fd)

  Closes an open file.
- int k_unlink (const char ∗fname)

Removes a file from the file system.

- int k_lseek (int fd, int offset, int whence)

  Repositions the file offset of an open file.

- int k_ls (const char *filename)

  Lists files or file information.

4.6.1 Macro Definition Documentation

4.6.1.1 SEEK_CUR

```
#define SEEK_CUR 1
```

Definition at line 17 of file fs_kfuncs.h.

4.6.1.2 SEEK_END

```
#define SEEK_END 2
```

Definition at line 18 of file fs_kfuncs.h.

4.6.1.3 SEEK_SET

```
#define SEEK_SET 0
```

Definition at line 16 of file fs_kfuncs.h.

4.6.2 Function Documentation

4.6.2.1 k_close()

```
int k_close (
            int fd )
```

Closes an open file.

This is a kernel-level function that closes an open file and releases the associated file descriptor. Any unsaved changes are flushed to disk.

Parameters

fd	File descriptor of the open file.

Returns

0 on success, -1 on error with P_ERRNO set. Possible error codes:

- P_EBADF: Invalid file descriptor.

Closes an open file.

Definition at line 526 of file fs_kfuncs.c.

```
526                       {
527   // validate the file descriptor
528   if (fd < 0 || fd >= MAX_FDS) {
529     P_ERRNO = P_EBADF;
530     return -1;
531   }
532
533   // ensure any pending changes are written to disk
534   // update the directory entry with the current file size
535   dir_entry_t entry;
536   int file_offset = find_file(fd_table[fd].filename, &entry);
537
538   if (file_offset >= 0) {
539     // update file size if it changed
540     if (entry.size != fd_table[fd].size) {
541       entry.size = fd_table[fd].size;
542       entry.mtime = time(NULL);
543
544       if (lseek(fs_fd, file_offset, SEEK_SET) == -1) {
545         P_ERRNO = P_ELSEEK;
546         return -1;
547       }
548       if (write(fs_fd, &entry, sizeof(entry)) != sizeof(entry)) {
549         P_ERRNO = P_EWRITE;
550         return -1;
551       }
552     }
553   }
554
555   // decrement the reference count
556   decrement_fd_ref_count(fd);
557
558   return 0;
559 }
```

4.6.2.2 k_ls()

```
int k_ls (
            const char * filename )
```

Lists files or file information.

This is a kernel-level function that provides directory listing functionality. If filename is NULL or refers to a directory, it lists all files in that directory. If filename refers to a specific file, it displays detailed information about that file.

Parameters

filename	The name of the file or directory to list, or NULL for the current directory.

Returns

0 on success, -1 on error with P_ERRNO set. Possible error codes:

- P_ENOENT: Specified file or directory doesn't exist.

Lists files or file information.

Definition at line 666 of file fs_kfuncs.c.

```
666                              {
667   if (!is_mounted) {
668     P_ERRNO = P_EFS_NOT_MOUNTED;
669     return -1;
670   }
671 
672   // start with root directory block
673   uint16_t current_block = 1;
674   dir_entry_t dir_entry;
675   uint32_t offset = 0;
676 
677   // if filename is null, list all files in the current directory
678   if (filename == NULL) {
679     while (1) {
680       // adjust pointer to beginning of current block
681       if (lseek(fs_fd, fat_size + (current_block - 1) * block_size, SEEK_SET) ==
682           -1) {
683         P_ERRNO = P_ELSEEK;
684         return -1;
685       }
686 
687       offset = 0;
688 
689       // search current block
690       while (offset < block_size) {
691         if (read(fs_fd, &dir_entry, sizeof(dir_entry)) != sizeof(dir_entry)) {
692           P_ERRNO = P_EREAD;
693           return -1;
694         }
695 
696         // check if we've reached the end of directory
697         if (dir_entry.name[0] == 0) {
698           break;
699         }
700 
701         // skip deleted entries
702         if (dir_entry.name[0] == 1 || dir_entry.name[0] == 2) {
703           offset += sizeof(dir_entry);
704           continue;
705         }
706 
707         // format permission string
708         char perm_str[4] = "---";
709         if (dir_entry.perm & PERM_READ)
710           perm_str[0] = 'r';
711         if (dir_entry.perm & PERM_WRITE)
712           perm_str[1] = 'w';
713         if (dir_entry.perm & PERM_EXEC)
714           perm_str[2] = 'x';
715 
716         // format time
717         struct tm* tm_info = localtime(&dir_entry.mtime);
718         char time_str[50];
719         strftime(time_str, sizeof(time_str), "%b %d %H:%M:%S %Y", tm_info);
720 
721         // print entry details
722         char buffer[128];
723         int len;
724         if (dir_entry.firstBlock == 0) {
725           len = snprintf(buffer, sizeof(buffer), "   -%s- %6d %s %s\n",
726                          perm_str, dir_entry.size, time_str, dir_entry.name);
727         } else {
728           len = snprintf(buffer, sizeof(buffer), "%2d -%s- %6d %s %s\n",
729                          dir_entry.firstBlock, perm_str, dir_entry.size,
730                          time_str, dir_entry.name);
731         }
732 
733         if (len < 0 || len >= (int)sizeof(buffer)) {
734           P_ERRNO = P_EUNKNOWN;
735           return -1;
736         }
737 
738         if (k_write(STDOUT_FILENO, buffer, len) != len) {
739           P_ERRNO = P_EWRITE;
740           return -1;
```

```
        }

        offset += sizeof(dir_entry);
      }

      // move to the next block if there is one
      if (fat[current_block] != FAT_EOF) {
        current_block = fat[current_block];
        continue;
      }

      // no more blocks to search
      break;
    }
  } else {
    // find and display specific file
    int file_offset = find_file(filename, &dir_entry);
    if (file_offset < 0) {
      P_ERRNO = P_ENOENT;
      return -1;
    }

    if (dir_entry.name[0] == 0) {
      P_ERRNO = P_ENOENT;
      return -1;
    }

    // skip deleted entries
    if (dir_entry.name[0] == 1 || dir_entry.name[0] == 2) {
      P_ERRNO = P_ENOENT;
      return -1;
    }

    // format permission string
    char perm_str[4] = "---";
    if (dir_entry.perm & PERM_READ)
      perm_str[0] = 'r';
    if (dir_entry.perm & PERM_WRITE)
      perm_str[1] = 'w';
    if (dir_entry.perm & PERM_EXEC)
      perm_str[2] = 'x';

    // format time
    struct tm* tm_info = localtime(&dir_entry.mtime);
    char time_str[50];
    strftime(time_str, sizeof(time_str), "%b %d %H:%M:%S %Y", tm_info);

    // print entry details
    char buffer[128];
    int len;
    if (dir_entry.firstBlock == 0) {
      len = snprintf(buffer, sizeof(buffer), "   -%s- %6d %s %s\n", perm_str,
                     dir_entry.size, time_str, dir_entry.name);
    } else {
      len = snprintf(buffer, sizeof(buffer), "%2d -%s- %6d %s %s\n",
                     dir_entry.firstBlock, perm_str, dir_entry.size, time_str,
                     dir_entry.name);
    }

    if (len < 0 || len >= (int)sizeof(buffer)) {
      P_ERRNO = P_EUNKNOWN;
      return -1;
    }

    if (k_write(STDOUT_FILENO, buffer, len) != len) {
      P_ERRNO = P_EWRITE;
      return -1;
    }
  }

  return 0;
}
```

4.6.2.3 k_lseek()

```
int k_lseek (
        int fd,
        int offset,
        int whence )
```

Repositions the file offset of an open file.

This is a kernel-level function that changes the current position within an open file. The interpretation of the offset depends on the whence parameter.

Parameters

fd	File descriptor of the open file.
offset	The offset in bytes to set the position to.
whence	How to interpret the offset: • SEEK_SET (0): Offset is from the beginning of the file. • SEEK_CUR (1): Offset is from the current position. • SEEK_END (2): Offset is from the end of the file.

Returns

The new offset location on success, -1 on error with P_ERRNO set. Possible error codes:

- P_EBADF: Invalid file descriptor.
- P_EINVAL: Invalid whence or the resulting position would be negative.

Repositions the file offset of an open file.

Definition at line 620 of file fs_kfuncs.c.

```
620                                             {
621   // standard file descriptors don't support lseek
622   if (fd == STDIN_FILENO || fd == STDOUT_FILENO || fd == STDERR_FILENO) {
623     P_ERRNO = P_EINVAL;
624     return -1;
625   }
626
627   // validate the file descriptor
628   if (fd < 0 || fd >= MAX_FDS || !fd_table[fd].in_use) {
629     P_ERRNO = P_EBADF;
630     return -1;
631   }
632
633   // calculate new position based on whence
634   int32_t new_position;
635
636   switch (whence) {
637     case SEEK_SET:
638       new_position = offset;
639       break;
640     case SEEK_CUR:
641       new_position = fd_table[fd].position + offset;
642       break;
643     case SEEK_END:
644       new_position = fd_table[fd].size + offset;
645       break;
646     default:
647       P_ERRNO = P_EINVAL;
648       return -1;
649   }
650
651   // check if new position is valid
652   if (new_position < 0) {
653     P_ERRNO = P_EINVAL;
654     return -1;
655   }
656
657   // update file position
658   fd_table[fd].position = new_position;
659
660   return new_position;
661 }
```

4.6.2.4 k_open()

```
int k_open (
            const char * fname,
            int mode )
```

Opens a file with the specified mode.

This is a kernel-level function that opens a file and returns a file descriptor. The file is created if it doesn't exist and the mode includes F_WRITE. If the file exists and F_APPEND is specified, the file position is set to the end.

Parameters

fname	The name of the file to open.
mode	A combination of F_READ, F_WRITE, and F_APPEND.

Returns

A non-negative file descriptor on success, -1 on error with P_ERRNO set. Possible error codes:

- P_ENOENT: File doesn't exist and F_READ only.
- P_EFULL: Cannot create file (file system full).
- P_EINVAL: Invalid mode or filename.

Opens a file with the specified mode.

Definition at line 31 of file fs_kfuncs.c.

```
31                                           {
32   // validate arguments
33   if (fname == NULL || *fname == '\0') {
34     P_ERRNO = P_EINVAL;
35     return -1;
36   }
37   if ((mode & (F_READ | F_WRITE | F_APPEND)) == 0) {
38     P_ERRNO = P_EINVAL;
39     return -1;
40   }
41 
42   // check if the file system is mounted
43   if (!is_mounted) {
44     P_ERRNO = P_EFS_NOT_MOUNTED;
45     return -1;
46   }
47 
48   // get a free file descriptor
49   int fd = get_free_fd(fd_table);
50   if (fd < 0) {
51     P_ERRNO = P_EFULL;  // no free file descriptors
52     return -1;
53   }
54 
55   // check if the file exists
56   dir_entry_t entry;
57   int file_offset = find_file(fname, &entry);
58 
59   // file exists
60   if (file_offset >= 0) {
61     // check if the file is already open in write mode by another descriptor
62     if ((mode & (F_WRITE | F_APPEND)) != 0) {
63       for (int i = 0; i < MAX_FDS; i++) {
64         if (i != fd && fd_table[i].in_use &&
65             strcmp(fd_table[i].filename, fname) == 0 &&
66             (fd_table[i].mode & (F_WRITE | F_APPEND)) != 0) {
67           P_ERRNO = P_EBUSY;  // file is already open for writing
68           return -1;
69         }
70       }
71     }
72 
73     // fill in the file descriptor entry
```

```
   fd_table[fd].in_use = 1;
   fd_table[fd].ref_count++;
   strncpy(fd_table[fd].filename, fname, 31);
   fd_table[fd].filename[31] = '\0';
   fd_table[fd].size = entry.size;
   fd_table[fd].first_block = entry.firstBlock;
   fd_table[fd].mode = mode;

   // set the initial position
   if (mode & F_APPEND) {
     fd_table[fd].position = entry.size;
   } else {
     fd_table[fd].position = 0;
   }

   // if mode includes F_WRITE and not F_APPEND, truncate the file
   if ((mode & F_WRITE) && !(mode & F_APPEND)) {
     // free all blocks except the first one
     uint16_t block = entry.firstBlock;
     uint16_t next_block;

     if (block != 0 && block != FAT_EOF) {
       next_block = fat[block];
       fat[block] = FAT_EOF;  // terminate the chain at the first block
       block = next_block;

        // free the rest of the chain
        while (block != 0 && block != FAT_EOF) {
          next_block = fat[block];
          fat[block] = FAT_FREE;
          block = next_block;
        }
      }

      // update file size to 0
      fd_table[fd].size = 0;
      entry.size = 0;
      entry.mtime = time(NULL);

      // update the file system with the truncated file
      if (lseek(fs_fd, file_offset, SEEK_SET) == -1) {
        P_ERRNO = P_ELSEEK;
        return -1;
      }
      if (write(fs_fd, &entry, sizeof(entry)) != sizeof(entry)) {
        P_ERRNO = P_EWRITE;
        return -1;
      }
    }
  } else {
    // file doesn't exist

    // we can only create it if we are reading the file
    if (!(mode & F_WRITE)) {
      P_ERRNO = P_ENOENT;
      return -1;
    }

    // allocate the first block
    uint16_t first_block = allocate_block();
    if (first_block == 0) {
      P_ERRNO = P_EFULL;
      return -1;
    }

    // create a new file entry
    if (add_file_entry(fname, 0, first_block, TYPE_REGULAR, PERM_READ_WRITE) ==
        -1) {
      // error code already set by add_file_entry
      fat[first_block] = FAT_FREE;
      return -1;
    }

    // fill in the file descriptor entry
    fd_table[fd].in_use = 1;
    fd_table[fd].ref_count++;
    strncpy(fd_table[fd].filename, fname, 31);
    fd_table[fd].filename[31] = '\0';
    fd_table[fd].size = 0;
    fd_table[fd].first_block = first_block;
    fd_table[fd].position = 0;
    fd_table[fd].mode = mode;
  }

  return fd;
}
```

4.6.2.5 k_read()

```
int k_read (
            int fd,
            char * buf,
            int n )
```

Reads data from an open file.

This is a kernel-level function that reads up to n bytes from an open file into the provided buffer. The file position is advanced by the number of bytes read.

Parameters

fd	File descriptor of the open file.
buf	Buffer to store the read data.
n	Maximum number of bytes to read.

Returns

The number of bytes read on success, -1 on error with P_ERRNO set. Possible error codes:

- P_EBADF: Invalid file descriptor.
- P_EINVAL: Invalid buffer or count.

Reads data from an open file.

Definition at line 164 of file fs_kfuncs.c.

```
164                                         {
165   // handle terminal control (if doesn't control, send a STOP signal)
166   if (fd == STDIN_FILENO && current_running_pcb != NULL) {
167     if (current_running_pcb->pid != current_fg_pid) {
168       s_kill(current_running_pcb->pid, P_SIGSTOP);
169     }
170   }
171
172   // handle standard input
173   if (fd == STDIN_FILENO) {
174     return read(STDIN_FILENO, buf, n);
175   }
176
177   // validate inputs
178   if (fd < 0 || fd >= MAX_FDS || !fd_table[fd].in_use) {
179     P_ERRNO = P_EBADF;
180     return -1;
181   }
182   if (buf == NULL || n < 0) {
183     P_ERRNO = P_EINVAL;
184     return -1;
185   }
186   if (n == 0) {
187     return 0;
188   }
189
190   // check if we're at EOF already
191   if (fd_table[fd].position >= fd_table[fd].size) {
192     return 0;
193   }
194
195   // determine how many bytes we can actually read
196   uint32_t bytes_to_read = n;
197   if (fd_table[fd].position + bytes_to_read > fd_table[fd].size) {
198     bytes_to_read = fd_table[fd].size - fd_table[fd].position;
199   }
```

```

  // find the block containing the current position
  uint16_t current_block = fd_table[fd].first_block;
  uint32_t block_index = fd_table[fd].position / block_size;
  uint32_t block_offset = fd_table[fd].position % block_size;

  // navigate to the correct block in the chain
  for (uint32_t i = 0; i < block_index; i++) {
    if (current_block == 0 || current_block == FAT_EOF) {
      // unexpected end of chain
      P_ERRNO = P_EINVAL;
      return -1;
    }
    current_block = fat[current_block];
  }

  // now we're at the right block, start reading
  uint32_t bytes_read = 0;

  while (bytes_read < bytes_to_read) {
    // how much data can we read from the current block
    uint32_t bytes_left_in_block = block_size - block_offset;
    uint32_t bytes_to_read_now =
        (bytes_to_read - bytes_read) < bytes_left_in_block
            ? (bytes_to_read - bytes_read)
            : bytes_left_in_block;

    // seek to the right position in the file
    if (lseek(fs_fd, fat_size + (current_block - 1) * block_size + block_offset,
              SEEK_SET) == -1) {
      P_ERRNO = P_ELSEEK;
      if (bytes_read > 0) {
        fd_table[fd].position += bytes_read;
        return bytes_read;
      }
      return -1;
    }

    // read the data from the file
    ssize_t read_result = read(fs_fd, buf + bytes_read, bytes_to_read_now);
    if (read_result <= 0) {
      P_ERRNO = P_EREAD;
      // if we already read some data, return that count
      if (bytes_read > 0) {
        fd_table[fd].position += bytes_read;
        return bytes_read;
      }
      return -1;
    }

    bytes_read += read_result;
    block_offset += read_result;

    // if we've read all data from this block and still have more to read, go to
    // the next block
    if (block_offset == block_size && bytes_read < bytes_to_read) {
      if (current_block == FAT_EOF) {
        // unexpected end of chain
        break;
      }
      current_block = fat[current_block];
      block_offset = 0;
    }

    // if we read less than expected, we might have hit EOF
    if (read_result < bytes_to_read_now) {
      break;
    }
  }

  // update file position
  fd_table[fd].position += bytes_read;

  return bytes_read;
}
```

4.6.2.6 k_unlink()

```
int k_unlink (
        const char * fname )
```

Removes a file from the file system.

This is a kernel-level function that deletes the specified file from the file system. The file must not be open by any process.

Parameters

fname	The name of the file to remove.

Returns

0 on success, -1 on error with P_ERRNO set. Possible error codes:

- P_ENOENT: File doesn't exist.
- P_EBUSY: File is still open by some process.

Removes a file from the file system.

Definition at line 564 of file fs_kfuncs.c.

```
564                                  {
565    if (fname == NULL || *fname == '\0') {
566      P_ERRNO = P_EINVAL;
567      return -1;
568    }
569
570    if (!is_mounted) {
571      P_ERRNO = P_EFS_NOT_MOUNTED;
572      return -1;
573    }
574
575    // check if file is currently open by any process
576    for (int i = 0; i < MAX_FDS; i++) {
577      if (fd_table[i].in_use && strcmp(fd_table[i].filename, fname) == 0) {
578        P_ERRNO = P_EBUSY;
579        return -1;
580      }
581    }
582
583    // find the file in directory
584    dir_entry_t entry;
585    int file_offset = find_file(fname, &entry);
586    if (file_offset < 0) {
587      P_ERRNO = P_ENOENT;
588      return -1;
589    }
590
591    // mark the directory entry as deleted (set first byte to 1)
592    entry.name[0] = 1;
593
594    // write the modified directory entry back
595    if (lseek(fs_fd, file_offset, SEEK_SET) == -1) {
596      P_ERRNO = P_ELSEEK;
597      return -1;
598    }
599    if (write(fs_fd, &entry, sizeof(entry)) != sizeof(entry)) {
600      P_ERRNO = P_EWRITE;
601      return -1;
602    }
603
604    // free all blocks in the file chain
605    uint16_t current_block = entry.firstBlock;
606    uint16_t next_block;
607
608    while (current_block != FAT_FREE && current_block != FAT_EOF) {
609      next_block = fat[current_block];
610      fat[current_block] = FAT_FREE;
611      current_block = next_block;
612    }
613
614    return 0;
615 }
```

4.6.2.7 k_write()

```
int k_write (
        int fd,
        const char * str,
        int n )
```

Writes data to an open file.

This is a kernel-level function that writes n bytes from the provided buffer to an open file. The file position is advanced by the number of bytes written. If necessary, the file is extended.

Parameters

fd	File descriptor of the open file.
str	Buffer containing the data to write.
n	Number of bytes to write.

Returns

The number of bytes written on success, -1 on error with P_ERRNO set. Possible error codes:

- P_EBADF: Invalid file descriptor.
- P_EINVAL: Invalid buffer or count.
- P_EFULL: File system is full.

Writes data to an open file.

Definition at line 279 of file fs_kfuncs.c.

```
279                                               {
280     // handle standard output and error
281     if (fd == STDOUT_FILENO) {
282       return write(STDOUT_FILENO, str, n);
283     }
284     if (fd == STDERR_FILENO) {
285       return write(STDERR_FILENO, str, n);
286     }
287
288     // validate inputs
289     if (fd < 0 || fd >= MAX_FDS || !fd_table[fd].in_use) {
290       P_ERRNO = P_EBADF;
291       return -1;
292     }
293     if (str == NULL || n < 0) {
294       P_ERRNO = P_EINVAL;
295       return -1;
296     }
297     if (n == 0) {
298       return 0;
299     }
300
301     // check if filesystem is mounted and FAT is valid
302     if (!is_mounted || fat == NULL) {
303       P_ERRNO = P_EFS_NOT_MOUNTED;
304       return -1;
305     }
306
307     // get file information
308     uint16_t current_block = fd_table[fd].first_block;
309     uint32_t current_position = fd_table[fd].position;
310
311     // create a local buffer for block data
312     char* block_buffer = (char*)malloc(block_size);
313     if (block_buffer == NULL) {
314       P_ERRNO = P_EMALLOC;
315       return -1;
316     }
317
```

```
    // calculate initial block position
    uint32_t block_index = current_position / block_size;
    uint32_t block_offset = current_position % block_size;

    // if the file doesn't have a first block yet, allocate one
    if (current_block == 0) {
      current_block = allocate_block();
      if (current_block == 0) {
        P_ERRNO = P_EFULL;
        free(block_buffer);
        return -1;
      }
      fd_table[fd].first_block = current_block;
    }

    // navigate to the appropriate block
    uint16_t prev_block = 0;
    for (uint32_t i = 0; i < block_index; i++) {
      if (current_block == 0 || current_block == FAT_EOF ||
          current_block >= fat_size / 2) {
        // reached the end of chain prematurely, need to allocate a new block
        uint16_t new_block = allocate_block();
        if (new_block == 0) {
          P_ERRNO = P_EFULL;
          free(block_buffer);
          return -1;
        }

        // update the chain
        if (prev_block != 0 && prev_block < fat_size / 2) {
          fat[prev_block] = new_block;
        } else {
          // if there's no previous block, this must be the first one
          fd_table[fd].first_block = new_block;
        }

        current_block = new_block;
      }

      prev_block = current_block;

      // validate the block number before accessing FAT
      if (current_block >= fat_size / 2) {
        P_ERRNO = P_EINVAL;
        free(block_buffer);
        return -1;
      }

      current_block = fat[current_block];
    }

    // if we ended up without a valid block, go back to the last valid one
    if (current_block == 0 || current_block == FAT_EOF ||
        current_block >= fat_size / 2) {
      if (prev_block != 0 && prev_block < fat_size / 2) {
        uint16_t new_block = allocate_block();
        if (new_block == 0) {
          P_ERRNO = P_EFULL;
          free(block_buffer);
          return -1;
        }

        fat[prev_block] = new_block;
        current_block = new_block;
      } else {
        P_ERRNO = P_EINVAL;
        free(block_buffer);
        return -1;
      }
    }

    // start writing data
    uint32_t bytes_written = 0;

    while (bytes_written < n) {
      // validate current block
      if (current_block == 0 || current_block == FAT_EOF ||
          current_block >= fat_size / 2) {
        P_ERRNO = P_EINVAL;
        break;
      }

      // how much can we write to this block
      uint32_t space_in_block = block_size - block_offset;
      uint32_t bytes_to_write = (n - bytes_written) < space_in_block
                                    ? (n - bytes_written)
                                    : space_in_block;
```

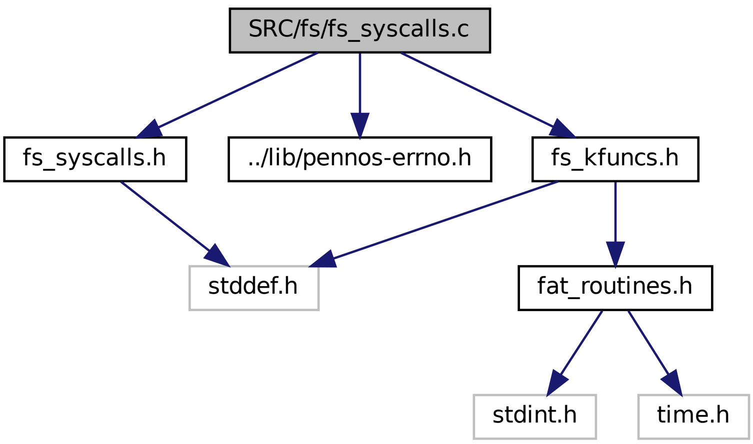
```

    // position in filesystem
    off_t block_position = fat_size + (current_block - 1) * block_size;

    // if we're not writing a full block or not starting at the beginning, we
    // need to read-modify-write
    if (bytes_to_write < block_size || block_offset > 0) {
      // read the current block
      if (lseek(fs_fd, block_position, SEEK_SET) == -1) {
        P_ERRNO = P_ELSEEK;
        break;
      }

      // read the current block data
      ssize_t read_result = read(fs_fd, block_buffer, block_size);
      if (read_result < 0) {
        P_ERRNO = P_EREAD;
        break;
      }

      // copy the new data into the block buffer
      memcpy(block_buffer + block_offset, str + bytes_written, bytes_to_write);

      // seek back to write the modified block
      if (lseek(fs_fd, block_position, SEEK_SET) == -1) {
        P_ERRNO = P_ELSEEK;
        break;
      }

      // write the full block back
      ssize_t write_result = write(fs_fd, block_buffer, block_size);
      if (write_result != block_size) {
        P_ERRNO = P_EWRITE;
        // we might have a partial write, but that's hard to handle correctly
        break;
      }
    } else {
      // we're writing a full block from the beginning
      if (lseek(fs_fd, block_position, SEEK_SET) == -1) {
        P_ERRNO = P_ELSEEK;
        break;
      }

      ssize_t write_result = write(fs_fd, str + bytes_written, bytes_to_write);
      if (write_result != bytes_to_write) {
        P_ERRNO = P_EWRITE;
        break;
      }
    }

    // update counters
    bytes_written += bytes_to_write;
    block_offset = (block_offset + bytes_to_write) % block_size;

    // if we've filled this block and still have more to write, go to the next
    // block
    if (block_offset == 0 && bytes_written < n) {
      // validate current block before accessing FAT
      if (current_block >= fat_size / 2) {
        P_ERRNO = P_EINVAL;
        break;
      }

      // check if there's a next block
      if (fat[current_block] == FAT_EOF) {
        // allocate a new block
        uint16_t new_block = allocate_block();
        if (new_block == 0) {
          P_ERRNO = P_EFULL;
          break;
        }

        // Update the FAT safely
        if (current_block < fat_size / 2) {
          fat[current_block] = new_block;
        } else {
          P_ERRNO = P_EINVAL;
          break;
        }

        current_block = new_block;
      } else {
        current_block = fat[current_block];
      }
    }
  }

```

```
    // free the block buffer
    free(block_buffer);

    // update file position
    fd_table[fd].position += bytes_written;

    // update file size if needed
    if (fd_table[fd].position > fd_table[fd].size) {
      fd_table[fd].size = fd_table[fd].position;

      // update the directory entry
      dir_entry_t entry;
      int dir_offset = find_file(fd_table[fd].filename, &entry);
      if (dir_offset >= 0) {
        entry.size = fd_table[fd].size;
        entry.mtime = time(NULL);

        if (lseek(fs_fd, dir_offset, SEEK_SET) == -1) {
          P_ERRNO = P_ELSEEK;
          return -1;
        }
        if (write(fs_fd, &entry, sizeof(entry)) != sizeof(entry)) {
          P_ERRNO = P_EWRITE;
          return -1;
        }
      }
    }

    return bytes_written;
}
```

4.7 SRC/fs/fs_syscalls.c File Reference

```
#include "fs_syscalls.h"
#include "../lib/pennos-errno.h"
#include "fs_kfuncs.h"
```

Include dependency graph for fs_syscalls.c:



Functions

- int s_open (const char ∗fname, int mode)

    System call to open a file.

- int s_read (int fd, char ∗buf, int n)

    System call to read from a file.
- int s_write (int fd, const char ∗str, int n)

    System call to write to a file.
- int s_close (int fd)

    System call to close a file.
- int s_unlink (const char ∗fname)

    System call to remove a file.
- int s_lseek (int fd, int offset, int whence)

    System call to reposition the file offset.
- int s_ls (const char ∗filename)

    System call to list files.

4.7.1 Function Documentation

4.7.1.1 s_close()

```
int s_close (
            int fd )
```

System call to close a file.

Closes an open file descriptor.

This is a wrapper around the kernel function k_close.

Definition at line 42 of file fs_syscalls.c.

```
42                    {
43   return k_close(fd);
44 }
```

4.7.1.2 s_ls()

```
int s_ls (
            const char * filename )
```

System call to list files.

Lists files in the current directory or displays file information.

This is a wrapper around the kernel function k_ls.

Definition at line 69 of file fs_syscalls.c.

```
69                                {
70   return k_ls(filename);
71 }
```

4.7.1.3 s_lseek()

```
int s_lseek (
        int fd,
        int offset,
        int whence )
```

System call to reposition the file offset.

Repositions the file offset of an open file.

This is a wrapper around the kernel function k_lseek.

Definition at line 60 of file fs_syscalls.c.

```
60                                              {
61    return k_lseek(fd, offset, whence);
62 }
```

4.7.1.4 s_open()

```
int s_open (
        const char * fname,
        int mode )
```

System call to open a file.

Opens a file with the specified access mode.

This is a wrapper around the kernel function k_open.

Definition at line 15 of file fs_syscalls.c.

```
15                                          {
16    return k_open(fname, mode);
17 }
```

4.7.1.5 s_read()

```
int s_read (
        int fd,
        char * buf,
        int n )
```

System call to read from a file.

Reads data from an open file.

This is a wrapper around the kernel function k_read.

Definition at line 24 of file fs_syscalls.c.

```
24                                       {
25    return k_read(fd, buf, n);
26 }
```

4.7.1.6 s_unlink()

```
int s_unlink (
        const char * fname )
```

System call to remove a file.

Removes a file from the file system.

This is a wrapper around the kernel function k_unlink.

Definition at line 51 of file fs_syscalls.c.

```
51                                {
52     return k_unlink(fname);
53 }
```

4.7.1.7 s_write()

```
int s_write (
        int fd,
        const char * str,
        int n )
```

System call to write to a file.

Writes data to an open file.

This is a wrapper around the kernel function k_write.

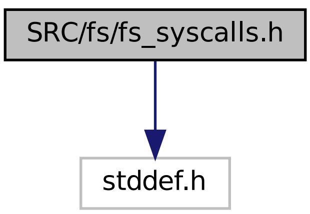
Definition at line 33 of file fs_syscalls.c.

```
33                                           {
34     return k_write(fd, str, n);
35 }
```

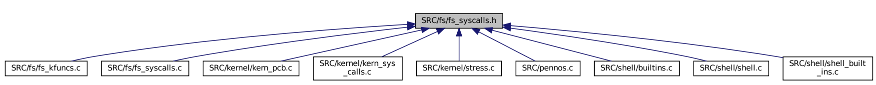
4.8 SRC/fs/fs_syscalls.h File Reference

`#include <stddef.h>`

Include dependency graph for fs_syscalls.h:



This graph shows which files directly or indirectly include this file:



Macros

- #define STDIN_FILENO 0
- #define STDOUT_FILENO 1
- #define STDERR_FILENO 2

Functions

- int s_open (const char ∗fname, int mode)

  Opens a file with the specified access mode.
- int s_read (int fd, char ∗buf, int n)

  Reads data from an open file.
- int s_write (int fd, const char ∗str, int n)

  Writes data to an open file.
- int s_close (int fd)

  Closes an open file descriptor.
- int s_unlink (const char ∗fname)

  Removes a file from the file system.
- int s_lseek (int fd, int offset, int whence)

  Repositions the file offset of an open file.
- int s_ls (const char ∗filename)

  Lists files in the current directory or displays file information.

4.8.1 Macro Definition Documentation

4.8.1.1 STDERR_FILENO

```
#define STDERR_FILENO 2
```

Definition at line 18 of file fs_syscalls.h.

4.8.1.2 STDIN_FILENO

```
#define STDIN_FILENO 0
```

Definition at line 16 of file fs_syscalls.h.

4.8.1.3 STDOUT_FILENO

```
#define STDOUT_FILENO 1
```

Definition at line 17 of file fs_syscalls.h.

4.8.2 Function Documentation

4.8.2.1 s_close()

```
int s_close (
            int fd )
```

Closes an open file descriptor.

This function closes the file descriptor fd, making it available for reuse. If this is the last reference to the underlying file, any necessary cleanup is performed.

Parameters

fd	The file descriptor to close.

Returns

On success, returns 0. On error, returns -1 and sets P_ERRNO appropriately:

- P_EBADF: fd is not a valid file descriptor.

Closes an open file descriptor.

This is a wrapper around the kernel function k_close.

Definition at line 42 of file fs_syscalls.c.

```
42                     {
43   return k_close(fd);
44 }
```

4.8.2.2 s_ls()

```
int s_ls (
            const char * filename )
```

Lists files in the current directory or displays file information.

If filename is NULL, this function lists all files in the current directory. If filename refers to a specific file, it displays detailed information about that file.

Parameters

filename	The name of the file to get information about, or NULL to list all files.

Returns

On success, returns 0. On error, returns -1 and sets P_ERRNO appropriately:

- P_ENOENT: The specified file does not exist.

Lists files in the current directory or displays file information.

This is a wrapper around the kernel function k_ls.

Definition at line 69 of file fs_syscalls.c.
```
69 {
70   return k_ls(filename);
71 }
```

4.8.2.3 s_lseek()

```
int s_lseek (
        int fd,
        int offset,
        int whence )
```

Repositions the file offset of an open file.

This function repositions the offset of the file descriptor fd to the argument offset according to the directive whence.

Parameters

fd	The file descriptor of an open file.
offset	The offset in bytes.
whence	Specifies the reference position: • SEEK_SET (0): The offset is set relative to the start of the file. • SEEK_CUR (1): The offset is set relative to the current position. • SEEK_END (2): The offset is set relative to the end of the file.

Returns

On success, returns the resulting offset from the beginning of the file. On error, returns -1 and sets P_ERRNO appropriately:

- P_EBADF: fd is not a valid file descriptor.
- P_EINVAL: whence is not valid or the resulting offset would be negative.

Repositions the file offset of an open file.

This is a wrapper around the kernel function k_lseek.

Definition at line 60 of file fs_syscalls.c.
```
60 {
61   return k_lseek(fd, offset, whence);
62 }
```

4.8.2.4 s_open()

```
int s_open (
            const char * fname,
            int mode )
```

Opens a file with the specified access mode.

This function provides a user-level interface to the kernel's file open operation. It opens the specified file with the given access mode and returns a file descriptor that can be used in subsequent operations on the file.

Parameters

fname	The name of the file to open.
mode	A combination of F_READ, F_WRITE, and F_APPEND.

Returns

On success, returns a non-negative integer representing the file descriptor. On error, returns -1 and sets P_ERRNO appropriately:

- P_ENOENT: The file does not exist and F_READ was specified.
- P_EINVAL: Invalid parameters (NULL filename or invalid mode).
- P_EFULL: No space left on device or file descriptor table is full.

Opens a file with the specified access mode.

This is a wrapper around the kernel function k_open.

Definition at line 15 of file fs_syscalls.c.

```
15                                   {
16   return k_open(fname, mode);
17 }
```

4.8.2.5 s_read()

```
int s_read (
            int fd,
            char * buf,
            int n )
```

Reads data from an open file.

This function reads up to n bytes from the file associated with the file descriptor fd into the buffer starting at buf. The file offset is advanced by the number of bytes read.

Parameters

fd	The file descriptor of an open file.
n	The maximum number of bytes to read.
buf	The buffer to store the read data.

Returns

On success, returns the number of bytes read (0 indicates end of file). On error, returns -1 and sets P_ERRNO appropriately:

- P_EBADF: fd is not a valid file descriptor or is not open for reading.
- P_EINVAL: Invalid parameters (NULL buffer or negative count).

Reads data from an open file.

This is a wrapper around the kernel function k_read.

Definition at line 24 of file fs_syscalls.c.

```
24                                {
25   return k_read(fd, buf, n);
26 }
```

4.8.2.6 s_unlink()

```
int s_unlink (
            const char * fname )
```

Removes a file from the file system.

This function removes the specified file from the file system. If the file is currently open, the behavior depends on the implementation.

Parameters

fname	The name of the file to remove.

Returns

On success, returns 0. On error, returns -1 and sets P_ERRNO appropriately:

- P_ENOENT: The file does not exist.
- P_EBUSY: The file is currently in use.
- P_EINVAL: Invalid parameter (NULL filename).

Removes a file from the file system.

This is a wrapper around the kernel function k_unlink.

Definition at line 51 of file fs_syscalls.c.

```
51                           {
52   return k_unlink(fname);
53 }
```

4.8.2.7 s_write()

```
int s_write (
            int fd,
            const char * str,
            int n )
```

Writes data to an open file.

This function writes up to n bytes from the buffer starting at str to the file associated with the file descriptor fd. The file offset is advanced by the number of bytes written.

Parameters

fd	The file descriptor of an open file.
str	The buffer containing the data to be written.
n	The number of bytes to write.

Returns

On success, returns the number of bytes written. On error, returns -1 and sets P_ERRNO appropriately:

- P_EBADF: fd is not a valid file descriptor or is not open for writing.
- P_EINVAL: Invalid parameters (NULL buffer or negative count).
- P_EFULL: No space left on device.

Writes data to an open file.

This is a wrapper around the kernel function k_write.

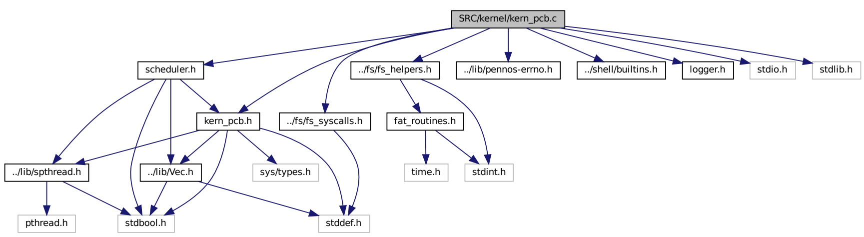
Definition at line 33 of file fs_syscalls.c.

```
33                                    {
34   return k_write(fd, str, n);
35 }
```

4.9 SRC/kernel/kern_pcb.c File Reference

```
#include "kern_pcb.h"
#include "../fs/fs_helpers.h"
#include "../fs/fs_syscalls.h"
#include "../lib/pennos-errno.h"
#include "../shell/builtins.h"
#include "logger.h"
#include "scheduler.h"
#include "stdio.h"
#include "stdlib.h"
```

Include dependency graph for kern_pcb.c:



Functions

- void free_pcb (void *pcb)

  Free resources associated with a PCB.
- pcb_t * create_pcb (pid_t pid, pid_t par_pid, int priority, int input_fd, int output_fd)

  Initializes a PCB with the given parameters.
- void remove_child_in_parent (pcb_t *parent, pcb_t *child)

  Removes a child PCB from its parent's child list.
- pcb_t * k_proc_create (pcb_t *parent, int priority)

  Creates a new process. If the parent is NULL, it creates the init process.
- void k_proc_cleanup (pcb_t *proc)

  Cleans up a process by removing it from its parent's child list, removing its children, decrementing file descriptor reference counts, closing files, and freeing the PCB.

Variables

- int next_pid = 2
- Vec current_pcbs
- pcb_t * current_running_pcb

4.9.1 Function Documentation

4.9.1.1 create_pcb()

```
pcb_t* create_pcb (
            pid_t pid,
            pid_t par_pid,
            int priority,
            int input_fd,
            int output_fd )
```

Initializes a PCB with the given parameters.

Creates a new PCB and initializes its fields. Notably, the thread handle and cmd are left out. It's up to the user to assign them post-call.

Definition at line 42 of file kern_pcb.c.

```
                                    {
  pcb_t* ret_pcb = malloc(sizeof(pcb_t));
  if (ret_pcb == NULL) {
    perror("malloc failed for PCB creation");
    return NULL;
  }

  ret_pcb->pid = pid;
  ret_pcb->par_pid = par_pid;
  ret_pcb->priority = priority;
  ret_pcb->process_state = 'R';  // running by default
  ret_pcb->input_fd = input_fd;
  ret_pcb->output_fd = output_fd;
  ret_pcb->process_status = 0;  // default status

  ret_pcb->child_pcbs = vec_new(0, NULL);  // NULL deconstructor prevents
                                           // double free

  for (int i = 0; i < 3; i++) {
    ret_pcb->signals[i] = false;
  }

  ret_pcb->is_sleeping = false;
  ret_pcb->time_to_wake = -1;  // default to not sleeping

  return ret_pcb;
}
```

4.9.1.2 free_pcb()

```
void free_pcb (
            void * pcb )
```

Free resources associated with a PCB.

