mruby/c: Running on Less Than 64KB RAM Microcontroller

November 18-20, 2019

HASUMI Hitoshi @hasumikin

Me

- HASUMI Hitoshi
  @hasumikin
- Live in Matsue city,
  a holy place of Ruby
- Sake
  Soba
  Coffee

Me

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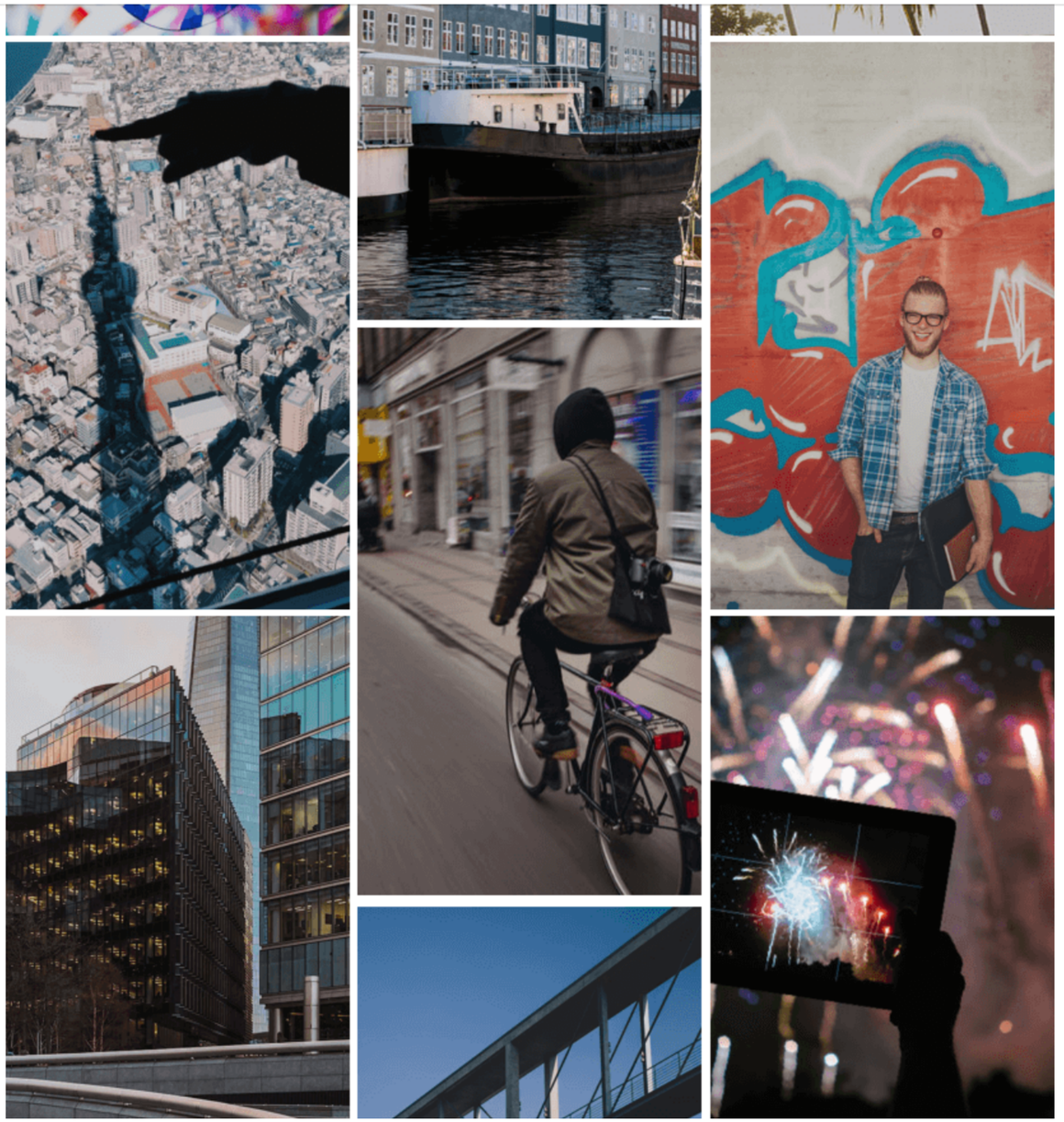

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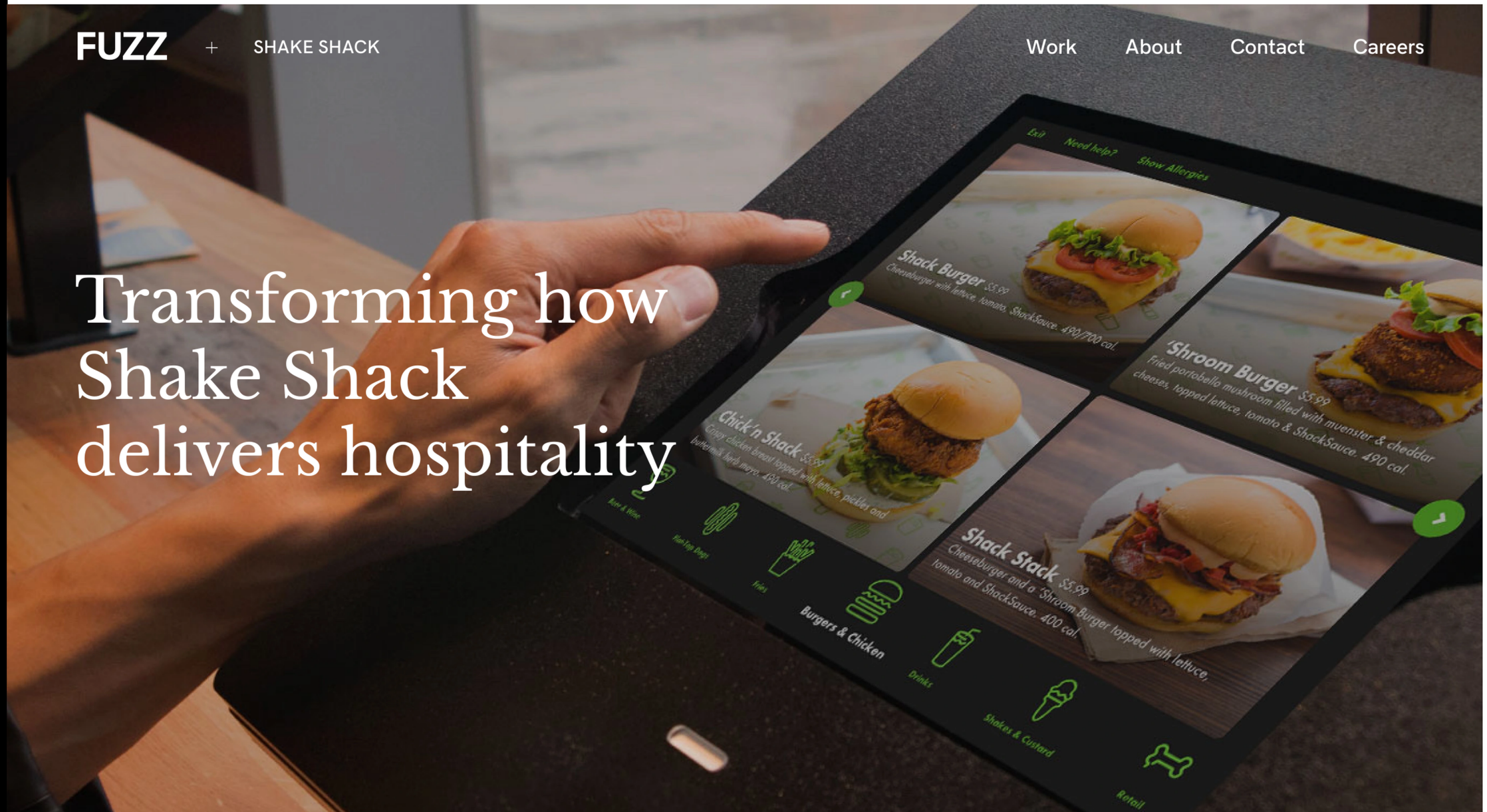
FUZZ



