CS 537
Section 4: Data Structures in C

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Project questions?

- strtok()?

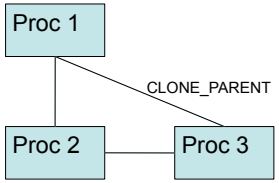
Linux Process Structure

- called a “task_struct”
- (see sched.h ~ line 917)
- Key points:
  - state field
  - lists: identified with “struct list_head”

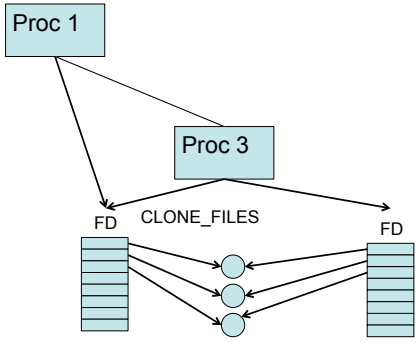
Linux Clone

- Until recently, child ran first
  - this just changed. why?
- Linux does not natively implement fork()
  - provides clone() function instead with options:
    - CLONE_PARENT: is parent clone() caller, or clone() caller’s parent
    - CLONE_FILES: are file descriptors copied or shared?
    - CLONE_VM: is memory copied or shared
- Clone takes a function, an argument, and a stack
  - new process calls function with argument, exits when function returns.
  - Uses new stack to avoid clobbering caller

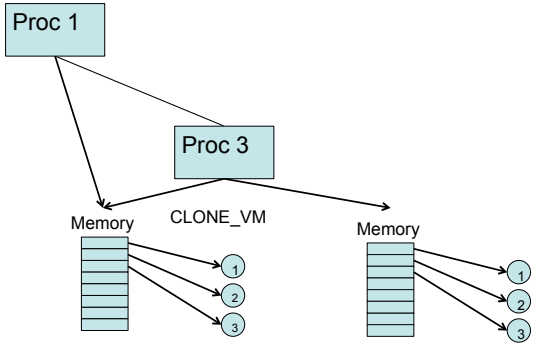
Clone options - parent



Clone options - files



Clone options - memory



Pointers in C

- Pointers are addresses
  - `char * c = (char *) malloc(10 * sizeof(char));`
  - c now contains the **address** of some memory
- '*' operator returns what is at an address
  - *c returns the character at address c
- '&' operator returns the address of a variable
  - int n;
  - int * p;
  - p = &n;
- p[n] operator returns what is at address:
  - p + n * sizeof(*p) – the size of the type p points to

Using 2-D arrays in C

- Uses array of pointers
  - int **p;
  - p[n] = what is at p+n*sizeof(int *); call this q: a pointer to integers
  - q[m] = what is at q + m*sizeof(int); an integer
- Allocation:
  - p = (int **) malloc(sizeof(int *) * y_dim);
  - for (int i = 0; i < y_dim; i++)
    - p[i] = (int *) malloc(sizeof(int) * x_dim);
- Use:
  - p[y][x] = 4;
- Freeing
  - for (int i = 0; i < y_dim; i++)
    - free(p[i]);
  - free(p);

Rules for allocating memory

- Call malloc() for any data returned from a function:

```
char * reverse(char * line) {
    char tmp[100];
    for (int j=0, i = strlen(line); i >= 0; i--)
        tmp[j++] = line[i];
    return(tmp)
```

- Call free() when you are done:

```
char * output;
fgets(line,MAX_LEN,file);
output = reverse(line);
free(output);
```


Memory Manipulation Functions

Header File:

```
<string.h>

void *memcpy (void *dest, const void *src, size_t n);
void *memmove(void *dest, const void *src, size_t n);
int memcmp (const void *s1, const void *s2, size_t n);
void *memset (void *s, int c, size_t n);
```