Frees all malloced memory associated with the PCB. Note that this will destroy children too, so be careful when using it. In particular, make sure to remove any children pcbs you want to preserve.

Definition at line 30 of file kern_pcb.c.

```
30                       {
31   pcb_t* casted_pcb = (pcb_t*)pcb;
32 
33   free(casted_pcb->cmd_str);
34   vec_destroy(&casted_pcb->child_pcbs);  // will free any remaining
35                                          // children too!
36   free(casted_pcb);
37 }
```

4.9.1.3 k_proc_cleanup()

```
void k_proc_cleanup (
            pcb_t * proc )
```

Cleans up a process by removing it from its parent's child list, removing its children, decrementing file descriptor reference counts, closing files, and freeing the PCB.

Clean up a terminated/finished thread's resources. This may include freeing the PCB, handling children, etc. If a child is orphaned, the INIT process becomes its parent.

Definition at line 152 of file kern_pcb.c.

```
152                                {
153   // if proc has parent (i.e. isn't init) then remove it from parent's child
154   // list
155   pcb_t* par_pcb = get_pcb_in_queue(&current_pcbs, proc->par_pid);
156   if (par_pcb != NULL) {
157     remove_child_in_parent(par_pcb, proc);
158   } else {
159     P_ERRNO = P_ENULL;
160     return;
161   }
162 
163   // if proc has children, remove them and assign them to init parent
164   if (vec_len(&proc->child_pcbs) > 0) {
165     // retrieve the init process
166     pcb_t* init_pcb =
167         get_pcb_in_queue(&current_pcbs, 1);  // init process has pid 1
168 
169     while (vec_len(&proc->child_pcbs) > 0) {
170       pcb_t* curr_child = vec_get(&proc->child_pcbs, 0);
171       vec_push_back(&init_pcb->child_pcbs, curr_child);
172       vec_erase_no_deletor(&proc->child_pcbs, 0);  // don't free in erase
173       curr_child->par_pid = 1;  // update parent to init (pid 1)
174       log_generic_event('O', curr_child->pid, curr_child->priority,
175                         curr_child->cmd_str);
176     }
177   }
178 
179   // decr reference counts + close files if necessary
180   for (int i = 0; i < FILE_DESCRIPTOR_TABLE_SIZE; i++) {
181     if (proc->fd_table[i] != -1) {
182       if (decrement_fd_ref_count(proc->fd_table[i]) == 0) {
183         if (s_close(proc->fd_table[i]) == -1) {
184           u_perror("closing on a non-valid fd");
185         }
186       }
187     }
188   }
189 
```

```
  // cancel + join this thread
  spthread_cancel(proc->thread_handle);
  spthread_continue(proc->thread_handle);
  spthread_suspend(proc->thread_handle);
  spthread_join(proc->thread_handle, NULL);

  // delete this process from any queue it's in + free it
  delete_process_from_all_queues(proc);
  free_pcb(proc);
}
```

4.9.1.4 k_proc_create()

```
pcb_t* k_proc_create (
        pcb_t * parent,
        int priority )
```

Creates a new process. If the parent is NULL, it creates the init process.

Create a new child process, inheriting applicable properties from the parent. Also inserts the created child into the correct scheduler queue based on its priority.

Definition at line 95 of file kern_pcb.c.

```
95                                                     {
96   if (parent == NULL) {  // init creation case
97     pcb_t* init = create_pcb(1, 0, 0, 0, 1);
98     if (init == NULL) {
99       P_ERRNO = P_ENULL;
100      return NULL;
101    }
102    init->fd_table[0] = STDIN_FILENO;
103    init->fd_table[1] = STDOUT_FILENO;
104    init->fd_table[2] = STDERR_FILENO;
105    for (int i = 3; i < FILE_DESCRIPTOR_TABLE_SIZE; i++) {
106      init->fd_table[i] = -1;
107    }
108
109    increment_fd_ref_count(STDIN_FILENO);
110    increment_fd_ref_count(STDOUT_FILENO);
111    increment_fd_ref_count(STDERR_FILENO);
112
113    current_running_pcb = init;
114    put_pcb_into_correct_queue(init);
115    vec_push_back(&current_pcbs, init);
116    return init;
117  }
118
119  pcb_t* child = create_pcb(next_pid++, parent->pid, priority, parent->input_fd,
120                            parent->output_fd);
121  if (child == NULL) {
122    P_ERRNO = P_ENULL;
123    return NULL;
124  }
125
126  // copy parent's fd table
127  for (int i = 0; i < FILE_DESCRIPTOR_TABLE_SIZE; i++) {
128    child->fd_table[i] = parent->fd_table[i];
129  }
130
131  for (int i = 0; i < FILE_DESCRIPTOR_TABLE_SIZE; i++) {
132    if (child->fd_table[i] != -1) {
133      increment_fd_ref_count(child->fd_table[i]);
134    }
135  }
136
137  // update parent as needed
138  vec_push_back(&parent->child_pcbs, child);
139
140  // add to appropriate queue
141  put_pcb_into_correct_queue(child);
142  vec_push_back(&current_pcbs, child);
143
144  return child;
145 }
```

4.9.1.5 remove_child_in_parent()

```
void remove_child_in_parent (
            pcb_t * parent,
            pcb_t * child )
```

Removes a child PCB from its parent's child list.

Given a parent, removes the child from the parent's child vector if its exists. Notably, it does not free the child but simply removes it via the vec_erase_no_deletor function.

Definition at line 77 of file kern_pcb.c.

```
77                                                             {
78   for (int i = 0; i < vec_len(&parent->child_pcbs); i++) {
79     pcb_t* curr_child = (pcb_t*)vec_get(&parent->child_pcbs, i);
80     if (curr_child->pid == child->pid) {
81       vec_erase_no_deletor(&parent->child_pcbs, i);
82       return;
83     }
84   }
85 }
```

4.9.2 Variable Documentation

4.9.2.1 current_pcbs

```
Vec current_pcbs [extern]
```

Definition at line 30 of file scheduler.c.

4.9.2.2 current_running_pcb

```
pcb_t* current_running_pcb [extern]
```

Definition at line 38 of file scheduler.c.

4.9.2.3 next_pid

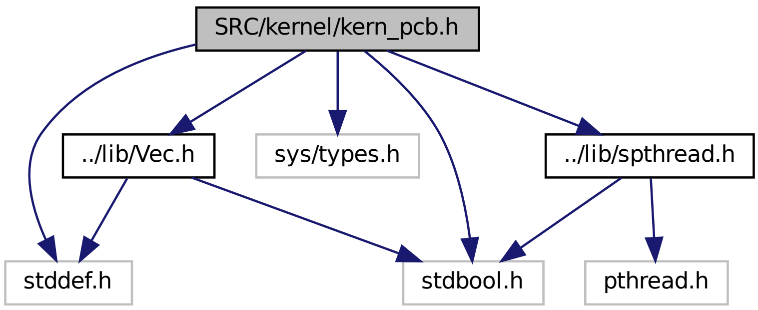
```
int next_pid = 2
```

Definition at line 17 of file kern_pcb.c.

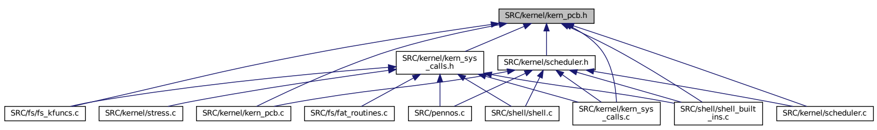
4.10 SRC/kernel/kern_pcb.h File Reference

```
#include <stdbool.h>
#include <stddef.h>
#include <sys/types.h>
#include "../lib/Vec.h"
#include "../lib/spthread.h"
```

Include dependency graph for kern_pcb.h:



This graph shows which files directly or indirectly include this file:



Classes

- struct pcb_st

  The PCB structure, which contains all the information about a process. Notably, it contains the thread handle, pid, parent pid, child pcbs, priority level, process state, command string, signals to be sent, input and output file descriptors, process status, sleeping status, and time to wake.

Macros

- #define FILE_DESCRIPTOR_TABLE_SIZE 100

Typedefs

- typedef struct pcb_st pcb_t

  The PCB structure, which contains all the information about a process. Notably, it contains the thread handle, pid, parent pid, child pcbs, priority level, process state, command string, signals to be sent, input and output file descriptors, process status, sleeping status, and time to wake.

Functions

- pcb_t * create_pcb (pid_t pid, pid_t par_pid, int priority, int input_fd, int output_fd)

  Creates a new PCB and initializes its fields. Notably, the thread handle and cmd are left out. It's up to the user to assign them post-call.
- void free_pcb (void *pcb)

  Frees all malloced memory associated with the PCB. Note that this will destroy children too, so be careful when using it. In particular, make sure to remove any children pcbs you want to preserve.
- void remove_child_in_parent (pcb_t *parent, pcb_t *child)

  Given a parent, removes the child from the parent's child vector if its exists. Notably, it does not free the child but simply removes it via the vec_erase_no_deletor function.
- pcb_t * k_proc_create (pcb_t *parent, int priority)

  Create a new child process, inheriting applicable properties from the parent. Also inserts the created child into the correct scheduler queue based on its priority.
- void k_proc_cleanup (pcb_t *proc)

  Clean up a terminated/finished thread's resources. This may include freeing the PCB, handling children, etc. If a child is orphaned, the INIT process becomes its parent.

4.10.1 Macro Definition Documentation

4.10.1.1 FILE_DESCRIPTOR_TABLE_SIZE

```
#define FILE_DESCRIPTOR_TABLE_SIZE 100
```

Definition at line 16 of file kern_pcb.h.

4.10.2 Typedef Documentation

4.10.2.1 pcb_t

```
typedef struct pcb_st pcb_t
```

The PCB structure, which contains all the information about a process. Notably, it contains the thread handle, pid, parent pid, child pcbs, priority level, process state, command string, signals to be sent, input and output file descriptors, process status, sleeping status, and time to wake.

4.10.3 Function Documentation

4.10.3.1 create_pcb()

```
pcb_t* create_pcb (
            pid_t pid,
            pid_t par_pid,
            int priority,
            int input_fd,
            int output_fd )
```

Creates a new PCB and initializes its fields. Notably, the thread handle and cmd are left out. It's up to the user to assign them post-call.

Parameters

pid	the new process id
par_pid	the parent process id
priority	the priority level (0,1,2)
input_fd	input fd
output_fd	output fd

Returns

pointer to the newly created and malloced PCB or NULL if failure

Creates a new PCB and initializes its fields. Notably, the thread handle and cmd are left out. It's up to the user to assign them post-call.

Definition at line 42 of file kern_pcb.c.

```
                                     {
  pcb_t* ret_pcb = malloc(sizeof(pcb_t));
  if (ret_pcb == NULL) {
    perror("malloc failed for PCB creation");
    return NULL;
  }

  ret_pcb->pid = pid;
  ret_pcb->par_pid = par_pid;
  ret_pcb->priority = priority;
  ret_pcb->process_state = 'R';  // running by default
  ret_pcb->input_fd = input_fd;
  ret_pcb->output_fd = output_fd;
  ret_pcb->process_status = 0;  // default status

  ret_pcb->child_pcbs = vec_new(0, NULL);  // NULL deconstructor prevents
                                           // double free

  for (int i = 0; i < 3; i++) {
    ret_pcb->signals[i] = false;
  }

  ret_pcb->is_sleeping = false;
  ret_pcb->time_to_wake = -1;  // default to not sleeping

  return ret_pcb;
}
```

4.10.3.2 free_pcb()

```
void free_pcb (
        void * pcb )
```

Frees all malloced memory associated with the PCB. Note that this will destroy children too, so be careful when using it. In particular, make sure to remove any children pcbs you want to preserve.

Parameters

pcb	Pointer to the PCB to be freed, NULL if error

Frees all malloced memory associated with the PCB. Note that this will destroy children too, so be careful when using it. In particular, make sure to remove any children pcbs you want to preserve.

Definition at line 30 of file kern_pcb.c.

```
30                      {
31   pcb_t* casted_pcb = (pcb_t*)pcb;
32
33   free(casted_pcb->cmd_str);
34   vec_destroy(&casted_pcb->child_pcbs);  // will free any remaining
35                                          // children too!
36   free(casted_pcb);
37 }
```

4.10.3.3 k_proc_cleanup()

```
void k_proc_cleanup (
            pcb_t * proc )
```

Clean up a terminated/finished thread's resources. This may include freeing the PCB, handling children, etc. If a child is orphaned, the INIT process becomes its parent.

Parameters

proc	a pcb ptr to the terminated/finished thread

Clean up a terminated/finished thread's resources. This may include freeing the PCB, handling children, etc. If a child is orphaned, the INIT process becomes its parent.

Definition at line 152 of file kern_pcb.c.

```
152                                {
153   // if proc has parent (i.e. isn't init) then remove it from parent's child
154   // list
155   pcb_t* par_pcb = get_pcb_in_queue(&current_pcbs, proc->par_pid);
156   if (par_pcb != NULL) {
157     remove_child_in_parent(par_pcb, proc);
158   } else {
159     P_ERRNO = P_ENULL;
160     return;
161   }
162
163   // if proc has children, remove them and assign them to init parent
164   if (vec_len(&proc->child_pcbs) > 0) {
165     // retrieve the init process
166     pcb_t* init_pcb =
167         get_pcb_in_queue(&current_pcbs, 1);  // init process has pid 1
168
169     while (vec_len(&proc->child_pcbs) > 0) {
170       pcb_t* curr_child = vec_get(&proc->child_pcbs, 0);
171       vec_push_back(&init_pcb->child_pcbs, curr_child);
172       vec_erase_no_deletor(&proc->child_pcbs, 0);  // don't free in erase
173       curr_child->par_pid = 1;  // update parent to init (pid 1)
174       log_generic_event('O', curr_child->pid, curr_child->priority,
175                         curr_child->cmd_str);
176     }
177   }
178
179   // decr reference counts + close files if necessary
180   for (int i = 0; i < FILE_DESCRIPTOR_TABLE_SIZE; i++) {
181     if (proc->fd_table[i] != -1) {
182       if (decrement_fd_ref_count(proc->fd_table[i]) == 0) {
183         if (s_close(proc->fd_table[i]) == -1) {
184           u_perror("closing on a non-valid fd");
185         }
186       }
187     }
188   }
189
190   // cancel + join this thread
191   spthread_cancel(proc->thread_handle);
192   spthread_continue(proc->thread_handle);
193   spthread_suspend(proc->thread_handle);
194   spthread_join(proc->thread_handle, NULL);
195
196   // delete this process from any queue it's in + free it
```

```
  delete_process_from_all_queues(proc);
  free_pcb(proc);
}
```

4.10.3.4 k_proc_create()

```
pcb_t* k_proc_create (
              pcb_t * parent,
              int priority )
```

Create a new child process, inheriting applicable properties from the parent. Also inserts the created child into the correct scheduler queue based on its priority.

Parameters

parent	a pointer to the parent pcb
priority	the priority of the child, usually 1 but exceptions like shell exist

Returns

Reference to the child PCB or NULL if error

Create a new child process, inheriting applicable properties from the parent. Also inserts the created child into the correct scheduler queue based on its priority.

Definition at line 95 of file kern_pcb.c.

```
95                                                    {
96   if (parent == NULL) {  // init creation case
97     pcb_t* init = create_pcb(1, 0, 0, 0, 1);
98     if (init == NULL) {
99       P_ERRNO = P_ENULL;
100      return NULL;
101    }
102    init->fd_table[0] = STDIN_FILENO;
103    init->fd_table[1] = STDOUT_FILENO;
104    init->fd_table[2] = STDERR_FILENO;
105    for (int i = 3; i < FILE_DESCRIPTOR_TABLE_SIZE; i++) {
106      init->fd_table[i] = -1;
107    }
108
109    increment_fd_ref_count(STDIN_FILENO);
110    increment_fd_ref_count(STDOUT_FILENO);
111    increment_fd_ref_count(STDERR_FILENO);
112
113    current_running_pcb = init;
114    put_pcb_into_correct_queue(init);
115    vec_push_back(&current_pcbs, init);
116    return init;
117  }
118
119  pcb_t* child = create_pcb(next_pid++, parent->pid, priority, parent->input_fd,
120                            parent->output_fd);
121  if (child == NULL) {
122    P_ERRNO = P_ENULL;
123    return NULL;
124  }
125
126  // copy parent's fd table
127  for (int i = 0; i < FILE_DESCRIPTOR_TABLE_SIZE; i++) {
128    child->fd_table[i] = parent->fd_table[i];
129  }
130
131  for (int i = 0; i < FILE_DESCRIPTOR_TABLE_SIZE; i++) {
132    if (child->fd_table[i] != -1) {
133      increment_fd_ref_count(child->fd_table[i]);
134    }
```

```
  }

  // update parent as needed
  vec_push_back(&parent->child_pcbs, child);

  // add to appropriate queue
  put_pcb_into_correct_queue(child);
  vec_push_back(&current_pcbs, child);

  return child;
}
```

4.10.3.5 remove_child_in_parent()

```
void remove_child_in_parent (
            pcb_t * parent,
            pcb_t * child )
```

Given a parent, removes the child from the parent's child vector if its exists. Notably, it does not free the child but simply removes it via the vec_erase_no_deletor function.

Parameters

parent	a ptr to the parent pcb with the child list
child	a ptr to the child pcb that we'd like to remove

Given a parent, removes the child from the parent's child vector if its exists. Notably, it does not free the child but simply removes it via the vec_erase_no_deletor function.

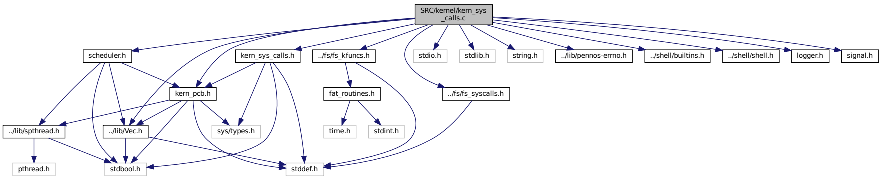
Definition at line 77 of file kern_pcb.c.

```
77                                                              {
78   for (int i = 0; i < vec_len(&parent->child_pcbs); i++) {
79     pcb_t* curr_child = (pcb_t*)vec_get(&parent->child_pcbs, i);
80     if (curr_child->pid == child->pid) {
81       vec_erase_no_deletor(&parent->child_pcbs, i);
82       return;
83     }
84   }
85 }
```

4.11 SRC/kernel/kern_sys_calls.c File Reference

```
#include "kern_sys_calls.h"
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include "../fs/fs_kfuncs.h"
#include "../fs/fs_syscalls.h"
#include "../lib/Vec.h"
#include "../lib/pennos-errno.h"
#include "../shell/builtins.h"
#include "../shell/shell.h"
#include "kern_pcb.h"
#include "logger.h"
#include "scheduler.h"
```

```
#include "signal.h"
```
Include dependency graph for kern_sys_calls.c:



Functions

- int determine_index_in_queue (Vec ∗queue, int pid)

  Determines the index of a PCB in a given queue.
- void move_pcb_correct_queue (int prev_priority, int new_priority, pcb_t ∗curr_pcb)

  Moves a PCB from its previous priority queue to its new priority queue.
- void delete_from_queue (int queue_id, int pid)

  Deletes a PCB from the specified queue based on its PID.
- void delete_from_explicit_queue (Vec ∗queue_to_delete_from, int pid)

  Deletes a PCB from the specified explicit queue based on its PID.
- void ∗ init_func (void ∗input)

  The function that runs the shell process.
- pid_t s_spawn_init ()

  Creates the init process and spawns the shell process.
- void s_cleanup_init_process ()

  Cleans up Init's resources.
- pid_t s_spawn (void ∗(∗func)(void ∗), char ∗argv[ ], int fd0, int fd1)

  Spawns a child process with the given function and arguments.
- pid_t s_waitpid (pid_t pid, int ∗wstatus, bool nohang)

  Waits for a child of the calling process.
- int s_kill (pid_t pid, int signal)

  Sends a signal to a process with specified pid.
- void s_exit (void)

  Exits the current process and cleans up its resources.
- int s_nice (pid_t pid, int priority)

  Sets the priority of a process with specified pid.
- void s_sleep (unsigned int ticks)

  Suspends the current process for a specified number of ticks.
- void ∗ s_echo (void ∗arg)

  System-level wrapper for the shell built-in command "echo".
- void ∗ s_ps (void ∗arg)

  System-level wrapper for the shell built-in command "ps".

Variables

- Vec zero_priority_queue
- Vec one_priority_queue
- Vec two_priority_queue
- Vec zombie_queue
- Vec sleep_blocked_queue
- Vec current_pcbs
- pcb_t ∗ current_running_pcb
- int tick_counter
- pid_t current_fg_pid = 2

4.11.1 Function Documentation

4.11.1.1 delete_from_explicit_queue()

```
void delete_from_explicit_queue (
            Vec * queue_to_delete_from,
            int pid )
```

Deletes a PCB from the specified explicit queue based on its PID.

Helper function that deletes the given PCB from the explicit queue passed in. Notably, it does not free the PCB but instead uses vec_erase_no_deletor to remove it from the queue.

Definition at line 108 of file kern_sys_calls.c.

```
108                                                                    {
109   int index = determine_index_in_queue(queue_to_delete_from, pid);
110   if (index != -1) {
111     vec_erase_no_deletor(queue_to_delete_from, index);
112   }
113 }
```

4.11.1.2 delete_from_queue()

```
void delete_from_queue (
            int queue_id,
            int pid )
```

Deletes a PCB from the specified queue based on its PID.

Deletes the PCB with the specified PID from one of the priority queues, selected by the provided queue_id (0, 1, or 2).

Definition at line 89 of file kern_sys_calls.c.

```
89                                               {
90   Vec* queue = NULL;
91   if (queue_id == 0) {
92     queue = &zero_priority_queue;
93   } else if (queue_id == 1) {
94     queue = &one_priority_queue;
95   } else {
96     queue = &two_priority_queue;
97   }
98 
99   int index = determine_index_in_queue(queue, pid);
100   if (index != -1) {
101     vec_erase_no_deletor(queue, index);
102   }
103 }
```

4.11.1.3 determine_index_in_queue()

```
int determine_index_in_queue (
            Vec * queue,
            int pid )
```

Determines the index of a PCB in a given queue.

Given a thread pid and Vec∗ queue, this helper function determines the vector index of the thread/pid in the queue. If the thread/pid is not found, it returns -1.

Definition at line 40 of file kern_sys_calls.c.

```
40                                               {
41   for (int i = 0; i < vec_len(queue); i++) {
42     pcb_t* curr_pcb = vec_get(queue, i);
43     if (curr_pcb->pid == pid) {
44       return i;
45     }
46   }
47
48   return -1;  // not found
49 }
```

4.11.1.4 init_func()

```
void* init_func (
            void * input )
```

The function that runs the shell process.

The init process function. It spawns the shell process and reaps zombie children.

Definition at line 118 of file kern_sys_calls.c.

```
118                              {
119   char* shell_argv[] = {"shell", NULL};
120   s_spawn(shell, shell_argv, STDIN_FILENO, STDOUT_FILENO);
121
122   // continuously wait for and reap zombie children
123   while (true) {
124     int status;
125     s_waitpid(-1, &status, false);
126   }
127
128   return NULL;  // should never reach
129 }
```

4.11.1.5 move_pcb_correct_queue()

```
void move_pcb_correct_queue (
            int prev_priority,
            int new_priority,
            pcb_t * curr_pcb )
```

Moves a PCB from its previous priority queue to its new priority queue.

Given a thread's previous priority, this helper checks if the thread is present in that priority's queue, removes it from that queue if so, and then puts it into the new priority level's queue.

Definition at line 55 of file kern_sys_calls.c.

```
                                                {
  Vec* prev_queue;
  Vec* new_queue;

  if (prev_priority == 0) {
    prev_queue = &zero_priority_queue;
  } else if (prev_priority == 1) {
    prev_queue = &one_priority_queue;
  } else {
    prev_queue = &two_priority_queue;
  }

  if (new_priority == 0) {
    new_queue = &zero_priority_queue;
  } else if (new_priority == 1) {
    new_queue = &one_priority_queue;
  } else {
    new_queue = &two_priority_queue;
  }

  // delete from prev_queue, if it's present at all
  int ind = determine_index_in_queue(prev_queue, curr_pcb->pid);
  if (ind != -1) {
    vec_erase_no_deletor(prev_queue, ind);
  }

  vec_push_back(new_queue, curr_pcb);
}
```

4.11.1.6 s_cleanup_init_process()

`void s_cleanup_init_process ( )`

Cleans up Init's resources.

Wrapper system-level function to be called in pennos's main method to clean up the init process.

Definition at line 158 of file kern_sys_calls.c.

```
                             {
  k_proc_cleanup(get_pcb_in_queue(&current_pcbs, 1));
}
```

4.11.1.7 s_echo()

```
void* s_echo (
              void * arg )
```

System-level wrapper for the shell built-in command "echo".

Parameters

arg	the pass along arguments to the u_echo function

Returns

NULL, dummy return value

Definition at line 361 of file kern_sys_calls.c.

```
                      {
  char** argv = (char**)arg;
  if (argv[1] == NULL) {  // no args case
    s_exit();
    return NULL;
  }

  int i = 1;                  // words after "echo"
  while (argv[i] != NULL) {  // while the arg isn't NULL
    if (s_write(current_running_pcb->output_fd, argv[i], strlen(argv[i])) ==
        -1) {
      u_perror("s_write error");
    }
    if (s_write(current_running_pcb->output_fd, " ", 1) == -1) {
      u_perror("s_write error");
    }
    i++;
  }

  if (s_write(current_running_pcb->output_fd, "\n", 1) == -1) {
    u_perror("s_write error");
  }
  return NULL;
}
```

4.11.1.8 s_exit()

```
void s_exit (
        void )
```

Exits the current process and cleans up its resources.

Unconditionally exit the calling process.

Definition at line 296 of file kern_sys_calls.c.

```
296                {
297   // Set process state to zombie
298   current_running_pcb->process_state = 'Z';
299   current_running_pcb->process_status = 20;  // EXITED_NORMALLY
300
301   // Log the exit
302   log_generic_event('E', current_running_pcb->pid,
303                     current_running_pcb->priority,
304                     current_running_pcb->cmd_str);
305
306   delete_from_queue(current_running_pcb->priority, current_running_pcb->pid);
307
308   log_generic_event('Z', current_running_pcb->pid,
309                     current_running_pcb->priority,
310                     current_running_pcb->cmd_str);
311 }
```

4.11.1.9 s_kill()

```
int s_kill (
        pid_t pid,
        int signal )
```

Sends a signal to a process with specified pid.

Send a signal to a particular process.

Definition at line 282 of file kern_sys_calls.c.

```
282                             {
283   pcb_t* pcb_with_pid = get_pcb_in_queue(&current_pcbs, pid);
284   if (pcb_with_pid == NULL) {
285     return -1;  // pid not found case
286   }
287
288   pcb_with_pid->signals[signal] = true;  // signal flagged
289   log_generic_event('S', pid, pcb_with_pid->priority, pcb_with_pid->cmd_str);
290   return 0;
291 }
```

4.11.1.10 s_nice()

```
int s_nice (
            pid_t pid,
            int priority )
```

Sets the priority of a process with specified pid.

Set the priority of the specified thread.

Definition at line 316 of file kern_sys_calls.c.

```
316                                          {
317   if (priority < 0 || priority > 2) {  // error check
318     return -1;
319   }
320 
321   pcb_t* curr_pcb = get_pcb_in_queue(&current_pcbs, pid);
322   if (curr_pcb != NULL) {  // found + exists
323     move_pcb_correct_queue(curr_pcb->priority, priority, curr_pcb);
324     log_nice_event(pid, curr_pcb->priority, priority, curr_pcb->cmd_str);
325     curr_pcb->priority = priority;
326     return 0;
327   }
328 
329   return -1;  // pid not found
330 }
```

4.11.1.11 s_ps()

```
void* s_ps (
            void * arg )
```

System-level wrapper for the shell built-in command "ps".

Parameters

arg	the pass along arguments to the u_ps function

Returns

NULL, dummy return value

Definition at line 389 of file kern_sys_calls.c.

```
389                           {
390   char pid_top[] = "PID\tPPID\tPRI\tSTAT\tCMD\n";
391   if (s_write(current_running_pcb->output_fd, pid_top, strlen(pid_top)) == -1) {
392     u_perror("s_write error");
393   }
394   for (int i = 0; i < vec_len(&current_pcbs); i++) {
395     pcb_t* curr_pcb = (pcb_t*)vec_get(&current_pcbs, i);
396     char buffer[100];
397     snprintf(buffer, sizeof(buffer), "%d\t%d\t%d\t%c\t%s\n", curr_pcb->pid,
398              curr_pcb->par_pid, curr_pcb->priority, curr_pcb->process_state,
399              curr_pcb->cmd_str);
400     if (s_write(current_running_pcb->output_fd, buffer, strlen(buffer)) == -1) {
401       u_perror("s_write error");
402     }
403   }
404   return NULL;
405 }
```

4.11.1.12 s_sleep()

```
void s_sleep (
            unsigned int ticks )
```

Suspends the current process for a specified number of ticks.

Suspends execution of the calling proces for a specified number of clock ticks.

Definition at line 335 of file kern_sys_calls.c.

```
335                                {
336   if (ticks <= 0) {
337     P_ERRNO = P_EINVAL;
338     return;
339   }
340
341   // block current process, set state to sleep
342   current_running_pcb->process_state = 'B';
343   current_running_pcb->is_sleeping = true;
344   current_running_pcb->time_to_wake = tick_counter + ticks;
345   log_generic_event('B', current_running_pcb->pid,
346                     current_running_pcb->priority,
347                     current_running_pcb->cmd_str);
348   if (spthread_suspend(current_running_pcb->thread_handle) !=
349       0) {  // give scheduler control
350     perror("Error in spthread_suspend in s_sleep call");
351   }
352 }
```

4.11.1.13 s_spawn()

```
pid_t s_spawn (
            void *(*)(void *) func,
            char * argv[],
            int fd0,
            int fd1 )
```

Spawns a child process with the given function and arguments.

Create a child process that executes the function `func`. The child will retain some attributes of the parent.

Definition at line 165 of file kern_sys_calls.c.

```
165                                                                    {
166   pcb_t* child;
167   if (strcmp(argv[0], "shell") == 0) {
168     child = k_proc_create(current_running_pcb, 0);
169   } else {
170     child = k_proc_create(current_running_pcb, 1);
171   }
172
173   if (child == NULL) {
174     P_ERRNO = P_ENULL;
175     return -1;
176   }
177
178   spthread_t thread_handle;
179
180   if (spthread_create(&thread_handle, NULL, func, argv) != 0) {
181     perror("Error in spthread_create in s_spawn call");
182   }
183
184   child->cmd_str = strdup(argv[0]);
185   child->thread_handle = thread_handle;
186   child->input_fd = fd0;
187   child->output_fd = fd1;
188   child->fd_table[0] = fd0;
189   child->fd_table[1] = fd1;
190
191   log_generic_event('C', child->pid, child->priority, child->cmd_str);
192
193   return child->pid;
194 }
```

4.11.1.14 s_spawn_init()

```
pid_t s_spawn_init ( )
```

Creates the init process and spawns the shell process.

Similar to s_spawn except only called when you want to spawn the init process. It will create the init process and also spawn in the shell.

Definition at line 138 of file kern_sys_calls.c.

```
138 {
139   pcb_t* init = k_proc_create(NULL, 0);
140   if (init == NULL) {
141     P_ERRNO = P_ENULL;
142     return -1;
143   }
144
145   spthread_t thread_handle;
146   if (spthread_create(&thread_handle, NULL, init_func, NULL) != 0) {
147     perror("Error in spthread_create in s_spawn_init call");
148   }
149
150   init->cmd_str = strdup("init");
151   init->thread_handle = thread_handle;
152   return init->pid;
153 }
```

4.11.1.15 s_waitpid()

```
pid_t s_waitpid (
            pid_t pid,
            int * wstatus,
            bool nohang )
```

Waits for a child of the calling process.

Wait on a child of the calling process, until it changes state. If `nohang` is true, this will not block the calling process and return immediately.

Definition at line 199 of file kern_sys_calls.c.

```
199 {
200   pcb_t* parent = current_running_pcb;
201   if (parent == NULL) {
202     return -1;
203   }
204
205   // if no children, return -1
206   bool has_child = false;
207   for (int i = 0; i < vec_len(&current_pcbs); i++) {
208     pcb_t* child = vec_get(&current_pcbs, i);
209     if (child->par_pid == parent->pid) {
210       has_child = true;
211       break;
212     }
213   }
214   if (!has_child) {
215     return -1;
216   }
217
218   // Scan the zombie queue first for terminated children.
219   for (int i = 0; i < vec_len(&zombie_queue); i++) {
220     pcb_t* child = vec_get(&zombie_queue, i);
221     if ((pid == -1 || child->pid == pid) && child->par_pid == parent->pid) {
222       if (wstatus != NULL) {
223         *wstatus = child->process_status;
224       }
225       log_generic_event('W', child->pid, child->priority, child->cmd_str);
226       vec_erase_no_deletor(&zombie_queue, i);
227       delete_from_explicit_queue(&parent->child_pcbs, child->pid);
228       k_proc_cleanup(child);
```

```
      return child->pid;
    }
  }

  // If nohang is true, return immediately if no child has exited
  if (nohang) {
    return 0;
  }

  // Block the parent until a child exits
  delete_from_queue(parent->priority, parent->pid);
  parent->process_state = 'B';
  log_generic_event('B', parent->pid, parent->priority, parent->cmd_str);

  while (true) {
    // Scan the zombie queue first for terminated children.
    for (int i = 0; i < vec_len(&zombie_queue); i++) {
      pcb_t* child = vec_get(&zombie_queue, i);
      if ((pid == -1 || child->pid == pid) && child->par_pid == parent->pid) {
        if (wstatus != NULL) {
          *wstatus = child->process_status;
        }
        log_generic_event('W', child->pid, child->priority, child->cmd_str);
        vec_erase_no_deletor(&zombie_queue, i);
        delete_from_explicit_queue(&parent->child_pcbs, child->pid);
        k_proc_cleanup(child);
        return child->pid;
      }
    }

    // scan children of current running process for non-terminated state changes
    for (int i = 0; i < vec_len(&parent->child_pcbs); i++) {
      pcb_t* child = vec_get(&parent->child_pcbs, i);
      if ((pid == -1 || child->pid == pid) &&
          (child->process_status == 21 ||
           child->process_status == 23)) {  // signaled
        if (wstatus != NULL) {
          *wstatus = child->process_status;
        }
        log_generic_event('W', child->pid, child->priority, child->cmd_str);
        child->process_status = 0;  // reset status
        return child->pid;
      }
    }
  }

  // If we get here, something went wrong
  return -1;
}
```

4.11.2 Variable Documentation

4.11.2.1 current_fg_pid

```
pid_t current_fg_pid = 2
```

Definition at line 31 of file kern_sys_calls.c.

4.11.2.2 current_pcbs

```
Vec current_pcbs [extern]
```

Definition at line 30 of file scheduler.c.

4.11.2.3 current_running_pcb

```
pcb_t* current_running_pcb [extern]
```

Definition at line 38 of file scheduler.c.

4.11.2.4 one_priority_queue

```
Vec one_priority_queue [extern]
```

Definition at line 25 of file scheduler.c.

4.11.2.5 sleep_blocked_queue

```
Vec sleep_blocked_queue [extern]
```

Definition at line 28 of file scheduler.c.

4.11.2.6 tick_counter

```
int tick_counter [extern]
```

Definition at line 35 of file scheduler.c.

4.11.2.7 two_priority_queue

```
Vec two_priority_queue [extern]
```

Definition at line 26 of file scheduler.c.

4.11.2.8 zero_priority_queue

```
Vec zero_priority_queue [extern]
```

Definition at line 24 of file scheduler.c.

4.11.2.9 zombie_queue

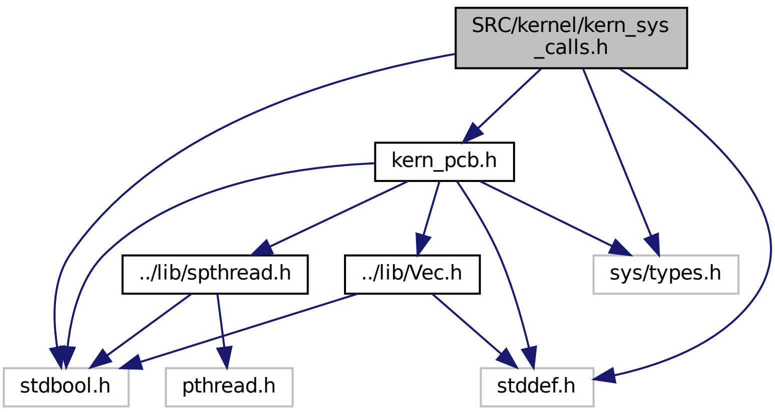
```
Vec zombie_queue [extern]
```

Definition at line 27 of file scheduler.c.

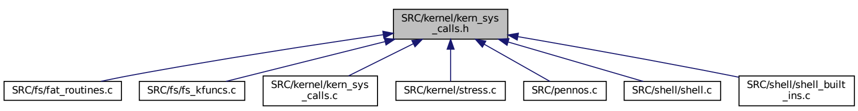
4.12 SRC/kernel/kern_sys_calls.h File Reference

```
#include <stdbool.h>
#include <stddef.h>
#include <sys/types.h>
#include "kern_pcb.h"
```

Include dependency graph for kern_sys_calls.h:



This graph shows which files directly or indirectly include this file:



Functions

- int determine_index_in_queue (Vec ∗queue, int pid)

  Given a thread pid and Vec∗ queue, this helper function determines the vector index of the thread/pid in the queue. If the thread/pid is not found, it returns -1.
- void move_pcb_correct_queue (int prev_priority, int new_priority, pcb_t ∗curr_pcb)

  Given a thread's previous priority, this helper checks if the thread is present in that priority's queue, removes it from that queue if so, and then puts it into the new priority level's queue.
- void delete_from_queue (int queue_id, int pid)

Deletes the PCB with the specified PID from one of the priority queues, selected by the provided queue_id (0, 1, or 2).

- void delete_from_explicit_queue (Vec *queue_to_delete_from, int pid)

  Helper function that deletes the given PCB from the explicit queue passed in. Notably, it does not free the PCB but instead uses vec_erase_no_deletor to remove it from the queue.
- void * init_func (void *input)

  The init process function. It spawns the shell process and reaps zombie children.
- pid_t s_spawn_init ()

  Similar to s_spawn except only called when you want to spawn the init process. It will create the init process and also spawn in the shell.
- void s_cleanup_init_process ()

  Wrapper system-level function to be called in pennos's main method to clean up the init process.
- pid_t s_spawn (void *(*func)(void *), char *argv[ ], int fd0, int fd1)

  Create a child process that executes the function `func`. The child will retain some attributes of the parent.
- pid_t s_waitpid (pid_t pid, int *wstatus, bool nohang)

  Wait on a child of the calling process, until it changes state. If `nohang` is true, this will not block the calling process and return immediately.
- int s_kill (pid_t pid, int signal)

  Send a signal to a particular process.
- void s_exit (void)

  Unconditionally exit the calling process.
- int s_nice (pid_t pid, int priority)

  Set the priority of the specified thread.
- void s_sleep (unsigned int ticks)

  Suspends execution of the calling proces for a specified number of clock ticks.
- void * s_echo (void *arg)

  System-level wrapper for the shell built-in command "echo".
- void * s_ps (void *arg)

  System-level wrapper for the shell built-in command "ps".

4.12.1 Function Documentation

4.12.1.1 delete_from_explicit_queue()

```
void delete_from_explicit_queue (
            Vec * queue_to_delete_from,
            int pid )
```

Helper function that deletes the given PCB from the explicit queue passed in. Notably, it does not free the PCB but instead uses vec_erase_no_deletor to remove it from the queue.

Parameters

queue_to_delete_from	ptr to Vec* queue to delete from
pid	the pid of the PCB to delete

Helper function that deletes the given PCB from the explicit queue passed in. Notably, it does not free the PCB but instead uses vec_erase_no_deletor to remove it from the queue.

Definition at line 108 of file kern_sys_calls.c.

```
108                                                                    {
109   int index = determine_index_in_queue(queue_to_delete_from, pid);
110   if (index != -1) {
111     vec_erase_no_deletor(queue_to_delete_from, index);
112   }
113 }
```

4.12.1.2 delete_from_queue()

```
void delete_from_queue (
              int queue_id,
              int pid )
```

Deletes the PCB with the specified PID from one of the priority queues, selected by the provided queue_id (0, 1, or 2).

Parameters

queue←_id	An integer representing the queue: 0 for zero_priority_queue, 1 for one_priority_queue, or 2 for two_priority_queue.
pid	The PID of the PCB to be removed.

Deletes the PCB with the specified PID from one of the priority queues, selected by the provided queue_id (0, 1, or 2).

Definition at line 89 of file kern_sys_calls.c.

```
89                                                {
90   Vec* queue = NULL;
91   if (queue_id == 0) {
92     queue = &zero_priority_queue;
93   } else if (queue_id == 1) {
94     queue = &one_priority_queue;
95   } else {
96     queue = &two_priority_queue;
97   }
98
99   int index = determine_index_in_queue(queue, pid);
100   if (index != -1) {
101     vec_erase_no_deletor(queue, index);
102   }
103 }
```

4.12.1.3 determine_index_in_queue()

```
int determine_index_in_queue (
              Vec * queue,
              int pid )
```

Given a thread pid and Vec∗ queue, this helper function determines the vector index of the thread/pid in the queue. If the thread/pid is not found, it returns -1.

