BS-Entwicklung mit Literate Programming

Foliensatz 9: Prozesse

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Chunk: ⟨constants⟩ (1)

- Jeder Prozess erhält einen eigenen Adressraum
- Threads (eines Prozesses) teilen sich einen Adressraum
- max. 1024 Prozesse
  → max. 1024 Adressräume

⟨constants⟩≡

```
#define MAX_ADDR_SPACES 1024
```

Chunk: ⟨elementary type definitions⟩ (1)

- Wir verwenden häufig Address-Space-IDs (als Index in die Adressraum-Tabelle)
- definieren eigenen Typ `addr_space_id` (`unsigned int`)

⟨elementary type definitions⟩≡

```
typedef unsigned int addr_space_id;
```

Chunk: ⟨more TCB entries⟩ (1)

- Jeder TCB verweist auf einen Adressraum
- Feld zur TCB-Struktur hinzufügen

⟨more TCB entries⟩≡

```
addr_space_id addr_space;  // memory usage
```

Speicher-Layout für Prozesse

Address Range	Usage	Access
0xD4000000 – 0xFFFFFFFF	*unused*	–
0xD0000000 – 0xD3FFFFFF	64 MByte Physical RAM (mapped)	K
0xC0000000 – 0xCFFFFFFF	Kernel Code and Data	K
0xBFFFF000 – 0xBFFFFFFF	Kernel Stack (4 KByte = one page)	K
0xB0000000 – 0xBFFFEFFF	*unused*	–
… – 0xAFFFFFFF	User Mode Stack	U
	Heap (can be grown with `sbrk`)	(U)
0x00000000 – …	Process Code and Data	U

Chunk: ⟨constants⟩ (2)

Speicher-Layout für Prozesse:

- Code / Daten / Heap:
  0 - ...
- User Mode Stack:
  ... - `0xB0000000` (exkl.)
- Kernel Mode Stack:
  ... - `0xC0000000` (exkl.)
- Kernel Code / Daten:
  `0xC0000000` - ...

⟨constants⟩+≡
```
#define BINARY_LOAD_ADDRESS 0x0
#define TOP_OF_USER_MODE_STACK 0xb0000000
#define TOP_OF_KERNEL_MODE_STACK 0xc0000000
```

Fragen

- Welche virtuellen Adressen nutzt ein Prozess exklusiv?
- Welche virtuellen Adressen nutzt der Kernel exklusiv?
- Was ist am Kernel Stack (`0xBFFFF000` - `0xBFFFFFFF`) besonders?

Chunk: ⟨type definitions⟩ (1)

⟨type definitions⟩≡
```
typedef struct {
  void         *pd;        // pointer to the page directory
  int          pid;        // process ID (if used by a process; -1 if not)
  short        status;     // are we using this address space?
  unsigned int memstart;   // first address below 0xc000.0000
  unsigned int memend;     // last  address below 0xc000.0000
  unsigned int stacksize;  // size of user mode stack
  unsigned int kstack_pt;  // stack page table (for kernel stack)
  unsigned int refcount;   // how many threads use this address space?
} address_space;
```

Chunk: ⟨constants⟩ (3)

- Zustände eines AS-Eintrags

⟨constants⟩+≡
```
#define AS_FREE   0
#define AS_USED   1
#define AS_DELETE 2
```

Chunk: ⟨global variables⟩ (1)

- Adressraum-Tabelle (Array),
- alles auf 0 setzen

⟨global variables⟩≡
```
address_space address_spaces[MAX_ADDR_SPACES] = ↩
…{ 0 };
```

Chunk: ⟨function prototypes⟩ (1)

- Funktion für die Suche nach einem freien Adressraum
- einfache Suche, Kriterium:
  `status == AS_FREE`

⟨function prototypes⟩≡
```
int get_free_address_space ();
```

Chunk: ⟨function implementations⟩ (1)

⟨function implementations⟩≡
```
int get_free_address_space () {
  addr_space_id id = 0;
  while ((address_spaces[id].status != AS_FREE) && (id<MAX_ADDR_SPACES)) id++;
  if (id==MAX_ADDR_SPACES) id = -1;
  return id;
}
```

Chunk: ⟨enable paging for the kernel⟩ (1)

- Adressraum 0 für Kernel

⟨enable paging for the kernel⟩≡
```
address_spaces[0].status   = AS_USED;
address_spaces[0].pd       = &kernel_pd;
address_spaces[0].pid      = -1;          // not ↩
…a process
```

Chunk: ⟨function prototypes⟩ (2)

- Neuen Adressraum erzeugen
- `initial_ram`: User Mode Speicher
- `initial_stack`: User Mode Stack

⟨function prototypes⟩+≡
```
int create_new_address_space (int initial_ram, i↩
…nt initial_stack);
```

Chunk: ⟨macro definitions⟩ (1)

⟨macro definitions⟩≡
```
#define MAKE_MULTIPLE_OF_PAGESIZE(x)  x = ((x+PAGE_SIZE-1)/PAGE_SIZE)*PAGE_SIZE
```

(Einfaches Makro, das Größenangaben so anpasst, dass sie immer ein Vielfaches der Seitengröße sind)

Chunk: ⟨function implementations⟩ (2)

