THINKING ABOUT IT:
CHANNELS MORE THAN CONNECT THREADS

THEY PROTECT THEM

LECTURE BY ØYVIND TEIG, SIV. ING. NTH (1975)

Version of 1. Feb. 2018 (2)

LECTURE BY ØYVIND TEIG, SIV. ING. NTH (1975)

AUTRONICA @ EMBEDDED SYSTEMS

Version of 1. Feb. 2018 (2)

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INVITED SPEAKER, 1. FEB. 2018 AT NTNU, TTK4145 SANNTIDSPROGRAMMERING (REAL-TIME PROGRAMMING)

Version of 1. Feb. 2018 (2)

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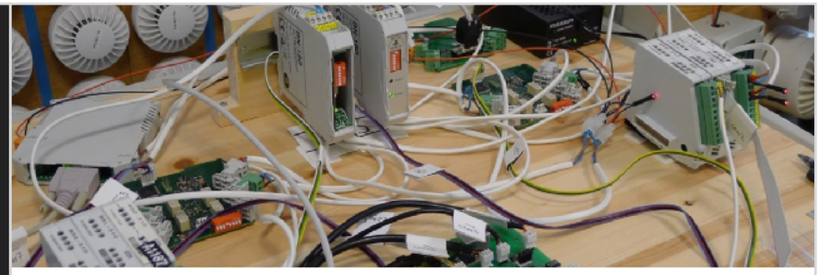

ØYVIND TEIG
SENIOR DEVELOPMENT ENGINEER, AUTRONICA

INVITED SPEAKER, 26. APRIL 2016 AT
NTNU, TTK4145 SANNTIDSPROGRAMMERING
(REAL-TIME PROGRAMMING)

Version of 26 April 2016 14.10

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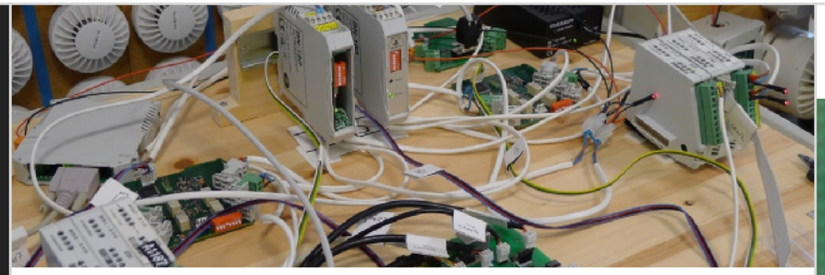

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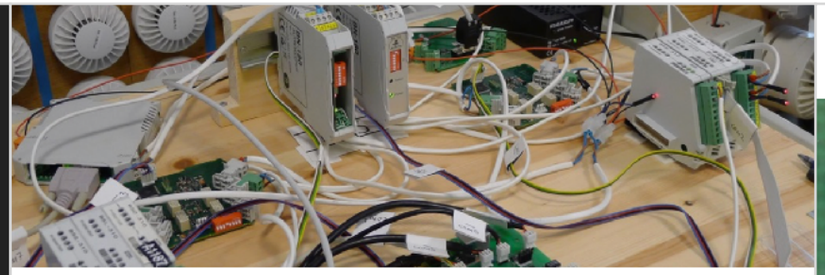

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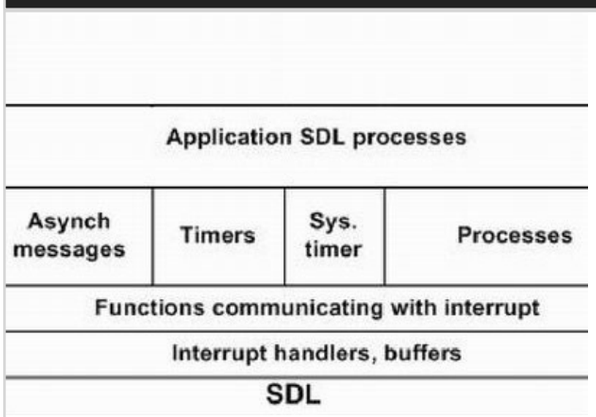

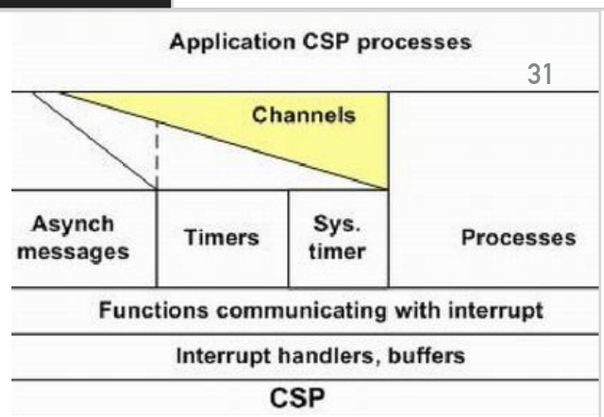

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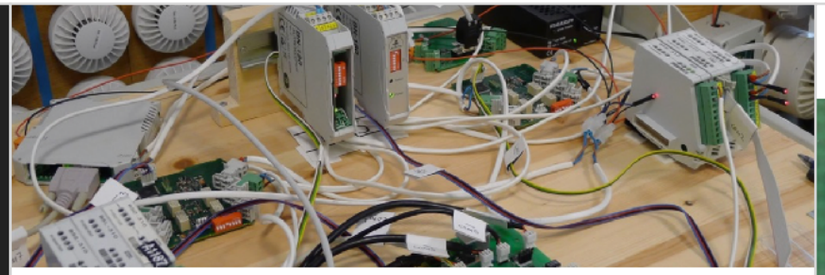

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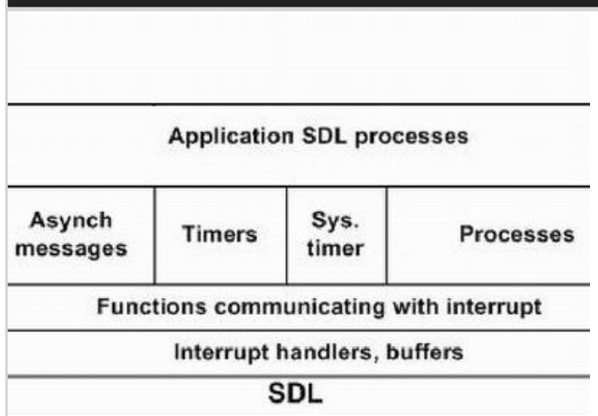

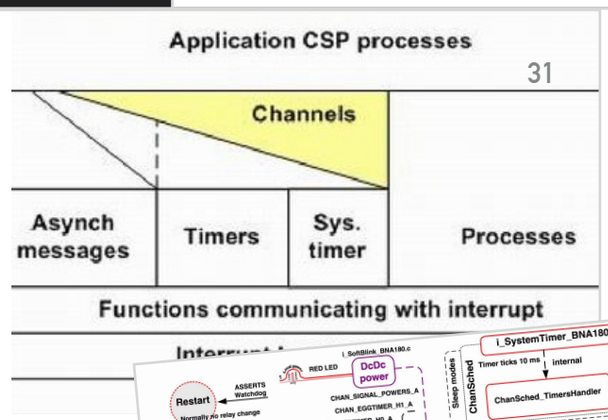

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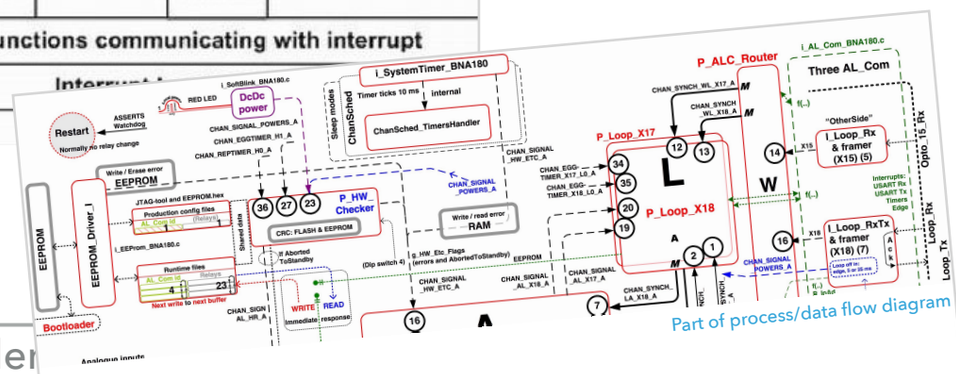

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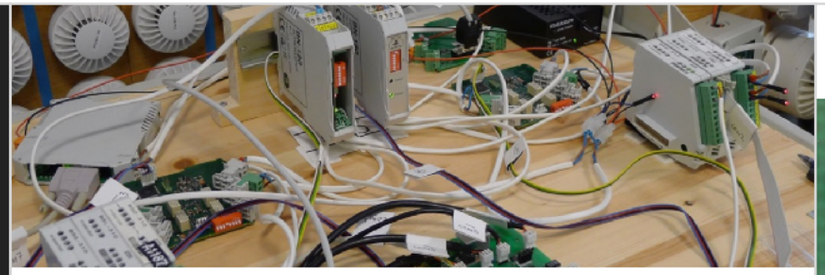

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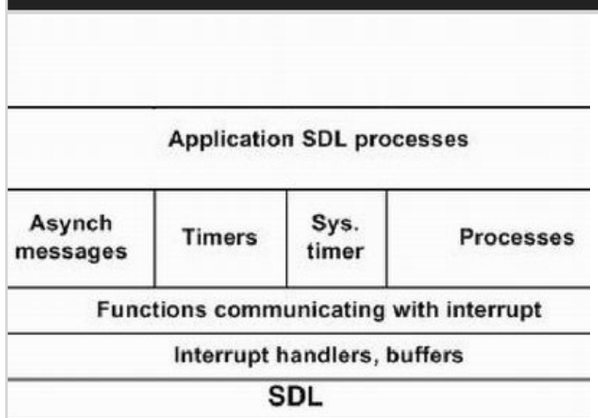

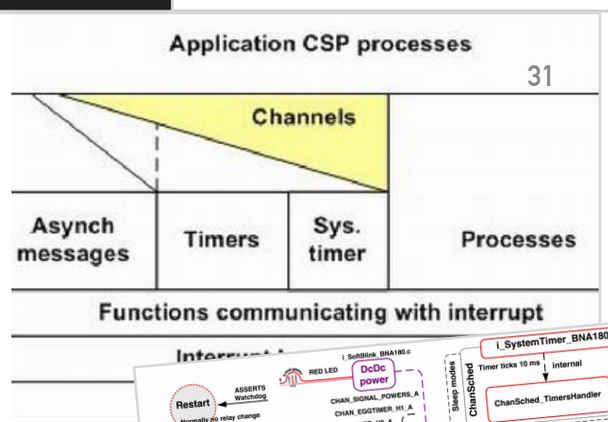

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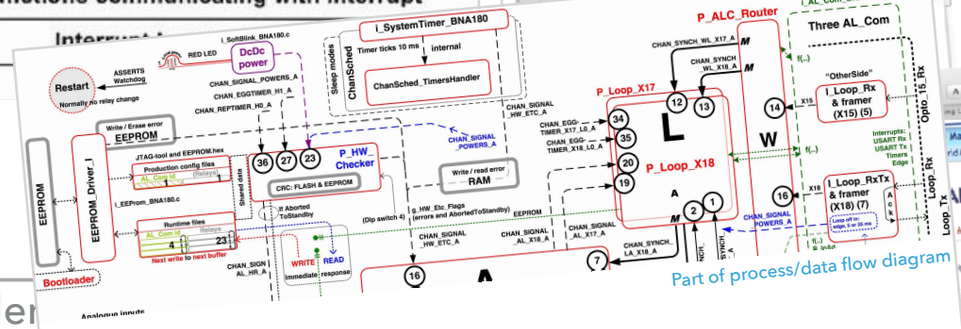

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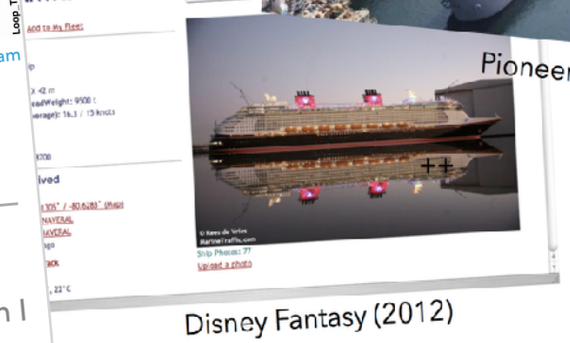
ALL THIS RUNS IN AN AUTRONICA «DUAL SAFETY» COMPONENT 53

«SAFE RETURN TO PORT» (IMO) OR JUST EXTRA SAFETY

Disney Dream (2011)

Pioneering Spirit (2013)



Disney Fantasy (2012)

#2353255)

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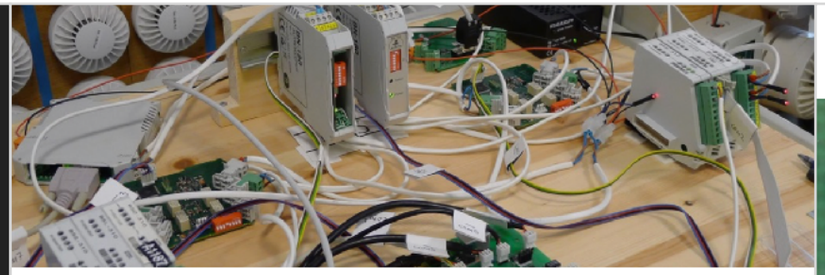

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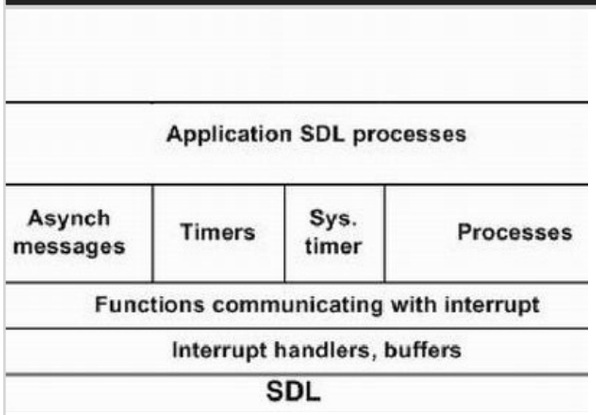

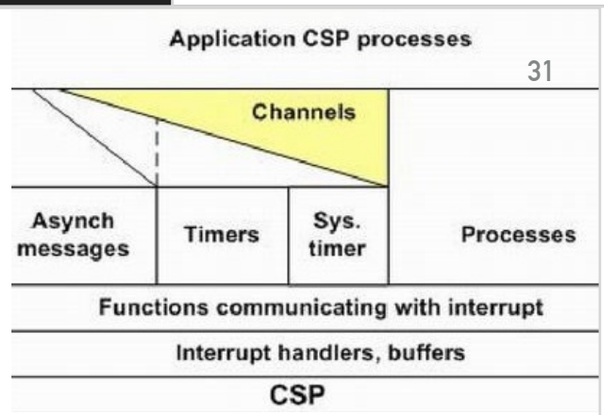

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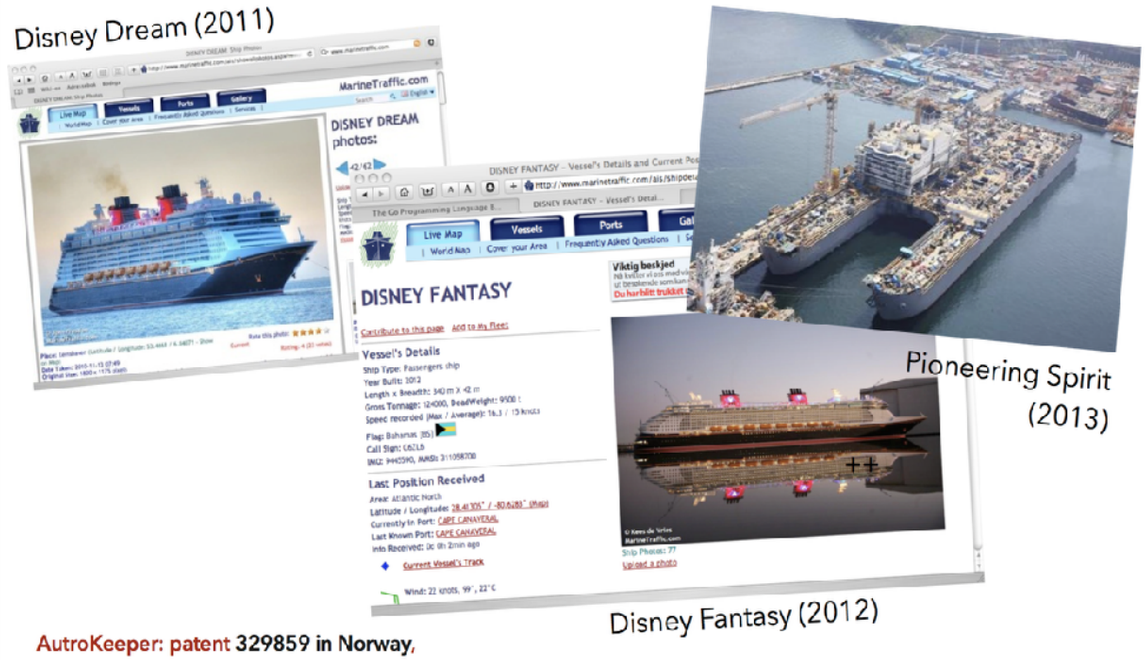

AutroKeeper: patent 329859 in Norway,
PCT/NO2009/000319 international (granted as #2353255)

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www.teigfam.net/oyvind/pub/pub.html

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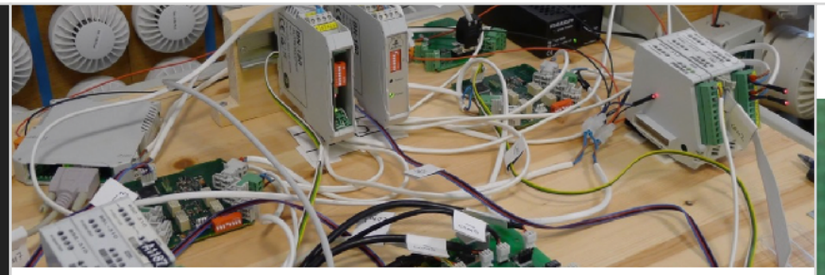

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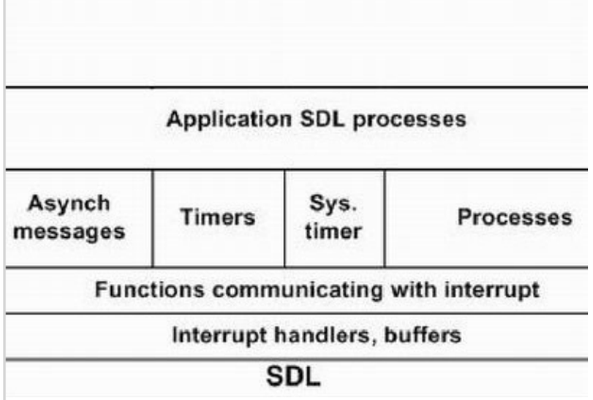

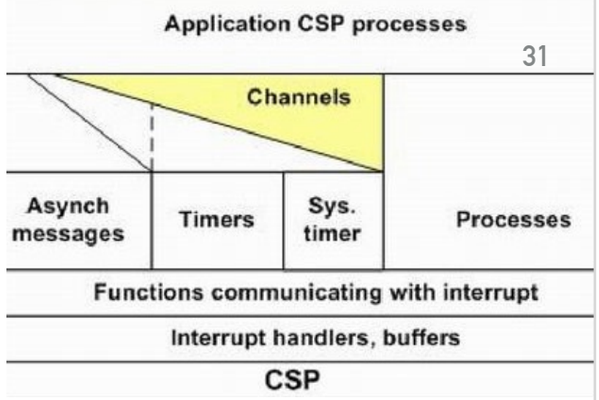

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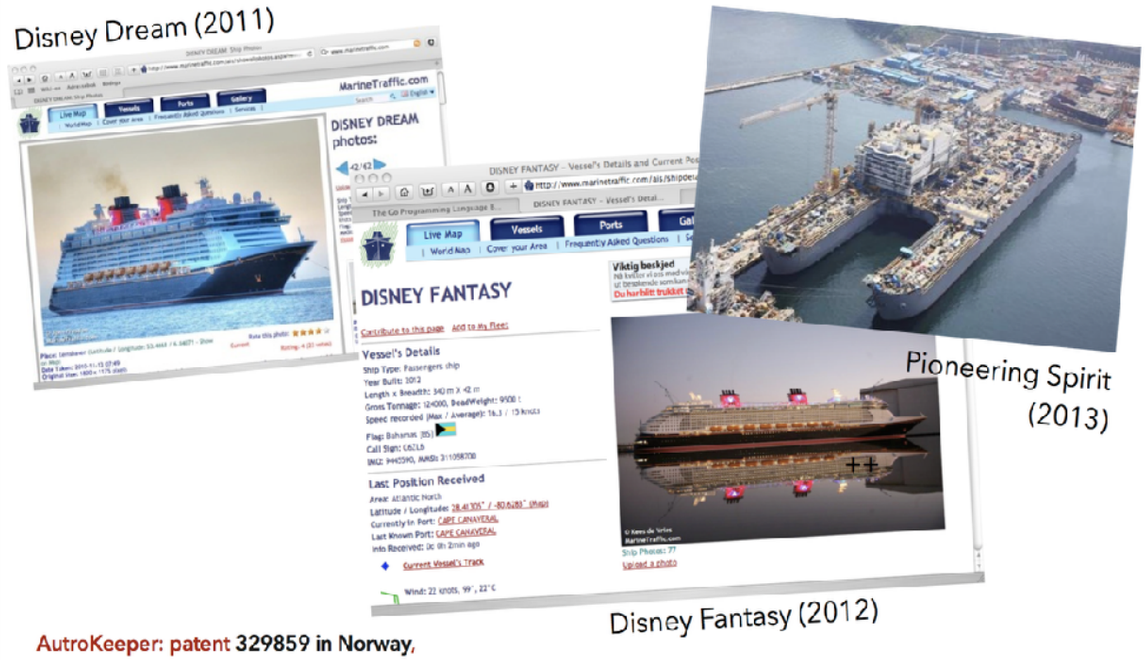

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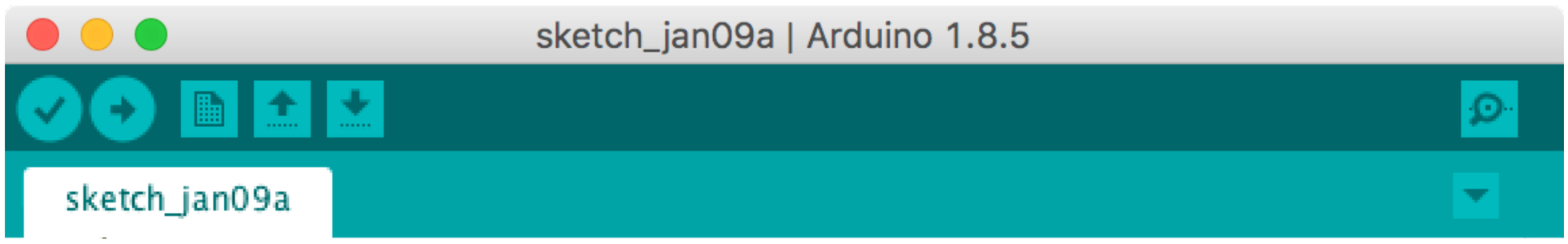
BARE MINIMUM CODE NEEDED



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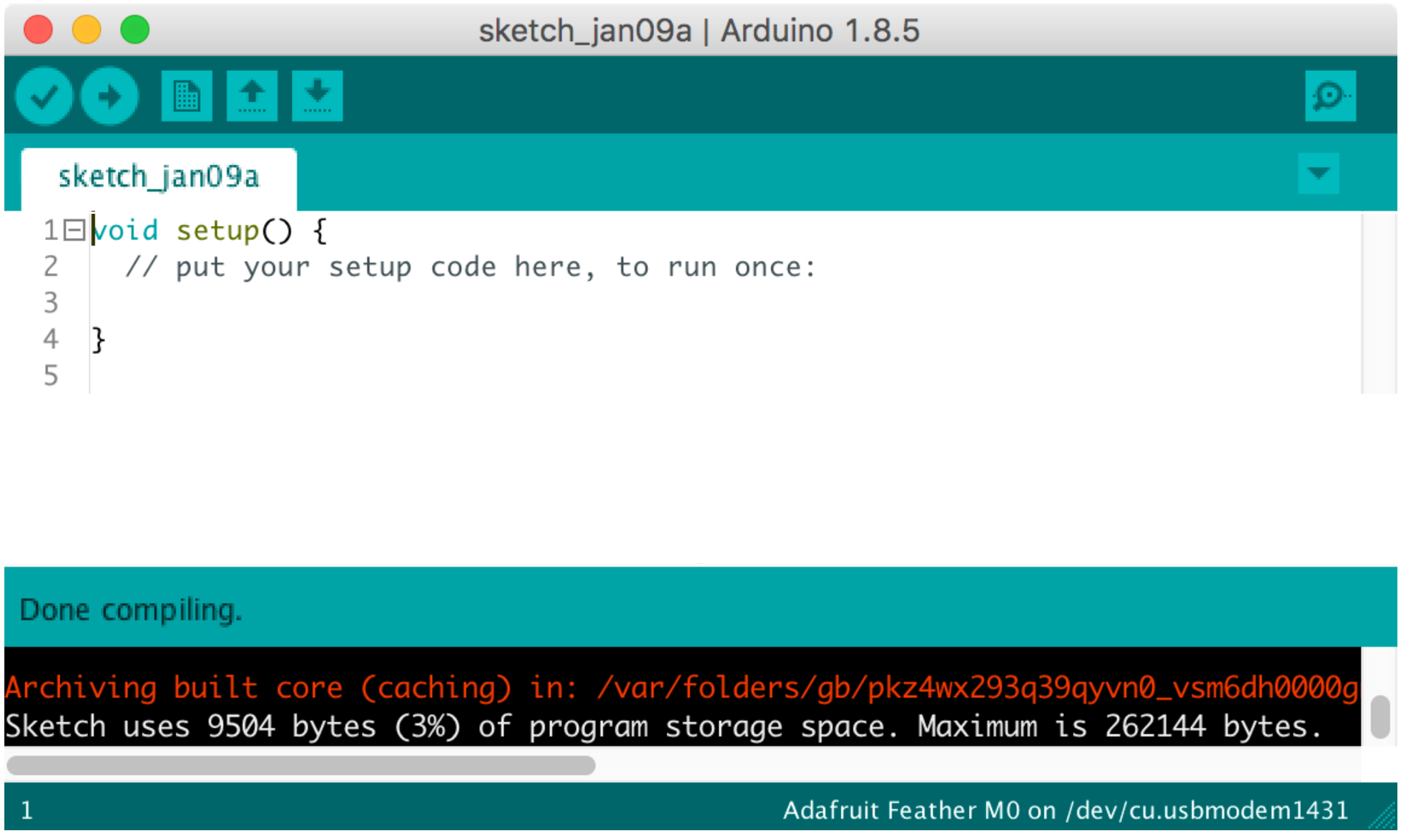

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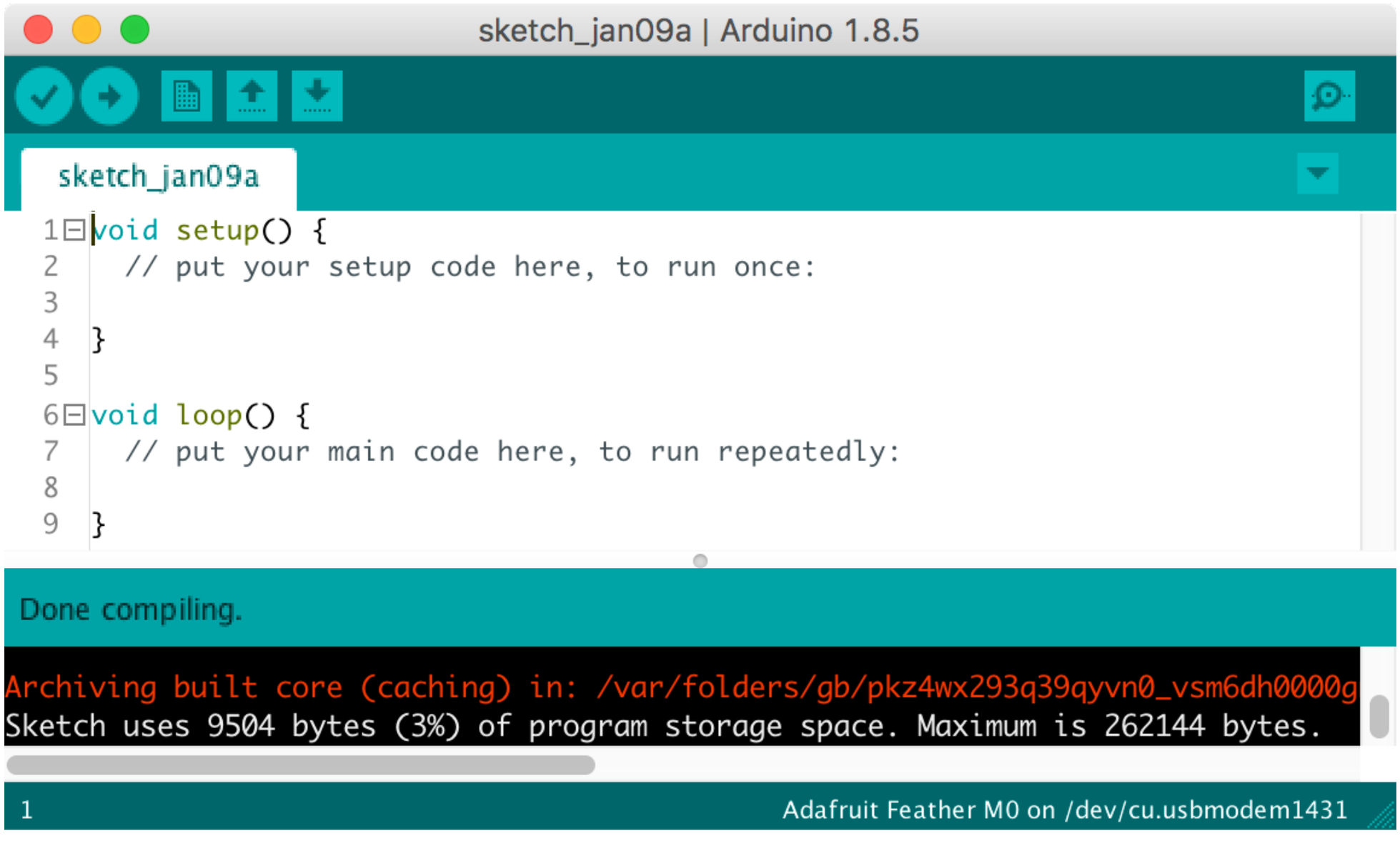

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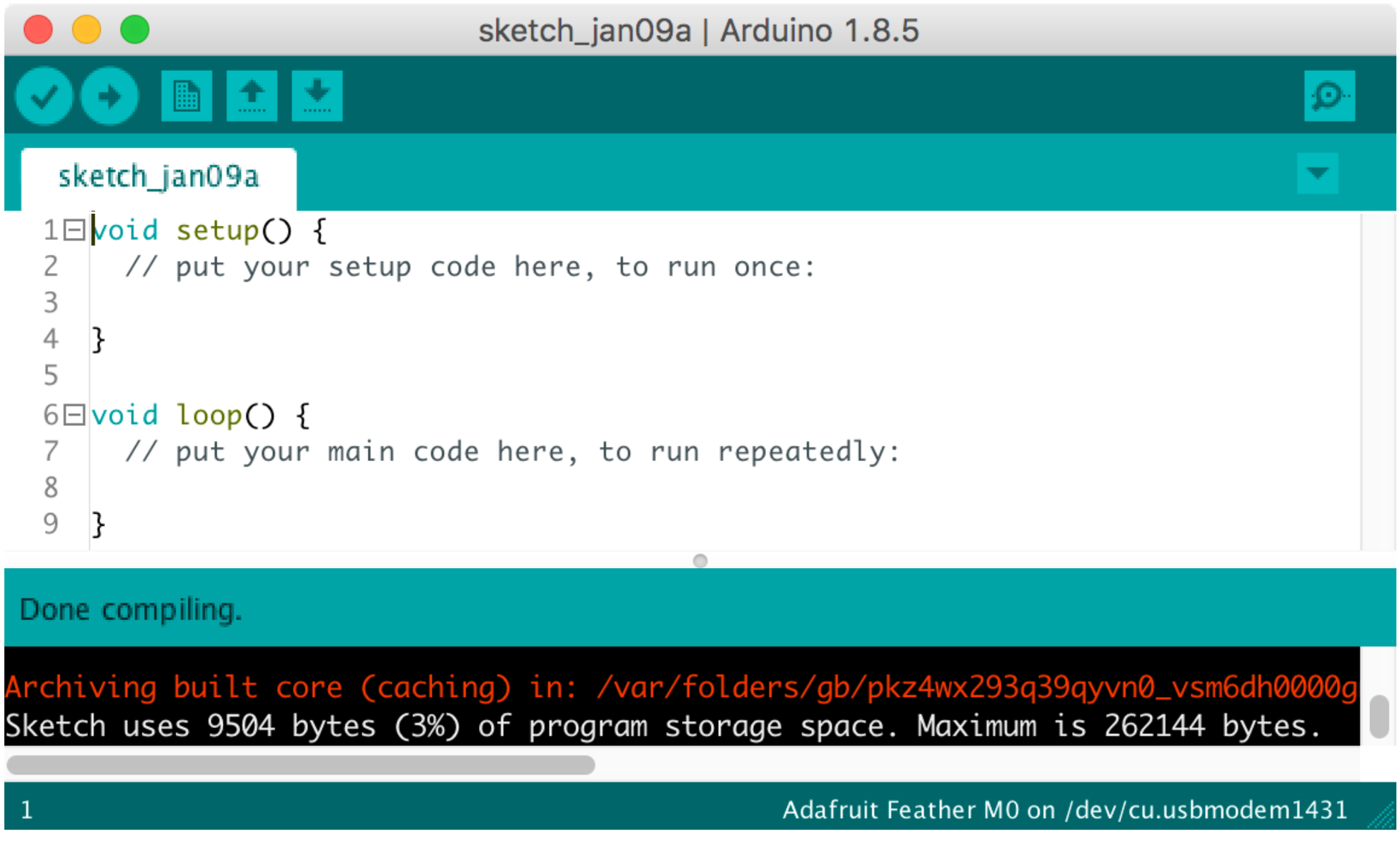

https://www.arduino.cc/en/Tutorial/BareMinimum

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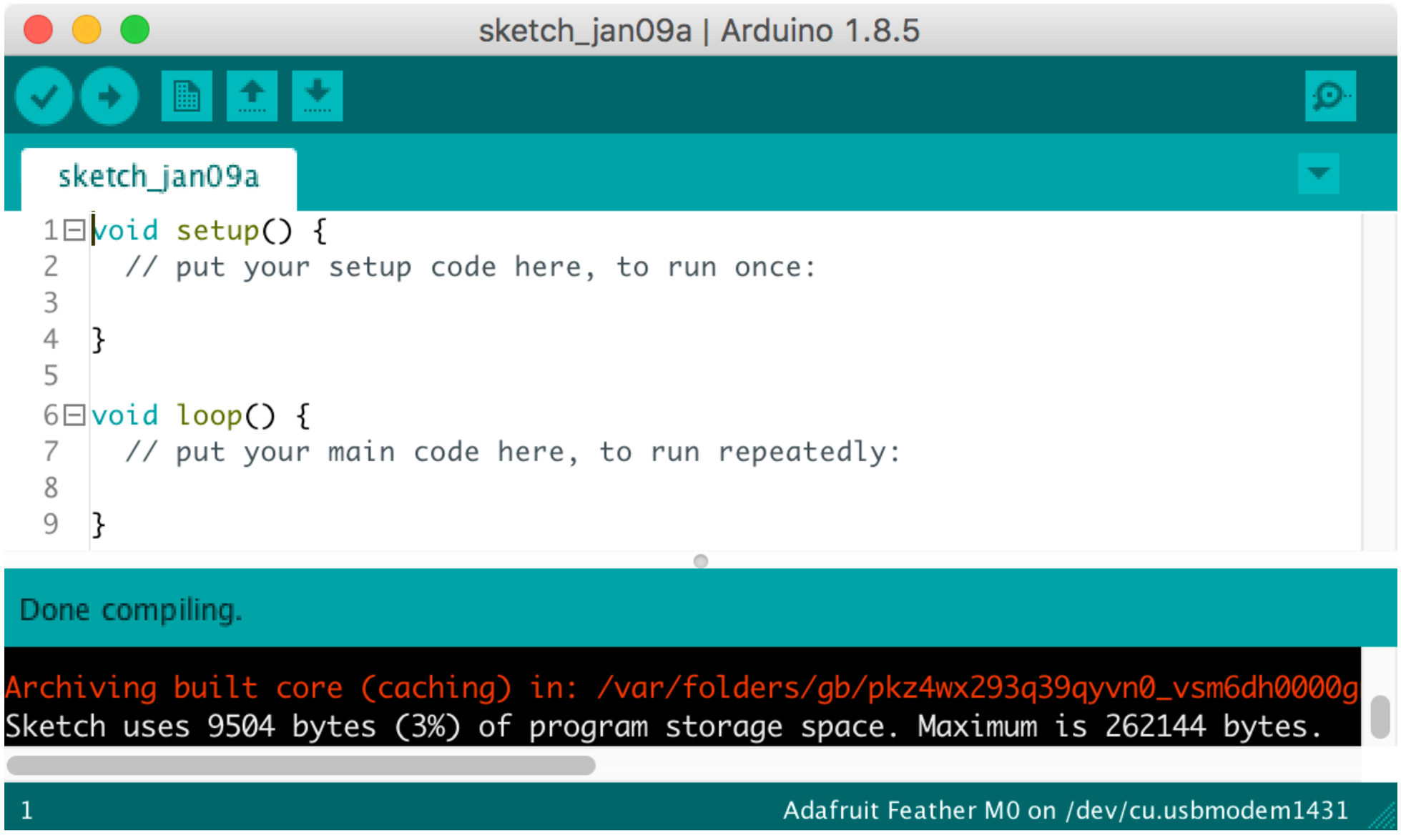

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https://arduino.stackexchange.com/questions/37684/can-i-make-multiple-void-loops-with-arduino-uno

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FINDING SCHEDULERS OR RUNTIME SYSTEMS

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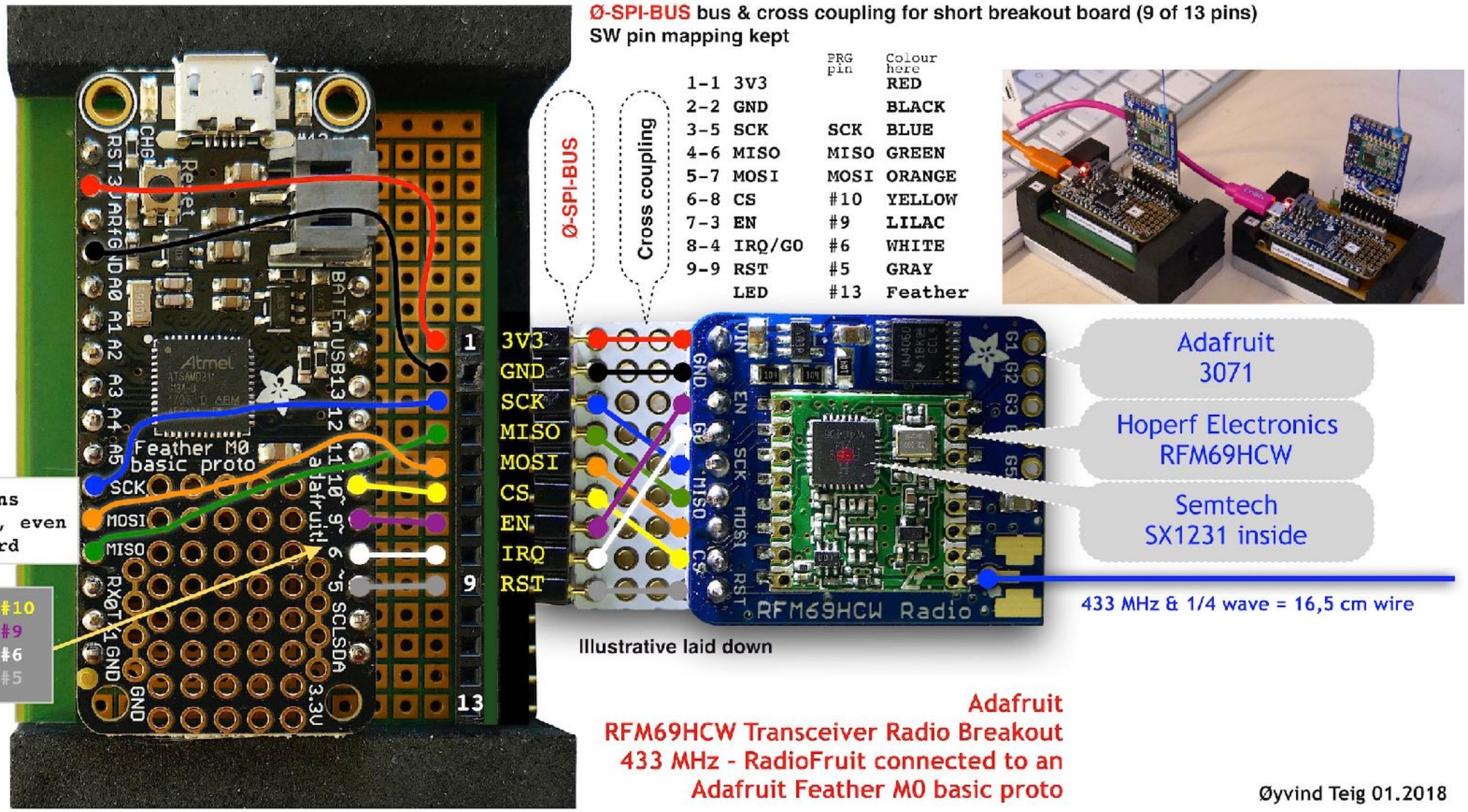
  - As I see it, they are all «toy» examples of regular scheduling of threads with no communication mechanism between them
  - Beware of «toy» schedulers!
- But Arduino is not a toy as such!