Parameters

queue	pointer to the vector queue that may contain the thread/pid
pid	the thread's pid

Returns

the index of the thread/pid in the queue, or -1 if not found

Given a thread pid and Vec∗ queue, this helper function determines the vector index of the thread/pid in the queue. If the thread/pid is not found, it returns -1.

Definition at line 40 of file kern_sys_calls.c.

```
40                                                     {
41   for (int i = 0; i < vec_len(queue); i++) {
42     pcb_t* curr_pcb = vec_get(queue, i);
43     if (curr_pcb->pid == pid) {
44       return i;
45     }
46   }
47
48   return -1;  // not found
49 }
```

4.12.1.4 init_func()

```
void* init_func (
            void * input )
```

The init process function. It spawns the shell process and reaps zombie children.

Parameters

input	unused but needed for typing reasons

Returns

irrelvant return value because never supposed to return

The init process function. It spawns the shell process and reaps zombie children.

Definition at line 118 of file kern_sys_calls.c.

```
118                                 {
119   char* shell_argv[] = {"shell", NULL};
120   s_spawn(shell, shell_argv, STDIN_FILENO, STDOUT_FILENO);
121
122   // continuously wait for and reap zombie children
123   while (true) {
124     int status;
125     s_waitpid(-1, &status, false);
126   }
127
128   return NULL;  // should never reach
129 }
```

4.12.1.5 move_pcb_correct_queue()

```
void move_pcb_correct_queue (
            int prev_priority,
            int new_priority,
            pcb_t * curr_pcb )
```

Given a thread's previous priority, this helper checks if the thread is present in that priority's queue, removes it from that queue if so, and then puts it into the new priority level's queue.

Parameters

prev_priority	thread's previous priority
new_priority	thread's new priority
curr_pcb	pointer to the thread's PCB

Precondition

assumes the prev_priority and new_priority falls in integers [0, 2]

Given a thread's previous priority, this helper checks if the thread is present in that priority's queue, removes it from that queue if so, and then puts it into the new priority level's queue.

Definition at line 55 of file kern_sys_calls.c.

```
                                          {
  Vec* prev_queue;
  Vec* new_queue;

  if (prev_priority == 0) {
    prev_queue = &zero_priority_queue;
  } else if (prev_priority == 1) {
    prev_queue = &one_priority_queue;
  } else {
    prev_queue = &two_priority_queue;
  }

  if (new_priority == 0) {
    new_queue = &zero_priority_queue;
  } else if (new_priority == 1) {
    new_queue = &one_priority_queue;
  } else {
    new_queue = &two_priority_queue;
  }

  // delete from prev_queue, if it's present at all
  int ind = determine_index_in_queue(prev_queue, curr_pcb->pid);
  if (ind != -1) {
    vec_erase_no_deletor(prev_queue, ind);
  }

  vec_push_back(new_queue, curr_pcb);
}
```

4.12.1.6 s_cleanup_init_process()

`void s_cleanup_init_process ( )`

Wrapper system-level function to be called in pennos's main method to clean up the init process.

Wrapper system-level function to be called in pennos's main method to clean up the init process.

Definition at line 158 of file kern_sys_calls.c.

```
158                              {
159   k_proc_cleanup(get_pcb_in_queue(&current_pcbs, 1));
160 }
```

4.12.1.7 s_echo()

```
void* s_echo (
              void * arg )
```

System-level wrapper for the shell built-in command "echo".

Parameters

arg	the pass along arguments to the u_echo function

Returns

NULL, dummy return value

Definition at line 361 of file kern_sys_calls.c.

```
361                      {
362   char** argv = (char**)arg;
363   if (argv[1] == NULL) {  // no args case
364     s_exit();
365     return NULL;
366   }
367 
368   int i = 1;                    // words after "echo"
369   while (argv[i] != NULL) {  // while the arg isn't NULL
370     if (s_write(current_running_pcb->output_fd, argv[i], strlen(argv[i])) ==
371         -1) {
372       u_perror("s_write error");
373     }
374     if (s_write(current_running_pcb->output_fd, " ", 1) == -1) {
375       u_perror("s_write error");
376     }
377     i++;
378   }
379 
380   if (s_write(current_running_pcb->output_fd, "\n", 1) == -1) {
381     u_perror("s_write error");
382   }
383   return NULL;
384 }
```

4.12.1.8 s_exit()

```
void s_exit (
             void )
```

Unconditionally exit the calling process.

Unconditionally exit the calling process.

Definition at line 296 of file kern_sys_calls.c.

```
296                  {
297   // Set process state to zombie
298   current_running_pcb->process_state = 'Z';
299   current_running_pcb->process_status = 20;  // EXITED_NORMALLY
300 
301   // Log the exit
302   log_generic_event('E', current_running_pcb->pid,
303                     current_running_pcb->priority,
304                     current_running_pcb->cmd_str);
305 
306   delete_from_queue(current_running_pcb->priority, current_running_pcb->pid);
307 
308   log_generic_event('Z', current_running_pcb->pid,
309                     current_running_pcb->priority,
310                     current_running_pcb->cmd_str);
311 }
```

4.12.1.9 s_kill()

```
int s_kill (
             pid_t pid,
             int signal )
```

Send a signal to a particular process.

Parameters

pid	Process ID of the target proces.
signal	Signal number to be sent 0 = P_SIGSTOP, 1 = P_SIGCONT, 2 = P_SIGTERM

Returns

0 on success, -1 on error.

Send a signal to a particular process.

Definition at line 282 of file kern_sys_calls.c.

```
282                                       {
283   pcb_t* pcb_with_pid = get_pcb_in_queue(&current_pcbs, pid);
284   if (pcb_with_pid == NULL) {
285     return -1;  // pid not found case
286   }
287
288   pcb_with_pid->signals[signal] = true;  // signal flagged
289   log_generic_event('S', pid, pcb_with_pid->priority, pcb_with_pid->cmd_str);
290   return 0;
291 }
```

4.12.1.10 s_nice()

```
int s_nice (
            pid_t pid,
            int priority )
```

Set the priority of the specified thread.

Parameters

pid	Process ID of the target thread.
priority	The new priorty value of the thread (0, 1, or 2)

Returns

0 on success, -1 on failure.

Set the priority of the specified thread.

Definition at line 316 of file kern_sys_calls.c.

```
316                                         {
317   if (priority < 0 || priority > 2) {  // error check
318     return -1;
319   }
320
321   pcb_t* curr_pcb = get_pcb_in_queue(&current_pcbs, pid);
322   if (curr_pcb != NULL) {  // found + exists
323     move_pcb_correct_queue(curr_pcb->priority, priority, curr_pcb);
324     log_nice_event(pid, curr_pcb->priority, priority, curr_pcb->cmd_str);
325     curr_pcb->priority = priority;
326     return 0;
327   }
328
329   return -1;  // pid not found
330 }
```

4.12.1.11 s_ps()

```
void* s_ps (
            void * arg )
```

System-level wrapper for the shell built-in command "ps".

Parameters

arg	the pass along arguments to the u_ps function

Returns

NULL, dummy return value

Definition at line 389 of file kern_sys_calls.c.

```
389                     {
390   char pid_top[] = "PID\tPPID\tPRI\tSTAT\tCMD\n";
391   if (s_write(current_running_pcb->output_fd, pid_top, strlen(pid_top)) == -1) {
392     u_perror("s_write error");
393   }
394   for (int i = 0; i < vec_len(&current_pcbs); i++) {
395     pcb_t* curr_pcb = (pcb_t*)vec_get(&current_pcbs, i);
396     char buffer[100];
397     snprintf(buffer, sizeof(buffer), "%d\t%d\t%d\t%c\t%s\n", curr_pcb->pid,
398              curr_pcb->par_pid, curr_pcb->priority, curr_pcb->process_state,
399              curr_pcb->cmd_str);
400     if (s_write(current_running_pcb->output_fd, buffer, strlen(buffer)) == -1) {
401       u_perror("s_write error");
402     }
403   }
404   return NULL;
405 }
```

4.12.1.12 s_sleep()

```
void s_sleep (
            unsigned int ticks )
```

Suspends execution of the calling proces for a specified number of clock ticks.

This function is analogous to `sleep(3)` in Linux, with the behavior that the system clock continues to tick even if the call is interrupted. The sleep can be interrupted by a P_SIGTERM signal, after which the function will return prematurely.

Parameters

ticks	Duration of the sleep in system clock ticks. Must be greater than 0.

Suspends execution of the calling proces for a specified number of clock ticks.

Definition at line 335 of file kern_sys_calls.c.

```
335                                {
336   if (ticks <= 0) {
337     P_ERRNO = P_EINVAL;
338     return;
339   }
```

```

  // block current process, set state to sleep
  current_running_pcb->process_state = 'B';
  current_running_pcb->is_sleeping = true;
  current_running_pcb->time_to_wake = tick_counter + ticks;
  log_generic_event('B', current_running_pcb->pid,
                    current_running_pcb->priority,
                    current_running_pcb->cmd_str);
  if (spthread_suspend(current_running_pcb->thread_handle) !=
      0) {  // give scheduler control
    perror("Error in spthread_suspend in s_sleep call");
  }
}
```

4.12.1.13 s_spawn()

```
pid_t s_spawn (
            void *(*)(void *) func,
            char * argv[ ],
            int fd0,
            int fd1 )
```

Create a child process that executes the function `func`. The child will retain some attributes of the parent.

Parameters

func	Function to be executed by the child process.
argv	Null-terminated array of args, including the command name as argv[0].
fd0	Input file descriptor.
fd1	Output file descriptor.

Returns

pid_t The process ID of the created child process or -1 on error

Create a child process that executes the function `func`. The child will retain some attributes of the parent.

Definition at line 165 of file kern_sys_calls.c.

```
165                                                                 {
166   pcb_t* child;
167   if (strcmp(argv[0], "shell") == 0) {
168     child = k_proc_create(current_running_pcb, 0);
169   } else {
170     child = k_proc_create(current_running_pcb, 1);
171   }
172
173   if (child == NULL) {
174     P_ERRNO = P_ENULL;
175     return -1;
176   }
177
178   spthread_t thread_handle;
179
180   if (spthread_create(&thread_handle, NULL, func, argv) != 0) {
181     perror("Error in spthread_create in s_spawn call");
182   }
183
184   child->cmd_str = strdup(argv[0]);
185   child->thread_handle = thread_handle;
186   child->input_fd = fd0;
187   child->output_fd = fd1;
188   child->fd_table[0] = fd0;
189   child->fd_table[1] = fd1;
190
191   log_generic_event('C', child->pid, child->priority, child->cmd_str);
```

```

  return child->pid;
}
```

4.12.1.14 s_spawn_init()

```
pid_t s_spawn_init ( )
```

Similar to s_spawn except only called when you want to spawn the init process. It will create the init process and also spawn in the shell.

Returns

the pid_t of the created process on success or -1 on error

Similar to s_spawn except only called when you want to spawn the init process. It will create the init process and also spawn in the shell.

Definition at line 138 of file kern_sys_calls.c.

```
138                            {
139   pcb_t* init = k_proc_create(NULL, 0);
140   if (init == NULL) {
141     P_ERRNO = P_ENULL;
142     return -1;
143   }
144
145   spthread_t thread_handle;
146   if (spthread_create(&thread_handle, NULL, init_func, NULL) != 0) {
147     perror("Error in spthread_create in s_spawn_init call");
148   }
149
150   init->cmd_str = strdup("init");
151   init->thread_handle = thread_handle;
152   return init->pid;
153 }
```

4.12.1.15 s_waitpid()

```
pid_t s_waitpid (
            pid_t pid,
            int * wstatus,
            bool nohang )
```

Wait on a child of the calling process, until it changes state. If `nohang` is true, this will not block the calling process and return immediately.

Parameters

pid	Process ID of the child to wait for.
wstatus	Pointer to an integer variable where the status will be stored.
nohang	If true, return immediately if no child has exited.

Returns

pid_t The process ID of the child which has changed state on success, -1 on error.

Wait on a child of the calling process, until it changes state. If `nohang` is true, this will not block the calling process and return immediately.

Definition at line 199 of file kern_sys_calls.c.

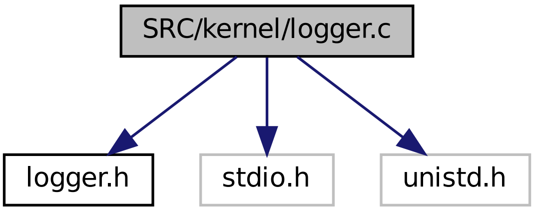
```
199                                                           {
200   pcb_t* parent = current_running_pcb;
201   if (parent == NULL) {
202     return -1;
203   }
204
205   // if no children, return -1
206   bool has_child = false;
207   for (int i = 0; i < vec_len(&current_pcbs); i++) {
208     pcb_t* child = vec_get(&current_pcbs, i);
209     if (child->par_pid == parent->pid) {
210       has_child = true;
211       break;
212     }
213   }
214   if (!has_child) {
215     return -1;
216   }
217
218   // Scan the zombie queue first for terminated children.
219   for (int i = 0; i < vec_len(&zombie_queue); i++) {
220     pcb_t* child = vec_get(&zombie_queue, i);
221     if ((pid == -1 || child->pid == pid) && child->par_pid == parent->pid) {
222       if (wstatus != NULL) {
223         *wstatus = child->process_status;
224       }
225       log_generic_event('W', child->pid, child->priority, child->cmd_str);
226       vec_erase_no_deletor(&zombie_queue, i);
227       delete_from_explicit_queue(&parent->child_pcbs, child->pid);
228       k_proc_cleanup(child);
229       return child->pid;
230     }
231   }
232
233   // If nohang is true, return immediately if no child has exited
234   if (nohang) {
235     return 0;
236   }
237
238   // Block the parent until a child exits
239   delete_from_queue(parent->priority, parent->pid);
240   parent->process_state = 'B';
241   log_generic_event('B', parent->pid, parent->priority, parent->cmd_str);
242
243   while (true) {
244     // Scan the zombie queue first for terminated children.
245     for (int i = 0; i < vec_len(&zombie_queue); i++) {
246       pcb_t* child = vec_get(&zombie_queue, i);
247       if ((pid == -1 || child->pid == pid) && child->par_pid == parent->pid) {
248         if (wstatus != NULL) {
249           *wstatus = child->process_status;
250         }
251         log_generic_event('W', child->pid, child->priority, child->cmd_str);
252         vec_erase_no_deletor(&zombie_queue, i);
253         delete_from_explicit_queue(&parent->child_pcbs, child->pid);
254         k_proc_cleanup(child);
255         return child->pid;
256       }
257     }
258
259     // scan children of current running process for non-terminated state changes
260     for (int i = 0; i < vec_len(&parent->child_pcbs); i++) {
261       pcb_t* child = vec_get(&parent->child_pcbs, i);
262       if ((pid == -1 || child->pid == pid) &&
263           (child->process_status == 21 ||
264            child->process_status == 23)) {  // signaled
265         if (wstatus != NULL) {
266           *wstatus = child->process_status;
267         }
268         log_generic_event('W', child->pid, child->priority, child->cmd_str);
269         child->process_status = 0;  // reset status
270         return child->pid;
271       }
272     }
273   }
274
```

```
  // If we get here, something went wrong
  return -1;
}
```

4.13 SRC/kernel/logger.c File Reference

```
#include "logger.h"
#include <stdio.h>
#include <unistd.h>
```

Include dependency graph for logger.c:



Functions

- void log_scheduling_event (int pid, int queue_num, char ∗process_name)

  Logs when an event is scheduled.
- void log_generic_event (char event_type, int pid, int nice_value, char ∗process_name)

  Logs non-nice, non-scheduling events since they have same format.
- void log_nice_event (int pid, int old_nice_value, int new_nice_value, char ∗process_name)

  Logs a nice-related event.

4.13.1 Function Documentation

4.13.1.1 log_generic_event()

```
void log_generic_event (
            char event_type,
            int pid,
            int nice_value,
            char * process_name )
```

Logs non-nice, non-scheduling events since they have same format.

Logs a non-nice, non-scheduling event (i.e any event that follows the EVENT PID NICE_VALUE PROCESS_NAME format)

Definition at line 20 of file logger.c.

```
                                              {
  char* operation;

  switch (event_type) {
    case 'C':
      operation = "CREATE";
      break;
    case 'S':
      operation = "SIGNALED";
      break;
    case 'E':
      operation = "EXITED";
      break;
    case 'Z':
      operation = "ZOMBIE";
      break;
    case 'O':
      operation = "ORPHAN";
      break;
    case 'W':
      operation = "WAITED";
      break;
    case 'B':
      operation = "BLOCKED";
      break;
    case 'U':
      operation = "UNBLOCKED";
      break;
    case 's':
      operation = "STOPPED";
      break;
    default:
      operation = "CONTINUED";
      break;
  }

  char buffer[200];
  int str_len =
      snprintf(buffer, sizeof(buffer), "[%d]\t%s\t%d\t%d\t%s\n", tick_counter,
               operation, pid, nice_value, process_name);
  if (write(log_fd, buffer, str_len) == -1) {
    perror("error in writing to the log file for generic event");
  }
}
```

4.13.1.2 log_nice_event()

```
void log_nice_event (
            int pid,
            int old_nice_value,
            int new_nice_value,
            char * process_name )
```

Logs a nice-related event.

Logs a nice event, which is the adjusting of a process's nice value.

Definition at line 71 of file logger.c.

```
                                           {
  char buffer[200];
  int str_len =
      snprintf(buffer, sizeof(buffer), "[%d]\tNICE\t%d\t%d\t%d\t%s\n",
               tick_counter, pid, old_nice_value, new_nice_value, process_name);
  if (write(log_fd, buffer, str_len) == -1) {
    perror("error in writing to the log file for nice event");
  }
}
```

4.13.1.3 log_scheduling_event()

```
void log_scheduling_event (
            int pid,
            int queue_num,
            char * process_name )
```

Logs when an event is scheduled.

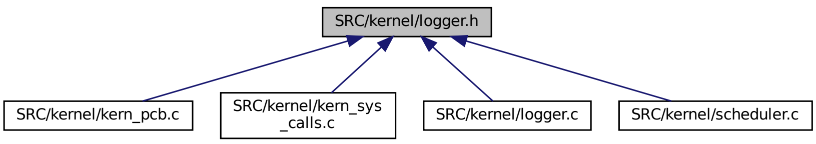
Logs a scheduling event i.e. the scheduling of a process for this clock tick.

Definition at line 8 of file logger.c.

```
8                                                                         {
9    char buffer[200];
10    int str_len = snprintf(buffer, sizeof(buffer), "[%d]\tSCHEDULE\t%d\t%d\t%s\n",
11                           tick_counter, pid, queue_num, process_name);
12    if (write(log_fd, buffer, str_len) == -1) {
13      perror("error in writing to the log file for scheduling event");
14    }
15 }
```

4.14 SRC/kernel/logger.h File Reference

This graph shows which files directly or indirectly include this file:



Functions

- void log_scheduling_event (int pid, int queue_num, char ∗process_name)

    Logs a scheduling event i.e. the scheduling of a process for this clock tick.
- void log_generic_event (char event_type, int pid, int nice_value, char ∗process_name)

    Logs a non-nice, non-scheduling event (i.e any event that follows the EVENT PID NICE_VALUE PROCESS_NAME format)
- void log_nice_event (int pid, int old_nice_value, int new_nice_value, char ∗process_name)

    Logs a nice event, which is the adjusting of a process's nice value.

Variables

- int tick_counter
- int log_fd

4.14.1 Function Documentation

4.14.1.1 log_generic_event()

```
void log_generic_event (
            char event_type,
            int pid,
            int nice_value,
            char * process_name )
```

Logs a non-nice, non-scheduling event (i.e any event that follows the EVENT PID NICE_VALUE PROCESS_NAME format)

Parameters

event_type	the type of event, defined by: 'C' = CREATE, 'S' = SIGNALED, 'E' = EXITED, 'Z' = ZOMBIE, 'O' = ORPHAN, 'W' = WAITED 'B' = BLOCKED, 'U' = UNBLOCKED 's' = STOPPED, 'c' = CONTINUED (notably lower-cased)
pid	process pid
nice_value	process nice value
process_name	string containing process name

Precondition

assumes event_type matches one of the above characters

Postcondition

will perror if the write fails

Logs a non-nice, non-scheduling event (i.e any event that follows the EVENT PID NICE_VALUE PROCESS_NAME format)

Definition at line 20 of file logger.c.

```
{
  char* operation;

  switch (event_type) {
    case 'C':
      operation = "CREATE";
      break;
    case 'S':
      operation = "SIGNALED";
      break;
    case 'E':
      operation = "EXITED";
      break;
    case 'Z':
      operation = "ZOMBIE";
      break;
    case 'O':
      operation = "ORPHAN";
      break;
    case 'W':
      operation = "WAITED";
      break;
    case 'B':
      operation = "BLOCKED";
      break;
    case 'U':
      operation = "UNBLOCKED";
      break;
    case 's':
      operation = "STOPPED";
      break;
    default:
      operation = "CONTINUED";
      break;
```

```
  }

  char buffer[200];
  int str_len =
      snprintf(buffer, sizeof(buffer), "[%d]\t%s\t%d\t%d\t%s\n", tick_counter,
               operation, pid, nice_value, process_name);
  if (write(log_fd, buffer, str_len) == -1) {
    perror("error in writing to the log file for generic event");
  }
}
```

4.14.1.2 log_nice_event()

```
void log_nice_event (
            int pid,
            int old_nice_value,
            int new_nice_value,
            char * process_name )
```

Logs a nice event, which is the adjusting of a process's nice value.

Parameters

pid	process pid
old_nice_value	old nice value
new_nice_value	new nice value
process_name	string containing process name

Postcondition

will perror if the write fails

Logs a nice event, which is the adjusting of a process's nice value.

Definition at line 71 of file logger.c.

```
                                            {
  char buffer[200];
  int str_len =
      snprintf(buffer, sizeof(buffer), "[%d]\tNICE\t%d\t%d\t%d\t%s\n",
               tick_counter, pid, old_nice_value, new_nice_value, process_name);
  if (write(log_fd, buffer, str_len) == -1) {
    perror("error in writing to the log file for nice event");
  }
}
```

4.14.1.3 log_scheduling_event()

```
void log_scheduling_event (
            int pid,
            int queue_num,
            char * process_name )
```

Logs a scheduling event i.e. the scheduling of a process for this clock tick.

Parameters

pid	pid of the process being scheduled
queue_num	the priority queue num of the process
process_name	string containing scheduled process's name

Postcondition

will perror if the write fails

Logs a scheduling event i.e. the scheduling of a process for this clock tick.

Definition at line 8 of file logger.c.

```
8                                                                         {
9   char buffer[200];
10   int str_len = snprintf(buffer, sizeof(buffer), "[%d]\tSCHEDULE\t%d\t%d\t%s\n",
11                          tick_counter, pid, queue_num, process_name);
12   if (write(log_fd, buffer, str_len) == -1) {
13     perror("error in writing to the log file for scheduling event");
14   }
15 }
```

4.14.2 Variable Documentation

4.14.2.1 log_fd

```
int log_fd [extern]
```

Definition at line 36 of file scheduler.c.

4.14.2.2 tick_counter

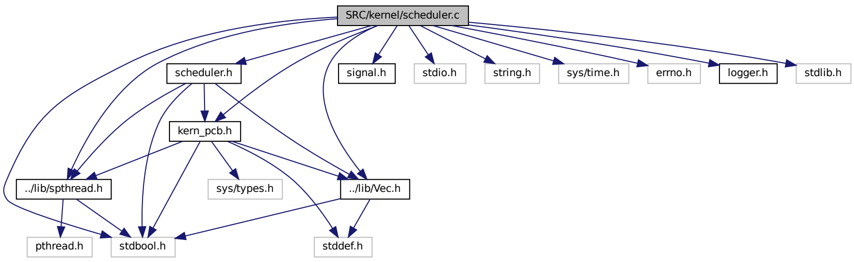
```
int tick_counter [extern]
```

Definition at line 35 of file scheduler.c.

4.15 SRC/kernel/scheduler.c File Reference

```
#include "scheduler.h"
#include <signal.h>
#include <stdbool.h>
#include <stdio.h>
#include <string.h>
#include <sys/time.h>
#include "../lib/Vec.h"
#include "../lib/spthread.h"
#include "errno.h"
#include "kern_pcb.h"
#include "logger.h"
#include "stdlib.h"
```

Include dependency graph for scheduler.c:



Functions

- void initialize_scheduler_queues ()

  Initializes the scheduler queues.
- void free_scheduler_queues ()

  Frees the scheduler queues.
- int generate_next_priority ()

  Generates the next priority for scheduling based on the defined probabilities.
- pcb_t ∗ get_next_pcb (int priority)

  Gets the next PCB from the specified priority queue.
- void put_pcb_into_correct_queue (pcb_t ∗pcb)

  Puts the given PCB into the correct queue based on its priority and state.
- void delete_process_from_particular_queue (pcb_t ∗pcb, Vec ∗queue)

  Deletes the given PCB from the specified queue.
- void delete_process_from_all_queues_except_current (pcb_t ∗pcb)

  Deletes the given PCB from all queues except the current one.
- void delete_process_from_all_queues (pcb_t ∗pcb)

  Deletes the given PCB from all queues.
- pcb_t ∗ get_pcb_in_queue (Vec ∗queue, pid_t pid)

  Gets the PCB with the specified PID from the given queue.
- bool child_in_zombie_queue (pcb_t ∗parent)

  Checks if the given parent PCB has any children in the zombie queue.
- bool child_with_changed_process_status (pcb_t ∗parent)

  Checks if the given parent PCB has any children with a changed process status.

- void alarm_handler (int signum)

  Signal handler for SIGALRM.
- void handle_signal (pcb_t *pcb, int signal)

  Handles the specified signal for the given PCB.
- void s_shutdown_pennos (void)

  Shuts down the scheduler and cleans up resources.
- void scheduler ()

  The main scheduler function for PennOS.

Variables

- Vec zero_priority_queue
- Vec one_priority_queue
- Vec two_priority_queue
- Vec zombie_queue
- Vec sleep_blocked_queue
- Vec current_pcbs
- int tick_counter = 0
- int log_fd
- pcb_t * current_running_pcb
- int curr_priority_arr_index = 0
- int det_priorities_arr [19]

4.15.1 Function Documentation

4.15.1.1 alarm_handler()

```
void alarm_handler (
            int signum )
```

Signal handler for SIGALRM.

Handles the alarm signal.

Definition at line 228 of file scheduler.c.

```
228                                 {
229   tick_counter++;
230 }
```

4.15.1.2 child_in_zombie_queue()

```
bool child_in_zombie_queue (
            pcb_t * parent )
```

Checks if the given parent PCB has any children in the zombie queue.

Checks if a child of the given parent process is in the zombie queue.

Definition at line 201 of file scheduler.c.

```
201                                          {
202   for (int i = 0; i < vec_len(&zombie_queue); i++) {
203     pcb_t* child = vec_get(&zombie_queue, i);
204     if (child->par_pid == parent->pid) {
205       return true;
206     }
207   }
208   return false;
209 }
```

4.15.1.3 child_with_changed_process_status()

```
bool child_with_changed_process_status (
            pcb_t * parent )
```

Checks if the given parent PCB has any children with a changed process status.

Checks if a child of the given parent process has a changed process status.

Definition at line 215 of file scheduler.c.

```
215                                                      {
216   for (int i = 0; i < vec_len(&current_pcbs); i++) {
217     pcb_t* child = vec_get(&current_pcbs, i);
218     if (child->par_pid == parent->pid && child->process_status != 0) {
219       return true;
220     }
221   }
222   return false;
223 }
```

4.15.1.4 delete_process_from_all_queues()

```
void delete_process_from_all_queues (
            pcb_t * pcb )
```

Deletes the given PCB from all queues.

Searches through all of the scheduler's queues and deletes the the given pcb from all of them. Notably, it does not free the pcb via calling vec_erase_no_deletor instead of vec_erase. If a particular queue does not contain the pcb, nothing occurs.

Definition at line 179 of file scheduler.c.

```
179                                                {
180   delete_process_from_all_queues_except_current(pcb);
181   delete_process_from_particular_queue(pcb, &current_pcbs);
182 }
```

4.15.1.5 delete_process_from_all_queues_except_current()

```
void delete_process_from_all_queues_except_current (
            pcb_t * pcb )
```

Deletes the given PCB from all queues except the current one.

Searches through all of the scheduler's queues except the one containing all of the current processes and deletes the given pcb from all of them Notably, it does not free the pcb via calling vec_erase_no_deletor instead of vec_↩erase. If a particular queue does not contain the pcb, nothing occurs.

Definition at line 168 of file scheduler.c.

```
168                                                            {
169   delete_process_from_particular_queue(pcb, &zero_priority_queue);
170   delete_process_from_particular_queue(pcb, &one_priority_queue);
171   delete_process_from_particular_queue(pcb, &two_priority_queue);
172   delete_process_from_particular_queue(pcb, &zombie_queue);
173   delete_process_from_particular_queue(pcb, &sleep_blocked_queue);
174 }
```

4.15.1.6 delete_process_from_particular_queue()

```
void delete_process_from_particular_queue (
            pcb_t * pcb,
            Vec * queue )
```

Deletes the given PCB from the specified queue.

Given a queue in the form of a vector, searches through it for the given pcb and deletes it from the queue if found. Notably, it does not free the pcb. Instead, the implmentation calls vec_erase_no_deletor instead of vec_erase. If the pcb isn't in the queue, this function does nothing.

Definition at line 155 of file scheduler.c.

```
155                                                               {
156   for (int i = 0; i < vec_len(queue); i++) {
157     pcb_t* curr_pcb = vec_get(queue, i);
158     if (curr_pcb->pid == pcb->pid) {
159       vec_erase_no_deletor(queue, i);
160       return;
161     }
162   }
163 }
```

4.15.1.7 free_scheduler_queues()

```
void free_scheduler_queues ( )
```

Frees the scheduler queues.

Frees the scheduler queues. This function should be called when the scheduler is no longer needed.

Definition at line 66 of file scheduler.c.

```
66                             {
67   vec_destroy(&zero_priority_queue);
68   vec_destroy(&one_priority_queue);
69   vec_destroy(&two_priority_queue);
70   vec_destroy(&zombie_queue);
71   vec_destroy(&sleep_blocked_queue);
72   vec_destroy(&current_pcbs);
73 }
```

4.15.1.8 generate_next_priority()

```
int generate_next_priority ( )
```

Generates the next priority for scheduling based on the defined probabilities.

Deterministically chooses an integer from 0, 1, 2 at the prescribed probabilites. In particular, 0 is output 1.5x more than 1, which is output 1.5x more than 2. Notably, it accounts for cases where some of the queues are empty. If all queues are empty, it'll return -1.

Definition at line 83 of file scheduler.c.

```
83                              {
84   // check if all queues are empty
85   if (vec_is_empty(&zero_priority_queue) && vec_is_empty(&one_priority_queue) &&
86       vec_is_empty(&two_priority_queue)) {
87     return -1;
88   }
89
90   int priorities_attempted = 0;
91   while (priorities_attempted < 19) {
92     int curr_pri = det_priorities_arr[curr_priority_arr_index];
93     curr_priority_arr_index = (curr_priority_arr_index + 1) % 19;
94     if (curr_pri == 0 && !vec_is_empty(&zero_priority_queue)) {
95       priorities_attempted++;
96       return 0;
97     } else if (curr_pri == 1 && !vec_is_empty(&one_priority_queue)) {
98       priorities_attempted++;
99       return 1;
100     } else if (curr_pri == 2 && !vec_is_empty(&two_priority_queue)) {
101       priorities_attempted++;
102       return 2;
103     }
104   }
105
106   return -1;  // should never reach
107 }
```

4.15.1.9 get_next_pcb()

```
pcb_t* get_next_pcb (
               int priority )
```

Gets the next PCB from the specified priority queue.

Returns the next PCB in the queue of the specified priority. or NULL if that queue is empty. Notably, it removes the PCB from the queue.

Definition at line 112 of file scheduler.c.

```
112                                    {
113   if (priority == -1) {  // all queues empty
114     return NULL;
115   }
116
117   pcb_t* next_pcb = NULL;
118   if (priority == 0) {
119     next_pcb = vec_get(&zero_priority_queue, 0);
120     vec_erase_no_deletor(&zero_priority_queue, 0);
121   } else if (priority == 1) {
122     next_pcb = vec_get(&one_priority_queue, 0);
123     vec_erase_no_deletor(&one_priority_queue, 0);
124   } else if (priority == 2) {
125     next_pcb = vec_get(&two_priority_queue, 0);
126     vec_erase_no_deletor(&two_priority_queue, 0);
127   }
128
129   return next_pcb;
130 }
```

4.15.1.10 get_pcb_in_queue()

```
pcb_t* get_pcb_in_queue (
            Vec * queue,
            pid_t pid )
```

Gets the PCB with the specified PID from the given queue.

Given a queue, searches for a particular pid inside that queue and, if found, returns the pcb_t* associated with that pid.

Definition at line 187 of file scheduler.c.

```
187                                             {
188   for (int i = 0; i < vec_len(queue); i++) {
189     pcb_t* curr_pcb = vec_get(queue, i);
190     if (curr_pcb->pid == pid) {
191       return curr_pcb;
192     }
193   }
194 
195   return NULL;
196 }
```

4.15.1.11 handle_signal()

```
void handle_signal (
            pcb_t * pcb,
            int signal )
```

Handles the specified signal for the given PCB.

Handles a signal for a given process.

Definition at line 235 of file scheduler.c.

```
235                                             {
236   switch (signal) {
237     case 0:  // P_SIGSTOP
238       if (pcb->process_state == 'R' || pcb->process_state == 'B') {
239         pcb->process_state = 'S';
240         log_generic_event('s', pcb->pid, pcb->priority, pcb->cmd_str);
241         delete_process_from_all_queues_except_current(pcb);
242         pcb->process_status = 21;  // STOPPED_BY_SIG
243       }
244       pcb->signals[0] = false;
245       break;
246     case 1:                           // P_SIGCONT
247       if (pcb->process_state == 'S') {  // Only continue if stopped
248         if (pcb->is_sleeping) {
249           pcb->process_state = 'B';
250           delete_process_from_all_queues_except_current(pcb);
251           put_pcb_into_correct_queue(pcb);
252         } else {
253           pcb->process_state = 'R';
254           delete_process_from_all_queues_except_current(pcb);
255           put_pcb_into_correct_queue(pcb);
256         }
257         log_generic_event('c', pcb->pid, pcb->priority, pcb->cmd_str);
258         pcb->process_status = 23;  // CONT_BY_SIG
259       }
260       pcb->signals[1] = false;
261       break;
262     case 2:                           // P_SIGTERM
263       if (pcb->process_state != 'Z') {  // Don't terminate if already zombie
264         pcb->process_state = 'Z';
265         pcb->process_status = 22;  // TERM_BY_SIG
266         log_generic_event('Z', pcb->pid, pcb->priority, pcb->cmd_str);
267         delete_process_from_all_queues_except_current(pcb);
268         put_pcb_into_correct_queue(pcb);
269         pcb->process_status = 22;  // TERM_BY_SIG
270       }
271       pcb->signals[2] = false;
272       break;
273   }
274 }
```

4.15.1.12 initialize_scheduler_queues()

```
void initialize_scheduler_queues ( )
```

Initializes the scheduler queues.

Initializes the scheduler queues. This function should be called before any other scheduler functions are called.

Note

The deconstructors for the queues are set to NULL to prevent double freeing when exiting PennOS.

Definition at line 54 of file scheduler.c.

```
54                                     {
55   zero_priority_queue = vec_new(0, NULL);
56   one_priority_queue = vec_new(0, NULL);
57   two_priority_queue = vec_new(0, NULL);
58   zombie_queue = vec_new(0, NULL);
59   sleep_blocked_queue = vec_new(0, NULL);
60   current_pcbs = vec_new(0, free_pcb);
61 }
```

4.15.1.13 put_pcb_into_correct_queue()

```
void put_pcb_into_correct_queue (
              pcb_t * pcb )
```

Puts the given PCB into the correct queue based on its priority and state.

Puts the given pcb struct pointer into its appropriate queue. Notably, it solely uses the pcb's interal fields to determine the correct queue (priority and state).

Definition at line 136 of file scheduler.c.

```
136                                              {
137   if (pcb->process_state == 'R') {
138     if (pcb->priority == 0) {
139       vec_push_back(&zero_priority_queue, pcb);
140     } else if (pcb->priority == 1) {
141       vec_push_back(&one_priority_queue, pcb);
142     } else if (pcb->priority == 2) {
143       vec_push_back(&two_priority_queue, pcb);
144     }
145   } else if (pcb->process_state == 'Z') {
146     vec_push_back(&zombie_queue, pcb);
147   } else if (pcb->process_state == 'B' || pcb->is_sleeping) {
148     vec_push_back(&sleep_blocked_queue, pcb);
149   }
150 }
```

4.15.1.14 s_shutdown_pennos()

```
void s_shutdown_pennos (
              void  )
```

Shuts down the scheduler and cleans up resources.

Shuts down the PennOS scheduler.

Definition at line 279 of file scheduler.c.

```
279                              {
280   scheduling_done = true;
281 }
```

4.15.1.15 scheduler()

```
void scheduler ( )
```

The main scheduler function for PennOS.

This function manages process scheduling, signal handling, and timer-based preemption. It ensures that processes are executed based on their priority and handles signals for both the currently running process and other processes.

Definition at line 286 of file scheduler.c.

```
286                {
287   int curr_priority_queue_num;
288 
289   // mask for while scheduler is waiting for alarm
290   sigset_t suspend_set;
291   sigfillset(&suspend_set);
292   sigdelset(&suspend_set, SIGALRM);
293 
294   // ensure sigarlm doesn't terminate the process
295   struct sigaction act = (struct sigaction){
296       .sa_handler = alarm_handler,
297       .sa_mask = suspend_set,
298       .sa_flags = SA_RESTART,
299   };
300   sigaction(SIGALRM, &act, NULL);
301 
302   // make sure SIGALRM is unblocked
303   sigset_t alarm_set;
304   sigemptyset(&alarm_set);
305   sigaddset(&alarm_set, SIGALRM);
306   pthread_sigmask(SIG_UNBLOCK, &alarm_set, NULL);
307 
308   struct itimerval it;
309   it.it_interval = (struct timeval){.tv_usec = hundred_millisec};
310   it.it_value = it.it_interval;
311   setitimer(ITIMER_REAL, &it, NULL);
312 
313   while (!scheduling_done) {
314     // handle signals for the currently running process
315     if (current_running_pcb != NULL) {
316       for (int i = 0; i < 3; i++) {
317         if (current_running_pcb->signals[i]) {
318           handle_signal(current_running_pcb, i);
319           // If process was terminated, don't continue scheduling it
320           if (current_running_pcb->process_state != 'R') {
321             current_running_pcb = NULL;
322             break;
323           }
324         }
325       }
326     }
327 
328     // handle signals for all other processes (currently running or not)
329     for (int i = 0; i < vec_len(&current_pcbs); i++) {
330       pcb_t* curr_pcb = vec_get(&current_pcbs, i);
331       for (int j = 0; j < 3; j++) {
332         if (curr_pcb->signals[j]) {
333           handle_signal(curr_pcb, j);
334         }
335       }
336     }
337 
338     // Check sleep/blocked queue to move processes back to scheduable queues
339     for (int i = 0; i < vec_len(&sleep_blocked_queue); i++) {
340       pcb_t* blocked_proc = vec_get(&sleep_blocked_queue, i);
341       bool make_runnable = false;
342       if (blocked_proc->is_sleeping &&
343           blocked_proc->time_to_wake <= tick_counter) {
344         blocked_proc->is_sleeping = false;
345         blocked_proc->time_to_wake = -1;
346         blocked_proc->signals[2] = false;  // Unlikely, but reset signal
347         make_runnable = true;
348       } else if (blocked_proc->is_sleeping &&
349                  blocked_proc->signals[2]) {  // P_SIGTERM received
350         blocked_proc->is_sleeping = false;
351         blocked_proc->process_state = 'Z';
352         blocked_proc->process_status = 22;  // TERM_BY_SIG
353         blocked_proc->signals[2] = false;
354         delete_process_from_all_queues_except_current(blocked_proc);
355         put_pcb_into_correct_queue(blocked_proc);
356         log_generic_event('Z', blocked_proc->pid, blocked_proc->priority,
357                           blocked_proc->cmd_str);
```

```
        i--;
      } else if (child_in_zombie_queue(blocked_proc)) {
        make_runnable = true;
      } else if (child_with_changed_process_status(blocked_proc)) {
        make_runnable = true;
      }

      if (make_runnable) {
        blocked_proc->process_state = 'R';
        vec_erase_no_deletor(&sleep_blocked_queue, i);
        delete_process_from_all_queues_except_current(blocked_proc);
        put_pcb_into_correct_queue(blocked_proc);
        log_generic_event('U', blocked_proc->pid, blocked_proc->priority,
                          blocked_proc->cmd_str);
        i--;
      }
    }

    curr_priority_queue_num = generate_next_priority();

    current_running_pcb = get_next_pcb(curr_priority_queue_num);
    if (current_running_pcb == NULL) {
      sigsuspend(&suspend_set);  // idle until signal received
      continue;
    }

    log_scheduling_event(current_running_pcb->pid, curr_priority_queue_num,
                         current_running_pcb->cmd_str);

    if (spthread_continue(current_running_pcb->thread_handle) != 0 &&
        errno != EINTR) {
      perror("spthread_continue failed in scheduler");
    }
    sigsuspend(&suspend_set);
    if (spthread_suspend(current_running_pcb->thread_handle) != 0 &&
        errno != EINTR) {
      perror("spthread_suspend failed in scheduler");
    }
    put_pcb_into_correct_queue(current_running_pcb);
  }
}
```

4.15.2 Variable Documentation

4.15.2.1 curr_priority_arr_index

```
int curr_priority_arr_index = 0
```

Definition at line 40 of file scheduler.c.