⟨function implementations⟩+≡
```
int create_new_address_space (int initial_ram, int initial_stack) {
  MAKE_MULTIPLE_OF_PAGESIZE (initial_ram);
  MAKE_MULTIPLE_OF_PAGESIZE (initial_stack);
  // reserve address space table entry
  addr_space_id id;
  if ( (id = get_free_address_space()) == -1 )  return -1;    // fail
  address_spaces[id].status    = AS_USED;
  address_spaces[id].memstart  = BINARY_LOAD_ADDRESS;
  address_spaces[id].memend    = BINARY_LOAD_ADDRESS + initial_ram;
  address_spaces[id].stacksize = initial_stack;
  address_spaces[id].refcount  = 1;  // default: used by one process
  ⟨reserve memory for new page directory⟩     // sets new_pd
  address_spaces[id].pd = new_pd;
  ⟨copy master page directory to new directory⟩

  int frameno, pageno;  // used in the following two code chunks
  if (initial_ram > 0)    {  ⟨create initial user mode memory⟩  }
  if (initial_stack > 0) {  ⟨create initial user mode stack⟩      }
  return id;
};
```

Chunk: ⟨reserve memory for new page directory⟩ (1)

⟨reserve memory for new page directory⟩≡
```
page_directory *new_pd = (void*)request_new_page ();
if (new_pd == NULL) {  // Error
  printf ("\nERROR: no free page, aborting create_new_address_space\n");
  return -1;
};
memset (new_pd, 0, sizeof(page_directory));
```

Chunk: ⟨copy master page directory to new directory⟩ (1)

⟨copy master page directory to new directory⟩≡
```
*new_pd = kernel_pd;
memset ((char*)new_pd, 0, 4);    // clear first entry (kernel pd contains
                                 // old reference to some page table)
```

Fragen

- Warum kopieren wir mit

  `*new_pd = kernel_pd`

  die Einträge im *Page Directory*, aber keine Einträge aus einer oder mehreren *Page Tables*?

Chunk: ⟨function prototypes⟩ (3)

- Im nächsten Code Chunk werden wir die Funktion `as_map_page_to_frame()` verwenden
- Implementation später...

⟨function prototypes⟩+≡
```
int as_map_page_to_frame (int as, unsigned int p↩
…ageno, unsigned int frameno);
```

Chunk: ⟨create initial user mode memory⟩ (1)

- User Mode Speicher:
- richtige Anzahl Frames reservieren
- und in die Seitentabelle eintragen

⟨create initial user mode memory⟩≡
```
pageno = 0;
while (initial_ram > 0) {
  if ((frameno = request_new_frame ()) < 0) {
    printf ("\nERROR: no free frame, aborting cr↩
…eate_new_address_space\n");
    return -1;
  };
  as_map_page_to_frame (id, pageno, frameno);
  pageno++;
  initial_ram -= PAGE_SIZE;
};
```

Chunk: ⟨create initial user mode stack⟩ (1)

- User Mode Stack:
- richtige Anzahl Frames reservieren
- und in die Seitentabelle eintragen
- diesmal zählt die Schleife runter (Stack wächst nach unten, feste Anfangsadresse)

⟨create initial user mode stack⟩≡

```
  pageno = TOP_OF_USER_MODE_STACK / PAGE_SIZE;
  while (initial_stack > 0) {
    if ((frameno = request_new_frame ()) < 0) {
      printf ("\nERROR: no free frame, aborting cr↩
…eate_new_address_space\n");
      return -1;
    };
    pageno--;
    as_map_page_to_frame (id, pageno, frameno);
    initial_stack -= PAGE_SIZE;
  }
```

Fragen

- Beim Reservieren von Speicher für User Mode Memory/Stack nutzen wir `request_new_frame()`. Aber es geht doch um virtuellen Speicher -- warum nicht `request_new_page()` verwenden?

Chunk: ⟨function implementations⟩ (3)

⟨function implementations⟩+≡

```
int as_map_page_to_frame (int as, unsigned int pageno, unsigned int frameno) {
  // for address space as, map page #pageno to frame #frameno
  page_table *pt;     page_directory *pd;

  pd = address_spaces[as].pd;           // use the right address space
  unsigned int pdindex = pageno/1024;   // calculuate pd entry
  unsigned int ptindex = pageno%1024;   // ... and pt entry

  if ( ! pd->ptds[pdindex].present ) {
    // page table is not present
    ⟨create new page table for this address space⟩    // sets pt
  } else {
    // get the page table
    pt = (page_table*) PHYSICAL(pd->ptds[pdindex].frame_addr << 12);
  };
  if (pdindex < 704)   // address below 0xb0000000 -> user access
    UMAP ( &(pt->pds[ptindex]), frameno << 12 );
  else
    KMAP ( &(pt->pds[ptindex]), frameno << 12 );
  return 0;
};
```

Fragen

- Warum verwenden wir `UMAP` (bei `pdindex < 704`) und `KMAP` (bei `pdindex >= 704`)?
- Was würde passieren, wenn immer `KMAP` benutzt wird?
- Können wir `as_map_page_to_frame()` auch verwenden, um dem Kernel neue Seiten (oberhalb `0xC0000000`) zur Verfügung zu stellen?

Chunk: ⟨create new page table for this address space⟩ (1)

⟨create new page table for this address space⟩≡

```
    int new_frame_id = request_new_frame ();
    unsigned int address = PHYSICAL (new_frame_id << 12);
    pt = (page_table *) address;
    memset (pt, 0, sizeof(page_table));
    UMAPD ( &(pd->ptds[pdindex]), new_frame_id << 12);
```

Fragen

- Die neue Seitentabelle wird immer mit `UMAPD` in das Page Directory eingetragen. Müsste das nicht in einigen Fällen `KMAPD` sein?