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Matsue.rb

Chapter 1

Introduction

Terminology

- mruby/c
  - A language implementation I will talk about today
  - I say mrubyc since **/c** [slˈæʃ síː] is hard to pronounce
- Microcontroller
  - Small computer contains CPU, memory and programmable I/O peripherals

Terminology

- RTOS
  - Real-time OS. Usually used for microcontroller
- Task
  - Almost equivalent to `Thread` in Linux. We say `Task` in microcontroller world

Terminology

- 旭日酒造 (Asahi-Shuzo)
  - Shuzo means `Sake brewery`
  - One of the best Japanese Sake brewery
  - FYI, Asahi Breweries (famous for SUPER DRY) has no concern with Asahi-Shuzo
  - Asahi-Shuzo and I make an IoT system using mruby/c

Why microcontroller?

- I don't use single board computer like Raspberry Pi for production environment.
- I use microcontroller, instead
  - It starts immediately right after plugged in
  - End-users, brewery workers in my case, can use it simply like home electical appliance

Why microcontroller?

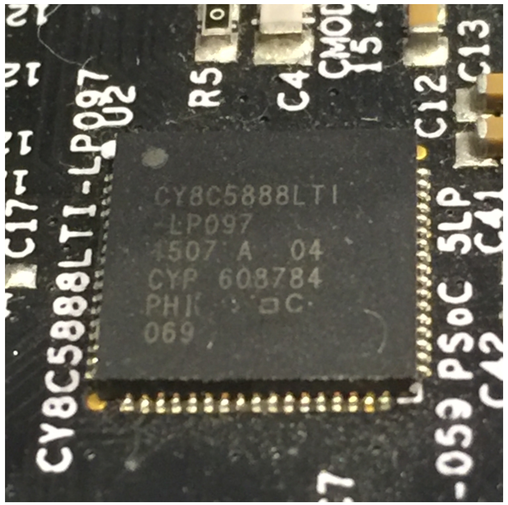
- Microcontroller can run without OS
  - So-called `Bare Metal`
- You can narrow security issue list
  - Many a malware aims at Linux or Windows platform as a target
  - You don't need to consider unnecessary deamon
  - You don't need to do `apt upgrade`
- (RasPi can be bare metal device if you want)

Why microcontroller?

- Low energy
  - Rarely overheated
  - Many choices of power supply
- Mass production
  - You can choose appropriate chipset (number of GPIO, memory size, etc.) for your application
  - Cost advantage for parts supply and subcontractor manufacturing

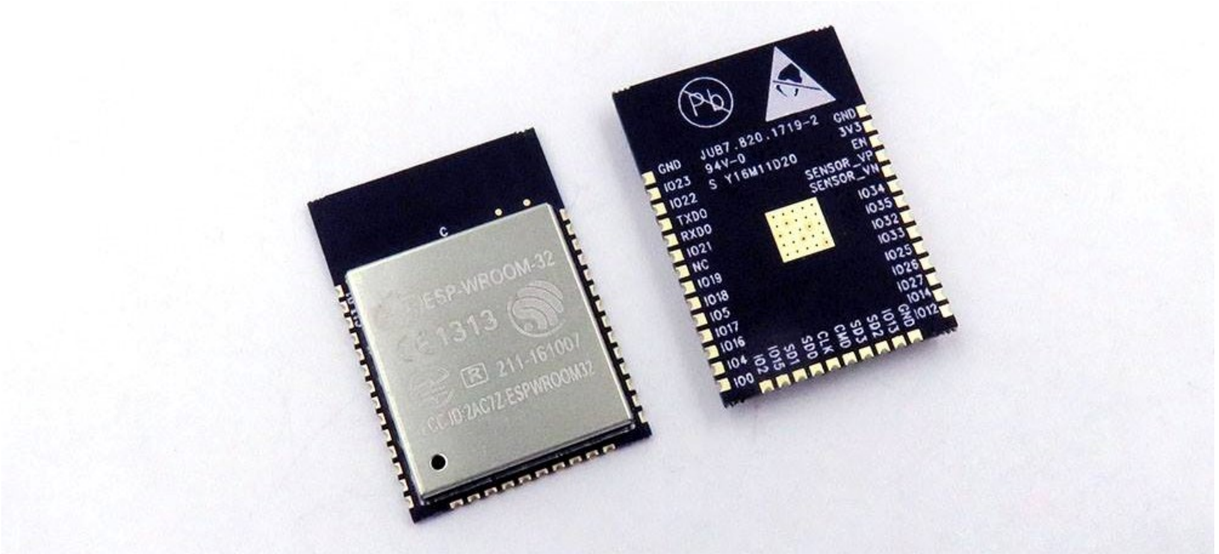
Which microcontroller?

Which microcontroller?



- e.g. CYPRESS PSoC5LP
  - 32 bit Arm Cortex-M3 CPU
  - Flash: 256KB
  - SRAM: 64KB (target size of mruby/c)

Which microcontroller?



- e.g. Espressif ESP-WROOM-32 (ESP32)
  - 32 bit dual core LX6 CPU
  - Flash: 4MB
  - SRAM: 520KB

My IoT project

My IoT project

- IoT system for Sake brewing
- PSoC5LP
- Delivered to actual brew work in January 2018
- Devices post temperature of Sake ingredient in brewing, surrounding temperature and humidity to server
- Data is displayed on mobile app

