Operating Systems

Stack and Context Switch

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Context of a Process

Process: running program

Context:

- CPU registers
- Process Memory
  - Stack (.stack)
  - Program code (.text), typically read only during execution
  - Initialized Variables (.data)
  - Global Uninitialized Variables (.bss)

If each process uses only its own memory, the execution can be stopped and later recovered by saving/restoring the CPU registers

Coroutines

Coroutine: piece of program that can be "jumped in" and "out"

- In assembly "jmp".
- In C: need to preserve consistency of the stack.

- Ucontext: portable C library for user level control of contexts

Ucontext: concepts

`struct ucontext_t`; datatype to store a context

- **`ucontext_t *uc_link`**: pointer to the context that will be resumed when this context returns
- **`sigset_t uc_sigmask`**: the set of signals that are blocked when this context is active
- **`stack_t uc_stack`**: the stack used by this context
- **`mcontext_t  uc_mcontext`**: a machine-specific representation of the saved context

getContext

`int getcontext(ucontext_t *ucp);`

- Saves the current context in ucp.
- A subsequent call to setcontext(ucp) will result in the flow of the program continuing from the instruction following setcontext(ucp);

```
struct ucontext_t ctx;      ← Here we store our jump point

int f2(){
  setContext(&ctx);
}

int f1(){
  ….
  getContext(&ctx);         ← set ctx to jump to the next instruction after
  …                           getcontext
  f2();
}
```

setContext

`int setcontext(const ucontext_t *ucp)`

- Sets the current context to ucp, a context that was previously saved.
- The flow will continue from the instruction following the
- getcontext(ucp) call issued when SAVING the context

```
struct ucontext_t ctx;

int f2(){
  setContext(&ctx);    ← We jump to a saved context [1]
}

int f1(){          [1]
  ….
  getContext(&ctx);
  …
  f2();
}
```

makeContext

`void makecontext(ucontext_t *ucp, void (*func)(), int argc, ...);`

- creates a trampoline context for function func.
- the context is initialized so that when jumping to it it will start executing the function func
- ucp should have the stack and the signal mask already set before calling makecontext

```
struct ucontext_t ctx;

int f2(){
    …
}

int main(){
    ….
    makeContext(&ctx, f2,...);      ← ctx initialized so that when called starts f2
    …
    setContext(&ctx);               ← flow continues from f2
}
```

swapContext

```
int swapcontext(ucontext_t *oucp,
const ucontext_t *ucp);
```

- saves the current context in oucp, and jumps to ucp

Full example

```
ucontext_t main_context, f1_context, f2_context;

void f1(){
  printf("f1 started\n");
  for (int i=0; i<num_iterations; i++) {
    printf("f1: %d\n", i);
    swapcontext(&f1_context, &f2_context);
  }
  setcontext(&main_context);
}

void f2(){
  printf("f2 started\n");
  for (int i=0; i<num_iterations; i++) {
    printf("f2: %d\n", i);
    swapcontext(&f2_context, &f1_context);
  }
  setcontext(&main_context);
}

char f1_stack[STACK_SIZE];
char f2_stack[STACK_SIZE];
```

```
int main(){
  //get a context from main
  getcontext(&f1_context);

  // set the stack of f1 to the right place
  f1_context.uc_stack.ss_sp=f1_stack;
  f1_context.uc_stack.ss_size = STACK_SIZE;
  f1_context.uc_stack.ss_flags = 0;
  f1_context.uc_link=&main_context;

  // create a trampoline for the first function
  makecontext(&f1_context, f1, 0, 0);

  // always remember to initialize
  // a new context from something known
  f2_context=f1_context;

  f2_context.uc_stack.ss_sp=f2_stack;
  f2_context.uc_stack.ss_size = STACK_SIZE;
  f2_context.uc_stack.ss_flags = 0;
  f2_context.uc_link=&main_context;

  // create a trampoline for the second function
  makecontext(&f2_context, f2, 0, 0);

  // this passes control to f2.
  // and saves the current context in main_context

  swapcontext(&main_context, &f1_context);
  // we will jump back here

  printf("exiting\n");
}
```

Exercise

- Modify the program above to spin on 10 different threads instead of two

Preemptive multitasking on AVR

We want to implement an timer controlled preemptive task switcher on our arduino.