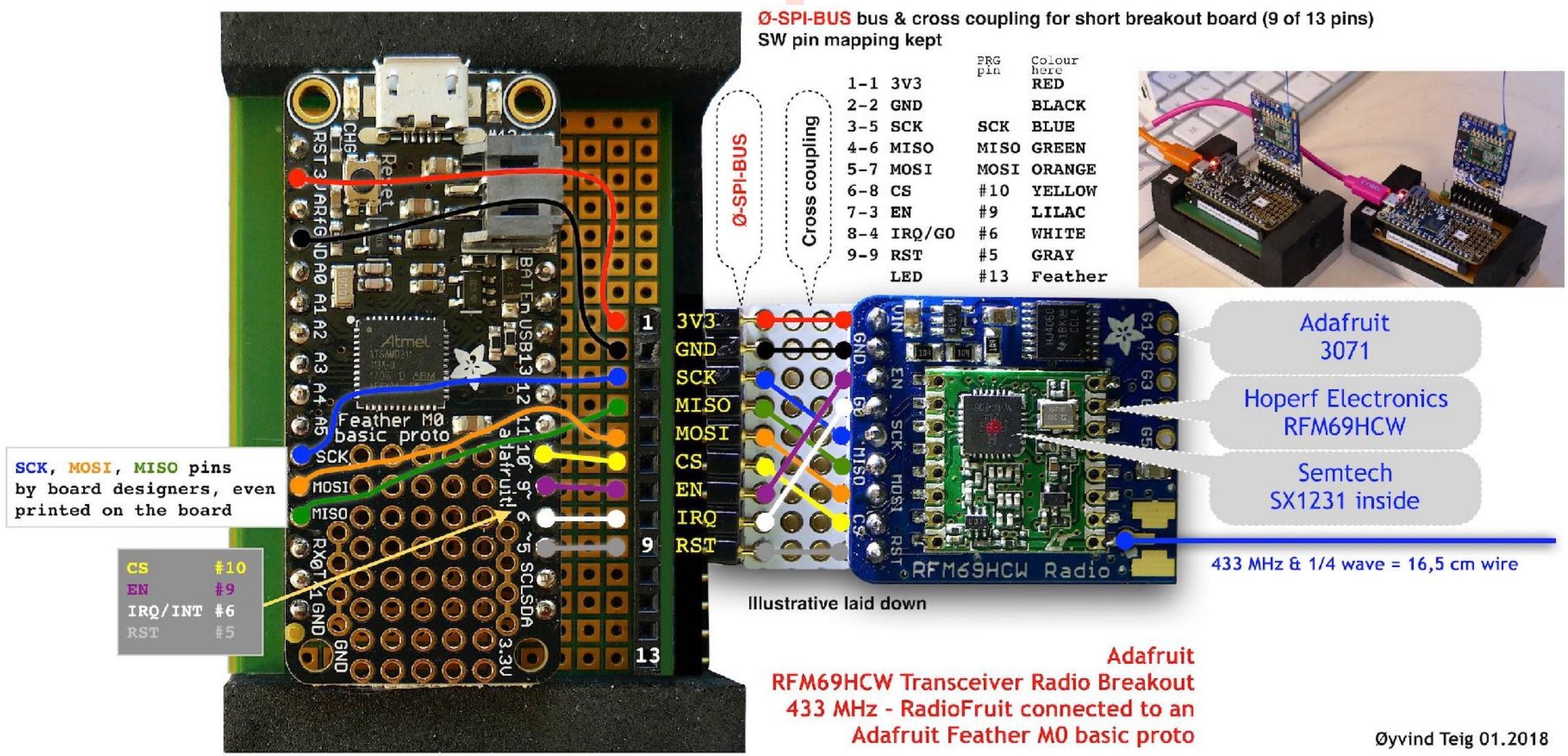
From a blog note

«void loop» ON MY DESK

ARDUINO



ARDUINO «void loop» ON MY DESK



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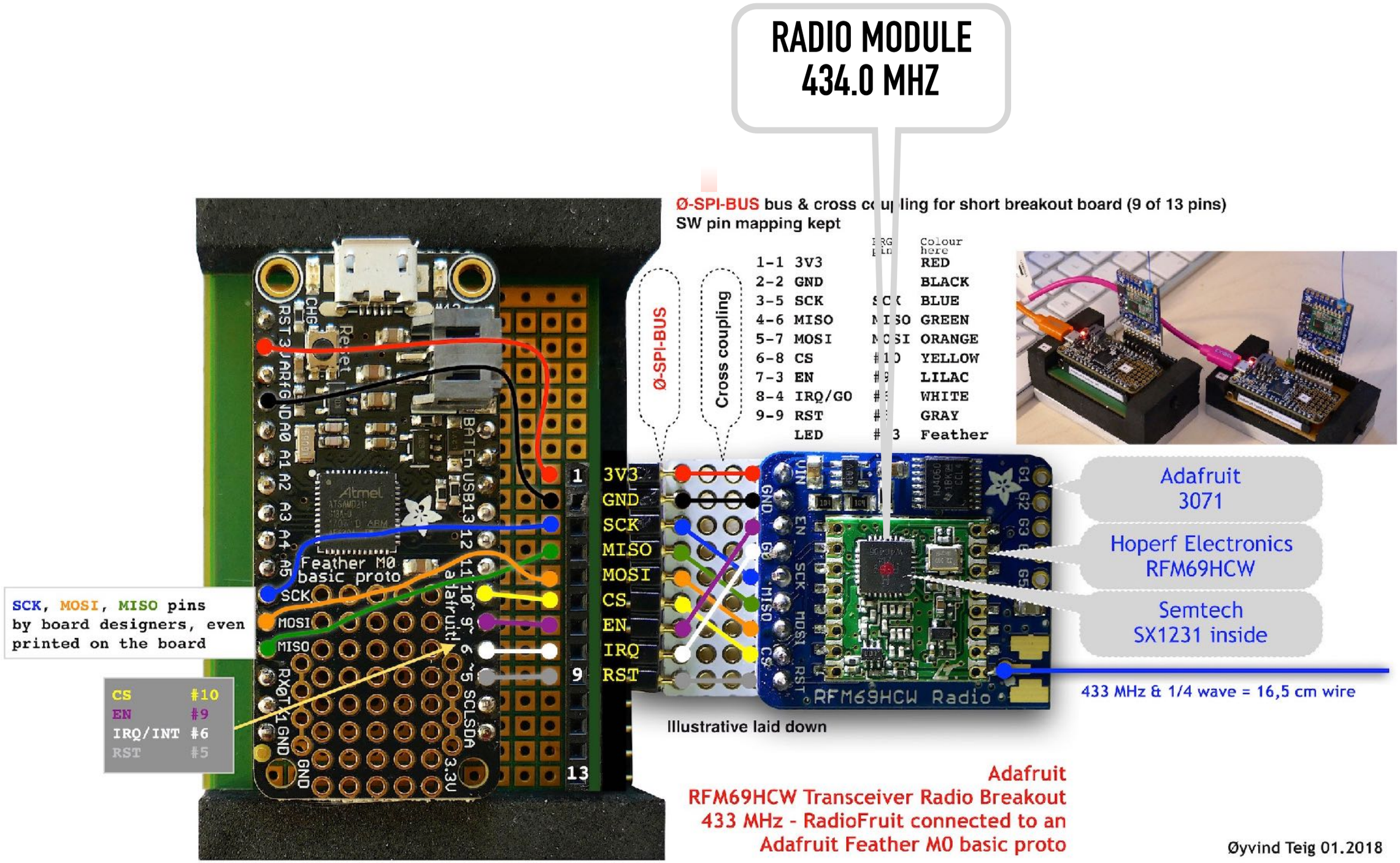
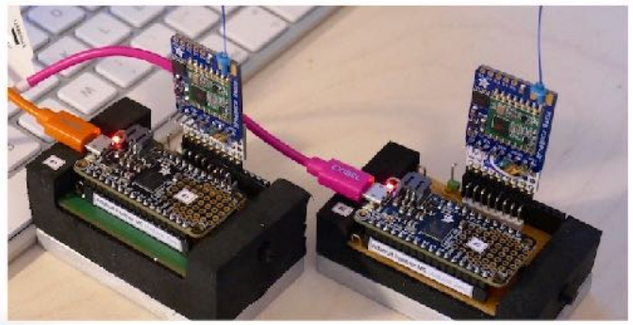


ARDUINO «void loop» ON MY DESK

RADIO MODULE 434.0 MHZ

Ø-SPI-BUS bus & cross coupling for short breakout board (9 of 13 pins)
SW pin mapping kept

		RG pin	Colour here
1-1	3V3		RED
2-2	GND		BLACK
3-5	SCK	SCK	BLUE
4-6	MISO	MISO	GREEN
5-7	MOSI	MOSI	ORANGE
6-8	CS	#10	YELLOW
7-3	EN	#9	LILAC
8-4	IRQ/GO	#6	WHITE
9-9	RST	#5	GRAY
	LED	#13	Feather



Ø-SPI-BUS

Cross coupling

3V3
GND
SCK
MISO
MOSI
CS
EN
IRQ
RST

Adafruit
3071

Hoperf Electronics
RFM69HCW

Semtech
SX1231 inside

433 MHz & 1/4 wave = 16,5 cm wire

Illustrative laid down

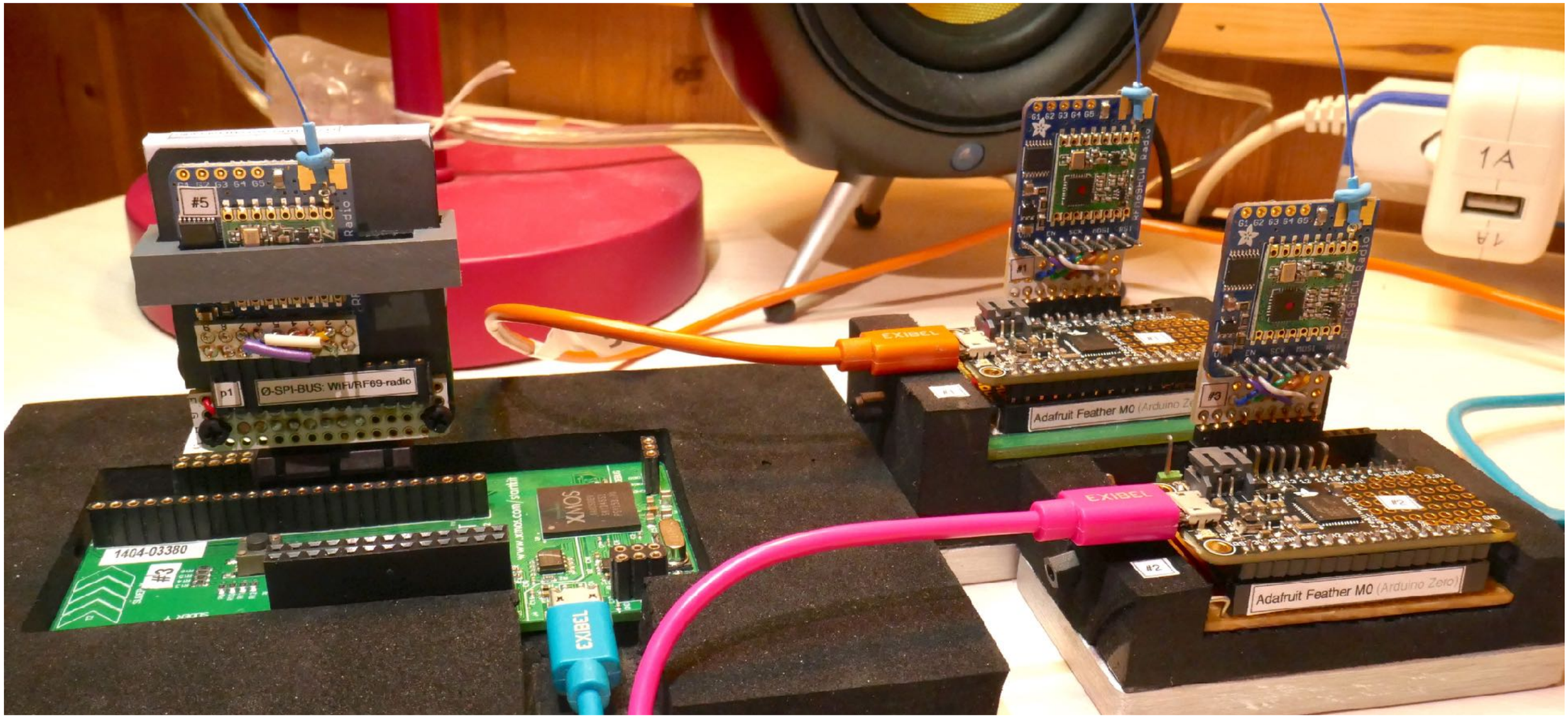
SCK, MOSI, MISO pins
by board designers, even
printed on the board

CS	#10
EN	#9
IRQ/INT	#6
RST	#5

Adafruit
RFM69HCW Transceiver Radio Breakout
433 MHz - RadioFruit connected to an
Adafruit Feather M0 basic proto

Øyvind Teig 01.2018

ARDUINO «void loop» ON MY DESK - PLUS AN XMOS BOARD



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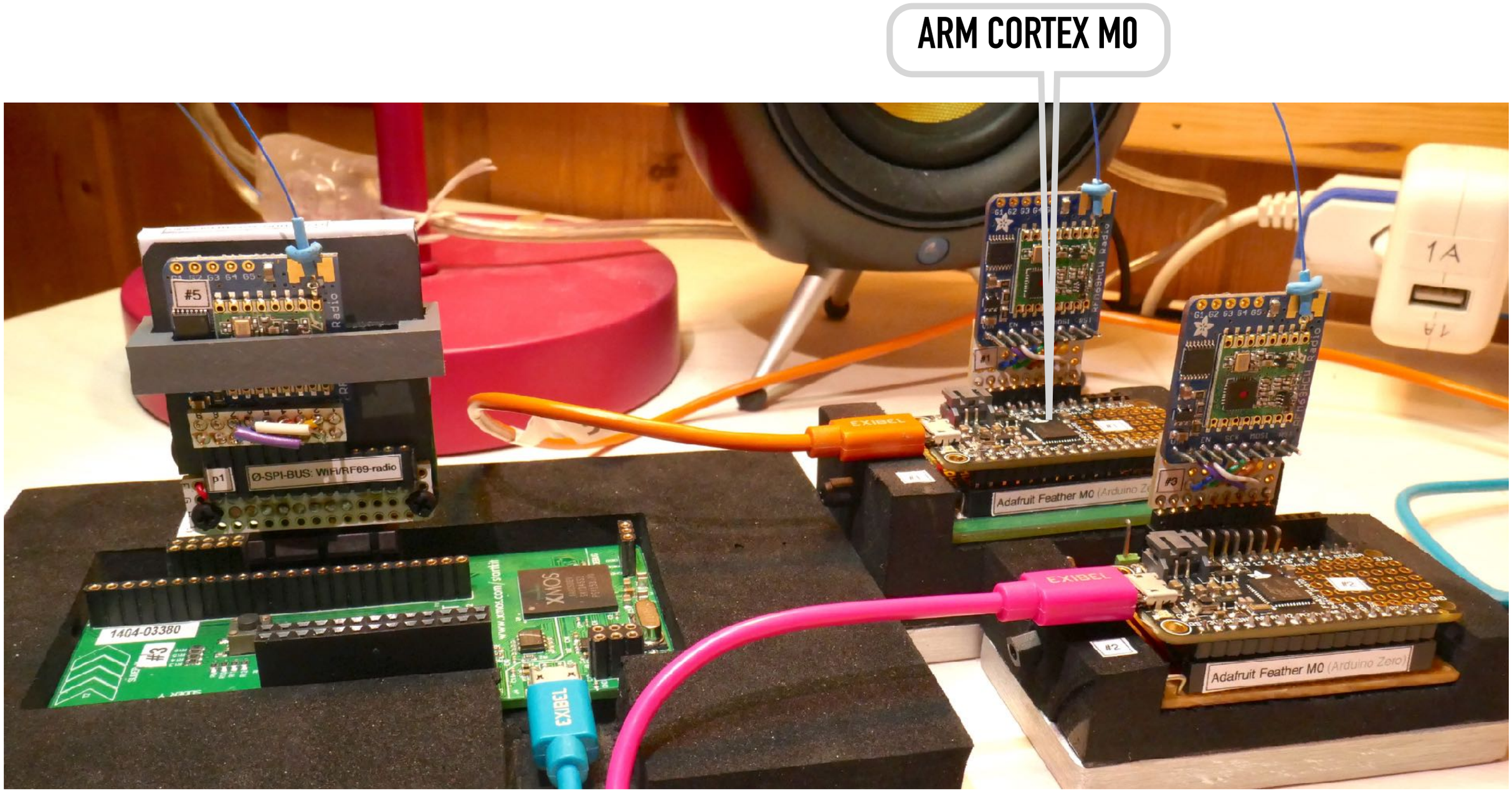

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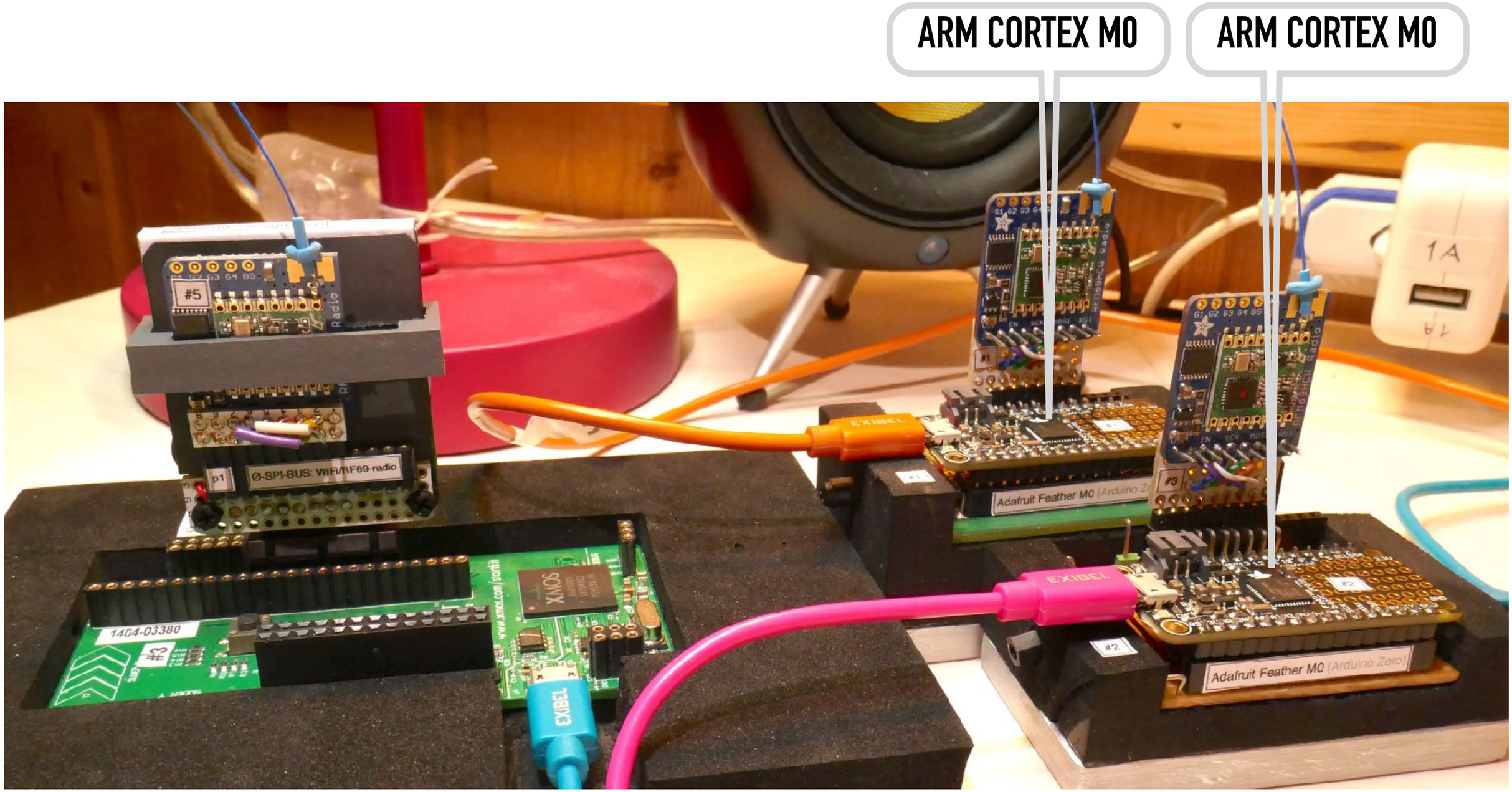

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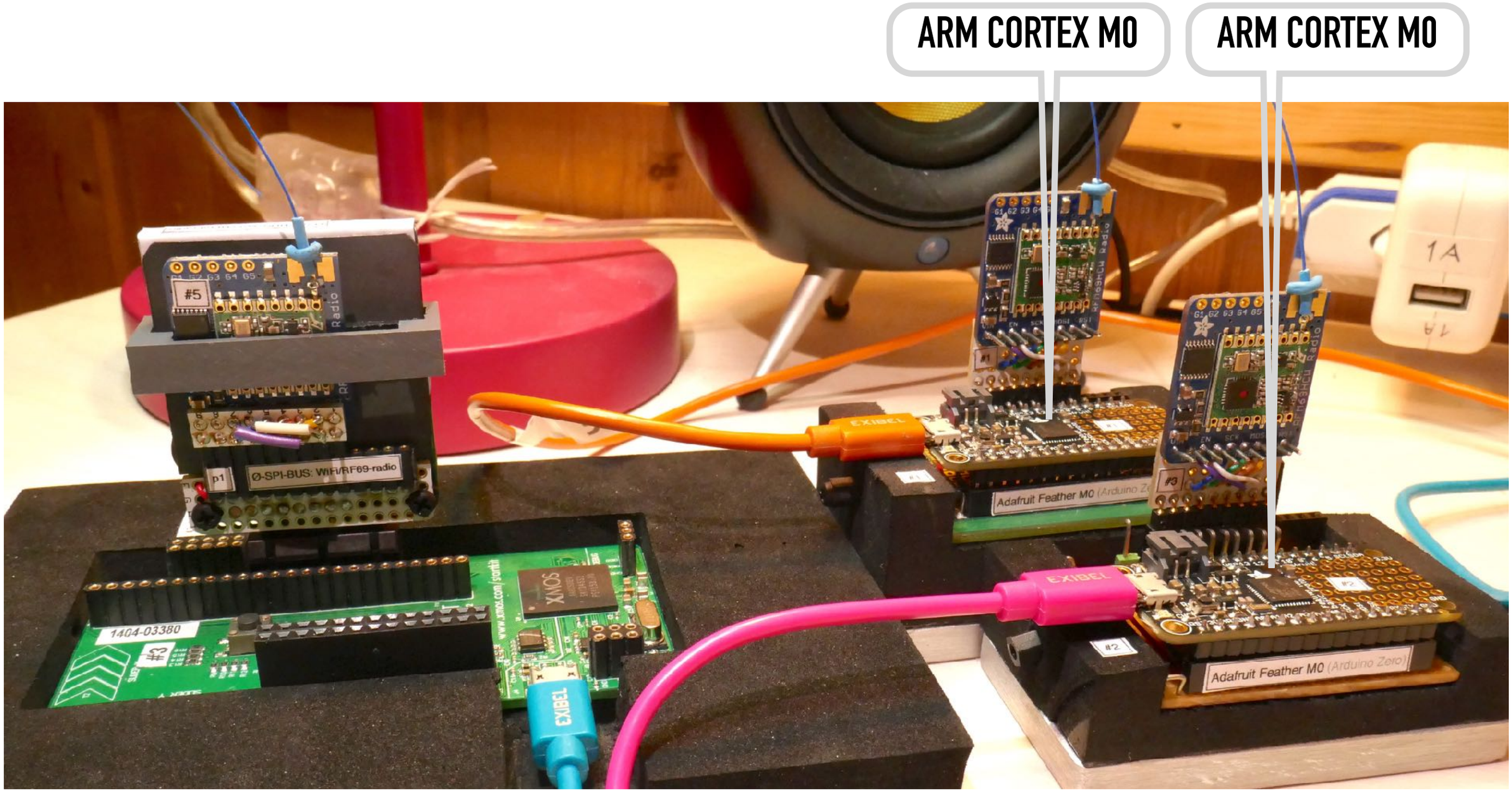

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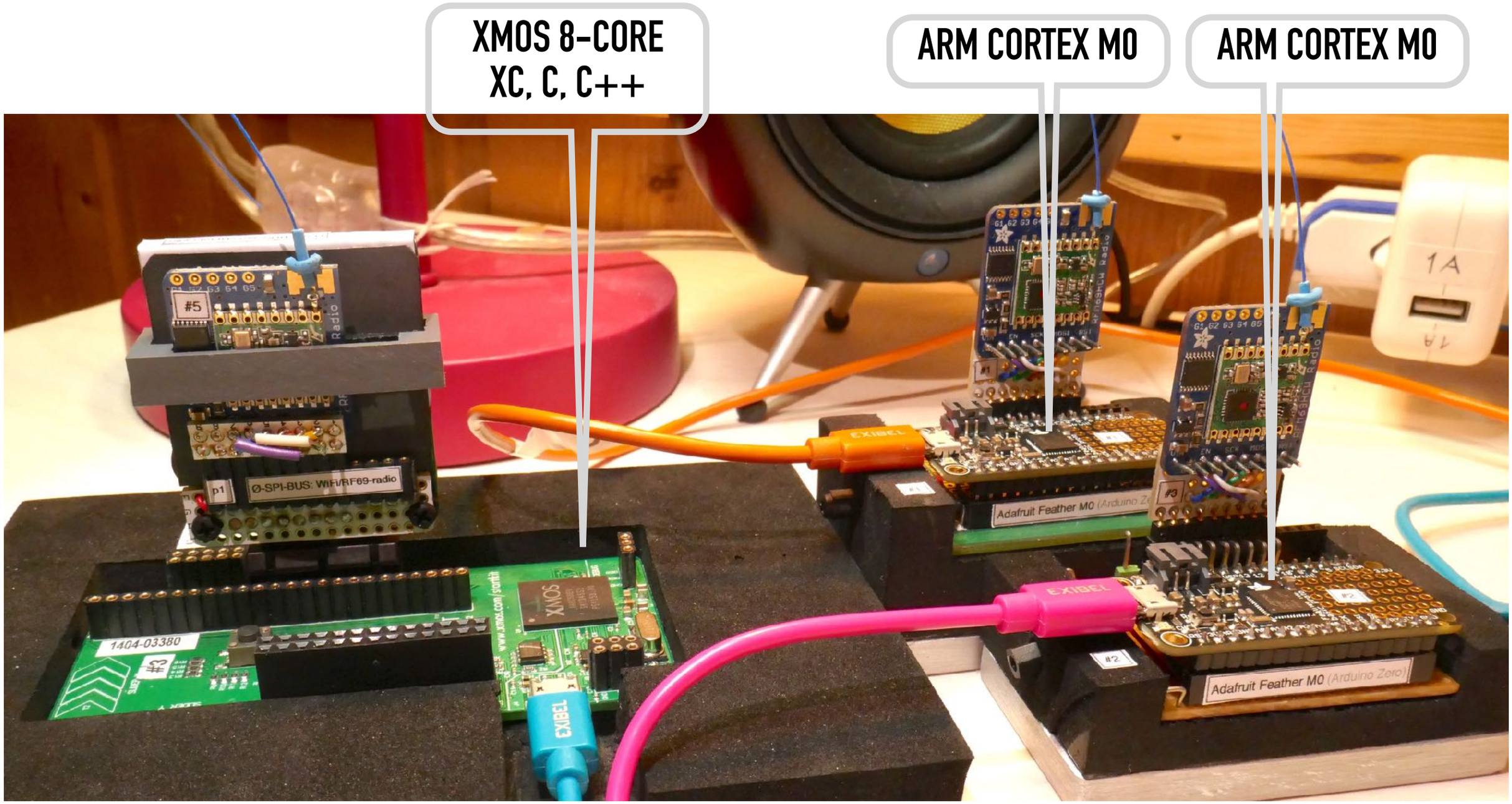

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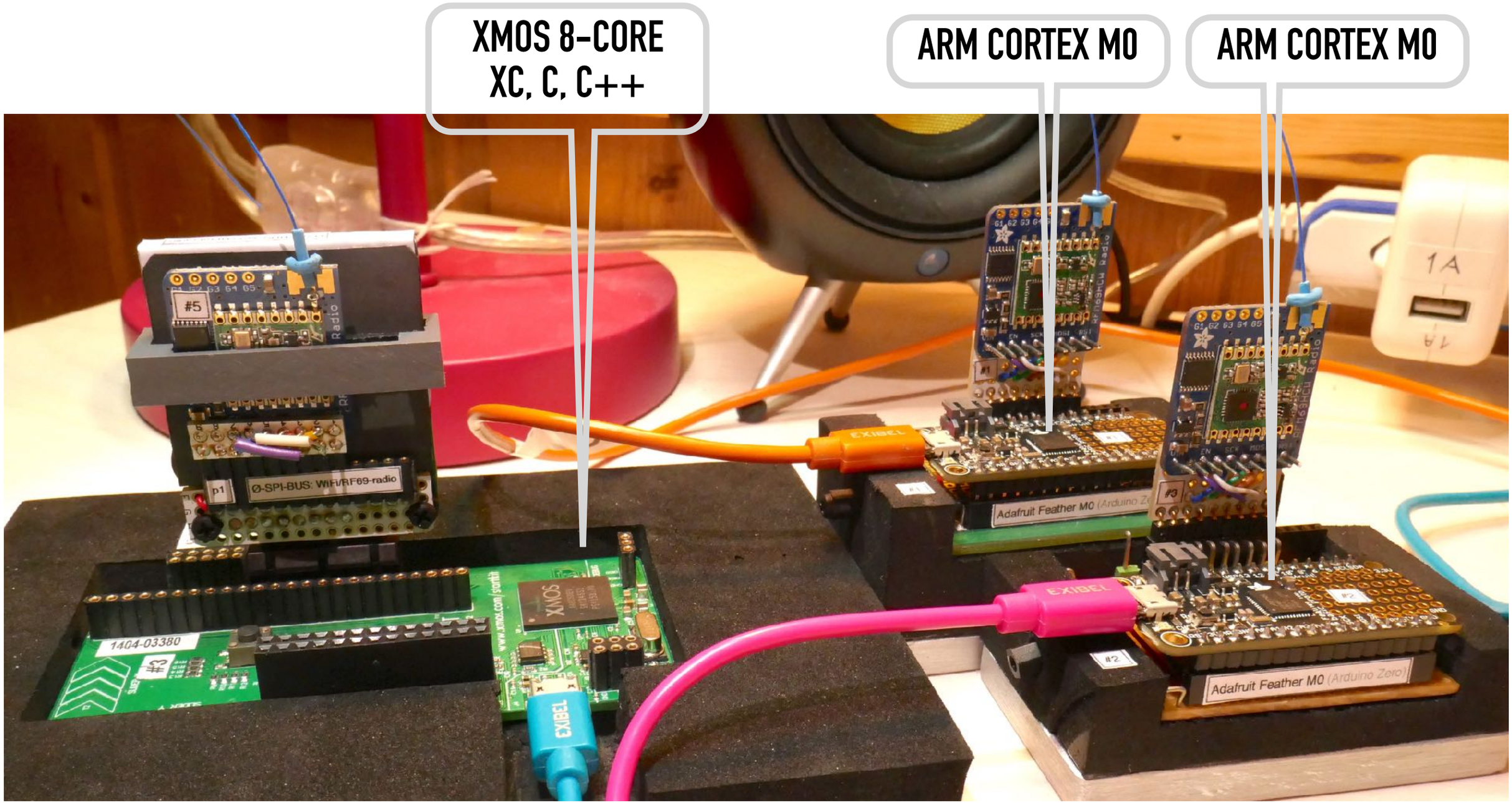

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XC, C, C++

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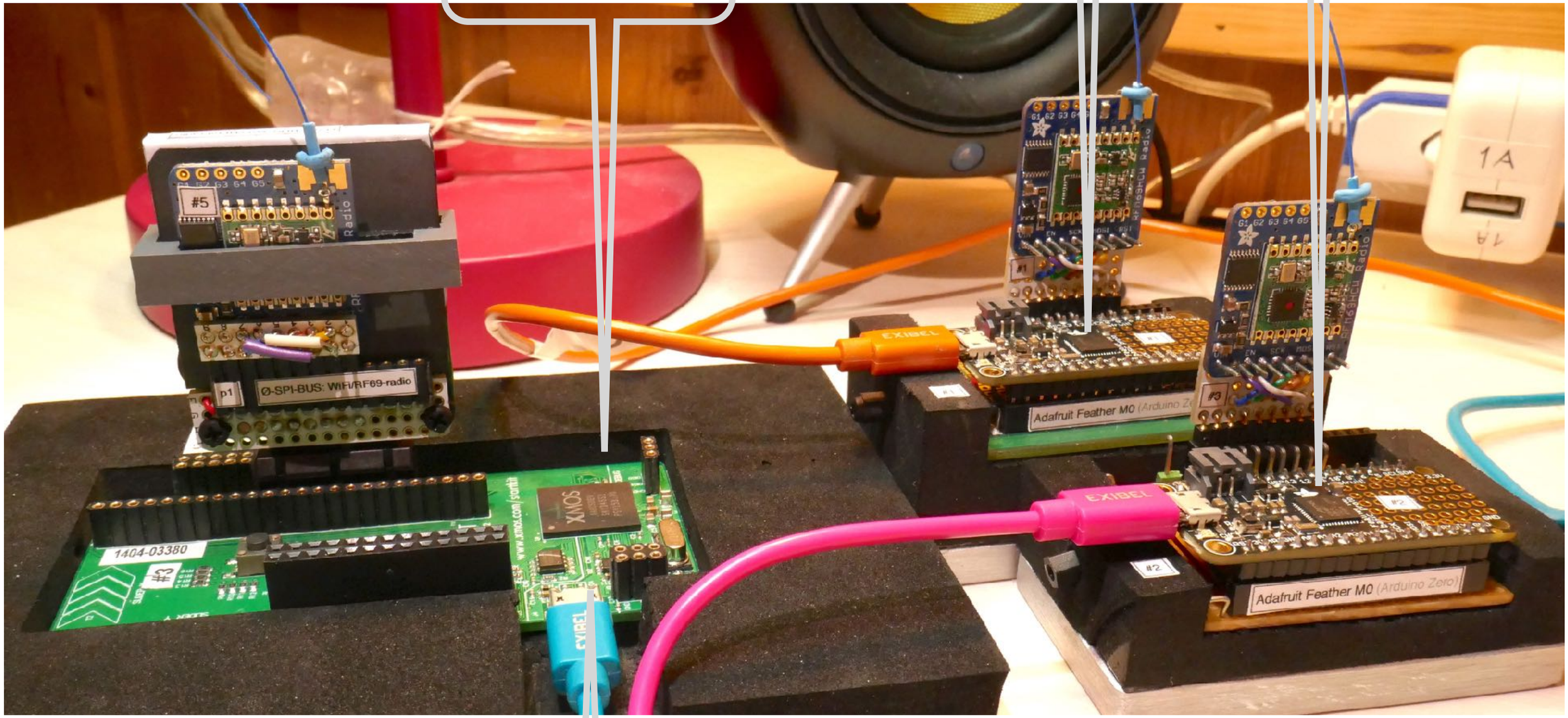

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MORE LATER

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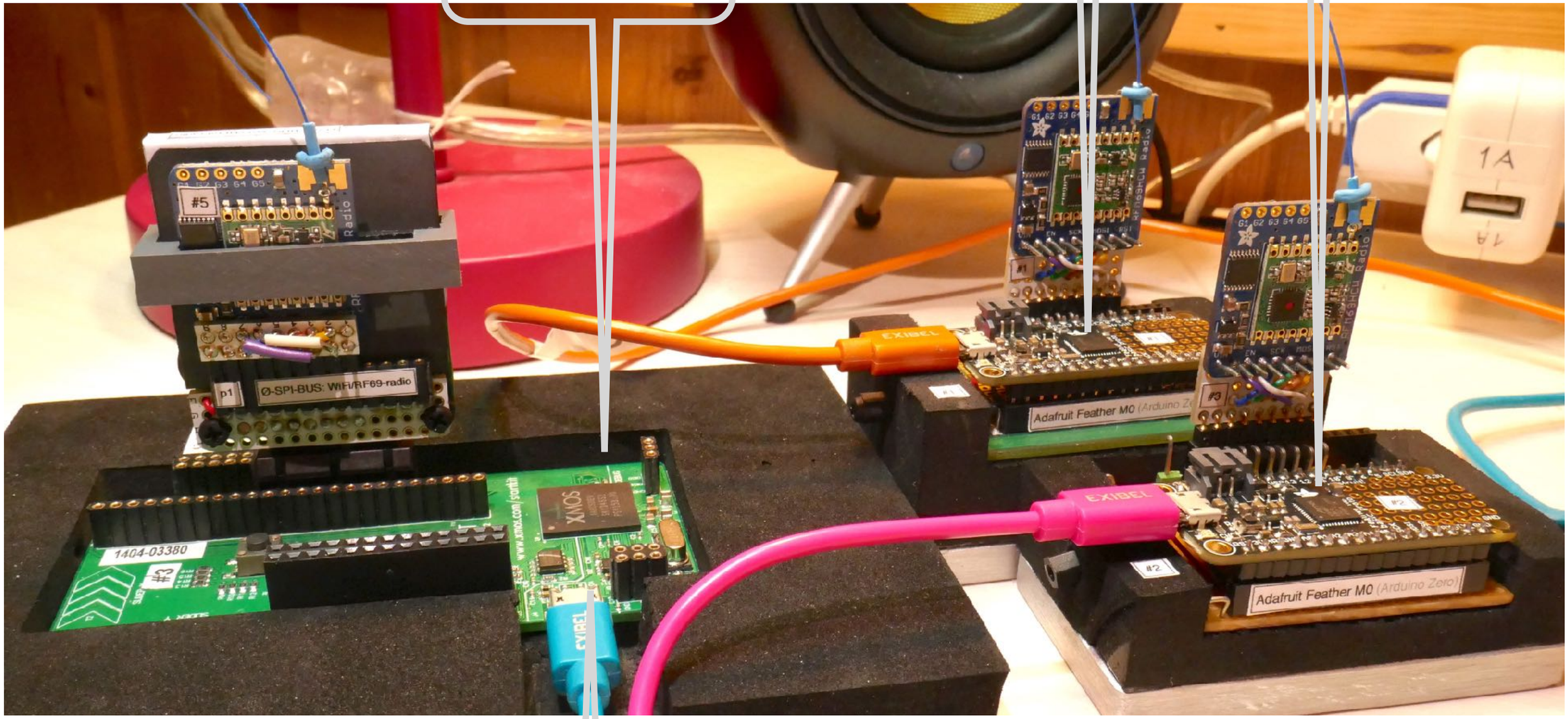

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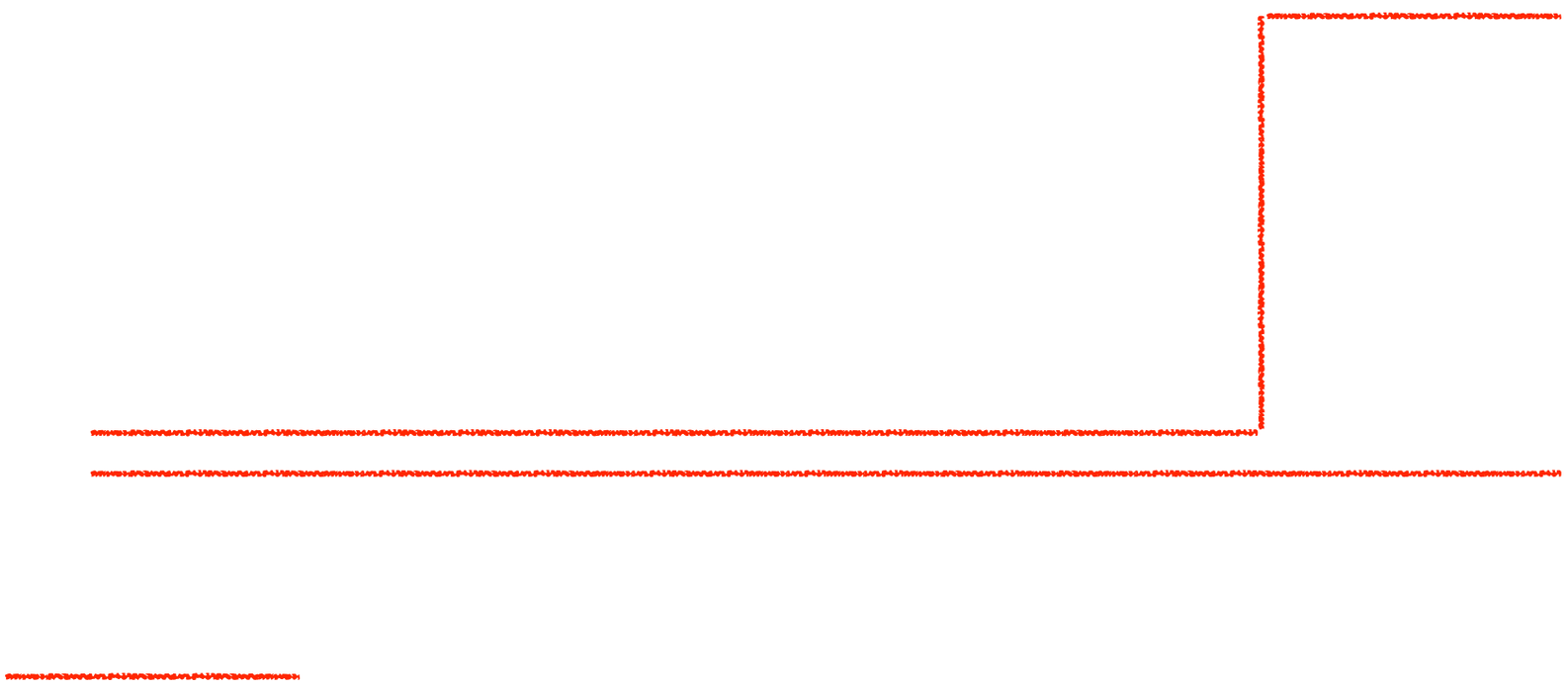
NEXT: `Scheduler`

ARDUINO: `Scheduler` AND THREE `loop()`



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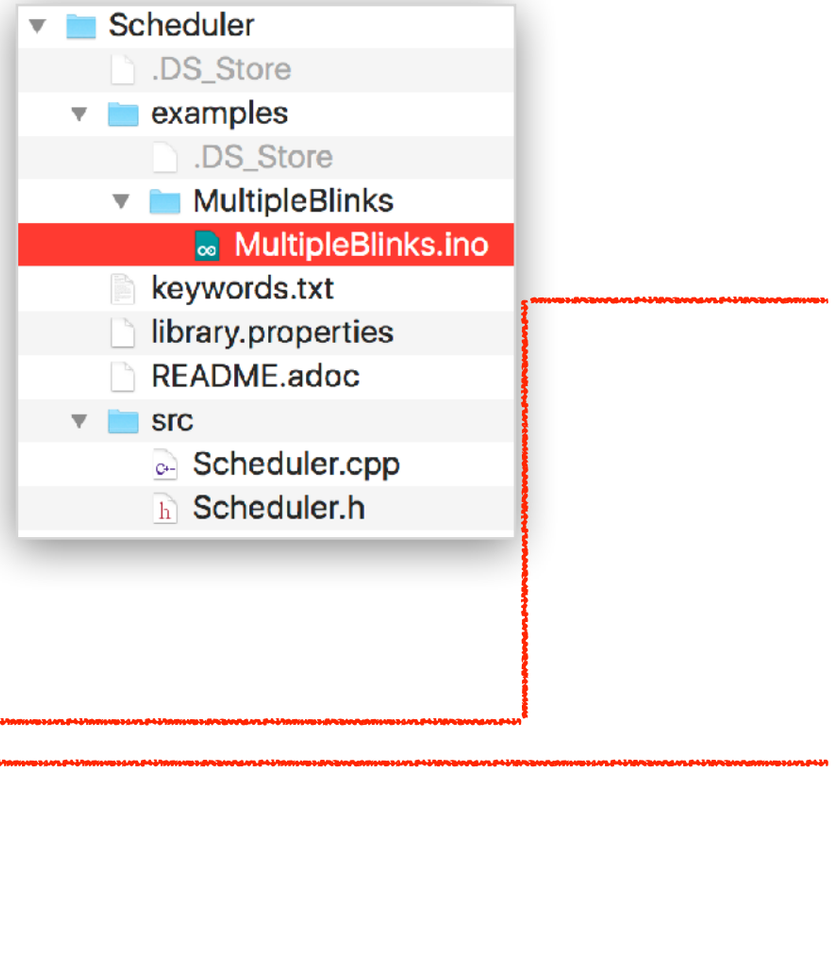

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#include <Scheduler.h>

int led1 = 13;
int led2 = 12;
int led3 = 11;

void setup() {
  Serial.begin(9600);

  // Setup the 3 pins as OUTPUT
  pinMode(led1, OUTPUT);
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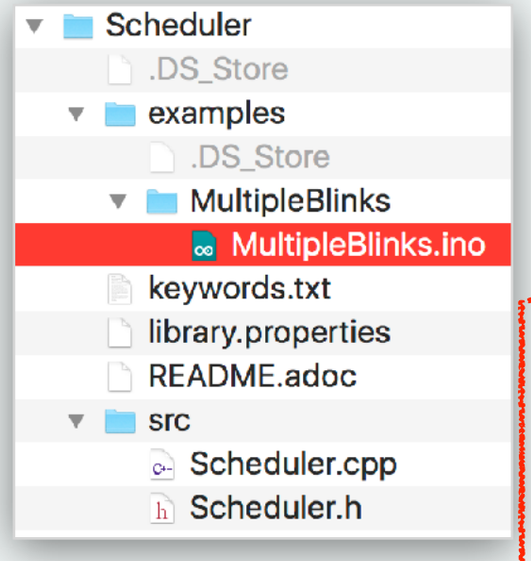