Chunk: ⟨function prototypes⟩ (4)

- Adressraum zerstören (nach Prozessende)
- relativ komplex: alle reservierten Frames bzw. Pages wieder freigeben
- Problem: Kernel-Stack → den nutzen wir gerade!
- Lösung: Eintragen in *kstack delete list*

⟨function prototypes⟩+≡

```
void destroy_address_space (addr_space_id id);
```

Chunk: ⟨function implementations⟩ (4)

⟨function implementations⟩+≡

```
void destroy_address_space (addr_space_id id) {
  // called only from syscall_exit(), holding thread_list_lock, interrupts off
  if (--address_spaces[id].refcount > 0) return;
  addr_space_id as = current_as;           // remember current address space
  current_as = id;                         // set current_as: we call release_page()

  ⟨destroy AS: release user mode pages⟩  // all pages used by the process
  ⟨destroy AS: release user mode stack⟩   // all its user mode stack pages
  ⟨destroy AS: release page tables⟩       // the page tables (0..703)

  current_as = as;                         // restore current_as
  address_spaces[id].status = AS_DELETE;  // change AS status

  // remove kernel stack (cannot do this here, this stack is in use right now)
  add_to_kstack_delete_list (id);
  return;
}
```

Chunk: ⟨destroy AS: release user mode pages⟩ (1)

⟨destroy AS: release user mode pages⟩≡

```
for ( int i = address_spaces[id].memstart / PAGE_SIZE;
      i < address_spaces[id].memend / PAGE_SIZE;
      i++ ) {
  release_page (i);
};
```

Chunk: ⟨destroy AS: release user mode stack⟩ (1)

⟨destroy AS: release user mode stack⟩≡

```
for ( int i = TOP_OF_USER_MODE_STACK / PAGE_SIZE - 1;
      i > (TOP_OF_USER_MODE_STACK-address_spaces[id].stacksize) / PAGE_SIZE - 1;
      i-- ) {
  release_page (i);
};
```

Chunk: ⟨destroy AS: release page tables⟩ (1)

⟨destroy AS: release page tables⟩≡

```
page_directory *tmp_pd = address_spaces[id].pd;
for ( int i = 0;  i < 704;  i++ ) {
  if ( tmp_pd->ptds[i].present )
    release_frame ( tmp_pd->ptds[i].frame_addr );
}
```

Chunk: ⟨function prototypes⟩ (5)

- *kstack delete list*: Funktion zum Eintragen
- Bearbeiten der Aufträge: im Scheduler

⟨function prototypes⟩+≡

```
void add_to_kstack_delete_list (addr_space_id id↩
…);
```

Chunk: ⟨constants⟩ (4)

- maximal 1024 Einträge

⟨constants⟩+≡

```
#define KSTACK_DELETE_LIST_SIZE 1024
```

Chunk: ⟨global variables⟩ (2)

- *kstack delete list* ist Array von Adressraum-IDs
- Zugriff darauf mit Lock schützen

⟨global variables⟩+≡

```
addr_space_id kstack_delete_list[KSTACK_DELETE_L↩
…IST_SIZE] = { 0 };
lock kstack_delete_list_lock;
```

Chunk: ⟨initialize kernel global variables⟩ (1)

- Lock initialisieren
- (mehr zu Locks: später, Thema *Synchronisation*)

⟨initialize kernel global variables⟩≡

```
kstack_delete_list_lock = get_new_lock ("kstack"↩
…);
```

Chunk: ⟨function implementations⟩ (5)

⟨function implementations⟩+≡

```
void add_to_kstack_delete_list (addr_space_id id) {
  int i;
  LOCK (kstack_delete_list_lock);
  for (i = 0;  i < KSTACK_DELETE_LIST_SIZE;  i++) {
    // try to enter it here
    if (kstack_delete_list[i] == 0) {
      // found a free entry
      kstack_delete_list[i] = id;
      break;
    }
  }
  UNLOCK (kstack_delete_list_lock);
  if (i == KSTACK_DELETE_LIST_SIZE)
    printf ("ERROR ADDING ADDRESS SPACE TO KSTACK DELETE LIST!\n");
}
```

Chunk: ⟨scheduler: free old kernel stacks⟩ (1)

⟨scheduler: free old kernel stacks⟩≡

```
// check all entries in the to-be-freed list
int            i, entry, frameno;
page_directory *tmp_pd;
page_table     *tmp_pt;
LOCK (kstack_delete_list_lock);
for (entry = 0; entry < KSTACK_DELETE_LIST_SIZE; entry++) {
  if (kstack_delete_list[entry] != 0 && kstack_delete_list[entry] != current_as) {
    // remove it
    addr_space_id id = kstack_delete_list[entry];
    tmp_pd = address_spaces[id].pd;
    tmp_pt = (page_table *) address_spaces[id].kstack_pt;
    // this is the page table which maps the last 4 MB below 0xC0000000
    for (i = 0; i < KERNEL_STACK_PAGES; i++) {
      frameno = tmp_pt->pds[1023-i].frame_addr;
      release_frame (frameno);
    }
    kstack_delete_list[entry] = 0;   // remove entry from kstack delete list

    release_page (((unsigned int)tmp_pt) >> 12);  // free memory for page table
    release_page (((unsigned int)tmp_pd) >> 12);  // ... and page directory
    address_spaces[id].status = AS_FREE;          // mark address space as free
  }
}
UNLOCK (kstack_delete_list_lock);
```

Fragen

- Warum brauchen wir die Kernel Stack Delete List?
- Was genau würde passieren, wenn wir den Kernel Stack in `destroy_address_space()` sofort entfernen?