4.15.2.2 current_pcbs

```
Vec current_pcbs
```

Definition at line 30 of file scheduler.c.

4.15.2.3 current_running_pcb

```
pcb_t* current_running_pcb
```

Definition at line 38 of file scheduler.c.

4.15.2.4 det_priorities_arr

```
int det_priorities_arr[19]
```

Initial value:

```
= {0, 1, 2, 0, 0, 1, 0, 1, 2, 0,
                              0, 1, 2, 0, 1, 0, 0, 1, 2}
```

Definition at line 41 of file scheduler.c.

4.15.2.5 log_fd

```
int log_fd
```

Definition at line 36 of file scheduler.c.

4.15.2.6 one_priority_queue

```
Vec one_priority_queue
```

Definition at line 25 of file scheduler.c.

4.15.2.7 sleep_blocked_queue

```
Vec sleep_blocked_queue
```

Definition at line 28 of file scheduler.c.

4.15.2.8 tick_counter

```
int tick_counter = 0
```

Definition at line 35 of file scheduler.c.

4.15.2.9 two_priority_queue

```
Vec two_priority_queue
```

Definition at line 26 of file scheduler.c.

4.15.2.10 zero_priority_queue

```
Vec zero_priority_queue
```

Definition at line 24 of file scheduler.c.

4.15.2.11 zombie_queue

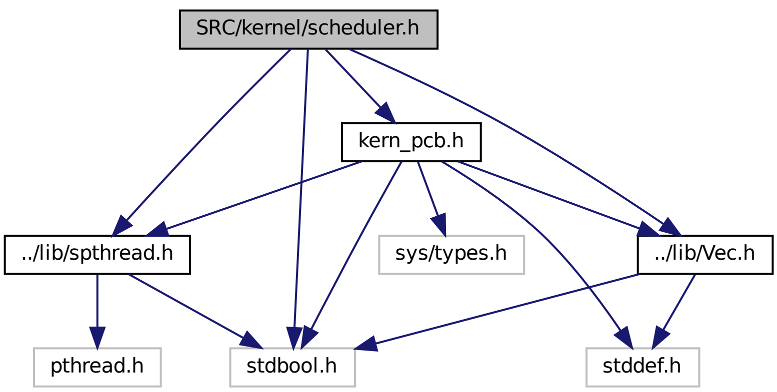
```
Vec zombie_queue
```

Definition at line 27 of file scheduler.c.

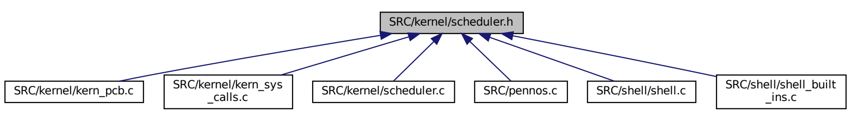
4.16 SRC/kernel/scheduler.h File Reference

```
#include <stdbool.h>
#include "../lib/Vec.h"
#include "../lib/spthread.h"
#include "kern_pcb.h"
```

Include dependency graph for scheduler.h:



This graph shows which files directly or indirectly include this file:



Functions

- void initialize_scheduler_queues ()

  Initializes the scheduler queues. This function should be called before any other scheduler functions are called.
- void free_scheduler_queues ()

  Frees the scheduler queues. This function should be called when the scheduler is no longer needed.
- int generate_next_priority ()

  Deterministically chooses an integer from 0, 1, 2 at the prescribed probabilites. In particular, 0 is output 1.5x more than 1, which is output 1.5x more than 2. Notably, it accounts for cases where some of the queues are empty. If all queues are empty, it'll return -1.
- pcb_t * get_next_pcb (int priority)

  Returns the next PCB in the queue of the specified priority. or NULL if that queue is empty. Notably, it removes the PCB from the queue.
- void put_pcb_into_correct_queue (pcb_t *pcb)

  Puts the given pcb struct pointer into its appropriate queue. Notably, it solely uses the pcb's interal fields to determine the correct queue (priority and state).
- void delete_process_from_particular_queue (pcb_t *pcb, Vec *queue)

  Given a queue in the form of a vector, searches through it for the given pcb and deletes it from the queue if found. Notably, it does not free the pcb. Instead, the implmentation calls vec_erase_no_deletor instead of vec_erase. If the pcb isn't in the queue, this function does nothing.
- void delete_process_from_all_queues_except_current (pcb_t *pcb)

  Searches through all of the scheduler's queues except the one containing all of the current processes and deletes the given pcb from all of them Notably, it does not free the pcb via calling vec_erase_no_deletor instead of vec_erase. If a particular queue does not contain the pcb, nothing occurs.
- void delete_process_from_all_queues (pcb_t *pcb)

  Searches through all of the scheduler's queues and deletes the the given pcb from all of them. Notably, it does not free the pcb via calling vec_erase_no_deletor instead of vec_erase. If a particular queue does not contain the pcb, nothing occurs.
- pcb_t * get_pcb_in_queue (Vec *queue, pid_t pid)

  Given a queue, searches for a particular pid inside that queue and, if found, returns the pcb_t associated with that pid.*
- bool child_in_zombie_queue (pcb_t *parent)

  Checks if a child of the given parent process is in the zombie queue.
- bool child_with_changed_process_status (pcb_t *parent)

  Checks if a child of the given parent process has a changed process status.
- void alarm_handler (int signum)

  Handles the alarm signal.
- void handle_signal (pcb_t *pcb, int signal)

  Handles a signal for a given process.
- void scheduler ()

  The main scheduler function for PennOS.
- void s_shutdown_pennos ()

  Shuts down the PennOS scheduler.

4.16.1 Function Documentation

4.16.1.1 alarm_handler()

```
void alarm_handler (
             int signum )
```

Handles the alarm signal.

This function is triggered when the alarm signal is received. It increments the global tick counter, which is used for scheduling and timing purposes.

Parameters

signum	The signal number (unused in this implementation).

Handles the alarm signal.

Definition at line 228 of file scheduler.c.

```
228                              {
229   tick_counter++;
230 }
```

4.16.1.2 child_in_zombie_queue()

```
bool child_in_zombie_queue (
            pcb_t * parent )
```

Checks if a child of the given parent process is in the zombie queue.

This function iterates through the zombie queue to determine if any process in the queue has the given parent process as its parent.

Parameters

parent	A pointer to the parent PCB.

Returns

true if a child of the parent is in the zombie queue, false otherwise.

Checks if a child of the given parent process is in the zombie queue.

Definition at line 201 of file scheduler.c.

```
201                                           {
202   for (int i = 0; i < vec_len(&zombie_queue); i++) {
203     pcb_t* child = vec_get(&zombie_queue, i);
204     if (child->par_pid == parent->pid) {
205       return true;
206     }
207   }
208   return false;
209 }
```

4.16.1.3 child_with_changed_process_status()

```
bool child_with_changed_process_status (
            pcb_t * parent )
```

Checks if a child of the given parent process has a changed process status.

This function iterates through the current PCBs to determine if any child of the given parent process has a non-zero process status, indicating a change.

Parameters

parent	A pointer to the parent PCB.

Returns

true if a child of the parent has a changed process status, false otherwise.

Checks if a child of the given parent process has a changed process status.

Definition at line 215 of file scheduler.c.

```
215                                                         {
216   for (int i = 0; i < vec_len(&current_pcbs); i++) {
217     pcb_t* child = vec_get(&current_pcbs, i);
218     if (child->par_pid == parent->pid && child->process_status != 0) {
219       return true;
220     }
221   }
222   return false;
223 }
```

4.16.1.4 delete_process_from_all_queues()

```
void delete_process_from_all_queues (
            pcb_t * pcb )
```

Searches through all of the scheduler's queues and deletes the the given pcb from all of them. Notably, it does not free the pcb via calling vec_erase_no_deletor instead of vec_erase. If a particular queue does not contain the pcb, nothing occurs.

Parameters

pcb	a pointer to the pcb with the pid to delete

Searches through all of the scheduler's queues and deletes the the given pcb from all of them. Notably, it does not free the pcb via calling vec_erase_no_deletor instead of vec_erase. If a particular queue does not contain the pcb, nothing occurs.

Definition at line 179 of file scheduler.c.

```
179                                                  {
180   delete_process_from_all_queues_except_current(pcb);
181   delete_process_from_particular_queue(pcb, &current_pcbs);
182 }
```

4.16.1.5 delete_process_from_all_queues_except_current()

```
void delete_process_from_all_queues_except_current (
            pcb_t * pcb )
```

Searches through all of the scheduler's queues except the one containing all of the current processes and deletes the given pcb from all of them Notably, it does not free the pcb via calling vec_erase_no_deletor instead of vec_erase. If a particular queue does not contain the pcb, nothing occurs.

Parameters

pcb	a pointer to the pcb with the pid to delete

Searches through all of the scheduler's queues except the one containing all of the current processes and deletes the given pcb from all of them Notably, it does not free the pcb via calling vec_erase_no_deletor instead of vec_erase. If a particular queue does not contain the pcb, nothing occurs.

Definition at line 168 of file scheduler.c.

```
168                                                                {
169   delete_process_from_particular_queue(pcb, &zero_priority_queue);
170   delete_process_from_particular_queue(pcb, &one_priority_queue);
171   delete_process_from_particular_queue(pcb, &two_priority_queue);
172   delete_process_from_particular_queue(pcb, &zombie_queue);
173   delete_process_from_particular_queue(pcb, &sleep_blocked_queue);
174 }
```

4.16.1.6 delete_process_from_particular_queue()

```
void delete_process_from_particular_queue (
            pcb_t * pcb,
            Vec * queue )
```

Given a queue in the form of a vector, searches through it for the given pcb and deletes it from the queue if found. Notably, it does not free the pcb. Instead, the implmentation calls vec_erase_no_deletor instead of vec_erase. If the pcb isn't in the queue, this function does nothing.

Given a queue in the form of a vector, searches through it for the given pcb and deletes it from the queue if found. Notably, it does not free the pcb. Instead, the implmentation calls vec_erase_no_deletor instead of vec_erase. If the pcb isn't in the queue, this function does nothing.

Definition at line 155 of file scheduler.c.

```
155                                                                   {
156   for (int i = 0; i < vec_len(queue); i++) {
157     pcb_t* curr_pcb = vec_get(queue, i);
158     if (curr_pcb->pid == pcb->pid) {
159       vec_erase_no_deletor(queue, i);
160       return;
161     }
162   }
163 }
```

4.16.1.7 free_scheduler_queues()

```
void free_scheduler_queues ( )
```

Frees the scheduler queues. This function should be called when the scheduler is no longer needed.

Frees the scheduler queues. This function should be called when the scheduler is no longer needed.

Definition at line 66 of file scheduler.c.

```
66                              {
67   vec_destroy(&zero_priority_queue);
68   vec_destroy(&one_priority_queue);
69   vec_destroy(&two_priority_queue);
70   vec_destroy(&zombie_queue);
71   vec_destroy(&sleep_blocked_queue);
72   vec_destroy(&current_pcbs);
73 }
```

4.16.1.8 generate_next_priority()

```
int generate_next_priority ( )
```

Deterministically chooses an integer from 0, 1, 2 at the prescribed probabilites. In particular, 0 is output 1.5x more than 1, which is output 1.5x more than 2. Notably, it accounts for cases where some of the queues are empty. If all queues are empty, it'll return -1.

Precondition

assumes that at least one of the scheduler queues in non-empty

Returns

int 0, 1, or 2 for priority or -1 to signify that all queues are empty

Deterministically chooses an integer from 0, 1, 2 at the prescribed probabilites. In particular, 0 is output 1.5x more than 1, which is output 1.5x more than 2. Notably, it accounts for cases where some of the queues are empty. If all queues are empty, it'll return -1.

Definition at line 83 of file scheduler.c.

```
83                                {
84    // check if all queues are empty
85    if (vec_is_empty(&zero_priority_queue) && vec_is_empty(&one_priority_queue) &&
86        vec_is_empty(&two_priority_queue)) {
87      return -1;
88    }
89
90    int priorities_attempted = 0;
91    while (priorities_attempted < 19) {
92      int curr_pri = det_priorities_arr[curr_priority_arr_index];
93      curr_priority_arr_index = (curr_priority_arr_index + 1) % 19;
94      if (curr_pri == 0 && !vec_is_empty(&zero_priority_queue)) {
95        priorities_attempted++;
96        return 0;
97      } else if (curr_pri == 1 && !vec_is_empty(&one_priority_queue)) {
98        priorities_attempted++;
99        return 1;
100     } else if (curr_pri == 2 && !vec_is_empty(&two_priority_queue)) {
101       priorities_attempted++;
102       return 2;
103     }
104   }
105
106   return -1;  // should never reach
107 }
```

4.16.1.9 get_next_pcb()

```
pcb_t* get_next_pcb (
              int priority )
```

Returns the next PCB in the queue of the specified priority. or NULL if that queue is empty. Notably, it removes the PCB from the queue.

Parameters

priority	queue priority to get next PCB from, or -1 if none

Returns

a ptr to the next pcb struct in queue or NULL if the queue is empty

Returns the next PCB in the queue of the specified priority. or NULL if that queue is empty. Notably, it removes the PCB from the queue.

Definition at line 112 of file scheduler.c.

```
112                                   {
113   if (priority == -1) {  // all queues empty
114     return NULL;
115   }
116
117   pcb_t* next_pcb = NULL;
118   if (priority == 0) {
119     next_pcb = vec_get(&zero_priority_queue, 0);
120     vec_erase_no_deletor(&zero_priority_queue, 0);
121   } else if (priority == 1) {
122     next_pcb = vec_get(&one_priority_queue, 0);
123     vec_erase_no_deletor(&one_priority_queue, 0);
124   } else if (priority == 2) {
125     next_pcb = vec_get(&two_priority_queue, 0);
126     vec_erase_no_deletor(&two_priority_queue, 0);
127   }
128
129   return next_pcb;
130 }
```

4.16.1.10 get_pcb_in_queue()

```
pcb_t* get_pcb_in_queue (
            Vec * queue,
            pid_t pid )
```

Given a queue, searches for a particular pid inside that queue and, if found, returns the pcb_t* associated with that pid.

Parameters

queue	the queue of pcb_t* ptrs to search
pid	the pid to search for

Returns

a ptr to the pcb w/ the desired pid if found, NULL otherwise

Given a queue, searches for a particular pid inside that queue and, if found, returns the pcb_t* associated with that pid.

Definition at line 187 of file scheduler.c.

```
187                                                {
188   for (int i = 0; i < vec_len(queue); i++) {
189     pcb_t* curr_pcb = vec_get(queue, i);
190     if (curr_pcb->pid == pid) {
191       return curr_pcb;
192     }
193   }
194
195   return NULL;
196 }
```

4.16.1.11 handle_signal()

```
void handle_signal (
            pcb_t * pcb,
            int signal )
```

Handles a signal for a given process.

This function processes a signal sent to a process and updates its state accordingly. Supported signals include:

- P_SIGSTOP: Stops the process.
- P_SIGCONT: Continues a stopped process.
- P_SIGTERM: Terminates the process.

Parameters

pcb	A pointer to the PCB of the process receiving the signal.
signal	The signal to handle (0 for P_SIGSTOP, 1 for P_SIGCONT, 2 for P_SIGTERM).

Handles a signal for a given process.

Definition at line 235 of file scheduler.c.

```
235                                         {
236   switch (signal) {
237     case 0:  // P_SIGSTOP
238       if (pcb->process_state == ’R’ || pcb->process_state == ’B’) {
239         pcb->process_state = ’S’;
240         log_generic_event(’s’, pcb->pid, pcb->priority, pcb->cmd_str);
241         delete_process_from_all_queues_except_current(pcb);
242         pcb->process_status = 21;  // STOPPED_BY_SIG
243       }
244       pcb->signals[0] = false;
245       break;
246     case 1:                             // P_SIGCONT
247       if (pcb->process_state == ’S’) {  // Only continue if stopped
248         if (pcb->is_sleeping) {
249           pcb->process_state = ’B’;
250           delete_process_from_all_queues_except_current(pcb);
251           put_pcb_into_correct_queue(pcb);
252         } else {
253           pcb->process_state = ’R’;
254           delete_process_from_all_queues_except_current(pcb);
255           put_pcb_into_correct_queue(pcb);
256         }
257         log_generic_event(’c’, pcb->pid, pcb->priority, pcb->cmd_str);
258         pcb->process_status = 23;  // CONT_BY_SIG
259       }
260       pcb->signals[1] = false;
261       break;
262     case 2:                             // P_SIGTERM
263       if (pcb->process_state != ’Z’) {  // Don’t terminate if already zombie
264         pcb->process_state = ’Z’;
265         pcb->process_status = 22;  // TERM_BY_SIG
266         log_generic_event(’Z’, pcb->pid, pcb->priority, pcb->cmd_str);
267         delete_process_from_all_queues_except_current(pcb);
268         put_pcb_into_correct_queue(pcb);
269         pcb->process_status = 22;  // TERM_BY_SIG
270       }
271       pcb->signals[2] = false;
272       break;
273   }
274 }
```

4.16.1.12 initialize_scheduler_queues()

```
void initialize_scheduler_queues ( )
```

Initializes the scheduler queues. This function should be called before any other scheduler functions are called.

Initializes the scheduler queues. This function should be called before any other scheduler functions are called.

Note

The deconstructors for the queues are set to NULL to prevent double freeing when exiting PennOS.

Definition at line 54 of file scheduler.c.

```
54                                    {
55   zero_priority_queue = vec_new(0, NULL);
56   one_priority_queue = vec_new(0, NULL);
57   two_priority_queue = vec_new(0, NULL);
58   zombie_queue = vec_new(0, NULL);
59   sleep_blocked_queue = vec_new(0, NULL);
60   current_pcbs = vec_new(0, free_pcb);
61 }
```

4.16.1.13 put_pcb_into_correct_queue()

```
void put_pcb_into_correct_queue (
              pcb_t * pcb )
```

Puts the given pcb struct pointer into its appropriate queue. Notably, it solely uses the pcb's interal fields to determine the correct queue (priority and state).

Puts the given pcb struct pointer into its appropriate queue. Notably, it solely uses the pcb's interal fields to determine the correct queue (priority and state).

Definition at line 136 of file scheduler.c.

```
136                                              {
137   if (pcb->process_state == 'R') {
138     if (pcb->priority == 0) {
139       vec_push_back(&zero_priority_queue, pcb);
140     } else if (pcb->priority == 1) {
141       vec_push_back(&one_priority_queue, pcb);
142     } else if (pcb->priority == 2) {
143       vec_push_back(&two_priority_queue, pcb);
144     }
145   } else if (pcb->process_state == 'Z') {
146     vec_push_back(&zombie_queue, pcb);
147   } else if (pcb->process_state == 'B' || pcb->is_sleeping) {
148     vec_push_back(&sleep_blocked_queue, pcb);
149   }
150 }
```

4.16.1.14 s_shutdown_pennos()

```
void s_shutdown_pennos (
              void )
```

Shuts down the PennOS scheduler.

This function sets the scheduling_done flag to true, signaling the scheduler to terminate its loop and shut down.

Shuts down the PennOS scheduler.

Definition at line 279 of file scheduler.c.

```
279                              {
280   scheduling_done = true;
281 }
```

4.16.1.15 scheduler()

```
void scheduler ( )
```

The main scheduler function for PennOS.

This function manages process scheduling, signal handling, and timer-based preemption. It ensures that processes are executed based on their priority and handles signals for both the currently running process and other processes.

Definition at line 286 of file scheduler.c.

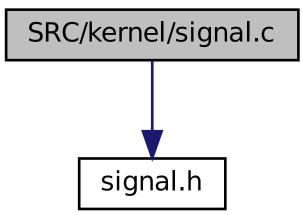
```
286                {
287   int curr_priority_queue_num;
288
289   // mask for while scheduler is waiting for alarm
290   sigset_t suspend_set;
291   sigfillset(&suspend_set);
292   sigdelset(&suspend_set, SIGALRM);
293
294   // ensure sigarlm doesn't terminate the process
295   struct sigaction act = (struct sigaction){
296       .sa_handler = alarm_handler,
297       .sa_mask = suspend_set,
298       .sa_flags = SA_RESTART,
299   };
300   sigaction(SIGALRM, &act, NULL);
301
302   // make sure SIGALRM is unblocked
303   sigset_t alarm_set;
304   sigemptyset(&alarm_set);
305   sigaddset(&alarm_set, SIGALRM);
306   pthread_sigmask(SIG_UNBLOCK, &alarm_set, NULL);
307
308   struct itimerval it;
309   it.it_interval = (struct timeval){.tv_usec = hundred_millisec};
310   it.it_value = it.it_interval;
311   setitimer(ITIMER_REAL, &it, NULL);
312
313   while (!scheduling_done) {
314     // handle signals for the currently running process
315     if (current_running_pcb != NULL) {
316       for (int i = 0; i < 3; i++) {
317         if (current_running_pcb->signals[i]) {
318           handle_signal(current_running_pcb, i);
319           // If process was terminated, don't continue scheduling it
320           if (current_running_pcb->process_state != 'R') {
321             current_running_pcb = NULL;
322             break;
323           }
324         }
325       }
326     }
327
328     // handle signals for all other processes (currently running or not)
329     for (int i = 0; i < vec_len(&current_pcbs); i++) {
330       pcb_t* curr_pcb = vec_get(&current_pcbs, i);
331       for (int j = 0; j < 3; j++) {
332         if (curr_pcb->signals[j]) {
333           handle_signal(curr_pcb, j);
334         }
335       }
336     }
337
338     // Check sleep/blocked queue to move processes back to scheduable queues
339     for (int i = 0; i < vec_len(&sleep_blocked_queue); i++) {
340       pcb_t* blocked_proc = vec_get(&sleep_blocked_queue, i);
341       bool make_runnable = false;
342       if (blocked_proc->is_sleeping &&
343           blocked_proc->time_to_wake <= tick_counter) {
344         blocked_proc->is_sleeping = false;
345         blocked_proc->time_to_wake = -1;
346         blocked_proc->signals[2] = false;  // Unlikely, but reset signal
347         make_runnable = true;
348       } else if (blocked_proc->is_sleeping &&
349                  blocked_proc->signals[2]) {  // P_SIGTERM received
350         blocked_proc->is_sleeping = false;
351         blocked_proc->process_state = 'Z';
352         blocked_proc->process_status = 22;  // TERM_BY_SIG
353         blocked_proc->signals[2] = false;
354         delete_process_from_all_queues_except_current(blocked_proc);
355         put_pcb_into_correct_queue(blocked_proc);
356         log_generic_event('Z', blocked_proc->pid, blocked_proc->priority,
357                           blocked_proc->cmd_str);
```

```
        i--;
      } else if (child_in_zombie_queue(blocked_proc)) {
        make_runnable = true;
      } else if (child_with_changed_process_status(blocked_proc)) {
        make_runnable = true;
      }

      if (make_runnable) {
        blocked_proc->process_state = 'R';
        vec_erase_no_deletor(&sleep_blocked_queue, i);
        delete_process_from_all_queues_except_current(blocked_proc);
        put_pcb_into_correct_queue(blocked_proc);
        log_generic_event('U', blocked_proc->pid, blocked_proc->priority,
                          blocked_proc->cmd_str);
        i--;
      }
    }

    curr_priority_queue_num = generate_next_priority();

    current_running_pcb = get_next_pcb(curr_priority_queue_num);
    if (current_running_pcb == NULL) {
      sigsuspend(&suspend_set);  // idle until signal received
      continue;
    }

    log_scheduling_event(current_running_pcb->pid, curr_priority_queue_num,
                         current_running_pcb->cmd_str);

    if (spthread_continue(current_running_pcb->thread_handle) != 0 &&
        errno != EINTR) {
      perror("spthread_continue failed in scheduler");
    }
    sigsuspend(&suspend_set);
    if (spthread_suspend(current_running_pcb->thread_handle) != 0 &&
        errno != EINTR) {
      perror("spthread_suspend failed in scheduler");
    }
    put_pcb_into_correct_queue(current_running_pcb);
  }
}
```

4.17 SRC/kernel/signal.c File Reference

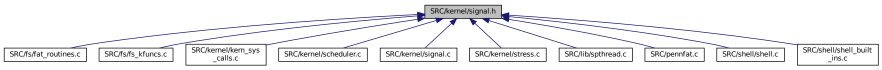
`#include <signal.h>`

Include dependency graph for signal.c:



4.18 SRC/kernel/signal.h File Reference

This graph shows which files directly or indirectly include this file:



Macros

- #define P_SIGSTOP 0

    Signals for PennOS.
- #define P_SIGCONT 1
- #define P_SIGTERM 2
- #define EXITED_NORMALLY 20

    Status definitions.
- #define STOPPED_BY_SIG 21
- #define TERM_BY_SIG 22
- #define CONT_BY_SIG 23
- #define P_WIFEXITED(status) ((status) == EXITED_NORMALLY)

    User-level macros for waitpid status.
- #define P_WIFSTOPPED(status) ((status) == STOPPED_BY_SIG)
- #define P_WIFSIGNALED(status) ((status) == TERM_BY_SIG)

4.18.1 Macro Definition Documentation

4.18.1.1 CONT_BY_SIG

```
#define CONT_BY_SIG 23
```

Definition at line 17 of file signal.h.

4.18.1.2 EXITED_NORMALLY

```
#define EXITED_NORMALLY 20
```

Status definitions.

Definition at line 14 of file signal.h.

4.18.1.3 P_SIGCONT

```
#define P_SIGCONT 1
```

Definition at line 8 of file signal.h.

4.18.1.4 P_SIGSTOP

```
#define P_SIGSTOP 0
```

Signals for PennOS.

Definition at line 7 of file signal.h.

4.18.1.5 P_SIGTERM

```
#define P_SIGTERM 2
```

Definition at line 9 of file signal.h.

4.18.1.6 P_WIFEXITED

```
#define P_WIFEXITED(
              status ) ((status) == EXITED_NORMALLY)
```

User-level macros for waitpid status.

Definition at line 22 of file signal.h.

4.18.1.7 P_WIFSIGNALED

```
#define P_WIFSIGNALED(
              status ) ((status) == TERM_BY_SIG)
```

Definition at line 24 of file signal.h.

4.18.1.8 P_WIFSTOPPED

```
#define P_WIFSTOPPED(
              status ) ((status) == STOPPED_BY_SIG)
```

Definition at line 23 of file signal.h.

4.18.1.9 STOPPED_BY_SIG

```
#define STOPPED_BY_SIG 21
```

Definition at line 15 of file signal.h.

4.18.1.10 TERM_BY_SIG

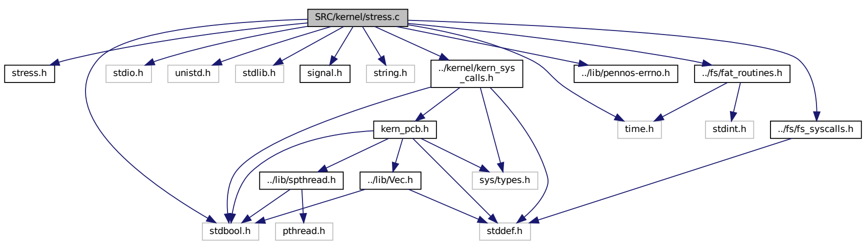
```
#define TERM_BY_SIG 22
```

Definition at line 16 of file signal.h.

4.19 SRC/kernel/stress.c File Reference

```
#include "stress.h"
#include <stdbool.h>
#include <stdio.h>
#include <unistd.h>
#include <stdlib.h>
#include <signal.h>
#include <string.h>
#include <time.h>
#include "../kernel/kern_sys_calls.h"
#include "../lib/pennos-errno.h"
#include "../fs/fs_syscalls.h"
#include "../fs/fat_routines.h"
```

Include dependency graph for stress.c:



Functions

- void ∗ hang (void ∗arg)
- void ∗ nohang (void ∗arg)
- void ∗ recur (void ∗arg)
- void ∗ crash (void ∗arg)

4.19.1 Function Documentation

4.19.1.1 crash()

```
void* crash (
            void * arg )
```

Definition at line 233 of file stress.c.

```
233                         {
234     // This one only works on a file system big enough to hold 5480 bytes
235     crash_main();
236     s_exit();
237     return NULL;
238   }
```

4.19.1.2 hang()

```
void* hang (
            void * arg )
```

Definition at line 215 of file stress.c.

```
215                        {
216     spawn(false);
217     s_exit();
218     return NULL;
219   }
```

4.19.1.3 nohang()

```
void* nohang (
            void * arg )
```

Definition at line 221 of file stress.c.

```
221                          {
222      spawn(true);
223      s_exit();
224      return NULL;
225   }
```

4.19.1.4 recur()

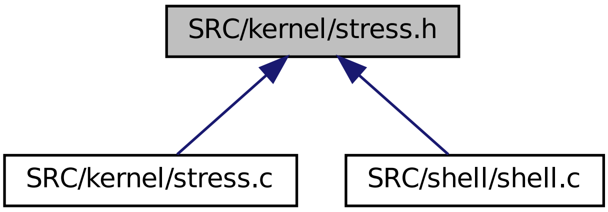
```
void* recur (
            void * arg )
```

Definition at line 227 of file stress.c.

```
227                         {
228     spawn_r(NULL);
229     s_exit();
230     return NULL;
231 }
```

4.20 SRC/kernel/stress.h File Reference

This graph shows which files directly or indirectly include this file:



Functions

- void ∗ hang (void ∗)
- void ∗ nohang (void ∗)
- void ∗ recur (void ∗)
- void ∗ crash (void ∗)

4.20.1 Function Documentation

4.20.1.1 crash()

```
void* crash (
            void * arg )
```

Definition at line 233 of file stress.c.

```
233                         {
234     // This one only works on a file system big enough to hold 5480 bytes
235     crash_main();
236     s_exit();
237     return NULL;
238 }
```

4.20.1.2 hang()

```
void* hang (
            void * arg )
```

Definition at line 215 of file stress.c.

```
215                         {
216     spawn(false);
217     s_exit();
218     return NULL;
219 }
```

4.20.1.3 nohang()

```
void* nohang (
            void * arg )
```

Definition at line 221 of file stress.c.

```
221                           {
222     spawn(true);
223     s_exit();
224     return NULL;
225 }
```

4.20.1.4 recur()

```
void* recur (
            void * arg )
```

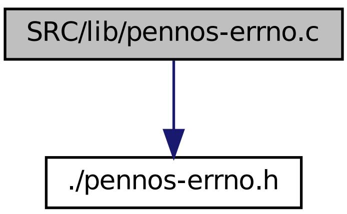
Definition at line 227 of file stress.c.

```
227                          {
228     spawn_r(NULL);
229     s_exit();
230     return NULL;
231 }
```

4.21 SRC/lib/pennos-errno.c File Reference

`#include "./pennos-errno.h"`

Include dependency graph for pennos-errno.c:



Variables

- int P_ERRNO = 0

4.21.1 Variable Documentation

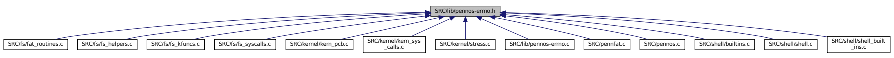
4.21.1.1 P_ERRNO

```
int P_ERRNO = 0
```

Definition at line 8 of file pennos-errno.c.

4.22 SRC/lib/pennos-errno.h File Reference

This graph shows which files directly or indirectly include this file:



Macros

- #define P_ENOENT 1
- #define P_EBADF 2
- #define P_EPERM 3
- #define P_EINVAL 4
- #define P_EEXIST 5
- #define P_EBUSY 6
- #define P_EFULL 7
- #define P_EFS_NOT_MOUNTED 8
- #define P_EINTR 9
- #define P_ENULL 10
- #define P_EREAD 11
- #define P_ELSEEK 12
- #define P_EMAP 13
- #define P_EFUNC 14
- #define P_EOPEN 15
- #define P_EMALLOC 16
- #define P_ESIGNAL 17
- #define P_EWRITE 18
- #define P_ECLOSE 19
- #define P_EPARSE 20
- #define P_ECOMMAND 21
- #define P_NEEDF 22
- #define P_INITFAIL 23
- #define P_EREDIR 24
- #define P_EUNKNOWN 99

Variables

- int P_ERRNO

4.22.1 Macro Definition Documentation

4.22.1.1 P_EBADF

```
#define P_EBADF 2
```

Definition at line 9 of file pennos-errno.h.

4.22.1.2 P_EBUSY

```
#define P_EBUSY 6
```

Definition at line 13 of file pennos-errno.h.

4.22.1.3 P_ECLOSE

```
#define P_ECLOSE 19
```

Definition at line 26 of file pennos-errno.h.

4.22.1.4 P_ECOMMAND

```
#define P_ECOMMAND 21
```

Definition at line 28 of file pennos-errno.h.

4.22.1.5 P_EEXIST

```
#define P_EEXIST 5
```

Definition at line 12 of file pennos-errno.h.

4.22.1.6 P_EFS_NOT_MOUNTED

```
#define P_EFS_NOT_MOUNTED 8
```

Definition at line 15 of file pennos-errno.h.

4.22.1.7 P_EFULL

```
#define P_EFULL 7
```

Definition at line 14 of file pennos-errno.h.

4.22.1.8 P_EFUNC

```
#define P_EFUNC 14
```

Definition at line 21 of file pennos-errno.h.

4.22.1.9 P_EINTR

```
#define P_EINTR 9
```

Definition at line 16 of file pennos-errno.h.

4.22.1.10 P_EINVAL

```
#define P_EINVAL 4
```

Definition at line 11 of file pennos-errno.h.

4.22.1.11 P_ELSEEK

```
#define P_ELSEEK 12
```

Definition at line 19 of file pennos-errno.h.

4.22.1.12 P_EMALLOC

```
#define P_EMALLOC 16
```

Definition at line 23 of file pennos-errno.h.

4.22.1.13 P_EMAP

```
#define P_EMAP 13
```

Definition at line 20 of file pennos-errno.h.

4.22.1.14 P_ENOENT

```
#define P_ENOENT 1
```

Definition at line 8 of file pennos-errno.h.

4.22.1.15 P_ENULL

```
#define P_ENULL 10
```

Definition at line 17 of file pennos-errno.h.

4.22.1.16 P_EOPEN

```
#define P_EOPEN 15
```

Definition at line 22 of file pennos-errno.h.

4.22.1.17 P_EPARSE

```
#define P_EPARSE 20
```

Definition at line 27 of file pennos-errno.h.

4.22.1.18 P_EPERM

```
#define P_EPERM 3
```

Definition at line 10 of file pennos-errno.h.

4.22.1.19 P_EREAD

```
#define P_EREAD 11
```

Definition at line 18 of file pennos-errno.h.

4.22.1.20 P_EREDIR

```
#define P_EREDIR 24
```

Definition at line 31 of file pennos-errno.h.

4.22.1.21 P_ESIGNAL

```
#define P_ESIGNAL 17
```

Definition at line 24 of file pennos-errno.h.

4.22.1.22 P_EUNKNOWN

```
#define P_EUNKNOWN 99
```

Definition at line 32 of file pennos-errno.h.

4.22.1.23 P_EWRITE

```
#define P_EWRITE 18
```

Definition at line 25 of file pennos-errno.h.

4.22.1.24 P_INITFAIL

```
#define P_INITFAIL 23
```

Definition at line 30 of file pennos-errno.h.

4.22.1.25 P_NEEDF

```
#define P_NEEDF 22
```

Definition at line 29 of file pennos-errno.h.

4.22.2 Variable Documentation

4.22.2.1 P_ERRNO

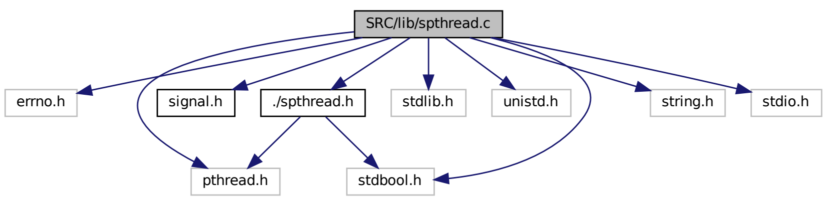
```
int P_ERRNO [extern]
```

Definition at line 8 of file pennos-errno.c.

4.23 SRC/lib/spthread.c File Reference

```
#include <errno.h>
#include <pthread.h>
#include <signal.h>
#include <stdbool.h>
#include <stdlib.h>
#include <unistd.h>
#include "./spthread.h"
#include <string.h>
#include <stdio.h>
```

Include dependency graph for spthread.c:



Classes

- struct spthread_fwd_args_st
- struct spthread_signal_args_st
- struct spthread_meta_st

Macros

- #define _GNU_SOURCE
- #define MILISEC_IN_NANO 100000
- #define SPTHREAD_RUNNING_STATE 0
- #define SPTHREAD_SUSPENDED_STATE 1
- #define SPTHREAD_TERMINATED_STATE 2
- #define SPTHREAD_SIG_SUSPEND -1
- #define SPTHREAD_SIG_CONTINUE -2

Typedefs

- typedef void ∗(∗ pthread_fn) (void ∗)
- typedef struct spthread_fwd_args_st spthread_fwd_args
- typedef struct spthread_signal_args_st spthread_signal_args
- typedef struct spthread_meta_st spthread_meta_t

Functions

- int spthread_create (spthread_t ∗thread, const pthread_attr_t ∗attr, pthread_fn start_routine, void ∗arg)
- int spthread_suspend (spthread_t thread)
- int spthread_suspend_self ()
- int spthread_continue (spthread_t thread)
- int spthread_cancel (spthread_t thread)
- bool spthread_self (spthread_t ∗thread)
- int spthread_join (spthread_t thread, void ∗∗retval)
- void spthread_exit (void ∗status)
- bool spthread_equal (spthread_t first, spthread_t second)
- int spthread_disable_interrupts_self ()
- int spthread_enable_interrupts_self ()

4.23.1 Macro Definition Documentation

4.23.1.1 _GNU_SOURCE

```
#define _GNU_SOURCE
```

Definition at line 1 of file spthread.c.

4.23.1.2 MILISEC_IN_NANO

```
#define MILISEC_IN_NANO 100000
```

Definition at line 12 of file spthread.c.

4.23.1.3 SPTHREAD_RUNNING_STATE

```
#define SPTHREAD_RUNNING_STATE 0
```

Definition at line 76 of file spthread.c.

4.23.1.4 SPTHREAD_SIG_CONTINUE

```
#define SPTHREAD_SIG_CONTINUE -2
```

Definition at line 85 of file spthread.c.

4.23.1.5 SPTHREAD_SIG_SUSPEND

```
#define SPTHREAD_SIG_SUSPEND -1
```

Definition at line 84 of file spthread.c.

4.23.1.6 SPTHREAD_SUSPENDED_STATE

```
#define SPTHREAD_SUSPENDED_STATE 1
```

Definition at line 77 of file spthread.c.

4.23.1.7 SPTHREAD_TERMINATED_STATE

```
#define SPTHREAD_TERMINATED_STATE 2
```

Definition at line 78 of file spthread.c.

4.23.2 Typedef Documentation

4.23.2.1 pthread_fn

```
typedef void*(* pthread_fn) (void *)
```

Definition at line 20 of file spthread.c.