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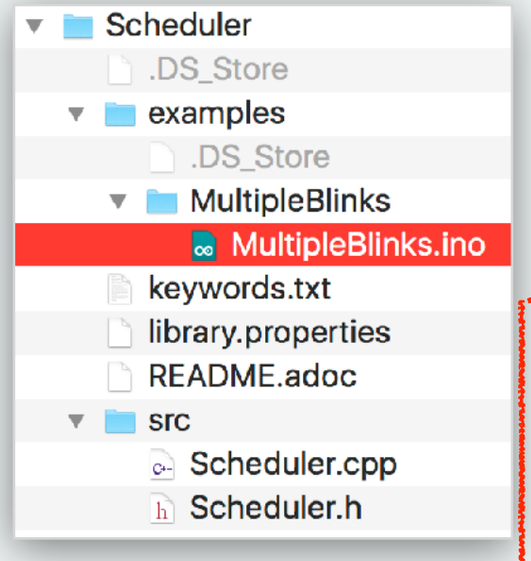


```
// Task no.1: blink LED with 1 second delay.
void loop() {
  digitalWrite(led1, HIGH);

  // IMPORTANT:
  // When multiple tasks are running 'delay' passes control
  // to other tasks while waiting and guarantees they get
  // executed.
  delay(1000);

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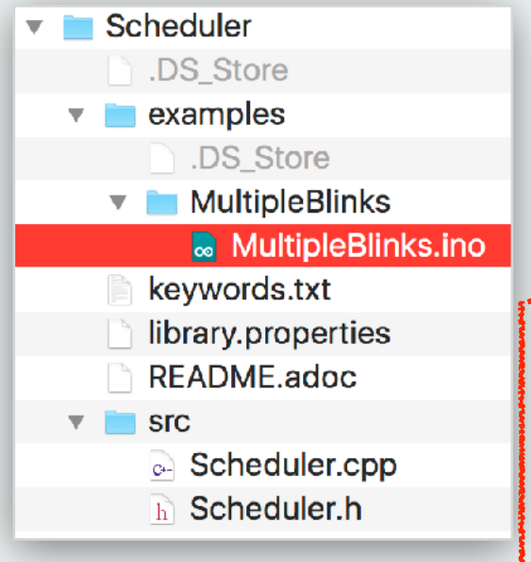


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// Task no.2: blink LED with 0.1 second delay.
void loop2() {
  digitalWrite(led2, HIGH);
  delay(100);
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}
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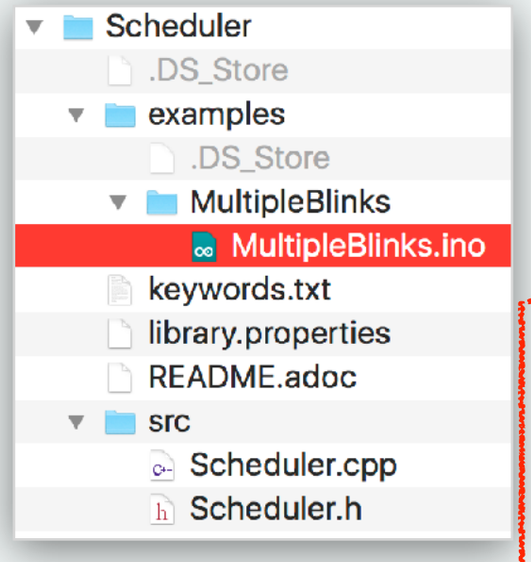


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```
// Task no.3: accept commands from Serial port
// '0' turns off LED
// '1' turns on LED
void loop3() {
  if (Serial.available()) {
    char c = Serial.read();
    if (c=='0') {
      digitalWrite(led3, LOW);
      Serial.println("Led turned off!");
    }
    if (c=='1') {
      digitalWrite(led3, HIGH);
      Serial.println("Led turned on!");
    }
  }

  // IMPORTANT:
  // We must call 'yield' at a regular basis to pass
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  yield();
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ARDUINO: `Scheduler` AND THREE `loop()`

https://www.arduino.cc/en/Tutorial/MultipleBlinks

https://www.arduino.cc/en/Reference/Scheduler

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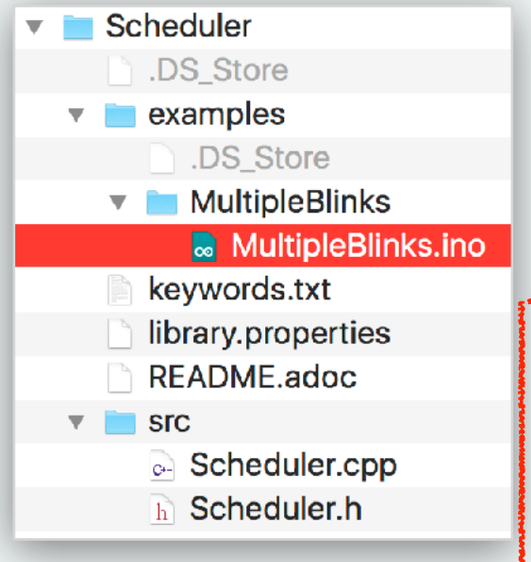


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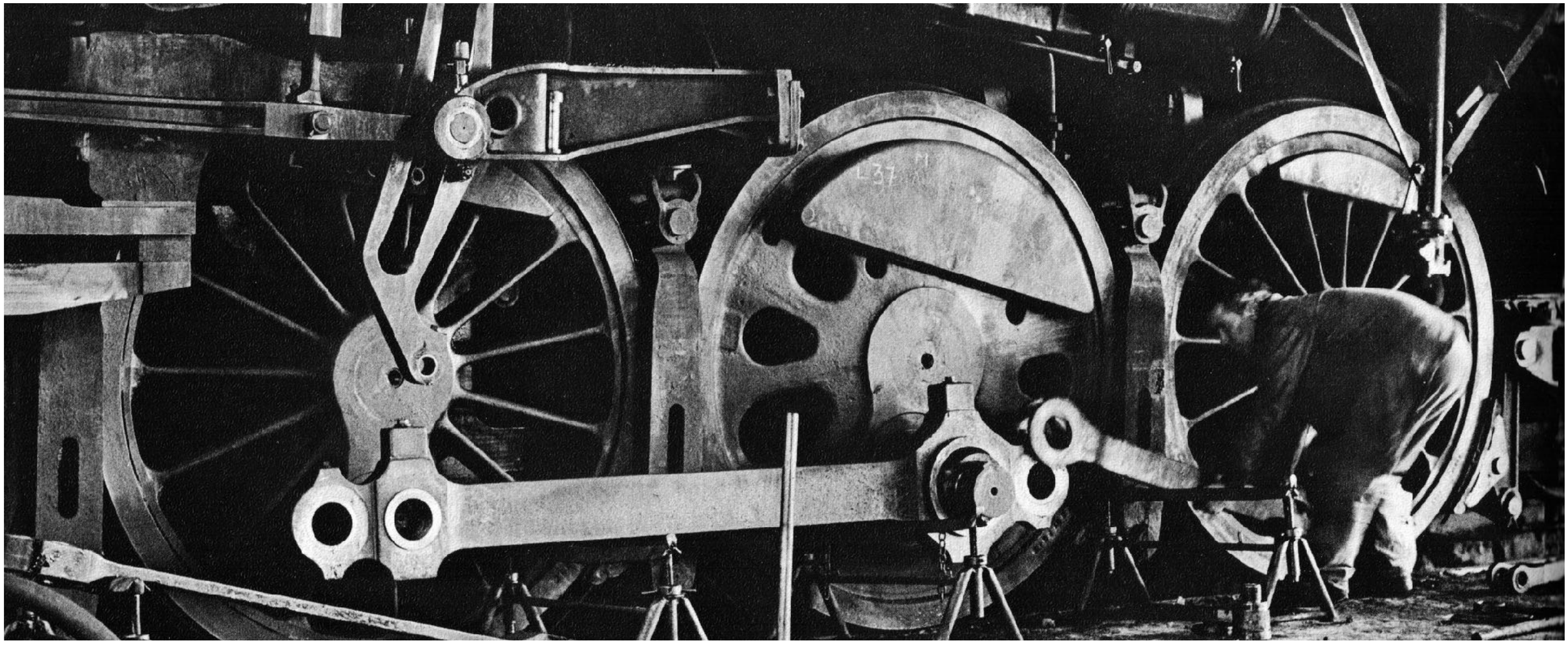

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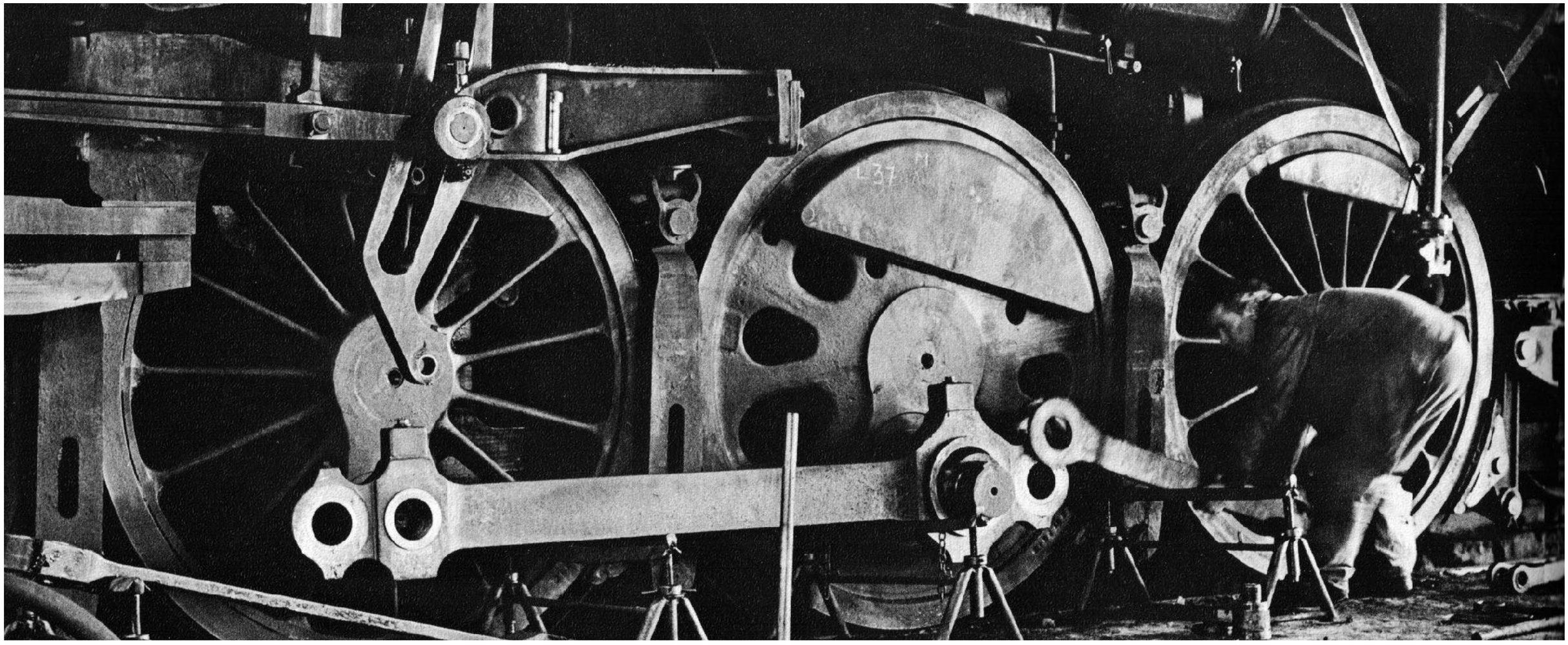

In **All Trains to Stop** by **Hans Steeneken** (1979)

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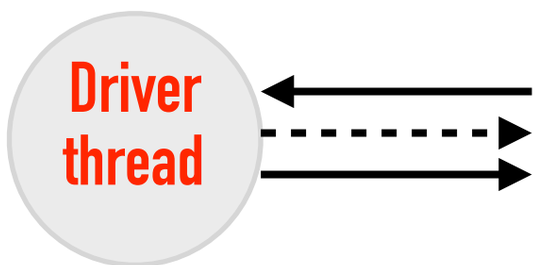

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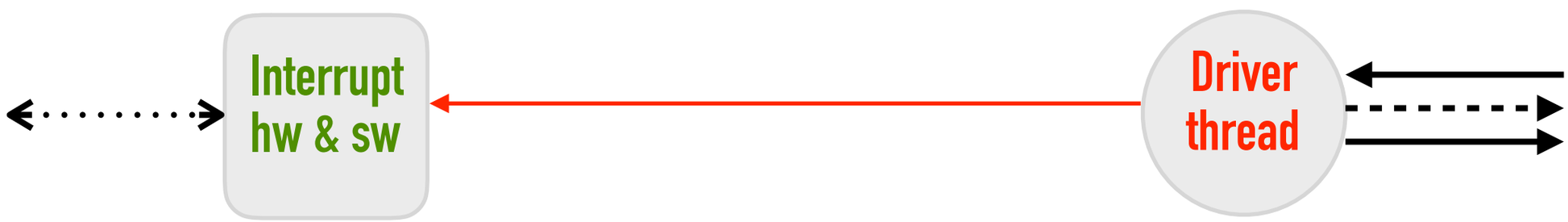

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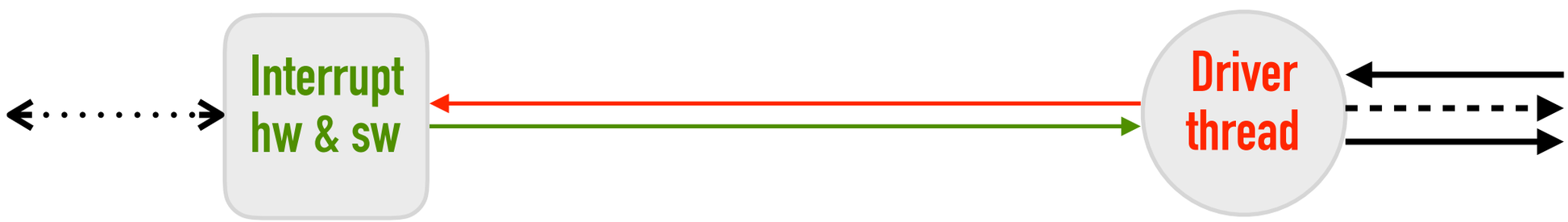

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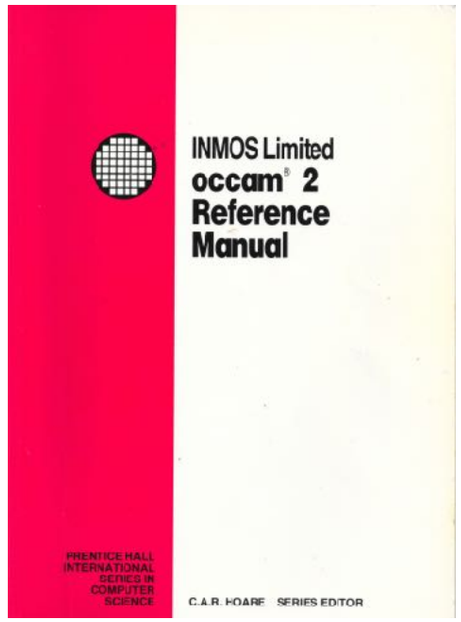
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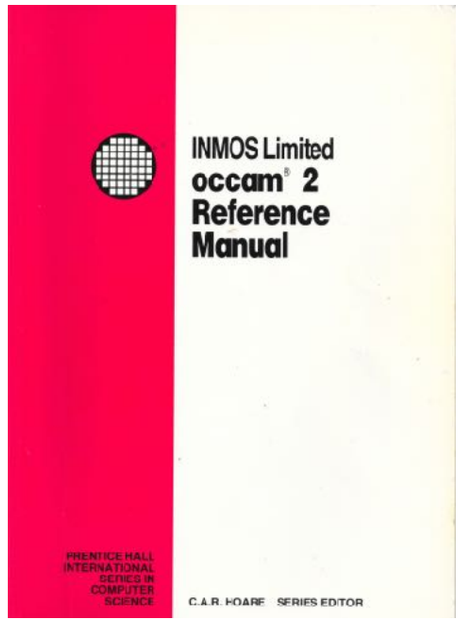

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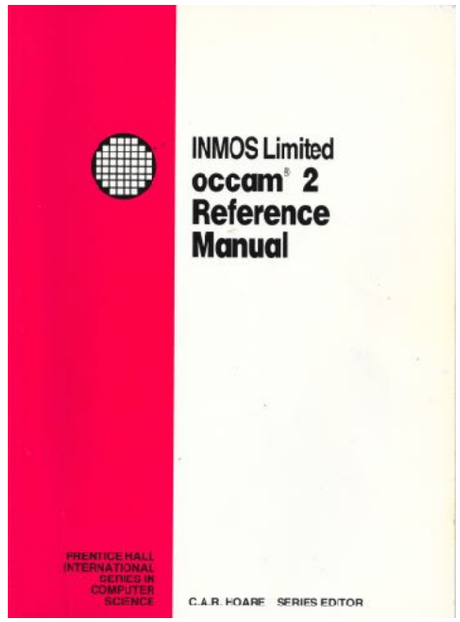

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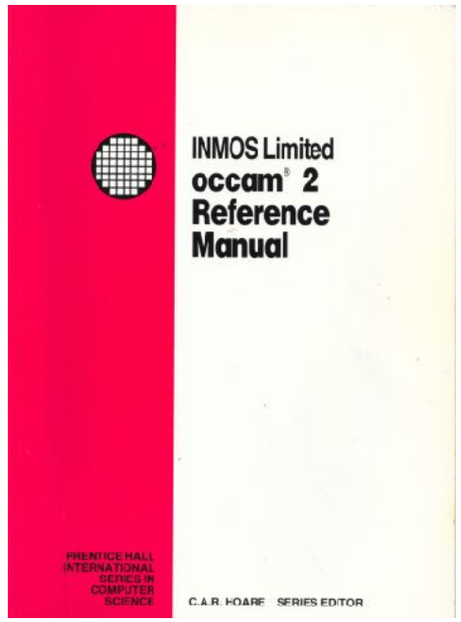

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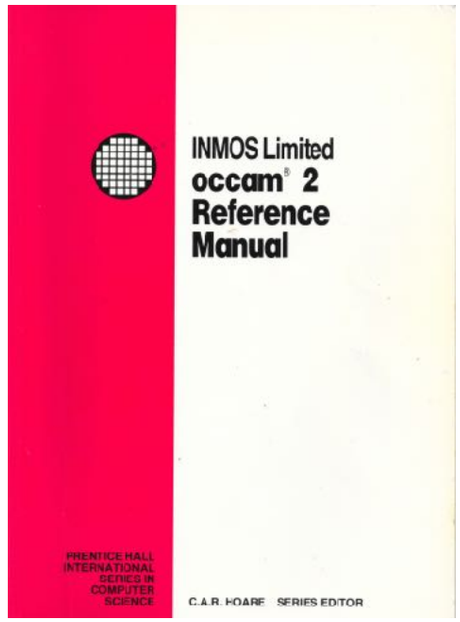

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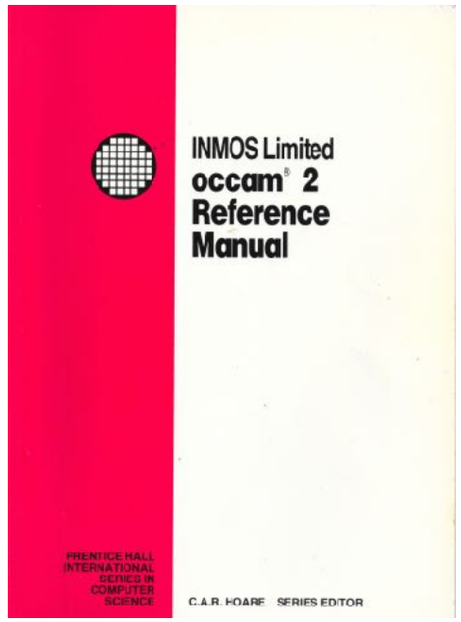

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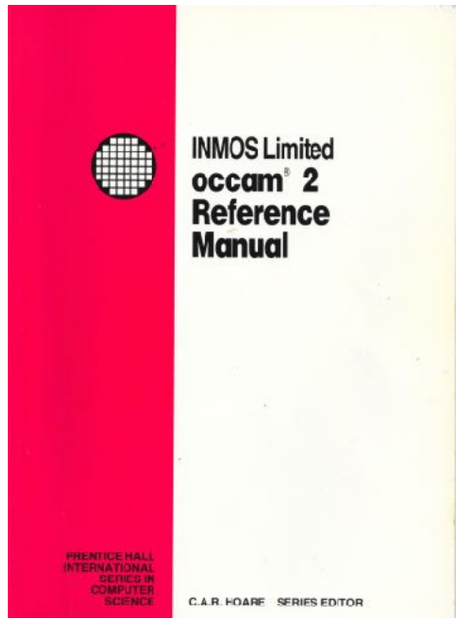

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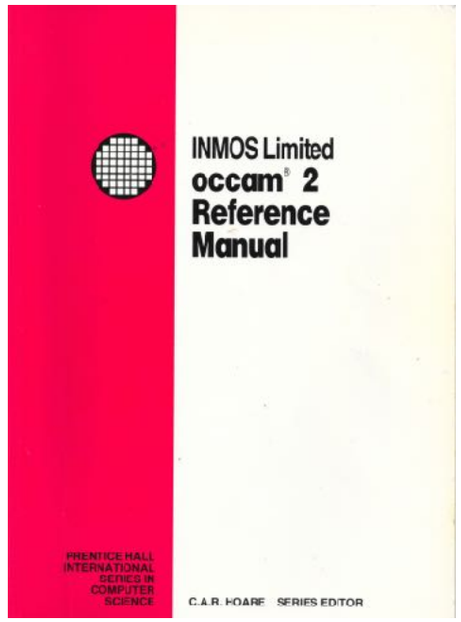

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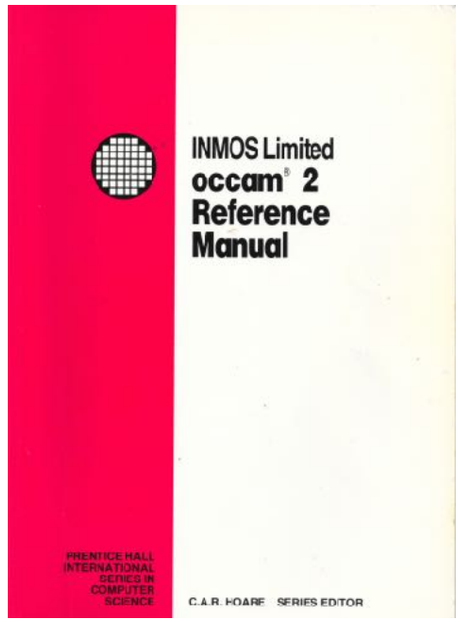

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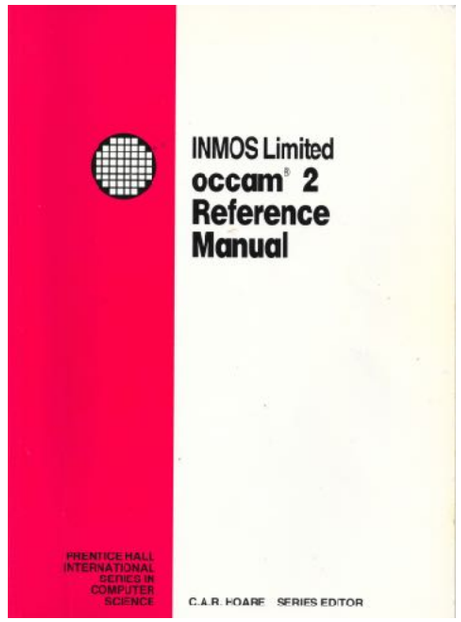

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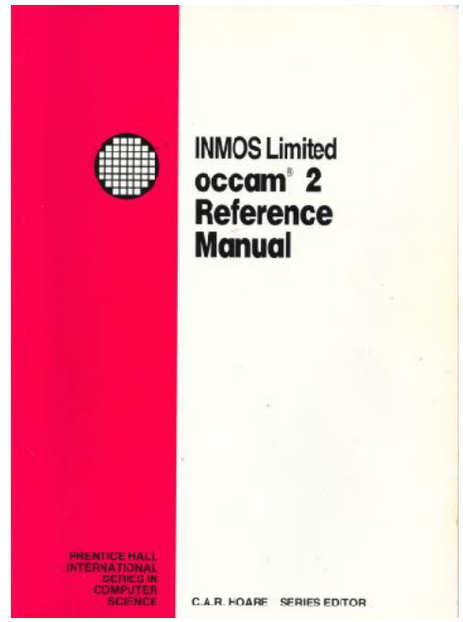

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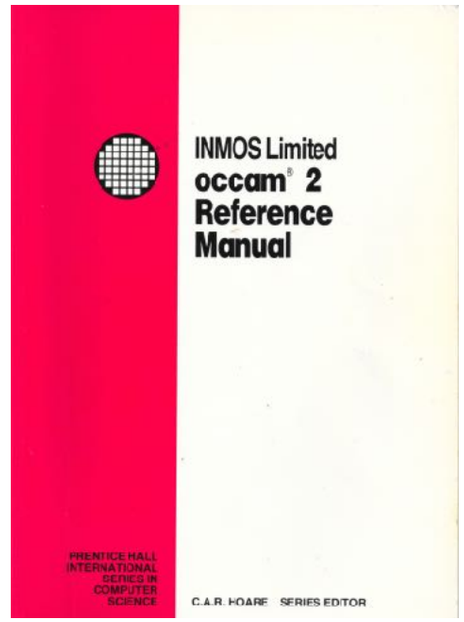

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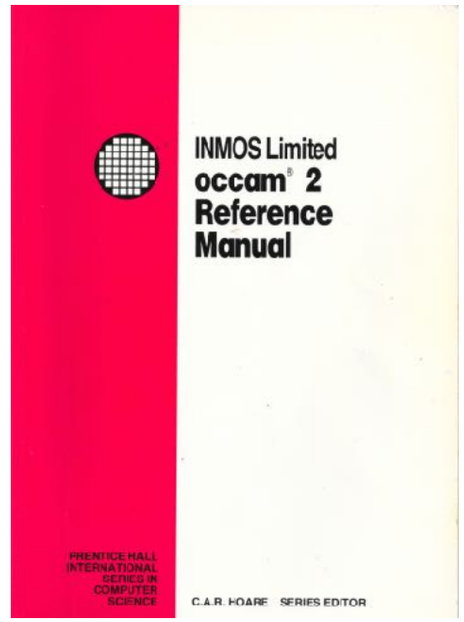

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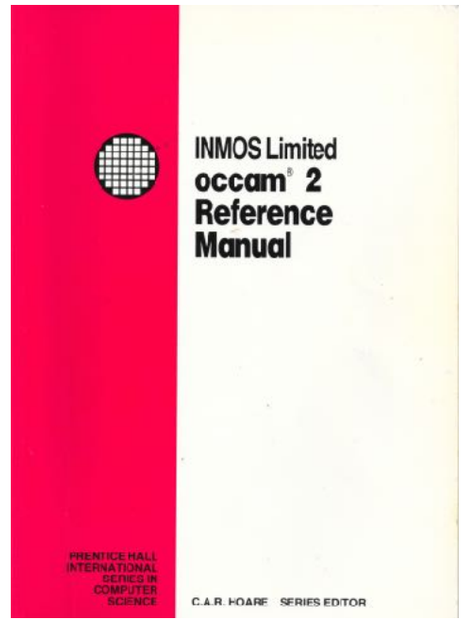

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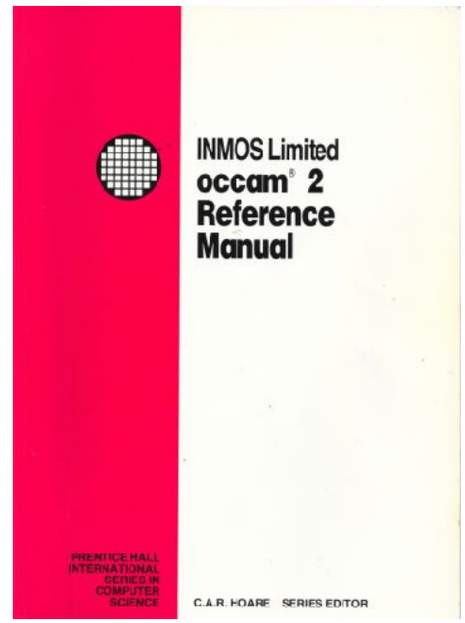

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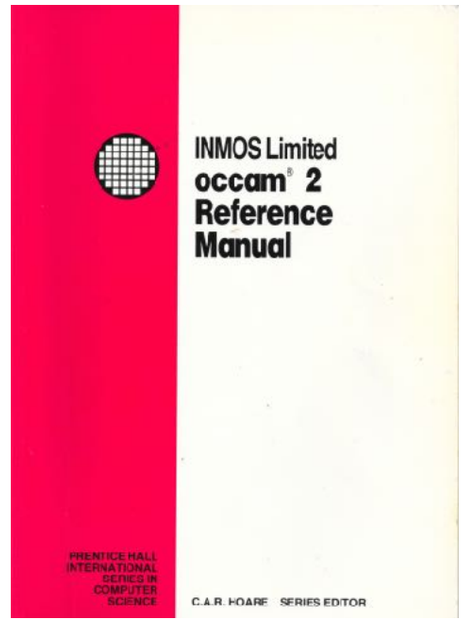

GO: FREQUENTLY ASKED QUESTIONS (FAQ)

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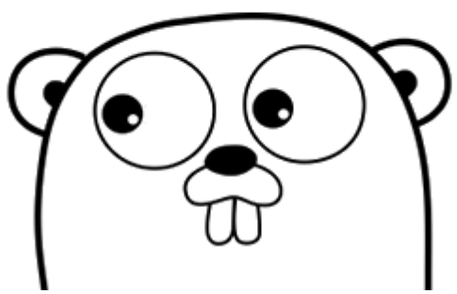

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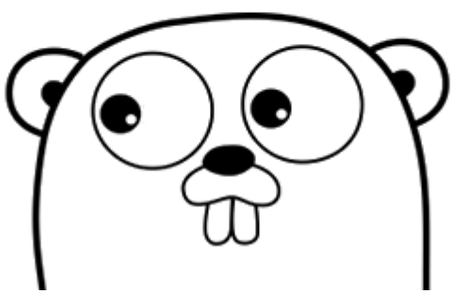

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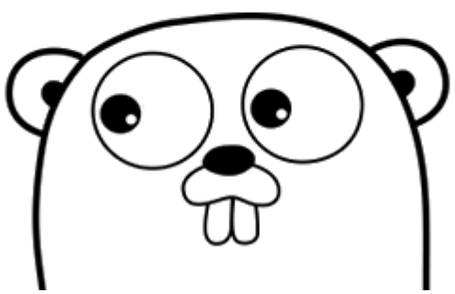

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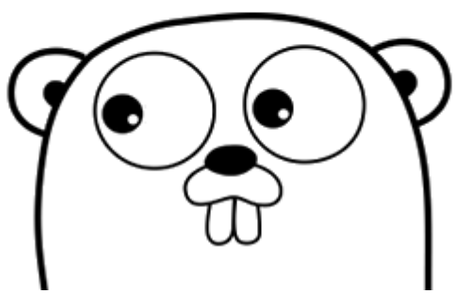

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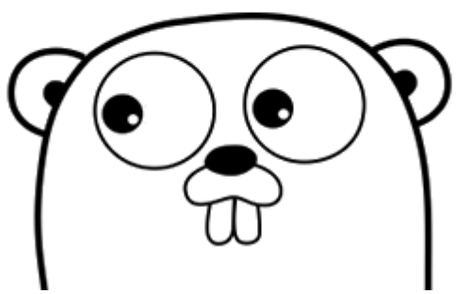

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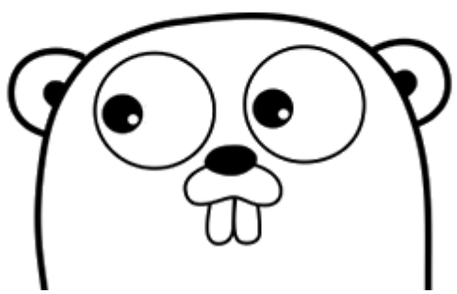

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MORE THAN CONNECT THREADS ?

SOME IMPORTANT PROPERTIES

CONCURRENT?

CONCURRENT?

PARALLEL?

CONCURRENT?

PARALLEL?

REAL-TIME?

CONCURRENT? PARALLEL? REAL-TIME?

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- Occam on many transputers and one transputer; different properties. Not really relevant any more, or.. yet(?)

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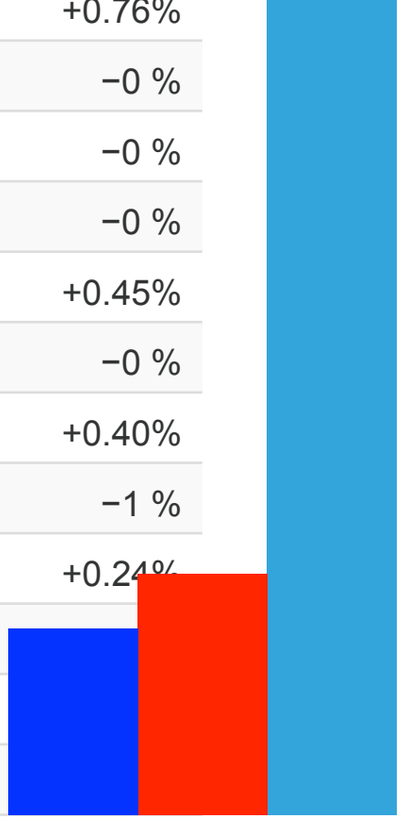

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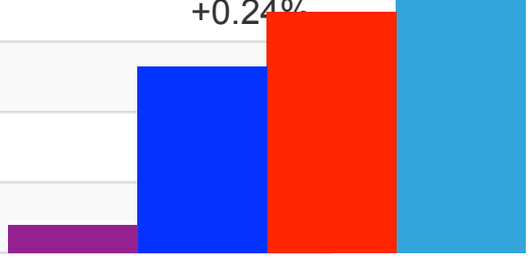

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Who code with chan!

1/7

Showing
a forest
for some trees

Showing
a forest
for some trees

MULTIPLE LOOPS WITH par: XC

Showing a forest for some trees

MULTIPLE LOOPS WITH par: XC

```
int main() {
    par {
    }
    return 0;
}
```

Showing a forest for some trees

MULTIPLE LOOPS WITH par: XC

```
port but_left                = on tile[0]:XS1_PORT_1N;
port but_center              = on tile[0]:XS1_PORT_1O;
port but_right               = on tile[0]:XS1_PORT_1P;
out buffered port:32 p_miso  = XS1_PORT_1A;
out port             p_ss[1] = {XS1_PORT_1B};
out buffered port:22 p_sclk  = XS1_PORT_1C;
out buffered port:32 p_mosi  = XS1_PORT_1D;
clock                clk_spi = XS1_CLKBLK_1;

int main() {
    par {
    }
    return 0;
}
```

Showing a forest for some trees

MULTIPLE LOOPS WITH par: XC

```
port but_left                = on tile[0]:XS1_PORT_1N;
port but_center              = on tile[0]:XS1_PORT_1O;
port but_right               = on tile[0]:XS1_PORT_1P;
out buffered port:32 p_miso  = XS1_PORT_1A;
out port             p_ss[1] = {XS1_PORT_1B};
out buffered port:22 p_sclk  = XS1_PORT_1C;
out buffered port:32 p_mosi  = XS1_PORT_1D;
clock                clk_spi = XS1_CLKBLK_1;

int main() {
    par {
    }
    return 0;
}
```

Showing a forest for some trees

MULTIPLE LOOPS WITH par: XC

```
port but_left                = on tile[0]:XS1_PORT_1N;
port but_center              = on tile[0]:XS1_PORT_1O;
port but_right               = on tile[0]:XS1_PORT_1P;
out buffered port:32 p_miso  = XS1_PORT_1A;
out port             p_ss[1] = {XS1_PORT_1B};
out buffered port:22 p_sclk  = XS1_PORT_1C;
out buffered port:32 p_mosi  = XS1_PORT_1D;
clock                clk_spi = XS1_CLKBLK_1;

int main() {
    par {
    }
    return 0;
}
```

Showing a forest for some trees

MULTIPLE LOOPS WITH par: XC

```
port but_left                = on tile[0]:XS1_PORT_1N;
port but_center              = on tile[0]:XS1_PORT_1O;
port but_right               = on tile[0]:XS1_PORT_1P;
out buffered port:32 p_miso  = XS1_PORT_1A;
out port             p_ss[1] = {XS1_PORT_1B};
out buffered port:22 p_sclk  = XS1_PORT_1C;
out buffered port:32 p_mosi  = XS1_PORT_1D;
clock                clk_spi = XS1_CLKBLK_1;

int main() {
    //             c_is_channel
    chan           c_buts[NUM_BUTTONS];
    chan           c_ana;
    //             i_is_interface, a collection of RPC-type functions with defined roles (none, client, server)
    i2c_ext_if     i_i2c_ext[NUM_I2C_EX];
    i2c_int_if     i_i2c_int[NUM_I2C_IN];
    adc_acq_if     i_adc_acq;
    adc_lib_if     i_adc_lib[NUM_ADC];
    heat_light_if i_heat_light[NUM_HEAT_LIGHT];
    heat_if        i_heat[NUM_HEAT_CTRL];
    water_if       i_water;
    radio_if       i_radio;
    spi_master_if i_spi[1];
    par {




    }
    return 0;
}
```

Showing a forest for some trees

MULTIPLE LOOPS WITH par: XC

```
port but_left                = on tile[0]:XS1_PORT_1N;
port but_center              = on tile[0]:XS1_PORT_1O;
port but_right               = on tile[0]:XS1_PORT_1P;
out buffered port:32 p_miso  = XS1_PORT_1A;
out port             p_ss[1] = {XS1_PORT_1B};
out buffered port:22 p_sclk  = XS1_PORT_1C;
out buffered port:32 p_mosi  = XS1_PORT_1D;
clock                clk_spi = XS1_CLKBLK_1;

int main() {
    //             c_is_channel
    chan           c_buts[NUM_BUTTONS];
    chan           c_ana;
    //             i_is_interface, a collection of RPC-type functions with defined roles (none, client, server)
    i2c_ext_if     i_i2c_ext[NUM_I2C_EX];
    i2c_int_if     i_i2c_int[NUM_I2C_IN];
    adc_acq_if     i_adc_acq;
    adc_lib_if     i_adc_lib[NUM_ADC];
    heat_light_if  i_heat_light[NUM_HEAT_LIGHT];
    heat_if        i_heat[NUM_HEAT_CTRL];
    water_if       i_water;
    radio_if       i_radio;
    spi_master_if  i_spi[1];
    par {




    }
    return 0;
}
```

Showing a forest for some trees

MULTIPLE LOOPS WITH par: XC

```
port but_left                = on tile[0]:XS1_PORT_1N;
port but_center              = on tile[0]:XS1_PORT_1O;
port but_right               = on tile[0]:XS1_PORT_1P;
out buffered port:32 p_miso  = XS1_PORT_1A;
out port             p_ss[1] = {XS1_PORT_1B};
out buffered port:22 p_sclk  = XS1_PORT_1C;
out buffered port:32 p_mosi  = XS1_PORT_1D;
clock                clk_spi = XS1_CLKBLK_1;

int main() {
    //             c_is_channel
    chan           c_buts[NUM_BUTTONS];
    chan           c_ana;
    //             i_is_interface, a collection of RPC-type functions with defined roles (none, client, server)
    i2c_ext_if     i_i2c_ext[NUM_I2C_EX];
    i2c_int_if     i_i2c_int[NUM_I2C_IN];
    adc_acq_if     i_adc_acq;
    adc_lib_if     i_adc_lib[NUM_ADC];
    heat_light_if  i_heat_light[NUM_HEAT_LIGHT];
    heat_if        i_heat[NUM_HEAT_CTRL];
    water_if       i_water;
    radio_if       i_radio;
    spi_master_if  i_spi[1];
    par {
    }
    return 0;
}
```

Showing a forest for some trees

MULTIPLE LOOPS WITH par: XC

```
port but_left                = on tile[0]:XS1_PORT_1N;
port but_center              = on tile[0]:XS1_PORT_1O;
port but_right               = on tile[0]:XS1_PORT_1P;
out buffered port:32 p_miso  = XS1_PORT_1A;
out port             p_ss[1] = {XS1_PORT_1B};
out buffered port:22 p_sclk  = XS1_PORT_1C;
out buffered port:32 p_mosi  = XS1_PORT_1D;
clock                clk_spi = XS1_CLKBLK_1;

int main() {
    //             c_is_channel
    chan           c_buts[NUM_BUTTONS];
    chan           c_ana;
    //             i_is_interface, a collection of RPC-type functions with defined roles (none, client, server)
    i2c_ext_if     i_i2c_ext[NUM_I2C_EX];
    i2c_int_if     i_i2c_int[NUM_I2C_IN];
    adc_acq_if     i_adc_acq;
    adc_lib_if     i_adc_lib[NUM_ADC];
    heat_light_if  i_heat_light[NUM_HEAT_LIGHT];
    heat_if        i_heat[NUM_HEAT_CTRL];
    water_if       i_water;
    radio_if       i_radio;
    spi_master_if  i_spi[1];
    par {
    }
    return 0;
}
```

Showing a forest for some trees

MULTIPLE LOOPS WITH par: XC

```
port but_left                = on tile[0]:XS1_PORT_1N;
port but_center              = on tile[0]:XS1_PORT_1O;
port but_right               = on tile[0]:XS1_PORT_1P;
out buffered port:32 p_miso  = XS1_PORT_1A;
out port             p_ss[1] = {XS1_PORT_1B};
out buffered port:22 p_sclk  = XS1_PORT_1C;
out buffered port:32 p_mosi  = XS1_PORT_1D;
clock                clk_spi = XS1_CLKBLK_1;

int main() {
    //             c_is_channel
    chan           c_buts[NUM_BUTTONS];
    chan           c_ana;
    //             i_is_interface, a collection of RPC-type functions with defined roles (none, client, server)
    i2c_ext_if     i_i2c_ext[NUM_I2C_EX];
    i2c_int_if     i_i2c_int[NUM_I2C_IN];
    adc_acq_if     i_adc_acq;
    adc_lib_if     i_adc_lib[NUM_ADC];
    heat_light_if i_heat_light[NUM_HEAT_LIGHT];
    heat_if        i_heat[NUM_HEAT_CTRL];
    water_if       i_water;
    radio_if       i_radio;
    spi_master_if i_spi[1];
    par {
        on tile[0]:                          installExceptionHandler();
        on tile[0].core[0]: I2C_In_Task      (i_i2c_int);
        on tile[0].core[4]: I2C_Ex_Task      (i_i2c_ext);
        on tile[0]:         Sys_Task         (i_i2c_int[0], i_i2c_ext[0], i_adc_lib[0],
                                              i_heat_light[0], i_heat[0], i_water, c_buts,
                                              i_radio);
        on tile[0].core[0]: Temp_Heater_Task (i_heat, i_i2c_ext[1], i_heat_light[1]);
        on tile[0].core[5]: Temp_Water_Task  (i_water, i_heat[1]);
        on tile[0].core[1]: Button_Task      (BUT_L, but_left,   c_buts[BUT_L]);
        on tile[0].core[1]: Button_Task      (BUT_C, but_center, c_buts[BUT_C]);
        on tile[0].core[1]: Button_Task      (BUT_R, but_right,  c_buts[BUT_R]);
        on tile[0]:         ADC_Task         (i_adc_acq, i_adc_lib, NUM_ADC_DATA);
        on tile[0].core[5]: Port_HL_Task     (i_heat_light);
        on tile[0].core[4]: adc_Task         (i_adc_acq, c_ana, ADC_QUERY);
                            startkit_adc     (c_ana); // XMOS lib
        on tile[0].core[6]: Radio_Task       (i_radio, i_spi);
        on tile[0].core[7]: spi_master       (i_spi, 1, p_sclk, p_mosi, p_miso,
                                              p_ss, 1, clk_spi); // XMOS lib
    }
    return 0;
}
```

Showing a forest for some trees

MULTIPLE LOOPS WITH par: XC

```
port but_left                = on tile[0]:XS1_PORT_1N;
port but_center              = on tile[0]:XS1_PORT_1O;
port but_right               = on tile[0]:XS1_PORT_1P;
out buffered port:32 p_miso  = XS1_PORT_1A;
out port             p_ss[1] = {XS1_PORT_1B};
out buffered port:22 p_sclk  = XS1_PORT_1C;
out buffered port:32 p_mosi  = XS1_PORT_1D;
clock                clk_spi = XS1_CLKBLK_1;

int main() {
    //             c_is_channel
    chan           c_buts[NUM_BUTTONS];
    chan           c_ana;
    //             i_is_interface, a collection of RPC-type functions with defined roles (none, client, server)
    i2c_ext_if     i_i2c_ext[NUM_I2C_EX];
    i2c_int_if     i_i2c_int[NUM_I2C_IN];
    adc_acq_if     i_adc_acq;
    adc_lib_if     i_adc_lib[NUM_ADC];
    heat_light_if i_heat_light[NUM_HEAT_LIGHT];
    heat_if        i_heat[NUM_HEAT_CTRL];
    water_if       i_water;
    radio_if       i_radio;
    spi_master_if i_spi[1];
    par {
        on tile[0]:                          installExceptionHandler();
        on tile[0].core[0]: I2C_In_Task      (i_i2c_int);
        on tile[0].core[4]: I2C_Ex_Task      (i_i2c_ext);
        on tile[0]:         Sys_Task         (i_i2c_int[0], i_i2c_ext[0], i_adc_lib[0],
                                              i_heat_light[0], i_heat[0], i_water, c_buts,
                                              i_radio);
        on tile[0].core[0]: Temp_Heater_Task (i_heat, i_i2c_ext[1], i_heat_light[1]);
        on tile[0].core[5]: Temp_Water_Task  (i_water, i_heat[1]);
        on tile[0].core[1]: Button_Task      (BUT_L, but_left,   c_buts[BUT_L]);
        on tile[0].core[1]: Button_Task      (BUT_C, but_center, c_buts[BUT_C]);
        on tile[0].core[1]: Button_Task      (BUT_R, but_right,  c_buts[BUT_R]);
        on tile[0]:         ADC_Task         (i_adc_acq, i_adc_lib, NUM_ADC_DATA);
        on tile[0].core[5]: Port_HL_Task     (i_heat_light);
        on tile[0].core[4]: adc_Task         (i_adc_acq, c_ana, ADC_QUERY);
                            startkit_adc     (c_ana); // XMOS lib
        on tile[0].core[6]: Radio_Task       (i_radio, i_spi);
        on tile[0].core[7]: spi_master       (i_spi, 1, p_sclk, p_mosi, p_miso,
                                              p_ss, 1, clk_spi); // XMOS lib
    }
    return 0;
}
```

Showing a forest for some trees

MULTIPLE LOOPS WITH par: XC

```
port but_left                = on tile[0]:XS1_PORT_1N;
port but_center              = on tile[0]:XS1_PORT_1O;
port but_right               = on tile[0]:XS1_PORT_1P;
out buffered port:32 p_miso  = XS1_PORT_1A;
out port             p_ss[1] = {XS1_PORT_1B};
out buffered port:22 p_sclk  = XS1_PORT_1C;
out buffered port:32 p_mosi  = XS1_PORT_1D;
clock                clk_spi = XS1_CLKBLK_1;

int main() {
    //             c_is_channel
    chan           c_buts[NUM_BUTTONS];
    chan           c_ana;
    //             i_is_interface, a collection of RPC-type functions with defined roles (none, client, server)
    i2c_ext_if     i_i2c_ext[NUM_I2C_EX];
    i2c_int_if     i_i2c_int[NUM_I2C_IN];
    adc_acq_if     i_adc_acq;
    adc_lib_if     i_adc_lib[NUM_ADC];
    heat_light_if  i_heat_light[NUM_HEAT_LIGHT];
    heat_if        i_heat[NUM_HEAT_CTRL];
    water_if       i_water;
    radio_if       i_radio;
    spi_master_if  i_spi[1];
    par {
        on tile[0]:                          installExceptionHandler();
        on tile[0].core[0]: I2C_In_Task      (i_i2c_int);
        on tile[0].core[4]: I2C_Ex_Task      (i_i2c_ext);
        on tile[0]:         Sys_Task         (i_i2c_int[0], i_i2c_ext[0], i_adc_lib[0],
                                              i_heat_light[0], i_heat[0], i_water, c_buts,
                                              i_radio);
        on tile[0].core[0]: Temp_Heater_Task (i_heat, i_i2c_ext[1], i_heat_light[1]);
        on tile[0].core[5]: Temp_Water_Task  (i_water, i_heat[1]);
        on tile[0].core[1]: Button_Task      (BUT_L, but_left,   c_buts[BUT_L]);
        on tile[0].core[1]: Button_Task      (BUT_C, but_center, c_buts[BUT_C]);
        on tile[0].core[1]: Button_Task      (BUT_R, but_right,  c_buts[BUT_R]);
        on tile[0]:         ADC_Task         (i_adc_acq, i_adc_lib, NUM_ADC_DATA);
        on tile[0].core[5]: Port_HL_Task     (i_heat_light);
        on tile[0].core[4]: adc_Task         (i_adc_acq, c_ana, ADC_QUERY);
                            startkit_adc     (c_ana); // XMOS lib
        on tile[0].core[6]: Radio_Task       (i_radio, i_spi);
        on tile[0].core[7]: spi_master       (i_spi, 1, p_sclk, p_mosi, p_miso,
                                              p_ss, 1, clk_spi); // XMOS lib
    }
    return 0;
}
```

Showing a forest for some trees

MULTIPLE LOOPS WITH par: XC

```
port but_left                = on tile[0]:XS1_PORT_1N;
port but_center              = on tile[0]:XS1_PORT_1O;
port but_right               = on tile[0]:XS1_PORT_1P;
out buffered port:32 p_miso  = XS1_PORT_1A;
out port             p_ss[1] = {XS1_PORT_1B};
out buffered port:22 p_sclk  = XS1_PORT_1C;
out buffered port:32 p_mosi  = XS1_PORT_1D;
clock                clk_spi = XS1_CLKBLK_1;

int main() {
    //             c_is_channel
    chan           c_buts[NUM_BUTTONS];
    chan           c_ana;
    //             i_is_interface, a collection of RPC-type functions with defined roles (none, client, server)
    i2c_ext_if     i_i2c_ext[NUM_I2C_EX];
    i2c_int_if     i_i2c_int[NUM_I2C_IN];
    adc_acq_if     i_adc_acq;
    adc_lib_if     i_adc_lib[NUM_ADC];
    heat_light_if  i_heat_light[NUM_HEAT_LIGHT];
    heat_if        i_heat[NUM_HEAT_CTRL];
    water_if       i_water;
    radio_if       i_radio;
    spi_master_if  i_spi[1];
    par {
        on tile[0]:                          installExceptionHandler();
        on tile[0].core[0]: I2C_In_Task      (i_i2c_int);
        on tile[0].core[4]: I2C_Ex_Task      (i_i2c_ext);
        on tile[0]:         Sys_Task         (i_i2c_int[0], i_i2c_ext[0], i_adc_lib[0],
                                              i_heat_light[0], i_heat[0], i_water, c_buts,
                                              i_radio);
        on tile[0].core[0]: Temp_Heater_Task (i_heat, i_i2c_ext[1], i_heat_light[1]);
        on tile[0].core[5]: Temp_Water_Task  (i_water, i_heat[1]);
        on tile[0].core[1]: Button_Task      (BUT_L, but_left,   c_buts[BUT_L]);
        on tile[0].core[1]: Button_Task      (BUT_C, but_center, c_buts[BUT_C]);
        on tile[0].core[1]: Button_Task      (BUT_R, but_right,  c_buts[BUT_R]);
        on tile[0]:         ADC_Task         (i_adc_acq, i_adc_lib, NUM_ADC_DATA);
        on tile[0].core[5]: Port_HL_Task     (i_heat_light);
        on tile[0].core[4]: adc_Task         (i_adc_acq, c_ana, ADC_QUERY);
                            startkit_adc     (c_ana); // XMOS lib
        on tile[0].core[6]: Radio_Task       (i_radio, i_spi);
        on tile[0].core[7]: spi_master       (i_spi, 1, p_sclk, p_mosi, p_miso,
                                              p_ss, 1, clk_spi); // XMOS lib
    }
    return 0;
}
```

Showing a forest for some trees

MULTIPLE LOOPS WITH par: XC

```
port but_left                = on tile[0]:XS1_PORT_1N;
port but_center              = on tile[0]:XS1_PORT_1O;
port but_right               = on tile[0]:XS1_PORT_1P;
out buffered port:32 p_miso  = XS1_PORT_1A;
out port             p_ss[1] = {XS1_PORT_1B};
out buffered port:22 p_sclk  = XS1_PORT_1C;
out buffered port:32 p_mosi  = XS1_PORT_1D;
clock                clk_spi = XS1_CLKBLK_1;

int main() {
    //            c_is_channel
    chan          c_buts[NUM_BUTTONS];
    chan          c_ana;
    //            i_is_interface, a collection of RPC-type functions with defined roles (none, client, server)
    i2c_ext_if    i_i2c_ext[NUM_I2C_EX];
    i2c_int_if    i_i2c_int[NUM_I2C_IN];
    adc_acq_if    i_adc_acq;
    adc_lib_if    i_adc_lib[NUM_ADC];
    heat_light_if i_heat_light[NUM_HEAT_LIGHT];
    heat_if       i_heat[NUM_HEAT_CTRL];
    water_if      i_water;
    radio_if      i_radio;
    spi_master_if i_spi[1];
    par {
        on tile[0]:                          installExceptionHandler();
        on tile[0].core[0]: I2C_In_Task      (i_i2c_int);
        on tile[0].core[4]: I2C_Ex_Task      (i_i2c_ext);
        on tile[0]:         Sys_Task         (i_i2c_int[0], i_i2c_ext[0], i_adc_lib[0],
                                              i_heat_light[0], i_heat[0], i_water, c_buts,
                                              i_radio);
        on tile[0].core[0]: Temp_Heater_Task (i_heat, i_i2c_ext[1], i_heat_light[1]);
        on tile[0].core[5]: Temp_Water_Task  (i_water, i_heat[1]);
        on tile[0].core[1]: Button_Task      (BUT_L, but_left,   c_buts[BUT_L]);
        on tile[0].core[1]: Button_Task      (BUT_C, but_center, c_buts[BUT_C]);
        on tile[0].core[1]: Button_Task      (BUT_R, but_right,  c_buts[BUT_R]);
        on tile[0]:         ADC_Task         (i_adc_acq, i_adc_lib, NUM_ADC_DATA);
        on tile[0].core[5]: Port_HL_Task     (i_heat_light);
        on tile[0].core[4]: adc_Task         (i_adc_acq, c_ana, ADC_QUERY);
                            startkit_adc     (c_ana); // XMOS lib
        on tile[0].core[6]: Radio_Task       (i_radio, i_spi);
        on tile[0].core[7]: spi_master       (i_spi, 1, p_sclk, p_mosi, p_miso,
                                              p_ss, 1, clk_spi); // XMOS lib
    }
    return 0;
}
```

THIS IS PARALLEL

Showing a forest for some trees

MULTIPLE LOOPS WITH par: XC