Chunk: ⟨constants⟩ (5)

- Wie groß ist der Kernel Stack?
- 16 KByte (4 Seiten)

⟨constants⟩+≡

```
// kernel stack (per process): 1 page = 4 KByte
#define KERNEL_STACK_PAGES 4
#define KERNEL_STACK_SIZE PAGE_SIZE * KERNEL_STA↩
…CK_PAGES
```

Chunk: ⟨function prototypes⟩ (6)

- Aktivieren eines Adressraums:
- Laden der **phys.** Page-Directory-Adresse in Register `CR3`
- Vorsicht: tauscht auch den gerade verwendeten Kernel Stack aus
- darum Funktion nicht aus dem Scheduler heraus aufrufen

⟨function prototypes⟩+≡

```
inline void activate_address_space (addr_space_i↩
…d id)  __attribute__((always_inline));
```

Chunk: ⟨global variables⟩ (3)

- `current_as`: aktueller Adressraum

⟨global variables⟩+≡

```
addr_space_id current_as = 0;  // global variabl↩
…e: current address space
addr_space_id tmp_as;          // temp. address ↩
…space variable, for context switch
```

Chunk: ⟨function implementations⟩ (6)

⟨function implementations⟩+≡
```
inline void activate_address_space (addr_space_id id) {
  // NOTE: Do not call this from the scheduler; where needed, replicate the code
  unsigned int virt = (unsigned int)address_spaces[id].pd;  // get PD address
  unsigned int phys = mmu (0, virt);             // and find its physical address
  asm volatile ("mov %0, %%cr3" : : "r"(phys)); // write CR3 register
  current_as = id;                              // set current address space
  current_pd = address_spaces[id].pd;           // set current page directory
  return;
};
```

Fragen

- Was ist problematisch daran, `activate_address_space()` als Funktion zu verwenden?

Chunk: ⟨function prototypes⟩ (8)

Adressübersetzung

- Funktion der MMU nachbilden
- `mmu_p()`: einer Seite ihren Frame zuordnen
- `mmu()`: einer virt. Adresse die phys. Adresse zuordnen
- jeweils bezogen auf einen bestimmten Adressraum
- Aufruf möglich, *ohne* den Adressraum vorher zu wechseln

⟨function prototypes⟩+≡
```
unsigned int mmu_p (addr_space_id id, unsigned int pageno); // pageno -> frameno
unsigned int mmu (addr_space_id id, unsigned int vaddress); // virt. -> phys. addr.
```

Chunk: ⟨function implementations⟩ (8)

⟨function implementations⟩+≡
```
unsigned int mmu_p (addr_space_id id, unsigned int pageno) {
  unsigned int pdindex, ptindex;
  page_directory *pd;
  page_table     *pt;
  pdindex = pageno/1024;
  ptindex = pageno%1024;
  pd = address_spaces[id].pd;
  if ( ! pd->ptds[pdindex].present ) {
    return -1;
  } else {
    pt = (page_table*) PHYSICAL(pd->ptds[pdindex].frame_addr << 12);
    if ( pt->pds[ptindex].present ) {
      return pt->pds[ptindex].frame_addr;
    } else {
      return -1;
    };
  }
};
```

Chunk: ⟨function implementations⟩ (9)

- `mmu()` verwendet einfach `mmu_p()`
- vorher Offset ausblenden
- nachher wieder drauf addieren
- (oberste 20 Bits: Seitennummer; untere 12 Bits: Offset)

⟨function implementations⟩+≡
```
unsigned int mmu (addr_space_id id, unsigned int↩
… vaddress) {
  unsigned int tmp = mmu_p (id, (vaddress >> 12);
  if (tmp == -1)
    return -1;  // fail
  else
    return (tmp << 12) + (vaddress % PAGE_SIZE);
}
```

Fragen

- Warum implementieren wir `mmu()` mit Hilfe von `mmu_p()` und nicht anders rum?

Chunk: ⟨function prototypes⟩ (9)

- Adressraum vergrößern mit `u_sbrk()`
- fügt eine oder mehrere Seiten hinzu (Heap)

⟨function prototypes⟩+≡
```
void *u_sbrk (int incr);
```

Chunk: ⟨function implementations⟩ (10)

⟨function implementations⟩+≡
```
void *u_sbrk (int incr) {
  int pages = incr / PAGE_SIZE;
  int i, frame;
  address_space *aspace = &address_spaces[current_as];

  unsigned int oldbrk = aspace->memend;

  for (i = 0; i < pages; i++) {
    frame = request_new_frame ();
    if (frame == -1) { return (void*)(-1); } // error!
    as_map_page_to_frame (current_as, aspace->memend/PAGE_SIZE, frame);
    aspace->memend += PAGE_SIZE;
  }
  return (void*) oldbrk;
}
```

Chunk: ⟨syscall prototypes⟩ (1)

- Zugehöriger System Call Handler

⟨syscall prototypes⟩≡
```
void syscall_sbrk (context_t *r);
```

Chunk: ⟨syscall functions⟩ (1)

⟨syscall functions⟩≡
```
void syscall_sbrk (context_t *r) {
  // ebx: increment
  r->eax = (unsigned int)u_sbrk (r->ebx);
  return;
}
```

Fragen

- In:

  ```
  r->eax = (unsigned int)u_sbrk (r->ebx);
  ```

  -- Was war nochmal die Rolle von `r->eax` und `r->ebx`?