4.23.2.2 spthread_fwd_args

```
typedef struct spthread_fwd_args_st spthread_fwd_args
```

4.23.2.3 spthread_meta_t

```
typedef struct spthread_meta_st spthread_meta_t
```

4.23.2.4 spthread_signal_args

```
typedef struct spthread_signal_args_st spthread_signal_args
```

4.23.3 Function Documentation

4.23.3.1 spthread_cancel()

```
int spthread_cancel (
            spthread_t thread )
```

Definition at line 293 of file spthread.c.

```
293                                    {
294   return pthread_cancel(thread.thread);
295 }
```

4.23.3.2 spthread_continue()

```
int spthread_continue (
            spthread_t thread )
```

Definition at line 241 of file spthread.c.

```
241                                      {
242   pthread_t pself = pthread_self();
243 
244   if (pthread_equal(pself, thread.thread) != 0) {
245     // I am already runnning... so just return 0
246     my_meta->state = SPTHREAD_RUNNING_STATE;
247     return 0;
248   }
249 
250   spthread_signal_args args = (spthread_signal_args){
251       .signal = SPTHREAD_SIG_CONTINUE,
252       .ack = 0,
253   };
254   pthread_mutex_init(&args.shutup_mutex, NULL);
255 
256   int ret = pthread_sigqueue(thread.thread, SIGPTHD,
257                              (union sigval){
258                                  .sival_ptr = &args,
259                              });
260   if (ret != 0) {
261     pthread_mutex_destroy(&args.shutup_mutex);
262     // handles the case where the thread is already dead.
263     return ret;
264   }
265 
266   // wait for our signal to be ack'd
267 
268   // setting up args to nanosleep
269   const struct timespec t = (struct timespec){
270       .tv_nsec = MILISEC_IN_NANO,
271   };
272 
273   pthread_mutex_lock(&args.shutup_mutex);
274   while (args.ack != 1) {
275     // wait for a mili second
276     pthread_mutex_unlock(&args.shutup_mutex);
277 
278     nanosleep(&t, NULL);
279 
280     // fprintf(stderr, "susp checking...\n");
281     pthread_mutex_lock(&args.shutup_mutex);
282 
283     if (thread.meta->state == SPTHREAD_TERMINATED_STATE) {
284       // child called exit, can break
285       break;
286     }
287   }
288   pthread_mutex_unlock(&args.shutup_mutex);
289   pthread_mutex_destroy(&args.shutup_mutex);
290   return ret;
291 }
```

4.23.3.3 spthread_create()

```
int spthread_create (
            spthread_t * thread,
            const pthread_attr_t * attr,
            pthread_fn start_routine,
            void * arg )
```

Definition at line 114 of file spthread.c.

```
117                                 {
118   spthread_meta_t* child_meta = malloc(sizeof(spthread_meta_t));
119   if (child_meta == NULL) {
120     return EAGAIN;
121   }
122 
```

```
  spthread_fwd_args* fwd_args = malloc(sizeof(spthread_fwd_args));
  if (fwd_args == NULL) {
    free(child_meta);
    return EAGAIN;
  }
  *fwd_args = (spthread_fwd_args){
      .actual_routine = start_routine,
      .actual_arg = arg,
      .setup_done = false,
      .child_meta = child_meta,
  };

  int ret = pthread_mutex_init(&(fwd_args->setup_mutex), NULL);
  if (ret != 0) {
    free(child_meta);
    free(fwd_args);
    return EAGAIN;
  }

  ret = pthread_cond_init(&(fwd_args->setup_cond), NULL);
  if (ret != 0) {
    free(child_meta);
    pthread_mutex_destroy(&(fwd_args->setup_mutex));
    free(fwd_args);
    return EAGAIN;
  }

  pthread_t pthread;
  int result = pthread_create(&pthread, attr, spthread_start, fwd_args);

  pthread_mutex_lock(&(fwd_args->setup_mutex));
  while (fwd_args->setup_done == false) {
    pthread_cond_wait(&(fwd_args->setup_cond), &(fwd_args->setup_mutex));
  }
  pthread_mutex_unlock(&(fwd_args->setup_mutex));

  pthread_cond_destroy(&(fwd_args->setup_cond));
  pthread_mutex_destroy(&(fwd_args->setup_mutex));
  free(fwd_args);

  *thread = (spthread_t){
      .thread = pthread,
      .meta = child_meta,
  };

  return result;
}
```

4.23.3.4 spthread_disable_interrupts_self()

`int spthread_disable_interrupts_self ( )`

Definition at line 326 of file spthread.c.

```
326                                        {
327   sigset_t block_set;
328   int res = sigemptyset(&block_set);
329   if (res != 0) {
330     return res;
331   }
332   res = sigaddset(&block_set, SIGPTHD);
333   if (res != 0) {
334     return res;
335   }
336   res = pthread_sigmask(SIG_BLOCK, &block_set, NULL);
337   if (res != 0) {
338     return res;
339   }
340   return 0;
341 }
```

4.23.3.5 spthread_enable_interrupts_self()

```
int spthread_enable_interrupts_self ( )
```

Definition at line 345 of file spthread.c.

```
345                                    {
346   sigset_t block_set;
347   int res = sigemptyset(&block_set);
348   if (res != 0) {
349     return res;
350   }
351   res = sigaddset(&block_set, SIGPTHD);
352   if (res != 0) {
353     return res;
354   }
355   res = pthread_sigmask(SIG_UNBLOCK, &block_set, NULL);
356   if (res != 0) {
357     return res;
358   }
359   return 0;
360 }
```

4.23.3.6 spthread_equal()

```
bool spthread_equal (
            spthread_t first,
            spthread_t second )
```

Definition at line 322 of file spthread.c.

```
322                                                           {
323   return pthread_equal(first.thread, second.thread) && (first.meta == second.meta);
324 }
```

4.23.3.7 spthread_exit()

```
void spthread_exit (
            void * status )
```

Definition at line 315 of file spthread.c.

```
315                               {
316   // necessary cleanup is registered
317   // in a cleanup routine
318   // that is pushed at start of an spthread
319   pthread_exit(status);
320 }
```

4.23.3.8 spthread_join()

```
int spthread_join (
            spthread_t thread,
            void ** retval )
```

Definition at line 308 of file spthread.c.

```
308                                                    {
309   int res = pthread_join(thread.thread, retval);
310   pthread_mutex_destroy(&thread.meta->meta_mutex);
311   free(thread.meta);
312   return res;
313 }
```

4.23.3.9 spthread_self()

```
bool spthread_self (
              spthread_t * thread )
```

Definition at line 297 of file spthread.c.

```
297                                        {
298   if (my_meta == NULL) {
299     return false;
300   }
301   *thread = (spthread_t){
302       .thread = pthread_self(),
303       .meta = my_meta,
304   };
305   return true;
306 }
```

4.23.3.10 spthread_suspend()

```
int spthread_suspend (
              spthread_t thread )
```

Definition at line 171 of file spthread.c.

```
171                                         {
172   pthread_t pself = pthread_self();
173
174   if (pthread_equal(pself, thread.thread) != 0) {
175     return spthread_suspend_self();
176   }
177
178   spthread_signal_args args = (spthread_signal_args){
179       .signal = SPTHREAD_SIG_SUSPEND,
180       .ack = 0,
181   };
182   pthread_mutex_init(&args.shutup_mutex, NULL);
183
184   int ret = pthread_sigqueue(thread.thread, SIGPTHD,
185                              (union sigval){
186                                  .sival_ptr = &args,
187                              });
188   if (ret != 0) {
189     pthread_mutex_destroy(&args.shutup_mutex);
190     // handles the case where the thread is already dead.
191     return ret;
192   }
193
194   // wait for our signal to be ack'd
195
196   // setting up args to nanosleep
197   const struct timespec t = (struct timespec){
198       .tv_nsec = MILISEC_IN_NANO,
199   };
200
201   nanosleep(&t, NULL);
202
203   pthread_mutex_lock(&args.shutup_mutex);
204   while (args.ack != 1) {
205     // wait for a mili second
206     pthread_mutex_unlock(&args.shutup_mutex);
207
208
209     nanosleep(&t, NULL);
210
211     // fprintf(stderr, "susp checking...\n");
212     pthread_mutex_lock(&args.shutup_mutex);
213
214     if (thread.meta->state == SPTHREAD_TERMINATED_STATE) {
215       // child called exit, can break
216       break;
217     }
218   }
219   pthread_mutex_unlock(&args.shutup_mutex);
220
221   pthread_mutex_destroy(&args.shutup_mutex);
222   return ret;
223 }
```

4.23.3.11 spthread_suspend_self()

```
int spthread_suspend_self ( )
```

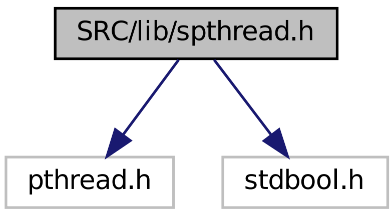
Definition at line 225 of file spthread.c.

```
                           {
  spthread_t self;
  bool am_sp = spthread_self(&self);
  if (!am_sp) {
    return ESRCH;
  }

  my_meta->state = SPTHREAD_SUSPENDED_STATE;

  do {
    sigsuspend(&my_meta->suspend_set);
  } while (my_meta->state == SPTHREAD_SUSPENDED_STATE);

  return 0;
}
```

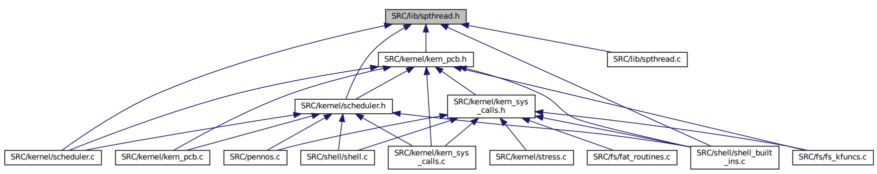
4.24 SRC/lib/spthread.h File Reference

```
#include <pthread.h>
#include <stdbool.h>
```

Include dependency graph for spthread.h:



This graph shows which files directly or indirectly include this file:



Classes

- struct spthread_st

Macros

- #define SIGPTHD SIGUSR1

Typedefs

- typedef struct spthread_meta_st spthread_meta_t
- typedef struct spthread_st spthread_t

Functions

- int spthread_create (spthread_t *thread, const pthread_attr_t *attr, void *(*start_routine)(void *), void *arg)
- int spthread_suspend (spthread_t thread)
- int spthread_suspend_self ()
- int spthread_continue (spthread_t thread)
- int spthread_cancel (spthread_t thread)
- bool spthread_self (spthread_t *thread)
- int spthread_join (spthread_t thread, void **retval)
- void spthread_exit (void *status)
- bool spthread_equal (spthread_t first, spthread_t second)
- int spthread_disable_interrupts_self ()
- int spthread_enable_interrupts_self ()

4.24.1 Macro Definition Documentation

4.24.1.1 SIGPTHD

```
#define SIGPTHD SIGUSR1
```

Definition at line 19 of file spthread.h.

4.24.2 Typedef Documentation

4.24.2.1 spthread_meta_t

```
typedef struct spthread_meta_st spthread_meta_t
```

Definition at line 1 of file spthread.h.

4.24.2.2 spthread_t

```
typedef struct spthread_st spthread_t
```

4.24.3 Function Documentation

4.24.3.1 spthread_cancel()

```
int spthread_cancel (
            spthread_t thread )
```

Definition at line 293 of file spthread.c.

```
293                                          {
294   return pthread_cancel(thread.thread);
295 }
```

4.24.3.2 spthread_continue()

```
int spthread_continue (
            spthread_t thread )
```

Definition at line 241 of file spthread.c.

```
241                                            {
242   pthread_t pself = pthread_self();
243 
244   if (pthread_equal(pself, thread.thread) != 0) {
245     // I am already runnning... so just return 0
246     my_meta->state = SPTHREAD_RUNNING_STATE;
247     return 0;
248   }
249 
250   spthread_signal_args args = (spthread_signal_args){
251       .signal = SPTHREAD_SIG_CONTINUE,
252       .ack = 0,
253   };
254   pthread_mutex_init(&args.shutup_mutex, NULL);
255 
256   int ret = pthread_sigqueue(thread.thread, SIGPTHD,
257                              (union sigval){
258                                  .sival_ptr = &args,
259                              });
260   if (ret != 0) {
261     pthread_mutex_destroy(&args.shutup_mutex);
262     // handles the case where the thread is already dead.
263     return ret;
264   }
265 
266   // wait for our signal to be ack'd
267 
268   // setting up args to nanosleep
269   const struct timespec t = (struct timespec){
270       .tv_nsec = MILISEC_IN_NANO,
271   };
272 
273   pthread_mutex_lock(&args.shutup_mutex);
274   while (args.ack != 1) {
275     // wait for a mili second
276     pthread_mutex_unlock(&args.shutup_mutex);
277 
278     nanosleep(&t, NULL);
279 
280     // fprintf(stderr, "susp checking...\n");
281     pthread_mutex_lock(&args.shutup_mutex);
```

```
    if (thread.meta->state == SPTHREAD_TERMINATED_STATE) {
      // child called exit, can break
      break;
    }
  }
  pthread_mutex_unlock(&args.shutup_mutex);
  pthread_mutex_destroy(&args.shutup_mutex);
  return ret;
}
```

4.24.3.3 spthread_create()

```
int spthread_create (
            spthread_t * thread,
            const pthread_attr_t * attr,
            void *(*)(void *) start_routine,
            void * arg )
```

Definition at line 114 of file spthread.c.

```
                                {
  spthread_meta_t* child_meta = malloc(sizeof(spthread_meta_t));
  if (child_meta == NULL) {
    return EAGAIN;
  }

  spthread_fwd_args* fwd_args = malloc(sizeof(spthread_fwd_args));
  if (fwd_args == NULL) {
    free(child_meta);
    return EAGAIN;
  }
  *fwd_args = (spthread_fwd_args){
      .actual_routine = start_routine,
      .actual_arg = arg,
      .setup_done = false,
      .child_meta = child_meta,
  };

  int ret = pthread_mutex_init(&(fwd_args->setup_mutex), NULL);
  if (ret != 0) {
    free(child_meta);
    free(fwd_args);
    return EAGAIN;
  }

  ret = pthread_cond_init(&(fwd_args->setup_cond), NULL);
  if (ret != 0) {
    free(child_meta);
    pthread_mutex_destroy(&(fwd_args->setup_mutex));
    free(fwd_args);
    return EAGAIN;
  }

  pthread_t pthread;
  int result = pthread_create(&pthread, attr, spthread_start, fwd_args);

  pthread_mutex_lock(&(fwd_args->setup_mutex));
  while (fwd_args->setup_done == false) {
    pthread_cond_wait(&(fwd_args->setup_cond), &(fwd_args->setup_mutex));
  }
  pthread_mutex_unlock(&(fwd_args->setup_mutex));

  pthread_cond_destroy(&(fwd_args->setup_cond));
  pthread_mutex_destroy(&(fwd_args->setup_mutex));
  free(fwd_args);

  *thread = (spthread_t){
      .thread = pthread,
      .meta = child_meta,
  };

  return result;
}
```

4.24.3.4 spthread_disable_interrupts_self()

```
int spthread_disable_interrupts_self ( )
```

Definition at line 326 of file spthread.c.

```
                                        {
  sigset_t block_set;
  int res = sigemptyset(&block_set);
  if (res != 0) {
    return res;
  }
  res = sigaddset(&block_set, SIGPTHD);
  if (res != 0) {
    return res;
  }
  res = pthread_sigmask(SIG_BLOCK, &block_set, NULL);
  if (res != 0) {
    return res;
  }
  return 0;
}
```

4.24.3.5 spthread_enable_interrupts_self()

```
int spthread_enable_interrupts_self ( )
```

Definition at line 345 of file spthread.c.

```
                                       {
  sigset_t block_set;
  int res = sigemptyset(&block_set);
  if (res != 0) {
    return res;
  }
  res = sigaddset(&block_set, SIGPTHD);
  if (res != 0) {
    return res;
  }
  res = pthread_sigmask(SIG_UNBLOCK, &block_set, NULL);
  if (res != 0) {
    return res;
  }
  return 0;
}
```

4.24.3.6 spthread_equal()

```
bool spthread_equal (
             spthread_t first,
             spthread_t second )
```

Definition at line 322 of file spthread.c.

```
                                                          {
  return pthread_equal(first.thread, second.thread) && (first.meta == second.meta);
}
```

4.24.3.7 spthread_exit()

```
void spthread_exit (
            void * status )
```

Definition at line 315 of file spthread.c.

```
315                              {
316   // necessary cleanup is registered
317   // in a cleanup routine
318   // that is pushed at start of an spthread
319   pthread_exit(status);
320 }
```

4.24.3.8 spthread_join()

```
int spthread_join (
            spthread_t thread,
            void ** retval )
```

Definition at line 308 of file spthread.c.

```
308                                             {
309   int res = pthread_join(thread.thread, retval);
310   pthread_mutex_destroy(&thread.meta->meta_mutex);
311   free(thread.meta);
312   return res;
313 }
```

4.24.3.9 spthread_self()

```
bool spthread_self (
            spthread_t * thread )
```

Definition at line 297 of file spthread.c.

```
297                                   {
298   if (my_meta == NULL) {
299     return false;
300   }
301   *thread = (spthread_t){
302       .thread = pthread_self(),
303       .meta = my_meta,
304   };
305   return true;
306 }
```

4.24.3.10 spthread_suspend()

```
int spthread_suspend (
            spthread_t thread )
```

Definition at line 171 of file spthread.c.

```
171                                         {
172   pthread_t pself = pthread_self();
173 
174   if (pthread_equal(pself, thread.thread) != 0) {
175     return spthread_suspend_self();
176   }
177 
178   spthread_signal_args args = (spthread_signal_args){
179       .signal = SPTHREAD_SIG_SUSPEND,
180       .ack = 0,
181   };
182   pthread_mutex_init(&args.shutup_mutex, NULL);
183 
184   int ret = pthread_sigqueue(thread.thread, SIGPTHD,
185                              (union sigval){
186                                  .sival_ptr = &args,
187                              });
188   if (ret != 0) {
189     pthread_mutex_destroy(&args.shutup_mutex);
190     // handles the case where the thread is already dead.
191     return ret;
192   }
193 
194   // wait for our signal to be ack'd
195 
196   // setting up args to nanosleep
197   const struct timespec t = (struct timespec){
198       .tv_nsec = MILISEC_IN_NANO,
199   };
200 
201   nanosleep(&t, NULL);
202 
203   pthread_mutex_lock(&args.shutup_mutex);
204   while (args.ack != 1) {
205     // wait for a mili second
206     pthread_mutex_unlock(&args.shutup_mutex);
207 
208 
209     nanosleep(&t, NULL);
210 
211     // fprintf(stderr, "susp checking...\n");
212     pthread_mutex_lock(&args.shutup_mutex);
213 
214     if (thread.meta->state == SPTHREAD_TERMINATED_STATE) {
215       // child called exit, can break
216       break;
217     }
218   }
219   pthread_mutex_unlock(&args.shutup_mutex);
220 
221   pthread_mutex_destroy(&args.shutup_mutex);
222   return ret;
223 }
```

4.24.3.11 spthread_suspend_self()

```
int spthread_suspend_self ( )
```

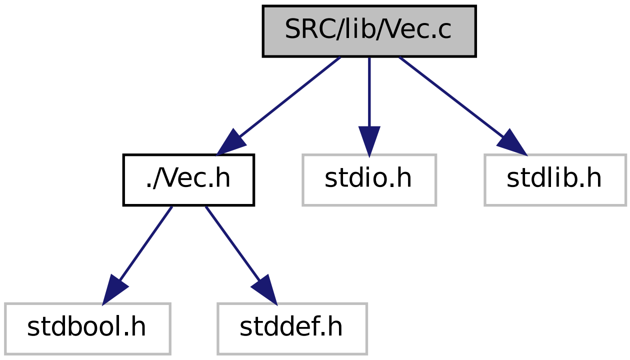
Definition at line 225 of file spthread.c.

```
225                               {
226   spthread_t self;
227   bool am_sp = spthread_self(&self);
228   if (!am_sp) {
229     return ESRCH;
230   }
231 
232   my_meta->state = SPTHREAD_SUSPENDED_STATE;
233 
234   do {
235     sigsuspend(&my_meta->suspend_set);
236   } while (my_meta->state == SPTHREAD_SUSPENDED_STATE);
237 
238   return 0;
239 }
```

4.25 SRC/lib/Vec.c File Reference

```
#include "./Vec.h"
#include <stdio.h>
#include <stdlib.h>
```

Include dependency graph for Vec.c:



Functions

- Vec vec_new (size_t initial_capacity, ptr_dtor_fn ele_dtor_fn)
- void vec_destroy (Vec ∗self)
- void vec_clear (Vec ∗self)
- void vec_resize (Vec ∗self, size_t new_capacity)
- void vec_erase (Vec ∗self, size_t index)
- void vec_erase_no_deletor (Vec ∗self, size_t index)
- void vec_insert (Vec ∗self, size_t index, ptr_t new_ele)
- bool vec_pop_back (Vec ∗self)
- void vec_push_back (Vec ∗self, ptr_t new_ele)
- void vec_set (Vec ∗self, size_t index, ptr_t new_ele)
- ptr_t vec_get (Vec ∗self, size_t index)

4.25.1 Function Documentation

4.25.1.1 vec_clear()

```
void vec_clear (
            Vec * self )
```

Erases all elements from the container. After this, the length of the vector is zero. Capacity of the vector is unchanged.

Parameters

self	a pointer to the vector we want to clear.

Precondition

Assumes self points to a valid vector.

Postcondition

The removed elements are destructed (cleaned up).

Definition at line 34 of file Vec.c.

```
34                             {
35   if (self->ele_dtor_fn) {
36     for (int i = 0; i < self->length; i++) {
37       self->ele_dtor_fn(self->data[i]);
38     }
39   }
40
41   self->length = 0;
42 }
```

4.25.1.2 vec_destroy()

```
void vec_destroy (
              Vec * self )
```

Destruct the vector. All elements are destructed and storage is deallocated. Must set capacity and length to zero. Data is set to NULL.

Parameters

self	a pointer to the vector we want to destruct.

Precondition

Assumes self points to a valid vector.

Postcondition

The removed elements are destructed (cleaned up) and data storage deallocated.

Definition at line 17 of file Vec.c.

```
17                               {
18   if (self->ele_dtor_fn) {
19     for (int i = 0; i < self->length; i++) {
20       self->ele_dtor_fn(self->data[i]);
21     }
22   }
23   free(self->data);
24 }
```

4.25.1.3 vec_erase()

```
void vec_erase (
            Vec * self,
            size_t index )
```

Erases an element at the specified valid location in the container

Parameters

self	a pointer to the vector we want to erase from.
index	the index of the element we want to erase at. Elements after this index are "shifted" down one position.

Precondition

Assumes self points to a valid vector. If the index is >= self->length then this function will call perror

Definition at line 63 of file Vec.c.

```
63                                          {
64   if (index >= self->length) {
65     perror("vec_erase: index >= vec length");
66   }
67
68   if (self->ele_dtor_fn) {
69     self->ele_dtor_fn(self->data[index]);
70   }
71
72   for (unsigned int i = index; i < self->length - 1; i++) {
73     self->data[i] = self->data[i + 1];
74   }
75
76   self->length--;
77 }
```

4.25.1.4 vec_erase_no_deletor()

```
void vec_erase_no_deletor (
            Vec * self,
            size_t index )
```

Erases an element at the specified location in the container, except it does not call the element deletor function on the element.

Parameters

self	a pointer to the vector we want to erase from
index	the index of the element we want to erase at

Definition at line 79 of file Vec.c.

```
79                                                      {
80   if (index >= self->length) {
81     perror("vec_erase: index >= vec length");
82   }
83
84   for (unsigned int i = index; i < self->length - 1; i++) {
85     self->data[i] = self->data[i + 1];
86   }
87
```

```
88   self->length--;
89 }
```

4.25.1.5 vec_get()

```
ptr_t vec_get (
            Vec * self,
            size_t index )
```

Gets the specified element of the Vec

Parameters

self	a pointer to the vector who's element we want to get.
index	the index of the element to get.

Returns

the element at the specified index.

Precondition

Assumes self points to a valid vector. If the index is >= self->length then this function will call perror

Definition at line 152 of file Vec.c.

```
152                                     {
153   if (index >= self->length) {
154     perror("vec_get: index greater than length");
155   }
156   return self->data[index];
157 }
```

4.25.1.6 vec_insert()

```
void vec_insert (
            Vec * self,
            size_t index,
            ptr_t new_ele )
```

Inserts an element at the specified location in the container

Parameters

self	a pointer to the vector we want to insert into.
index	the index of the element we want to insert at. Elements at this index and after it are "shifted" up one position. If index is equal to the length, then we insert at the end of the vector.
new_ele	the value we want to insert

Precondition

Assumes self points to a valid vector. If the index is > self->length then this function will call perror

Postcondition

If after the operation the new length is greater than the old capacity then a reallocation takes place and all elements are copied over. Capacity is doubled. Any pointers to elements prior to this reallocation are invalidated.

Definition at line 91 of file Vec.c.

```
91                                                            {
92   if (index > self->length) {
93     perror("vec_insert: index > vec length");
94   }
95
96   if (index == self->length) {  // Insertion at end = Adding at end
97     vec_push_back(self, new_ele);
98   } else {  // Inserting not at the end
99     // Vector is full
100     if (self->length == self->capacity) {
101       vec_resize(self, self->capacity * 2);
102     }
103     // Insertion + Displacement
104     for (unsigned int i = self->length; i > index; i--) {
105       self->data[i] = self->data[i - 1];
106     }
107     self->data[index] = new_ele;
108
109     self->length++;
110   }
111 }
```

4.25.1.7 vec_new()

```
Vec vec_new (
            size_t initial_capacity,
            ptr_dtor_fn ele_dtor_fn )
```

Creates a new empty Vec(tor) with the specified initial_capacity and specified function to clean up elements in the vector.

Parameters

initial_capacity	the initial capacity of the newly created vector, non negative
ele_dtor_fn	a function pointer to a function that takes in a ptr_t (a vector element) and cleans it up. This is commonly just `free` but custom functions can be passed in. NULL can also be passed in to specify that there is no cleanup function that needs to be called on each element.

Returns

a newly created vector with specified capacity, 0 length and the specified element destructor (cleanup) function.

Postcondition

if memory allocation fails, the function will perror

Definition at line 5 of file Vec.c.

```
5                                                              {
6   Vec vector;
7   vector.capacity = initial_capacity;
8   vector.data = malloc(sizeof(void*) * initial_capacity);
9   if (vector.data == NULL) {
10     perror("vec_new: malloc failed");
11   }
12   vector.ele_dtor_fn = ele_dtor_fn;
13   vector.length = 0;
14   return vector;
15 }
```

4.25.1.8 vec_pop_back()

```
bool vec_pop_back (
              Vec * self )
```

Removes and destroys the last element of the Vec

Parameters

self	a pointer to the vector we are popping.

Returns

true iff an element was removed.

Precondition

Assumes self points to a valid vector.

Postcondition

The capacity of self stays the same. The removed element is destructed (cleaned up) as specified by the dtor_fn provided in vec_new.

Definition at line 113 of file Vec.c.

```
113                                {
114   if (self->length == 0) {
115     return false;
116   }
117   if (self->ele_dtor_fn) {
118     self->ele_dtor_fn(self->data[--self->length]);
119   } else {
120     self->length--;
121   }
122   return true;
123 }
```

4.25.1.9 vec_push_back()

```
void vec_push_back (
              Vec * self,
              ptr_t new_ele )
```

Appends the given element to the end of the Vec

Parameters

self	a pointer to the vector we are pushing onto
new_ele	the value we want to add to the end of the container

Precondition

Assumes self points to a valid vector.

Postcondition

If a resize is needed and it fails, then this function will call perror

If after the operation the new length is greater than the old capacity then a reallocation takes place and all elements are copied over. Capacity is doubled. If initial capacity is zero, it is resized to capacity 1. Any pointers to elements prior to this reallocation are invalidated.

Definition at line 125 of file Vec.c.

```
125                                          {
126   if (self->capacity == self->length) {
127     if (self->capacity == 0) {
128       vec_resize(self, 1);
129     } else {
130       vec_resize(self, self->capacity * 2);
131     }
132   }
133
134   if (self->capacity == self->length) {
135     perror("vec_push_back: resize failed");
136   }
137
138   // The array is 0 indexed
139   self->data[self->length++] = new_ele;
140 }
```

4.25.1.10 vec_resize()

```
void vec_resize (
            Vec * self,
            size_t new_capacity )
```

Resizes the container to a new specified capacity. Does nothing if new_capacity <= self->length

Parameters

self	a pointer to the vector we want to resize.
new_capacity	the new capacity of the vector.

Precondition

Assumes self points to a valid vector.

Postcondition

If a resize takes place, then a reallocation takes place and all elements are copied over. Any pointers to elements prior to this reallocation are invalidated.

The removed elements are destructed (cleaned up).

Definition at line 44 of file Vec.c.

```
44                                                {
45   if (new_capacity * sizeof(void*) < new_capacity) {
46     perror("vec_resize: new capacity too large");
47   }
48   if (new_capacity > self->length) {
49     self->capacity = new_capacity;
50     ptr_t* new_data = malloc(sizeof(void*) * self->capacity);
51 
52     // Copy over old elements
53     for (int i = 0; i < self->length; i++) {
54       new_data[i] = self->data[i];
55     }
56 
57     free(self->data);
58 
59     self->data = new_data;
60   }
61 }
```

4.25.1.11 vec_set()

```
void vec_set (
              Vec * self,
              size_t index,
              ptr_t new_ele )
```

Sets the specified element of the Vec to the specified value

Parameters

self	a pointer to the vector who's element we want to set.
index	the index of the element to set.
new_ele	the value we want to set the element at that index to

Returns

the element at the specified index.

Precondition

Assumes self points to a valid vector. If the index is >= self->length then this function will call perror

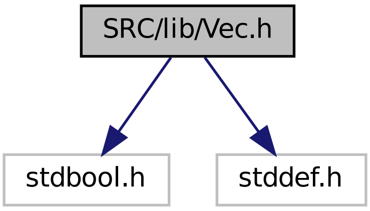
Definition at line 142 of file Vec.c.

```
142                                                       {
143   if (index >= self->length) {
144     perror("vec_set: idx >= len");
145   }
146   if (self->ele_dtor_fn) {
147     self->ele_dtor_fn(self->data[index]);
148   }
149   self->data[index] = new_ele;
150 }
```

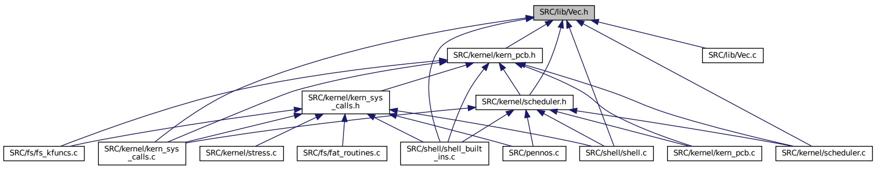
4.26 SRC/lib/Vec.h File Reference

```
#include <stdbool.h>
#include <stddef.h>
```

Include dependency graph for Vec.h:



This graph shows which files directly or indirectly include this file:



Classes

- struct vec_st

Macros

- #define vec_capacity(vec) ((vec)->capacity)
- #define vec_len(vec) ((vec)->length)
- #define vec_is_empty(vec) ((vec)->length == 0)

Typedefs

- typedef void ∗ ptr_t
- typedef void(∗ ptr_dtor_fn) (ptr_t)
- typedef struct vec_st Vec

Functions

- Vec vec_new (size_t initial_capacity, ptr_dtor_fn ele_dtor_fn)
- ptr_t vec_get (Vec *self, size_t index)
- void vec_set (Vec *self, size_t index, ptr_t new_ele)
- void vec_push_back (Vec *self, ptr_t new_ele)
- bool vec_pop_back (Vec *self)
- void vec_insert (Vec *self, size_t index, ptr_t new_ele)
- void vec_erase (Vec *self, size_t index)
- void vec_erase_no_deletor (Vec *self, size_t index)
- void vec_resize (Vec *self, size_t new_capacity)
- void vec_clear (Vec *self)
- void vec_destroy (Vec *self)

4.26.1 Macro Definition Documentation

4.26.1.1 vec_capacity

```
#define vec_capacity(
              vec ) ((vec)->capacity)
```

Returns the current capacity of the Vec Written as a function-like macro

Parameters

vec,a	pointer to the vector we want to grab the capacity of.

Definition at line 40 of file Vec.h.

4.26.1.2 vec_is_empty

```
#define vec_is_empty(
              vec ) ((vec)->length == 0)
```

Checks if the Vec is empty written as a function-like macro

Parameters

vec,a	pointer to the vector we want to check emptiness of.

Definition at line 54 of file Vec.h.

4.26.1.3 vec_len

```
#define vec_len(
            vec ) ((vec)->length)
```

Returns the current length of the Vec written as a function-like macro

Parameters

vec,a	pointer to the vector we want to grab the len of.

Definition at line 47 of file Vec.h.

4.26.2 Typedef Documentation

4.26.2.1 ptr_dtor_fn

```
typedef void(* ptr_dtor_fn) (ptr_t)
```

Definition at line 8 of file Vec.h.

4.26.2.2 ptr_t

```
typedef void* ptr_t
```

Definition at line 7 of file Vec.h.

4.26.2.3 Vec

```
typedef struct vec_st Vec
```

4.26.3 Function Documentation

4.26.3.1 vec_clear()

```
void vec_clear (
            Vec * self )
```

Erases all elements from the container. After this, the length of the vector is zero. Capacity of the vector is unchanged.

Parameters

self	a pointer to the vector we want to clear.

Precondition

Assumes self points to a valid vector.

Postcondition

The removed elements are destructed (cleaned up).

Definition at line 34 of file Vec.c.

```
                        {
  if (self->ele_dtor_fn) {
    for (int i = 0; i < self->length; i++) {
      self->ele_dtor_fn(self->data[i]);
    }
  }

  self->length = 0;
}
```

4.26.3.2 vec_destroy()

```
void vec_destroy (
            Vec * self )
```

Destruct the vector. All elements are destructed and storage is deallocated. Must set capacity and length to zero. Data is set to NULL.

Parameters

self	a pointer to the vector we want to destruct.

Precondition

Assumes self points to a valid vector.

Postcondition

The removed elements are destructed (cleaned up) and data storage deallocated.

Definition at line 17 of file Vec.c.

```
                          {
  if (self->ele_dtor_fn) {
    for (int i = 0; i < self->length; i++) {
      self->ele_dtor_fn(self->data[i]);
    }
  }
  free(self->data);
}
```

4.26.3.3 vec_erase()

```
void vec_erase (
            Vec * self,
            size_t index )
```

Erases an element at the specified valid location in the container

Parameters

self	a pointer to the vector we want to erase from.
index	the index of the element we want to erase at. Elements after this index are "shifted" down one position.

Precondition

Assumes self points to a valid vector. If the index is >= self->length then this function will call perror

Definition at line 63 of file Vec.c.

```
63                                            {
64   if (index >= self->length) {
65     perror("vec_erase: index >= vec length");
66   }
67
68   if (self->ele_dtor_fn) {
69     self->ele_dtor_fn(self->data[index]);
70   }
71
72   for (unsigned int i = index; i < self->length - 1; i++) {
73     self->data[i] = self->data[i + 1];
74   }
75
76   self->length--;
77 }
```

4.26.3.4 vec_erase_no_deletor()

```
void vec_erase_no_deletor (
            Vec * self,
            size_t index )
```

Erases an element at the specified location in the container, except it does not call the element deletor function on the element.

Parameters

self	a pointer to the vector we want to erase from
index	the index of the element we want to erase at

Definition at line 79 of file Vec.c.

```
79                                                        {
80   if (index >= self->length) {
81     perror("vec_erase: index >= vec length");
82   }
83
84   for (unsigned int i = index; i < self->length - 1; i++) {
85     self->data[i] = self->data[i + 1];
86   }
87
```

```
  self->length--;
}
```

4.26.3.5 vec_get()

```
ptr_t vec_get (
            Vec * self,
            size_t index )
```

Gets the specified element of the Vec

Parameters

self	a pointer to the vector who's element we want to get.
index	the index of the element to get.

Returns

the element at the specified index.

Precondition

Assumes self points to a valid vector. If the index is >= self->length then this function will call perror

Definition at line 152 of file Vec.c.

```
152                                 {
153   if (index >= self->length) {
154     perror("vec_get: index greater than length");
155   }
156   return self->data[index];
157 }
```

4.26.3.6 vec_insert()

```
void vec_insert (
            Vec * self,
            size_t index,
            ptr_t new_ele )
```

Inserts an element at the specified location in the container

Parameters

self	a pointer to the vector we want to insert into.
index	the index of the element we want to insert at. Elements at this index and after it are "shifted" up one position. If index is equal to the length, then we insert at the end of the vector.
new_ele	the value we want to insert

Precondition

Assumes self points to a valid vector. If the index is > self->length then this function will call perror

Postcondition

If after the operation the new length is greater than the old capacity then a reallocation takes place and all elements are copied over. Capacity is doubled. Any pointers to elements prior to this reallocation are invalidated.

Definition at line 91 of file Vec.c.

```
91                                                           {
92    if (index > self->length) {
93      perror("vec_insert: index > vec length");
94    }
95
96    if (index == self->length) {  // Insertion at end = Adding at end
97      vec_push_back(self, new_ele);
98    } else {  // Inserting not at the end
99      // Vector is full
100      if (self->length == self->capacity) {
101        vec_resize(self, self->capacity * 2);
102      }
103      // Insertion + Displacement
104      for (unsigned int i = self->length; i > index; i--) {
105        self->data[i] = self->data[i - 1];
106      }
107      self->data[index] = new_ele;
108
109      self->length++;
110    }
111 }
```

4.26.3.7 vec_new()

```
Vec vec_new (
            size_t initial_capacity,
            ptr_dtor_fn ele_dtor_fn )
```

Creates a new empty Vec(tor) with the specified initial_capacity and specified function to clean up elements in the vector.

Parameters

initial_capacity	the initial capacity of the newly created vector, non negative
ele_dtor_fn	a function pointer to a function that takes in a ptr_t (a vector element) and cleans it up. This is commonly just `free` but custom functions can be passed in. NULL can also be passed in to specify that there is no cleanup function that needs to be called on each element.

Returns

a newly created vector with specified capacity, 0 length and the specified element destructor (cleanup) function.

Postcondition

if memory allocation fails, the function will perror

Definition at line 5 of file Vec.c.

```
                                                            {
  Vec vector;
  vector.capacity = initial_capacity;
  vector.data = malloc(sizeof(void*) * initial_capacity);
  if (vector.data == NULL) {
     perror("vec_new: malloc failed");
   }
   vector.ele_dtor_fn = ele_dtor_fn;
   vector.length = 0;
   return vector;
}
```

4.26.3.8 vec_pop_back()

```
bool vec_pop_back (
              Vec * self )
```

Removes and destroys the last element of the Vec

Parameters

self	a pointer to the vector we are popping.

Returns

true iff an element was removed.

Precondition

Assumes self points to a valid vector.

Postcondition

The capacity of self stays the same. The removed element is destructed (cleaned up) as specified by the dtor_fn provided in vec_new.

Definition at line 113 of file Vec.c.

```
                              {
   if (self->length == 0) {
     return false;
   }
   if (self->ele_dtor_fn) {
     self->ele_dtor_fn(self->data[--self->length]);
   } else {
     self->length--;
   }
   return true;
}
```

4.26.3.9 vec_push_back()

```
void vec_push_back (
              Vec * self,
              ptr_t new_ele )
```

Appends the given element to the end of the Vec

Parameters

self	a pointer to the vector we are pushing onto
new_ele	the value we want to add to the end of the container

Precondition

Assumes self points to a valid vector.

Postcondition

If a resize is needed and it fails, then this function will call perror

If after the operation the new length is greater than the old capacity then a reallocation takes place and all elements are copied over. Capacity is doubled. If initial capacity is zero, it is resized to capacity 1. Any pointers to elements prior to this reallocation are invalidated.

Definition at line 125 of file Vec.c.

```
125                                       {
126   if (self->capacity == self->length) {
127     if (self->capacity == 0) {
128       vec_resize(self, 1);
129     } else {
130       vec_resize(self, self->capacity * 2);
131     }
132   }
133
134   if (self->capacity == self->length) {
135     perror("vec_push_back: resize failed");
136   }
137
138   // The array is 0 indexed
139   self->data[self->length++] = new_ele;
140 }
```

4.26.3.10 vec_resize()

```
void vec_resize (
            Vec * self,
            size_t new_capacity )
```

Resizes the container to a new specified capacity. Does nothing if new_capacity <= self->length

Parameters

self	a pointer to the vector we want to resize.
new_capacity	the new capacity of the vector.

Precondition

Assumes self points to a valid vector.

Postcondition

If a resize takes place, then a reallocation takes place and all elements are copied over. Any pointers to elements prior to this reallocation are invalidated.

The removed elements are destructed (cleaned up).

Definition at line 44 of file Vec.c.

```
44                                                    {
45   if (new_capacity * sizeof(void*) < new_capacity) {
46     perror("vec_resize: new capacity too large");
47   }
48   if (new_capacity > self->length) {
49     self->capacity = new_capacity;
50     ptr_t* new_data = malloc(sizeof(void*) * self->capacity);
51 
52     // Copy over old elements
53     for (int i = 0; i < self->length; i++) {
54       new_data[i] = self->data[i];
55     }
56 
57     free(self->data);
58 
59     self->data = new_data;
60   }
61 }
```

4.26.3.11 vec_set()

```
void vec_set (
              Vec * self,
              size_t index,
              ptr_t new_ele )
```

Sets the specified element of the Vec to the specified value

Parameters

self	a pointer to the vector who's element we want to set.
index	the index of the element to set.
new_ele	the value we want to set the element at that index to

Returns

the element at the specified index.

Precondition

Assumes self points to a valid vector. If the index is >= self->length then this function will call perror

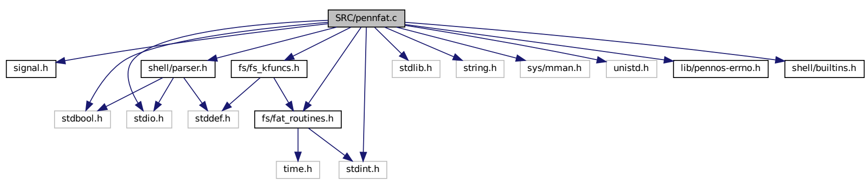
Definition at line 142 of file Vec.c.

```
142                                                        {
143   if (index >= self->length) {
144     perror("vec_set: idx >= len");
145   }
146   if (self->ele_dtor_fn) {
147     self->ele_dtor_fn(self->data[index]);
148   }
149   self->data[index] = new_ele;
150 }
```

4.27 SRC/pennfat.c File Reference

```
#include <signal.h>
#include <stdbool.h>
#include <stdint.h>
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <sys/mman.h>
#include <unistd.h>
#include "fs/fat_routines.h"
#include "fs/fs_kfuncs.h"
#include "lib/pennos-errno.h"
#include "shell/builtins.h"
#include "shell/parser.h"
```

Include dependency graph for pennfat.c:



Macros

- #define PROMPT "pennfat# "

Functions

- int main (int argc, char ∗argv[ ])

4.27.1 Macro Definition Documentation

4.27.1.1 PROMPT

```
#define PROMPT "pennfat# "
```

Definition at line 16 of file pennfat.c.