```
port but_left                = on tile[0]:XS1_PORT_1N;
port but_center              = on tile[0]:XS1_PORT_1O;
port but_right               = on tile[0]:XS1_PORT_1P;
out buffered port:32 p_miso  = XS1_PORT_1A;
out port             p_ss[1] = {XS1_PORT_1B};
out buffered port:22 p_sclk  = XS1_PORT_1C;
out buffered port:32 p_mosi  = XS1_PORT_1D;
clock                clk_spi = XS1_CLKBLK_1;

int main() {
    //            c_is_channel
    chan          c_buts[NUM_BUTTONS];
    chan          c_ana;
    //            i_is_interface, a collection of RPC-type functions with defined roles (none, client, server)
    i2c_ext_if    i_i2c_ext[NUM_I2C_EX];
    i2c_int_if    i_i2c_int[NUM_I2C_IN];
    adc_acq_if    i_adc_acq;
    adc_lib_if    i_adc_lib[NUM_ADC];
    heat_light_if i_heat_light[NUM_HEAT_LIGHT];
    heat_if       i_heat[NUM_HEAT_CTRL];
    water_if      i_water;
    radio_if      i_radio;
    spi_master_if i_spi[1];
    par {
        on tile[0]:                          installExceptionHandler();
        on tile[0].core[0]: I2C_In_Task      (i_i2c_int);
        on tile[0].core[4]: I2C_Ex_Task      (i_i2c_ext);
        on tile[0]:         Sys_Task         (i_i2c_int[0], i_i2c_ext[0], i_adc_lib[0],
                                              i_heat_light[0], i_heat[0], i_water, c_buts,
                                              i_radio);
        on tile[0].core[0]: Temp_Heater_Task (i_heat, i_i2c_ext[1], i_heat_light[1]);
        on tile[0].core[5]: Temp_Water_Task  (i_water, i_heat[1]);
        on tile[0].core[1]: Button_Task      (BUT_L, but_left,   c_buts[BUT_L]);
        on tile[0].core[1]: Button_Task      (BUT_C, but_center, c_buts[BUT_C]);
        on tile[0].core[1]: Button_Task      (BUT_R, but_right,  c_buts[BUT_R]);
        on tile[0]:         ADC_Task         (i_adc_acq, i_adc_lib, NUM_ADC_DATA);
        on tile[0].core[5]: Port_HL_Task     (i_heat_light);
        on tile[0].core[4]: adc_Task         (i_adc_acq, c_ana, ADC_QUERY);
                            startkit_adc     (c_ana); // XMOS lib
        on tile[0].core[6]: Radio_Task       (i_radio, i_spi);
        on tile[0].core[7]: spi_master       (i_spi, 1, p_sclk, p_mosi, p_miso,
                                              p_ss, 1, clk_spi); // XMOS lib
    }
    return 0;
}
```

THIS IS PARALLEL

XC from my aquarium controller and xTIMEcomposer

CHANNELS – AN ALTERNATIVE TO CALLBACKS AND FUTURES

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TS – Technical Specification

[1] Channels - An Alternative to Callbacks and Futures - John Bandela - CppCon 2016

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TS – Technical Specification

Watch it!

SELECT (ROB PIKE: «GO CONCURRENCY PATTERNS»)

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Google I/O 2012 - Go Concurrency Patterns

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    case c3 <- 23:
        fmt.Printf("sent %v to c3\n", 23)
    default:
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Alternative receives
x, ok       = <-ch
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https://talks.golang.org/2012/concurrency.slide#31

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Autronica

Discussing new runtime scheduler
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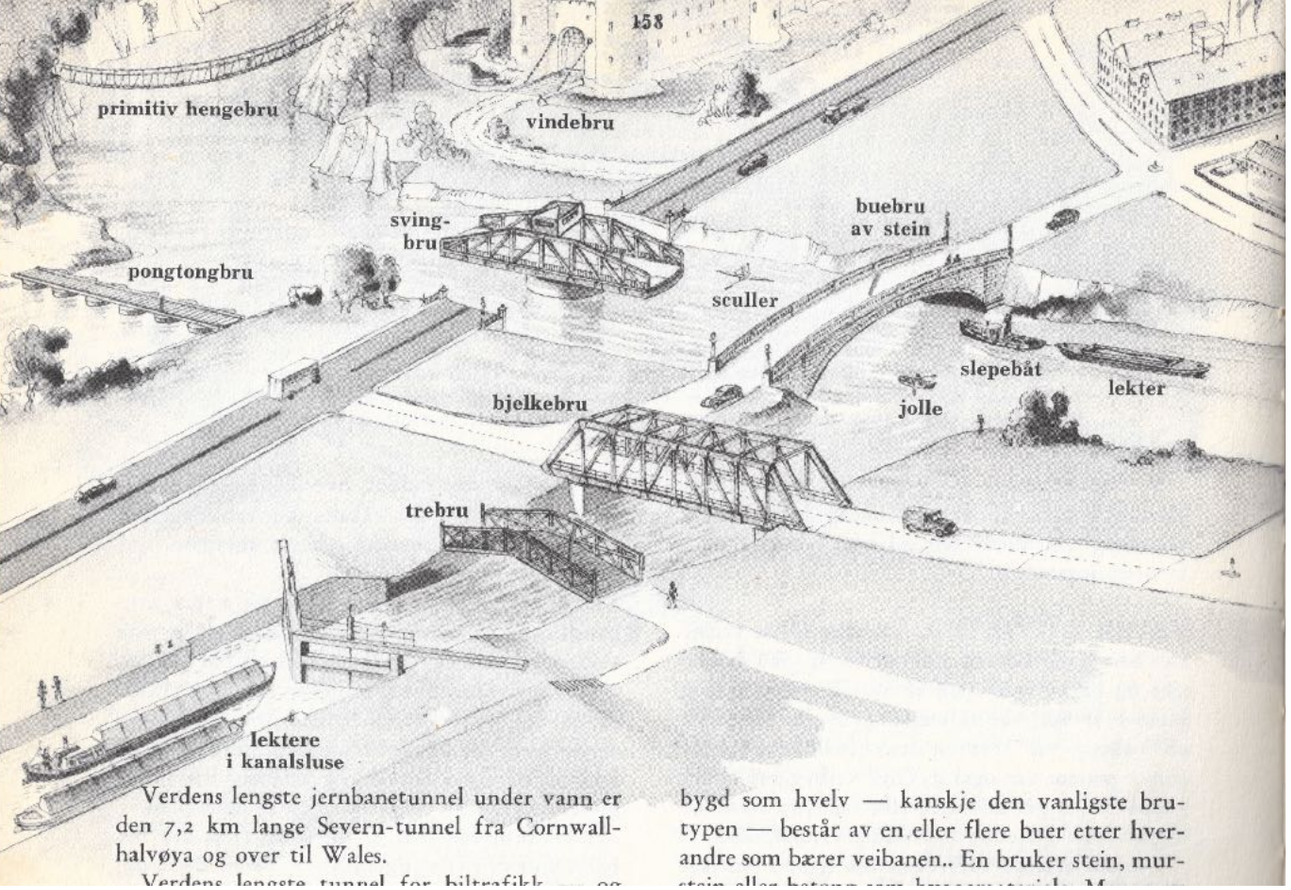
Starting with C CSP-type schedulers (2002)

"Verden omkring oss", 1955 ("Odhams Encyclopedia for Children")



Verdens lengste jernbanetunnel under vann er den 7,2 km lange Severn-tunnel fra Cornwall-halvøya og over til Wales.

Verdens lengste tunnel for biltrafikk — og

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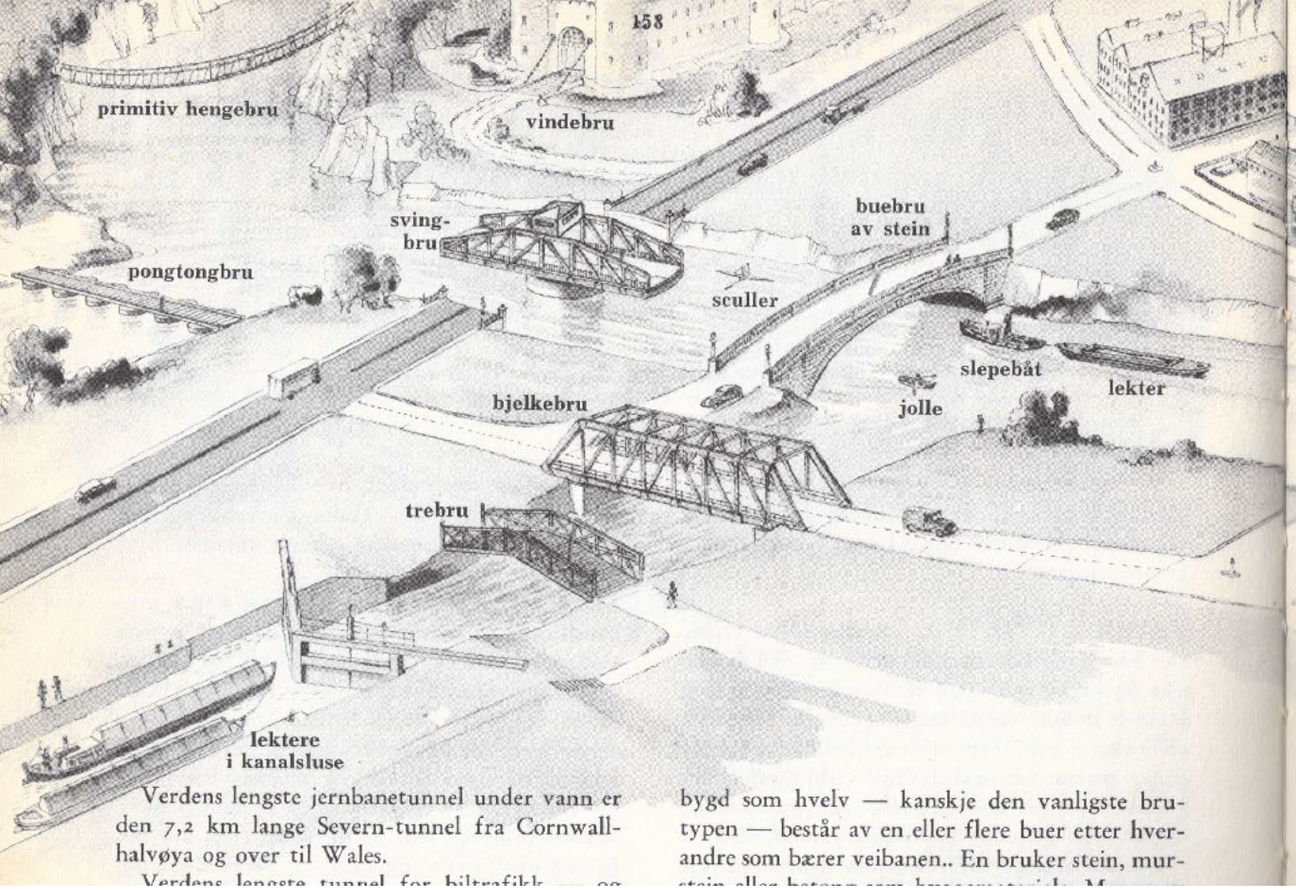

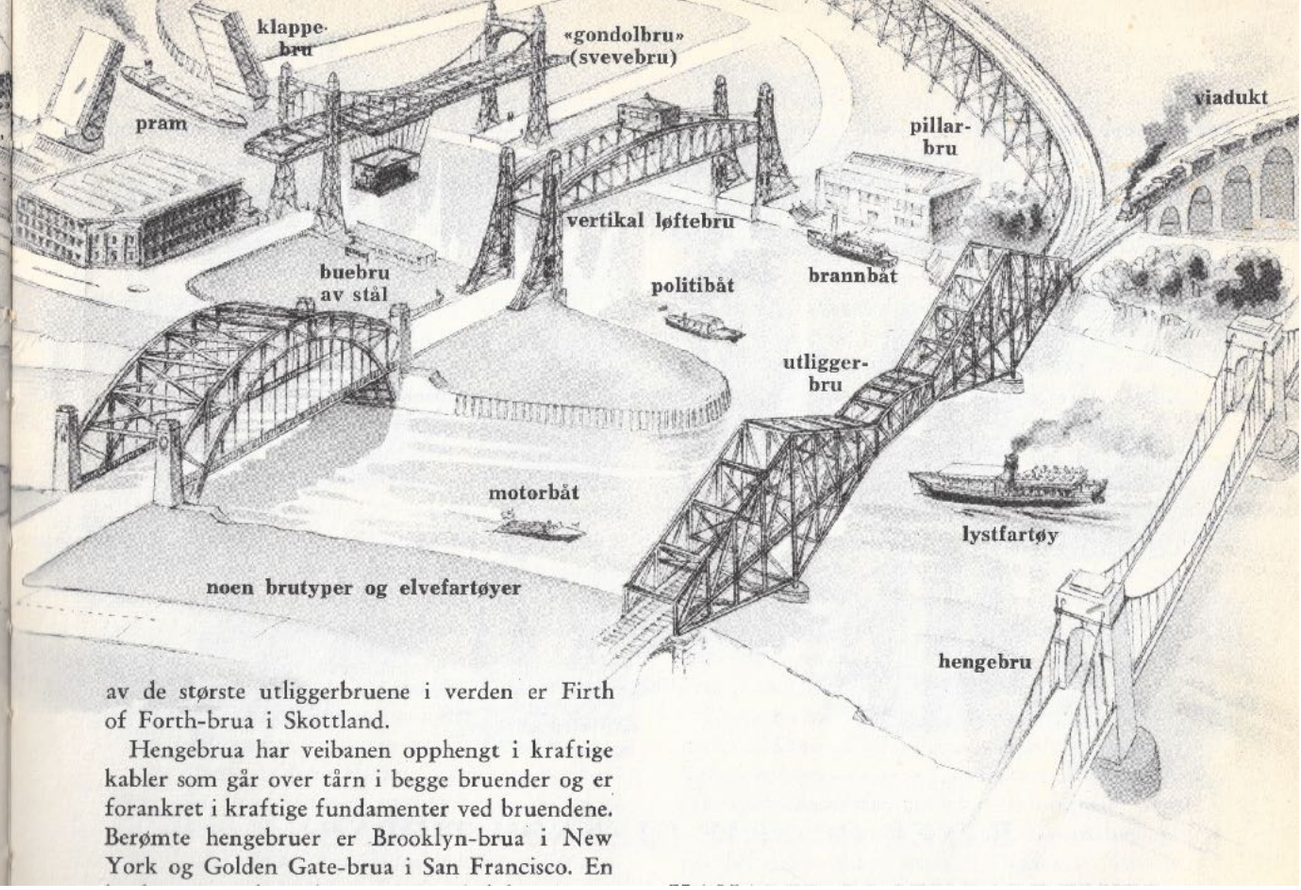

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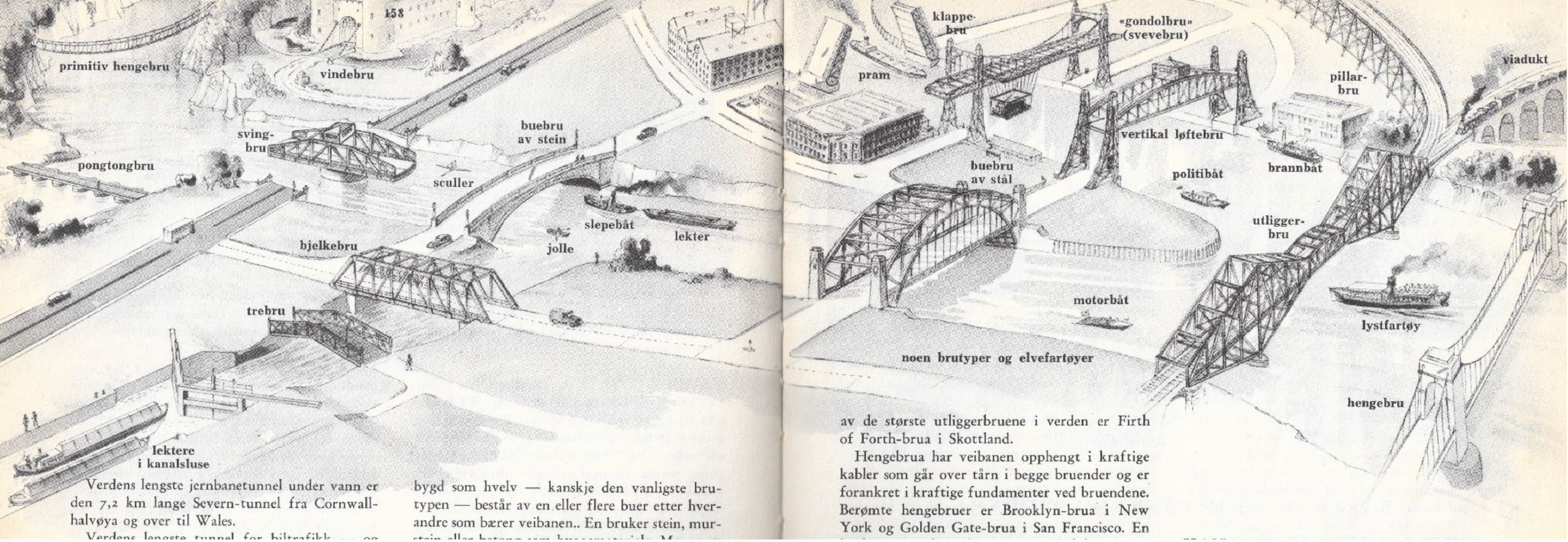

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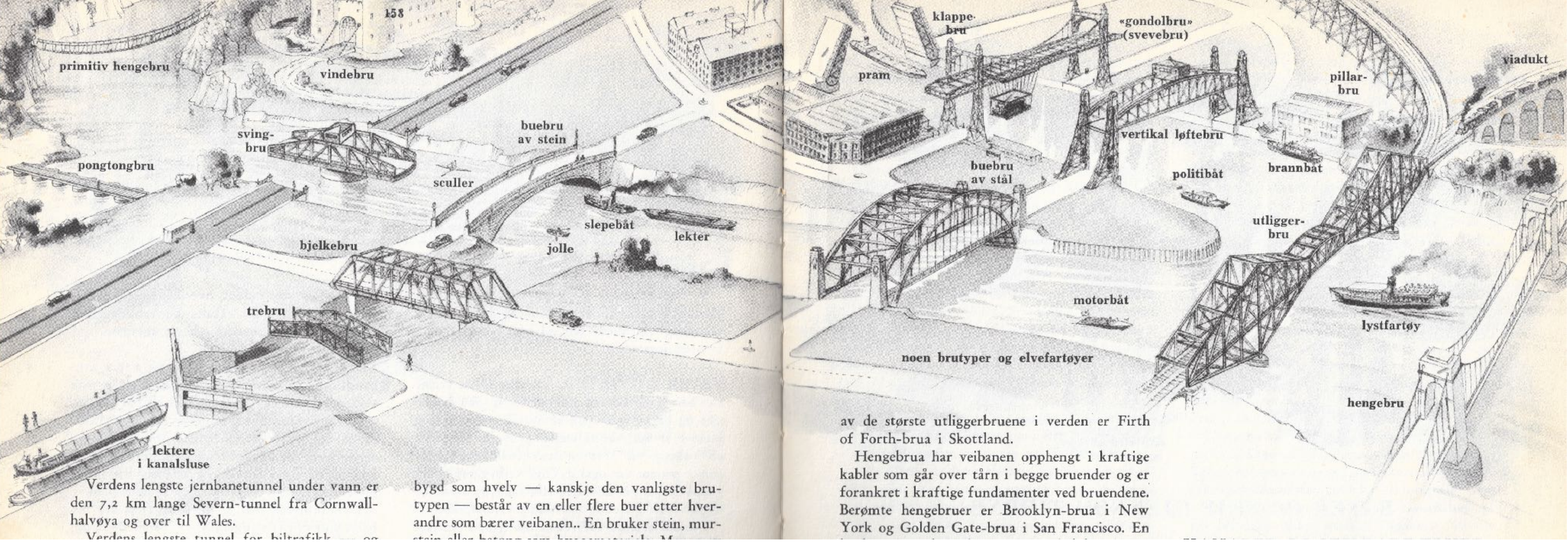

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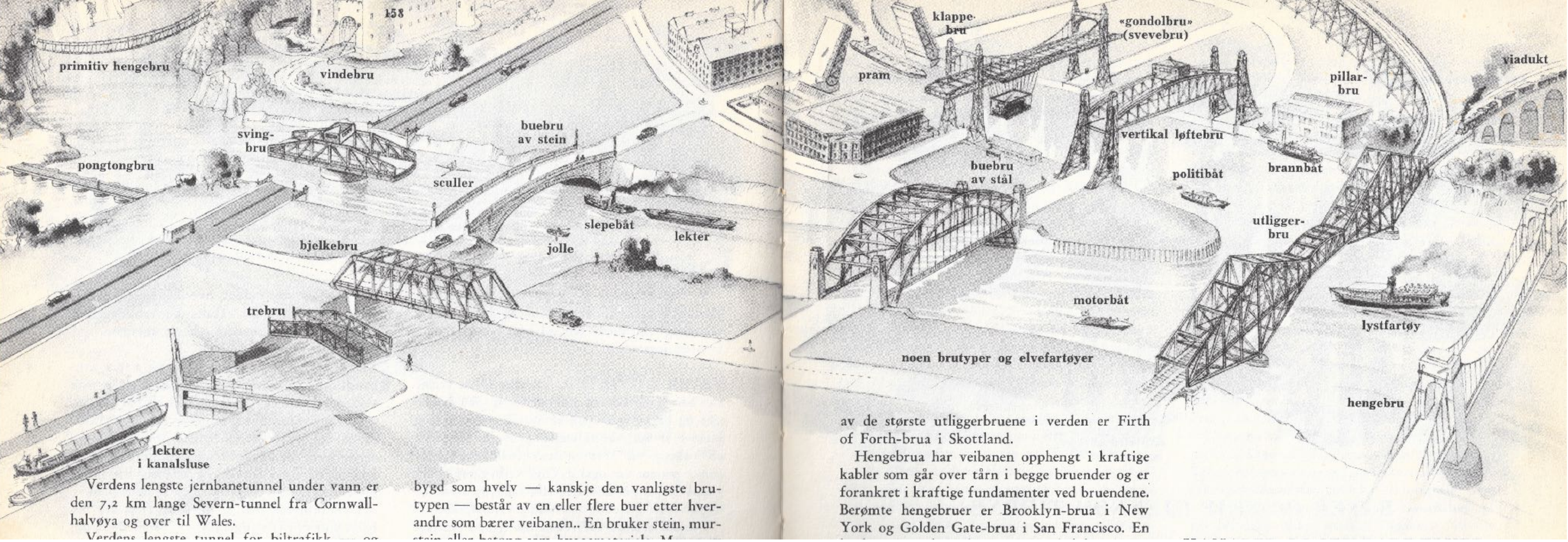

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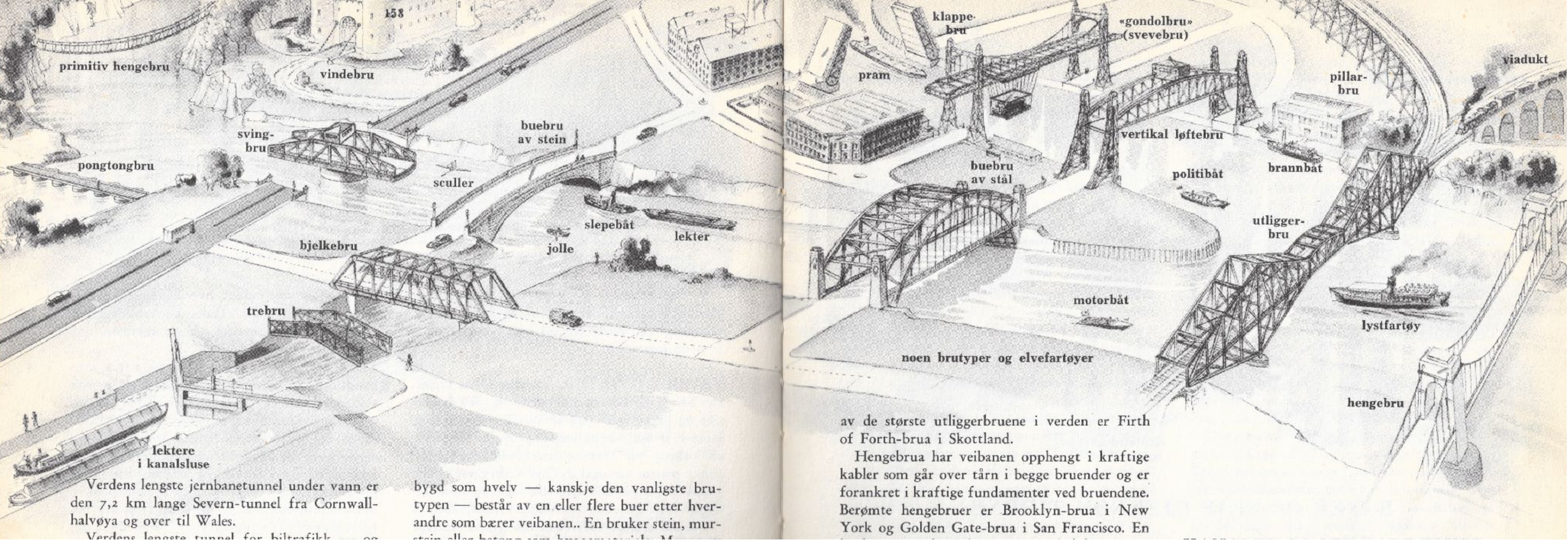

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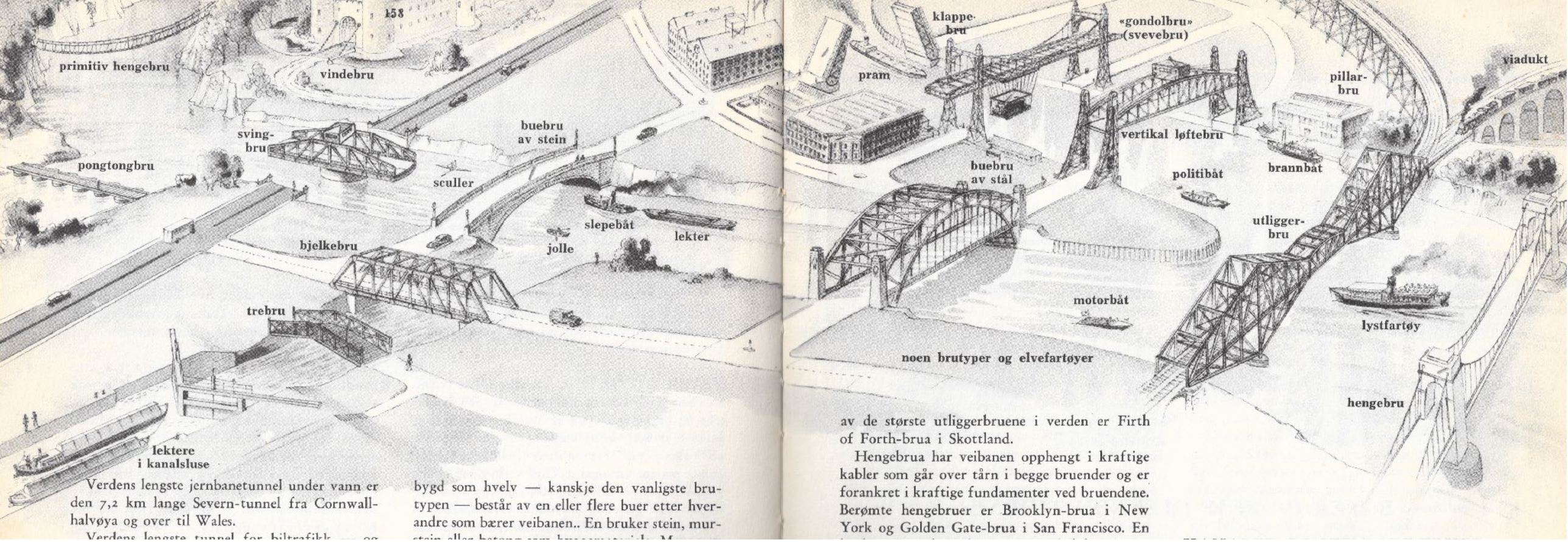

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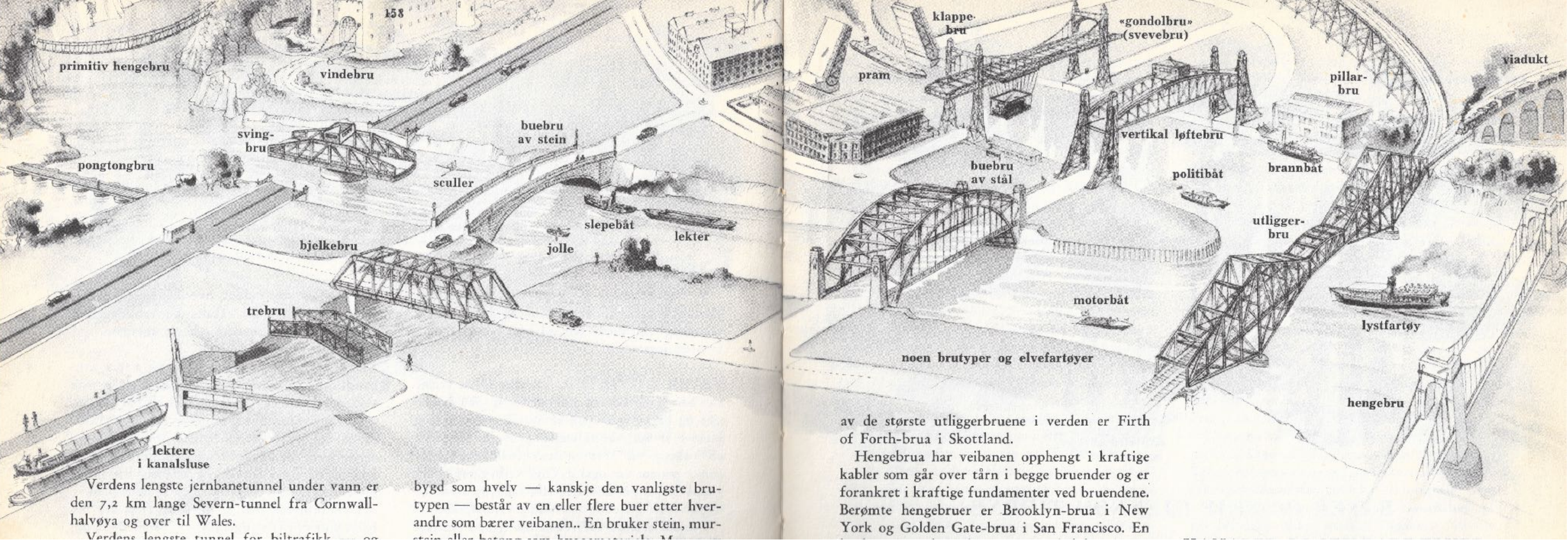

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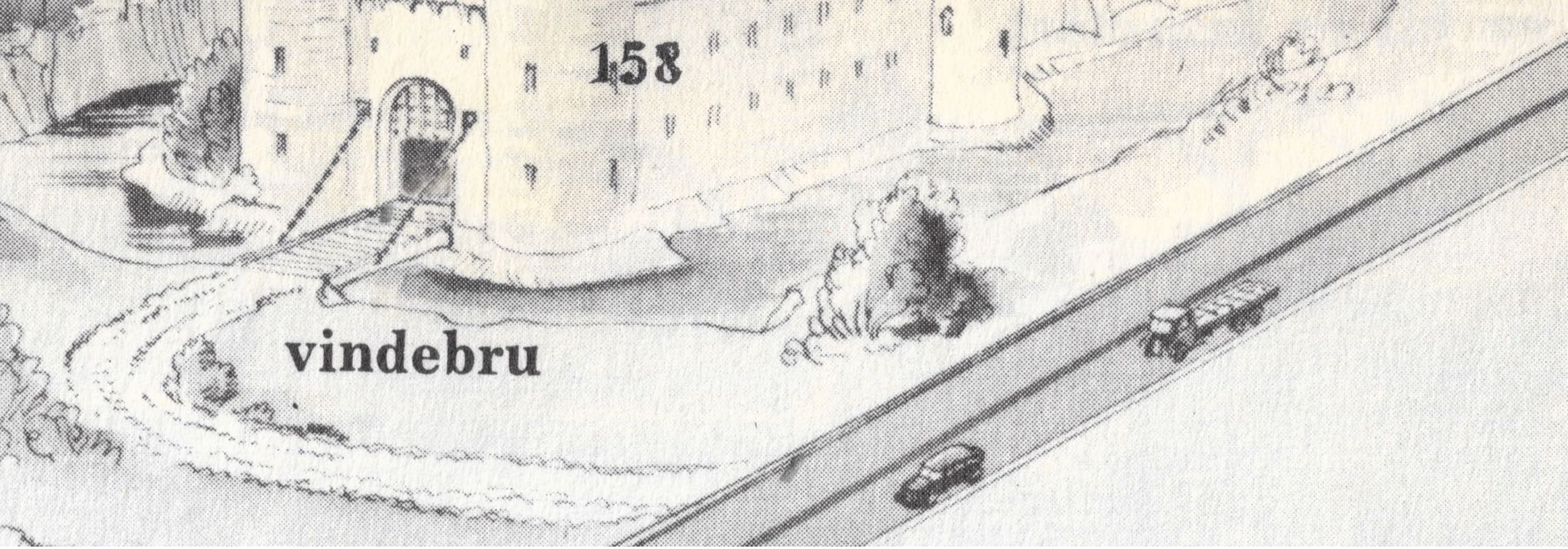
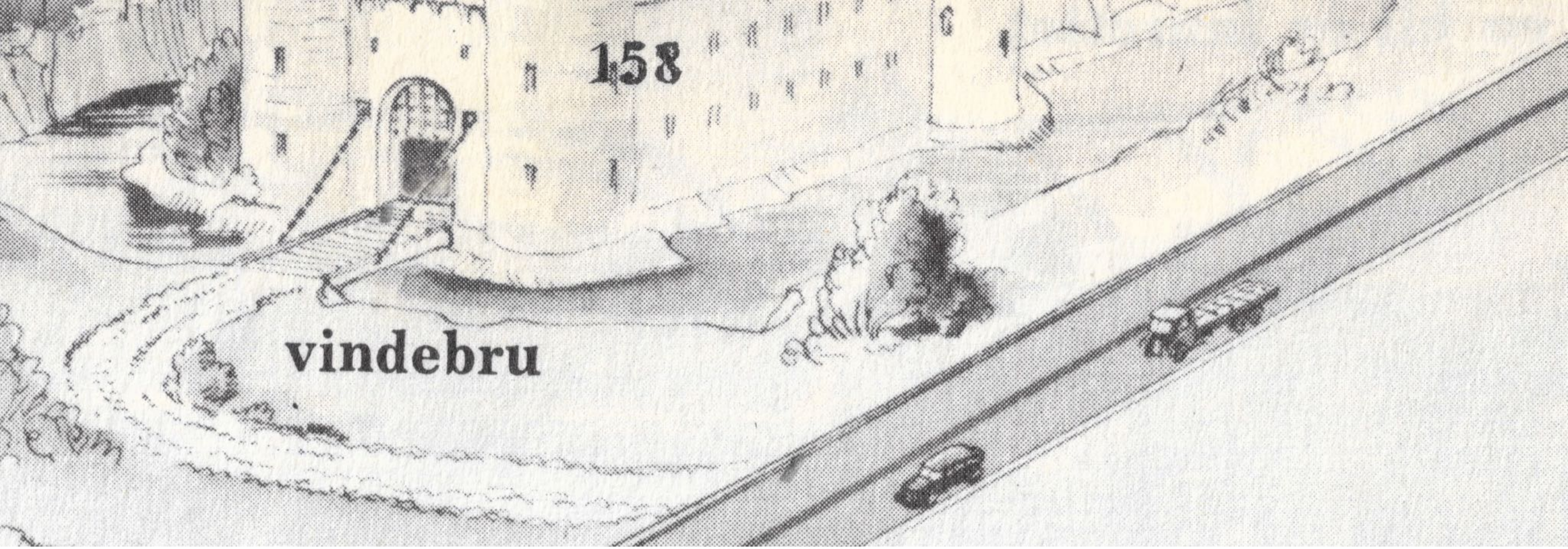
- Which part of this drawing might most resemble a CSP type system? (Even if CSPm may model everything)

THE CASTLE AND DRAWBRIDGE



THE CASTLE AND DRAWBRIDGE

- The castle allows all traffic in (ok!)



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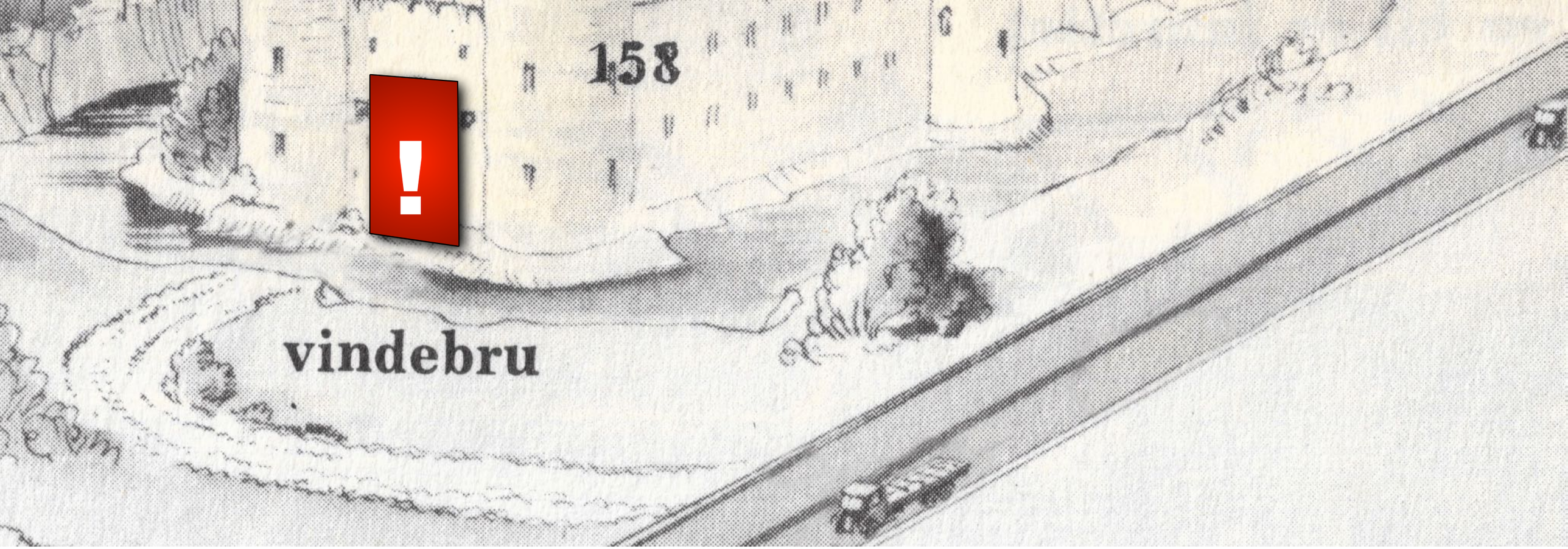

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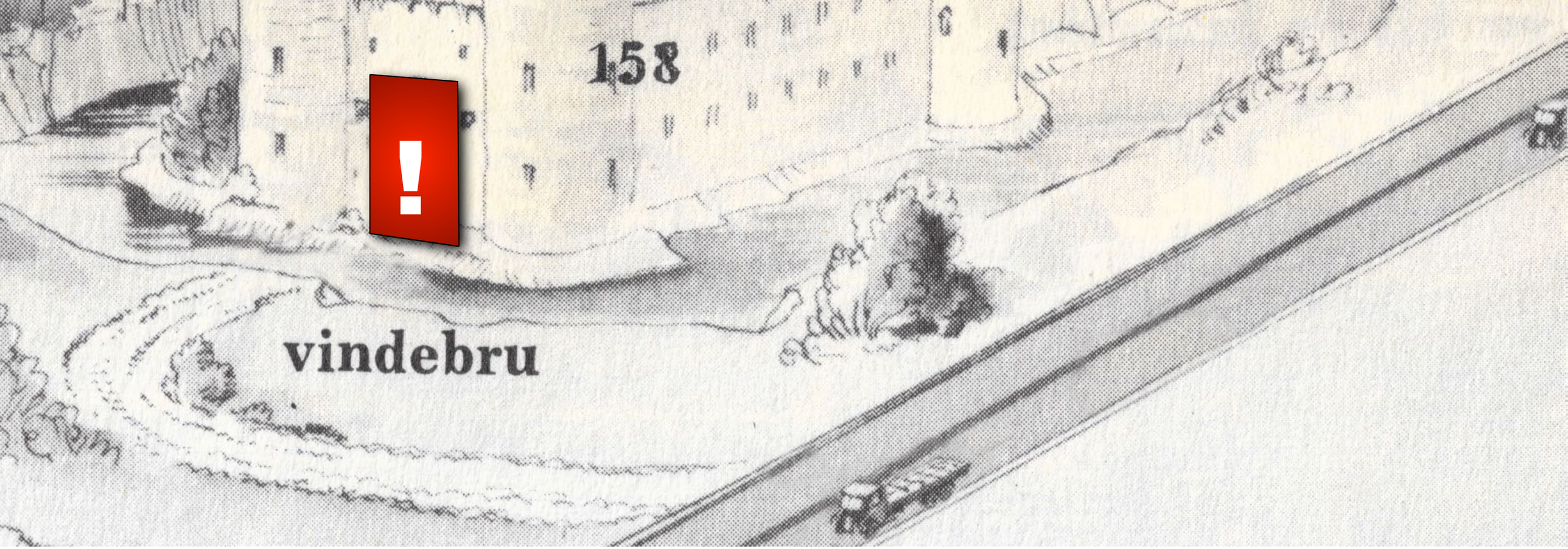
- Now it is protected!



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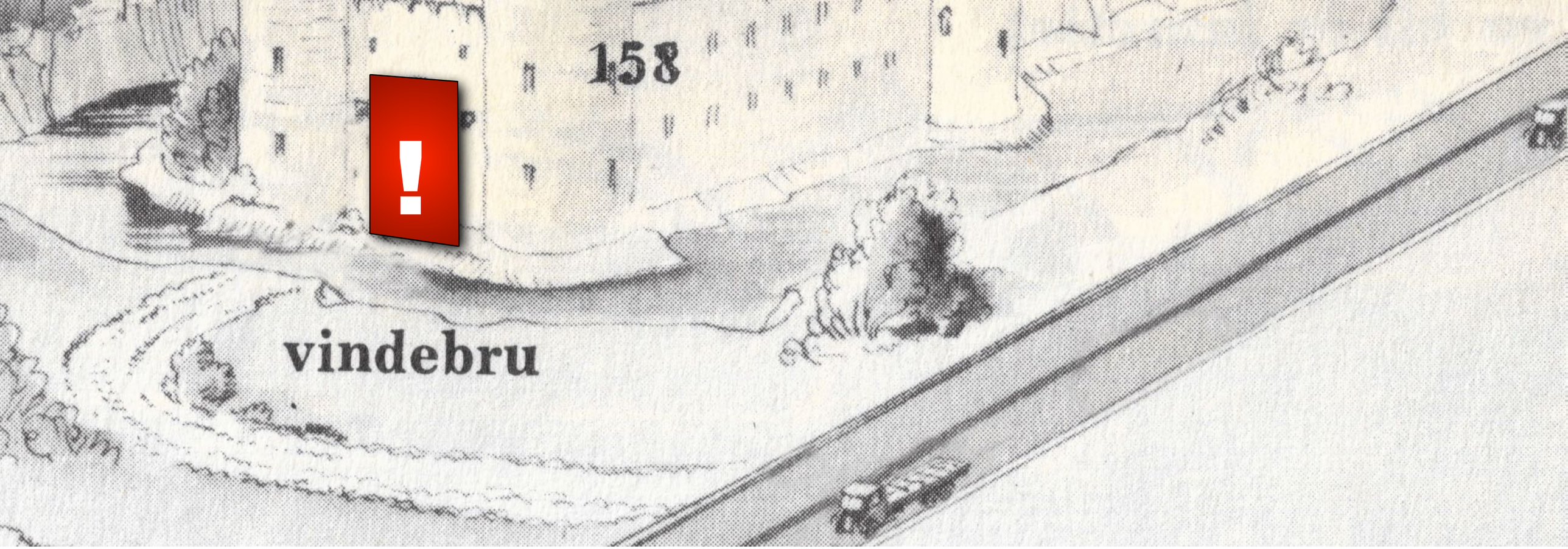

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- I guess that this is the most important page in this lecture!

TERMINOLOGY?

THINKING ABOUT IT:

CHANNELS MORE THAN CONNECT THREADS

THEY PROTECT THEM

TERMINOLOGY?

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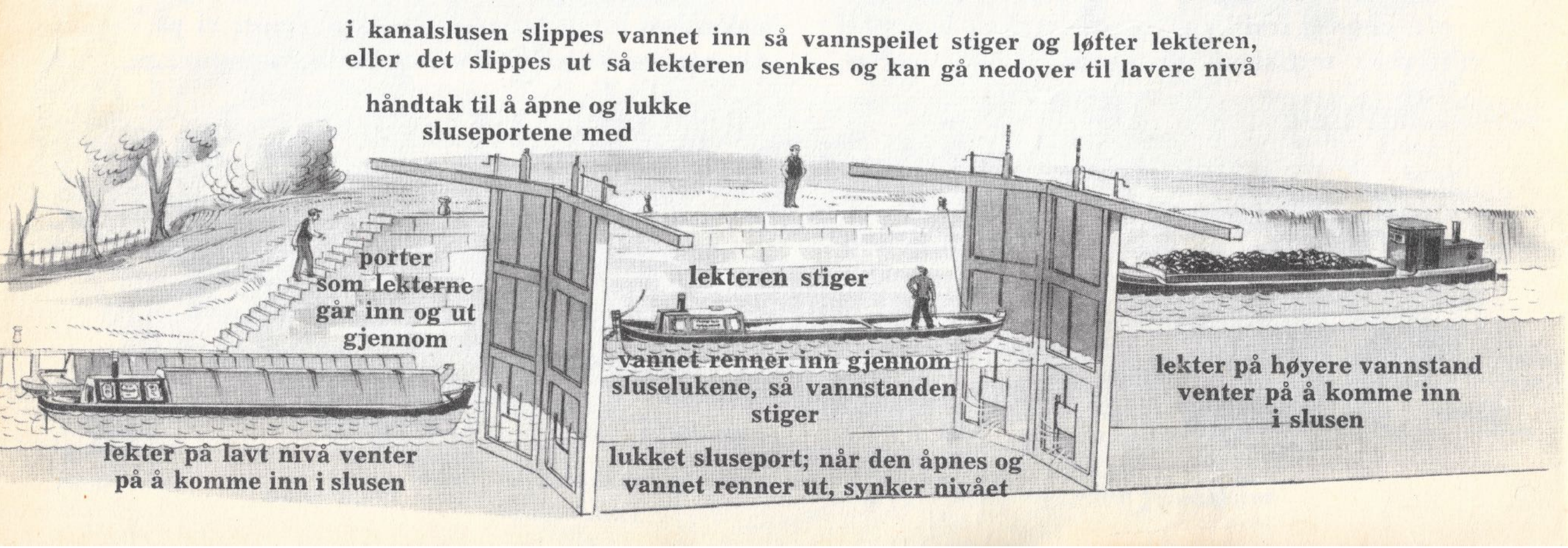
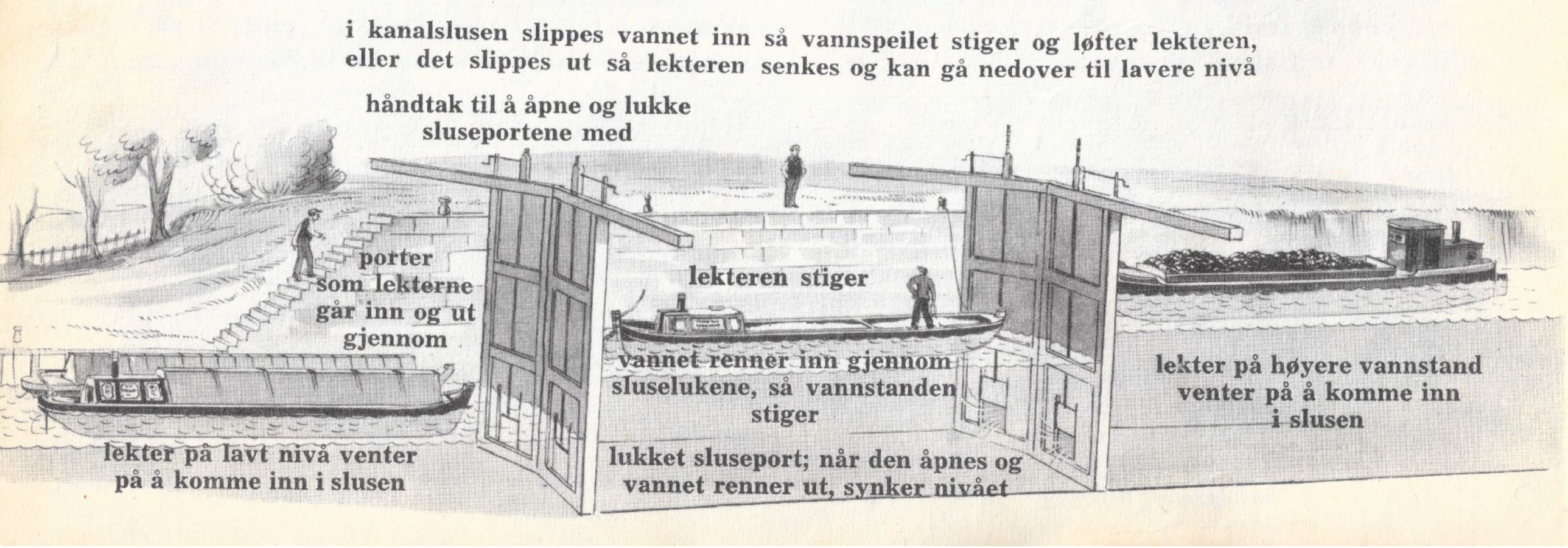
guards

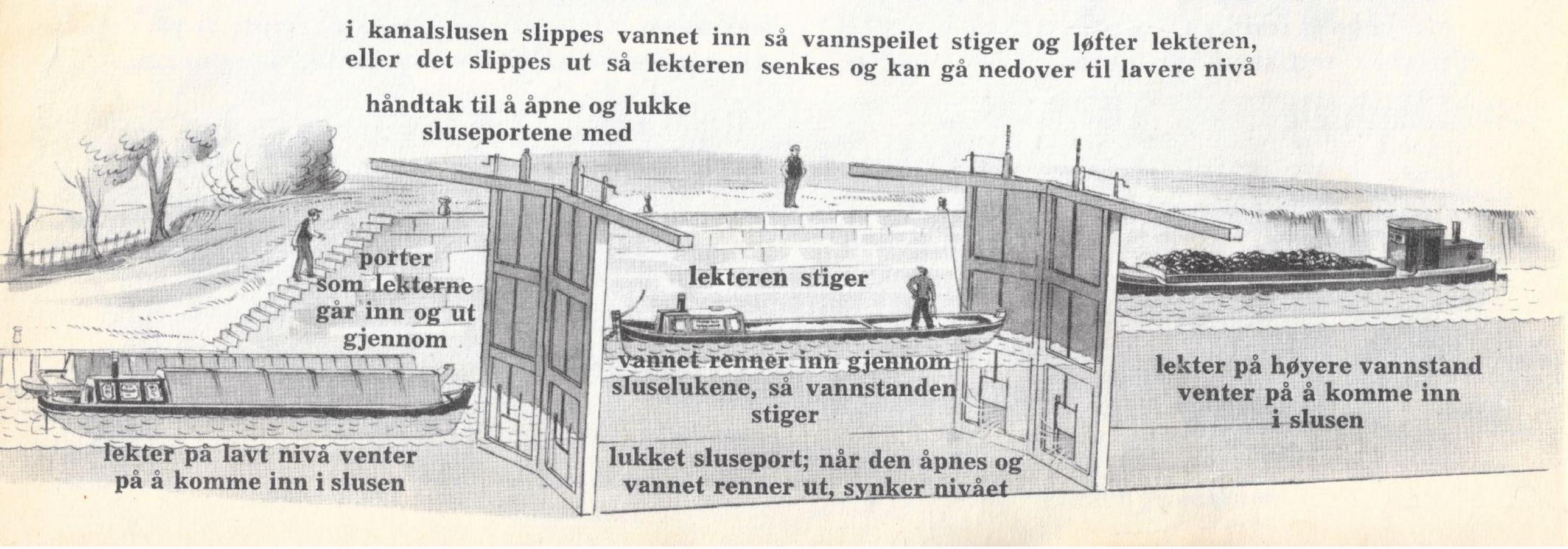
THEY PROTECT THEM



A CHANNEL HAS SEMANTICS

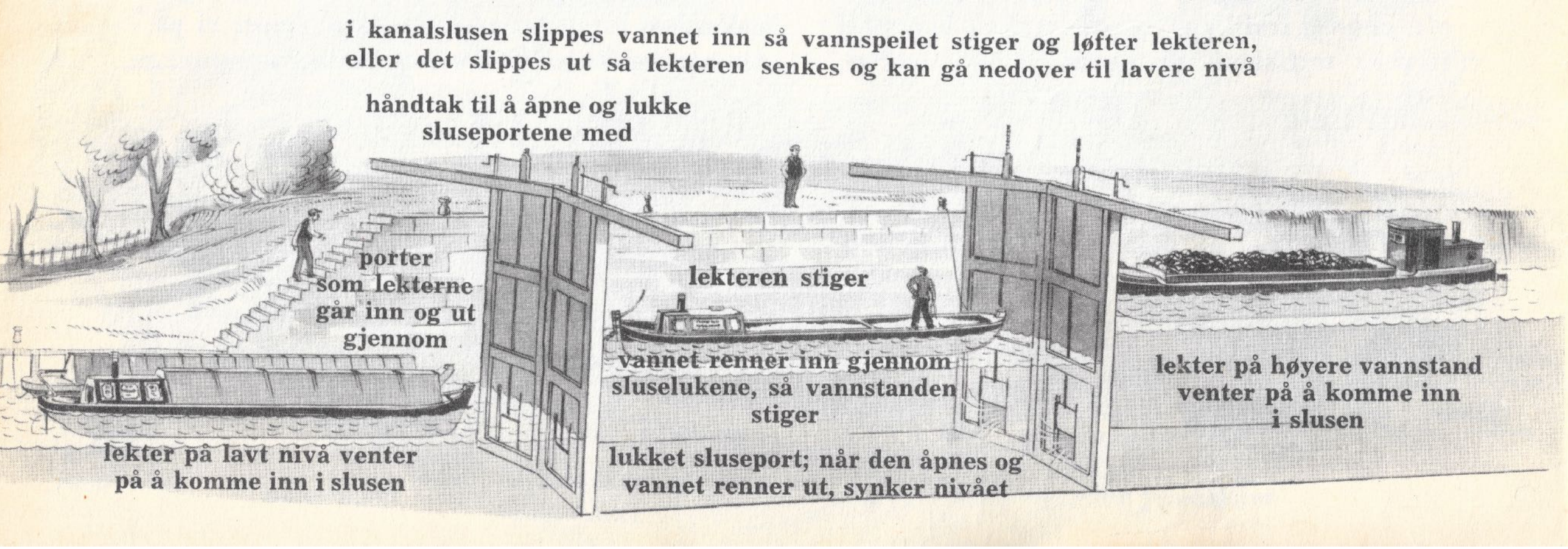


A CANAL LOCK HAS SEMANTICS



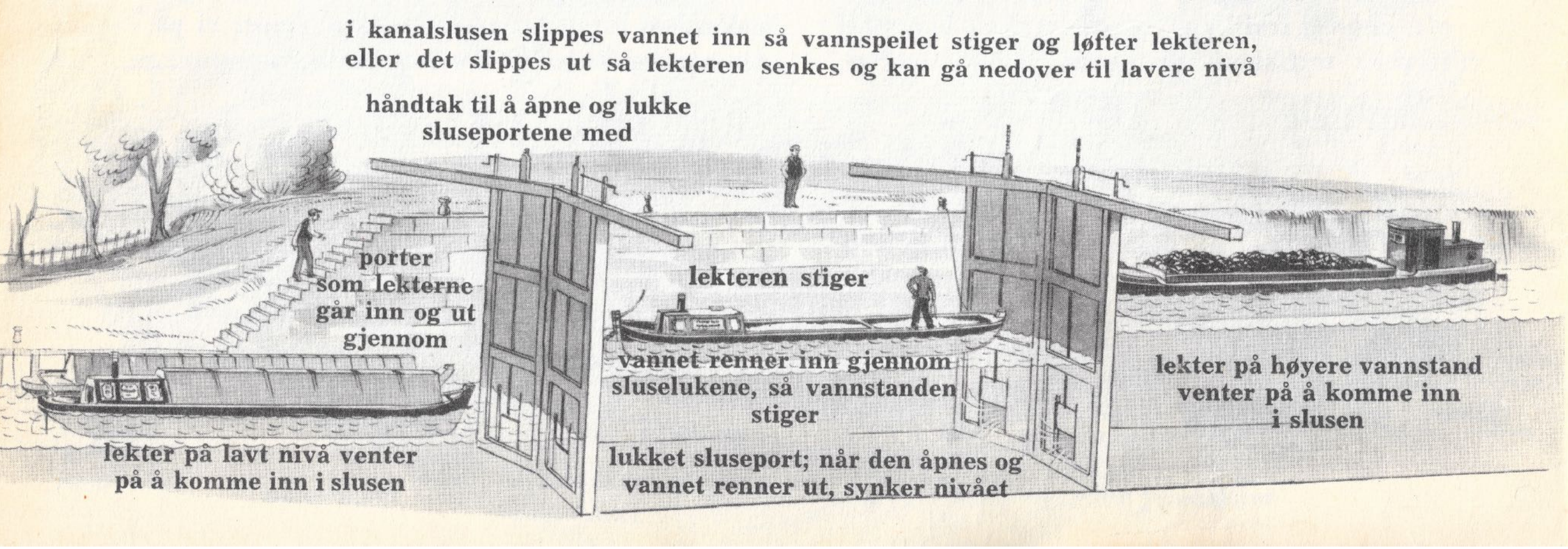
A CANAL LOCK HAS SEMANTICS

- Ship in one direction per turning



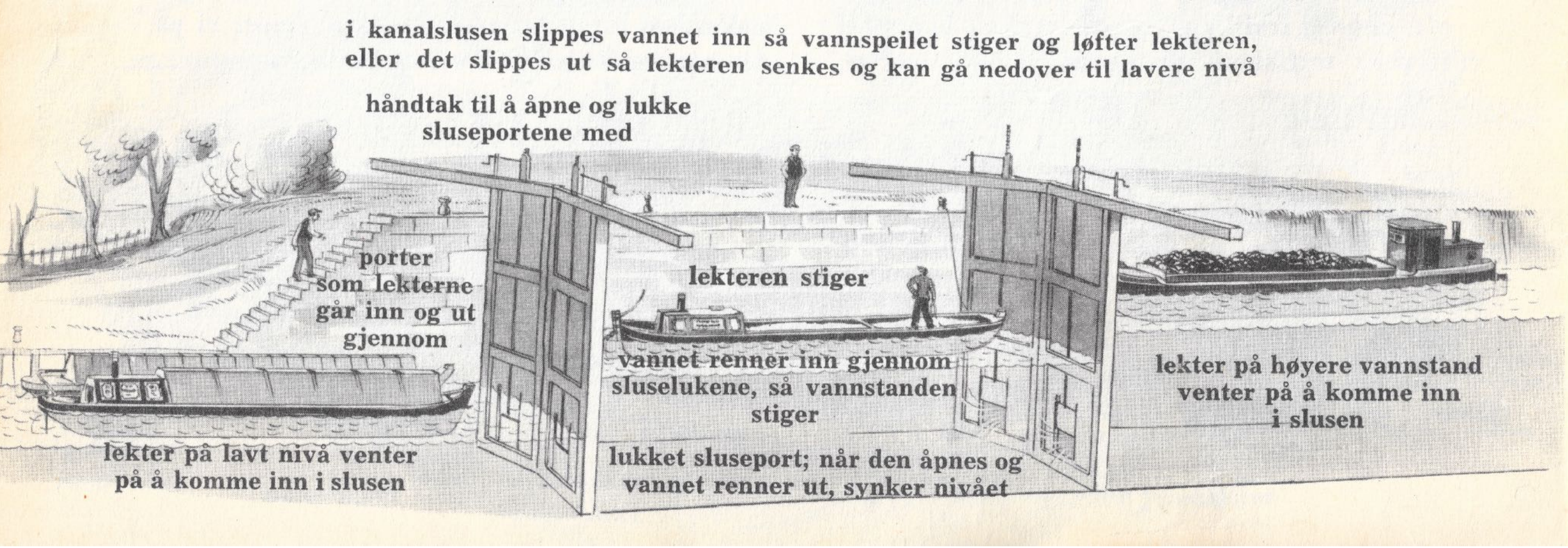
A CANAL LOCK HAS SEMANTICS

- Ship in one direction per turning
- The lock keeper operates it



A CANAL LOCK HAS SEMANTICS

- Ship in one direction per turning
- The lock keeper operates it
- It has «states»



A CANAL LOCK HAS SEMANTICS

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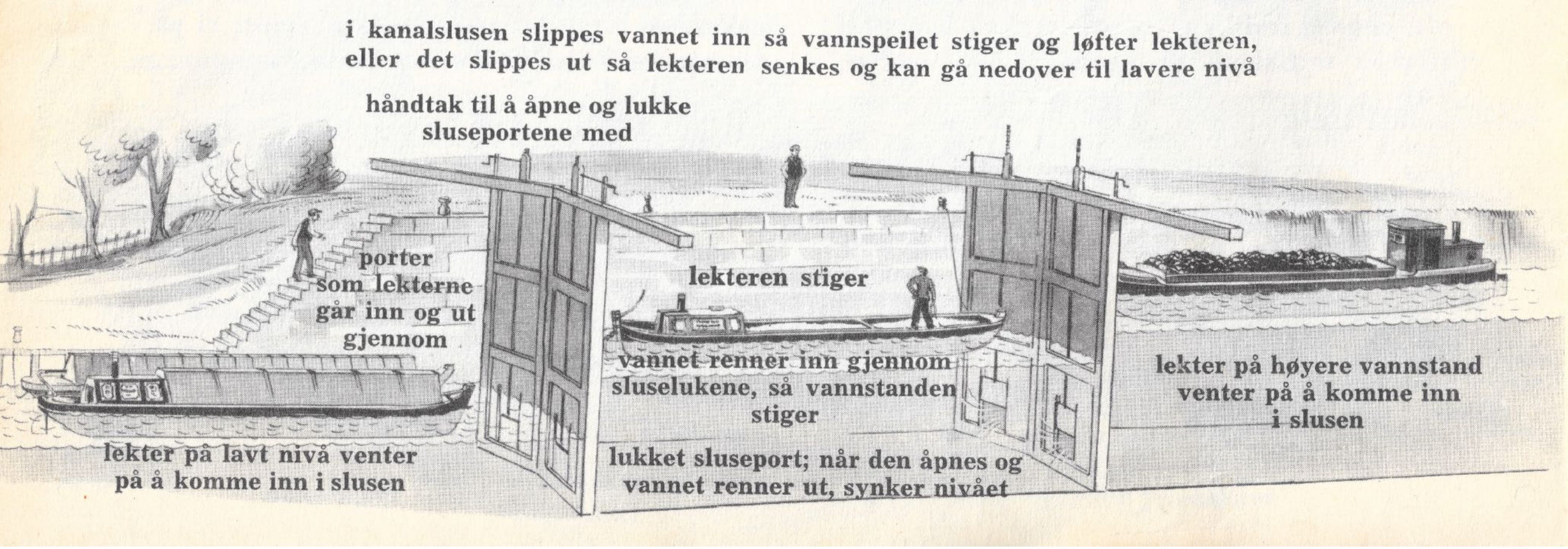
- Channels, buffers, queues, pipes also have their semantics



A CANAL LOCK HAS SEMANTICS

- Ship in one direction per turning
- The lock keeper operates it
- It has «states»
- Channels, buffers, queues, pipes also have their semantics
- Simplest CSP chan: synchronous, one-way, no buffer

CHANNEL SEMANTICS

A

B

X

CHANNEL SEMANTICS

CHANNEL SEMANTICS

CHANNEL SEMANTICS

CHANNEL SEMANTICS

A

B

X

CHANNEL SEMANTICS

A

B

X

A: run

CHANNEL SEMANTICS

A

B

X

A: run

B: dance

CHANNEL SEMANTICS

A

B

X

A: run

B: dance

CHANNEL SEMANTICS

A

B

X

A: run

B: dance - busy!

CHANNEL SEMANTICS

A

B

X

A: run

first: have result!

B: dance - busy!

CHANNEL SEMANTICS

A

B

X

A: run

first: have result!

B: dance - busy!

CHANNEL SEMANTICS

A

B

X

A: run

first: have result!

wait/sleep/block

B: dance - busy!

CHANNEL SEMANTICS

A

B

X

A: run

first: have result!

wait/sleep/block

B: dance - busy!

CHANNEL SEMANTICS

A

B

X

A: run

first: have result!

wait/sleep/block

B: dance - busy!

second: ready!

CHANNEL SEMANTICS

A

B

X

A: run

first: have result!

wait/sleep/block

B: dance - busy!

second: ready!

CHANNEL SEMANTICS

A

B

X

A: run

first: have result!

wait/sleep/block

B: dance - busy!

second: ready!

send > receive

CHANNEL SEMANTICS

A: run

first: have result!

wait/sleep/block

B: dance - busy!

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send > receive

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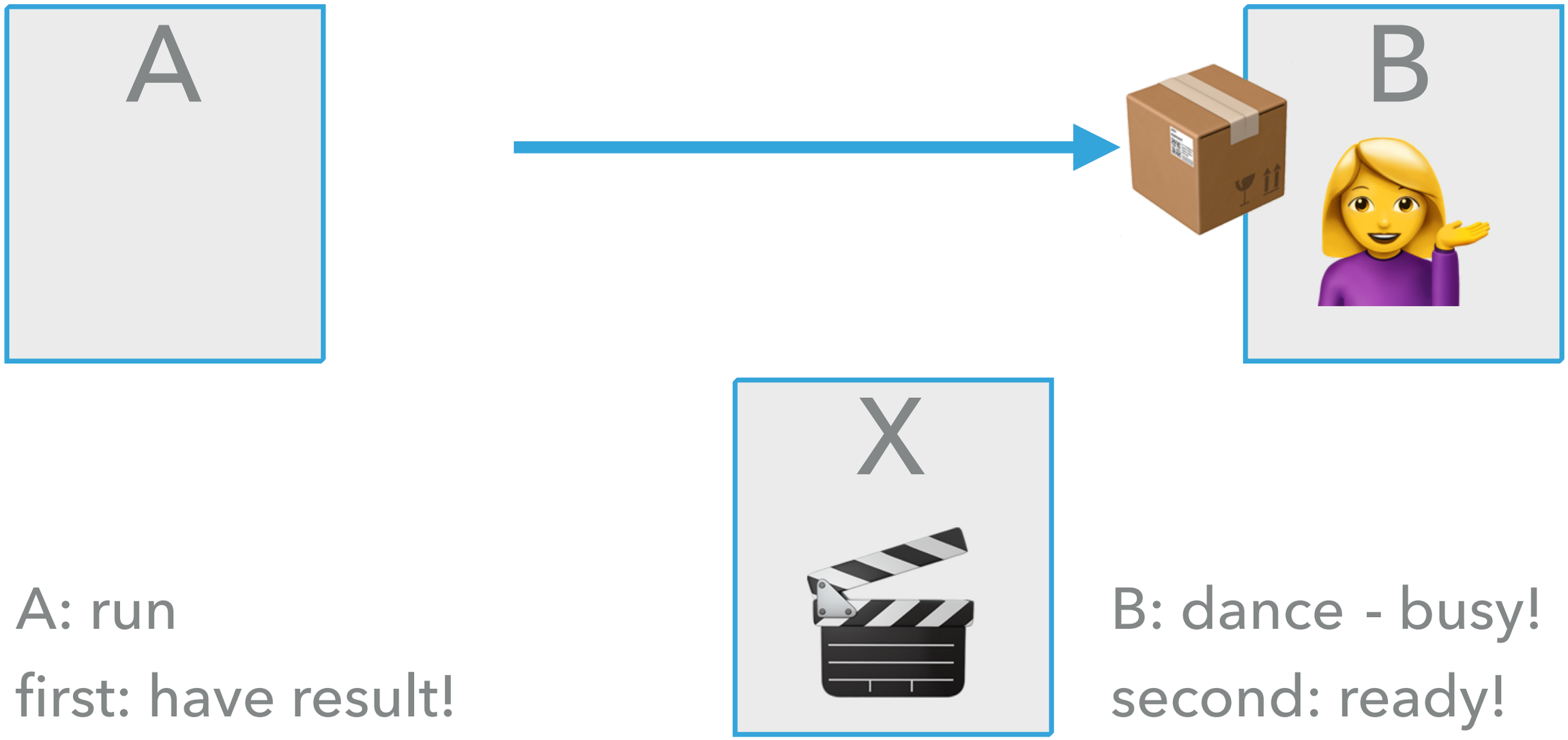
CHANNEL SEMANTICS



A: run

first: have result!

wait/sleep/block

B: dance - busy!

second: ready!

send > receive

CHANNEL SEMANTICS

A

B

X

A: run

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wait/sleep/block

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CHANNEL SEMANTICS

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A: run

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send > receive

thanks! paint

CHANNEL SEMANTICS

A

B

X

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wait/sleep/block

B: dance - busy!

second: ready!

send > receive

thanks! paint

CHANNEL SEMANTICS

A

B

X

A: run

first: have result!

wait/sleep/block

more to do?

send > receive

B: dance - busy!

second: ready!

thanks! paint

CHANNEL SEMANTICS

A

B

X

A: run

first: have result!

wait/sleep/block

more to do?

send > receive

B: dance - busy!

second: ready!

thanks! paint

CHANNEL SEMANTICS

A

B

X

A: run

first: have result!

wait/sleep/block

more to do?

send > receive

synchronous
unbuffered

B: dance - busy!

second: ready!

thanks! paint

CHANNEL SEMANTICS

A

B

Has been undisturbed and running all the time!

X

A: run

first: have result!

wait/sleep/block

more to do?

B: dance - busy!

second: ready!

send > receive

synchronous unbuffered

thanks! paint

SAFE MEMCPY, NO POINTERS TO SHARED DATA

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```
CHAN_OUT (Chan1, ACPtr->Data);
```