Memory Manipulation Functions

```
/* memcpy.c: memcpy example */
#include <stdio.h>
#include <string.h>

void main(void)
{
   char src[ ] = "************************";
   char dest[ ] = "abcdefghijlkmnopqrstuvwxyz01234";
   char *ptr;
   printf("destination before memcpy: %s\n", dest);
   ptr = (char *) memcpy(dest, src, strlen(src));
   if (ptr)
      printf("destination after memcpy: %s\n", dest);
   else
      printf("memcpy failed\n");  }
```

Memory Manipulation Functions

```
/* memmove.c memmove example */

#include <string.h>
#include <stdio.h>

void main(void)
{
  char dest [80] = “abcdefghijklmnopqrstuvwxyz012345” ;

  printf ( “dest prior to memmove: %s\n”, dest);
  memmove (&dest[5], &dest[26], 6);
  printf (“dest after memmove: %s\n”, dest);
}
```

Memory Manipulation Functions

```
/* memset.c: memset example */

#include <string.h>
#include <stdio.h>
#include <mem.h>

void main(void)
{
  char buffer[  ] = "Hello world\n";

  printf("Buffer before memset: %s\n", buffer);
  memset(buffer, '*', strlen(buffer) - 1);
  printf("Buffer after memset:  %s\n", buffer);
}
```

Memory Manipulation Functions

```
char *buf1 = "aaa”,  *buf2 = "bbb”,  *buf3 = "ccc";
int stat;
stat = memcmp(buf2, buf1, strlen(buf2));
if (stat > 0)
   printf("buffer 2 is greater than buffer 1\n");
else
   printf("buffer 2 is less than buffer 1\n");
stat = memcmp(buf2, buf3, strlen(buf2));
if (stat > 0)
   printf("buffer 2 is greater than buffer 3\n");
else
   printf("buffer 2 is less than buffer 3\n");
```

Data types in C

- structures: like a class without functions

```
struct node {
    int value;
    char name[10];
};
struct node node_instance;
struct node * ptr_to_node;
```

- typedef: give a name to another type

```
typedef struct node node_type;
typedef struct node * ptr_node_type;
```

- Recursive structures

```
struct node {
    int value;
    struct node * next;
};
```

Data Structures in C – Linked List

- Linked Lists

```
typedef struct node_s {
   char field_n;
   struct node_s *next;
} node, *node_ptr;

node_ptr my_ptr, ptr;
struct header {
  node_ptr first, last;
} my_list;
```

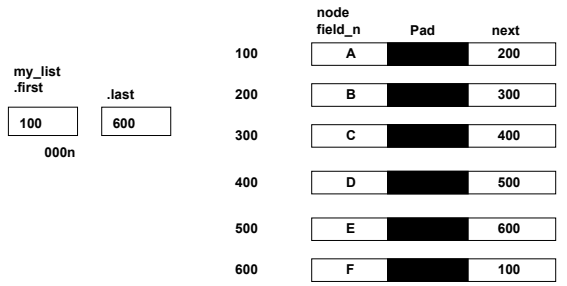

Allocating a List

```
int i;
/* allocate the first list record */
my_ptr = (node_ptr)malloc( sizeof(node));
if (!my_ptr) exit(1);
my_list.first = my_ptr;
my_list.last = my_ptr;
my_ptr->field_n = 'A';
my_ptr->next = my_list.first;  /* makes the list circular */
```


Allocating a List

```
/* allocate records 2 through 6 to the list */
for (i=2; i <= 6; i++)
{
  my_ptr = (node_ptr)malloc(sizeof(node));
      if(!my_ptr) exit(1);
  ptr = my_list.last; // find end of list
  my_list.last = my_ptr;
  ptr->next = my_ptr; // update ptr in former last
  my_ptr->field_n = ptr->field_n + 1; // move to next char
  my_ptr->next = my_list.first; // make circular again
}
```


Layout in Memory



Freeing a list

```
while (my_list.first != NULL ) {
  my_ptr = my_list.first;
  my_list.first = my_ptr->next;
  if (my_list.last == my_ptr) {
    my_list.last = NULL;
    my_list.first = NULL;
  }
  free(my_ptr);
}
```