4.27.2 Function Documentation

4.27.2.1 main()

```
int main (
        int argc,
        char * argv[] )
```

Definition at line 24 of file pennfat.c.

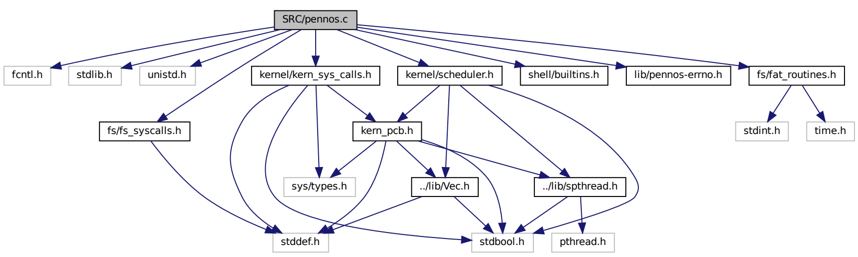
```
24                                 {
25   // register signal handlers
26   struct sigaction sa;
27   sa.sa_handler = signal_handler;
28   sigemptyset(&sa.sa_mask);
29   sa.sa_flags = SA_RESTART;
30
31   // set up handler for SIGINT (ctrl-c)
32   if (sigaction(SIGINT, &sa, NULL) == -1) {
33     P_ERRNO = P_ESIGNAL;
34     u_perror("Error setting up SIGINT handler");
35     return EXIT_FAILURE;
36   }
37
38   // set up handler for SIGTSTP (ctrl-z)
39   if (sigaction(SIGTSTP, &sa, NULL) == -1) {
40     P_ERRNO = P_ESIGNAL;
41     u_perror("Error setting up SIGTSTP handler");
42     return EXIT_FAILURE;
43   }
44
45   char input_buffer[1024];
46
47   while (true) {
48     // print prompt
49     if (k_write(STDOUT_FILENO, PROMPT, strlen(PROMPT)) < 0) {
50       P_ERRNO = P_EWRITE;
51       u_perror("prompt write error");
52       break;
53     }
54
55     // read user input
56     int bytes_read =
57         k_read(STDIN_FILENO, input_buffer, sizeof(input_buffer) - 1);
58
59     // check for EOF (ctrl-D)
60     if (bytes_read <= 0) {
61       k_write(STDOUT_FILENO, "\n", 1);
62       break;
63     }
64
65     // remove trailing newline if present
66     if (bytes_read > 0 && input_buffer[bytes_read - 1] == '\n') {
67       input_buffer[bytes_read - 1] = '\0';
68     }
69
70     // parse command and check error
71     struct parsed_command* parsed_command = NULL;
72     int parse_result = parse_command(input_buffer, &parsed_command);
73     if (parse_result != 0) {
74       if (parse_result == -1) {
75         P_ERRNO = P_EINVAL;
76         u_perror("Error parsing command");
77       } else {
78         print_parser_errcode(stderr, parse_result);
79       }
80       continue;
81     }
82
83     // skip empty commands
84     if (parsed_command->num_commands == 0) {
85       free(parsed_command);
86       continue;
87     }
88
89     // extract command and arguments
90     char** args = parsed_command->commands[0];
91
92     // execute command
93     if (strcmp(args[0], "mkfs") == 0) {
94       if (args[1] == NULL || args[2] == NULL || args[3] == NULL) {
95         P_ERRNO = P_EINVAL;
96         u_perror("mkfs");
97       } else {
98         int blocks_in_fat = atoi(args[2]);
99         int block_size = atoi(args[3]);
100         if (mkfs(args[1], blocks_in_fat, block_size) != 0) {
```

```
          u_perror("mkfs");
        }
      }
    } else if (strcmp(args[0], "mount") == 0) {
      if (args[1] == NULL) {
        P_ERRNO = P_EINVAL;
        u_perror("mount");
      } else {
        if (mount(args[1]) != 0) {
          u_perror("mount");
        }
      }
    } else if (strcmp(args[0], "unmount") == 0) {
      if (unmount() != 0) {
        u_perror("unmount");
      }
    } else if (strcmp(args[0], "ls") == 0) {
      ls(args);
    } else if (strcmp(args[0], "touch") == 0) {
      touch(args);
    } else if (strcmp(args[0], "cat") == 0) {
      cat(args);
    } else if (strcmp(args[0], "chmod") == 0) {
      chmod(args);
    } else if (strcmp(args[0], "mv") == 0) {
      mv(args);
    } else if (strcmp(args[0], "rm") == 0) {
      rm(args);
    } else if (strcmp(args[0], "cp") == 0) {
      cp(args);
    } else if (strcmp(args[0], "cmpctdir") == 0) {  // extra credit
      cmpctdir(args);
    } else {
      P_ERRNO = P_ECOMMAND;
      u_perror("shell");
    }

    free(parsed_command);
  }
  return EXIT_SUCCESS;
}
```

4.28 SRC/pennos.c File Reference

```
#include <fcntl.h>
#include <stdlib.h>
#include <unistd.h>
#include "fs/fs_syscalls.h"
#include "kernel/kern_sys_calls.h"
#include "kernel/scheduler.h"
#include "shell/builtins.h"
#include "lib/pennos-errno.h"
#include "fs/fat_routines.h"
```

Include dependency graph for pennos.c:



Functions

- int main (int argc, char ∗argv[ ])

Variables

- int tick_counter
- int log_fd

4.28.1 Function Documentation

4.28.1.1 main()

```
int main (
              int argc,
              char * argv[] )
```

Definition at line 14 of file pennos.c.

```
14                                  {
15   // mount the filesystem
16   if (argc < 2) {
17     P_ERRNO = P_NEEDF;
18     u_perror("need a pennfat file to mount");
19     return -1;
20   } else {
21     if (mount(argv[1]) == -1) {
22       u_perror("mount failed");
23       return -1;
24     }
25   }
26 
27   // get the log fd
28   if (argc >= 3) {
29     log_fd = open(argv[2], O_RDWR | O_CREAT | O_TRUNC, 0644);
30   } else {
31     log_fd = open("log/log", O_RDWR | O_CREAT | O_TRUNC, 0644);
32   }
33 
34   // initialize scheduler architecture and init process
35   initialize_scheduler_queues();
36 
37   pid_t init_pid = s_spawn_init();
38   if (init_pid == -1) {
39     P_ERRNO = P_INITFAIL;
40     u_perror("init spawn failed");
41     return -1;
42   }
43 
44   scheduler();
45 
46   // cleanup
47   s_cleanup_init_process();
48   free_scheduler_queues();
49   unmount();
50   close(log_fd);
51 }
```

4.28.2 Variable Documentation

4.28.2.1 log_fd

```
int log_fd [extern]
```

Definition at line 36 of file scheduler.c.

4.28.2.2 tick_counter

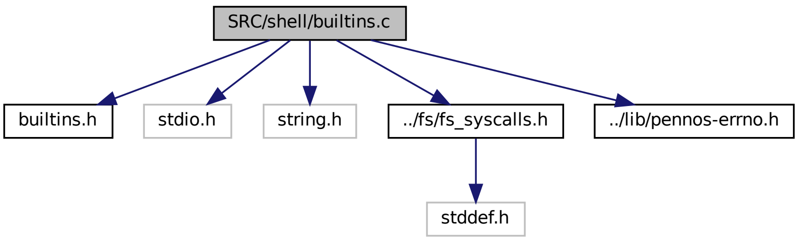
```
int tick_counter  [extern]
```

Definition at line 35 of file scheduler.c.

4.29 SRC/shell/builtins.c File Reference

```
#include "builtins.h"
#include <stdio.h>
#include <string.h>
#include "../fs/fs_syscalls.h"
#include "../lib/pennos-errno.h"
```

Include dependency graph for builtins.c:



Functions

- void u_perror (const char *msg)

  Creates a user-level error message similar to perror.

4.29.1 Function Documentation

4.29.1.1 u_perror()

```
void u_perror (
            const char * msg )
```

Creates a user-level error message similar to perror.

Parameters

msg	A string representing the error message from the shell.

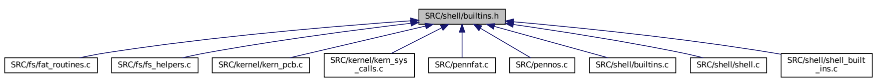
Definition at line 15 of file builtins.c.

```
                              {
  char buffer[256];
  const char *error_msg;

  switch (P_ERRNO) {
    case P_ENOENT:
      error_msg = "file does not exist";
      break;
    case P_EBADF:
      error_msg = "bad file descriptor";
      break;
    case P_EPERM:
      error_msg = "operation not permitted";
      break;
    case P_EINVAL:
      error_msg = "invalid arg";
      break;
    case P_EEXIST:
      error_msg = "file already exists";
      break;
    case P_EBUSY:
      error_msg = "file is busy or open";
      break;
    case P_EFULL:
      error_msg = "no space left on device";
      break;
    case P_EINTR:
      error_msg = "interrupted system call";
      break;
    case P_ENULL:
      error_msg = "NULL returned unexpectedly";
      break;
    case P_EUNKNOWN:
      error_msg = "unknown error";
      break;
    case P_EREAD:
      error_msg = "interrupted read call";
      break;
    case P_ELSEEK:
      error_msg = "interrupted lseek call";
      break;
    case P_EMAP:
      error_msg = "interrupted mmap/munmap call";
      break;
    case P_EFUNC:
      error_msg = "interrupted system call";
      break;
    case P_EOPEN:
      error_msg = "interrupted open call";
      break;
    case P_EMALLOC:
      error_msg = "error when trying to malloc";
      break;
    case P_EFS_NOT_MOUNTED:
      error_msg = "file system not mounted yet";
      break;
    case P_ESIGNAL:
      error_msg = "error with signal handling";
      break;
    case P_EWRITE:
      error_msg = "interrupted write call";
      break;
    case P_ECLOSE:
      error_msg = "interrupted close call";
      break;
    case P_EPARSE:
      error_msg = "error when trying to parse a command";
      break;
    case P_ECOMMAND:
      error_msg = "command not found";
      break;
    case P_NEEDF:
      error_msg = "no file provided to mount";
      break;
    case P_EREDIR:
      error_msg = "input and output cannot be the same when appending";
      break;
    default:
      error_msg = "Unknown error";
      break;
  }

  snprintf(buffer, sizeof(buffer), "%s: %s\n", msg, error_msg);
  if (s_write(STDERR_FILENO, buffer, strlen(buffer)) == -1) {
    perror("s_write");
  }
```

```
101 }
```

4.30 SRC/shell/builtins.h File Reference

This graph shows which files directly or indirectly include this file:



Functions

- void u_perror (const char ∗msg)
  Creates a user-level error message similar to perror.

4.30.1 Function Documentation

4.30.1.1 u_perror()

```
void u_perror (
            const char * msg )
```

Creates a user-level error message similar to perror.

Parameters

msg	A string representing the error message from the shell.

Definition at line 15 of file builtins.c.

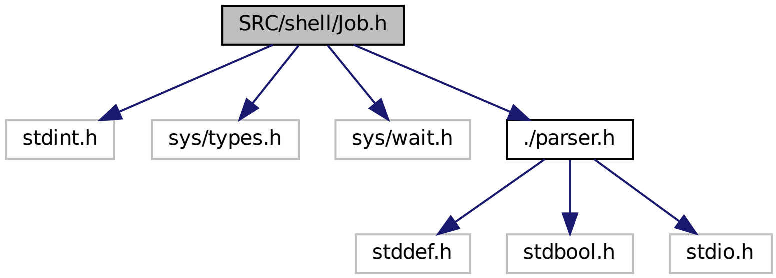
```
15                              {
16   char buffer[256];
17   const char *error_msg;
18
19   switch (P_ERRNO) {
20     case P_ENOENT:
21       error_msg = "file does not exist";
22       break;
23     case P_EBADF:
24       error_msg = "bad file descriptor";
25       break;
26     case P_EPERM:
27       error_msg = "operation not permitted";
28       break;
29     case P_EINVAL:
30       error_msg = "invalid arg";
31       break;
32     case P_EEXIST:
33       error_msg = "file already exists";
34       break;
35     case P_EBUSY:
36       error_msg = "file is busy or open";
37       break;
```

```
    case P_EFULL:
      error_msg = "no space left on device";
      break;
    case P_EINTR:
      error_msg = "interrupted system call";
      break;
    case P_ENULL:
      error_msg = "NULL returned unexpectedly";
      break;
    case P_EUNKNOWN:
      error_msg = "unknown error";
      break;
    case P_EREAD:
      error_msg = "interrupted read call";
      break;
    case P_ELSEEK:
      error_msg = "interrupted lseek call";
      break;
    case P_EMAP:
      error_msg = "interrupted mmap/munmap call";
      break;
    case P_EFUNC:
      error_msg = "interrupted system call";
      break;
    case P_EOPEN:
      error_msg = "interrupted open call";
      break;
    case P_EMALLOC:
      error_msg = "error when trying to malloc";
      break;
    case P_EFS_NOT_MOUNTED:
      error_msg = "file system not mounted yet";
      break;
    case P_ESIGNAL:
      error_msg = "error with signal handling";
      break;
    case P_EWRITE:
      error_msg = "interrupted write call";
      break;
    case P_ECLOSE:
      error_msg = "interrupted close call";
      break;
    case P_EPARSE:
      error_msg = "error when trying to parse a command";
      break;
    case P_ECOMMAND:
      error_msg = "command not found";
      break;
    case P_NEEDF:
      error_msg = "no file provided to mount";
      break;
    case P_EREDIR:
      error_msg = "input and output cannot be the same when appending";
      break;
    default:
      error_msg = "Unknown error";
      break;
  }

  snprintf(buffer, sizeof(buffer), "%s: %s\n", msg, error_msg);
  if (s_write(STDERR_FILENO, buffer, strlen(buffer)) == -1) {
    perror("s_write");
  }
}
```

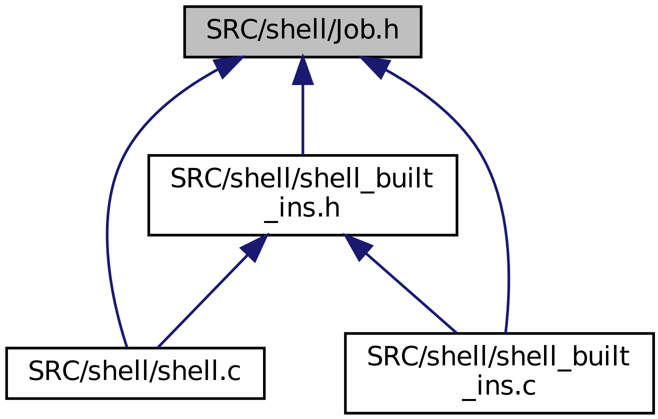
4.31 SRC/shell/Job.h File Reference

```
#include <stdint.h>
#include <sys/types.h>
#include <sys/wait.h>
#include "./parser.h"
```

Include dependency graph for Job.h:



This graph shows which files directly or indirectly include this file:



Classes

- struct job_st

Typedefs

- typedef uint64_t jid_t
- typedef struct job_st job

Enumerations

- enum job_state_t { RUNNING , STOPPED , FINISHED }

4.31.1 Typedef Documentation

4.31.1.1 jid_t

```
typedef uint64_t jid_t
```

Definition at line 10 of file Job.h.

4.31.1.2 job

```
typedef struct job_st job
```

4.31.2 Enumeration Type Documentation

4.31.2.1 job_state_t

```
enum job_state_t
```

Enumerator

RUNNING	
STOPPED	
FINISHED	

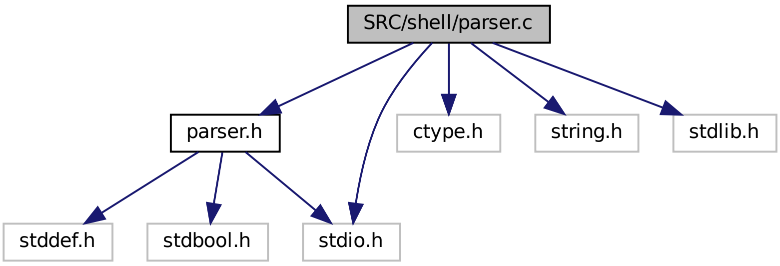
Definition at line 13 of file Job.h.

```
13 { RUNNING, STOPPED, FINISHED } job_state_t;
```

4.32 SRC/shell/parser.c File Reference

```
#include "parser.h"
#include <ctype.h>
#include <string.h>
#include <stdlib.h>
#include <stdio.h>
```

Include dependency graph for parser.c:



Macros

- #define JUMP_OUT(code) do {ret_code = code; goto PROCESS_ERROR;} while (0)

Functions

- int parse_command (const char ∗const cmd_line, struct parsed_command ∗∗const result)
- void print_parsed_command (const struct parsed_command ∗const cmd)
- void print_parser_errcode (FILE ∗output, int err_code)

4.32.1 Macro Definition Documentation

4.32.1.1 JUMP_OUT

```
#define JUMP_OUT(
              code ) do {ret_code = code; goto PROCESS_ERROR;} while (0)
```

4.32.2 Function Documentation

4.32.2.1 parse_command()

```
int parse_command (
            const char * cmd_line,
            struct parsed_command ** result )
```

Arguments: cmd_line: a null-terminated string that is the command line result: a non-null pointer to a `struct parsed_command *`

Return value (int): an error code which can be, 0: parser finished succesfully -1: parser encountered a system call error 1-7: parser specific error, see error type above

This function will parse the given `cmd_line` and store the parsed information into a `struct parsed_command`. The memory needed for the struct will be allocated by this function, and the pointer to the memory will be stored into the given `*result`.

You can directly use the result in system calls. See demo for more information.

If the function returns a successful value (0), a `struct parsed_command` is guareenteed to be allocated and stored in the given `*result`. It is the caller's responsibility to free the given pointer using `free(3)`.

Otherwise, no `struct parsed_command` is allocated and `*result` is unchanged. If a system call error (-1) is returned, the caller can use `errno(3)` or `perror(3)` to gain more information about the error. layout of memory for `struct parsed_command` bool is_background; bool is_file_append;

const char *stdin_file; const char *stdout_file;

size_t num_commands;

commands are pointers to `arguments` char **commands[num_commands];

below are hidden in memory **

arguments are pointers to `original_string + num_commands` because all argv are null-terminated char *arguments[total_strings + num_commands];

original_string is a copy of the cmdline but with each token null-terminated char *original_string;

Definition at line 16 of file parser.c.

```
16                                                                              {
17 #define JUMP_OUT(code) do {ret_code = code; goto PROCESS_ERROR;} while (0)
18
19     int ret_code = -1;
20
21     const char *start = cmd_line;
22     const char *end = cmd_line + strlen(cmd_line);
23
24     for (const char *cur = start; cur < end; ++cur)
25         if (*cur == '#') {
26             // all subsequent characters following '#'
27             // shall be discarded as a comment.
28             end = cur;
29             break;
30         }
31
32     // trimming leading and trailing whitespaces
33     while (start < end && isspace(*start)) ++start;
34     while (start < end && isspace(end[-1])) --end;
35
36     struct parsed_command *pcmd = calloc(1, sizeof(struct parsed_command));
37     if (pcmd == NULL) return -1;
38     if (start == end) goto PROCESS_SUCCESS; // empty line, fast pass
39
40     // If a command is terminated by the control operator ampersand ( '&' ),
41     // the shell shall execute the command in background.
42     if (end[-1] == '&') {
43         pcmd->is_background = true;
44         --end;
```

```
    }

    // first pass, check token
    int total_strings = 0; // number of total arguments
    {
        bool has_token_last = false, has_file_input = false, has_file_output = false;
        const char *skipped;
        for (const char *cur = start; cur < end; skip_space(&cur, end))
            switch (cur[0]) {
                case '&':
                    JUMP_OUT(UNEXPECTED_AMPERSAND); // does not expect anymore ampersand
                case '<':
                    // if already had pipeline or had file input, error
                    if (pcmd->num_commands > 0 || has_file_input) JUMP_OUT(UNEXPECTED_FILE_INPUT);

                    ++cur; // skip '<'
                    skip_space(&cur, end);

                    // test if we indeed have a filename following '<'
                    skipped = cur;
                    skip_word(&skipped, end);
                    if (skipped <= cur) JUMP_OUT(EXPECT_INPUT_FILENAME);

                    // fast-forward to the end of the filename
                    cur = skipped;
                    has_file_input = true;
                    break;
                case '>':
                    // if already had file output, error
                    if (has_file_output) JUMP_OUT(UNEXPECTED_FILE_OUTPUT);
                    if (cur + 1 < end && cur[1] == '>') { // dealing with '»' append
                        pcmd->is_file_append = true;
                        ++cur;
                    }

                    ++cur; // skip '>'
                    skip_space(&cur, end);

                    // test filename, as the case above
                    skipped = cur;
                    skip_word(&skipped, end);
                    if (skipped <= cur) JUMP_OUT(EXPECT_OUTPUT_FILENAME);

                    // fast-forward to the end of the filename
                    cur = skipped;
                    has_file_output = true;
                    break;
                case '|':
                    // if already had file output but encourter a pipeline, it should
                    // rather be a file output error instead of a pipeline one.
                    if (has_file_output) JUMP_OUT(UNEXPECTED_FILE_OUTPUT);
                    // if no tokens between two pipelines (or before the first one)
                    // should throw a pipeline error
                    if (!has_token_last) JUMP_OUT(UNEXPECTED_PIPELINE);
                    has_token_last = false;
                    ++pcmd->num_commands;
                    ++cur; // skip '|'
                    break;
                default:
                    has_token_last = true;
                    ++total_strings;
                    skip_word(&cur, end); // skip that argument
            }

        if (total_strings == 0) {
            // if there are no arguments but has ampersand or file input/output
            // then we have an error
            if (pcmd->is_background || has_file_input || has_file_output)
                JUMP_OUT(EXPECT_COMMANDS);
            // otherwise it's an empty line
            goto PROCESS_SUCCESS;
        }

        // handle edge case where the command ends with a pipeline
        // (not supporting line continuation)
        if (!has_token_last) JUMP_OUT(UNEXPECTED_PIPELINE);
    }
    ++pcmd->num_commands;


    const size_t start_of_array = offsetof(struct parsed_command, commands) +pcmd->num_commands * sizeof(char **);
    const size_t start_of_str = start_of_array + (pcmd->num_commands + total_strings) * sizeof(char *);
    const size_t slen = end - start;

    char *const new_buf = realloc(pcmd, start_of_str + slen + 1);
    if (new_buf == NULL) goto PROCESS_ERROR;
```

```
    pcmd = (struct parsed_command *) new_buf;

    // copy string to the new place
    char *const new_start = memcpy(new_buf + start_of_str, start, slen);

    // second pass, put stuff in
    // no need to check for error anymore
    size_t cur_cmd = 0;
    char **argv_ptr = (char **) (new_buf + start_of_array);

    pcmd->commands[cur_cmd] = argv_ptr;
    for (const char *cur = start; cur < end; skip_space(&cur, end)) {
        switch (cur[0]) {
            case '<':
                ++cur;
                skip_space(&cur, end);
                // store input file name into `stdin_file`
                pcmd->stdin_file = new_start + (cur - start);
                skip_word(&cur, end);
                // at end of the input file name
                new_start[cur - start] = '\0';
                break;
            case '>':
                if (pcmd->is_file_append) ++cur; // skip another '>'
                ++cur;
                skip_space(&cur, end);
                // store output file name into `stdout_file`
                pcmd->stdout_file = new_start + (cur - start);
                skip_word(&cur, end);
                // at end of the output file name
                new_start[cur - start] = '\0';
                break;
            case '|':
                // null-terminate the current argv
                *(argv_ptr++) = NULL;
                // store the next argv head
                pcmd->commands[++cur_cmd] = argv_ptr;
                ++cur;
                break;
            default:
                // at start of the argument string
                // store it into the arguments array
                *(argv_ptr++) = new_start + (cur - start);
                skip_word(&cur, end);
                // at end of the argument string
                new_start[cur - start] = '\0';
        }
    }
    // null-terminate the last argv
    *argv_ptr = NULL;

PROCESS_SUCCESS:
    *result = pcmd;
    return 0;
PROCESS_ERROR:
    free(pcmd);
    return ret_code;
}
```

4.32.2.2 print_parsed_command()

```
void print_parsed_command (
            const struct parsed_command *const cmd )
```

Definition at line 214 of file parser.c.

```
214                                                                     {
215     for (size_t i = 0; i < cmd->num_commands; ++i) {
216         for (char **arguments = cmd->commands[i]; *arguments != NULL; ++arguments)
217             printf("%s ", *arguments);
218 
219         if (i == 0 && cmd->stdin_file != NULL)
220             printf("< %s ", cmd->stdin_file);
221 
222         if (i == cmd->num_commands - 1) {
223             if (cmd->stdout_file != NULL)
224                 printf(cmd->is_file_append ? "» %s " : "> %s ", cmd->stdout_file);
225         } else printf("| ");
226     }
227     puts(cmd->is_background ? "&" : "");
228 }
```

4.32.2.3 print_parser_errcode()

```
void print_parser_errcode (
        FILE * output,
        int err_code )
```

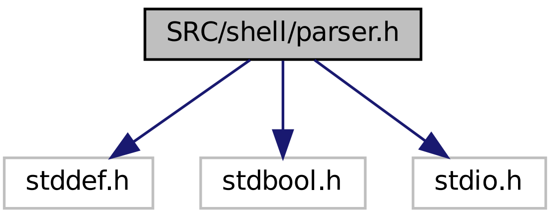
Definition at line 230 of file parser.c.

```
230                                                         {
231   switch (err_code) {
232     case UNEXPECTED_FILE_INPUT:
233       fprintf(output, "UNEXPECTED INPUT REDIRECTION TO A FILE\n");
234       break;
235     case UNEXPECTED_FILE_OUTPUT:
236       fprintf(output, "UNEXPECTED OUTPUT REDIRECTION TO A FILE\n");
237       break;
238     case UNEXPECTED_PIPELINE:
239       fprintf(output, "UNEXPECTED PIPE\n");
240       break;
241     case UNEXPECTED_AMPERSAND:
242       fprintf(output, "UNEXPECTED AMPERESAND\n");
243       break;
244     case EXPECT_INPUT_FILENAME:
245       fprintf(output, "COULD NOT FINE FILENAME FOR INPUT REDIRECTION \"<\"\n");
246       break;
247     case EXPECT_OUTPUT_FILENAME:
248       fprintf(output, "COULD NOT FIND FILENAME FOR OUTPUT REDIRECTION \"<\"\n");
249       break;
250     case EXPECT_COMMANDS:
251       fprintf(output, "COULD NOT FIND ANY COMMANDS OR ARGS\n");
252       break;
253     default:
254       break;
255   }
256 }
```

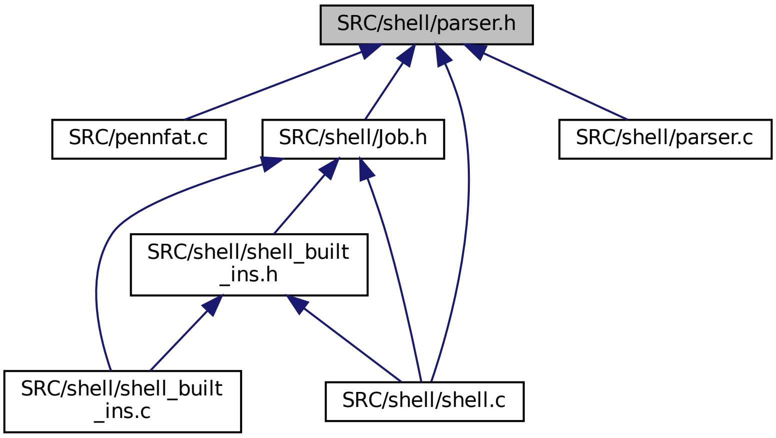
4.33 SRC/shell/parser.h File Reference

```
#include <stddef.h>
#include <stdbool.h>
#include <stdio.h>
```

Include dependency graph for parser.h:



This graph shows which files directly or indirectly include this file:



Classes

- struct parsed_command

Macros

- #define UNEXPECTED_FILE_INPUT 1
- #define UNEXPECTED_FILE_OUTPUT 2
- #define UNEXPECTED_PIPELINE 3
- #define UNEXPECTED_AMPERSAND 4
- #define EXPECT_INPUT_FILENAME 5
- #define EXPECT_OUTPUT_FILENAME 6
- #define EXPECT_COMMANDS 7

Functions

- int parse_command (const char *cmd_line, struct parsed_command **result)
- void print_parsed_command (const struct parsed_command *cmd)
- void print_parser_errcode (FILE *output, int err_code)

4.33.1 Macro Definition Documentation

4.33.1.1 EXPECT_COMMANDS

```
#define EXPECT_COMMANDS 7
```

Definition at line 30 of file parser.h.

4.33.1.2 EXPECT_INPUT_FILENAME

```
#define EXPECT_INPUT_FILENAME 5
```

Definition at line 24 of file parser.h.

4.33.1.3 EXPECT_OUTPUT_FILENAME

```
#define EXPECT_OUTPUT_FILENAME 6
```

Definition at line 27 of file parser.h.

4.33.1.4 UNEXPECTED_AMPERSAND

```
#define UNEXPECTED_AMPERSAND 4
```

Definition at line 21 of file parser.h.

4.33.1.5 UNEXPECTED_FILE_INPUT

```
#define UNEXPECTED_FILE_INPUT 1
```

Definition at line 12 of file parser.h.

4.33.1.6 UNEXPECTED_FILE_OUTPUT

```
#define UNEXPECTED_FILE_OUTPUT 2
```

Definition at line 15 of file parser.h.

4.33.1.7 UNEXPECTED_PIPELINE

```
#define UNEXPECTED_PIPELINE 3
```

Definition at line 18 of file parser.h.

4.33.2 Function Documentation

4.33.2.1 parse_command()

```
int parse_command (
            const char * cmd_line,
            struct parsed_command ** result )
```

Arguments: cmd_line: a null-terminated string that is the command line result: a non-null pointer to a `struct parsed_command *`

Return value (int): an error code which can be, 0: parser finished succesfully -1: parser encountered a system call error 1-7: parser specific error, see error type above

This function will parse the given `cmd_line` and store the parsed information into a `struct parsed_command`. The memory needed for the struct will be allocated by this function, and the pointer to the memory will be stored into the given `*result`.

You can directly use the result in system calls. See demo for more information.

If the function returns a successful value (0), a `struct parsed_command` is guareenteed to be allocated and stored in the given `*result`. It is the caller's responsibility to free the given pointer using `free(3)`.

Otherwise, no `struct parsed_command` is allocated and `*result` is unchanged. If a system call error (-1) is returned, the caller can use `errno(3)` or `perror(3)` to gain more information about the error. layout of memory for `struct parsed_command` bool is_background; bool is_file_append;

const char *stdin_file; const char *stdout_file;

size_t num_commands;

commands are pointers to `arguments` char **commands[num_commands];

below are hidden in memory **

arguments are pointers to `original_string + num_commands` because all argv are null-terminated char *arguments[total_strings + num_commands];

original_string is a copy of the cmdline but with each token null-terminated char *original_string;

Definition at line 16 of file parser.c.

```
16                                                                                     {
17 #define JUMP_OUT(code) do {ret_code = code; goto PROCESS_ERROR;} while (0)
18
19     int ret_code = -1;
20
21     const char *start = cmd_line;
22     const char *end = cmd_line + strlen(cmd_line);
23
24     for (const char *cur = start; cur < end; ++cur)
25         if (*cur == '#') {
26             // all subsequent characters following '#'
27             // shall be discarded as a comment.
28             end = cur;
29             break;
30         }
31
32     // trimming leading and trailing whitespaces
33     while (start < end && isspace(*start)) ++start;
34     while (start < end && isspace(end[-1])) --end;
35
36     struct parsed_command *pcmd = calloc(1, sizeof(struct parsed_command));
```

```
    if (pcmd == NULL) return -1;
    if (start == end) goto PROCESS_SUCCESS; // empty line, fast pass

    // If a command is terminated by the control operator ampersand ( '&' ),
    // the shell shall execute the command in background.
    if (end[-1] == '&') {
        pcmd->is_background = true;
        --end;
    }

    // first pass, check token
    int total_strings = 0; // number of total arguments
    {
        bool has_token_last = false, has_file_input = false, has_file_output = false;
        const char *skipped;
        for (const char *cur = start; cur < end; skip_space(&cur, end))
            switch (cur[0]) {
                case '&':
                    JUMP_OUT(UNEXPECTED_AMPERSAND); // does not expect anymore ampersand
                case '<':
                    // if already had pipeline or had file input, error
                    if (pcmd->num_commands > 0 || has_file_input) JUMP_OUT(UNEXPECTED_FILE_INPUT);

                    ++cur; // skip '<'
                    skip_space(&cur, end);

                    // test if we indeed have a filename following '<'
                    skipped = cur;
                    skip_word(&skipped, end);
                    if (skipped <= cur) JUMP_OUT(EXPECT_INPUT_FILENAME);

                    // fast-forward to the end of the filename
                    cur = skipped;
                    has_file_input = true;
                    break;
                case '>':
                    // if already had file output, error
                    if (has_file_output) JUMP_OUT(UNEXPECTED_FILE_OUTPUT);
                    if (cur + 1 < end && cur[1] == '>') { // dealing with '»' append
                        pcmd->is_file_append = true;
                        ++cur;
                    }

                    ++cur; // skip '>'
                    skip_space(&cur, end);

                    // test filename, as the case above
                    skipped = cur;
                    skip_word(&skipped, end);
                    if (skipped <= cur) JUMP_OUT(EXPECT_OUTPUT_FILENAME);

                    // fast-forward to the end of the filename
                    cur = skipped;
                    has_file_output = true;
                    break;
                case '|':
                    // if already had file output but encourter a pipeline, it should
                    // rather be a file output error instead of a pipeline one.
                    if (has_file_output) JUMP_OUT(UNEXPECTED_FILE_OUTPUT);
                    // if no tokens between two pipelines (or before the first one)
                    // should throw a pipeline error
                    if (!has_token_last) JUMP_OUT(UNEXPECTED_PIPELINE);
                    has_token_last = false;
                     ++pcmd->num_commands;
                     ++cur; // skip '|'
                     break;
                 default:
                     has_token_last = true;
                     ++total_strings;
                     skip_word(&cur, end); // skip that argument
             }

         if (total_strings == 0) {
             // if there are no arguments but has ampersand or file input/output
             // then we have an error
             if (pcmd->is_background || has_file_input || has_file_output)
                 JUMP_OUT(EXPECT_COMMANDS);
             // otherwise it's an empty line
             goto PROCESS_SUCCESS;
         }

         // handle edge case where the command ends with a pipeline
         // (not supporting line continuation)
         if (!has_token_last) JUMP_OUT(UNEXPECTED_PIPELINE);
     }
     ++pcmd->num_commands;

```

```c

    const size_t start_of_array = offsetof(struct parsed_command, commands) +pcmd->num_commands * sizeof(char **);
    const size_t start_of_str = start_of_array + (pcmd->num_commands + total_strings) * sizeof(char *);
    const size_t slen = end - start;

    char *const new_buf = realloc(pcmd, start_of_str + slen + 1);
    if (new_buf == NULL) goto PROCESS_ERROR;
    pcmd = (struct parsed_command *) new_buf;

    // copy string to the new place
    char *const new_start = memcpy(new_buf + start_of_str, start, slen);

    // second pass, put stuff in
    // no need to check for error anymore
    size_t cur_cmd = 0;
    char **argv_ptr = (char **) (new_buf + start_of_array);

    pcmd->commands[cur_cmd] = argv_ptr;
    for (const char *cur = start; cur < end; skip_space(&cur, end)) {
        switch (cur[0]) {
            case '<':
                ++cur;
                skip_space(&cur, end);
                // store input file name into `stdin_file`
                pcmd->stdin_file = new_start + (cur - start);
                skip_word(&cur, end);
                // at end of the input file name
                new_start[cur - start] = '\0';
                break;
            case '>':
                if (pcmd->is_file_append) ++cur; // skip another '>'
                ++cur;
                skip_space(&cur, end);
                // store output file name into `stdout_file`
                pcmd->stdout_file = new_start + (cur - start);
                skip_word(&cur, end);
                // at end of the output file name
                new_start[cur - start] = '\0';
                break;
            case '|':
                // null-terminate the current argv
                *(argv_ptr++) = NULL;
                // store the next argv head
                pcmd->commands[++cur_cmd] = argv_ptr;
                ++cur;
                break;
            default:
                // at start of the argument string
                // store it into the arguments array
                *(argv_ptr++) = new_start + (cur - start);
                skip_word(&cur, end);
                // at end of the argument string
                new_start[cur - start] = '\0';
        }
    }
    // null-terminate the last argv
    *argv_ptr = NULL;

PROCESS_SUCCESS:
    *result = pcmd;
    return 0;
PROCESS_ERROR:
    free(pcmd);
    return ret_code;
}
```

4.33.2.2 print_parsed_command()

```c
void print_parsed_command (
            const struct parsed_command * cmd )
```

Definition at line 214 of file parser.c.

```c
214                                                                     {
215     for (size_t i = 0; i < cmd->num_commands; ++i) {
216         for (char **arguments = cmd->commands[i]; *arguments != NULL; ++arguments)
217             printf("%s ", *arguments);
218
```

```
        if (i == 0 && cmd->stdin_file != NULL)
            printf("< %s ", cmd->stdin_file);

        if (i == cmd->num_commands - 1) {
            if (cmd->stdout_file != NULL)
                printf(cmd->is_file_append ? "» %s " : "> %s ", cmd->stdout_file);
        } else printf("| ");
    }
    puts(cmd->is_background ? "&" : "");
}
```

4.33.2.3 print_parser_errcode()

```
void print_parser_errcode (
            FILE * output,
            int err_code )
```

Definition at line 230 of file parser.c.

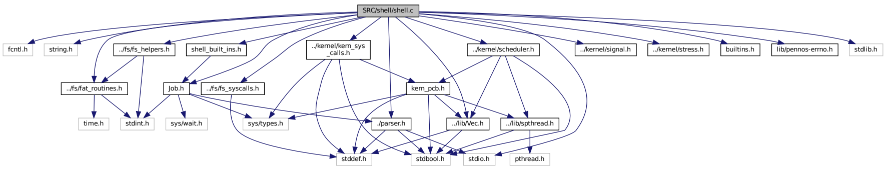
```
230                                                         {
231   switch (err_code) {
232     case UNEXPECTED_FILE_INPUT:
233       fprintf(output, "UNEXPECTED INPUT REDIRECTION TO A FILE\n");
234       break;
235     case UNEXPECTED_FILE_OUTPUT:
236       fprintf(output, "UNEXPECTED OUTPUT REDIRECTION TO A FILE\n");
237       break;
238     case UNEXPECTED_PIPELINE:
239       fprintf(output, "UNEXPECTED PIPE\n");
240       break;
241     case UNEXPECTED_AMPERSAND:
242       fprintf(output, "UNEXPECTED AMPERESAND\n");
243       break;
244     case EXPECT_INPUT_FILENAME:
245       fprintf(output, "COULD NOT FINE FILENAME FOR INPUT REDIRECTION \"<\"\n");
246       break;
247     case EXPECT_OUTPUT_FILENAME:
248       fprintf(output, "COULD NOT FIND FILENAME FOR OUTPUT REDIRECTION \"<\"\n");
249       break;
250     case EXPECT_COMMANDS:
251       fprintf(output, "COULD NOT FIND ANY COMMANDS OR ARGS\n");
252       break;
253     default:
254       break;
255   }
256 }
```

4.34 SRC/shell/shell.c File Reference

```
#include <fcntl.h>
#include <string.h>
#include "../fs/fat_routines.h"
#include "../fs/fs_helpers.h"
#include "../fs/fs_syscalls.h"
#include "../kernel/kern_sys_calls.h"
#include "../kernel/scheduler.h"
#include "../kernel/signal.h"
#include "../kernel/stress.h"
#include "../lib/Vec.h"
#include "Job.h"
#include "builtins.h"
#include "lib/pennos-errno.h"
#include "parser.h"
#include "shell_built_ins.h"
#include "stdio.h"
```

`#include "stdlib.h"`

Include dependency graph for shell.c:



Macros

- #define PROMPT "$ "
- #define MAX_BUFFER_SIZE 4096
- #define MAX_LINE_BUFFER_SIZE 128

Functions

- void shell_sigint_handler (int sig)
- void shell_sigstp_handler (int sig)
- void setup_terminal_signal_handlers (void)
- void free_job_ptr (void ∗ptr)
- void fill_buffer_until_full_or_newline (int fd, char ∗buffer)

  Helper function that fills a buffer with characters read from a given file descriptor until the buffer is full (rare and impractical case), a newline is encountered, or EOF is reached.
- pid_t u_execute_command (struct parsed_command ∗cmd)

  Helper function that will execute a given command so long as it's one of the built-ins. Notably, its output and input are determined by the spawning script process.
- void ∗ u_read_and_execute_script (void ∗arg)

  Helper function that reads a script file line by line, parses each line as a command, and executes it.
- pid_t execute_command (struct parsed_command ∗cmd)

  Helper function to execute a parsed command from the shell. In particular, it spawns a child process to execute the command if the built-in should run as a separate process. Otherwise, it just calls the subroutine directly.
- void ∗ shell (void ∗)

  The main shell function that runs the shell. This is run via an s_spawn call from init's process. It prompts the user for builtins and scripts to run.