Chan state (first, local ptr, length)

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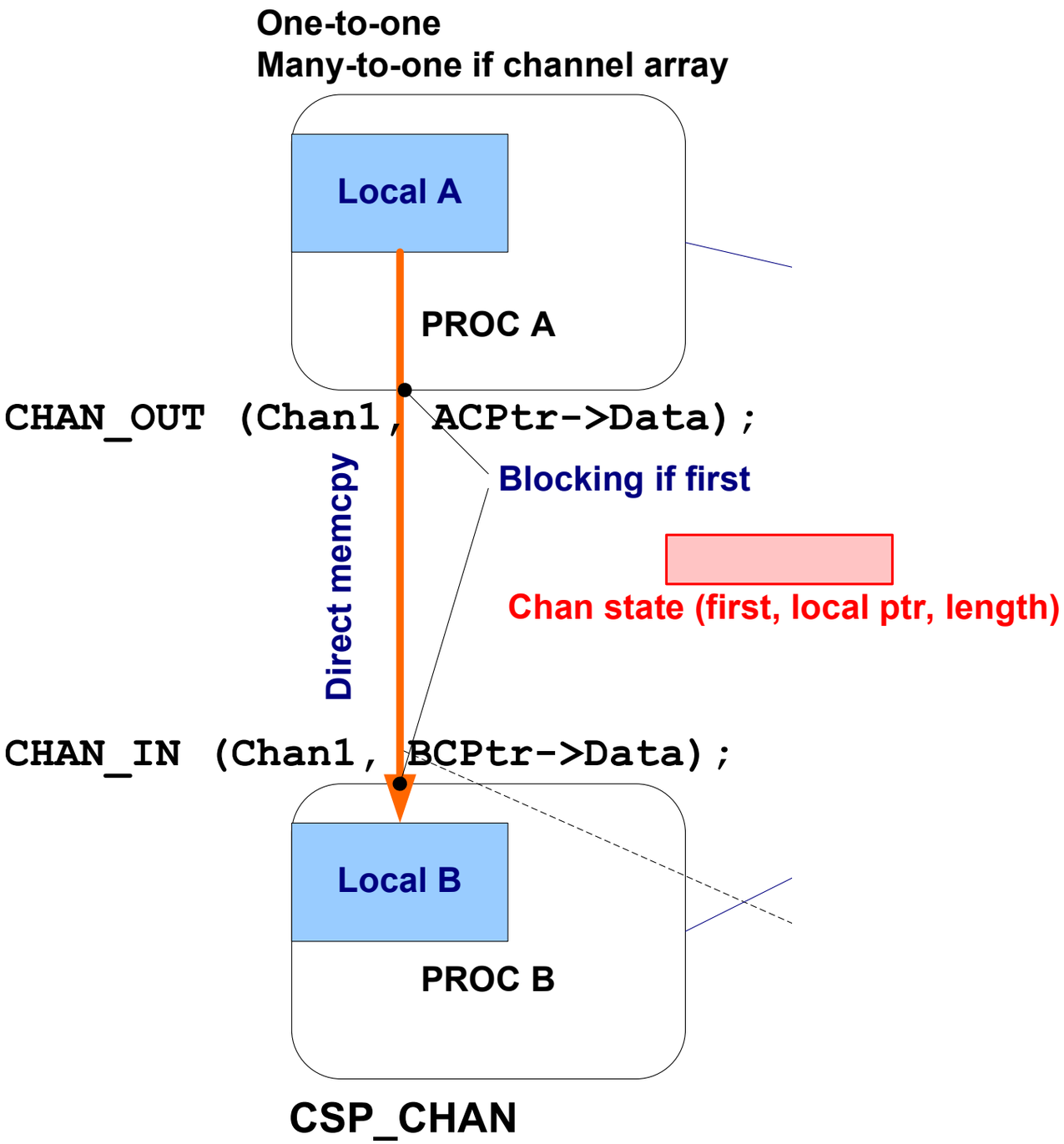
```
CHAN_IN (Chan1, BCPtr->Data);
```

SAFE MEMCPY, NO POINTERS TO SHARED DATA



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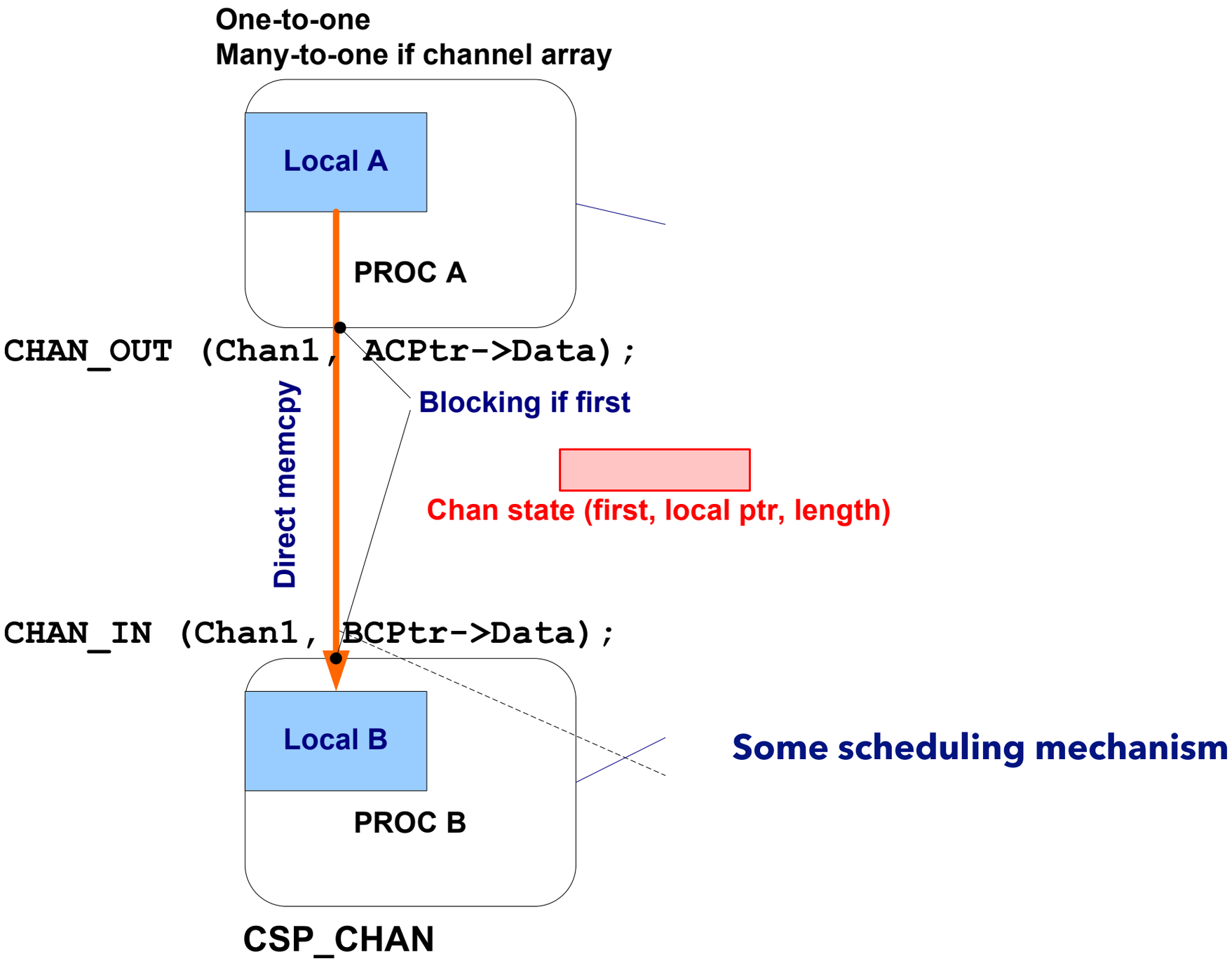
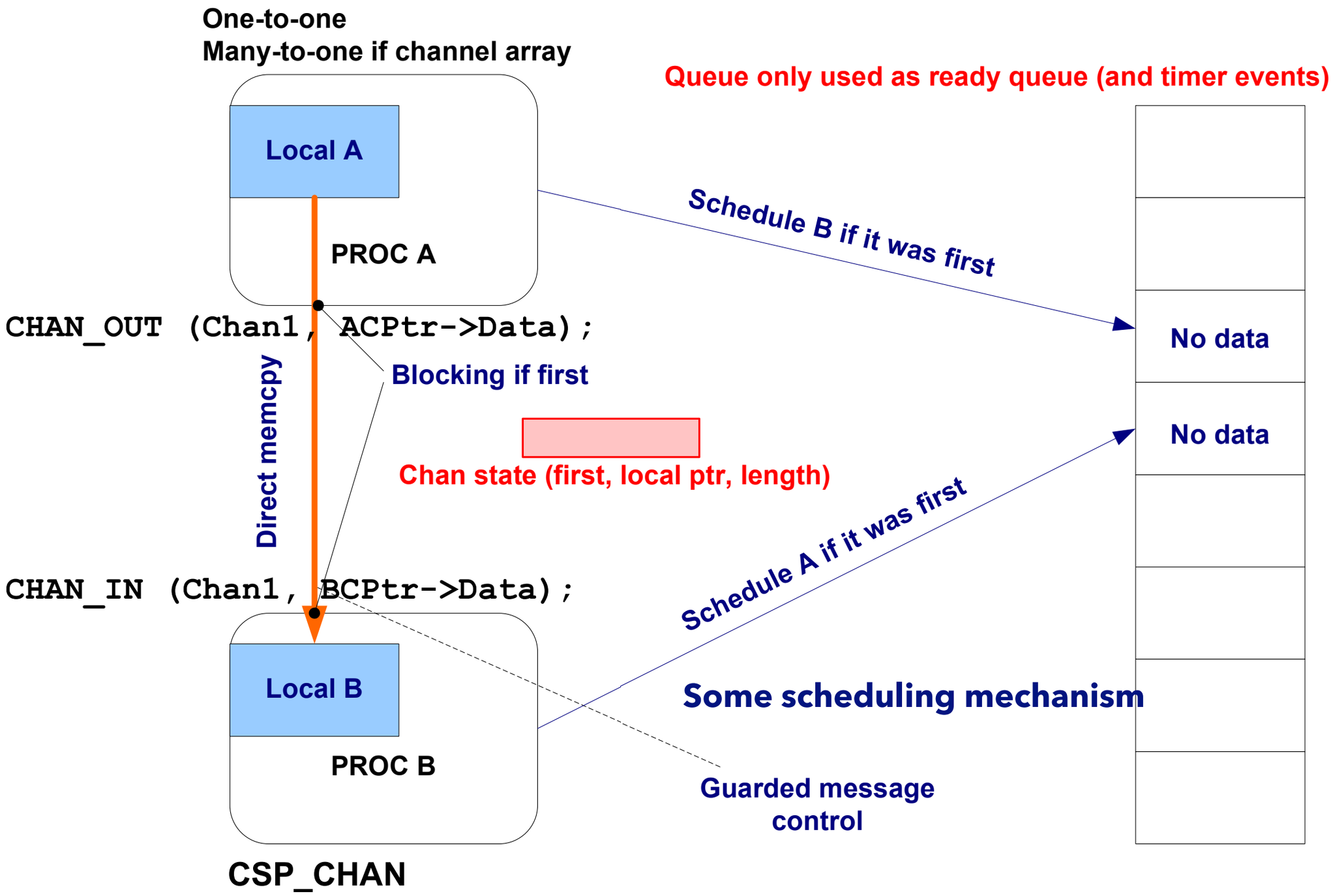


SAFE MEMCPY, NO POINTERS TO SHARED DATA



PLAN TO LOSE DATA!

I TALK 🤓 TALK TO YOU, BUT HOW MUCH DID WE LOSE? 😷

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  - Buffer full when no more memory: *restart*!😱
  - Therefore:

PAUSE!

From a blog note

«…-delay/timeout-pollRx» IS NOT A CONTRACT!

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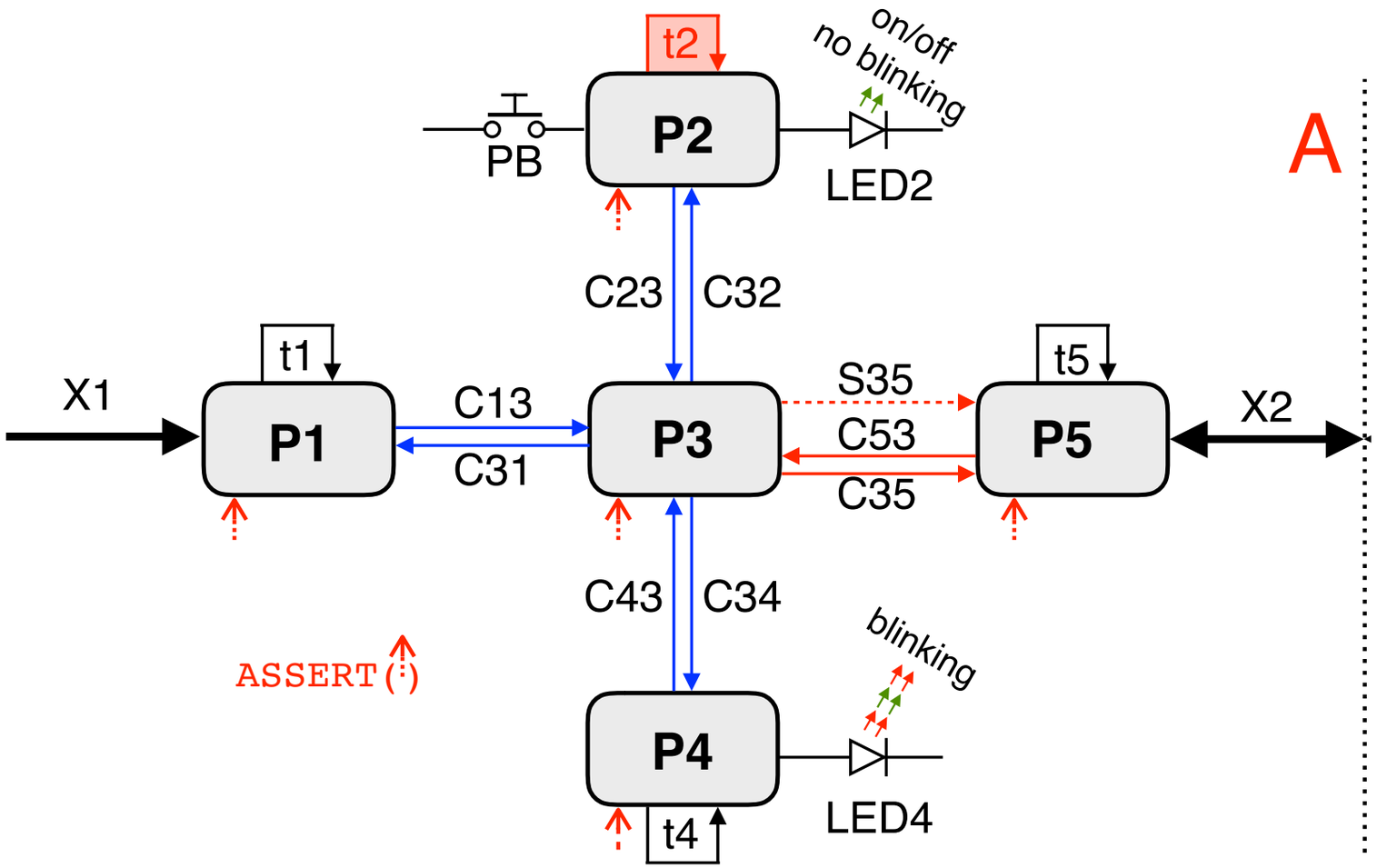

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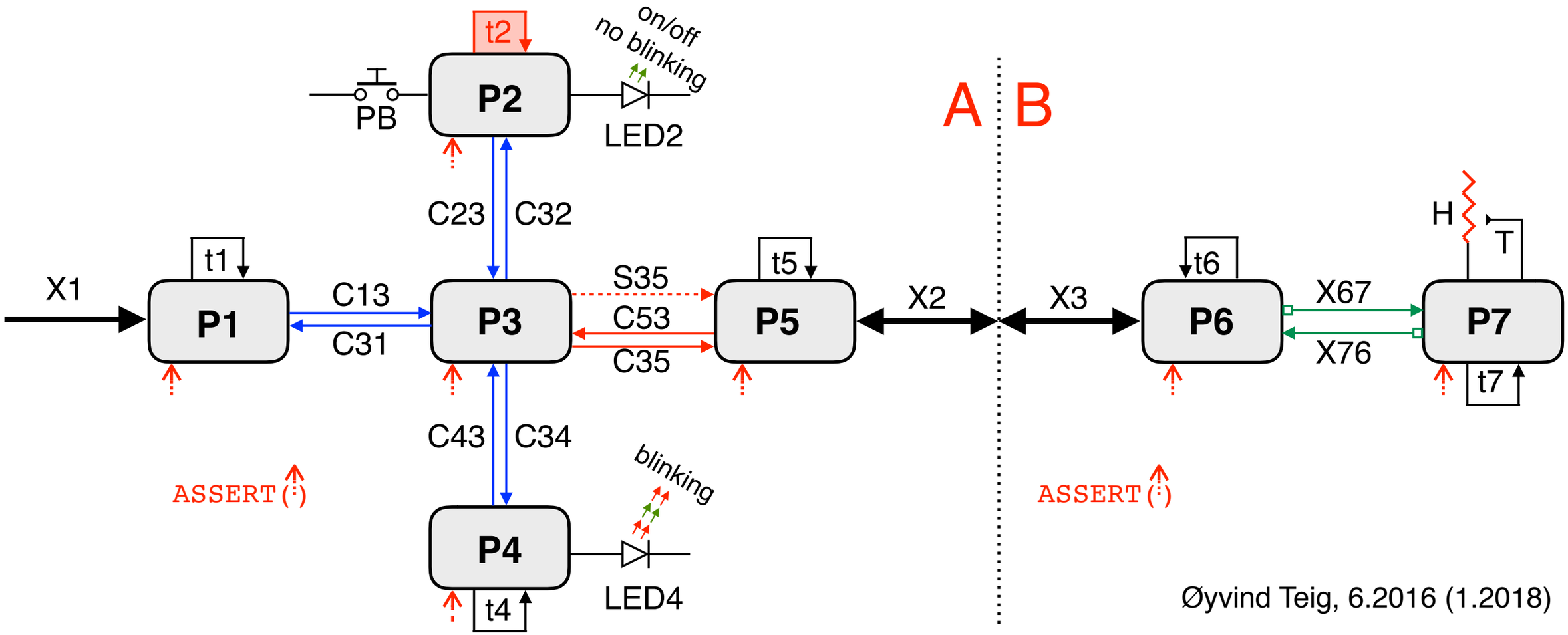

Øyvind Teig, 6.2016 (1.2018)

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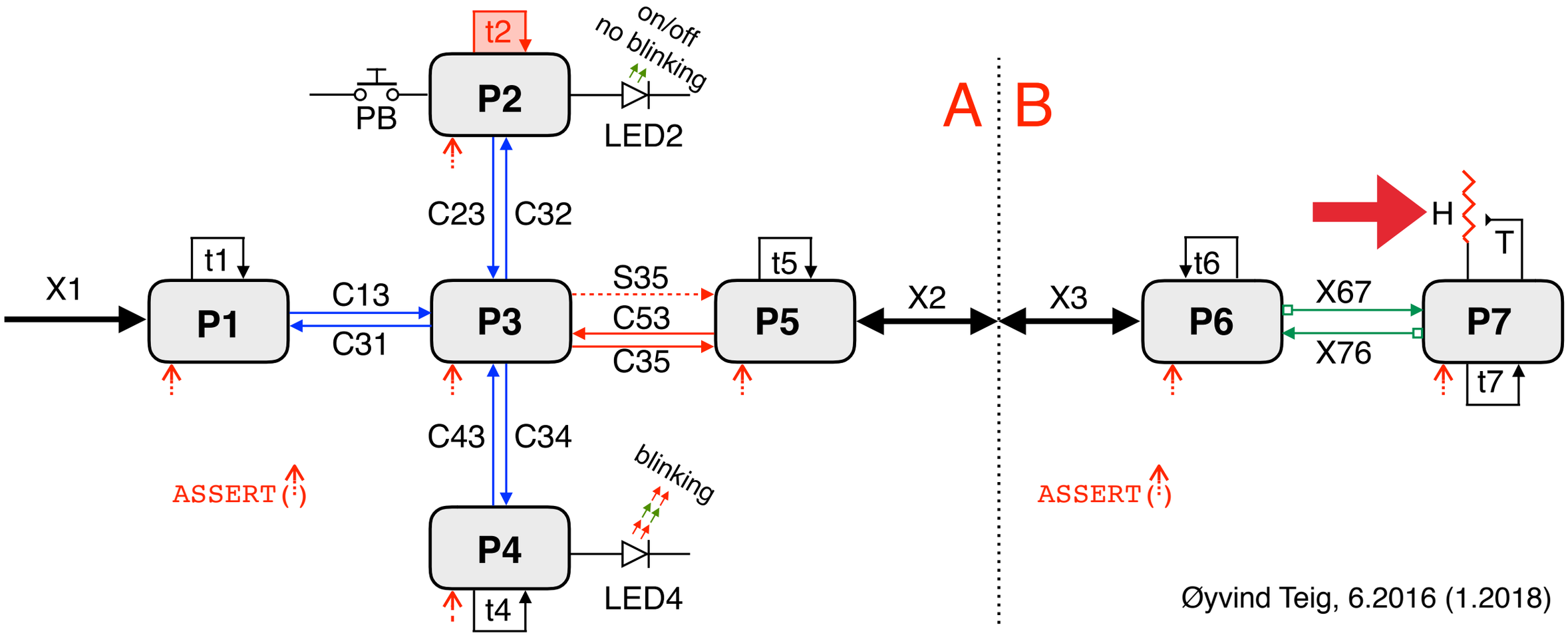

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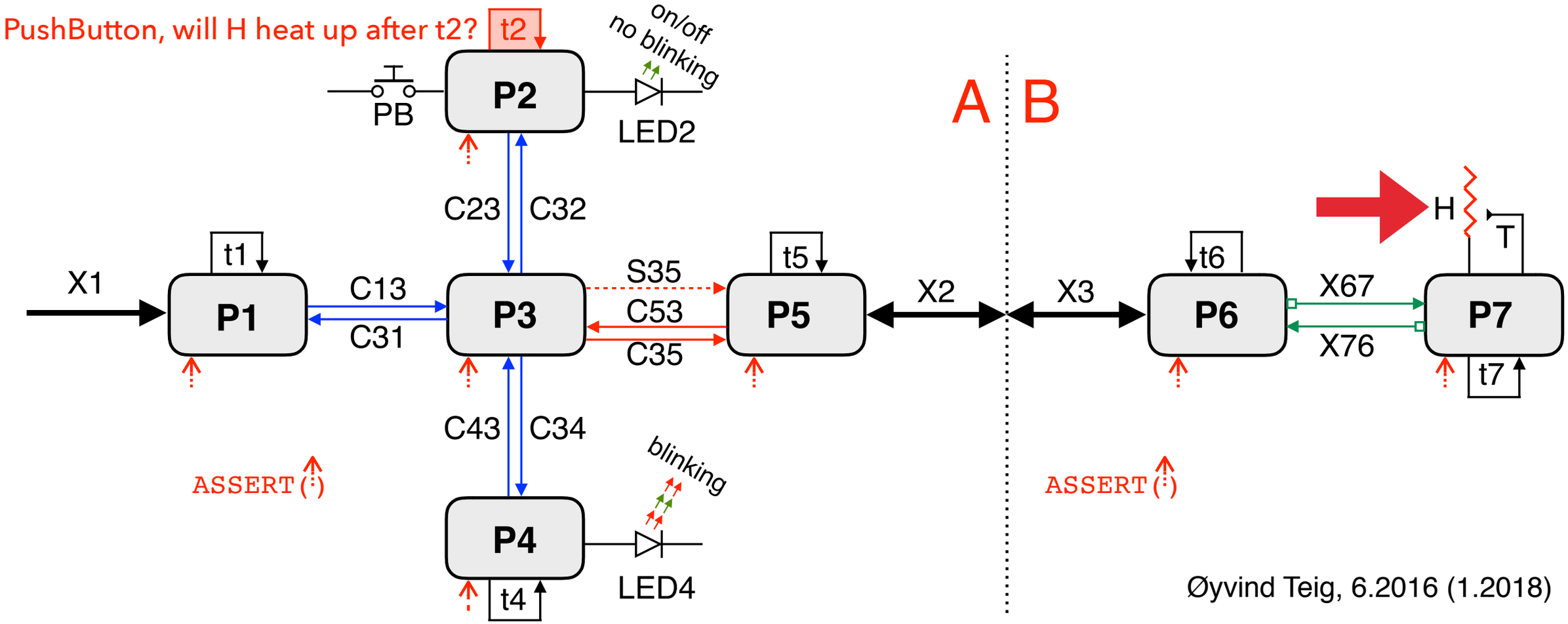

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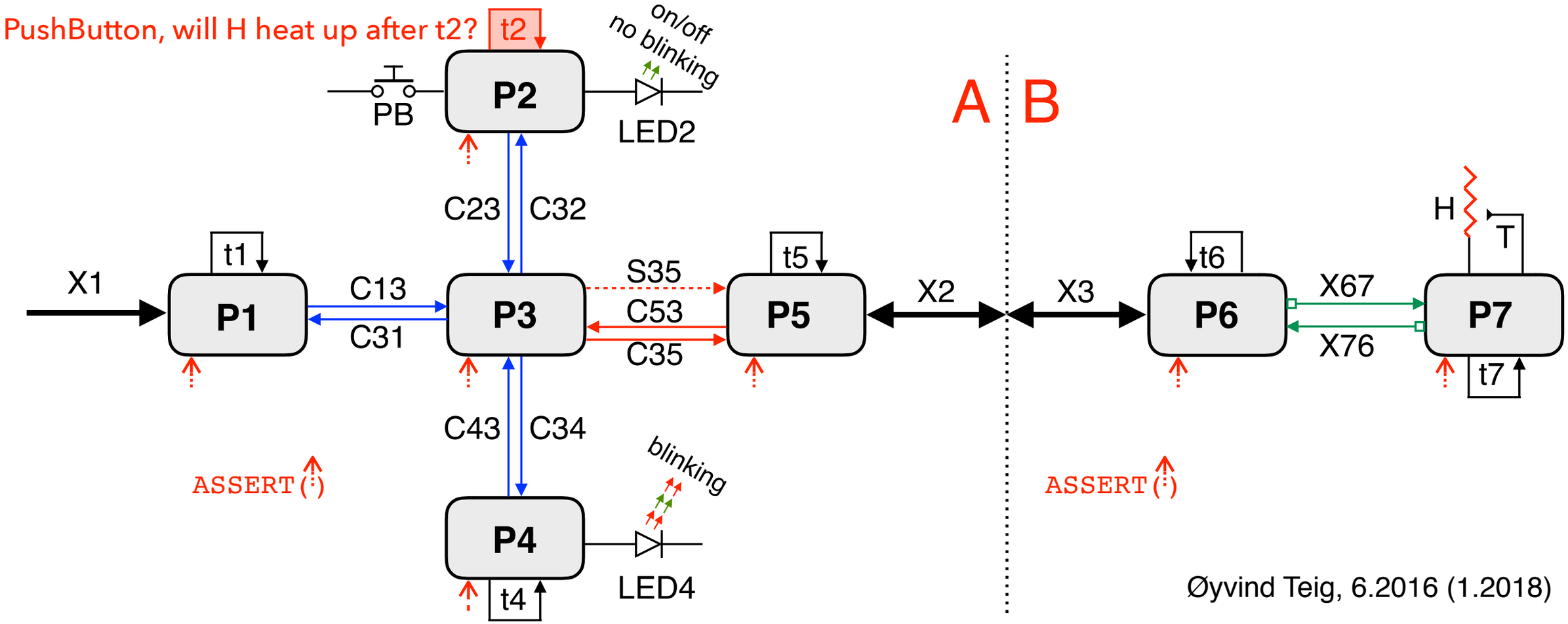

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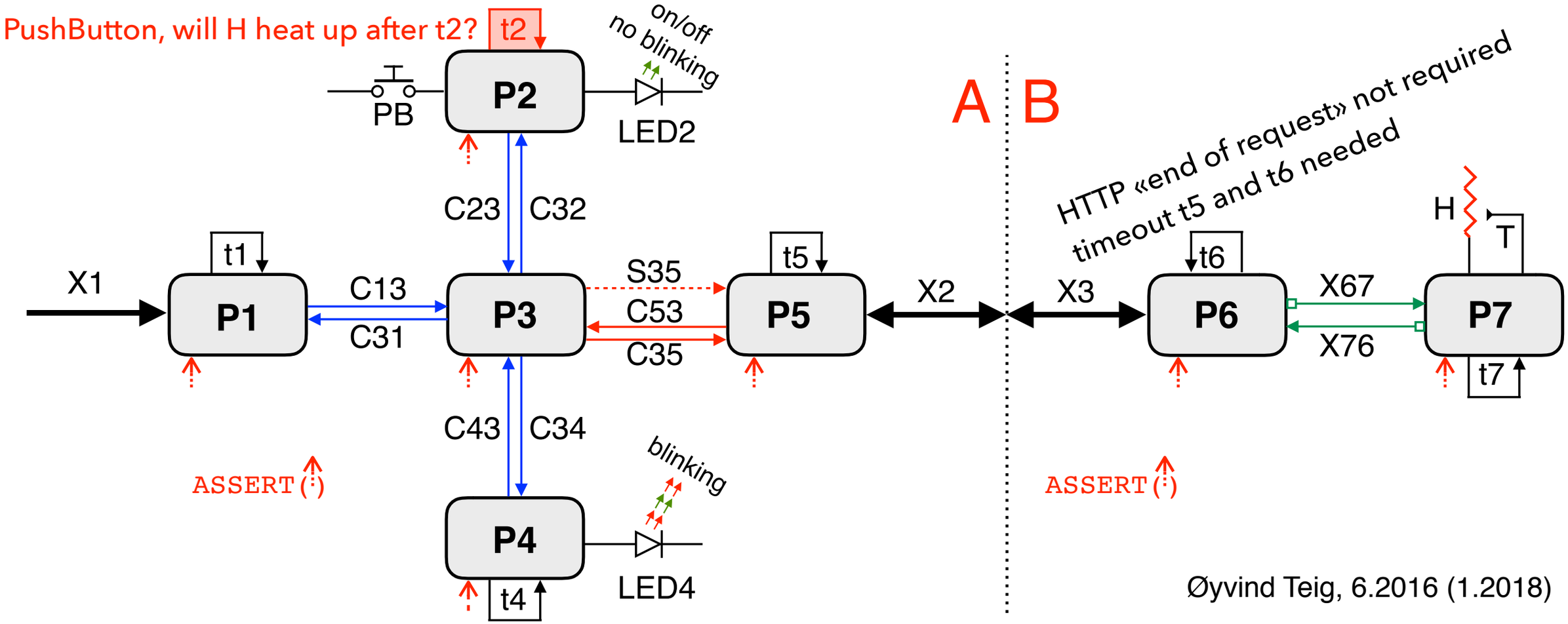