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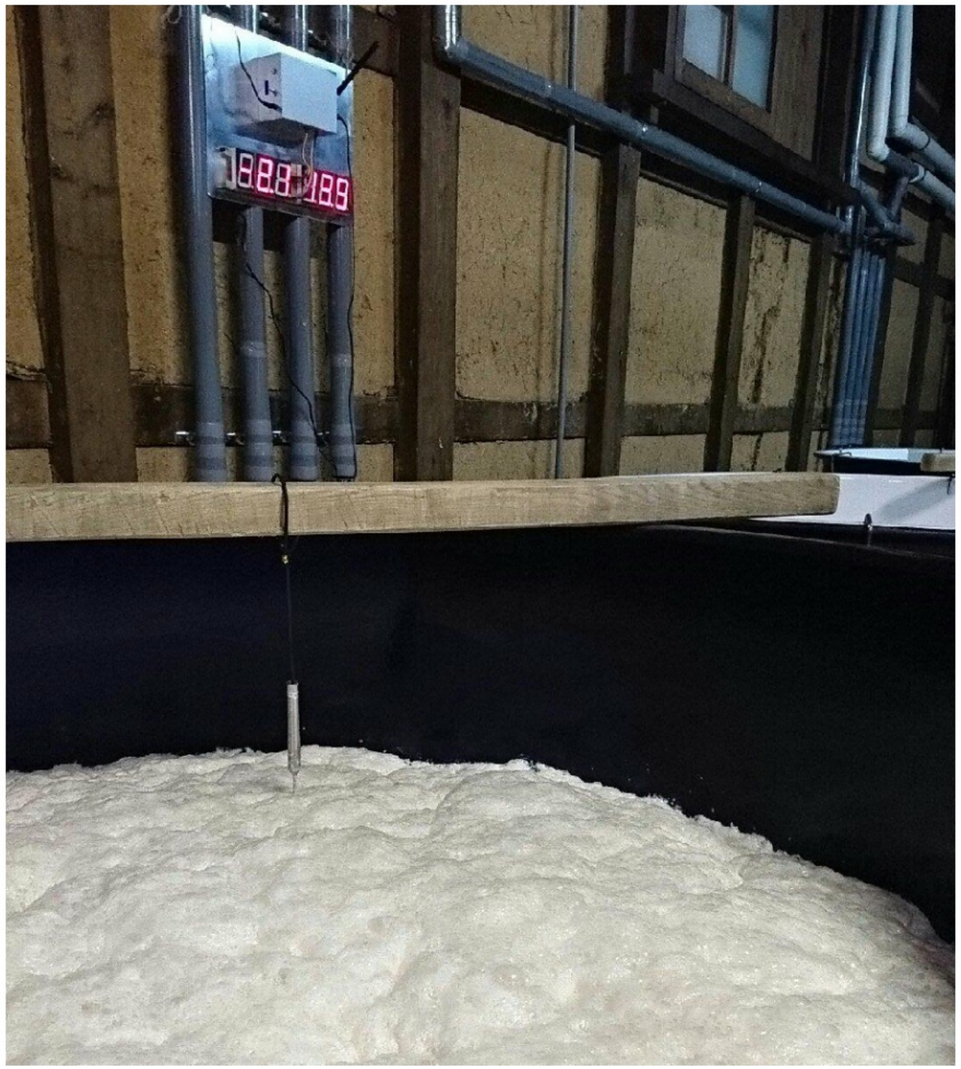
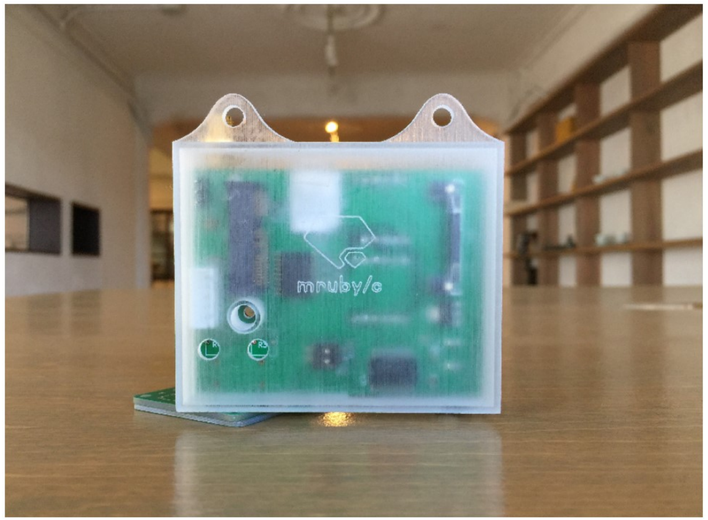
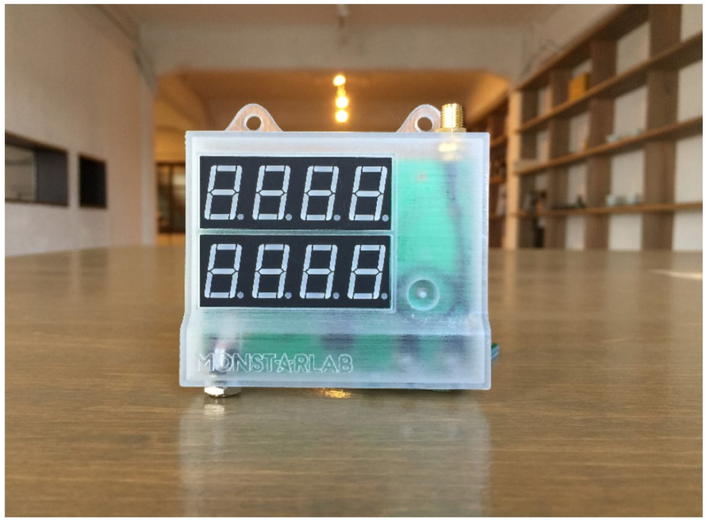
My IoT project



My IoT project





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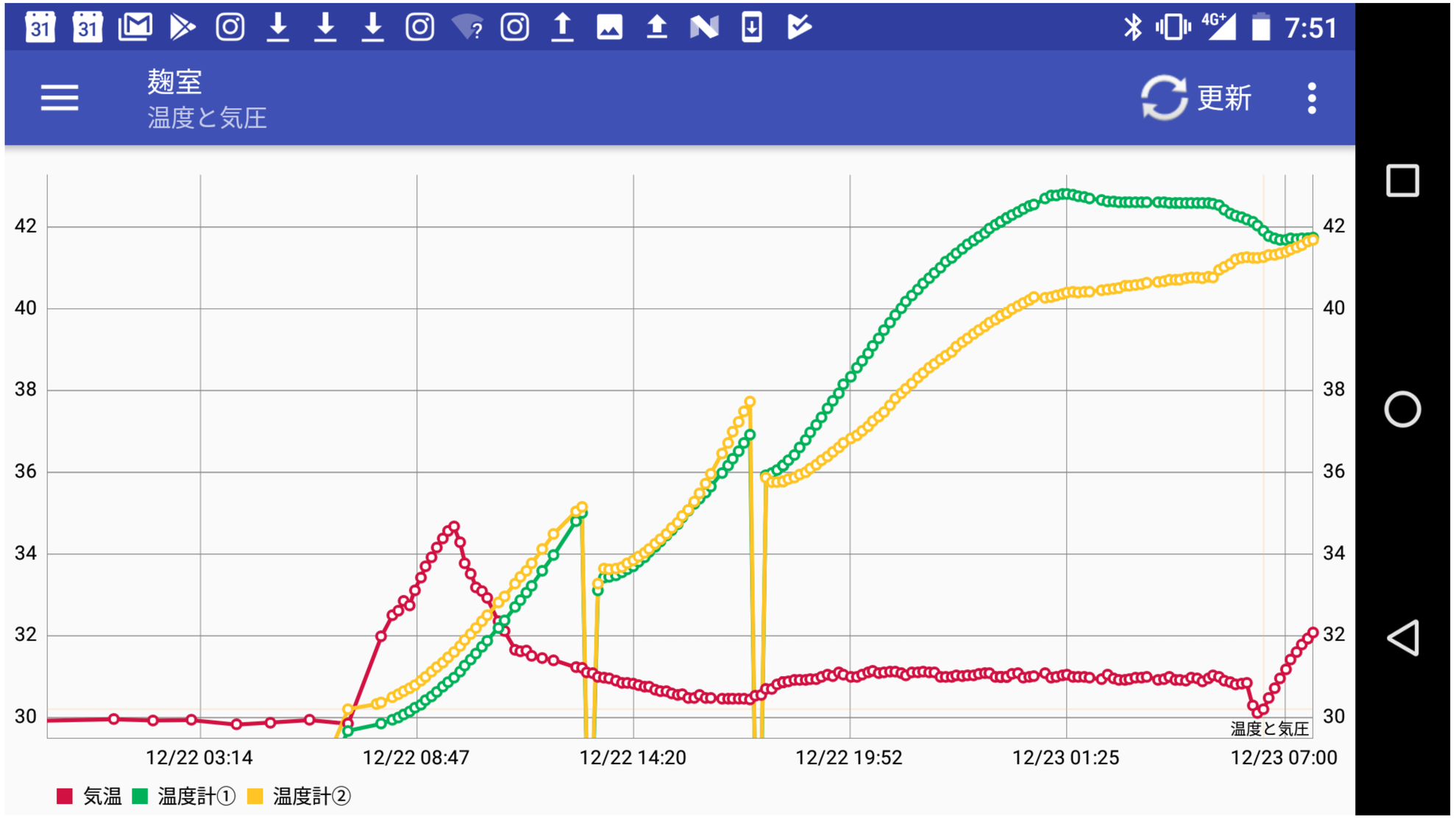
My IoT project