Chunk: ⟨initialize syscalls⟩ (1)

- Syscall eintragen

⟨initialize syscalls⟩≡
```
  install_syscall_handler (__NR_brk, syscall_sbrk)↩
…;
```

Thread Control Block

- `TCB`: zentrale Datenstruktur für Threads / Prozesse
- bei ULIX: Prozess-ID (oder Thread-ID) identisch mit Position in TCB-Liste
- enthält Feld vom Typ `context_t` für Context Switch
- Referenz auf Adressraum haben wir schon gesehen
- Thread-Liste: Array von TCBs

Chunk: ⟨type definitions⟩ (2)

⟨type definitions⟩+≡
```
  typedef struct {
    thread_id     tid;          // thread id
    thread_id     ppid;         // parent process
    int           state;        // state of the process
    context_t     regs;         // context
    unsigned int  esp0;         // kernel stack pointer
    unsigned int  eip;          // program counter
    unsigned int  ebp;          // base pointer
    ⟨more TCB entries⟩
  } TCB;
```

Chunk: ⟨constants⟩ (6)

- maximal 1024 Threads

⟨constants⟩+≡
```
  #define MAX_THREADS 1024
```

Chunk: ⟨global variables⟩ (4)

- Thread-Tabelle

⟨global variables⟩+≡
```
  TCB thread_table[MAX_THREADS];
```

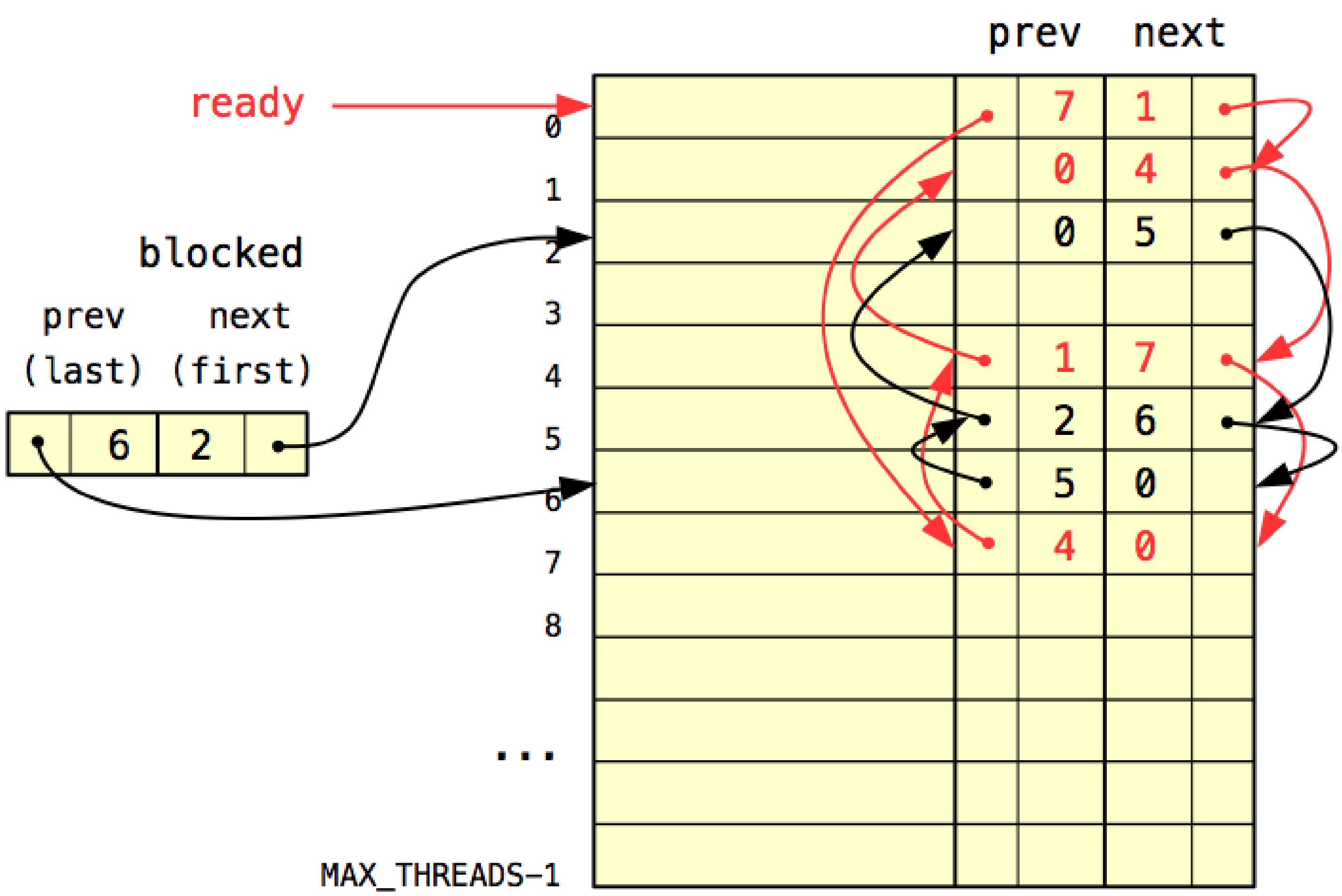
Chunk: ⟨more TCB entries⟩ (2)

- Wir brauchen Listen von Threads
- z. B. Liste der bereiten Threads,
- mehrere Blockiert-Listen
- Verwaltung über Zeiger `next`, `prev`; direkt im TCB
- ready queue: `thread_table[0].next` definiert Anfang (0 ist keine gültige Thread-ID!)

⟨more TCB entries⟩+≡

```
thread_id next; // id of the ``next'' thread
thread_id prev; // id of the ``previous'' thread
```

Listen-Verwaltung



Chunk: ⟨declaration of blocked queue⟩ (1)

- Blockiert-Liste:
- Struktur, die via `next` und `prev` auf TCBs zeigt

⟨declaration of blocked queue⟩≡

```
typedef struct {
  thread_id next; // id of the ``next'' thread
  thread_id prev; // id of the ``previous'' thre↩
…ad
} blocked_queue;
```

Chunk: ⟨function implementations⟩ (11)

⟨function implementations⟩+≡
```
void initialize_blocked_queue (blocked_queue* q) {
  q->prev = 0;
  q->next = 0;
}
```

Chunk: ⟨function prototypes⟩ (10)