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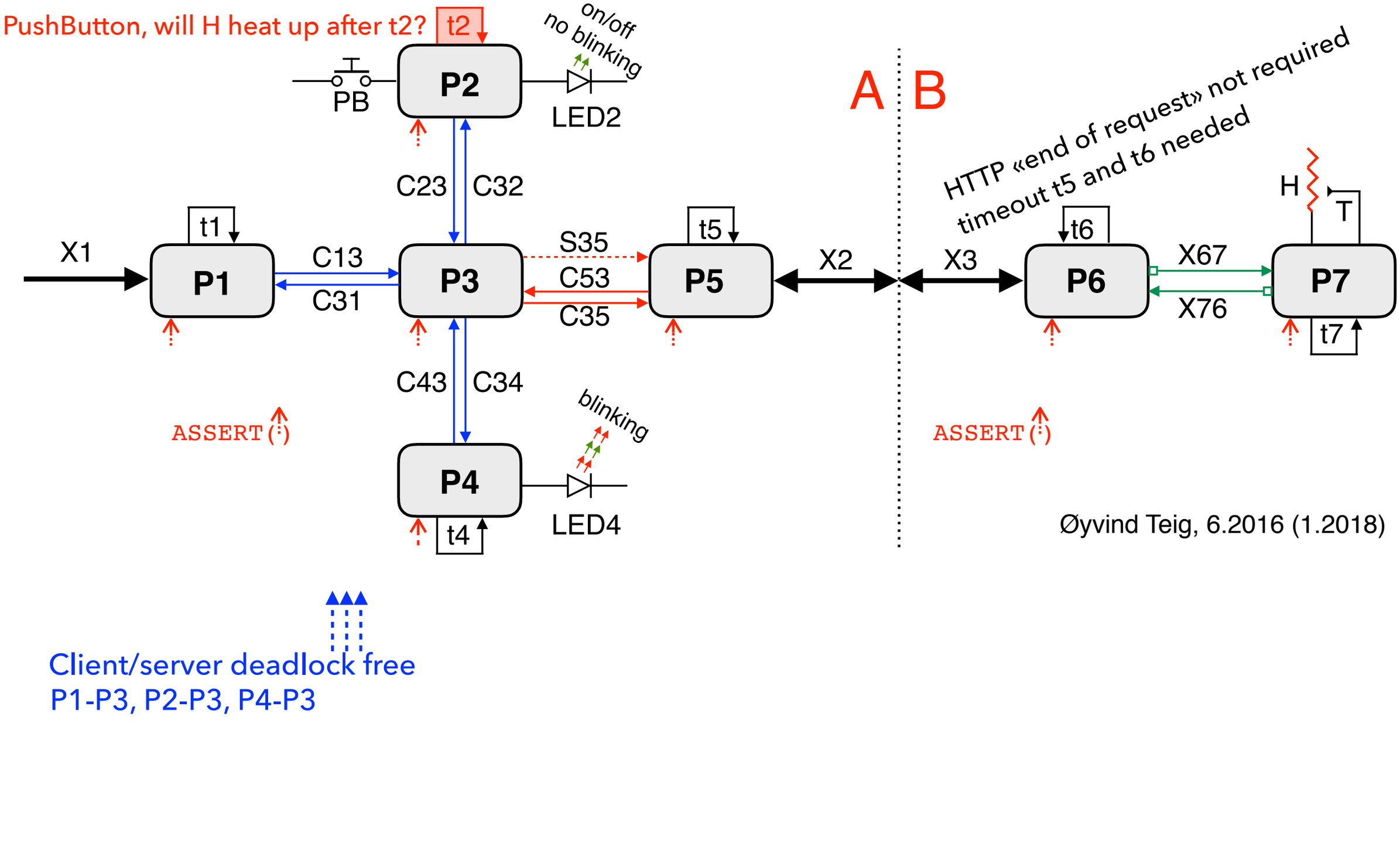

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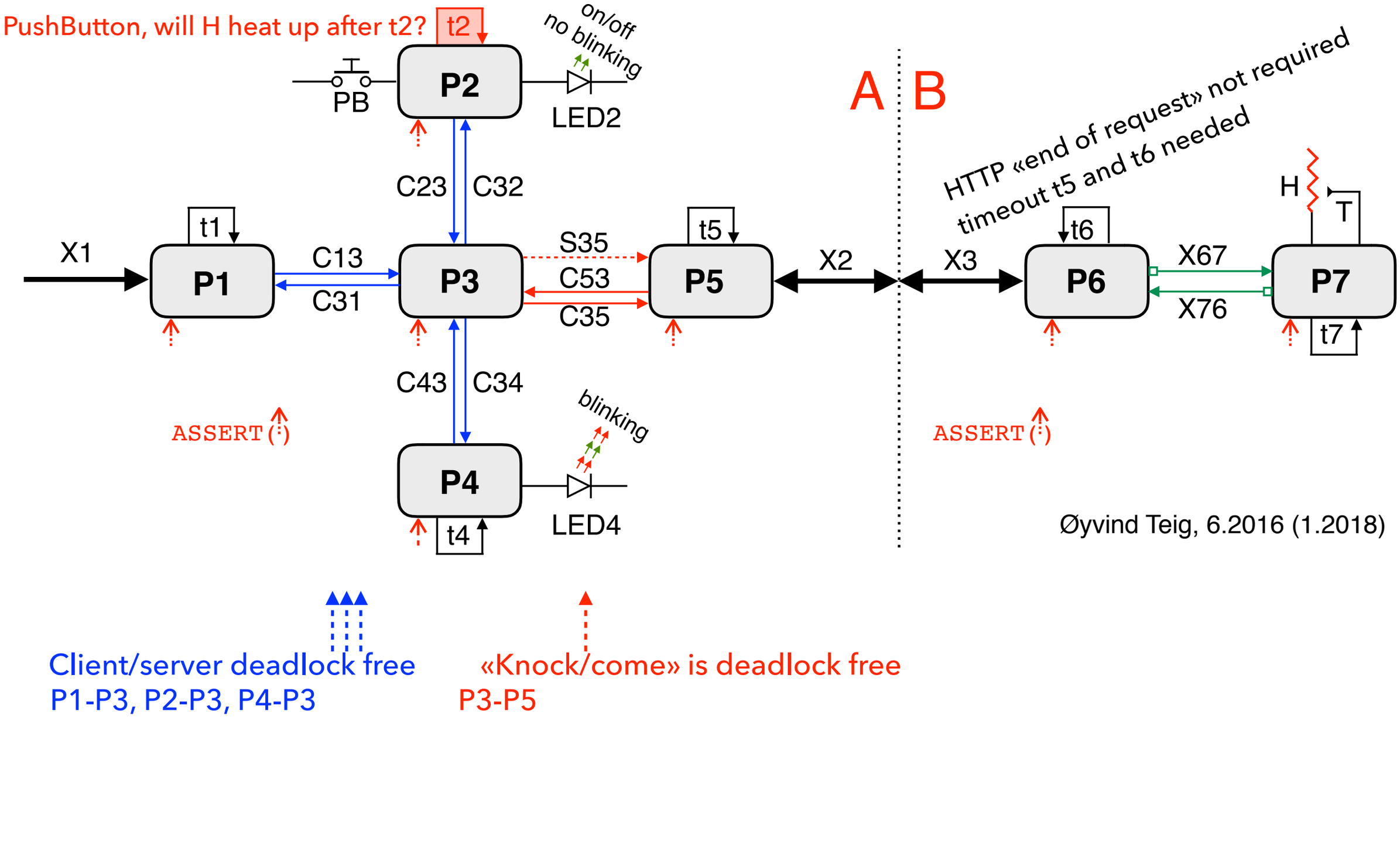

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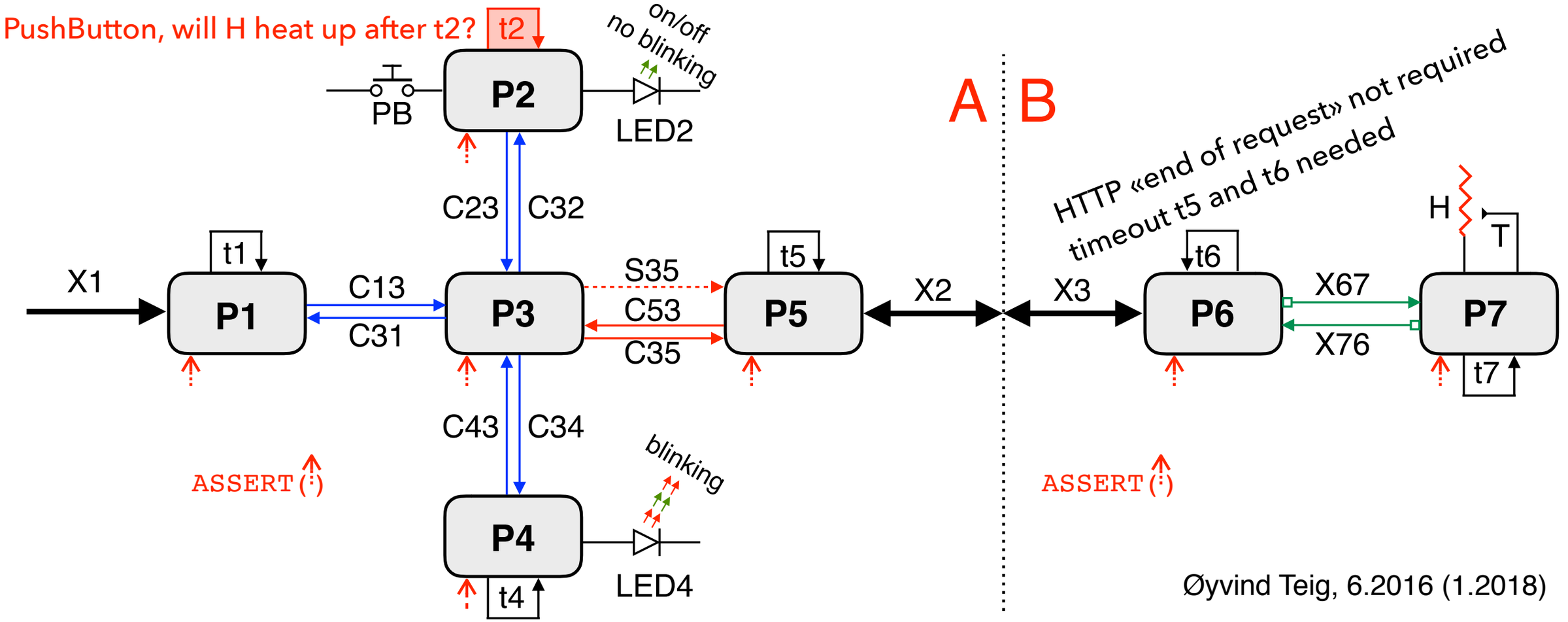

Client/server deadlock free
P1-P3, P2-P3, P4-P3

«Knock/come» is deadlock free
P3-P5

XCHAN is deadlock free [2]
P6-P7

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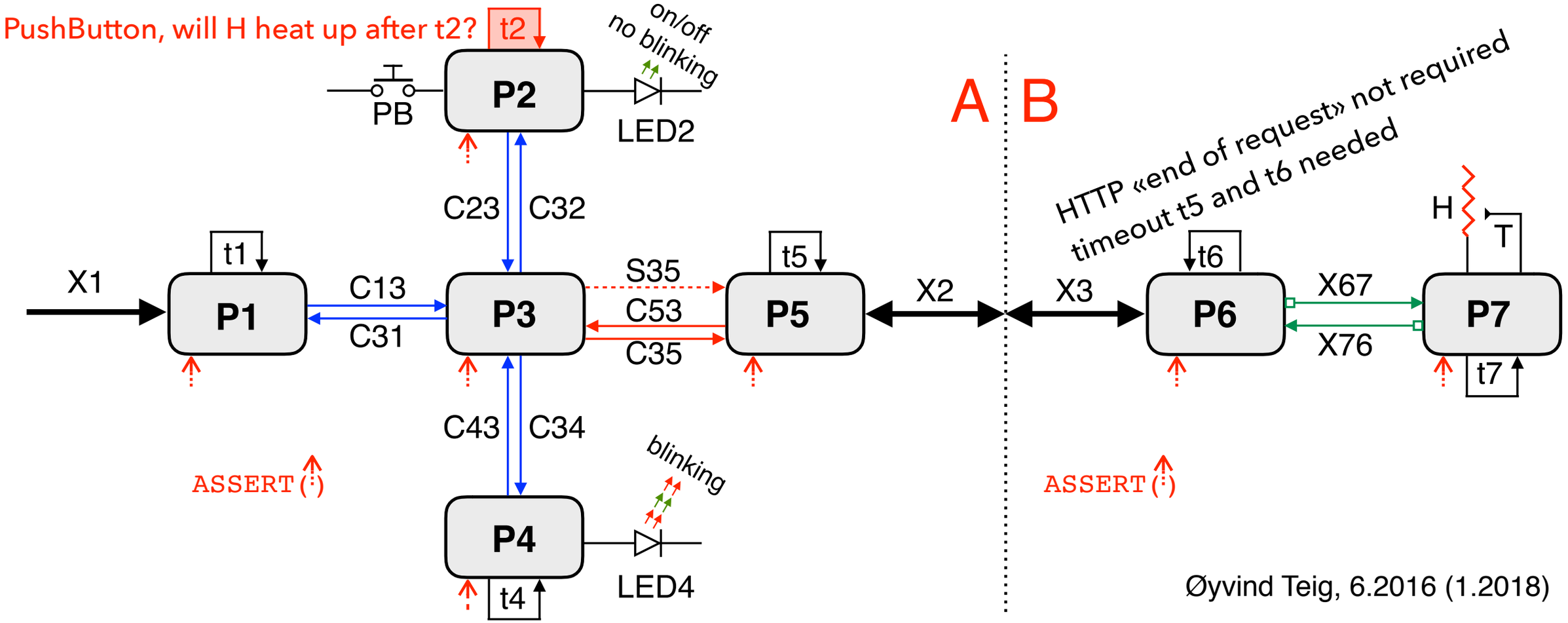

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No timeout between internal processes! If timeouts: mess guaranteed!

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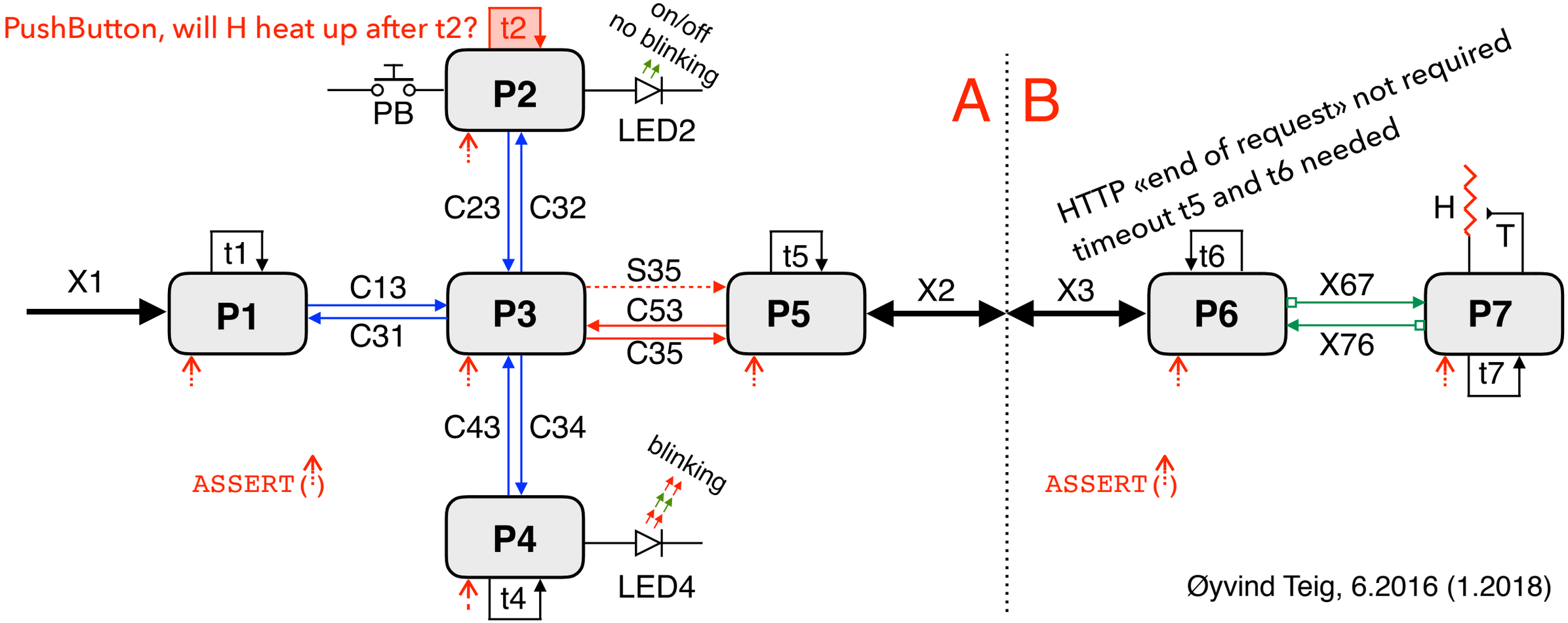
http://www.teigfam.net/oyvind/home/technology/128-timing-out-design-by-contract-with-a-stopwatch/



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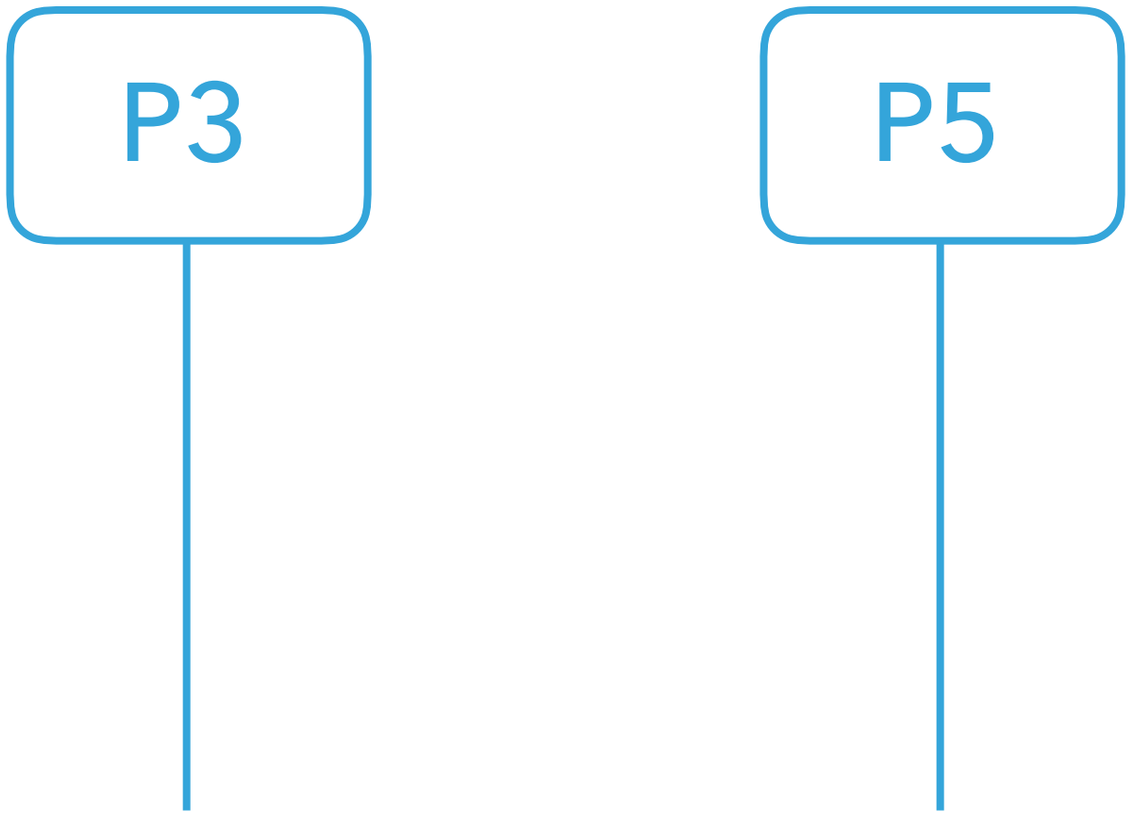
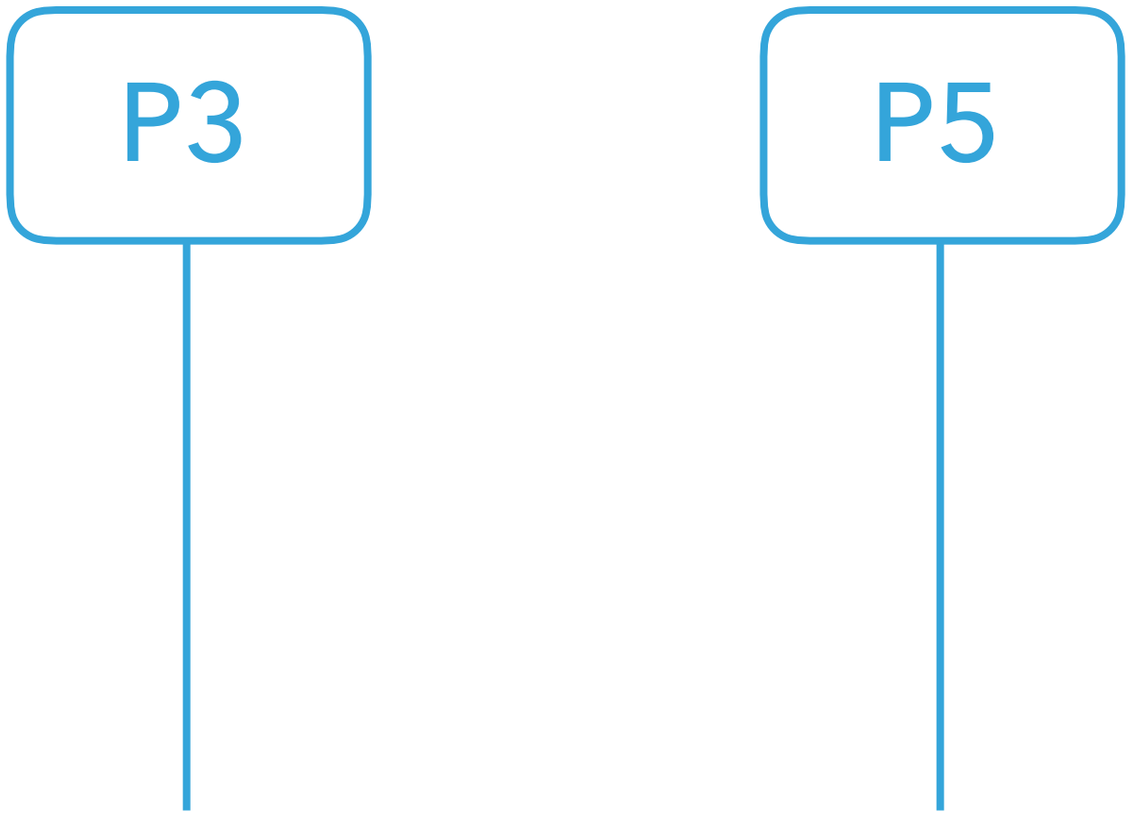
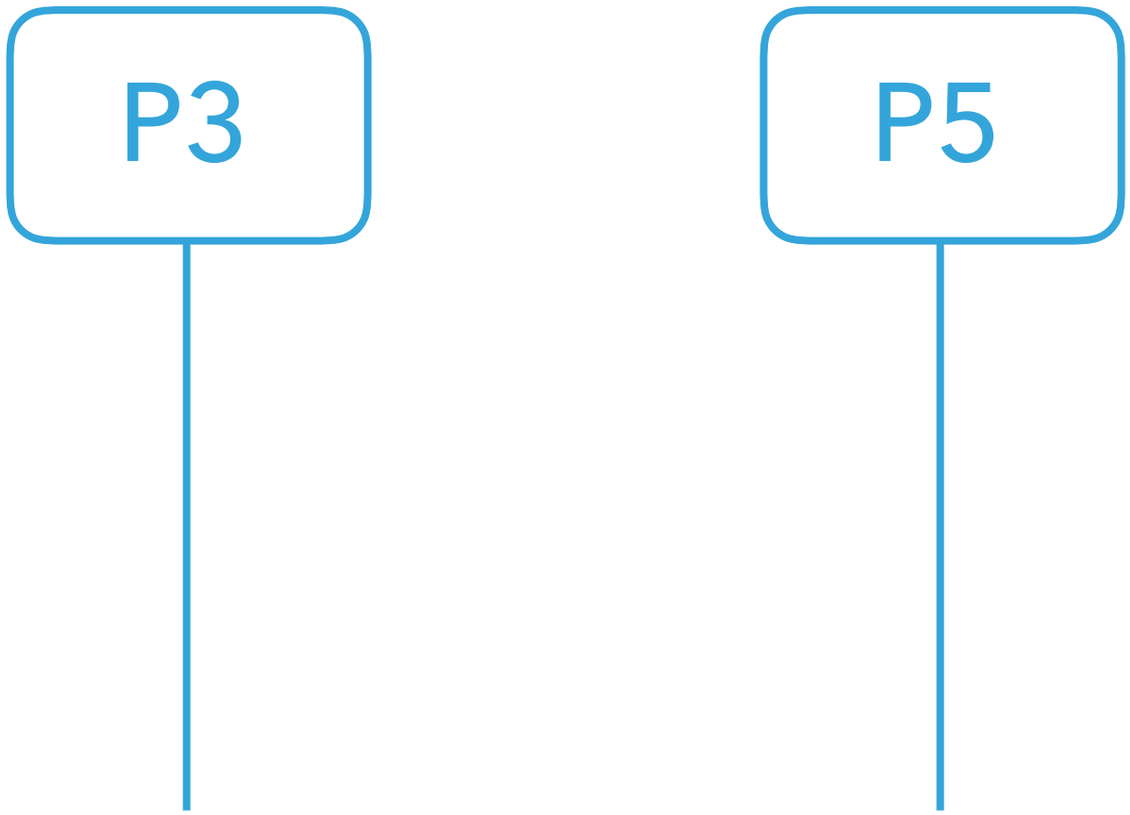


KNOCK-COME, THEN DATA



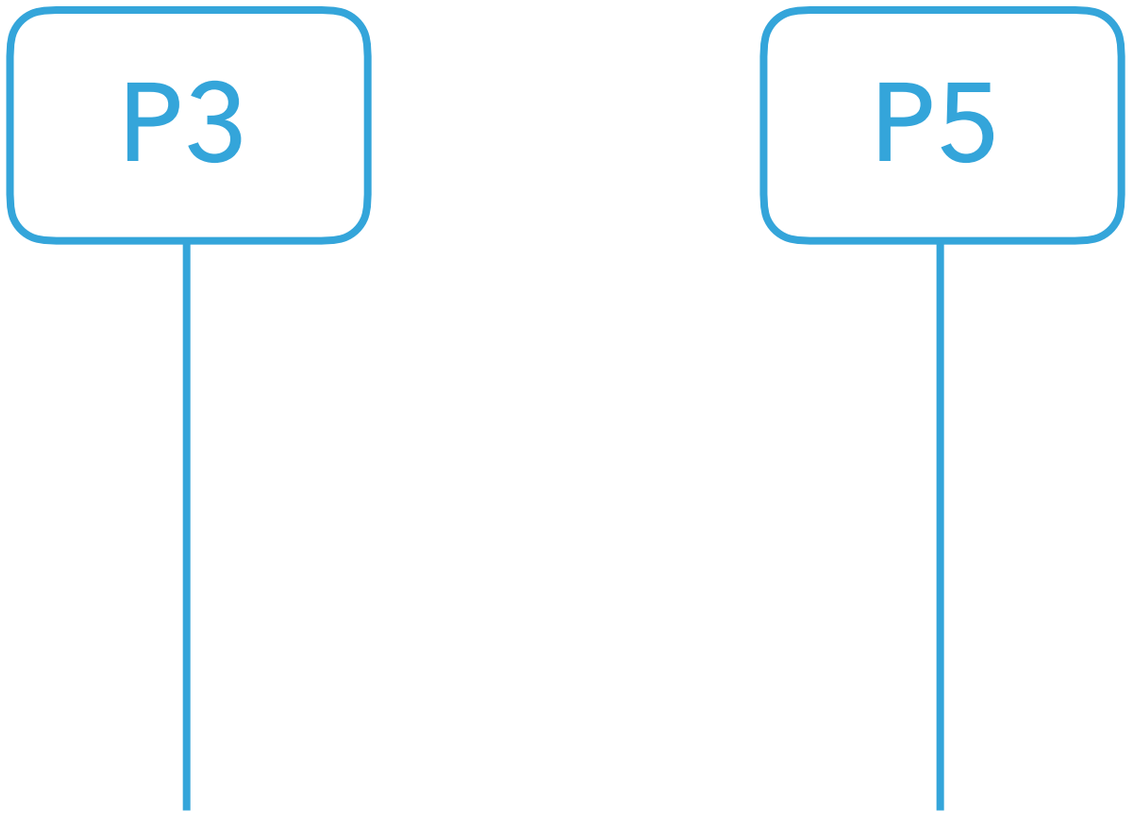
KNOCK-COME, THEN DATA

- Deadlock free communication pattern



KNOCK-COME, THEN DATA

- Deadlock free communication pattern
- Both directions



KNOCK-COME, THEN DATA

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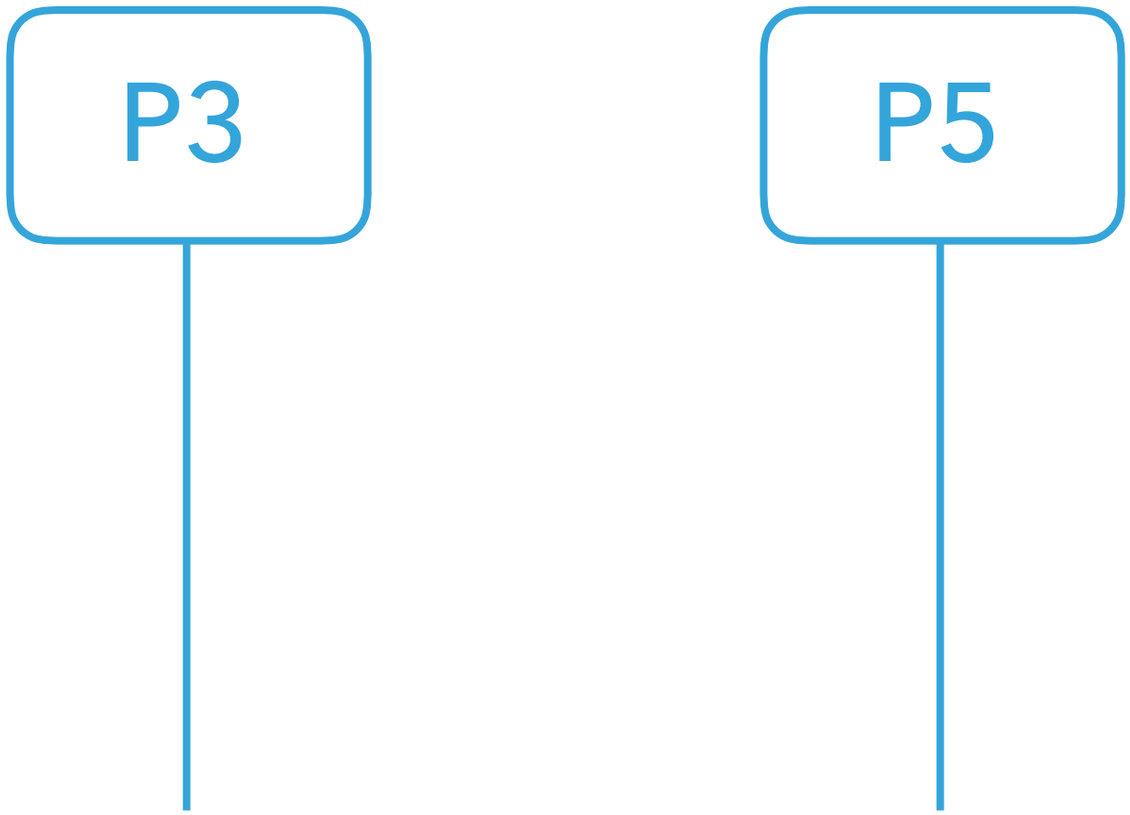
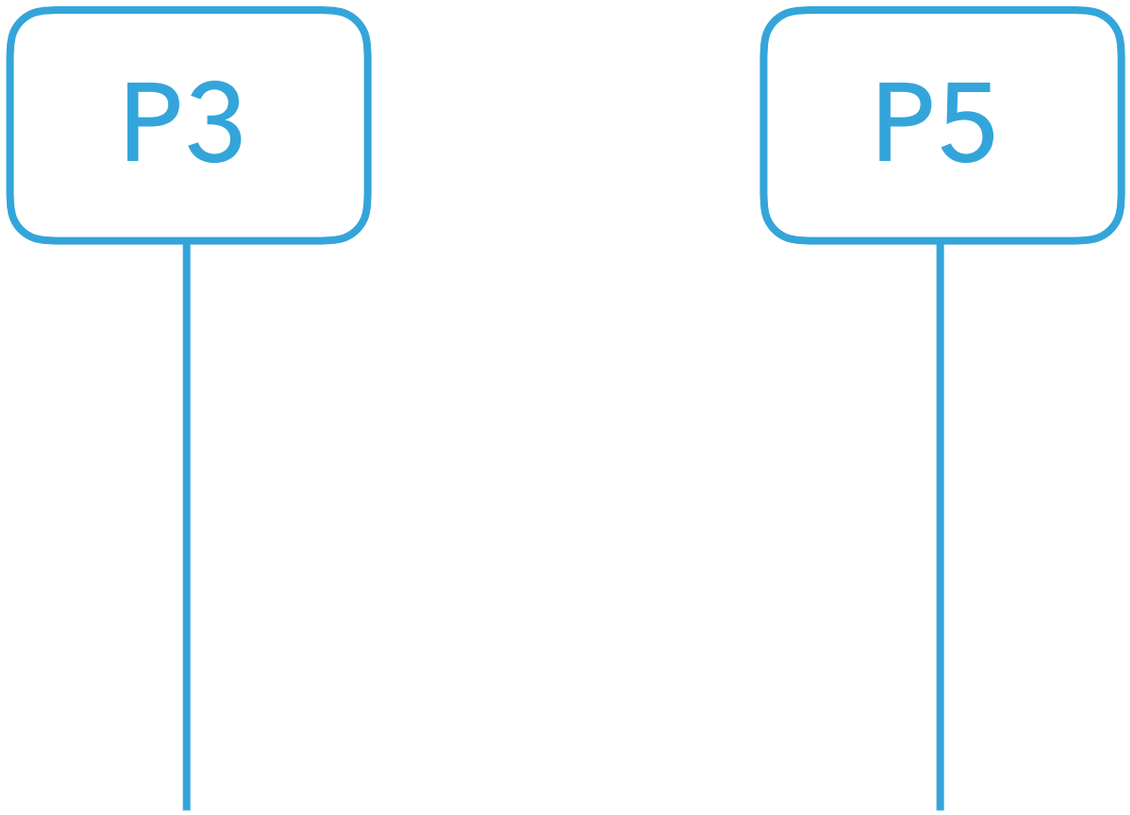
- Both directions
- Master can send data any time



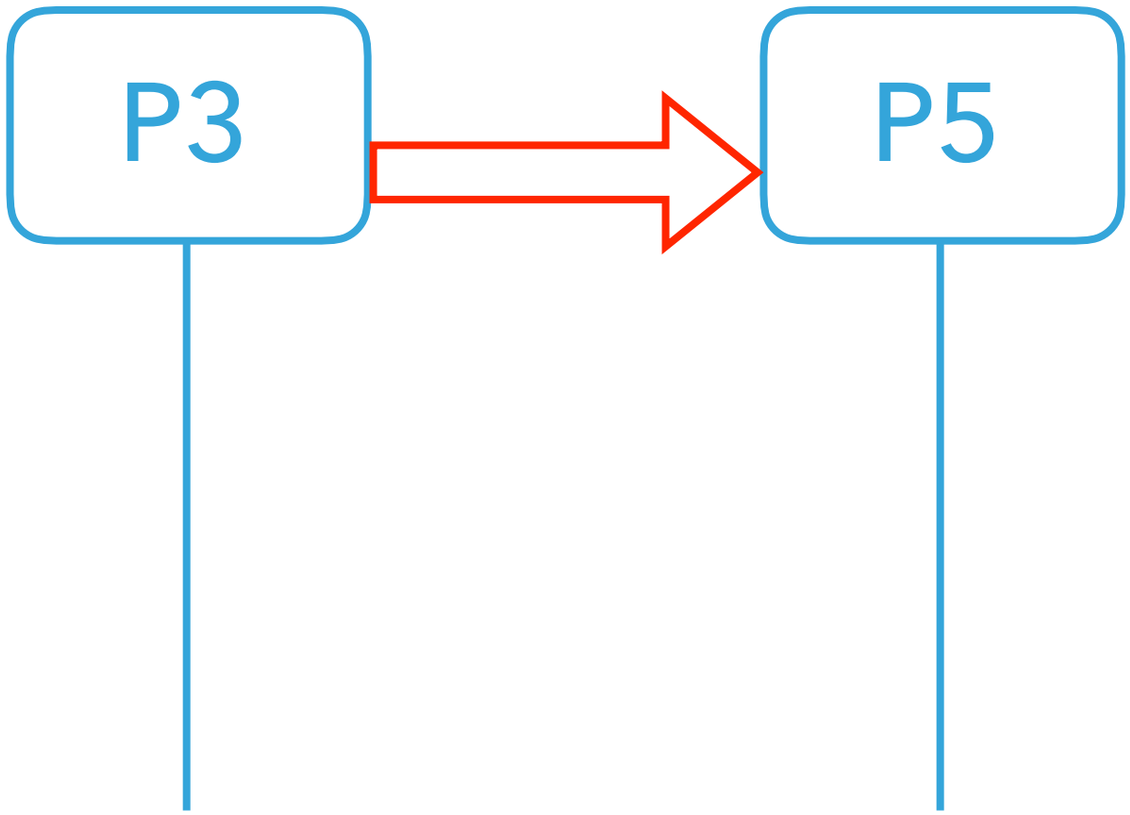
KNOCK-COME, THEN DATA

- Deadlock free communication pattern
- Both directions
- Master can send data any time
- Slave must «knock»



KNOCK-COME, THEN DATA

- Deadlock free communication pattern
- Both directions
- Master can send data any time
- Slave must «knock»
  - asynch signal channel, no data, doesn’t block



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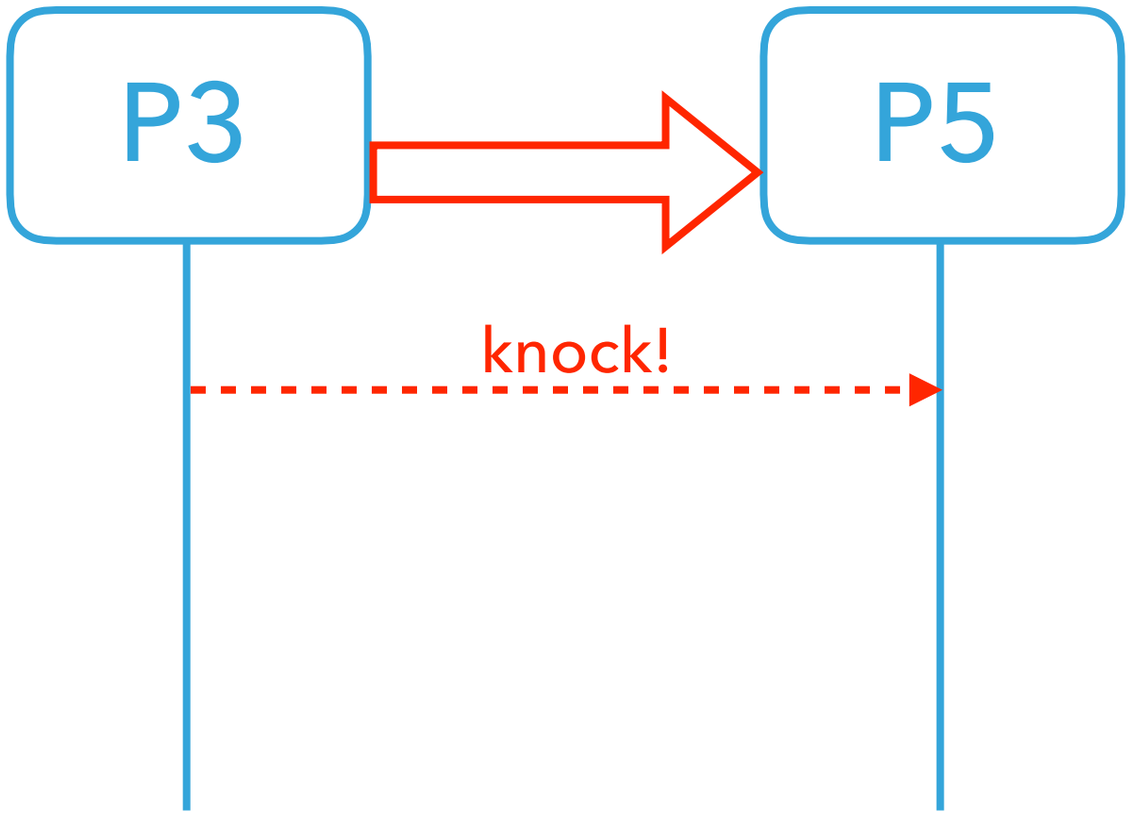

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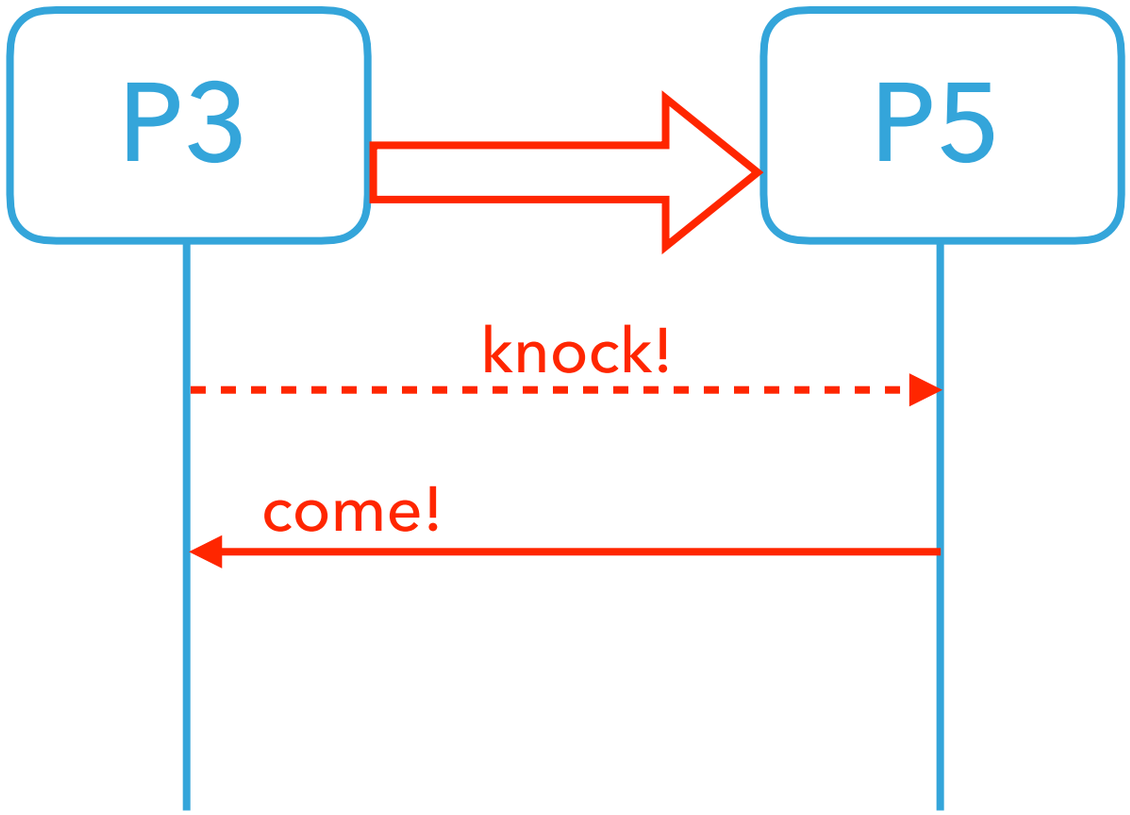

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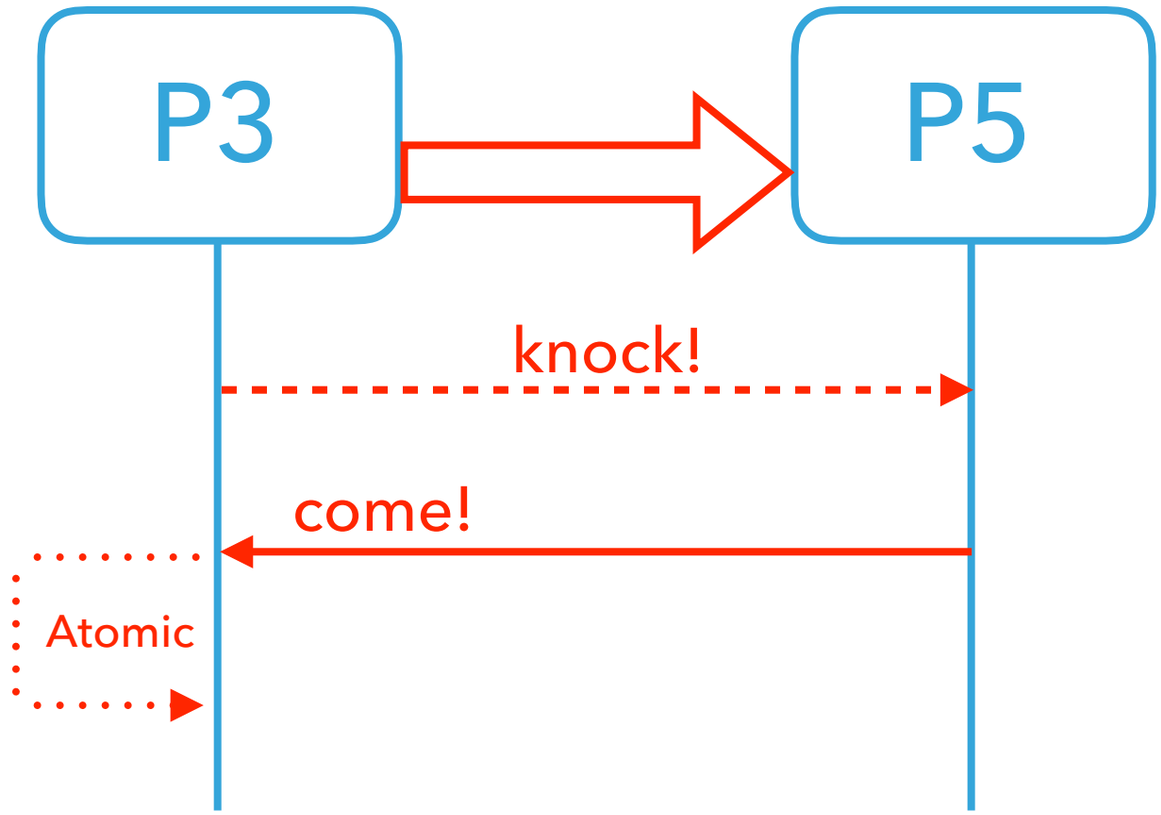

