EECS 192: Mechatronics Design Lab
Discussion 9 (Part 2): Embedded Software

GSI: Richard "Ducky" Lin

18 & 19 Feb 2015 (Week 9)

- Embedded Programming
- Software Engineering
Embedded Programming
Hardware Specs

Recall the hardware specs for your boards:

- MKL25Z128VLK4 microcontroller
  - 48MHz ARM Cortex-M0+
  - 128KB flash
  - 16KB SRAM

What might make embedded programming different from desktop programming?
Say, I want to allocate some storage when I read my camera array.

```c
uint16_t* read_camera() {
    uint16_t* camera_data = malloc(2*CAMERA_PIXELS);
    for (int i=0; i<CAMERA_PIXELS; i++) {
        camera_data[i] = camera_read_pixel();
    }
    return camera_data;
}
```

Why might this be a bad idea on a microcontroller?
Memory Use

Say, I want to allocate some storage when I read my camera array.

```c
uint16_t* read_camera() {
    uint16_t* camera_data = malloc(2*CAMERA_PIXELS);
    for (int i=0; i<CAMERA_PIXELS; i++) {
        camera_data[i] = camera_read_pixel();
    }
    return camera_data;
}
```

Why might this be a bad idea on a microcontroller?

- Not checking for `malloc` failures - can return NULL
  - (this isn’t an embedded-specific issue!)
- Dynamic (heap) memory allocation (`malloc/free`) is expensive
- Can cause heap fragmentation, especially when memory is scarce
Memory Use

Ok, so malloc is bad. I’m more an object-oriented C++ guy anyways!

```cpp
CameraArray* read_camera() {
    CameraArray* camera_data = new CameraArray();
    camera_data -> read_from(near_cam);
    return camera_data;
}

class CameraArray {
public:
    void read_from(Camera& camera);
    int8_t get_line_error();

protected:
    uint16_t camera_data[CAMERA_PIXELS];
}

Why is this also bad?
```
Ok, so malloc is bad. I’m more an object-oriented C++ guy anyways!

```
CameraArray* read_camera() {
    CameraArray* camera_data = new CameraArray();
    camera_data->read_from(near_cam);
    return camera_data;
}
```

```
class CameraArray {
public:
    void read_from(Camera& camera);
    int8_t get_line_error();
protected:
    uint16_t camera_data[CAMERA_PIXELS];
}
```

Why is this also bad?

- `new` also does dynamic memory allocation
  - So exactly the same issues as malloc, but perhaps a bit more sneaky
Pass-By-Value

Ok enough with dynamic memory allocation. No `new` either.

```cpp
CameraArray read_camera(CameraArray camera_data) {
    camera_data.read_from(near_cam);
    return camera_data;
}
```

```cpp
class CameraArray {
public:
    void read_from(Camera& camera);
    int8_t get_line_error();
protected:
    uint16_t camera_data[CAMERA_PIXELS];
}
```

What performance issues might arise from this?
Pass-By-Value

Ok enough with dynamic memory allocation. No `new` either.

```c++
CameraArray read_camera(CameraArray camera_data) {
    camera_data.read_from(near_cam);
    return camera_data;
}

class CameraArray {
public:
    void read_from(Camera& camera);
    int8_t get_line_error();
protected:
    uint16_t camera_data[CAMERA_PIXELS];
}
```

What performance issues might arise from this?

- C++ arguments are passed by value - it may create a copy
  - Copying large data structures is inefficient and can cause subtle bugs
- Pass pointers to objects or use references instead
Ok, let’s say I write a recursive image processing algorithm.

Bear with me on this crappy example; I’m not a CV guy

```c
uint8_t difference_gaussians(uint8_t level, uint16_t[] line_data) {
    uint16_t line_filtered[CAMERA_PIXELS];
    gaussian_blur(line_filtered /*dst*/, line_data /*src*/);
    if (level != 0) {
        uint8_t next_result = difference_gaussians(level - 1,
                                                  line_filtered);
    }
    return /*CV magic on filtered and original line data*/;
}
```

So what can go wrong here?
Ok, let’s say I write a recursive image processing algorithm.

Bear with me on this crappy example; I’m not a CV guy

```c
uint8_t difference_gaussians:uint8_t level, uint16_t * line_data) {
    uint16_t line_filtered[CAMERA_PIXELS];
    gaussian_blur(line_filtered /*dst*/, line_data /*src*/);
    if (level != 0) {
        uint8_t next_result = difference_gaussians(level - 1,
                                                  line_filtered);
    }
    return /*CV magic on filtered and original line data*/;
}
```

So what can go wrong here?

- Potential stack overflow if recursion runs deep enough
  - Each recursive call allocates a 2*CAMERA_PIXELS array on stack
  - Possibly undetected (no operating system or memory protection)!
Synchronization

Ok, let’s talk threads!

```c
uint16_t camera_data[CAMERA_PIXELS];
void camera_read_thread() {
    for (int i = 0; i < CAMERA_PIXELS; i++) {
        camera_data[i] = camera_read_pixel();
    }
    Thread.wait(INTEGRATION_TIME);
}
void camera_process_thread() {
    uint8_t line_camera_distance = /* magic filter */;
    servo_pwm.write(kp * line_camera_distance);
}
```

What might happen?