IoT in field makes you hurry

- Imagine,
  - You have to go back and forth between dark 5℃ (=41°F) storage cellar and humid 35℃ (=95°F) rice mold room
  - Brewery workers run around
  - You have to amend your firmware with your small laptop in 10 minutes
  - You will thank Ruby's descriptiveness and agility

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Policies Team

RubyKaigi 2020

Apr 9th (Thu) - 11th (Sat)

Matsumoto Performing Arts Centre (まつもと市民芸術館), Nagano, Japan

Demo

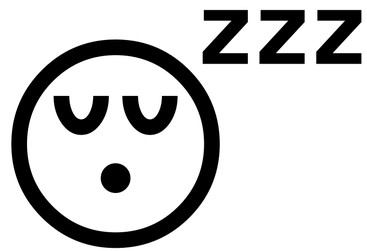
- CO_2 concentration
  - 400ppm : Atmospheric
  - 1000ppm : Your programming speed decreases
  - 1500ppm : FYI, tomatoes 🍅 may grow well
  - > 2000ppm : Sleepiness, headache
  - > 40000ppm : 💀
- (Please look at the screen)

Demo

- My device is taking CO_2 concentration
- CO_2 may increase because of your breathing

Demo

- My device is taking CO_2 concentration
- CO_2 may increase because of your breathing
- I will prove that it is due to CO_2 if you fell asleep while I was speaking



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Bugaboos in IoT

Bugaboos in IoT 

- Peripheral equipments ...★
- Circuit, wiring and housing
- Printed circuit board = PCB
- Soldering ...★
- Firmware with C, mruby and mruby/c ...★
- Network, TCP/IP, Bluetooth, etc.

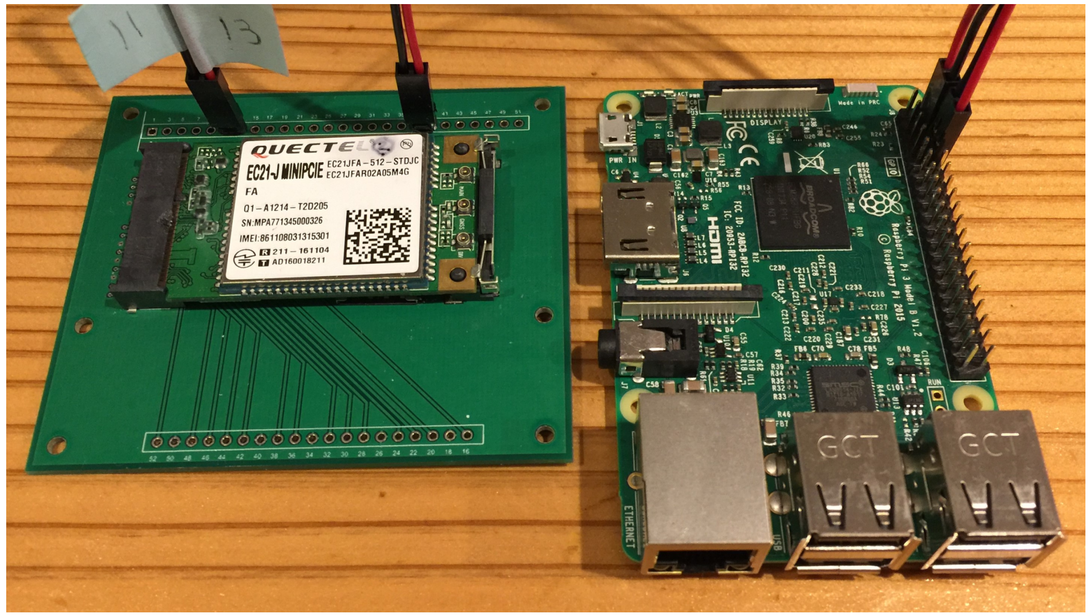
★...I will cover these topics today

Peripheral equipments

Peripheral equipments

- Very important to check the part before writing application code
  - Do equipments like sensor or communication module work as its spec sheets?
  - Whether or not the equipment is broken (sometimes broken by soldering heat 😭)
- Combining parts is unrevertable
  - We don't have a Git for hardware.