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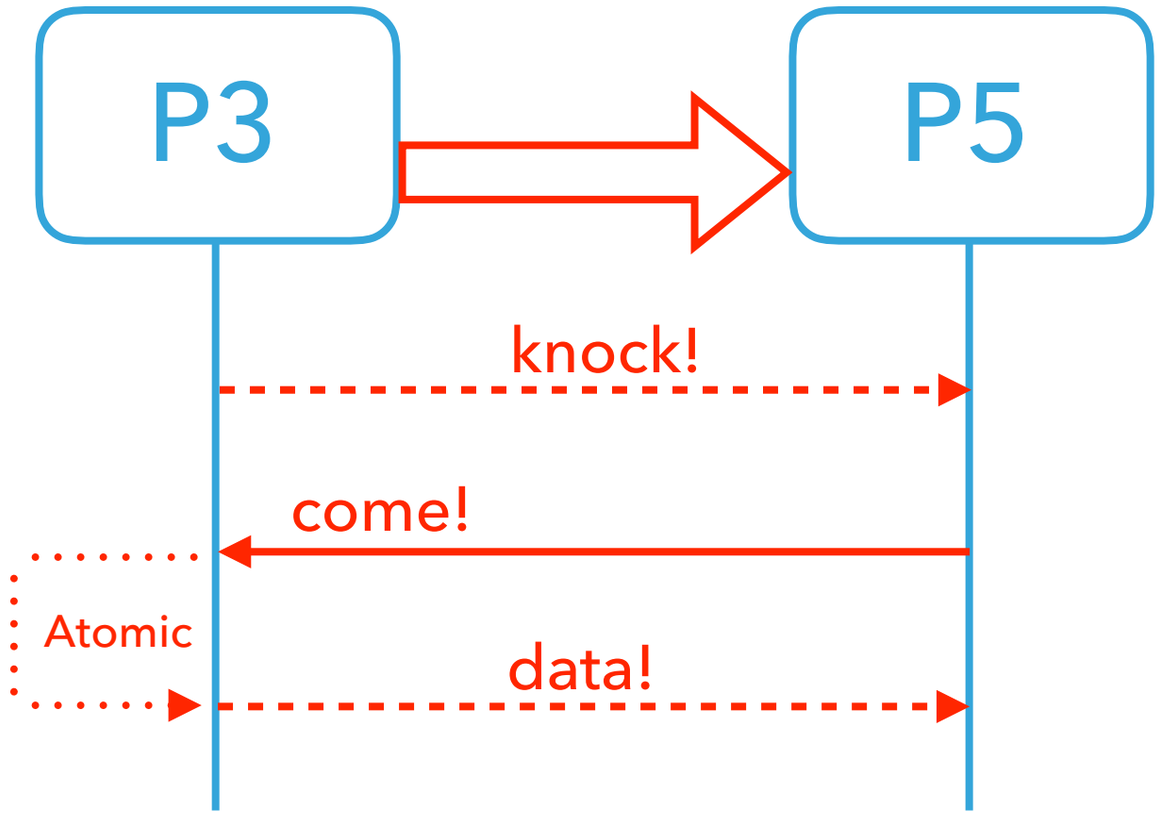

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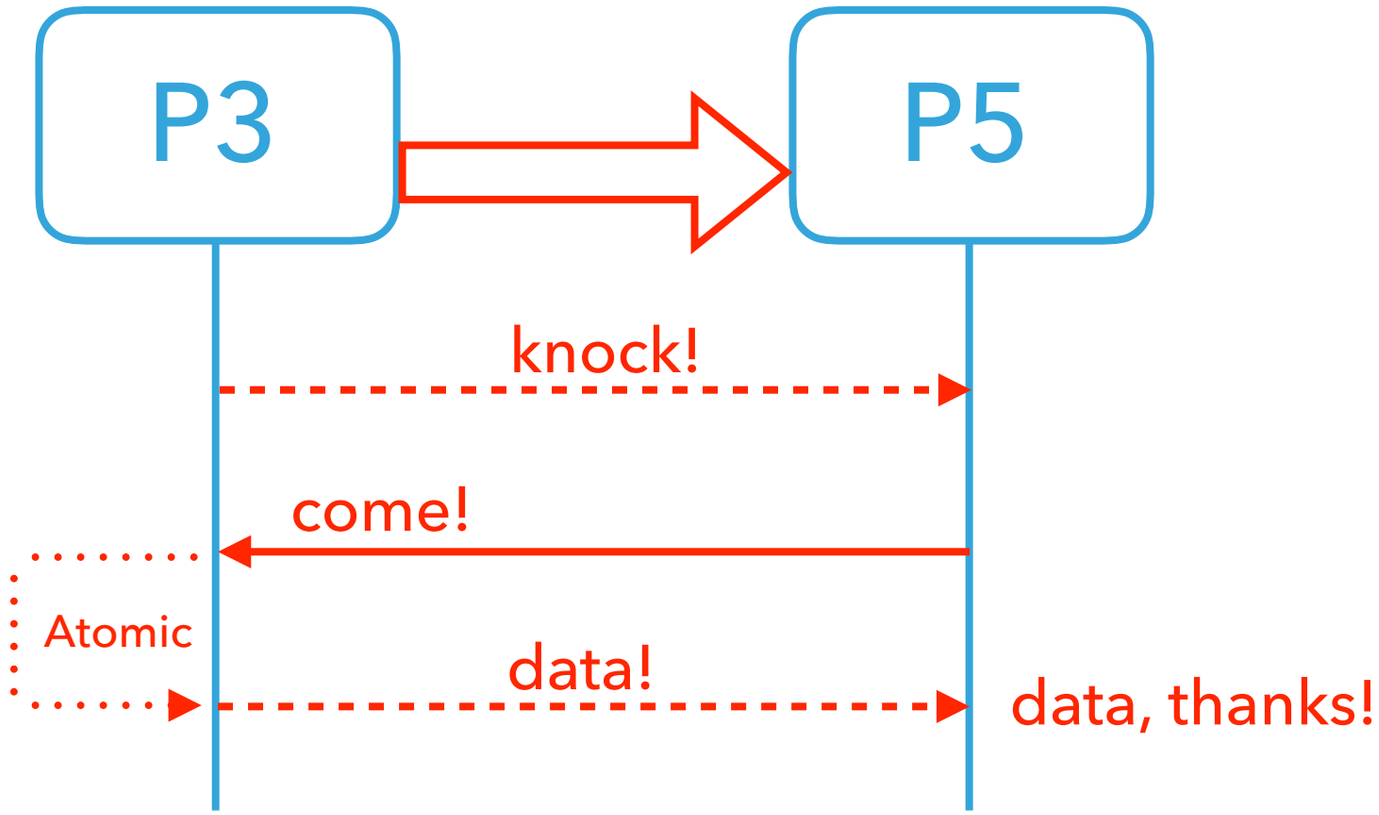

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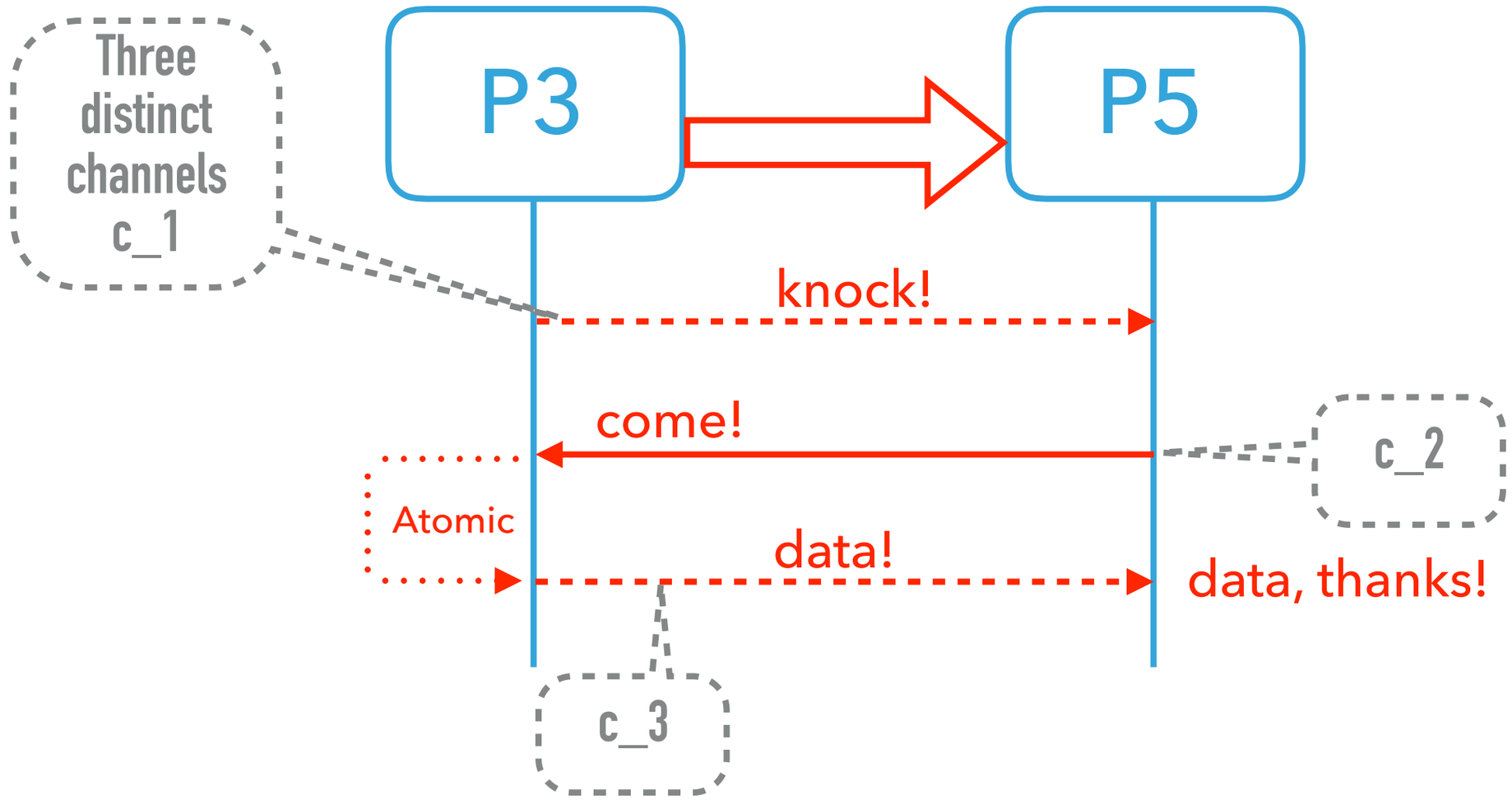

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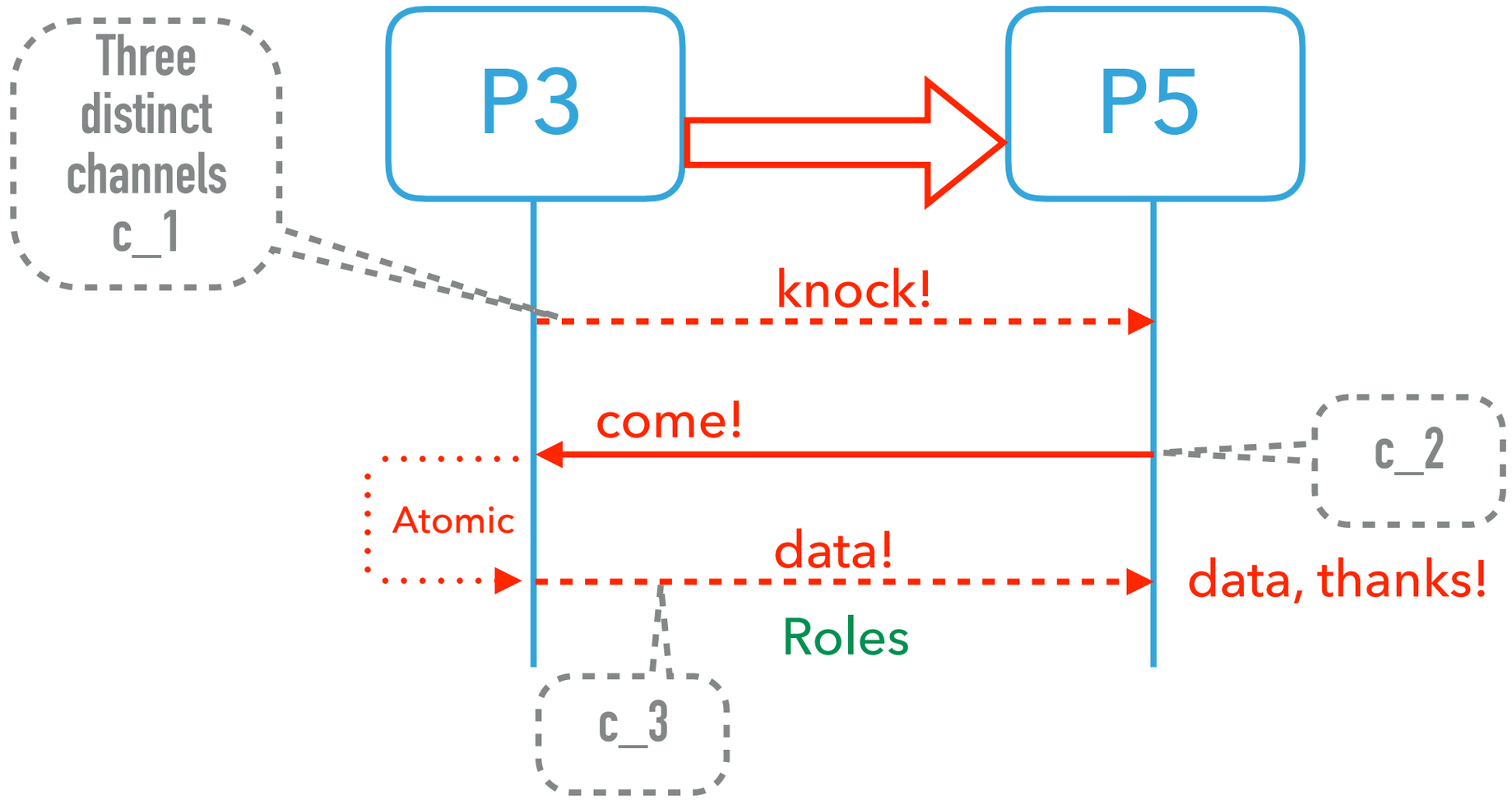

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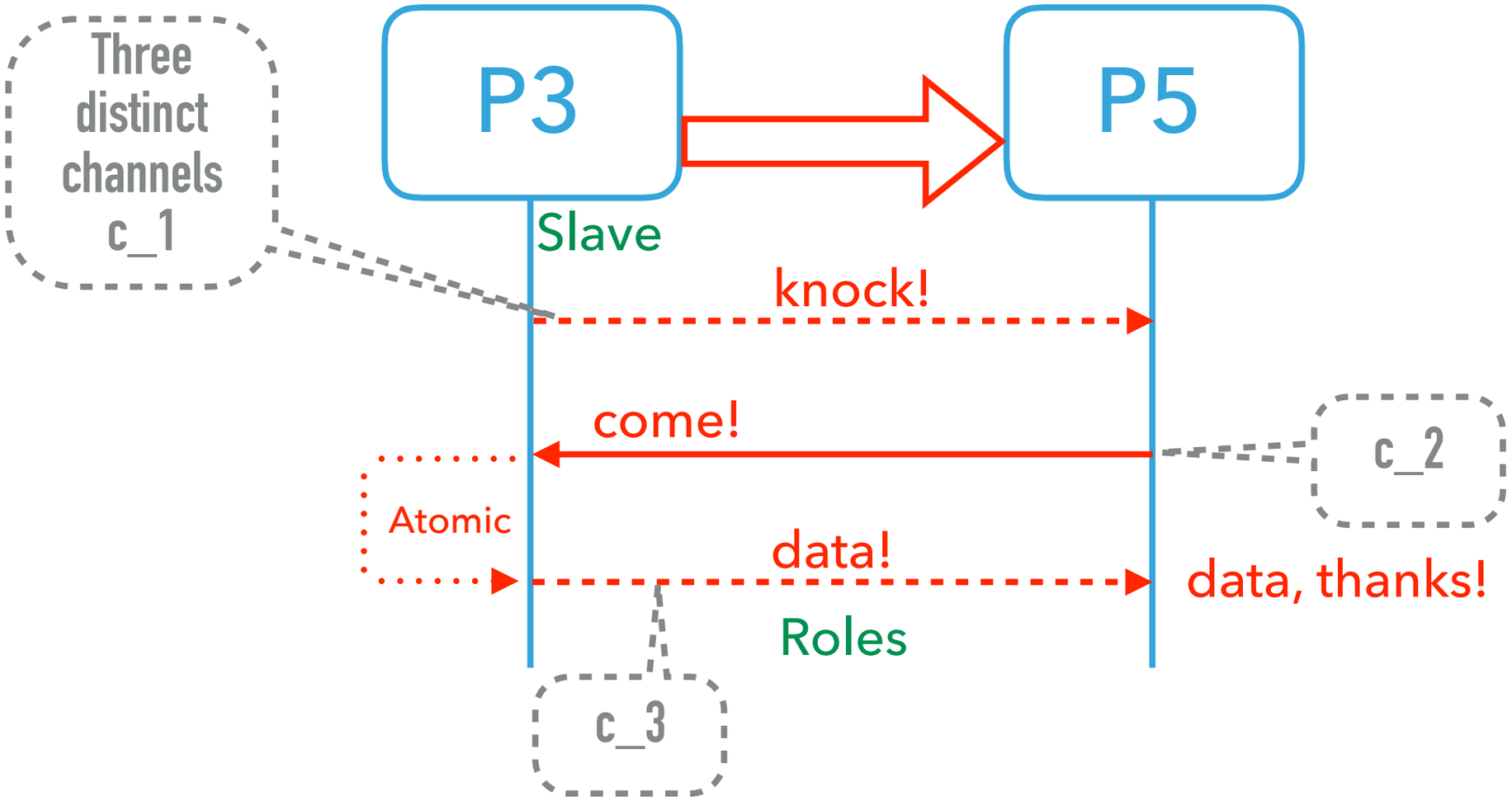

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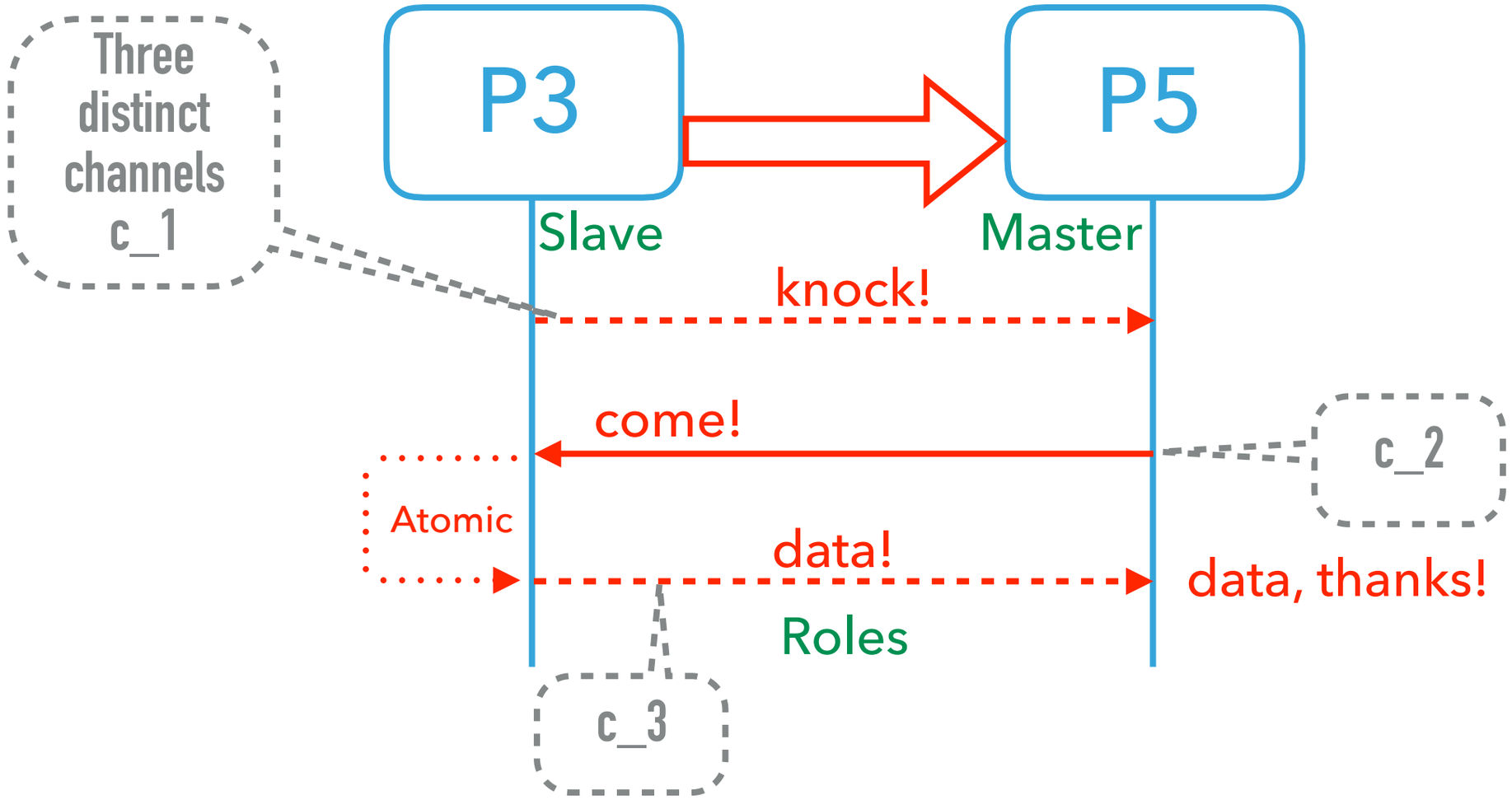

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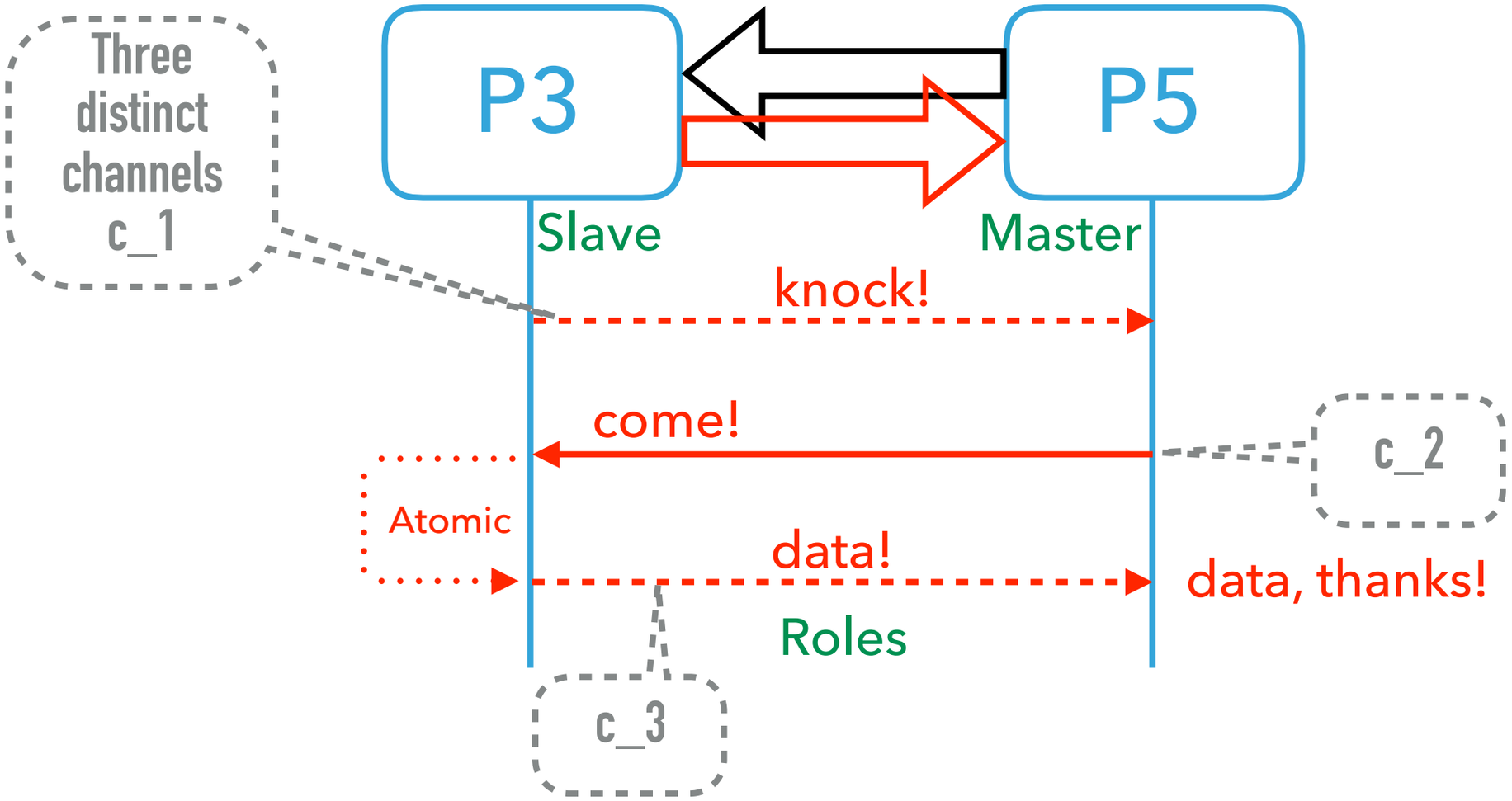

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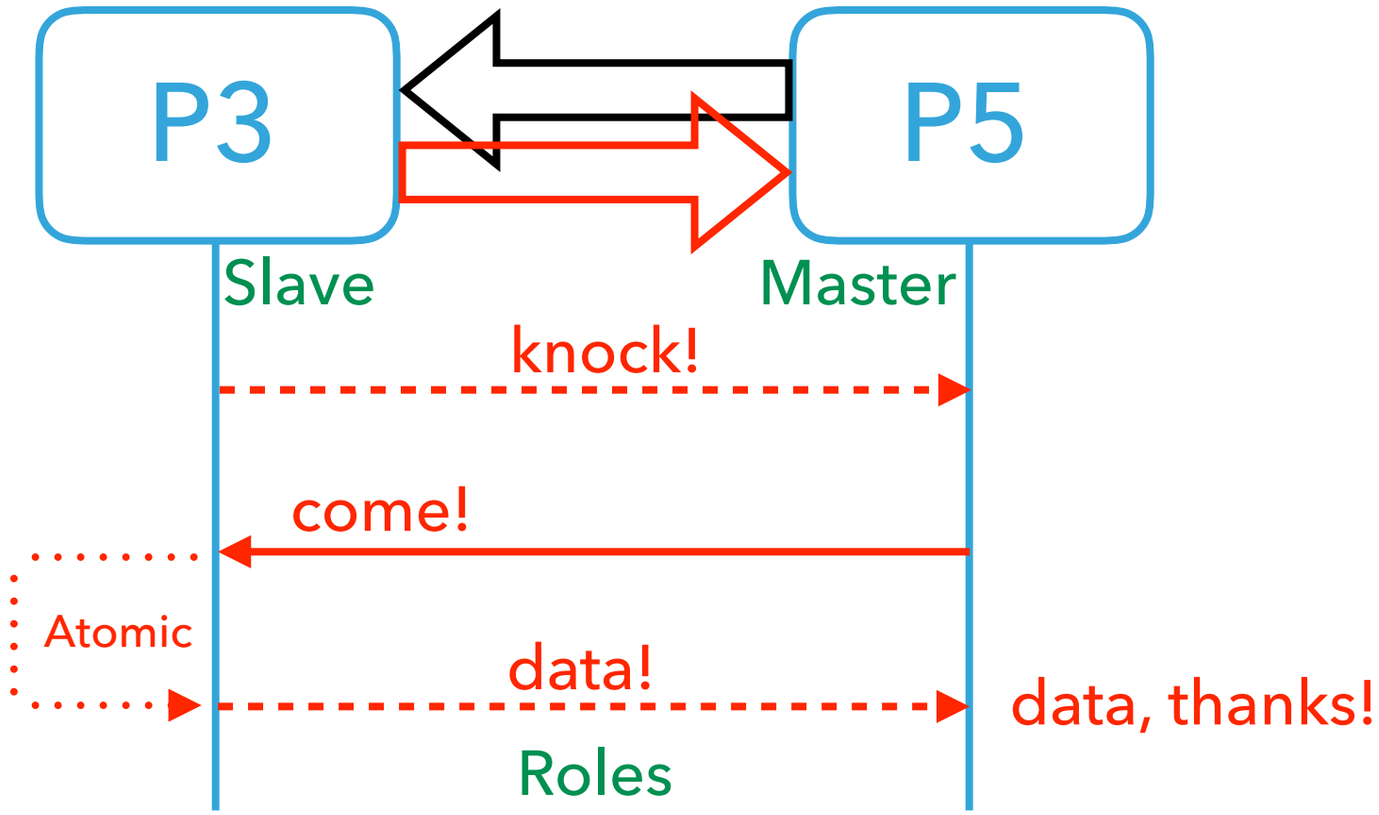

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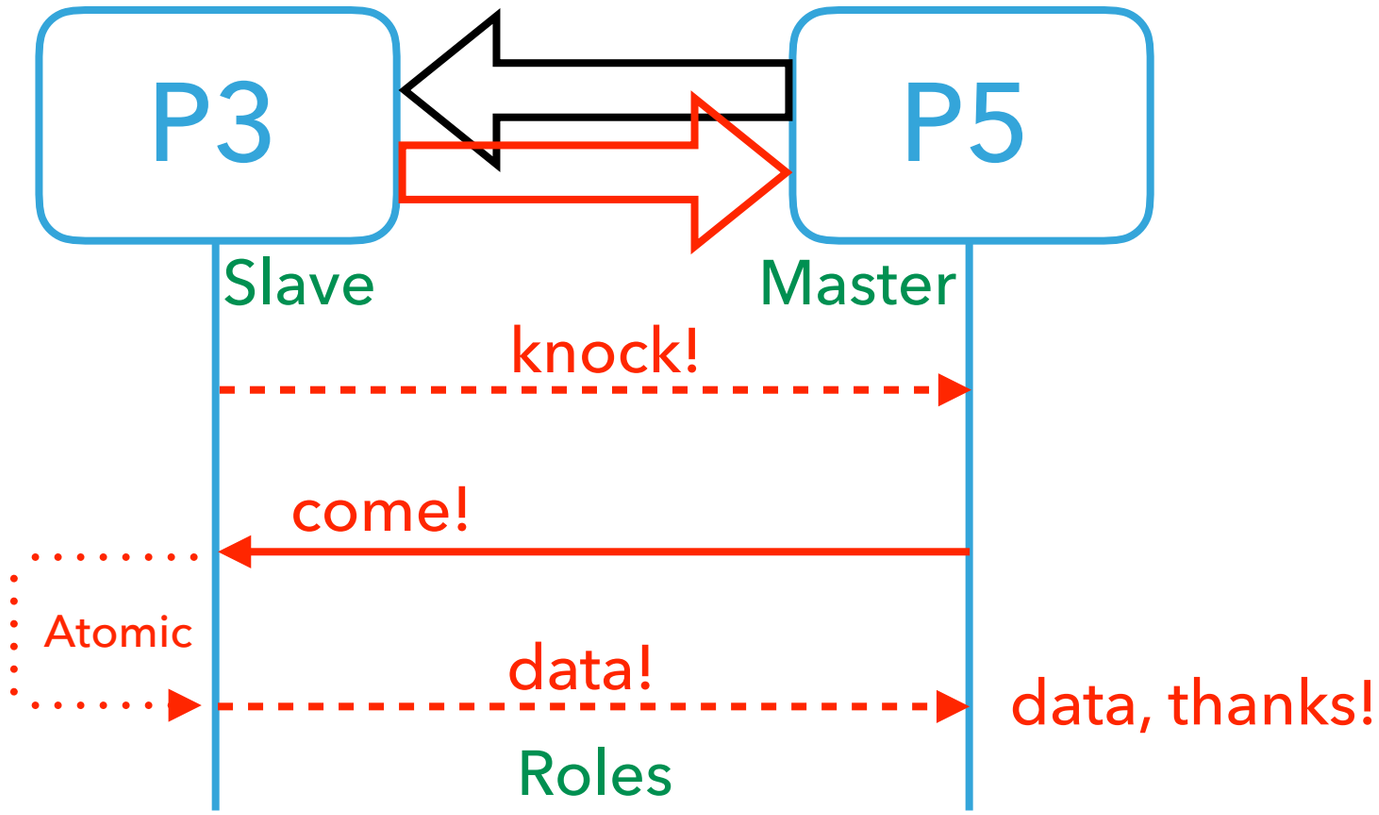

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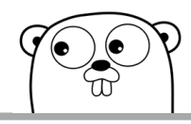

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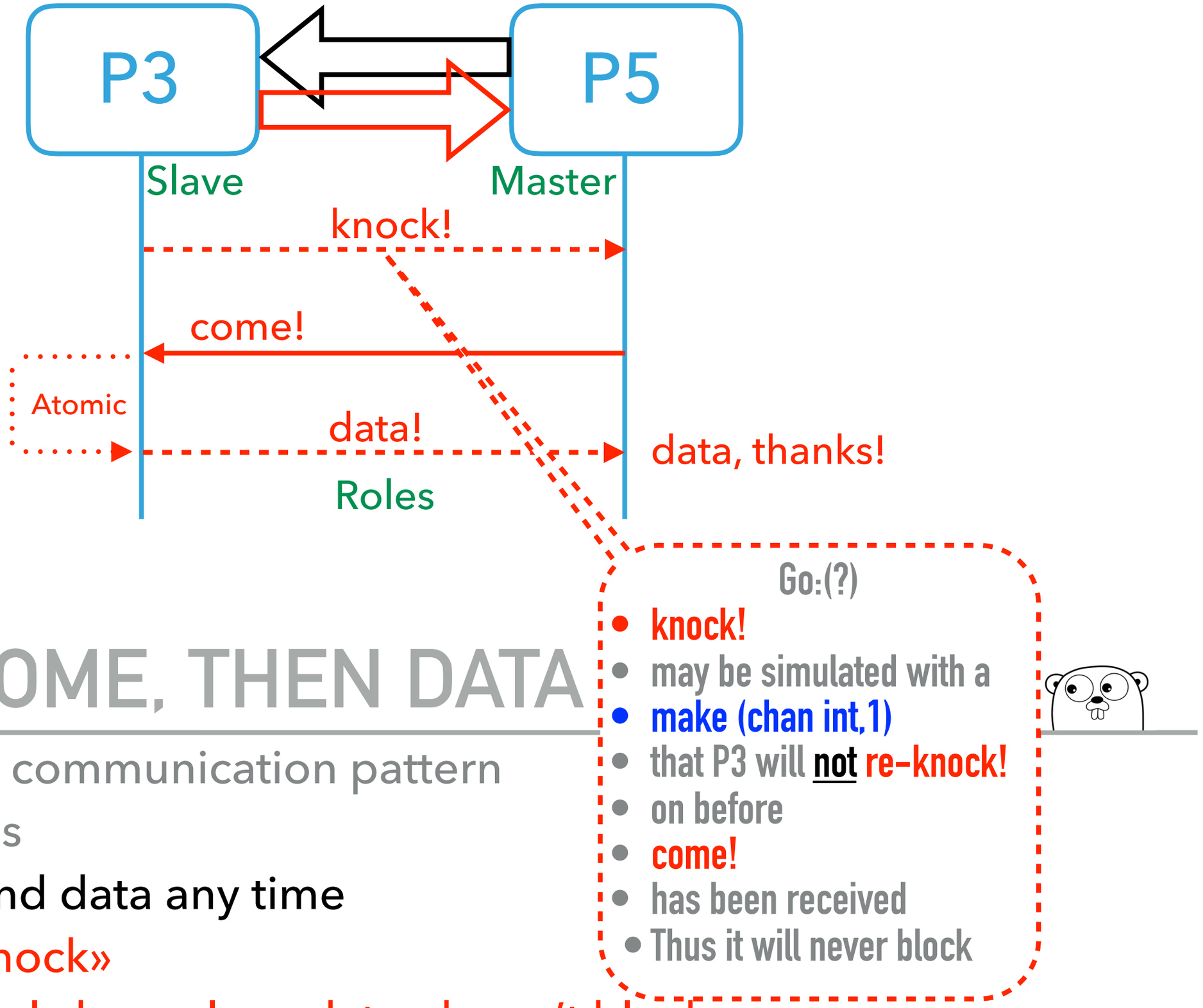

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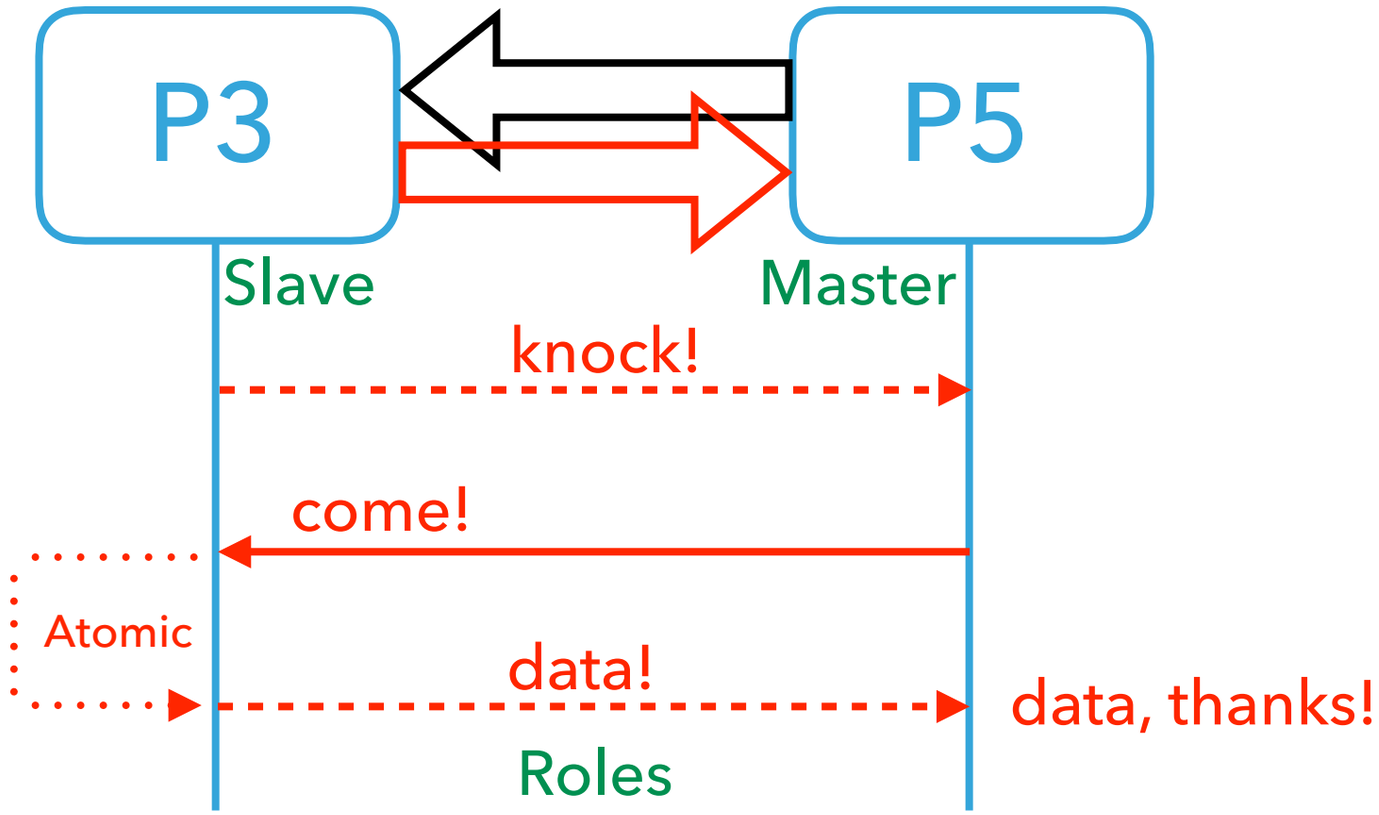

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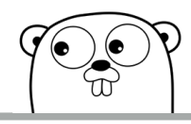

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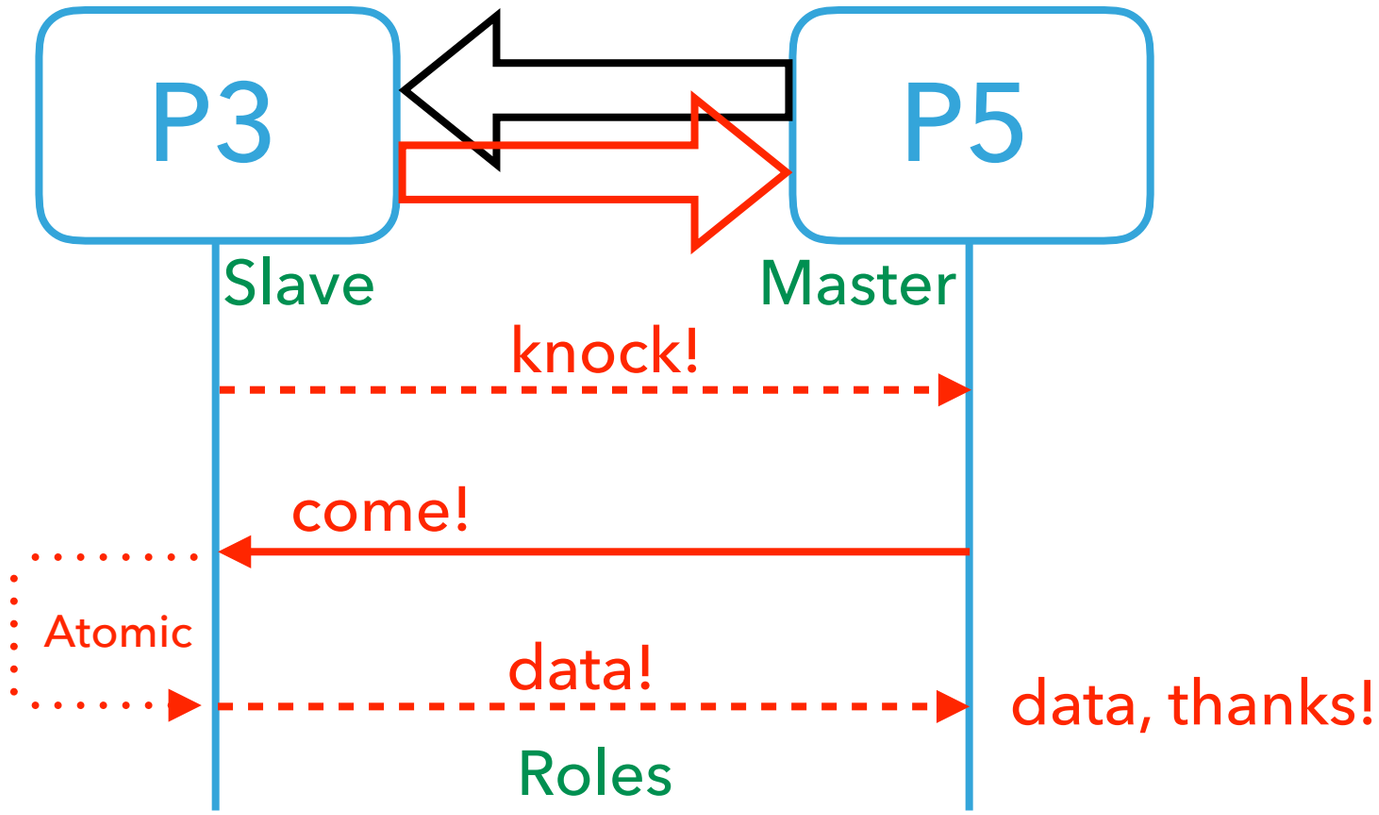

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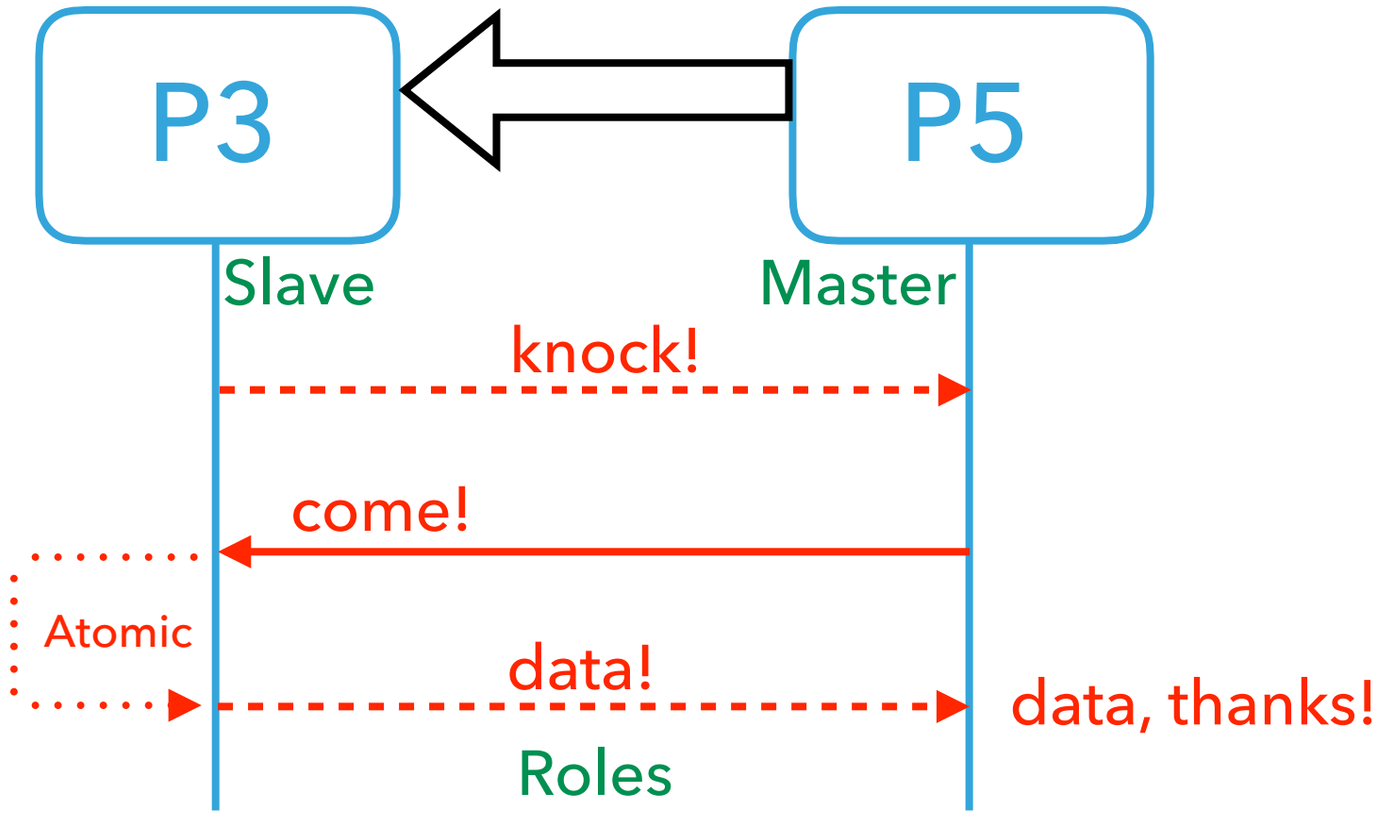

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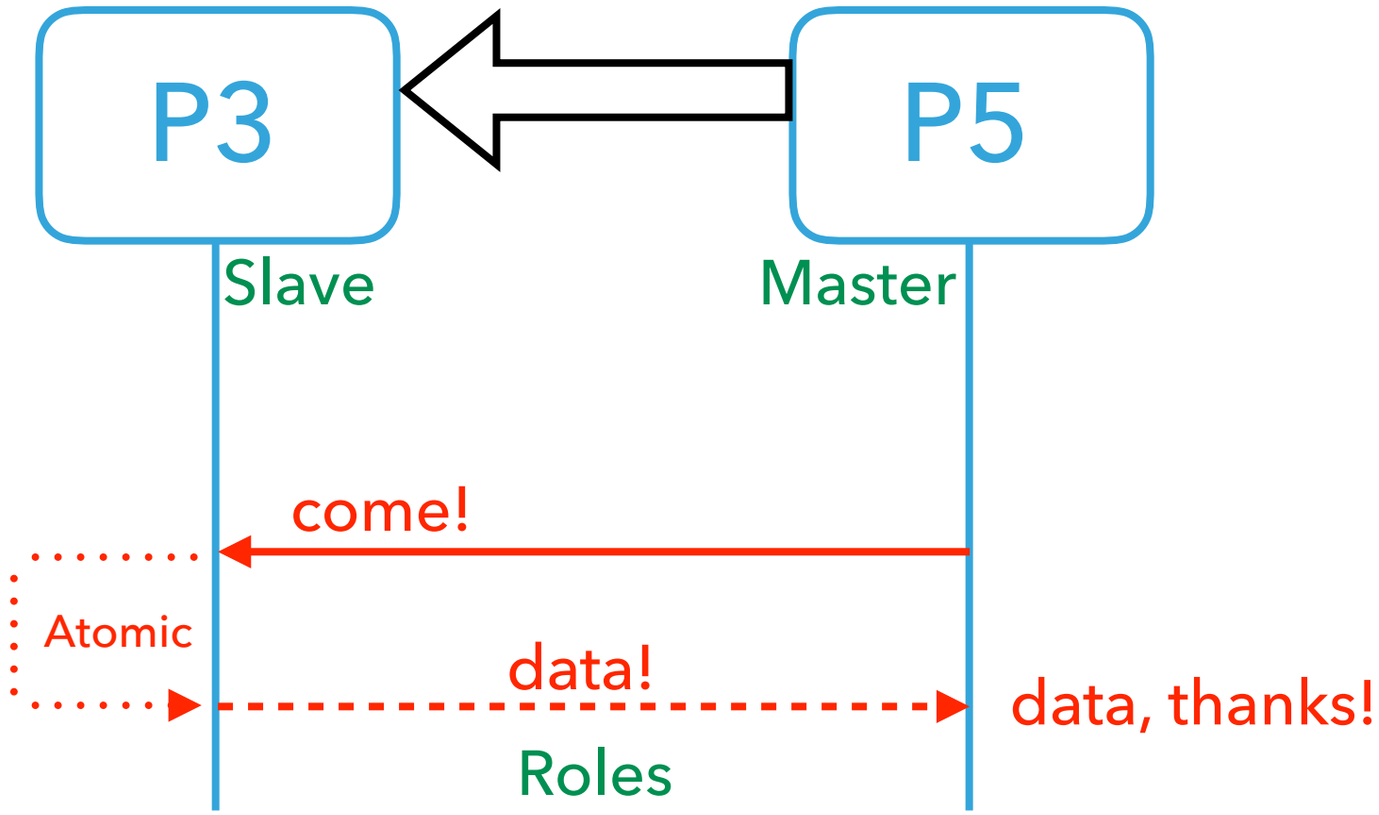