Variables

- pid_t current_fg_pid
- Vec job_list
- jid_t next_job_id = 1
- int script_fd = -1
- int input_fd_script = -1
- int output_fd_script = -1
- int is_append = 0

4.34.1 Macro Definition Documentation

4.34.1.1 MAX_BUFFER_SIZE

```
#define MAX_BUFFER_SIZE 4096
```

Definition at line 29 of file shell.c.

4.34.1.2 MAX_LINE_BUFFER_SIZE

```
#define MAX_LINE_BUFFER_SIZE 128
```

Definition at line 30 of file shell.c.

4.34.1.3 PROMPT

```
#define PROMPT "$ "
```

Definition at line 26 of file shell.c.

4.34.2 Function Documentation

4.34.2.1 execute_command()

```
pid_t execute_command (
            struct parsed_command * cmd )
```

Helper function to execute a parsed command from the shell. In particular, it spawns a child process to execute the command if the built-in should run as a separate process. Otherwise, it just calls the subroutine directly.

Parameters

cmd	the parsed command to execute, assumed non-null

Returns

the created child id on successful spawn, 0 on successful subroutine call, -1 when nothing was called

Definition at line 266 of file shell.c.

```
266                                                   {
267   // setup fds
268   int input_fd = STDIN_FILENO;  // standard fds
269   int output_fd = STDOUT_FILENO;
270
271   if (cmd->stdin_file != NULL) {
```

```
    input_fd = s_open(cmd->stdin_file, F_READ);
    if (input_fd < 0) {
      input_fd = STDIN_FILENO;  // reset to default
    }
  }

  if (cmd->is_file_append) {
    output_fd = s_open(cmd->stdout_file, F_APPEND);
    is_append = 1;
  } else {
    output_fd = s_open(cmd->stdout_file, F_WRITE);
    is_append = 0;
  }
  if (output_fd < 0) {
    output_fd = STDOUT_FILENO;  // reset to default
  }

  // check for independently scheduled processes
  if (strcmp(cmd->commands[0][0], "cat") == 0) {
    return s_spawn(u_cat, cmd->commands[0], input_fd, output_fd);
  } else if (strcmp(cmd->commands[0][0], "sleep") == 0) {
    return s_spawn(u_sleep, cmd->commands[0], input_fd, output_fd);
  } else if (strcmp(cmd->commands[0][0], "busy") == 0) {
    return s_spawn(u_busy, cmd->commands[0], input_fd, output_fd);
  } else if (strcmp(cmd->commands[0][0], "echo") == 0) {
    return s_spawn(u_echo, cmd->commands[0], input_fd, output_fd);
  } else if (strcmp(cmd->commands[0][0], "ls") == 0) {
    return s_spawn(u_ls, cmd->commands[0], input_fd, output_fd);
  } else if (strcmp(cmd->commands[0][0], "touch") == 0) {
    return s_spawn(u_touch, cmd->commands[0], input_fd, output_fd);
  } else if (strcmp(cmd->commands[0][0], "mv") == 0) {
    return s_spawn(u_mv, cmd->commands[0], input_fd, output_fd);
  } else if (strcmp(cmd->commands[0][0], "cp") == 0) {
    return s_spawn(u_cp, cmd->commands[0], input_fd, output_fd);
  } else if (strcmp(cmd->commands[0][0], "rm") == 0) {
    return s_spawn(u_rm, cmd->commands[0], input_fd, output_fd);
  } else if (strcmp(cmd->commands[0][0], "chmod") == 0) {
    return s_spawn(u_chmod, cmd->commands[0], input_fd, output_fd);
  } else if (strcmp(cmd->commands[0][0], "ps") == 0) {
    return s_spawn(u_ps, cmd->commands[0], input_fd, output_fd);
  } else if (strcmp(cmd->commands[0][0], "kill") == 0) {
    return s_spawn(u_kill, cmd->commands[0], input_fd, output_fd);
  } else if (strcmp(cmd->commands[0][0], "zombify") == 0) {
    return s_spawn(u_zombify, cmd->commands[0], input_fd, output_fd);
  } else if (strcmp(cmd->commands[0][0], "orphanify") == 0) {
    return s_spawn(u_orphanify, cmd->commands[0], input_fd, output_fd);
  } else if (strcmp(cmd->commands[0][0], "hang") == 0) {
    return s_spawn(hang, cmd->commands[0], input_fd, output_fd);
  } else if (strcmp(cmd->commands[0][0], "nohang") == 0) {
    return s_spawn(nohang, cmd->commands[0], input_fd, output_fd);
  } else if (strcmp(cmd->commands[0][0], "recur") == 0) {
    return s_spawn(recur, cmd->commands[0], input_fd, output_fd);
  } else if (strcmp(cmd->commands[0][0], "crash") == 0) {
    return s_spawn(crash, cmd->commands[0], input_fd, output_fd);
  }

  // check for sub-routines
  if (strcmp(cmd->commands[0][0], "nice") == 0) {
    u_nice(cmd->commands[0]);
    return 0;
  } else if (strcmp(cmd->commands[0][0], "nice_pid") == 0) {
    u_nice_pid(cmd->commands[0]);
    return 0;
  } else if (strcmp(cmd->commands[0][0], "man") == 0) {
    u_man(cmd->commands[0]);
    return 0;
  } else if (strcmp(cmd->commands[0][0], "bg") == 0) {
    u_bg(cmd->commands[0]);
    return 0;
  } else if (strcmp(cmd->commands[0][0], "fg") == 0) {
    u_fg(cmd->commands[0]);
    return 0;
  } else if (strcmp(cmd->commands[0][0], "jobs") == 0) {
    u_jobs(cmd->commands[0]);
    return 0;
  } else if (strcmp(cmd->commands[0][0], "logout") == 0) {
    u_logout(cmd->commands[0]);
    return 0;
  }

  // otherwise, try to run command as a script
  int script_fd_open = s_open(cmd->commands[0][0], F_READ);
  if (script_fd_open < 0) {  // if not a file, just move on
    return -1;
  }
  if (has_executable_permission(script_fd_open) != 1) {
    if (s_close(script_fd_open) == -1) {
```

```
359       u_perror("s_close error i.e. not a valid fd");
360     }
361     return -1;
362   } else {
363     script_fd = script_fd_open;  // update global
364     input_fd_script = input_fd;
365     output_fd_script = output_fd;
366
367     char* script_argv[] = {cmd->commands[0][0], NULL};
368     pid_t wait_on =
369         s_spawn(u_read_and_execute_script, script_argv, input_fd, output_fd);
370     int status;
371     s_waitpid(wait_on, &status, false);  // wait for script to finish
372     script_fd = -1;                      // reset global
373     input_fd_script = STDIN_FILENO;
374     output_fd_script = STDOUT_FILENO;
375     if (s_close(script_fd_open) == -1) {
376       u_perror("s_close error i.e. not a valid fd");
377     }
378     return 0;
379   }
380
381   return -1;  // no matches case
382 }
```

4.34.2.2 fill_buffer_until_full_or_newline()

```
void fill_buffer_until_full_or_newline (
            int fd,
            char * buffer )
```

Helper function that fills a buffer with characters read from a given file descriptor until the buffer is full (rare and impractical case), a newline is encountered, or EOF is reached.

Parameters

fd	the file descriptor to read from, assumed to be open
buffer	the buffer to fill with characters

Definition at line 120 of file shell.c.

```
120                                                                 {
121   int i = 0;
122   char currChar;
123   while (i < MAX_LINE_BUFFER_SIZE - 1) {
124     int bytes_read = s_read(fd, &currChar, 1);
125     if (bytes_read <= 0 || currChar == '\n') {  // EOF or newline cases
126       break;
127     }
128     buffer[i] = currChar;
129     i++;
130   }
131   buffer[i] = '\0';  // Null-terminate the string, replaces \n
132 }
```

4.34.2.3 free_job_ptr()

```
void free_job_ptr (
            void * ptr )
```

Definition at line 102 of file shell.c.

```
102                              {
103   job* job_ptr = (job*)ptr;
104   free(job_ptr->pids);
105   free(job_ptr);
106 }
```

4.34.2.4 setup_terminal_signal_handlers()

```
void setup_terminal_signal_handlers (
              void )
```

Definition at line 74 of file shell.c.

```
74                                           {
75   struct sigaction sa_int = {0};
76   sa_int.sa_handler = shell_sigint_handler;
77   sigemptyset(&sa_int.sa_mask);
78   sa_int.sa_flags = SA_RESTART;
79   if (sigaction(SIGINT, &sa_int, NULL) == -1) {
80     P_ERRNO = P_ESIGNAL;
81     u_perror("sigaction");
82     exit(EXIT_FAILURE);
83   }
84 
85   struct sigaction sa_stp = {0};
86   sa_stp.sa_handler = shell_sigstp_handler;
87   sigemptyset(&sa_stp.sa_mask);
88   sa_stp.sa_flags = SA_RESTART;
89   if (sigaction(SIGTSTP, &sa_stp, NULL) == -1) {
90     P_ERRNO = P_ESIGNAL;
91     u_perror("sigaction");
92     exit(EXIT_FAILURE);
93   }
94 }
```

4.34.2.5 shell()

```
void* shell (
              void * input )
```

The main shell function that runs the shell. This is run via an s_spawn call from init's process. It prompts the user for builtins and scripts to run.

Parameters

input	unused

Definition at line 388 of file shell.c.

```
388                  {
389   job_list = vec_new(0, free_job_ptr);
390 
391   setup_terminal_signal_handlers();
392 
393   while (true) {
394     // poll background jobs
395     int status;
396     pid_t child_pid;
397     while ((child_pid = s_waitpid(-1, &status, true)) > 0) {
398       // Find which job child_pid belongs to
399       for (size_t i = 0; i < vec_len(&job_list); i++) {
400         job* job = vec_get(&job_list, i);
401         bool in_this_job = false;
402         for (size_t j = 0; j < job->num_pids; j++) {
403           if (job->pids[j] == child_pid) {
404             in_this_job = true;
405             break;
406           }
407         }
408 
409         if (!in_this_job) {
410           continue;
411         }
412 
413         // If the process ended normally or via signal
414         if (P_WIFEXITED(status) || P_WIFSIGNALED(status)) {
415           job->finished_count++;
```

```
          if (job->finished_count == job->num_pids) {
            char buf[128];
            snprintf(buf, sizeof(buf), "Finished: ");
            s_write(STDOUT_FILENO, buf, strlen(buf));
            for (size_t cmdIdx = 0; cmdIdx < job->cmd->num_commands; cmdIdx++) {
              char** argv = job->cmd->commands[cmdIdx];
              int argIdx = 0;
              while (argv[argIdx] != NULL) {
                snprintf(buf, sizeof(buf), "%s ", argv[argIdx]);
                s_write(STDOUT_FILENO, buf, strlen(buf));
                argIdx++;
              }
            }
            snprintf(buf, sizeof(buf), "\n");
            s_write(STDOUT_FILENO, buf, strlen(buf));
            vec_erase(&job_list, i);
          }
        } else if (P_WIFSTOPPED(status) && job->state == RUNNING) {
          job->state = STOPPED;
          char buf[128];
          snprintf(buf, sizeof(buf), "Stopped: ");
          s_write(STDOUT_FILENO, buf, strlen(buf));
          for (size_t cmdIdx = 0; cmdIdx < job->cmd->num_commands; cmdIdx++) {
            char** argv = job->cmd->commands[cmdIdx];
            int argIdx = 0;
            while (argv[argIdx] != NULL) {
              snprintf(buf, sizeof(buf), "%s ", argv[argIdx]);
              s_write(STDOUT_FILENO, buf, strlen(buf));
              argIdx++;
            }
          }
          snprintf(buf, sizeof(buf), "\n");
          s_write(STDOUT_FILENO, buf, strlen(buf));
        }
        break;  // break from for-loop over job_list
      }
    }

    // prompt
    if (s_write(STDOUT_FILENO, PROMPT, strlen(PROMPT)) < 0) {
      u_perror("prompt s_write error");
      break;
    }

    // parse user input
    char buffer[MAX_BUFFER_SIZE];
    ssize_t user_input = s_read(STDIN_FILENO, buffer, MAX_BUFFER_SIZE);
    if (user_input < 0) {
      u_perror("shell read error");
      break;
    } else if (user_input == 0) {  // EOF case
      s_shutdown_pennos();
      break;
    }

    buffer[user_input] = '\0';
    if (buffer[user_input - 1] == '\n') {
      buffer[user_input - 1] = '\0';
    }

    struct parsed_command* cmd = NULL;
    int cmd_parse_res = parse_command(buffer, &cmd);
    if (cmd_parse_res != 0 || cmd == NULL) {
      P_ERRNO = P_EPARSE;
      u_perror("parse_command");
      continue;
    }

    // handle the command
    if (cmd->num_commands == 0) {
      free(cmd);
      continue;
    }

    child_pid = execute_command(cmd);
    if (child_pid < 0) {
      free(cmd);
      continue;
    } else if (child_pid == 0) {
      free(cmd);
      continue;
    }

    // If background, add the process to the job list.
    if (cmd->is_background) {
      // Create a new job entry.
      job* new_job = malloc(sizeof(job));
```

```
      if (new_job == NULL) {
        perror("Error: mallocing new_job failed");
        free(cmd);
        continue;
      }
      new_job->id = next_job_id++;
      new_job->pgid = child_pid;  // For single commands, child's pid = pgid.
      new_job->num_pids = 1;
      new_job->pids = malloc(sizeof(pid_t));
      if (new_job->pids == NULL) {
        perror("Error: mallocing new_job->pids failed");
        free(new_job);
        free(cmd);
        continue;
      }
      new_job->pids[0] = child_pid;
      new_job->state = RUNNING;
      new_job->cmd = cmd;  // Retain command info; do not free here.
      new_job->finished_count = 0;
      vec_push_back(&job_list, new_job);

      // Print job control information in the format: "[job_id] child_pid"
      char msg[128];
      snprintf(msg, sizeof(msg), "[%lu] %d\n", (unsigned long)new_job->id,
               child_pid);
      if (s_write(STDOUT_FILENO, msg, strlen(msg)) == -1) {
        u_perror("s_write error");
      }
    } else {
      // Foreground execution.
      current_fg_pid = child_pid;
      int status;
      s_waitpid(child_pid, &status, false);

      if (P_WIFSTOPPED(status)) {
        // Create a new job entry (this time for a stopped process)
        job* new_job = malloc(sizeof(job));
        if (new_job == NULL) {
          perror("Error: mallocing new_job failed");
          free(cmd);
          continue;
        }
        new_job->id = next_job_id++;
        new_job->pgid = child_pid;  // For single commands, child's pid = pgid.
        new_job->num_pids = 1;
        new_job->pids = malloc(sizeof(pid_t));
        if (new_job->pids == NULL) {
          perror("Error: mallocing new_job->pids failed");
          free(new_job);
          free(cmd);
          continue;
        }
        new_job->pids[0] = child_pid;
        new_job->state = STOPPED;
        new_job->cmd = cmd;  // Retain command info; do not free here.
        new_job->finished_count = 0;
        vec_push_back(&job_list, new_job);

        // Print stopped job
        char buf[128];
        snprintf(buf, sizeof(buf), "Stopped: ");
        s_write(STDOUT_FILENO, buf, strlen(buf));
        for (size_t cmdIdx = 0; cmdIdx < new_job->cmd->num_commands; cmdIdx++) {
          char** argv = new_job->cmd->commands[cmdIdx];
          int argIdx = 0;
          while (argv[argIdx] != NULL) {
            snprintf(buf, sizeof(buf), "%s ", argv[argIdx]);
            s_write(STDOUT_FILENO, buf, strlen(buf));
            argIdx++;
          }
        }
        snprintf(buf, sizeof(buf), "\n");
        s_write(STDOUT_FILENO, buf, strlen(buf));
      }

      current_fg_pid = 2;

      // Free cmd memory for foreground commands.
      // free(cmd); // TODO --> check if this is already freed, it may be
    }
  }

  vec_destroy(&job_list);
  s_exit();
  return 0;
}
```

4.34.2.6 shell_sigint_handler()

```
void shell_sigint_handler (
            int sig )
```

Definition at line 49 of file shell.c.

```
49                              {
50   // If there's a foreground process, forward SIGINT (terminate) to it, as long
51   // as it's not the shell current_fg_pid will also never be 1 (INIT)
52   if (current_fg_pid != 2) {
53     s_kill(current_fg_pid, 2);  // P_SIGTERM
54   }
55 
56   if (s_write(STDOUT_FILENO, "\n", 1) == -1) {
57     u_perror("s_write error");
58   }
59 }
```

4.34.2.7 shell_sigstp_handler()

```
void shell_sigstp_handler (
            int sig )
```

Definition at line 62 of file shell.c.

```
62                              {
63   // If there's a foreground process, forward SIGTSTP (stop) to it
64   if (current_fg_pid != 2) {
65     s_kill(current_fg_pid, 0);  // P_SIGSTOP
66   }
67 
68   if (s_write(STDOUT_FILENO, "\n", 1) == -1) {
69     u_perror("s_write error");
70   }
71 }
```

4.34.2.8 u_execute_command()

```
pid_t u_execute_command (
            struct parsed_command * cmd )
```

Helper function that will execute a given command so long as it's one of the built-ins. Notably, its output and input are determined by the spawning script process.

Parameters

cmd	the parsed command to try executing

Returns

the pid of the process if one was spawned, 0 if a routine was run or -1 if not matches found

Definition at line 143 of file shell.c.

```
                                                     {
  // check for independently scheduled processes
  if (strcmp(cmd->commands[0][0], "cat") == 0) {
    return s_spawn(u_cat, cmd->commands[0], input_fd_script, output_fd_script);
  } else if (strcmp(cmd->commands[0][0], "sleep") == 0) {
    return s_spawn(u_sleep, cmd->commands[0], input_fd_script,
                   output_fd_script);
  } else if (strcmp(cmd->commands[0][0], "busy") == 0) {
    return s_spawn(u_busy, cmd->commands[0], input_fd_script, output_fd_script);
  } else if (strcmp(cmd->commands[0][0], "echo") == 0) {
    return s_spawn(u_echo, cmd->commands[0], input_fd_script, output_fd_script);
  } else if (strcmp(cmd->commands[0][0], "ls") == 0) {
    return s_spawn(u_ls, cmd->commands[0], input_fd_script, output_fd_script);
  } else if (strcmp(cmd->commands[0][0], "touch") == 0) {
    return s_spawn(u_touch, cmd->commands[0], input_fd_script,
                   output_fd_script);
  } else if (strcmp(cmd->commands[0][0], "mv") == 0) {
    return s_spawn(u_mv, cmd->commands[0], input_fd_script, output_fd_script);
  } else if (strcmp(cmd->commands[0][0], "cp") == 0) {
    return s_spawn(u_cp, cmd->commands[0], input_fd_script, output_fd_script);
  } else if (strcmp(cmd->commands[0][0], "rm") == 0) {
    return s_spawn(u_rm, cmd->commands[0], input_fd_script, output_fd_script);
  } else if (strcmp(cmd->commands[0][0], "chmod") == 0) {
    return s_spawn(u_chmod, cmd->commands[0], input_fd_script,
                   output_fd_script);
  } else if (strcmp(cmd->commands[0][0], "ps") == 0) {
    return s_spawn(u_ps, cmd->commands[0], input_fd_script, output_fd_script);
  } else if (strcmp(cmd->commands[0][0], "kill") == 0) {
    return s_spawn(u_kill, cmd->commands[0], input_fd_script, output_fd_script);
  } else if (strcmp(cmd->commands[0][0], "zombify") == 0) {
    return s_spawn(u_zombify, cmd->commands[0], input_fd_script,
                   output_fd_script);
  } else if (strcmp(cmd->commands[0][0], "orphanify") == 0) {
    return s_spawn(u_orphanify, cmd->commands[0], input_fd_script,
                   output_fd_script);
  } else if (strcmp(cmd->commands[0][0], "hang") == 0) {
    return s_spawn(hang, cmd->commands[0], input_fd_script, output_fd_script);
  } else if (strcmp(cmd->commands[0][0], "nohang") == 0) {
    return s_spawn(nohang, cmd->commands[0], input_fd_script, output_fd_script);
  } else if (strcmp(cmd->commands[0][0], "recur") == 0) {
    return s_spawn(recur, cmd->commands[0], input_fd_script, output_fd_script);
  } else if (strcmp(cmd->commands[0][0], "crash") == 0) {
    return s_spawn(crash, cmd->commands[0], input_fd_script, output_fd_script);
  }

  // check for sub-routines
  if (strcmp(cmd->commands[0][0], "nice") == 0) {
    u_nice(cmd->commands[0]);
    return 0;
  } else if (strcmp(cmd->commands[0][0], "nice_pid") == 0) {
    u_nice_pid(cmd->commands[0]);
    return 0;
  } else if (strcmp(cmd->commands[0][0], "man") == 0) {
    u_man(cmd->commands[0]);
    return 0;
  } else if (strcmp(cmd->commands[0][0], "bg") == 0) {
    u_bg(cmd->commands[0]);
    return 0;
  } else if (strcmp(cmd->commands[0][0], "fg") == 0) {
    u_fg(cmd->commands[0]);
    return 0;
  } else if (strcmp(cmd->commands[0][0], "jobs") == 0) {
    u_jobs(cmd->commands[0]);
    return 0;
  } else if (strcmp(cmd->commands[0][0], "logout") == 0) {
    u_logout(cmd->commands[0]);
    return 0;
  } else {
    return -1;  // no matches, no scripts now
  }

  return 0;
}
```

4.34.2.9 u_read_and_execute_script()

```
void* u_read_and_execute_script (
               void * arg )
```

Helper function that reads a script file line by line, parses each line as a command, and executes it.

Parameters

arg	standard {function name, NULL} args

Returns

NULL

Definition at line 224 of file shell.c.

```
224                                                {
225   // read the script line by line, parse each line, and execute the command
226   while (true) {
227     char buffer[MAX_LINE_BUFFER_SIZE];
228     fill_buffer_until_full_or_newline(script_fd, buffer);
229     if (buffer[0] == '\0') {
230       break;  // EOF case
231     }
232 
233     // parse the command
234     struct parsed_command* cmd = NULL;
235     int parse_result = parse_command(buffer, &cmd);
236     if (parse_result != 0 || cmd == NULL) {
237       P_ERRNO = P_EPARSE;
238       u_perror("parse_command");
239       free(cmd);
240     }
241 
242     // execute the command
243     pid_t child_pid = u_execute_command(cmd);
244     if (child_pid > 0) {  // if process was spawned, wait for it to finish
245       int status;
246       s_waitpid(child_pid, &status, false);
247     } else if (child_pid < 0) {  // nothing spawning so safe to free cmd
248       free(cmd);
249     }
250   }
251 
252   s_exit();  // exit the script
253   return NULL;
254 }
```

4.34.3 Variable Documentation

4.34.3.1 current_fg_pid

```
pid_t current_fg_pid  [extern]
```

Definition at line 31 of file kern_sys_calls.c.

4.34.3.2 input_fd_script

```
int input_fd_script = -1
```

Definition at line 40 of file shell.c.

4.34.3.3 is_append

```
int is_append = 0
```

Definition at line 42 of file shell.c.

4.34.3.4 job_list

```
Vec job_list
```

Definition at line 35 of file shell.c.

4.34.3.5 next_job_id

```
jid_t next_job_id = 1
```

Definition at line 36 of file shell.c.

4.34.3.6 output_fd_script

```
int output_fd_script = -1
```

Definition at line 41 of file shell.c.

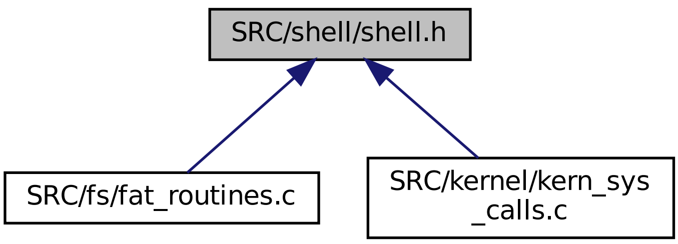
4.34.3.7 script_fd

```
int script_fd = -1
```

Definition at line 39 of file shell.c.

4.35 SRC/shell/shell.h File Reference

This graph shows which files directly or indirectly include this file:



Functions

- void ∗ shell (void ∗input)

  The main shell function that runs the shell. This is run via an s_spawn call from init's process. It prompts the user for builtins and scripts to run.

Variables

- int is_append

4.35.1 Function Documentation

4.35.1.1 shell()

```
void* shell (
            void * input )
```

The main shell function that runs the shell. This is run via an s_spawn call from init's process. It prompts the user for builtins and scripts to run.

Parameters

input	unused

Definition at line 388 of file shell.c.

```
388                    {
389   job_list = vec_new(0, free_job_ptr);
390 
391   setup_terminal_signal_handlers();
392 
393   while (true) {
394     // poll background jobs
395     int status;
396     pid_t child_pid;
397     while ((child_pid = s_waitpid(-1, &status, true)) > 0) {
398       // Find which job child_pid belongs to
399       for (size_t i = 0; i < vec_len(&job_list); i++) {
400         job* job = vec_get(&job_list, i);
401         bool in_this_job = false;
402         for (size_t j = 0; j < job->num_pids; j++) {
403           if (job->pids[j] == child_pid) {
404             in_this_job = true;
405             break;
406           }
407         }
408 
409         if (!in_this_job) {
410           continue;
411         }
412 
413         // If the process ended normally or via signal
414         if (P_WIFEXITED(status) || P_WIFSIGNALED(status)) {
415           job->finished_count++;
416           if (job->finished_count == job->num_pids) {
417             char buf[128];
418             snprintf(buf, sizeof(buf), "Finished: ");
419             s_write(STDOUT_FILENO, buf, strlen(buf));
420             for (size_t cmdIdx = 0; cmdIdx < job->cmd->num_commands; cmdIdx++) {
421               char** argv = job->cmd->commands[cmdIdx];
422               int argIdx = 0;
423               while (argv[argIdx] != NULL) {
```

```
                snprintf(buf, sizeof(buf), "%s ", argv[argIdx]);
                s_write(STDOUT_FILENO, buf, strlen(buf));
                argIdx++;
              }
            }
            snprintf(buf, sizeof(buf), "\n");
            s_write(STDOUT_FILENO, buf, strlen(buf));
            vec_erase(&job_list, i);
          }
        } else if (P_WIFSTOPPED(status) && job->state == RUNNING) {
          job->state = STOPPED;
          char buf[128];
          snprintf(buf, sizeof(buf), "Stopped: ");
          s_write(STDOUT_FILENO, buf, strlen(buf));
          for (size_t cmdIdx = 0; cmdIdx < job->cmd->num_commands; cmdIdx++) {
            char** argv = job->cmd->commands[cmdIdx];
            int argIdx = 0;
            while (argv[argIdx] != NULL) {
              snprintf(buf, sizeof(buf), "%s ", argv[argIdx]);
              s_write(STDOUT_FILENO, buf, strlen(buf));
              argIdx++;
            }
          }
          snprintf(buf, sizeof(buf), "\n");
          s_write(STDOUT_FILENO, buf, strlen(buf));
        }
        break;  // break from for-loop over job_list
      }
    }

    // prompt
    if (s_write(STDOUT_FILENO, PROMPT, strlen(PROMPT)) < 0) {
      u_perror("prompt s_write error");
      break;
    }

    // parse user input
    char buffer[MAX_BUFFER_SIZE];
    ssize_t user_input = s_read(STDIN_FILENO, buffer, MAX_BUFFER_SIZE);
    if (user_input < 0) {
      u_perror("shell read error");
      break;
    } else if (user_input == 0) {  // EOF case
      s_shutdown_pennos();
      break;
    }

    buffer[user_input] = '\0';
    if (buffer[user_input - 1] == '\n') {
      buffer[user_input - 1] = '\0';
    }

    struct parsed_command* cmd = NULL;
    int cmd_parse_res = parse_command(buffer, &cmd);
    if (cmd_parse_res != 0 || cmd == NULL) {
      P_ERRNO = P_EPARSE;
      u_perror("parse_command");
      continue;
    }

    // handle the command
    if (cmd->num_commands == 0) {
      free(cmd);
      continue;
    }

    child_pid = execute_command(cmd);
    if (child_pid < 0) {
      free(cmd);
      continue;
    } else if (child_pid == 0) {
      free(cmd);
      continue;
    }

    // If background, add the process to the job list.
    if (cmd->is_background) {
      // Create a new job entry.
      job* new_job = malloc(sizeof(job));
      if (new_job == NULL) {
        perror("Error: mallocing new_job failed");
        free(cmd);
        continue;
      }
      new_job->id = next_job_id++;
      new_job->pgid = child_pid;  // For single commands, child's pid = pgid.
      new_job->num_pids = 1;
```

```
      new_job->pids = malloc(sizeof(pid_t));
      if (new_job->pids == NULL) {
        perror("Error: mallocing new_job->pids failed");
        free(new_job);
        free(cmd);
        continue;
      }
      new_job->pids[0] = child_pid;
      new_job->state = RUNNING;
      new_job->cmd = cmd;  // Retain command info; do not free here.
      new_job->finished_count = 0;
      vec_push_back(&job_list, new_job);

      // Print job control information in the format: "[job_id] child_pid"
      char msg[128];
      snprintf(msg, sizeof(msg), "[%lu] %d\n", (unsigned long)new_job->id,
               child_pid);
      if (s_write(STDOUT_FILENO, msg, strlen(msg)) == -1) {
        u_perror("s_write error");
      }
    } else {
      // Foreground execution.
      current_fg_pid = child_pid;
      int status;
      s_waitpid(child_pid, &status, false);

      if (P_WIFSTOPPED(status)) {
        // Create a new job entry (this time for a stopped process)
        job* new_job = malloc(sizeof(job));
        if (new_job == NULL) {
          perror("Error: mallocing new_job failed");
          free(cmd);
          continue;
        }
        new_job->id = next_job_id++;
        new_job->pgid = child_pid;  // For single commands, child's pid = pgid.
        new_job->num_pids = 1;
        new_job->pids = malloc(sizeof(pid_t));
        if (new_job->pids == NULL) {
          perror("Error: mallocing new_job->pids failed");
          free(new_job);
          free(cmd);
          continue;
        }
        new_job->pids[0] = child_pid;
        new_job->state = STOPPED;
        new_job->cmd = cmd;  // Retain command info; do not free here.
        new_job->finished_count = 0;
        vec_push_back(&job_list, new_job);

        // Print stopped job
        char buf[128];
        snprintf(buf, sizeof(buf), "Stopped: ");
        s_write(STDOUT_FILENO, buf, strlen(buf));
        for (size_t cmdIdx = 0; cmdIdx < new_job->cmd->num_commands; cmdIdx++) {
          char** argv = new_job->cmd->commands[cmdIdx];
          int argIdx = 0;
          while (argv[argIdx] != NULL) {
            snprintf(buf, sizeof(buf), "%s ", argv[argIdx]);
            s_write(STDOUT_FILENO, buf, strlen(buf));
            argIdx++;
          }
        }
        snprintf(buf, sizeof(buf), "\n");
        s_write(STDOUT_FILENO, buf, strlen(buf));
      }

      current_fg_pid = 2;

      // Free cmd memory for foreground commands.
      // free(cmd); // TODO --> check if this is already freed, it may be
    }
  }

  vec_destroy(&job_list);
  s_exit();
  return 0;
}
```

4.35.2 Variable Documentation

4.35.2.1 is_append

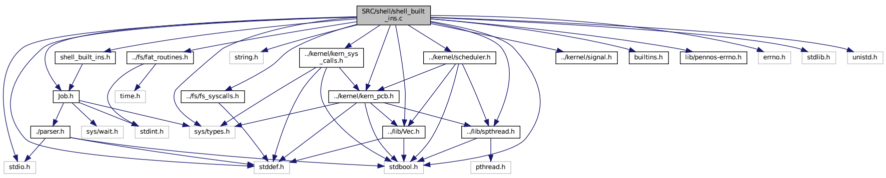
```
int is_append [extern]
```

Definition at line 42 of file shell.c.

4.36 SRC/shell/shell_built_ins.c File Reference

```
#include "shell_built_ins.h"
#include <stdbool.h>
#include <stddef.h>
#include <string.h>
#include <sys/types.h>
#include "../fs/fat_routines.h"
#include "../fs/fs_syscalls.h"
#include "../kernel/kern_pcb.h"
#include "../kernel/kern_sys_calls.h"
#include "../kernel/scheduler.h"
#include "../kernel/signal.h"
#include "../lib/Vec.h"
#include "../lib/spthread.h"
#include "builtins.h"
#include "lib/pennos-errno.h"
#include <errno.h>
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include "Job.h"
```

Include dependency graph for shell_built_ins.c:



Functions

- void ∗ u_cat (void ∗arg)

    The standard 'cat' program built-in.
- void ∗ u_sleep (void ∗arg)

    The standard 'sleep' program built-in.
- void ∗ u_busy (void ∗arg)

    Built-in that hangs indefinitely.
- void ∗ u_echo (void ∗arg)

    Standard 'echo' program built-in that reads a string and echos it backs.
- void ∗ u_ls (void ∗arg)

    Standard 'ls' program built-in that lists files in working directory.
- void ∗ u_chmod (void ∗arg)

Standard 'chmod' progrom built-in that changes the permissions of a given file.
- void * u_touch (void *arg)

  Standard 'touch' program built-in that creates empty files or updates timestamps.
- void * u_mv (void *arg)

  Standard 'mv' program built-in that renames files.
- void * u_cp (void *arg)

  Standard 'cp' program built-in that copies files.
- void * u_rm (void *arg)

  Standard 'rm' program built-in that removes files.
- void * u_ps (void *arg)

  Standard 'ps' program built-in that lists processes in PennOS.
- void * u_kill (void *arg)

  Standard 'kill' program built-in that sends the specified signal to a process.
- void * u_nice (void *arg)

  Spawns a new process for the given command and sets it priority to the given priority.
- void * u_nice_pid (void *arg)

  Adjusts priority level of an existing process.
- void * u_man (void *arg)

  Lists all available commands in PennOS in terminal.
- job * findJobByIdOrCurrent (const char *arg)

  Helper function. Finds a job by its id or the current job.
- void * u_bg (void *arg)

  Resumes the most recently stopped background jobs or a specified one.
- void * u_fg (void *arg)

  Brings the most recently stopped or background job to the foreground or a specified one.
- void * u_jobs (void *arg)

  Lists all jobs.
- void * u_logout (void *arg)

  Exits the shell and shuts down PennOS.
- void * zombie_child (void *arg)

  Helper for zombify.
- void * u_zombify (void *arg)

  Built-in that tests zombifying functionality of the kernel.
- void * orphan_child (void *arg)

  Helper for orphanify.
- void * u_orphanify (void *arg)

  Built-in that tests orphanifying functionality of the kernel.

Variables

- Vec job_list
- pid_t current_fg_pid
- void *(*)(void *) get_associated_ufunc (char *func)

  Helper function to get the associated "u-version" of a function given its standalone version. As a conrete example, if we pass in "cat", we will output "u_cat".

4.36.1 Function Documentation

4.36.1.1 findJobByIdOrCurrent()

```
job* findJobByIdOrCurrent (
            const char * arg )
```

Helper function. Finds a job by its id or the current job.

Example Usage: findJobByIdOrCurrent(a string representing the job id)

Definition at line 341 of file shell_built_ins.c.

```
341                                            {
342   if (vec_len(&job_list) == 0) {
343     return NULL;
344   }
345
346   if (arg != NULL) {
347     // parse numeric
348     char* endPtr = NULL;
349     long val = strtol(arg, &endPtr, 10);
350     if (*endPtr != '\0' || val < 1) {
351       return NULL;
352     }
353     for (size_t i = 0; i < vec_len(&job_list); i++) {
354       job* job_ptr = (job*)vec_get(&job_list, i);
355       if ((jid_t)val == job_ptr->id) {
356         return job_ptr;
357       }
358     }
359     return NULL;
360   }
361
362   // Look for most recently stopped job first
363   for (size_t i = vec_len(&job_list); i > 0; i--) {
364     job* job_ptr = (job*)vec_get(&job_list, i - 1);
365     if (job_ptr->state == STOPPED) {
366       return job_ptr;
367     }
368   }
369
370   return (job*)vec_get(&job_list, vec_len(&job_list) - 1);
371 }
```

4.36.1.2 orphan_child()

```
void* orphan_child (
            void * arg )
```

Helper for orphanify.

Definition at line 581 of file shell_built_ins.c.

```
581                               {
582   while (1)
583     ;
584   s_exit();
585 }
```

4.36.1.3 u_bg()

```
void* u_bg (
            void * arg )
```

Resumes the most recently stopped background jobs or a specified one.

Resumes the most recently stopped job in the background, or the job specified by job_id.

Definition at line 377 of file shell_built_ins.c.

```
377                    {
378   char buf[128];
379   char** argv = (char**)arg;
380   const char* jobArg = argv[1];  // NULL if no ID was given
381   job* job_ptr = findJobByIdOrCurrent(jobArg);
382   if (!job_ptr) {
383     snprintf(buf, sizeof(buf), "bg: no such job\n");
384     s_write(STDERR_FILENO, buf, strlen(buf));
385     return NULL;
386   }
387   if (job_ptr->state == STOPPED) {
388     job_ptr->state = RUNNING;
389     snprintf(buf, sizeof(buf), "Running: ");
390     s_write(STDOUT_FILENO, buf, strlen(buf));
391     for (size_t cmdIdx = 0; cmdIdx < job_ptr->cmd->num_commands; cmdIdx++) {
392       char** argv = job_ptr->cmd->commands[cmdIdx];
393       int argIdx = 0;
394       while (argv[argIdx] != NULL) {
395         snprintf(buf, sizeof(buf), "%s ", argv[argIdx]);
396         s_write(STDOUT_FILENO, buf, strlen(buf));
397         argIdx++;
398       }
399     }
400     snprintf(buf, sizeof(buf), "\n");
401     s_write(STDOUT_FILENO, buf, strlen(buf));
402     // P_SIGCONT is 1
403     s_kill(job_ptr->pids[0], P_SIGCONT);
404     return NULL;
405   } else if (job_ptr->state == RUNNING) {
406     snprintf(buf, sizeof(buf), "bg: job [%lu] is already running\n",
407              (unsigned long)job_ptr->id);
408     s_write(STDOUT_FILENO, buf, strlen(buf));
409     return NULL;
410   } else {
411     snprintf(buf, sizeof(buf), "bg: job [%lu] not stopped\n",
412              (unsigned long)job_ptr->id);
413     s_write(STDOUT_FILENO, buf, strlen(buf));
414     return NULL;
415   }
416 }
```

4.36.1.4 u_busy()

```
void* u_busy (
            void * arg )
```

Built-in that hangs indefinitely.

Busy wait indefinitely. It can only be interrupted via signals.

Definition at line 73 of file shell_built_ins.c.

```
73                         {
74   while (1)
75     ;
76   s_exit();
77   return NULL;
78 }
```

4.36.1.5 u_cat()

```
void* u_cat (
        void * arg )
```

The standard 'cat' program built-in.

The usual `cat` program.

Definition at line 42 of file shell_built_ins.c.

```
42                      {
43   cat(arg);
44   s_exit();
45   return NULL;
46 }
```

4.36.1.6 u_chmod()

```
void* u_chmod (
        void * arg )
```

Standard 'chmod' progrom built-in that changes the permissions of a given file.

Change permissions of a file. There's no need to error if a permission being added already exists, or if a permission being removed is already not granted.

Definition at line 104 of file shell_built_ins.c.

```
104                        {
105   chmod(arg);
106   s_exit();
107   return NULL;
108 }
```

4.36.1.7 u_cp()

```
void* u_cp (
        void * arg )
```

Standard 'cp' program built-in that copies files.

Copy a file. If the `dst_file` file already exists, overwrite it.

Print appropriate error message if:

- `src_file` is not a file that exists
- `src_file` does not have read permissions
- `dst_file` file already exists but does not have write permissions

Example Usage: cp src_file dst_file

Definition at line 132 of file shell_built_ins.c.

```
132                     {
133   cp(arg);
134   s_exit();
135   return NULL;
136 }
```

4.36.1.8 u_echo()

```
void* u_echo (
            void * arg )
```

Standard 'echo' program built-in that reads a string and echos it backs.

Echo back an input string.

Definition at line 84 of file shell_built_ins.c.

```
84                          {
85    s_echo(arg);
86    s_exit();
87    return NULL;
88 }
```

4.36.1.9 u_fg()

```
void* u_fg (
            void * arg )
```

Brings the most recently stopped or background job to the foreground or a specified one.

Brings the most recently stopped or background job to the foreground, or the job specified by job_id.