Peripheral equipments



- Raspberry Pi & CRuby are great for pre-prototyping
  - Use breadboard or make PCB for experiment

CRuby and serial port

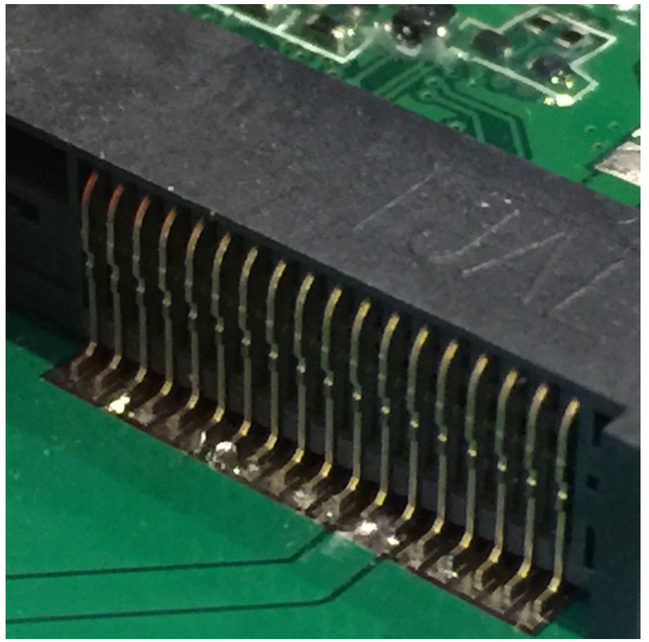
```ruby
# Notice: This is CRuby for RasPi
require "rubyserial"
require "timeout"
sp = Serial.new "/dev/serial0", 9600, 8
loop do
  puts "[command]"
  command = gets
  sp.write command.sub("\n", "\r") # replace LF if needed
  sleep 0.1
  result = ""
  begin
    Timeout.timeout(10) do
      loop do
        line = sp.read(128)
        break if line == "" && result != ""
        result << line
        sleep 0.1
      end
      puts "=> " + result
    end
  rescue Timeout::Error
```

CRuby and serial port

```
$ serial_communication_test.rb
[command]
AT                  # command
=> OK               # response
[command]
AT+CIMI             # command
=> 123456789012     # response
[command]
AT+XXX              # command
=> error            # response
```

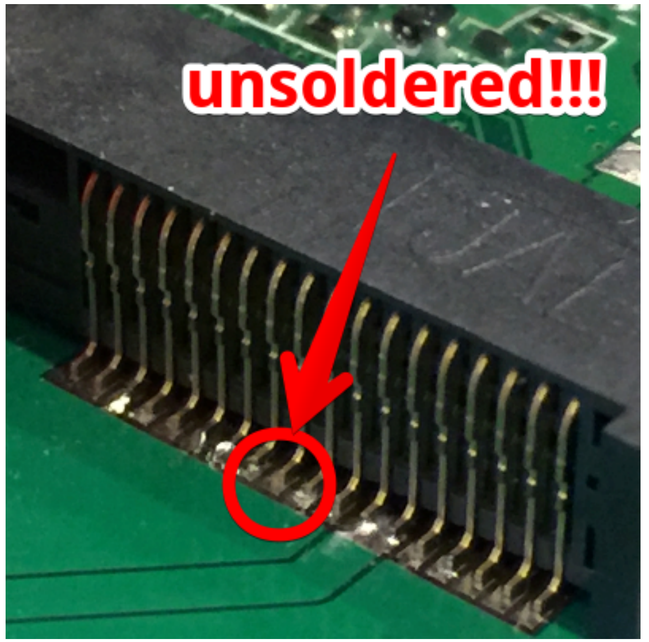
Soldering

Soldering



- It often works even if you leave a pin unsoldered on surface mounting
  - Because the pin touches circuit's plate
  - Then, it will come not to work one day

Soldering



- Discovering this kind of bug is much more difficult than software bug
- My teacher said "All the cause of failure, it is **impatience**"

Chapter 2

mruby/c

What is mruby?

What is mruby?

- github.com/mruby/mruby
- Another implemantation of Ruby for general embedded usage
- Easily combined with system programming like C/C++
- e.g. ngx_mruby is a popular product of mruby
- Good for making command line tool as one-binary executable

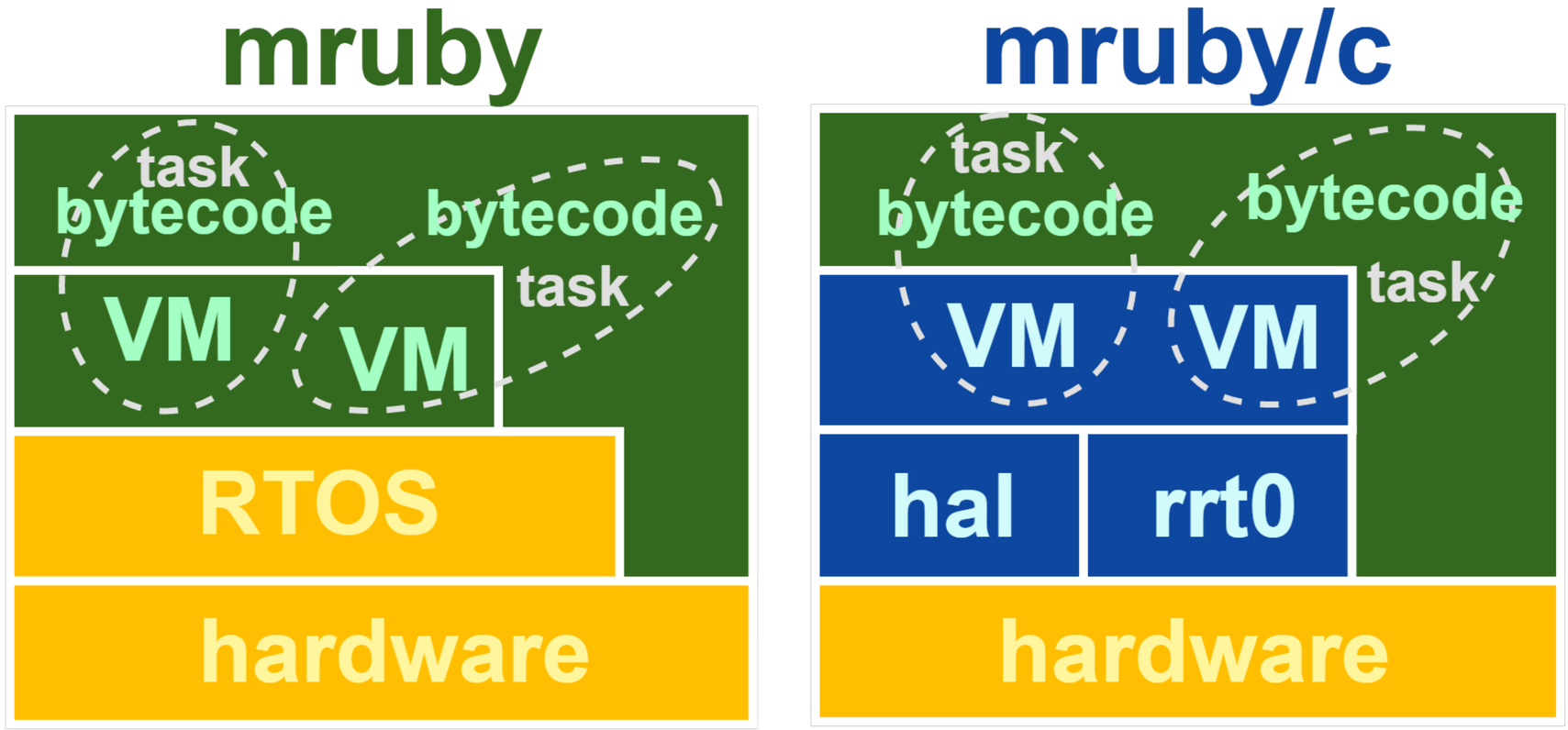
What is mruby/c?

What is mruby/c?