- Bereit-Warteschlange:
- Thread hinzufügen (setzt auch Status auf `TSTATE_READY`)
- Thread entfernen

⟨function prototypes⟩+≡
```
void add_to_ready_queue (thread_id t);
void remove_from_ready_queue (thread_id t);
```

Chunk: ⟨function implementations⟩ (12)

⟨function implementations⟩+≡
```
void add_to_ready_queue (thread_id t) {
  thread_id last = thread_table[0].prev;
  thread_table[0].prev = t;
  thread_table[t].next = 0;
  thread_table[t].prev = last;
  thread_table[last].next = t;
  thread_table[t].state = TSTATE_READY;  // set its state to ready
}
```

Chunk: ⟨function implementations⟩ (13)

⟨function implementations⟩+≡
```
void remove_from_ready_queue (thread_id t) {
  thread_id prev_thread = thread_table[t].prev;
  thread_id next_thread = thread_table[t].next;
  thread_table[prev_thread].next = next_thread;
  thread_table[next_thread].prev = prev_thread;
}
```

Chunk: ⟨initialize kernel global variables⟩ (2)

- Initialisierung: Bereit-Warteschlange ist leer

⟨initialize kernel global variables⟩+≡
```
thread_table[0].prev = 0;
thread_table[0].next = 0;
```

Chunk: ⟨function prototypes⟩ (11)

⟨function prototypes⟩+≡
```
void add_to_blocked_queue       (thread_id t, blocked_queue* bq);
void remove_from_blocked_queue  (thread_id t, blocked_queue* bq);
thread_id front_of_blocked_queue (blocked_queue bq);
```

Chunk: ⟨function implementations⟩ (14)

⟨function implementations⟩+≡

```
thread_id front_of_blocked_queue (blocked_queue bq) {
  return bq.next;
}
```

Chunk: ⟨function implementations⟩ (15)

⟨function implementations⟩+≡

```
void add_to_blocked_queue (thread_id t, blocked_queue* bq) {
  thread_id last = bq->prev;
  bq->prev = t;
  thread_table[t].next = 0; // [[t]] is ``last'' thread
  thread_table[t].prev = last;
  if (last == 0) {
    bq->next = t;
  } else {
    thread_table[last].next = t;
  }
}
```

Chunk: ⟨function implementations⟩ (16)

⟨function implementations⟩+≡

```
void remove_from_blocked_queue (thread_id t, blocked_queue* bq) {
  thread_id prev_thread = thread_table[t].prev;
  thread_id next_thread = thread_table[t].next;
  if (prev_thread == 0) {
    bq->next = next_thread;
  } else {
    thread_table[prev_thread].next = next_thread;
  }
  if (next_thread == 0) {
    bq->prev = prev_thread;
  } else {
    thread_table[next_thread].prev = prev_thread;
  }
}
```

Chunk: ⟨more TCB entries⟩ (3)

- Verwaltung der TCBs
- Feld used markiert, ob TCB frei ist

⟨more TCB entries⟩+≡

```
boolean used;
```

Chunk: ⟨global variables⟩ (5)

- Wir wollen Thread-IDs fortlaufend vergeben
- d.h.: auch wenn ein Thread beendet wird, vergeben wir dessen Nummer (zunächst) nicht neu
- später (wenn alle Nummern belegt waren) schon
- Suche beginnt immer bei `next_pid`

⟨global variables⟩+≡

```
int next_pid = 1;
```

Chunk: ⟨find free TCB entry⟩ (1)

⟨find free TCB entry⟩≡

```
boolean tcbfound = false;
int tcbid;
for ( tcbid = next_pid; ((tcbid < MAX_THREADS) && (!tcbfound)); tcbid++ ) {
  if (thread_table[tcbid].used == false) {
    tcbfound = true;
    break;
  }
};
```

Chunk: ⟨find free TCB entry⟩ (2)

⟨find free TCB entry⟩+≡

```
if (!tcbfound) {                                   // continue searching at 1
  for ( tcbid = 1; ((tcbid < next_pid) && (!tcbfound)); tcbid++ ) {
    if (thread_table[tcbid].used == false) {
      tcbfound = true;
      break;
    }
  };
};

if (tcbfound) next_pid = tcbid+1;                  // update next_pid:
// either tcbfound == false or tcbid == index of first free TCB
```

Chunk: ⟨function prototypes⟩ (12)

- Funktion verknüpft TCB und Adressraum

⟨function prototypes⟩+≡

```
int register_new_tcb (addr_space_id as_id);
```

Chunk: ⟨function implementations⟩ (18)

⟨function implementations⟩+≡

```
int register_new_tcb (addr_space_id as_id) {
  // called by ulix_fork() which aquires LOCK (thread_list_lock)
  ⟨find free TCB entry⟩
  if (!tcbfound) {
    return -1; // no free TCB!
  };
  thread_table[tcbid].used       = true;   // mark as used
  thread_table[tcbid].addr_space = as_id;  // enter address space ID
  return tcbid;
}
```

Start des ersten Prozesses

Schritte:

1. TCB und Adressraum reservieren
2. Speicher reservieren (User Mode Code/Data/Stack + Kernel Mode Stack)
3. Programm von Platte laden
4. TCB aktualisieren
5. Datenstruktur TSS (→ später) erzeugen
6. Sprung in den User Mode / Aktivierung des Prozess'

Chunk: ⟨global variables⟩ (6)

- Variable für aktuellen Thread,
- vgl. `current_as` für aktuellen Adressraum

⟨*global variables*⟩+≡
```
int current_task;
```

Chunk: ⟨constants⟩ (7)

- init-Prozess (u.a. Shell): max. 32 K
- könnte man auch variabel gestalten (erhöht Komplexität)