Definition at line 422 of file shell_built_ins.c.

```
422                         {
423   char buf[128];
424   char** argv = (char**)arg;
425   const char* jobArg = argv[1];  // NULL if no ID was given
426   job* job_ptr = findJobByIdOrCurrent(jobArg);
427   if (!job_ptr) {
428     snprintf(buf, sizeof(buf), "fg: no such job\n");
429     s_write(STDERR_FILENO, buf, strlen(buf));
430     return NULL;
431   }
432
433   if (job_ptr->state == FINISHED) {
434     snprintf(buf, sizeof(buf), "fg: job [%lu] is already finished\n",
435              (unsigned long)job_ptr->id);
436     s_write(STDOUT_FILENO, buf, strlen(buf));
437     return NULL;
438   }
439
440   if (job_ptr->state == STOPPED) {
441     job_ptr->state = RUNNING;
442     snprintf(buf, sizeof(buf), "Restarting: ");
443     s_write(STDOUT_FILENO, buf, strlen(buf));
444     for (size_t cmdIdx = 0; cmdIdx < job_ptr->cmd->num_commands; cmdIdx++) {
445       char** argv = job_ptr->cmd->commands[cmdIdx];
446       int argIdx = 0;
447       while (argv[argIdx] != NULL) {
448         snprintf(buf, sizeof(buf), "%s ", argv[argIdx]);
449         s_write(STDOUT_FILENO, buf, strlen(buf));
450         argIdx++;
451       }
452     }
453     snprintf(buf, sizeof(buf), "\n");
454     s_write(STDOUT_FILENO, buf, strlen(buf));
455     // P_SIGCONT is 1
456     s_kill(job_ptr->pids[0], P_SIGCONT);
457   } else {
458     snprintf(buf, sizeof(buf), "Bringing to foreground: ");
459     s_write(STDOUT_FILENO, buf, strlen(buf));
460     for (size_t cmdIdx = 0; cmdIdx < job_ptr->cmd->num_commands; cmdIdx++) {
461       char** argv = job_ptr->cmd->commands[cmdIdx];
462       int argIdx = 0;
463       while (argv[argIdx] != NULL) {
464         snprintf(buf, sizeof(buf), "%s ", argv[argIdx]);
465         s_write(STDOUT_FILENO, buf, strlen(buf));
466         argIdx++;
```

```
      }
    }
    snprintf(buf, sizeof(buf), "\n");
  }

  current_fg_pid = job_ptr->pids[0];

  while (true) {
    int status = 0;
    pid_t wpid = s_waitpid(job_ptr->pgid, &status, false);
    if (wpid < 0) {
      if (P_ERRNO == P_EINTR) {
        continue;
      }
      break;
    }
    if (P_WIFEXITED(status) || P_WIFSIGNALED(status)) {
      job_ptr->state = FINISHED;
      // Remove finished job from list
      for (size_t i = 0; i < vec_len(&job_list); i++) {
        if ((job*)vec_get(&job_list, i) == job_ptr) {
          vec_erase(&job_list, i);
          break;
        }
      }
      break;
    }
    if (P_WIFSTOPPED(status)) {
      job_ptr->state = STOPPED;
      snprintf(buf, sizeof(buf), "Stopped: ");
      s_write(STDOUT_FILENO, buf, strlen(buf));
      print_parsed_command(job_ptr->cmd);
      break;
    }
  }

  // back to shell
  current_fg_pid = 2;
  return NULL;
}
```

4.36.1.10 u_jobs()

```
void* u_jobs (
        void * arg )
```

Lists all jobs.

Example Usage: jobs

Definition at line 511 of file shell_built_ins.c.

```
511                            {
512   char buf[128];
513   if (vec_is_empty(&job_list)) {
514     return NULL;
515   }
516
517   for (size_t idx = 0; idx < vec_len(&job_list); idx++) {
518     job* job_ptr = (job*)vec_get(&job_list, idx);
519
520     const char* state = "unknown";
521     if (job_ptr->state == RUNNING) {
522       state = "running";
523     } else if (job_ptr->state == STOPPED) {
524       state = "stopped";
525     } else if (job_ptr->state == FINISHED) {
526       state = "finished";
527     }
528
529     snprintf(buf, sizeof(buf), "[%lu] ", (unsigned long)job_ptr->id);
530     s_write(STDOUT_FILENO, buf, strlen(buf));
531     for (size_t cmdIdx = 0; cmdIdx < job_ptr->cmd->num_commands; cmdIdx++) {
532       char** argv = job_ptr->cmd->commands[cmdIdx];
533       int argIdx = 0;
534       while (argv[argIdx] != NULL) {
535         snprintf(buf, sizeof(buf), "%s ", argv[argIdx]);
```

```
        s_write(STDOUT_FILENO, buf, strlen(buf));
        argIdx++;
      }
    }
    snprintf(buf, sizeof(buf), "(%s)\n", state);
    s_write(STDOUT_FILENO, buf, strlen(buf));
  }
  return NULL;
}
```

4.36.1.11 u_kill()

```
void* u_kill (
              void * arg )
```

Standard 'kill' program built-in that sends the specified signal to a process.

Sends a specified signal to a list of processes. If a signal name is not specified, default to "term". Valid signals are -term, -stop, and -cont.

Definition at line 161 of file shell_built_ins.c.

```
161                          {
162   char** argv = (char**)arg;
163   int sig = 2;            // Default signal: term (2)
164   int start_index = 1;    // Start after the "kill" command word.
165   char err_buf[128];
166 
167   // Check if the first argument specifies a signal
168   if (argv[start_index] && argv[start_index][0] == '-') {
169     if (strcmp(argv[start_index], "-term") == 0) {
170       sig = 2;
171     } else if (strcmp(argv[start_index], "-stop") == 0) {
172       sig = 0;
173     } else if (strcmp(argv[start_index], "-cont") == 0) {
174       sig = 1;
175     } else {
176       // Construct error message
177       s_exit();
178       return NULL;
179     }
180     start_index++;
181   }
182 
183   // Process each PID argument using strtol
184   for (int i = start_index; argv[i] != NULL; i++) {
185     char* endptr;
186     long pid_long = strtol(argv[i], &endptr, 10);
187     if (*endptr != '\0' || pid_long <= 0) {
188       snprintf(err_buf, 128, "Invalid PID: %s\n", argv[i]);
189       if (s_write(STDERR_FILENO, err_buf, strlen(err_buf)) == -1) {
190         u_perror("s_write error");
191       }
192       continue;
193     }
194     pid_t pid = (pid_t)pid_long;
195     if (s_kill(pid, sig) < 0) {
196       snprintf(err_buf, 128, "b_kill error on PID %d\n", pid);
197       if (s_write(STDERR_FILENO, err_buf, strlen(err_buf)) == -1) {
198         u_perror("s_write error");
199       }
200     }
201   }
202   s_exit();
203   return NULL;
204 }
```

4.36.1.12 u_logout()

```
void* u_logout (
             void * arg )
```

Exits the shell and shuts down PennOS.

Exits the shell and shutsdown PennOS.

Definition at line 549 of file shell_built_ins.c.

```
549                        {
550   s_shutdown_pennos();
551   return NULL;
552 }
```

4.36.1.13 u_ls()

```
void* u_ls (
             void * arg )
```

Standard 'ls' program built-in that lists files in working directory.

Lists all files in the working directory. For extra credit, it should support relative and absolute file paths.

Definition at line 94 of file shell_built_ins.c.

```
94                     {
95   ls(arg);
96   s_exit();
97   return NULL;
98 }
```

4.36.1.14 u_man()

```
void* u_man (
             void * arg )
```

Lists all available commands in PennOS in terminal.

Lists all available commands.

Definition at line 300 of file shell_built_ins.c.

```
300                     {
301   const char* man_string =
302       "cat f1 f2 ...         : concatenates provided files (if none, reads from "
303       "std in), and writes to std out\n"
304       "sleep n                : sleeps for n seconds\n"
305       "busy                   : busy waits indefinitely\n"
306       "echo str               : echoes back the input string str\n"
307       "ls                     : lists all files in the working directory\n"
308       "touch f1 f2 ...        : for each file, creates empty file if it doesn't "
309       "exist yet, otherwise updates its timestamp\n"
310       "mv f1 f2               : renames f1 to f2 (overwrites f2 if it exists)\n"
311       "cp f1 f2               : copies f1 to f2 (overwrites f2 if it exists)\n"
312       "rm f1 f2 ...           : removes the input list of files\n"
313       "chmod +_ f1            : changes f1 permissions to +_ specifications "
314       "(+x, +rw, etc)\n"
315       "ps                     : lists all processes on PennOS, displaying PID, "
316       "PPID, priority, status, and command name\n"
317       "kill (-__) pid1 pid 2 : sends specified signal (term default) to list "
318       "of processes\n"
```

```
    "nice n command        : spawns a new process for command and sets its "
    "priority to n\n"
    "nice_pid n pid        : adjusts the priority level of an existing "
    "process to n\n"
    "man                   : lists all available commands in PennOS\n"
    "bg                    : resumes most recently stopped process in "
    "background or the one specified by job_id\n"
    "fg                    : brings most recently stopped or background job "
    "to foreground or the one specifed by job_id\n"
    "jobs                  : lists all jobs\n"
    "logout                : exits the shell and shuts down PennOS\n"
    "zombify               : creates a child process that becomes a zombie\n"
    "orphanify             : creates a child process that becomes an "
    "orphan\n";

  s_write(STDOUT_FILENO, man_string, strlen(man_string));
  return NULL;
}
```

4.36.1.15 u_mv()

```
void* u_mv (
        void * arg )
```

Standard 'mv' program built-in that renames files.

Rename a file. If the `dst_file` file already exists, overwrite it.

Definition at line 123 of file shell_built_ins.c.

```
123                          {
124   mv(arg);
125   s_exit();
126   return NULL;
127 }
```

4.36.1.16 u_nice()

```
void* u_nice (
        void * arg )
```

Spawns a new process for the given command and sets it priority to the given priority.

Spawn a new process for `command` and set its priority to `priority`.

Definition at line 255 of file shell_built_ins.c.

```
255                            {
256   char* endptr;
257   errno = 0;
258   int new_priority = (int)strtol(((char**)arg)[1], &endptr, 10);
259   if (*endptr != '\0' || errno != 0 || new_priority > 2 ||
260       new_priority < 0) {  // error catch
261     return NULL;
262   }
263
264   char* command = ((char**)arg)[2];
265   void* (*ufunc)(void*) = get_associated_ufunc(command);
266   if (ufunc == NULL) {
267     return NULL;  // no matches, don't spawn
268   }
269
270   pid_t new_proc_pid = s_spawn(ufunc, &((char**)arg)[2], 0, 1);
271
272   if (new_proc_pid != -1) {  // non-error case
273     s_nice(new_proc_pid, new_priority);
274   }
275
276   return NULL;
277 }
```

4.36.1.17 u_nice_pid()

```
void* u_nice_pid (
            void * arg )
```

Adjusts priority level of an existing process.

Adjust the priority level of an existing process.

Definition at line 282 of file shell_built_ins.c.

```
282 {
283   char* endptr;
284   errno = 0;
285   int new_priority = (int)strtol(((char**)arg)[1], &endptr, 10);
286   if (*endptr != '\0' || errno != 0) {  // error catch
287     return NULL;
288   }
289   pid_t pid = (pid_t)strtol(((char**)arg)[2], &endptr, 10);
290   if (*endptr != '\0' || errno != 0) {
291     return NULL;
292   }
293   s_nice(pid, new_priority);
294   return NULL;
295 }
```

4.36.1.18 u_orphanify()

```
void* u_orphanify (
            void * arg )
```

Built-in that tests orphanifying functionality of the kernel.

Used to test orphanifying functionality of your kernel.

Definition at line 591 of file shell_built_ins.c.

```
591 {
592   char* orphan_child_argv[] = {"orphan_child", NULL};
593   s_spawn(orphan_child, orphan_child_argv, STDIN_FILENO, STDOUT_FILENO);
594   s_exit();
595   return NULL;
596 }
```

4.36.1.19 u_ps()

```
void* u_ps (
            void * arg )
```

Standard 'ps' program built-in that lists processes in PennOS.

List all processes on PennOS, displaying PID, PPID, priority, status, and command name.

Definition at line 151 of file shell_built_ins.c.

```
151 {
152   s_ps(arg);
153   s_exit();
154   return NULL;
155 }
```

4.36.1.20 u_rm()

```
void* u_rm (
            void * arg )
```

Standard 'rm' program built-in that removes files.

Remove a list of files. Treat each file in the list as a separate transaction. (i.e. if removing file1 fails, still attempt to remove file2, file3, etc.)

Definition at line 141 of file shell_built_ins.c.

```
141                     {
142   rm(arg);
143   s_exit();
144   return NULL;
145 }
```

4.36.1.21 u_sleep()

```
void* u_sleep (
            void * arg )
```

The standard 'sleep' program built-in.

Sleep for `n` seconds.

Definition at line 51 of file shell_built_ins.c.

```
51                         {
52   char* endptr;
53   errno = 0;
54   if (((char**)arg)[1] == NULL) {  // no arg case
55     s_exit();
56     return NULL;
57   }
58   int sleep_secs = (int)strtol(((char**)arg)[1], &endptr, 10);
59   if (*endptr != '\0' || errno != 0 || sleep_secs <= 0) {
60     s_exit();
61     return NULL;
62   }
63
64   int sleep_ticks = sleep_secs * 10;
65   s_sleep(sleep_ticks);
66   s_exit();
67   return NULL;
68 }
```

4.36.1.22 u_touch()

```
void* u_touch (
            void * arg )
```

Standard 'touch' program built-in that creates empty files or updates timestamps.

For each file, create an empty file if it doesn't exist, else update its timestamp.

Definition at line 114 of file shell_built_ins.c.

```
114                         {
115   touch(arg);
116   s_exit();
117   return NULL;
118 }
```

4.36.1.23 u_zombify()

```
void* u_zombify (
            void * arg )
```

Built-in that tests zombifying functionality of the kernel.

Used to test zombifying functionality of your kernel.

Definition at line 570 of file shell_built_ins.c.

```
570                              {
571   char* zombie_child_argv[] = {"zombie_child", NULL};
572   s_spawn(zombie_child, zombie_child_argv, STDIN_FILENO, STDOUT_FILENO);
573   while (1)
574     ;
575   return NULL;
576 }
```

4.36.1.24 zombie_child()

```
void* zombie_child (
            void * arg )
```

Helper for zombify.

Definition at line 561 of file shell_built_ins.c.

```
561                                 {
562   s_exit();
563   return NULL;
564 }
```

4.36.2 Variable Documentation

4.36.2.1 current_fg_pid

```
pid_t current_fg_pid [extern]
```

Definition at line 31 of file kern_sys_calls.c.

4.36.2.2 get_associated_ufunc

```
void*(*)(void*) get_associated_ufunc(char *func) (
            char * func )
```

Helper function to get the associated "u-version" of a function given its standalone version. As a conrete example, if we pass in "cat", we will output "u_cat".

Parameters

func	A string of the function name to get the associated ufunc for

Returns

A ptr to the associated u-version function or NULL if no matches are found

Definition at line 221 of file shell_built_ins.c.

```
221                                                     {
222   if (strcmp(func, "cat") == 0) {
223     return u_cat;
224   } else if (strcmp(func, "sleep") == 0) {
225     return u_sleep;
226   } else if (strcmp(func, "busy") == 0) {
227     return u_busy;
228   } else if (strcmp(func, "echo") == 0) {
229     return u_echo;
230   } else if (strcmp(func, "ls") == 0) {
231     return u_ls;
232   } else if (strcmp(func, "touch") == 0) {
233     return u_touch;
234   } else if (strcmp(func, "mv") == 0) {
235     return u_mv;
236   } else if (strcmp(func, "cp") == 0) {
237     return u_cp;
238   } else if (strcmp(func, "rm") == 0) {
239     return u_rm;
240   } else if (strcmp(func, "chmod") == 0) {
241     return u_chmod;
242   } else if (strcmp(func, "ps") == 0) {
243     return u_ps;
244   } else if (strcmp(func, "kill") == 0) {
245     return u_kill;
246   }
247
248   return NULL;  // no matches case
249 }
```

4.36.2.3 job_list

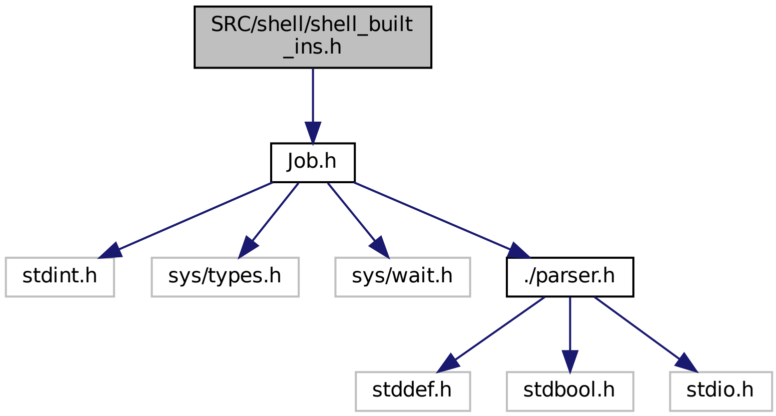
```
Vec job_list  [extern]
```

Definition at line 35 of file shell.c.

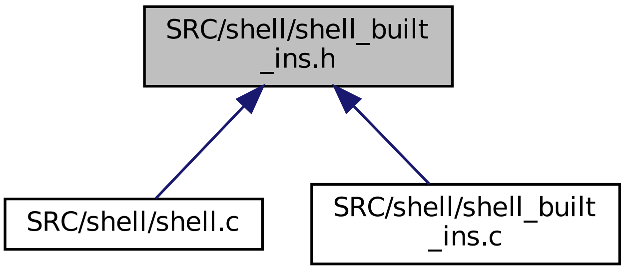
4.37 SRC/shell/shell_built_ins.h File Reference

```
#include "Job.h"
```

Include dependency graph for shell_built_ins.h:



This graph shows which files directly or indirectly include this file:



Functions

- void ∗ u_cat (void ∗arg)

  The usual `cat` *program.*
- void ∗ u_sleep (void ∗arg)

  Sleep for n *seconds.*
- void ∗ u_busy (void ∗arg)

  Busy wait indefinitely. It can only be interrupted via signals.
- void ∗ u_echo (void ∗arg)

  Echo back an input string.
- void ∗ u_ls (void ∗arg)

  Lists all files in the working directory. For extra credit, it should support relative and absolute file paths.
- void ∗ u_touch (void ∗arg)

For each file, create an empty file if it doesn't exist, else update its timestamp.
- void ∗ u_mv (void ∗arg)

  Rename a file. If the `dst_file` file already exists, overwrite it.
- void ∗ u_cp (void ∗arg)

  Standard 'cp' program built-in that copies files.
- void ∗ u_rm (void ∗arg)

  Remove a list of files. Treat each file in the list as a separate transaction. (i.e. if removing file1 fails, still attempt to remove file2, file3, etc.)
- void ∗ u_chmod (void ∗arg)

  Change permissions of a file. There's no need to error if a permission being added already exists, or if a permission being removed is already not granted.
- void ∗ u_ps (void ∗arg)

  List all processes on PennOS, displaying PID, PPID, priority, status, and command name.
- void ∗ u_kill (void ∗arg)

  Sends a specified signal to a list of processes. If a signal name is not specified, default to "term". Valid signals are -term, -stop, and -cont.
- void ∗ u_nice (void ∗arg)

  Spawn a new process for `command` and set its priority to `priority`.
- void ∗ u_nice_pid (void ∗arg)

  Adjust the priority level of an existing process.
- void ∗ u_man (void ∗arg)

  Lists all available commands.
- job ∗ findJobByIdOrCurrent (const char ∗arg)

  Helper function. Finds a job by its id or the current job.
- void ∗ u_bg (void ∗arg)

  Resumes the most recently stopped job in the background, or the job specified by job_id.
- void ∗ u_fg (void ∗arg)

  Brings the most recently stopped or background job to the foreground, or the job specified by job_id.
- void ∗ u_jobs (void ∗arg)

  Lists all jobs.
- void ∗ u_logout (void ∗arg)

  Exits the shell and shutsdown PennOS.
- void ∗ u_zombify (void ∗arg)

  Used to test zombifying functionality of your kernel.
- void ∗ u_orphanify (void ∗arg)

  Used to test orphanifying functionality of your kernel.

4.37.1 Function Documentation

4.37.1.1 findJobByIdOrCurrent()

```
job* findJobByIdOrCurrent (
            const char * arg )
```

Helper function. Finds a job by its id or the current job.

Example Usage: findJobByIdOrCurrent(a string representing the job id)

Definition at line 341 of file shell_built_ins.c.

```
341                                              {
342   if (vec_len(&job_list) == 0) {
343     return NULL;
344   }
345
346   if (arg != NULL) {
347     // parse numeric
348     char* endPtr = NULL;
349     long val = strtol(arg, &endPtr, 10);
350     if (*endPtr != '\0' || val < 1) {
351       return NULL;
352     }
353     for (size_t i = 0; i < vec_len(&job_list); i++) {
354       job* job_ptr = (job*)vec_get(&job_list, i);
355       if ((jid_t)val == job_ptr->id) {
356         return job_ptr;
357       }
358     }
359     return NULL;
360   }
361
362   // Look for most recently stopped job first
363   for (size_t i = vec_len(&job_list); i > 0; i--) {
364     job* job_ptr = (job*)vec_get(&job_list, i - 1);
365     if (job_ptr->state == STOPPED) {
366       return job_ptr;
367     }
368   }
369
370   return (job*)vec_get(&job_list, vec_len(&job_list) - 1);
371 }
```

4.37.1.2 u_bg()

```
void* u_bg (
              void * arg )
```

Resumes the most recently stopped job in the background, or the job specified by job_id.

Example Usage: bg Example Usage: bg 2 (job_id is 2)

Resumes the most recently stopped job in the background, or the job specified by job_id.

Definition at line 377 of file shell_built_ins.c.

```
377                         {
378   char buf[128];
379   char** argv = (char**)arg;
380   const char* jobArg = argv[1];  // NULL if no ID was given
381   job* job_ptr = findJobByIdOrCurrent(jobArg);
382   if (!job_ptr) {
383     snprintf(buf, sizeof(buf), "bg: no such job\n");
384     s_write(STDERR_FILENO, buf, strlen(buf));
385     return NULL;
386   }
387   if (job_ptr->state == STOPPED) {
388     job_ptr->state = RUNNING;
389     snprintf(buf, sizeof(buf), "Running: ");
390     s_write(STDOUT_FILENO, buf, strlen(buf));
391     for (size_t cmdIdx = 0; cmdIdx < job_ptr->cmd->num_commands; cmdIdx++) {
392       char** argv = job_ptr->cmd->commands[cmdIdx];
393       int argIdx = 0;
394       while (argv[argIdx] != NULL) {
395         snprintf(buf, sizeof(buf), "%s ", argv[argIdx]);
396         s_write(STDOUT_FILENO, buf, strlen(buf));
397         argIdx++;
398       }
399     }
400     snprintf(buf, sizeof(buf), "\n");
401     s_write(STDOUT_FILENO, buf, strlen(buf));
402     // P_SIGCONT is 1
403     s_kill(job_ptr->pids[0], P_SIGCONT);
404     return NULL;
405   } else if (job_ptr->state == RUNNING) {
406     snprintf(buf, sizeof(buf), "bg: job [%lu] is already running\n",
```

```
                  (unsigned long)job_ptr->id);
        s_write(STDOUT_FILENO, buf, strlen(buf));
        return NULL;
    } else {
        snprintf(buf, sizeof(buf), "bg: job [%lu] not stopped\n",
                  (unsigned long)job_ptr->id);
        s_write(STDOUT_FILENO, buf, strlen(buf));
        return NULL;
    }
}
```

4.37.1.3 u_busy()

```
void* u_busy (
            void * arg )
```

Busy wait indefinitely. It can only be interrupted via signals.

Example Usage: busy

Busy wait indefinitely. It can only be interrupted via signals.

Definition at line 73 of file shell_built_ins.c.

```
73                            {
74    while (1)
75      ;
76    s_exit();
77    return NULL;
78 }
```

4.37.1.4 u_cat()

```
void* u_cat (
            void * arg )
```

The usual `cat` program.

If `files` arg is provided, concatenate these files and print to stdout If `files` arg is *not* provided, read from stdin and print back to stdout

Example Usage: cat f1 f2 (concatenates f1 and f2 and print to stdout) Example Usage: cat f1 f2 $<$ f3 (concatenates f1 and f2 and prints to stdout, ignores f3) Example Usage: cat $<$ f3 (concatenates f3, prints to stdout)

The usual `cat` program.

Definition at line 42 of file shell_built_ins.c.

```
42                           {
43    cat(arg);
44    s_exit();
45    return NULL;
46 }
```

4.37.1.5 u_chmod()

```
void* u_chmod (
            void * arg )
```

Change permissions of a file. There's no need to error if a permission being added already exists, or if a permission being removed is already not granted.

Print appropriate error message if:

- `file` is not a file that exists
- `perms` is invalid

Example Usage: chmod +x file (adds executable permission to file) Example Usage: chmod +rw file (adds read + write permissions to file) Example Usage: chmod -wx file (removes write + executable permissions from file)

Change permissions of a file. There's no need to error if a permission being added already exists, or if a permission being removed is already not granted.

Definition at line 104 of file shell_built_ins.c.

```
104                            {
105     chmod(arg);
106     s_exit();
107     return NULL;
108 }
```

4.37.1.6 u_cp()

```
void* u_cp (
            void * arg )
```

Standard 'cp' program built-in that copies files.

Copy a file. If the `dst_file` file already exists, overwrite it.

Print appropriate error message if:

- `src_file` is not a file that exists
- `src_file` does not have read permissions
- `dst_file` file already exists but does not have write permissions

Example Usage: cp src_file dst_file

Definition at line 132 of file shell_built_ins.c.

```
132                         {
133     cp(arg);
134     s_exit();
135     return NULL;
136 }
```

4.37.1.7 u_echo()

```
void* u_echo (
              void * arg )
```

Echo back an input string.

Example Usage: echo Hello World

Echo back an input string.

Definition at line 84 of file shell_built_ins.c.

```
84                          {
85   s_echo(arg);
86   s_exit();
87   return NULL;
88 }
```

4.37.1.8 u_fg()

```
void* u_fg (
              void * arg )
```

Brings the most recently stopped or background job to the foreground, or the job specified by job_id.

Example Usage: fg Example Usage: fg 2 (job_id is 2)

Brings the most recently stopped or background job to the foreground, or the job specified by job_id.

Definition at line 422 of file shell_built_ins.c.

```
422                         {
423   char buf[128];
424   char** argv = (char**)arg;
425   const char* jobArg = argv[1];  // NULL if no ID was given
426   job* job_ptr = findJobByIdOrCurrent(jobArg);
427   if (!job_ptr) {
428     snprintf(buf, sizeof(buf), "fg: no such job\n");
429     s_write(STDERR_FILENO, buf, strlen(buf));
430     return NULL;
431   }
432
433   if (job_ptr->state == FINISHED) {
434     snprintf(buf, sizeof(buf), "fg: job [%lu] is already finished\n",
435              (unsigned long)job_ptr->id);
436     s_write(STDOUT_FILENO, buf, strlen(buf));
437     return NULL;
438   }
439
440   if (job_ptr->state == STOPPED) {
441     job_ptr->state = RUNNING;
442     snprintf(buf, sizeof(buf), "Restarting: ");
443     s_write(STDOUT_FILENO, buf, strlen(buf));
444     for (size_t cmdIdx = 0; cmdIdx < job_ptr->cmd->num_commands; cmdIdx++) {
445       char** argv = job_ptr->cmd->commands[cmdIdx];
446       int argIdx = 0;
447       while (argv[argIdx] != NULL) {
448         snprintf(buf, sizeof(buf), "%s ", argv[argIdx]);
449         s_write(STDOUT_FILENO, buf, strlen(buf));
450         argIdx++;
451       }
452     }
453     snprintf(buf, sizeof(buf), "\n");
454     s_write(STDOUT_FILENO, buf, strlen(buf));
455     // P_SIGCONT is 1
456     s_kill(job_ptr->pids[0], P_SIGCONT);
457   } else {
458     snprintf(buf, sizeof(buf), "Bringing to foreground: ");
459     s_write(STDOUT_FILENO, buf, strlen(buf));
460     for (size_t cmdIdx = 0; cmdIdx < job_ptr->cmd->num_commands; cmdIdx++) {
```

```
461       char** argv = job_ptr->cmd->commands[cmdIdx];
462       int argIdx = 0;
463       while (argv[argIdx] != NULL) {
464         snprintf(buf, sizeof(buf), "%s ", argv[argIdx]);
465         s_write(STDOUT_FILENO, buf, strlen(buf));
466         argIdx++;
467       }
468     }
469     snprintf(buf, sizeof(buf), "\n");
470   }
471
472   current_fg_pid = job_ptr->pids[0];
473
474   while (true) {
475     int status = 0;
476     pid_t wpid = s_waitpid(job_ptr->pgid, &status, false);
477     if (wpid < 0) {
478       if (P_ERRNO == P_EINTR) {
479         continue;
480       }
481       break;
482     }
483     if (P_WIFEXITED(status) || P_WIFSIGNALED(status)) {
484       job_ptr->state = FINISHED;
485       // Remove finished job from list
486       for (size_t i = 0; i < vec_len(&job_list); i++) {
487         if ((job*)vec_get(&job_list, i) == job_ptr) {
488           vec_erase(&job_list, i);
489           break;
490         }
491       }
492       break;
493     }
494     if (P_WIFSTOPPED(status)) {
495       job_ptr->state = STOPPED;
496       snprintf(buf, sizeof(buf), "Stopped: ");
497       s_write(STDOUT_FILENO, buf, strlen(buf));
498       print_parsed_command(job_ptr->cmd);
499       break;
500     }
501   }
502
503   // back to shell
504   current_fg_pid = 2;
505   return NULL;
506 }
```

4.37.1.9 u_jobs()

```
void* u_jobs (
              void * arg )
```

Lists all jobs.

Example Usage: jobs

Definition at line 511 of file shell_built_ins.c.

```
511                         {
512   char buf[128];
513   if (vec_is_empty(&job_list)) {
514     return NULL;
515   }
516
517   for (size_t idx = 0; idx < vec_len(&job_list); idx++) {
518     job* job_ptr = (job*)vec_get(&job_list, idx);
519
520     const char* state = "unknown";
521     if (job_ptr->state == RUNNING) {
522       state = "running";
523     } else if (job_ptr->state == STOPPED) {
524       state = "stopped";
525     } else if (job_ptr->state == FINISHED) {
526       state = "finished";
527     }
528
529     snprintf(buf, sizeof(buf), "[%lu] ", (unsigned long)job_ptr->id);
```

```
    s_write(STDOUT_FILENO, buf, strlen(buf));
    for (size_t cmdIdx = 0; cmdIdx < job_ptr->cmd->num_commands; cmdIdx++) {
      char** argv = job_ptr->cmd->commands[cmdIdx];
      int argIdx = 0;
      while (argv[argIdx] != NULL) {
        snprintf(buf, sizeof(buf), "%s ", argv[argIdx]);
        s_write(STDOUT_FILENO, buf, strlen(buf));
        argIdx++;
      }
    }
    snprintf(buf, sizeof(buf), "(%s)\n", state);
    s_write(STDOUT_FILENO, buf, strlen(buf));
  }
  return NULL;
}
```

4.37.1.10 u_kill()

```
void* u_kill (
            void * arg )
```

Sends a specified signal to a list of processes. If a signal name is not specified, default to "term". Valid signals are -term, -stop, and -cont.

Example Usage: kill 1 2 3 (sends term to processes 1, 2, and 3) Example Usage: kill -term 1 2 (sends term to processes 1 and 2) Example Usage: kill -stop 1 2 (sends stop to processes 1 and 2) Example Usage: kill -cont 1 (sends cont to process 1)

Sends a specified signal to a list of processes. If a signal name is not specified, default to "term". Valid signals are -term, -stop, and -cont.

Definition at line 161 of file shell_built_ins.c.

```
161                         {
162   char** argv = (char**)arg;
163   int sig = 2;          // Default signal: term (2)
164   int start_index = 1;  // Start after the "kill" command word.
165   char err_buf[128];
166
167   // Check if the first argument specifies a signal
168   if (argv[start_index] && argv[start_index][0] == '-') {
169     if (strcmp(argv[start_index], "-term") == 0) {
170       sig = 2;
171     } else if (strcmp(argv[start_index], "-stop") == 0) {
172       sig = 0;
173     } else if (strcmp(argv[start_index], "-cont") == 0) {
174       sig = 1;
175     } else {
176       // Construct error message
177       s_exit();
178       return NULL;
179     }
180     start_index++;
181   }
182
183   // Process each PID argument using strtol
184   for (int i = start_index; argv[i] != NULL; i++) {
185     char* endptr;
186     long pid_long = strtol(argv[i], &endptr, 10);
187     if (*endptr != '\0' || pid_long <= 0) {
188       snprintf(err_buf, 128, "Invalid PID: %s\n", argv[i]);
189       if (s_write(STDERR_FILENO, err_buf, strlen(err_buf)) == -1) {
190         u_perror("s_write error");
191       }
192       continue;
193     }
194     pid_t pid = (pid_t)pid_long;
195     if (s_kill(pid, sig) < 0) {
196       snprintf(err_buf, 128, "b_kill error on PID %d\n", pid);
197       if (s_write(STDERR_FILENO, err_buf, strlen(err_buf)) == -1) {
198         u_perror("s_write error");
199       }
200     }
201   }
202   s_exit();
203   return NULL;
204 }
```

4.37.1.11 u_logout()

```
void* u_logout (
            void * arg )
```

Exits the shell and shutsdown PennOS.

Example Usage: logout

Exits the shell and shutsdown PennOS.

Definition at line 549 of file shell_built_ins.c.

```
549                         {
550   s_shutdown_pennos();
551   return NULL;
552 }
```

4.37.1.12 u_ls()

```
void* u_ls (
            void * arg )
```

Lists all files in the working directory. For extra credit, it should support relative and absolute file paths.

Example Usage: ls (regular credit) Example Usage: ls ../../foo/./bar/sample (only for EC)

Lists all files in the working directory. For extra credit, it should support relative and absolute file paths.

Definition at line 94 of file shell_built_ins.c.

```
94                      {
95   ls(arg);
96   s_exit();
97   return NULL;
98 }
```

4.37.1.13 u_man()

```
void* u_man (
            void * arg )
```

Lists all available commands.

Example Usage: man

Lists all available commands.

Definition at line 300 of file shell_built_ins.c.

```
300                       {
301   const char* man_string =
302       "cat f1 f2 ...        : concatenates provided files (if none, reads from "
303       "std in), and writes to std out\n"
304       "sleep n               : sleeps for n seconds\n"
305       "busy                  : busy waits indefinitely\n"
306       "echo str              : echoes back the input string str\n"
307       "ls                    : lists all files in the working directory\n"
308       "touch f1 f2 ...       : for each file, creates empty file if it doesn't "
309       "exist yet, otherwise updates its timestamp\n"
310       "mv f1 f2              : renames f1 to f2 (overwrites f2 if it exists)\n"
```

```
    "cp f1 f2               : copies f1 to f2 (overwrites f2 if it exists)\n"
    "rm f1 f2 ...           : removes the input list of files\n"
    "chmod +_ f1            : changes f1 permissions to +_ specifications "
    "(+x, +rw, etc)\n"
    "ps                     : lists all processes on PennOS, displaying PID, "
    "PPID, priority, status, and command name\n"
    "kill (-__) pid1 pid 2 : sends specified signal (term default) to list "
    "of processes\n"
    "nice n command         : spawns a new process for command and sets its "
    "priority to n\n"
    "nice_pid n pid         : adjusts the priority level of an existing "
    "process to n\n"
    "man                    : lists all available commands in PennOS\n"
    "bg                     : resumes most recently stopped process in "
    "background or the one specified by job_id\n"
    "fg                     : brings most recently stopped or background job "
    "to foreground or the one specifed by job_id\n"
    "jobs                   : lists all jobs\n"
    "logout                 : exits the shell and shuts down PennOS\n"
    "zombify                : creates a child process that becomes a zombie\n"
    "orphanify              : creates a child process that becomes an "
    "orphan\n";

  s_write(STDOUT_FILENO, man_string, strlen(man_string));
  return NULL;
}
```

4.37.1.14 u_mv()

```
void* u_mv (
        void * arg )
```

Rename a file. If the `dst_file` file already exists, overwrite it.

Print appropriate error message if:

- `src_file` is not a file that exists
- `src_file` does not have read permissions
- `dst_file` file already exists but does not have write permissions

Example Usage: mv src_file dst_file

Rename a file. If the `dst_file` file already exists, overwrite it.

Definition at line 123 of file shell_built_ins.c.

```
                        {
  mv(arg);
  s_exit();
  return NULL;
}
```

4.37.1.15 u_nice()

```
void* u_nice (
        void * arg )
```

Spawn a new process for `command` and set its priority to `priority`.

Example Usage: nice 2 cat f1 f2 f3 (spawns cat with priority 2)

Spawn a new process for `command` and set its priority to `priority`.

Definition at line 255 of file shell_built_ins.c.

```
255                        {
256   char* endptr;
257   errno = 0;
258   int new_priority = (int)strtol(((char**)arg)[1], &endptr, 10);
259   if (*endptr != '\0' || errno != 0 || new_priority > 2 ||
260       new_priority < 0) {  // error catch
261     return NULL;
262   }
263
264   char* command = ((char**)arg)[2];
265   void* (*ufunc)(void*) = get_associated_ufunc(command);
266   if (ufunc == NULL) {
267     return NULL;  // no matches, don't spawn
268   }
269
270   pid_t new_proc_pid = s_spawn(ufunc, &((char**)arg)[2], 0, 1);
271
272   if (new_proc_pid != -1) {  // non-error case
273     s_nice(new_proc_pid, new_priority);
274   }
275
276   return NULL;
277 }
```

4.37.1.16 u_nice_pid()

```
void* u_nice_pid (
        void * arg )
```

Adjust the priority level of an existing process.

Example Usage: nice_pid 0 123 (sets priority 0 to PID 123)

Adjust the priority level of an existing process.

Definition at line 282 of file shell_built_ins.c.

```
282                            {
283   char* endptr;
284   errno = 0;
285   int new_priority = (int)strtol(((char**)arg)[1], &endptr, 10);
286   if (*endptr != '\0' || errno != 0) {  // error catch
287     return NULL;
288   }
289   pid_t pid = (pid_t)strtol(((char**)arg)[2], &endptr, 10);
290   if (*endptr != '\0' || errno != 0) {
291     return NULL;
292   }
293   s_nice(pid, new_priority);
294   return NULL;
295 }
```

4.37.1.17 u_orphanify()

```
void* u_orphanify (
            void * arg )
```

Used to test orphanifying functionality of your kernel.

Example Usage: orphanify

Used to test orphanifying functionality of your kernel.

Definition at line 591 of file shell_built_ins.c.

```
591                          {
592   char* orphan_child_argv[] = {"orphan_child", NULL};
593   s_spawn(orphan_child, orphan_child_argv, STDIN_FILENO, STDOUT_FILENO);
594   s_exit();
595   return NULL;
596 }
```

4.37.1.18 u_ps()

```
void* u_ps (
            void * arg )
```

List all processes on PennOS, displaying PID, PPID, priority, status, and command name.

Example Usage: ps

List all processes on PennOS, displaying PID, PPID, priority, status, and command name.

Definition at line 151 of file shell_built_ins.c.

```
151                    {
152   s_ps(arg);
153   s_exit();
154   return NULL;
155 }
```

4.37.1.19 u_rm()

```
void* u_rm (
            void * arg )
```

Remove a list of files. Treat each file in the list as a separate transaction. (i.e. if removing file1 fails, still attempt to remove file2, file3, etc.)

Print appropriate error message if:

- `file` is not a file that exists

Example Usage: rm f1 f2 f3 f4 f5

Remove a list of files. Treat each file in the list as a separate transaction. (i.e. if removing file1 fails, still attempt to remove file2, file3, etc.)

Definition at line 141 of file shell_built_ins.c.

```
141                    {
142   rm(arg);
143   s_exit();
144   return NULL;
145 }
```

4.37.1.20 u_sleep()

```
void* u_sleep (
        void * arg )
```

Sleep for n seconds.

Note that you'll have to convert the number of seconds to the correct number of ticks.

Example Usage: sleep 10

Sleep for n seconds.

Definition at line 51 of file shell_built_ins.c.

```
51                         {
52   char* endptr;
53   errno = 0;
54   if (((char**)arg)[1] == NULL) {  // no arg case
55     s_exit();
56     return NULL;
57   }
58   int sleep_secs = (int)strtol(((char**)arg)[1], &endptr, 10);
59   if (*endptr != '\0' || errno != 0 || sleep_secs <= 0) {
60     s_exit();
61     return NULL;
62   }
63 
64   int sleep_ticks = sleep_secs * 10;
65   s_sleep(sleep_ticks);
66   s_exit();
67   return NULL;
68 }
```

4.37.1.21 u_touch()

```
void* u_touch (
        void * arg )
```

For each file, create an empty file if it doesn't exist, else update its timestamp.

Example Usage: touch f1 f2 f3 f4 f5

For each file, create an empty file if it doesn't exist, else update its timestamp.

Definition at line 114 of file shell_built_ins.c.

```
114                         {
115   touch(arg);
116   s_exit();
117   return NULL;
118 }
```

4.37.1.22 u_zombify()

```
void* u_zombify (
        void * arg )
```

Used to test zombifying functionality of your kernel.

Example Usage: zombify

Used to test zombifying functionality of your kernel.

Definition at line 570 of file shell_built_ins.c.

```
570                           {
571   char* zombie_child_argv[] = {"zombie_child", NULL};
572   s_spawn(zombie_child, zombie_child_argv, STDIN_FILENO, STDOUT_FILENO);
573   while (1)
574     ;
575   return NULL;
576 }
```

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