- github.com/mrubyc/mrubyc
- Yet another implementation of mruby
- `/c` symbolizes compact, concurrent and capability
- Especially dedicated to one-chip microcontroller

Bytecode is a common stuff

- They are compiled by `mrbc` (mruby compiler) and each VM execute bytecode



Bytecode?

- A kind of intermediate representation
- mruby bytecode is designed for mruby VM
- mruby VM dynamically interprets the bytecode and processes the application

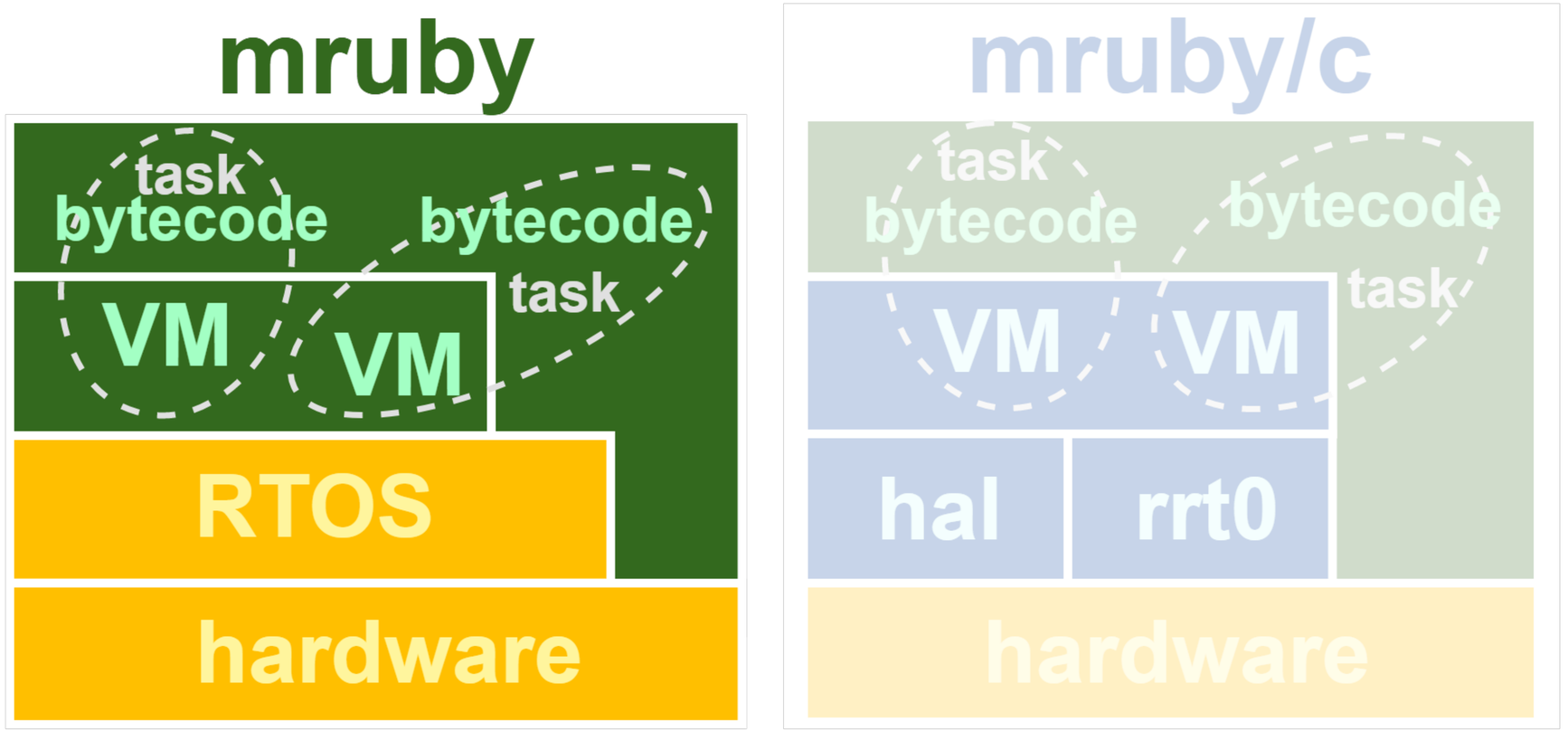
HEX dump of bytecode

Looks like this if you compile
`puts "Hello World!"`

```
5249 5445 3030 3036 9a78 0000 0062 4d41  RITE0006.x...bMA
545a 3030 3030 4952 4550 0000 0044 3030  TZ0000IREP...D00
3032 0000 0060 0001 0004 0000 0000 000c  02...`..........
1001 4f02 002e 0100 0137 0167 0000 0001  ..O......7.g....
0000 0c48 656c 6c6f 2057 6f72 6c64 2100  ...Hello World!.
0000 0100 0470 7574 7300 454e 4400 0000  .....puts.END...
0008                                     ..
```