Linux Linked Lists

List structure to embed:

```
struct list_head {
    struct list_head *next, *prev;
};
```

Initialize: make them point to themselves

```
void INIT_LIST_HEAD(struct list_head *list)
{
    list->next = list;
    list->prev = list;
}
```

Usage: embed in other structures

```
struct task_struct {
        struct list_head tasks;
        …
}
```


List Functions

Add to a list:

```
void __list_add(struct list_head *new, struct list_head *prev, struct list_head *next) {
    next->prev = new;
    new->next = next;
    new->prev = prev;
    prev->next = new;
}
void list_add(struct list_head *new, struct list_head *head) {
    __list_add(new, head, head->next);
}
```

Remove from a list

```
void __list_del(struct list_head * prev, struct list_head * next) {
    next->prev = prev;
    prev->next = next;
}
void list_del(struct list_head *entry) {
    __list_del(entry->prev, entry->next);
}
```


Using a linked list

- struct task_struct:
  - run_list,children, siblings
  - struct list_head tasks;
- kernel/fork.c: copy_process()
  - list_add(&p->tasks, &init_task.tasks);
  - Adds to global list of tasks
- kernel/exit:unhash_process()
  - list_del(&p->tasks);
  - deletes from global list

List iteration

- For loop

```
#define list_for_each(pos, head) \
    for (pos = (head)->next; prefetch(pos->next), pos != (head); \
            pos = pos->next)
```

You need to use list_entry here

```
#define list_for_each_entry(pos, head, member)              \
for (pos = list_entry((head)->next, typeof(*pos), member);  \
     prefetch(pos->member.next), &pos->member != (head);    \
     pos = list_entry(pos->member.next, typeof(*pos), member))
```

This version provides the list_entry() internally

- Example:

```
list_for_each_entry(mod, &modules, list) {
        if (strcmp(mod->name, name) == 0)
                return mod;
}
```


Linux Completely Fair Scheduler

- Written in 62 hours by Ingo Molnar at RedHat
- No scheduling queues
  - Runnable processes stored in a red-black tree
    - Left = run sooner, right = run later
  - Processes ordered by future time; when they should run
- Order tasks by “wait_runtime” field – indicating the greatest need for the CPU
  - When one task runs, the other tasks that are waiting for the CPU are at a disadvantage:
    - the current task gets an unfair amount of CPU time.
    - this fairness imbalance is expressed and tracked via wait_runtime.
    - "wait_runtime" is the amount of time the task should now run on the CPU for it to become completely fair and balanced.
- For example:
  - if there are 2 tasks running, after first runs, second is behind by equal amount of time.

More CFS

- Fairness
  - Idea: because you waited longer, you deserve more CPU later
  - runqueue fair_clock value tracks the 'CPU time a runnable task would have fairly gotten, had it been runnable during that time'.
    - As a task gets into the runqueue, the current time is recorded
    - while the process waits for the CPU, its wait_runtime value gets incremented by an amount depending on the number of processes currently in the runqueue.
  - rq->fair_clock values measure the 'expected CPU time' a task should have gotten.
  - A task that should get double the CPU of another has wait_runtime increase twice as fast
- All runnable tasks are sorted in the rbtree by the "rq->fair_clock - p->wait_runtime" key,
  - wait_runtime = 0 when inserted
  - CFS picks the 'leftmost' task and sticks to it

More CFS

- In practice it works like this:
  - the system runs a task a bit, and when the task schedules (or a scheduler tick happens) the task's CPU usage is 'accounted for':
    - When this task gets scheduled to the CPU, its wait_runtime value starts decrementing.
    - As this value falls to such a level that other tasks become the new left-most task of the red-black tree and the current one gets preempted
    - Newly woken tasks are put into the tree more and more to the right
  - slowly but surely giving a chance for every task to become the 'leftmost task' and thus get on the CPU within a deterministic amount of time.