⟨*constants*⟩+≡
```
#define PROGSIZE 32768
```

Chunk: ⟨global variables⟩ (7)

- Zugriff auf TCBs mit Lock schützen

⟨*global variables*⟩+≡
```
lock thread_list_lock = NULL;     // initialize ↩
…this when the first process starts
```

Chunk: ⟨function implementations⟩ (19)

⟨*function implementations*⟩+≡
```
void start_program_from_disk (char *progname) {
  if (thread_list_lock == NULL)              // initialize lock for thread list
    thread_list_lock = get_new_lock ("thread list");

  ⟨start program from disk: prepare address space and TCB entry⟩
  ⟨start program from disk: load binary⟩
  ⟨start program from disk: create kernel stack⟩

  current_task = tid;                        // make this the current task
  add_to_ready_queue (tid);                  // add process to ready queue
  ENABLE_SCHEDULER;
  cpu_usermode (BINARY_LOAD_ADDRESS,
                TOP_OF_USER_MODE_STACK);     // jump to user mode
};
```

Chunk: ⟨start program from disk: prepare address space and TCB entry⟩ (1)

⟨*start program from disk: prepare address space and TCB entry*⟩≡
```
addr_space_id as;
thread_id tid;
as = create_new_address_space(64*1024, 4096);   // 64 KB + 4 KB stack
tid = register_new_tcb (as);                     // get a fresh TCB
thread_table[tid].tid = tid;
thread_table[tid].ppid = 0;                      // parent: 0 (none)
thread_table[tid].new = false;                   // not freshly created via fork()
thread_table[tid].terminal = 0;                  // default terminal: 0
memcpy (thread_table[tid].cwd,     "/",   2);    // set current directory
memcpy (thread_table[tid].cmdline, "new", 4);    // set temporary command line
activate_address_space (as);                     // activate the new address space
```

Chunk: ⟨start program from disk: load binary⟩ (1)

⟨start program from disk: load binary⟩≡

```
// read binary
int mfd = mx_open (DEV_HDA, progname, O_RDONLY);
mx_read (DEV_HDA, mfd, (char*)BINARY_LOAD_ADDRESS, PROGSIZE);
                                               // load to virtual address 0
mx_close (DEV_HDA, mfd);
```

Chunk: ⟨start program from disk: create kernel stack⟩ (1)

⟨start program from disk: create kernel stack⟩≡

```
    unsigned int framenos[KERNEL_STACK_PAGES];   // frame numbers of kernel stack pages
    int i;
    for (i = 0; i < KERNEL_STACK_PAGES; i++)
      framenos[i] = request_new_frame();
    page_table* stackpgtable = (page_table*)request_new_page();
    memset (stackpgtable, 0, sizeof(page_table));
    KMAPD ( &current_pd->ptds[767], mmu (0, (unsigned int)stackpgtable) );
    for (i = 0; i < KERNEL_STACK_PAGES; i++)
      as_map_page_to_frame (current_as, 0xbffff - i, framenos[i]);
    char *kstack = (char*) (TOP_OF_KERNEL_MODE_STACK-KERNEL_STACK_SIZE);
    unsigned int adr = (uint)kstack;                     // one page for kernel stack
    tss_entry.esp0 = adr+KERNEL_STACK_SIZE;

    thread_table[tid].esp0 = (uint)kstack + KERNEL_STACK_SIZE;
    thread_table[tid].ebp  = (uint)kstack + KERNEL_STACK_SIZE;
```

Chunk: ⟨install GDTs for User Mode⟩ (1)

- bisher: Code- und Datensegmente `0x08`, `0x10` (Kernel)
- jetzt: Code- und Datensegmente `0x18`, `0x20` (User Mode)
- `0xFA` = 1**11**1 1010 (bin)
- `0xF2` = 1**11**1 0010 (bin)
- DPL: 3 = **11** (bin)
  Executable? 1 = yes

⟨install GDTs for User Mode⟩≡

```
fill_gdt_entry (3, 0, 0xFFFFFFFF, 0xFA, 0b1100);
fill_gdt_entry (4, 0, 0xFFFFFFFF, 0xF2, 0b1100);
```

Übersicht GDT-Einträge

Insgesamt 5 (echte) Einträge:

⟨*collection of* `fill_gdt_entry` *calls* 181a⟩≡

```
//              no base      limit          access      gran
// ---------------------------------------------------------------------------------
fill_gdt_entry (0, 0,        0,             0,          0     );  // null descriptor
fill_gdt_entry (1, 0,        0xFFFFFFFF,    0b10011010, 0b1100);  // kernel, code
fill_gdt_entry (2, 0,        0xFFFFFFFF,    0b10010010, 0b1100);  // kernel, data
fill_gdt_entry (3, 0,        0xFFFFFFFF,    0b11111010, 0b1100);  // user, code
fill_gdt_entry (4, 0,        0xFFFFFFFF,    0b11110010, 0b1100);  // user, data
//   write_tss (5, 0x10, (void*)TOP_OF_KERNEL_MODE_STACK);   calls...
fill_gdt_entry (5, TSS_ADDR, TSS_SIZE - 1, 0b11101001, 0b0000);  // TSS descriptor
//   with TSS_ADDR = &tss_entry and TSS_SIZE = sizeof (tss_entry)
```

(Erklärung zu TSS-Eintrag: folgt)

Chunk: ⟨type definitions⟩ (3)