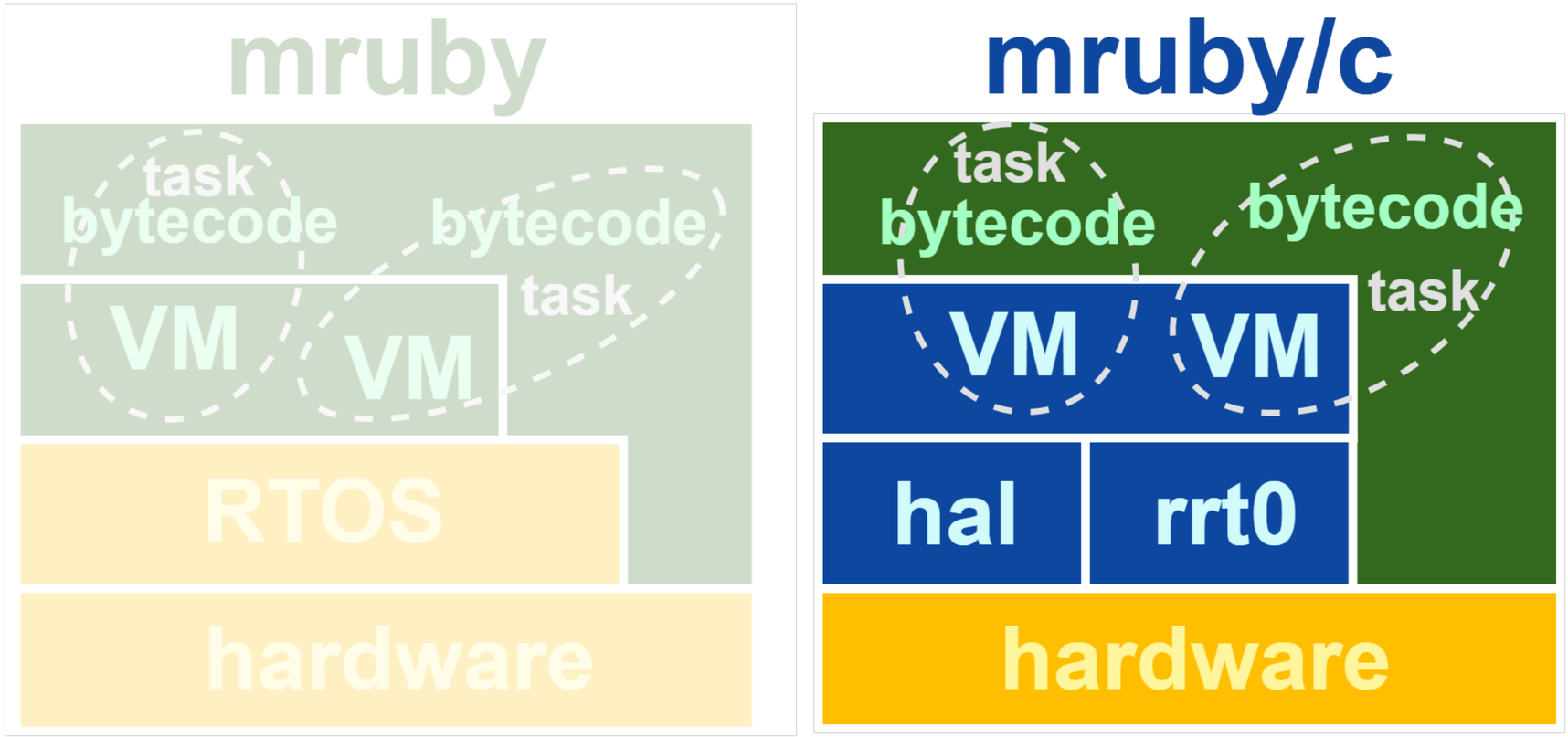
mruby on microcontroller

- RTOS (Real-Time OS) manages mruby VMs in order to realize multi tasking



mruby/c on microcontroller

- mruby/c has its own mechanism to manage multi tasks: **rrt0**



mruby and mruby/c

mruby	mruby/c
v1.0.0 in Jan 2014	v1.0 in Jan 2017
for general embedded software	for one-chip microcontroller
mrbgems	no package manager
RAM < 200KB ...(*)	RAM < 40KB ...(*)

(*)...It depends on the situation

mruby/c's Virtual Machine

- Much smaller than mruby's one
  - That's why mruby/c runs on smaller RAM
- Accordingly, mruby/c has **less** functionality than mruby and CRuby

How **less**?

How **less**? - For example

- mruby/c doesn't have module, hence there is no Kernel module
- Then you must wonder how can you `#puts`?
- In mruby/c, `#puts` is implemented in Object class
- mruby/c doesn't have #send, #eval, and #method_missing, etc.

How **less**? - For example

- The full list of mruby/c's classes
  - Array, FalseClass, Fixnum, Float, Hash, Math, Mutex, NilClass, Numeric, Object, Proc, Range, String, Symbol, TrueClass, VM

Despite the fact,

- No problem in practical usage of microcontroller
- As far as IoT goes, mruby/c is enough Ruby
- We can fully develop firmwares with these features of mruby/c

How does mruby/c work

```
~/project/sample_project
├── main.c
├── mrblib
│   ├── task_1.rb
│   └── task_2.rb
└── src
    ├── task_1.c
    └── task_2.c
```

- task_*.c is compliled bytecode from task_*.rb

How does mruby/c work

```c
/* main.c */
#include "src/task_1.c"
#include "src/task_2.c"
// using 40KB RAM for VM heap in this case
#define MEMORY_SIZE (1024 * 40)
static uint8_t memory_pool[MEMORY_SIZE];
int main(void) {
  mrbc_init(memory_pool, MEMORY_SIZE);
  mrbc_create_task(task_1, 0);
  mrbc_create_task(task_2, 0);
  mrbc_run(); // 2 tasks run concurrently!
  return 0;
}
```

How does mruby/c work

- We can run easily multiple VMs with **concurrency** feature of **rrt0**
- You might be disappointed to know you have to write C
  - Yes, we have to write **main.c**
  - Don't worry, it's almost boilerplate code

Chapter 3

Application code and tools

Application code

github.com/hasumikin/co2_demo

Application code

```
~/project/co2_demo
 ├── main.c
 └── mrblib
      ├── loops
      │    ├── primary.rb
      │    └── secondary.rb
      └── models
           ├── co2.rb
           ├── led.rb
           └── thermistor.rb
```

Application code

```
# loops/primary.rb
$co2 = Co2.new      # Makes it global so that secondary task can use it
$thermistor = $thermistor.new
led = Led.new(19)  # 19 is a pin number which LED connects
while true
  co2 = $co2.concentrate
  if co2 > 2000     # When CO2 reaches fatal level
    5.times do      # Turning LED on and off
      led.turn_on
      sleep 0.1
      led.turn_off
      sleep 0.1
    end
  else              # Safe level
    led.turn_off    # Turns off
    sleep 1
  end
end
```

Application code

How does **Led#trun_on** work?

Application code

```ruby
# models/led.rb
class Led
  def initialize(pin)
    @pin = pin
    gpio_init_output(@pin)
    turn_off
  end
  def turn_on
    gpio_set_level(@pin, 1) # high
  end
  def turn_off
    gpio_set_level(@pin, 0) # low
  end
end
```

Application code

```c
/* a part of main.c */
#include "models/led.c"
static void c_gpio_init_output(mrbc_vm *vm, mrbc_value *v, int argc) {
  int pin = GET_INT_ARG(1);
  // Function of microcontroller's library
  gpio_set_direction(pin, GPIO_MOĐE_OUTPUT);
}
static void c_gpio_set_level(mrbc_vm *vm, mrbc_value *v, int argc){
  int pin = GET_INT_ARG(1);
  int level = GET_INT_ARG(2);
  gpio_set_level(pin, level); // Function of microcontroller's library
}
int main(void){
  ...
  mrbc_define_method(0, mrbc_class_object, "gpio_init_output",
                                           c_gpio_init_output);
  mrbc_define_method(0, mrbc_class_object, "gpio_set_level",
                                           c_gpio_set_level);
  ...
}
```

Application code

```
/* a part of main.c */
#include "models/co2.c"
static void c_get_co2(struct VM *vm, mrbc_value v[], int argc){
  uint8_t command[] = { // Command to take CO2
    0xFF, 0x01, 0x86, 0x00, 0x00, 0x00, 0x00, 0x00, 0x79
  };
  uart_write_bytes(uart_num, (const char*)command, 9);
  // ↑Write then ↓Read data
  uint8_t data[10];
  int length = 0;
  length = uart_read_bytes(uart_num, data, length, 10);
  mrbc_value array = mrbc_array_new( vm, 9 ); // mrubyc's variable
  for( int i = 0; i < 9; i++ ) {
    mrbc_value value = mrbc_fixnum_value(data[i]);
    mrbc_array_set( &array, i, &value ); // Adding a value to array
  }
  SET_RETURN(array); // Returning the array object to mruby
}
int main(void){
  ...
  mrbc_define_method(0, mrbc_class_object, "get_co2", c_get_co2);
  ...
}
```

Application code

```
# models/co2.rb
class Co2
  def concentrate
    res = get_co2
    # checks if the sensor works
    if res[0] == 255 && res[1] == 134
      res[2] * 256 + res[3]
    else
      0
    end
  end
end
```