▶ No synchronization! Can read data in the middle of a write!
▶ Might get half of one frame and half of another...
Synchronization

Ok, let’s talk threads!

```c
uint16_t camera_data[CAMERA_PIXELS];
void camera_read_thread() {
    for (int i = 0; i < CAMERA_PIXELS; i++) {
        camera_data[i] = camera_read_pixel();
    }
    Thread.wait(INTEGRATION_TIME);
}
void camera_process_thread() {
    uint8_t line_camera_distance = /* magic filter */;
    servo_pwm.write(kp * line_camera_distance);
}
```

What might happen?

- No synchronization! Can read data in the middle of a write!
  - Might get half of one frame and half of another...
Synchronization

Ok, let’s talk threads!

```c
uint16_t camera_data[CAMERA_PIXELS];
void camera_read_thread() {
    for (int i=0; i<CAMERA_PIXELS; i++) {
        camera_data[i] = camera_read_pixel();
    }
    Thread.wait(INTEGRATION_TIME);
}
void camera_process_thread() {
    uint8_t line_camera_distance = /* magic filter */;
    servo_pwm.write(kp * line_camera_distance);
}

How do I prevent it?
```
Synchronization

Ok, let’s talk threads!

```c
uint16_t camera_data[CAMERA_PIXELS];
void camera_read_thread() {
    for (int i=0; i<CAMERA_PIXELS; i++) {
        camera_data[i] = camera_read_pixel();
    }
    Thread.wait(INTEGRATION_TIME);
}
void camera_process_thread() {
    uint8_t line_camera_distance = /* magic filter */;
    servo_pwm.write(kp * line_camera_distance);
}
```

How do I prevent it?

- Various synchronization constructs: mutexes/locks, semaphores, ...
- Nonblocking solutions: double/triple buffering
  - Or asynchronous FIFOs (efficiently implemented as a circular buffer)
Software Engineering
Two Cameras

I have some code to read a single camera.

```c
Camera near_cam(PTB2 /*CLK*/, PTB3 /*SI*/, PTC2 /*AO*/);

void control_loop () {
    servo_pwm . write (kp * near_cam . get_line_distance ());
}
```

Given the structure, how would I add another camera?
Two Cameras

I have some code to read a single camera.

```c
Camera near_cam(PTB2 /*CLK*/, PTB3 /*SI*/, PTC2 /*AO*/);

void control_loop () {
  servo_pwm.write(kp * near_cam.get_line_distance());
}
```

Given the structure, how would I add another camera?

- Simple, right? Instantiate another Camera?
  - Camera far_cam(PTB4, PTB5, PTC1);
Two Cameras

I have some code to read a single camera.

```c
Camera near_cam(PTB2 /*CLK*/, PTB3 /*SI*/, PTC2 /*AO*/);

void control_loop() {
    servo_pwm.write(kp * near_cam.get_line_distance());
}
```

Given the structure, how would I add another camera?

- Simple, right? Instantiate another Camera?
  - Camera far_cam(PTB4, PTB5, PTC1);

What hidden assumptions / expectations did I have for Camera?
Expectations

What if the Camera implementation looked like this?

```cpp
uint16_t camera_data[CAMERA_PIXELS]; // global

class Camera {
public:
    Camera(PinName clk, PinName si, PinName adc);
    void read() {
        /* ADC reads into global camera_data */
    }
    int8_t get_line_distance() {
        return /* some computation on global camera_data */;
    }
}
```

OH SH- ▶

Breaks user expectations of object encapsulation and independence

DON'T DO IT!

Ducky (UCB EECS)

Mechatronics Design Lab
What if the Camera implementation looked like this?

```cpp
uint16_t camera_data[CAMERA_PIXELS]; // global

class Camera {
public:
    Camera(PinName clk, PinName si, PinName adc);
    void read() {
        /* ADC reads into global camera_data */
    }
    int8_t get_line_distance() {
        return /* some computation on global camera_data */;
    }
}
```

OH SH-

- Breaks user expectations of object encapsulation and independence
  - DON’T DO IT!
Globals

While we’re talking about globals, what anti-patterns can arise from this?

```c
float motor_velocity_target; //global

void main() {
    motor_velocity_target = 3.0;
    // rest of code here
}
```

So far, so good, right?
While we’re talking about globals, what anti-patterns can arise from this?

```c
float motor_velocity_target; //global

void main() {
    motor_velocity_target = 3.0;
    // rest of code here
}
```

So far, so good, right?

Perhaps I also have a kill switch in another function:
```c
if (kill_switch) motor_velocity_target = 0;
```
While we’re talking about globals, what anti-patterns can arise from this?

```c
float motor_velocity_target; //global

void main() {
    motor_velocity_target = 3.0;
    // rest of code here
}
```

So far, so good, right?

Perhaps I also have a kill switch in another function:
```c
if (kill_switch) motor_velocity_target = 0;
```
And why not have it dependent on tracking, perhaps in a different .c file:
```c
if (bad_tracking) motor_velocity_target -= 0.1;
```
While we’re talking about globals, what anti-patterns can arise from this?

```c
float motor_velocity_target; // global

void main() {
    motor_velocity_target = 3.0;
    // rest of code here
}
```

So far, so good, right?

Perhaps I also have a kill switch in another function:
```c
if (kill_switch) motor_velocity_target = 0;
```
And why not have it dependent on tracking, perhaps in a different .c file:
```c
if (bad_tracking) motor_velocity_target -= 0.1;
```

Soon, you have no clue what the target actually is - dataflow spaghetti!
Avoid dynamic memory allocation
Watch out for the limited RAM and stack overflow
Watch out for synchronization errors
Write code that conforms to user expectations
Avoid dataflow spaghetti