⟨*type definitions*⟩+≡

```
typedef struct {
  unsigned int prev_tss     : 32;  // unused: previous TSS
  unsigned int esp0, ss0    : 32;  // ESP and SS to load when we switch to ring 0
  long long u1, u2          : 64;  // unused: esp1, ss1, esp2, ss2 for rings 1 and 2
  unsigned int cr3          : 32;  // unused: page directory
  unsigned int eip, eflags : 32;
  unsigned int eax, ecx, edx, ebx, esp, ebp, esi, edi, es, cs, ss, ds, fs, gs : 32;
                                   // unused (dynamic, filled by CPU)
  long long u3              : 64;  // unused: ldt, trap, iomap
} __attribute__((packed)) tss_entry_struct;
```

⟨*global variables*⟩+≡

```
tss_entry_struct tss_entry;
```

Chunk: ⟨install GDTs for User Mode⟩ (2)

- GDT erhält auch einen Eintrag für die TSS
- `write_tss`-Argumente:
  - GDT-Nummer,
  - SS0, ESP0

⟨*install GDTs for User Mode*⟩+≡

```
write_tss (5, 0x10, 0xc0000000);
```

Chunk: ⟨function implementations⟩ (20)

⟨function implementations⟩+≡
```
void write_tss (int num, unsigned short ss0, unsigned int esp0) {
   unsigned int base = (unsigned int) &tss_entry;
   unsigned int limit = sizeof (tss_entry) - 1;
   fill_gdt_entry (num, base, limit, 0xE9, 0b0000);   // enter it in GDT

   memset (&tss_entry, 0, sizeof(tss_entry));         // fill with zeros

   tss_entry.ss0  = ss0;  // Set the kernel stack segment.
   tss_entry.esp0 = esp0; // Set the kernel stack pointer.
}
```

- `0xE9` = 1**11**0 1001 (bin)
- DPL: 3 = **11** (bin)
  0: Das ist kein normaler GDT-Eintrag (sondern TSS)

Chunk: ⟨start.asm⟩ (1)

- `tss_flush()`: in Assembler-Datei
- muss Assembler-Befehl `ltr` (load *task register*) ausführen

⟨start.asm⟩≡
```
[section .text]
              global tss_flush

tss_flush:    mov ax, 0x28 | 0x03
              ltr ax                  ; load the tas↩
…k register
              ret
```

Chunk: ⟨function prototypes⟩ (14)

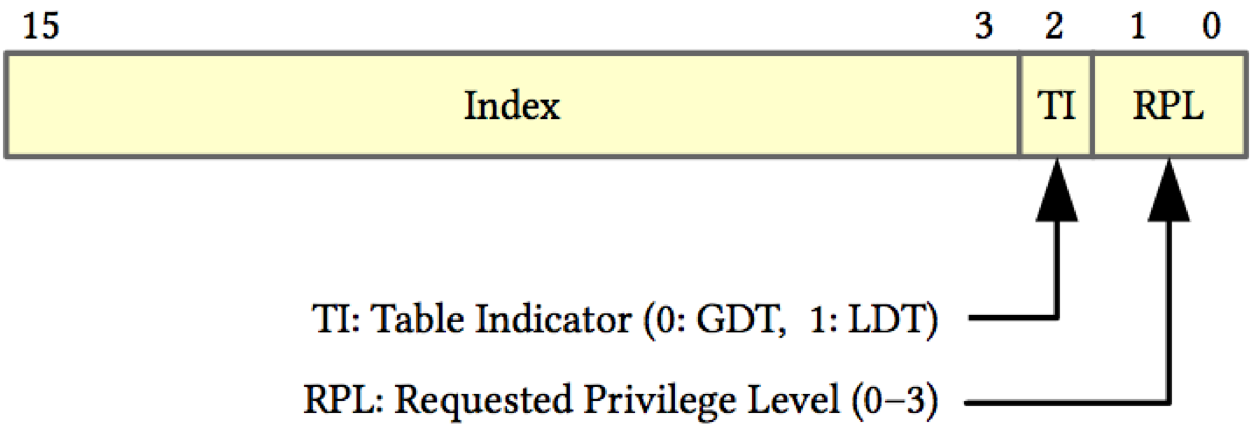
- Umschalten auf User Mode (Ring 3): mit Assembler-Funktion `cpu_usermode()`
- Trick: Stack so vorbereiten, dass `iret`-Aufruf zum Wechsel in Ring 3 führt
- auf Stack liegen dann u. a. die Segmentregister
- und die enthalten auch den einzustellenden Protection Level

⟨function prototypes⟩+≡
```
extern void cpu_usermode (unsigned int address, ↩
…unsigned int stack);   // assembler
```

Segment-Selektoren

- `iret` liest Werte auf dem Stack und füllt damit u. a. die Segment-Register
- Diese passend einstellen → schaltet User Mode ein

Segment-Selektor:



Chunk: ⟨start.asm⟩ (2)

⟨start.asm⟩+≡

```
; code from http://f.osdev.org/viewtopic.php?t=23890&p=194213 (Jezze)
; modified and comments added
              global cpu_usermode
cpu_usermode: cli                      ; disable interrupts
              mov  ebp, esp            ; remember current stack address
              mov  ax,  0x20 | 0x03    ; code selector 0x20 | RPL3: 0x03
                                       ; RPL = requested protection level
              mov  ds,  ax
              mov  es,  ax
              mov  fs,  ax
              mov  gs,  ax
              mov  eax, esp
              push 0x20 | 0x03         ; code selector 0x20 | RPL3: 0x03
              mov  eax, [ebp + 8]      ; stack address is 2nd argument
              push eax                 ; stack pointer
              pushf                    ; EFLAGS
              pop  eax                 ; trick: reenable interrupts when doing iret
              or   eax, 0x200
              push eax
              push 0x18 | 0x03         ; code selector 0x18 | RPL3: 0x03
              mov  eax, [ebp + 4]      ; return address (1st argument) for iret
              push eax
              iret
```