Application code

- Trivial tip to reduce memory usage
  - C function can return String instead of Array
  - `mrbc_array_new` will allocate larger memory than `mrbc_string_new`
  - So, you can use String instead of Array if memory becomes short
  - Remember STRING of C is just an array of char and '\0'

Application code

```
# loops/secondary.rb
http_client = HttpClient.new("http://data.server")
while true
  co2 = $co2.concentrate
  temperature = $thermistor.temperature
  if co2 > 0 # No trouble
    data = "co2=#{co2}&temperature=#{temperature}"
    http_client.post(data)
    sleep 180
  else         # A trouble happens?
    sleep 3    # Or you can retry
  end
end
```

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Dev tools for mruby/c

Dev tools for mruby/c

- mrubyc-utils
- mrubyc-test
- mrubyc-debugger

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Dev tools for mruby/c

I am trying to make mruby/c development

Rubyish

Rubyish? - IMHO

- Unix/Linux
- Command line
- No-IDE (as far as possible)

Rubyish? - IMHO

- Unix/Linux
- Command line
- No-IDE (as far as possible)

Taking full advantage of
our Laptop and Ruby World

mrubyc-utils

- github.com/hasumikin/mrubyc-utils
- One-binary tool made with mruby
- Helps to install boilerplate of application
- Utility subcommands like...

mrubyc-utils

```
$ mrubyc-utils classes
- Array
- FalseClass
- Fixnum
- Float
- Hash
- Math
- Mutex
- NilClass
- Numeric
- Object
- Proc
- Range
- String
- Symbol
- TrueClass
- VM
```

mrubyc-utils

```
$ mrubyc-utils methods --class=array
Array
- +                     - inspect
- <<                    - join
- []                    - last
- []=                   - length
- at                    - max
- clear                 - min
- collect               - minmax
- collect!              - new
- count                 - pop
- delete_at             - push
- dup                   - shift
- each                  - size
- each_index            - to_s
- each_with_index       - unshift
- empty?                < Object
- first                   - !
- index                   ...
```

mrubyc-test

- github.com/mrubyc/mrubyc-test
- Unit testing framework
- A RubyGem implemented with CRuby
- Supports stub and mock
- Official test tool of mruby/c dev team

mrubyc-test

- Gathers information from app and test code
- Internally generates stub and mock methods
- Makes all-in-one script: **test.rb**

```
class Sample
  def hoge
    "fuga"
  end
end
```

```
class SampleTest < MrubycTestCase
  def some_case
    obj = Sample.new
    assert_equal obj.hoge, "fuga"
  end
end
```

```
SampleTest#some_case
  assertion : assert_equal
  result    : fuga
Finished
1 examples, 0 failures
```

mrubyc-debugger

- github.com/hasumikin/mrubyc-debugger
- Debugger for mutiple infinite loops

DEMO

github.com/hasumikin/
mrubyc-debugger

DEMO

How is CO_2 going?

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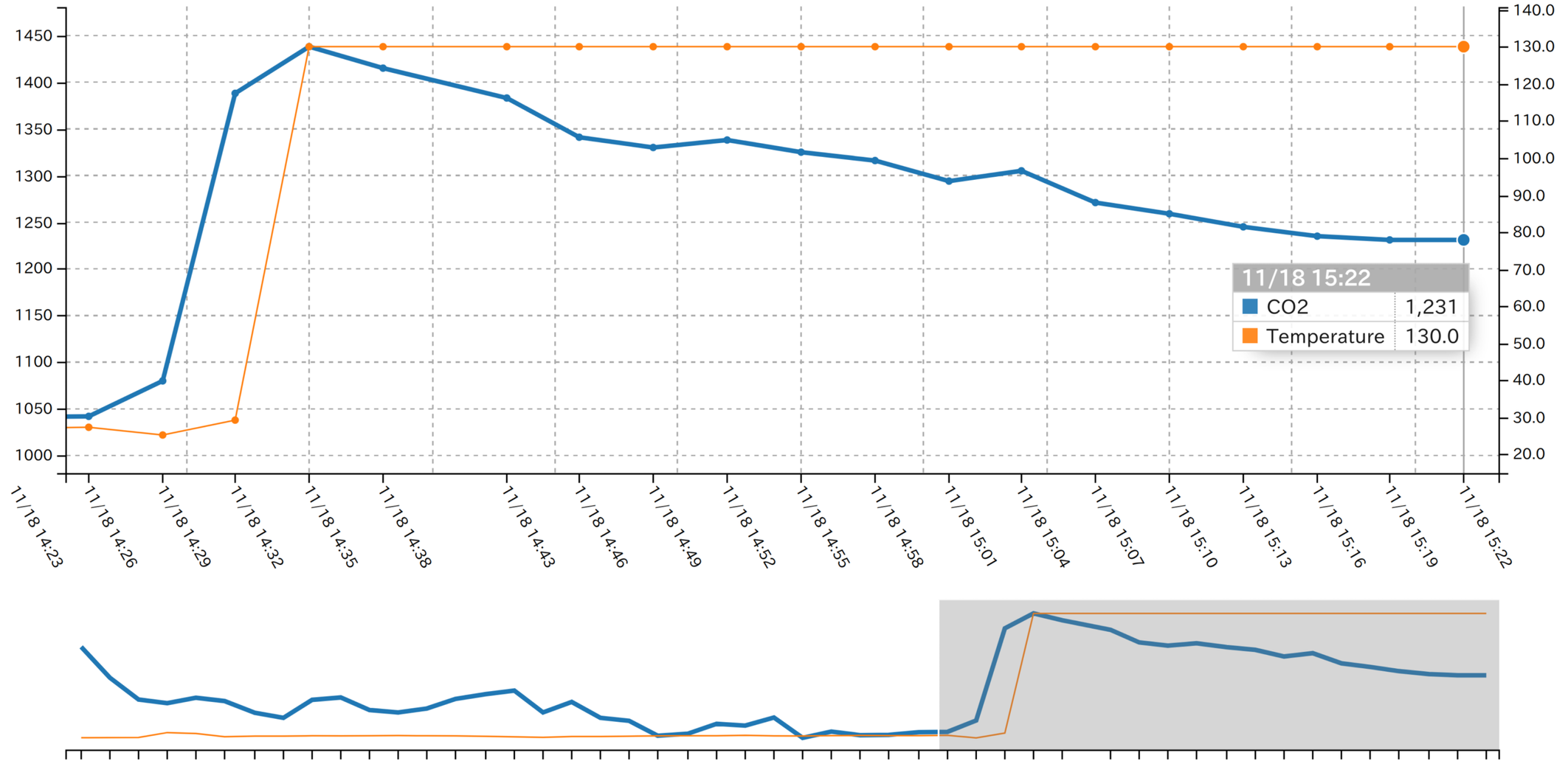
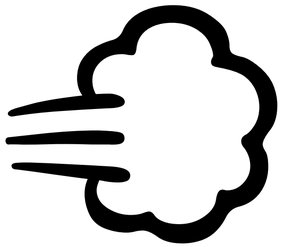
DEMO (added after the Conf)



Conclusion

Conclusion

You should refresh air 

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Thank you!