- **Task Control Blocks**: stored in double linked list
- Always at least one process in running

Initialization

- Fill in TCB data
- Prepare all stack frames so that the Program Counter stored on the stack points to a launcher for the thread function, and all registers clean

Start

- Change stack pointer to first tcb
- Pull all registers
- Return from function

Context switch (once all is set), on interrupt:

- Save all registers on stack
- Change stack pointer
- Pull all registers from stack
- Return from interrupt

Task Control Block

```
#pragma once
#include <stdint.h>
#include <stddef.h>

#define OK     0
#define ERROR -1

typedef uint8_t* Pointer;
typedef void (* ThreadFn)(uint32_t thread_args);

typedef enum {Running=0x0, Terminated=0x1, Ready=0x2} ThreadStatus;

// thread control block
typedef struct TCB {
  Pointer sp_save_ptr;

  ThreadFn thread_fn;
  uint32_t thread_arg;

  struct TCB* next;
  struct TCB* prev;

  Pointer stack_bottom;         /* Pointer to bottom of stack allocation */
  uint32_t stack_size;          /* Size of stack allocation in bytes */
  ThreadStatus status;
} TCB;


void TCB_create(TCB* tcb, Pointer stack_top, ThreadFn thread_fn, uint32_t thread_arg);
```

TCB Create

```
void TCB_create(TCB* tcb, Pointer stack_top, ThreadFn thread_fn, uint32_t thread_arg){
  //initialize variables
  tcb->thread_fn=thread_fn;
  tcb->thread_arg=thread_arg;
  tcb->prev=NULL;
  tcb->next=NULL;
  tcb->status=Ready;

  /** prepare stack for process **/

  uint8_t *stack_ptr = (uint8_t *)stack_top;
  //write the return address of the function being called (the trampoline)
  *stack_ptr-- = (uint8_t)((uint16_t)_trampoline & 0xFF);
  *stack_ptr-- = (uint8_t)(((uint16_t)_trampoline >> 8) & 0xFF);
  *stack_ptr-- = 0; // store an additional segment register (atMega2560)


  /**
   * Store starting register values for R2-R17, R28-R29
   */
  *stack_ptr-- = 0x00;    /* R2 */
  *stack_ptr-- = 0x00;    /* R3 */
  ……………………… // here we save all other registers………
  *stack_ptr-- = 0x00;    /* R28 */
  *stack_ptr-- = 0x00;    /* R29 */
  *stack_ptr-- = 0x00;    /* RAMPZ */
  *stack_ptr-- = 0x00;    /* EIND */

  // store stack pointer
  tcb->sp_save_ptr = stack_ptr;

}
```

TCB Create, trampoline

- The trampoline is a convenient function without parameters that calls the function whose pointer is stored in the current_tcb global variable
- Not to mess up with calling conventions ;-)

```
static void _trampoline(void){
  sei();
  /* Call the thread entry point */
  if (current_tcb && current_tcb->thread_fn) {
    (*current_tcb->thread_fn)(current_tcb->thread_arg);
  }

  // set the thread to terminated, when the above function finishes
  current_tcb->status=Terminated;
}
```

TCB Queue

The TCBs are stored in a double linked list

No memory allocation

- Two actions:
  - Take out the element at the beginning of the list
  - Put an element out of the list at its tail

```
// simple double linked list of TCBs
typedef struct {
  struct TCB* first;
  struct TCB* last;
  uint8_t size;
} TCBList;

// global list of tcbs containing the running processes
extern TCBList tcb_queue;

// removes (if any) first tcb from the list
TCB* TCBList_dequeue(TCBList* list);

// adds new detached tcb to the list
uint8_t TCBList_enqueue(TCBList* list, TCB* tcb);
```

Context Switch

```
//void archContextSwitch (ATOM_TCB *old_tcb_ptr, ATOM_TCB *new_tcb_ptr)

.global archContextSwitch
archContextSwitch:

    /**
     * Parameter locations:
     *  old_tcb_ptr = R25-R24
     *  new_tcb_ptr = R23-R22
     */


    /**
     * Save registers R2-R17, R28-R29.
     */
    push r2
    ……………………
    push r29
     // save RAMPZ and EIND
    in r0,_SFR_IO_ADDR(RAMPZ)
    push r0
    in r0,_SFR_IO_ADDR(EIND)
    push r0

    // Save the final stack pointer to the TCB.
    in  r16,_SFR_IO_ADDR(SPL)
    in  r17,_SFR_IO_ADDR(SPH)
    mov r28,r24
    mov r29,r25
    st  Y,r16
    std Y+1,r17
```

```
//get SP from  new TCB
mov r28,r22
mov r29,r23
ld r16,Y
ldd r17,Y+1

 // switch stack
out _SFR_IO_ADDR(SPL),r16
out _SFR_IO_ADDR(SPH),r17

// restore status
pop r0
in r0,_SFR_IO_ADDR(EIND)
pop r0
in r0,_SFR_IO_ADDR(RAMPZ)
pop r29
…
pop r2
ret
```

First Thread Restore

Is just the bottom part of the context switch

```
 void archFirstThreadRestore (ATOM_TCB *new_tcb_ptr)
 */
.global archFirstThreadRestore

archFirstThreadRestore:

    /**
     * Parameter locations:
     *  new_tcb_ptr = R25-R24
     */

    //get SP from  new TCB
    mov r28,r24
    mov r29,r25
    ld r16,Y
    ldd r17,Y+1

     // switch stack
    out _SFR_IO_ADDR(SPL),r16
    out _SFR_IO_ADDR(SPH),r17

    // restore status
    pop r0
    in r0,_SFR_IO_ADDR(EIND)
    pop r0
    in r0,_SFR_IO_ADDR(RAMPZ)
    pop r29
    …
    pop r2
    ret
```

Schedule

The final schduler consists of:

- The current process, and the head of a list of thread control blocks
- Two functions:
  - startSchedule (initializes timers, and gives control to first thread)
  - schedule (called in the timer interrupt), that switches context

```
TCB* current_tcb=NULL;

// the running queue
TCBList running_queue={
  .first=NULL,
  .last=NULL,
  .size=0
};


void startSchedule(void){
  cli();
  current_tcb=TCBList_dequeue(&running_queue);
  assert(current_tcb);
  timerStart();
  archFirstThreadRestore(current_tcb);
}

void schedule(void) {
  TCB* old_tcb=current_tcb;
  // we put back the current thread in the queue
  TCBList_enqueue(&running_queue, current_tcb);

  // we fetch the next;
  current_tcb=TCBList_dequeue(&running_queue);
  // we jump to it
  //(useless if it is the only process)
  if (old_tcb!=current_tcb)
    archContextSwitch(old_tcb, current_tcb);
}
```

Run, baby run

```
TCB idle_tcb;
uint8_t idle_stack[IDLE_STACK_SIZE];
void idle_fn(uint32_t thread_arg){
  while(1) {
    cli();
    printf("i\n");
    sei();
    _delay_ms(10);
  }
}

TCB p1_tcb;
uint8_t p1_stack[THREAD_STACK_SIZE];
void p1_fn(uint32_t arg ){
  while(1){
    cli();
    printf("p1\n");
    sei();
    _delay_ms(10);
  }
}

TCB p2_tcb;
uint8_t p2_stack[THREAD_STACK_SIZE];
void p2_fn(uint32_t arg ){
  while(1){
    cli();
    printf("p2\n");
    sei();
    _delay_ms(10);
  }
}
```

```
int main(void){
  // we need printf for debugging
  printf_init();

  TCB_create(&idle_tcb,
             idle_stack+IDLE_STACK_SIZE-1,
             idle_fn,
             0);

  TCB_create(&p1_tcb,
             p1_stack+THREAD_STACK_SIZE-1,
             p1_fn,
             0);

  TCB_create(&p2_tcb,
             p2_stack+THREAD_STACK_SIZE-1,
             p2_fn,
             0);


  TCBList_enqueue(&running_queue, &p1_tcb);
  TCBList_enqueue(&running_queue, &p2_tcb);
  TCBList_enqueue(&running_queue, &idle_tcb);

  printf("starting\n");
  startSchedule();
}
```