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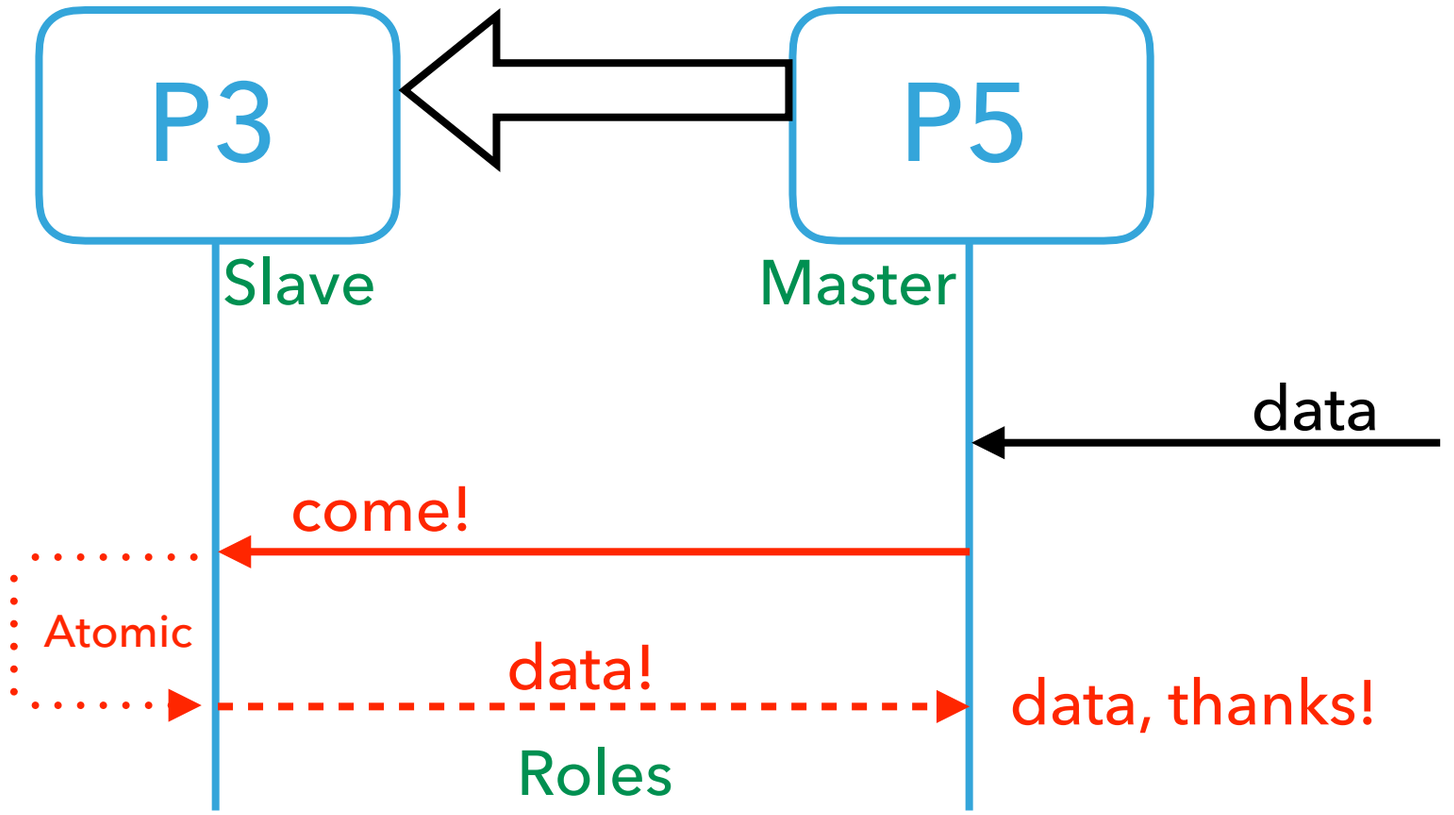

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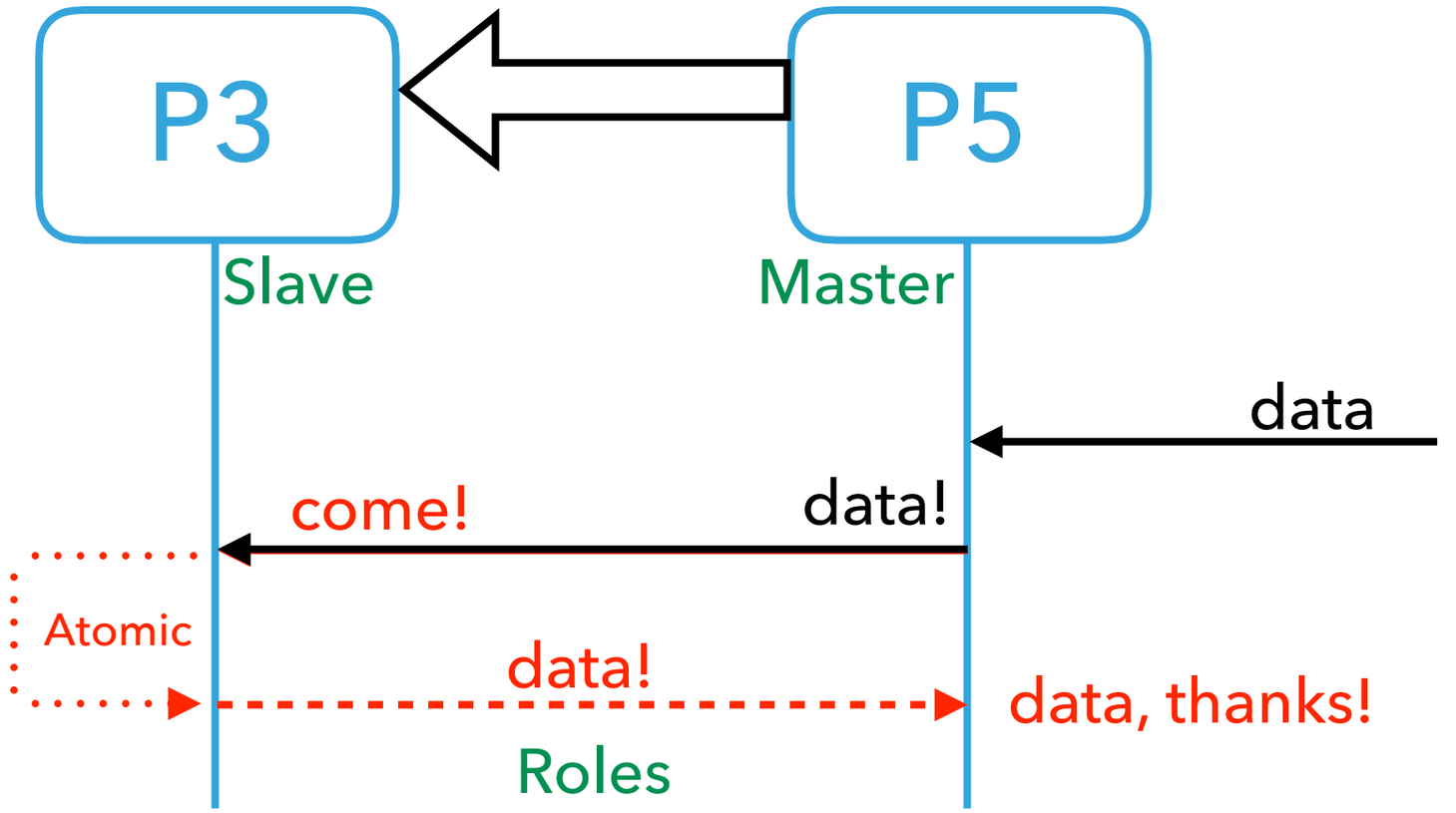

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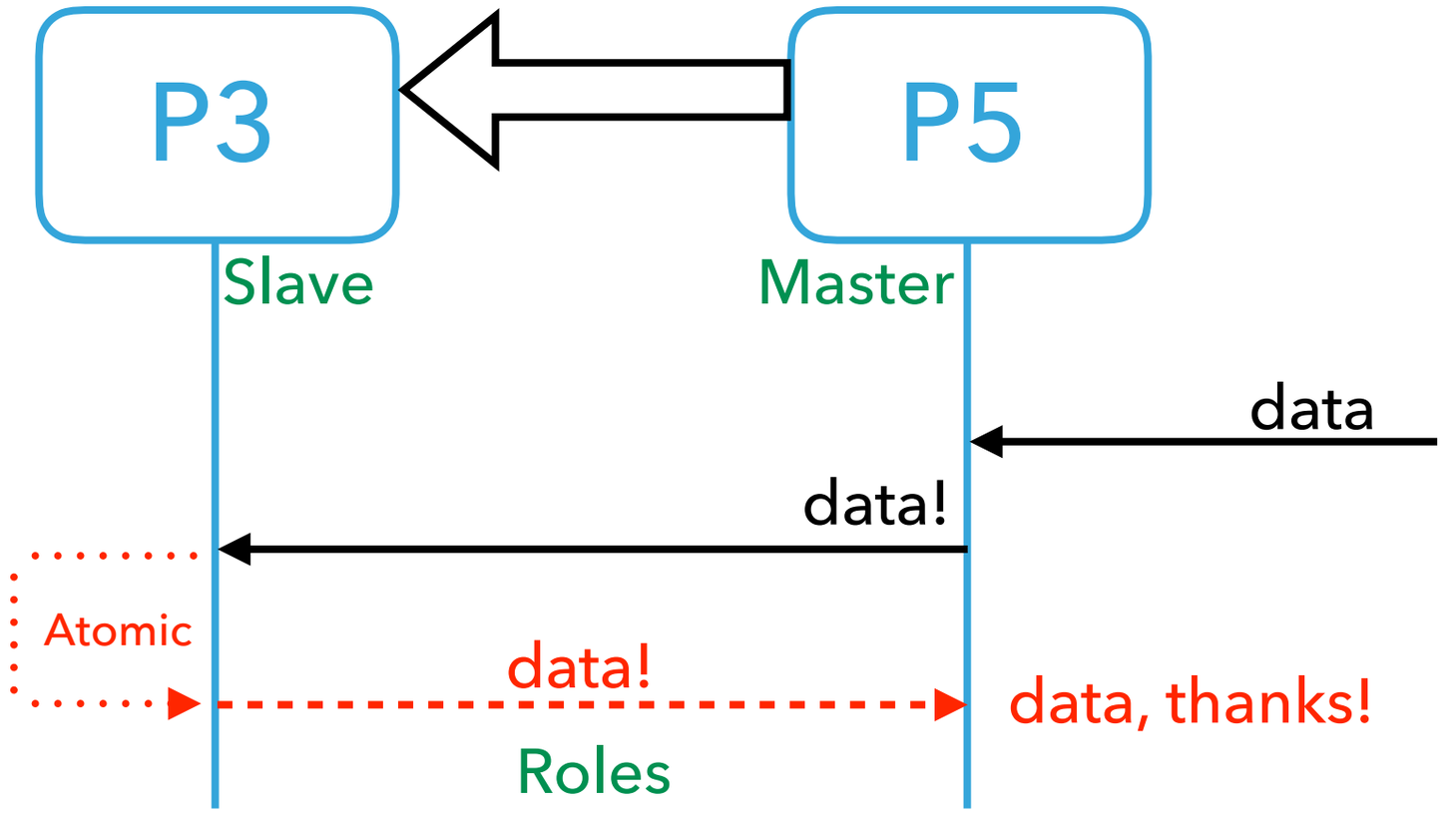

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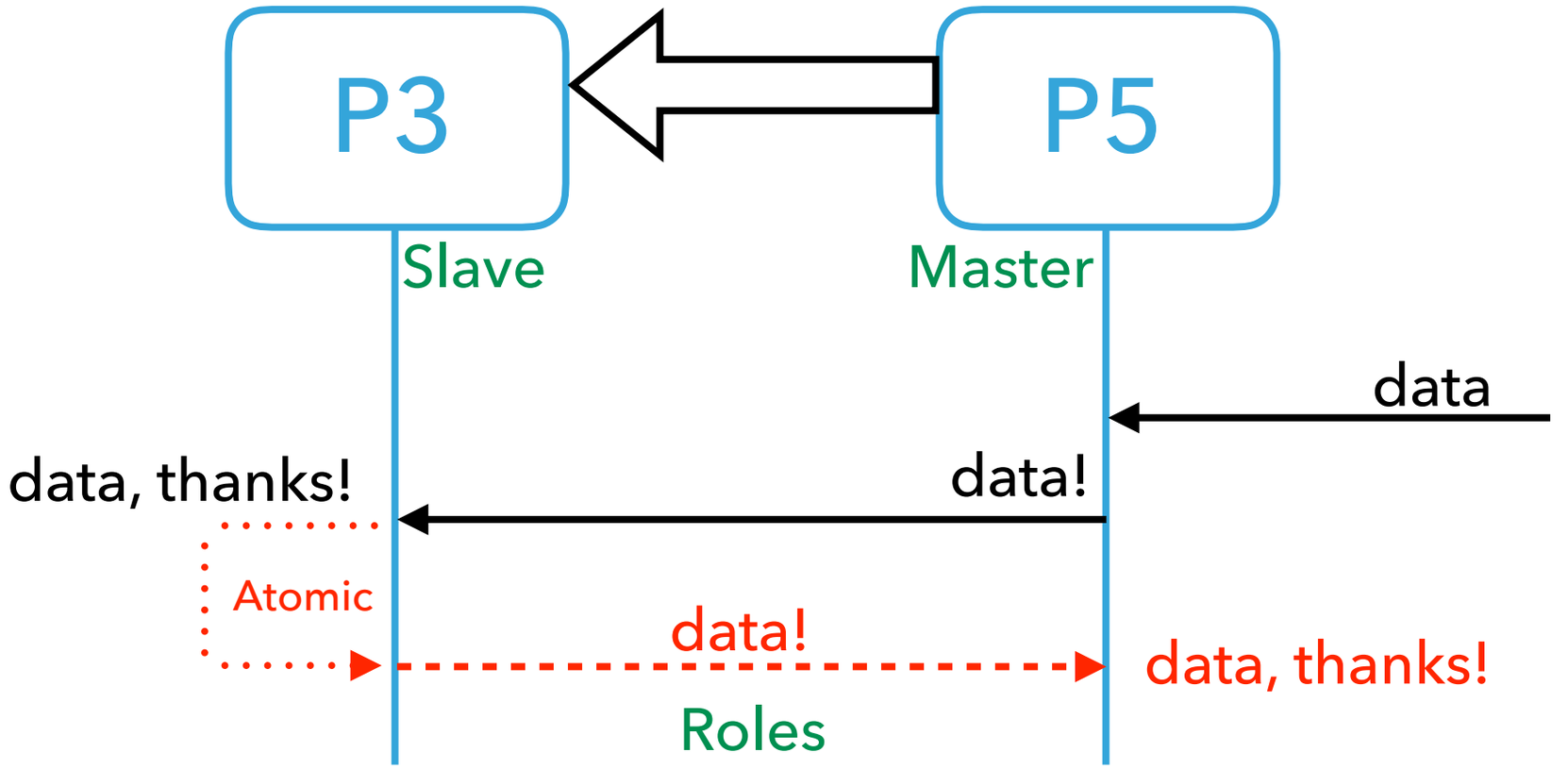

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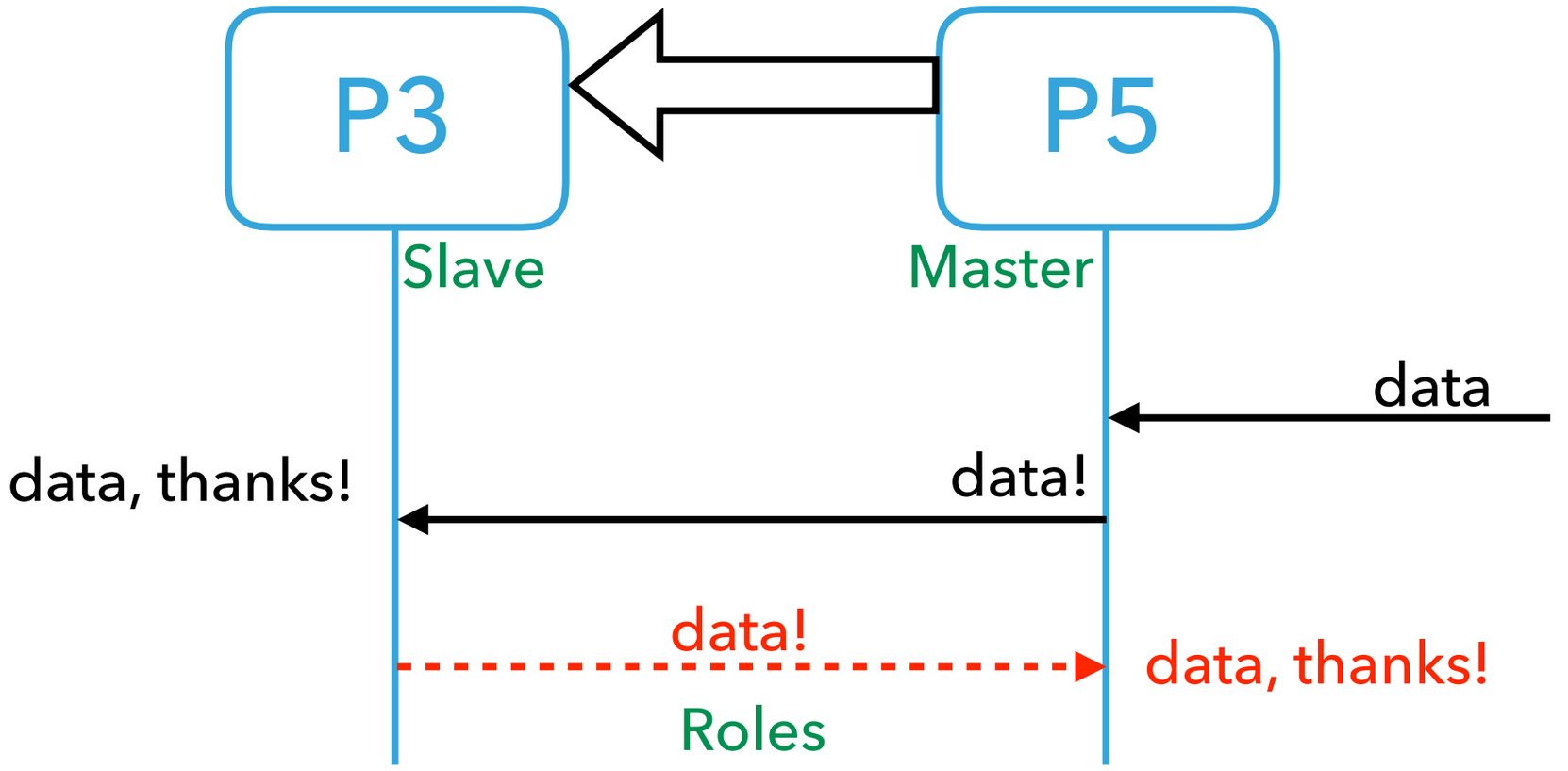

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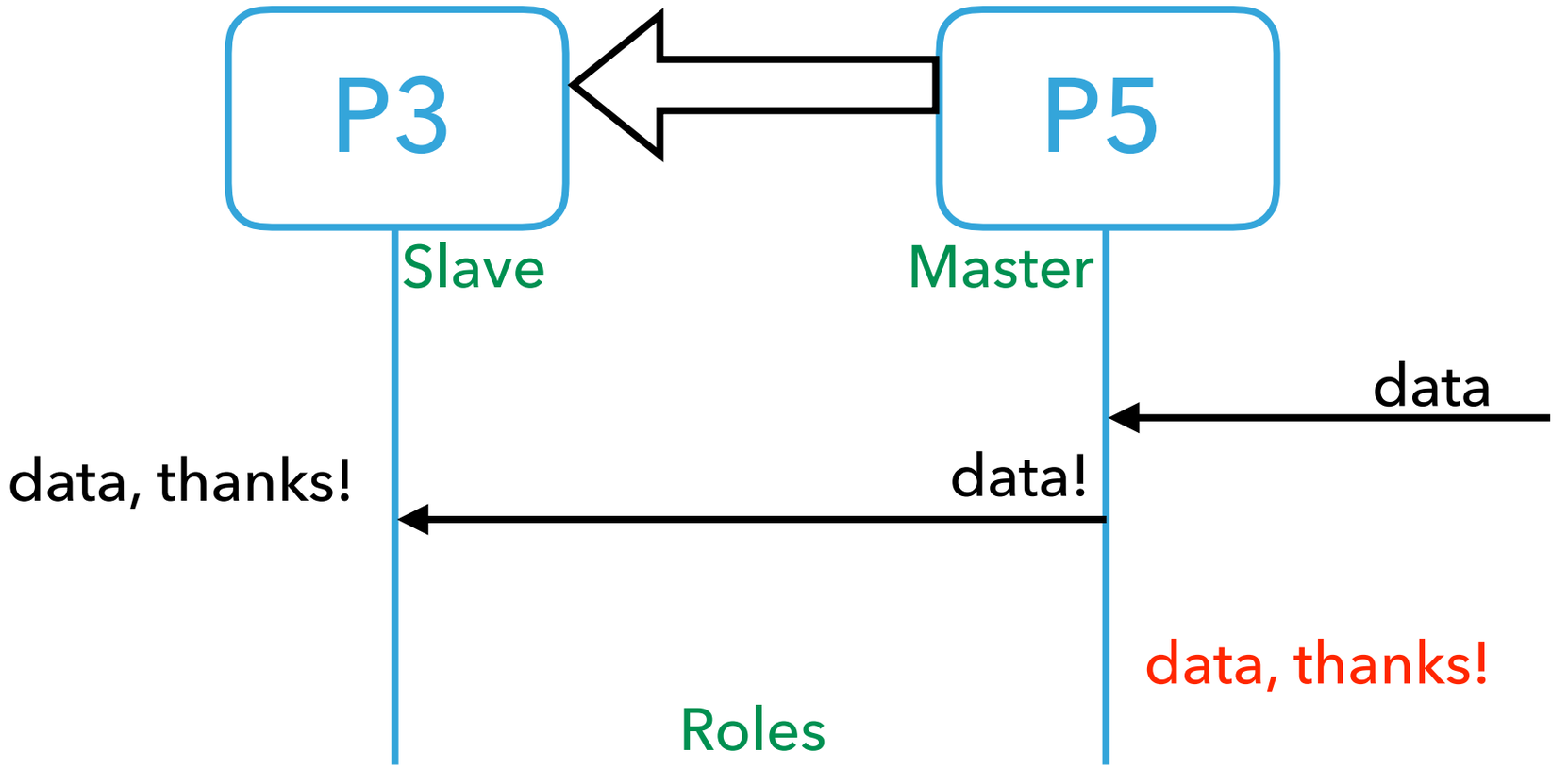

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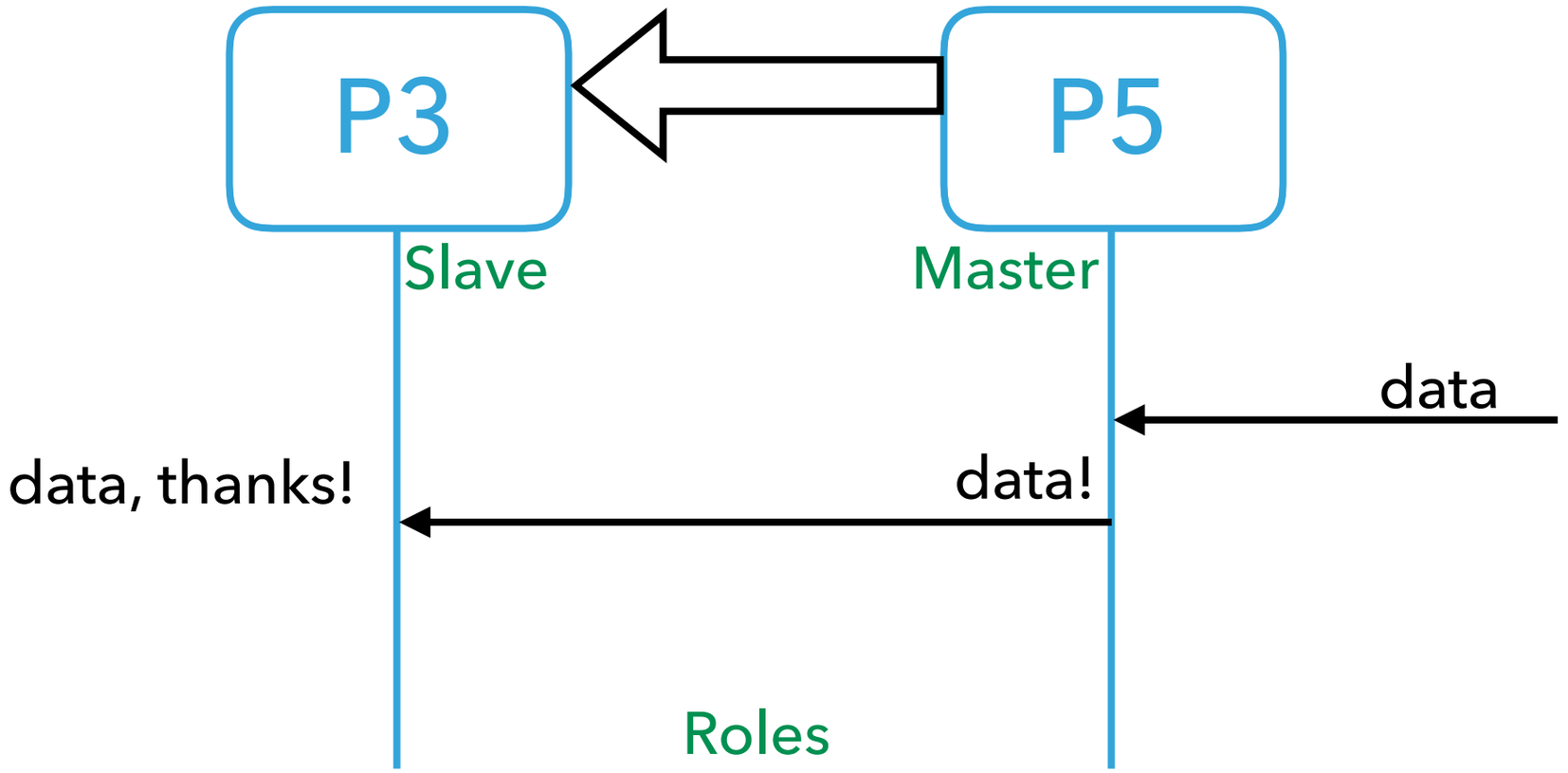

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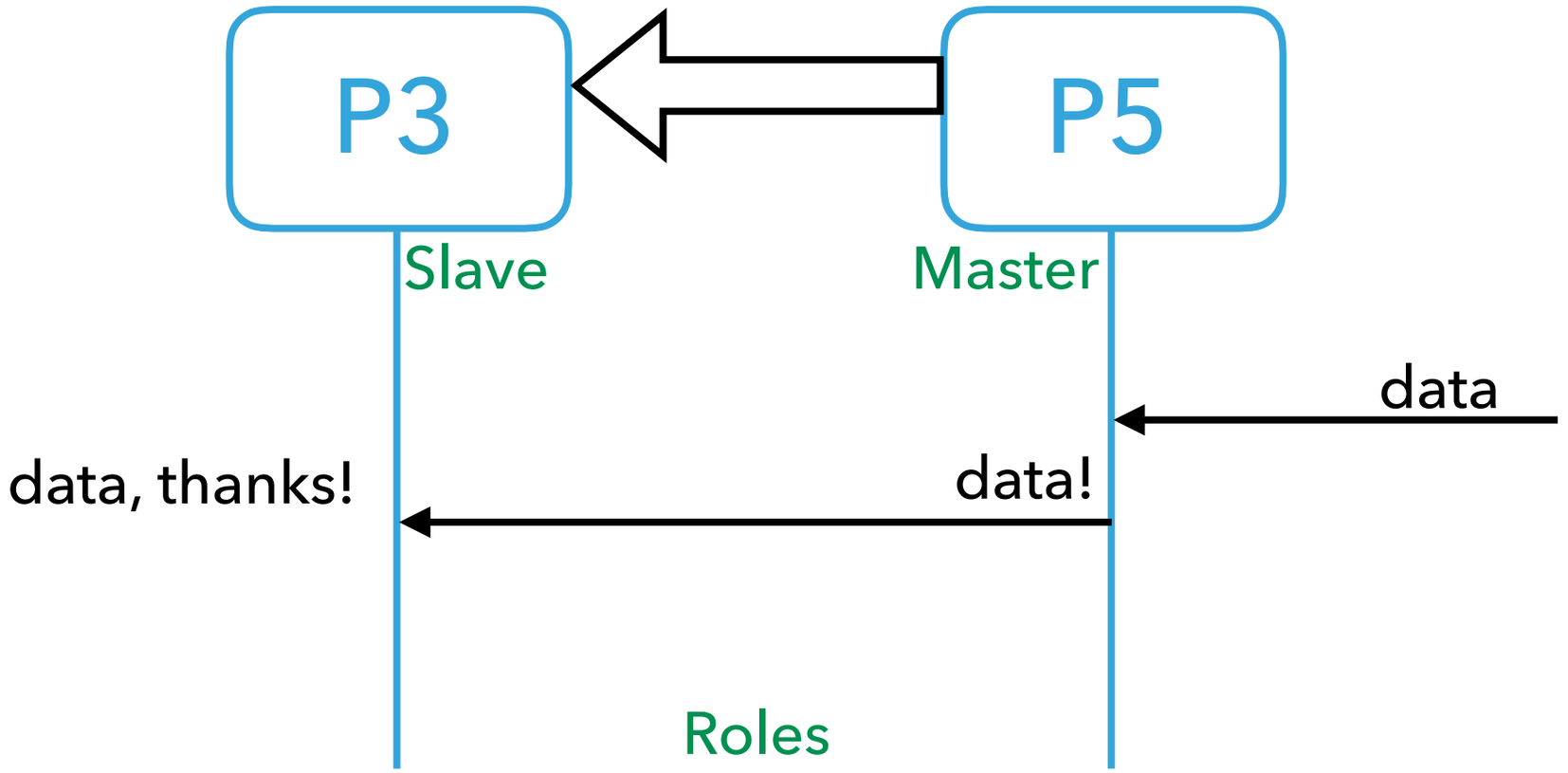

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oyvteig.blogspot.no/2009/03/009-knock-come-deadlock-free-pattern.html

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Referred in http://www.teigfam.net/oyvind/pub/pub_details.html#XCHAN

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I use this at home:

AQUARIUM CONTROL UNIT WITH XMOS `startKIT`, 8 LOGICAL CORES IN `xC`

Aside

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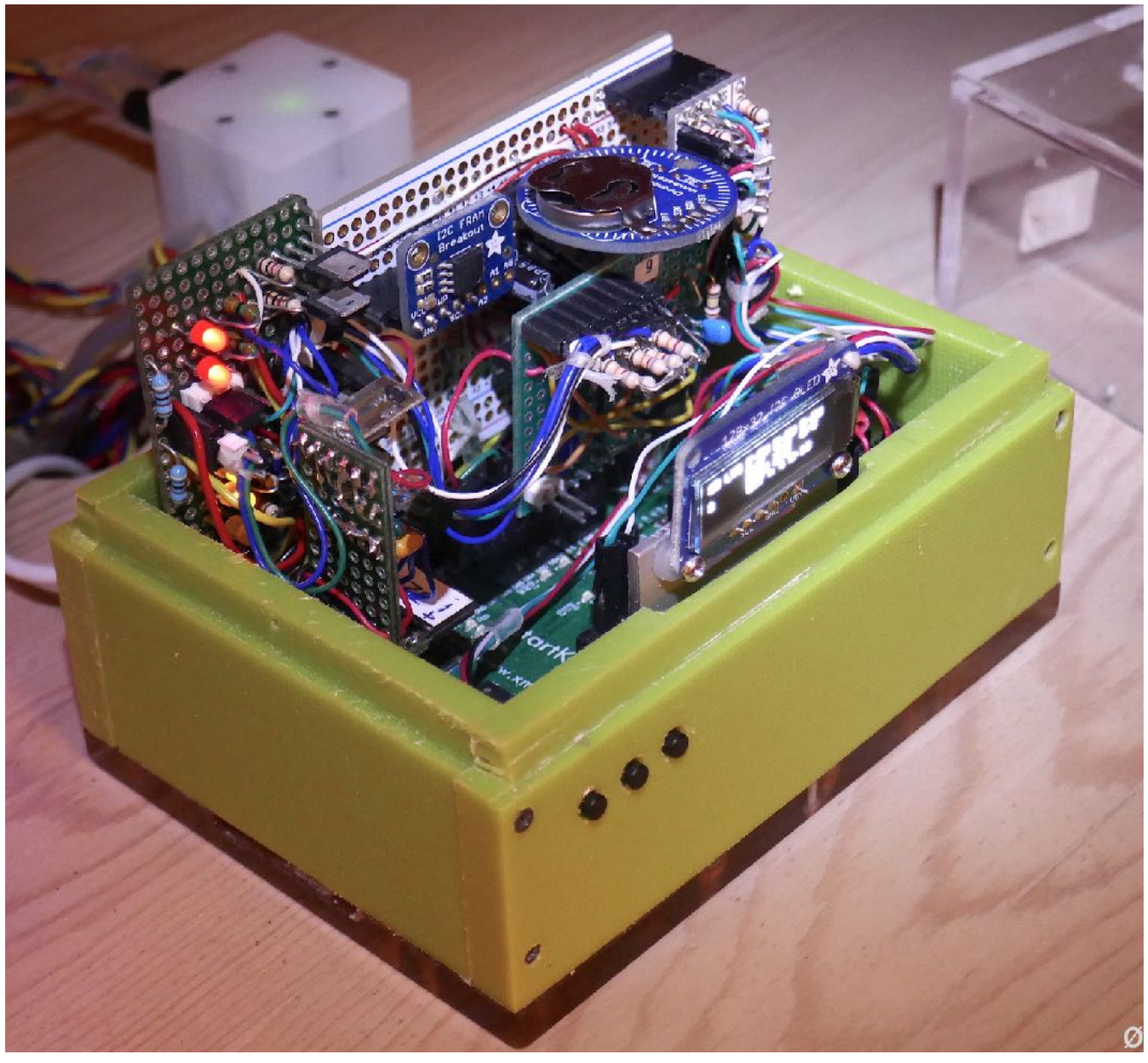
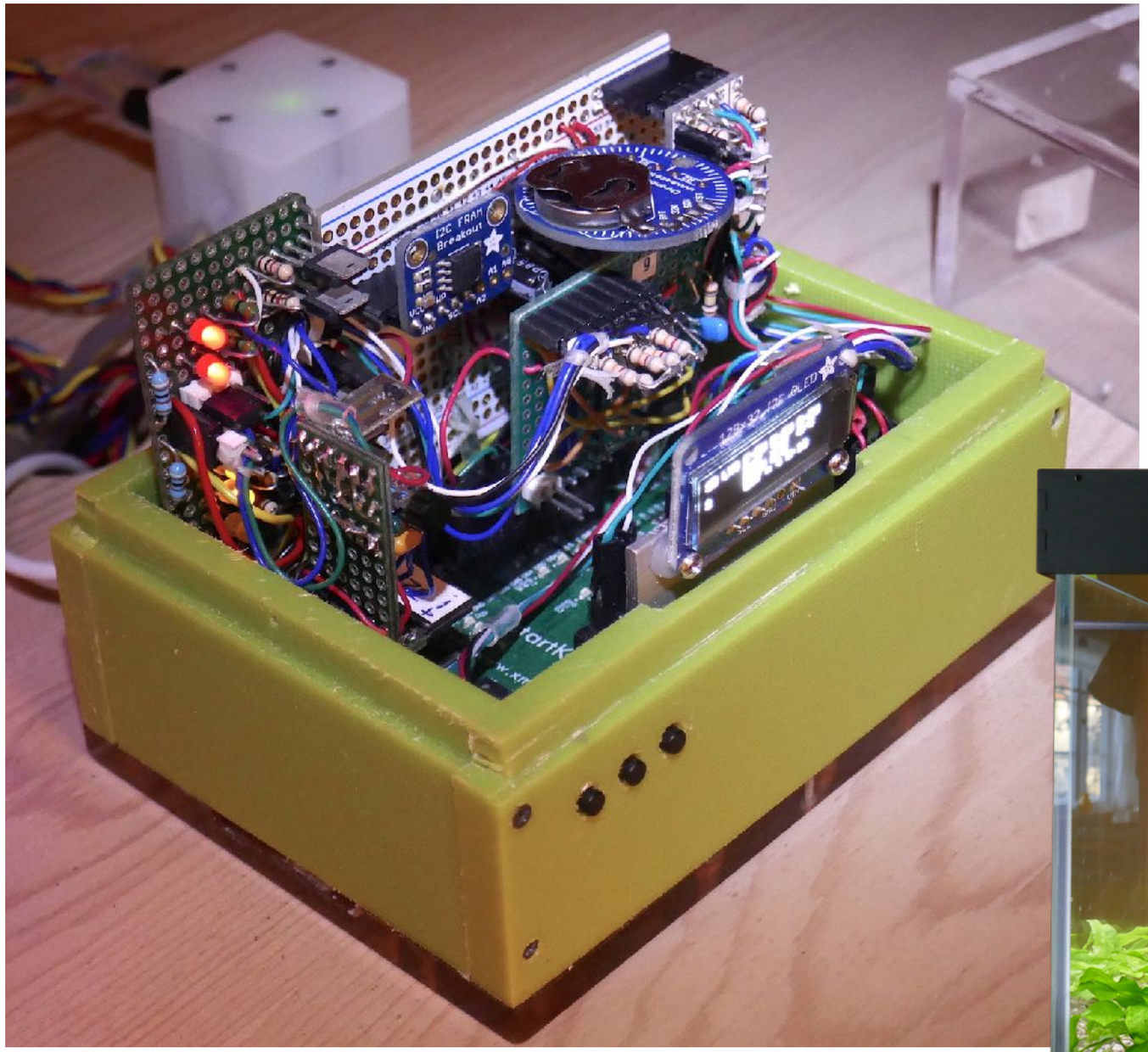


AQUARIUM CONTROL UNIT WITH XMOS `startKIT`, 8 LOGICAL CORES IN `xC`



Showing a forest for some trees 2

KEYWORDS interface, server, client AND slave etc.

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  [[guarded]]                void trigger(void);
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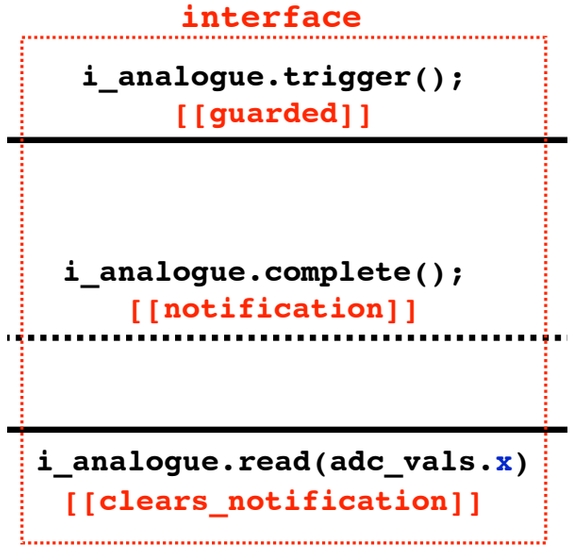


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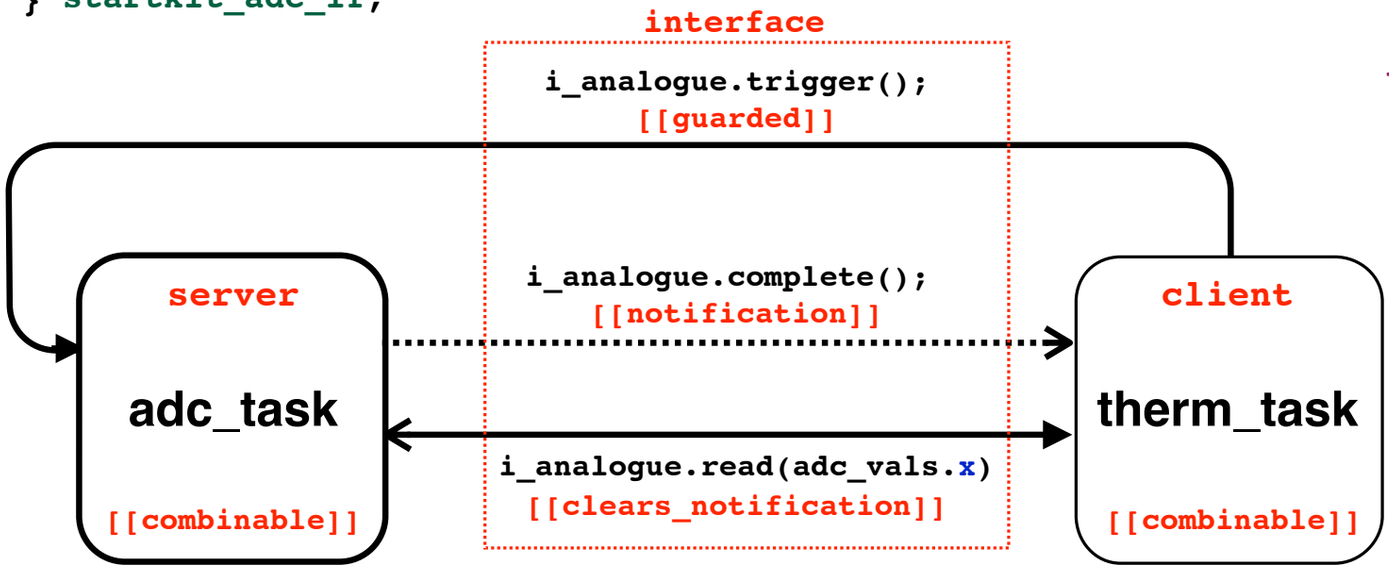

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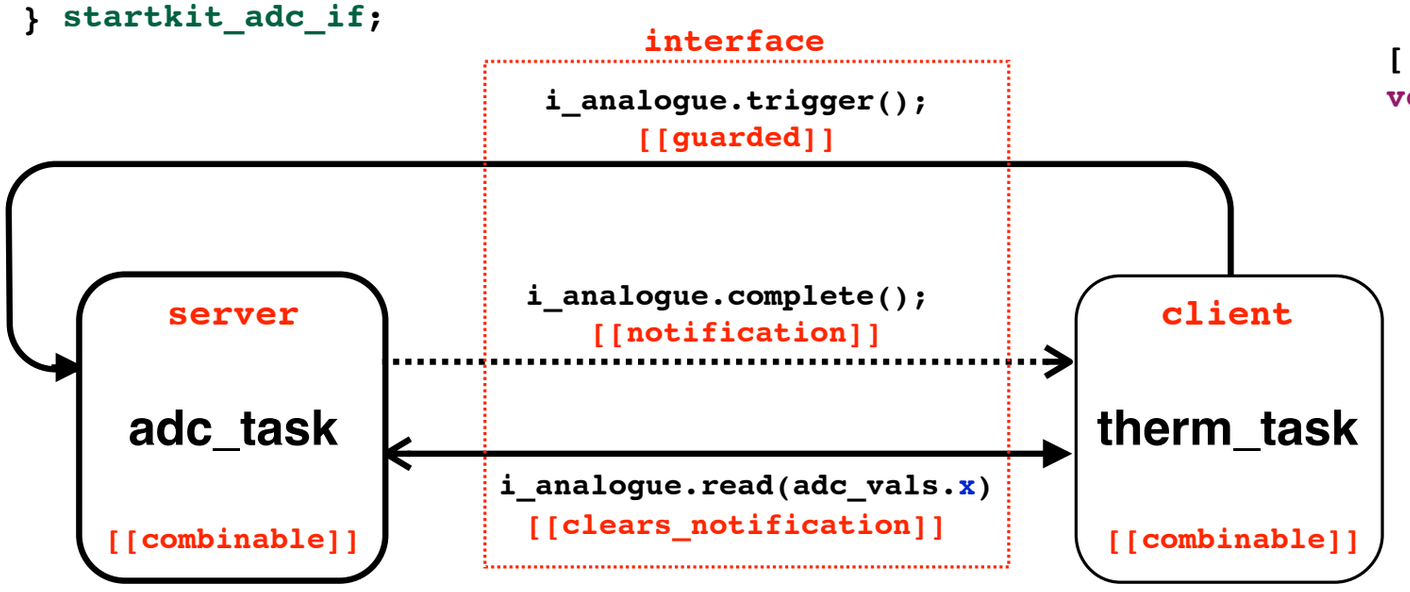


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  while(1) {
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      case wait_for_button => c_button_2 :> int x: {
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         break; }
      case wait_for_adc => i_analogue.complete(): {
         // ...
         if (i_analogue.read(adc_vals.x)) {
           // Use it
         } break;
      }
    }
  }
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Drawing by Øyvind Teig

Showing a forest for some trees 2

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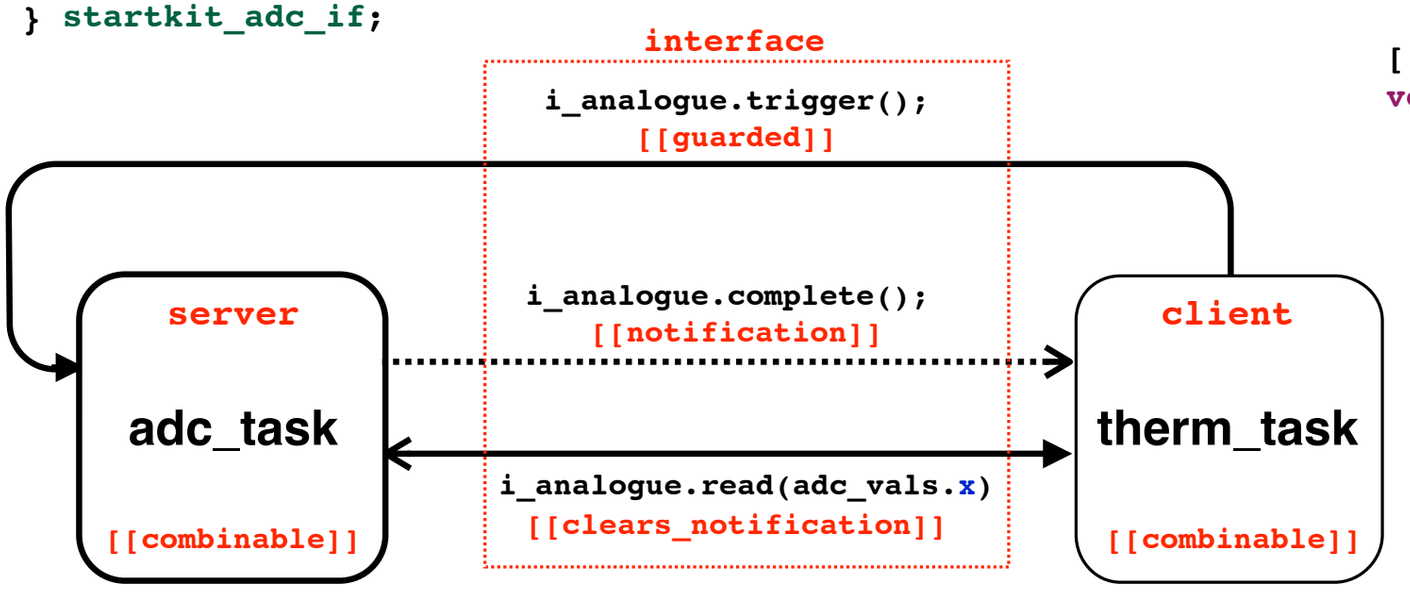

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Guaranteed deterministic real-time response

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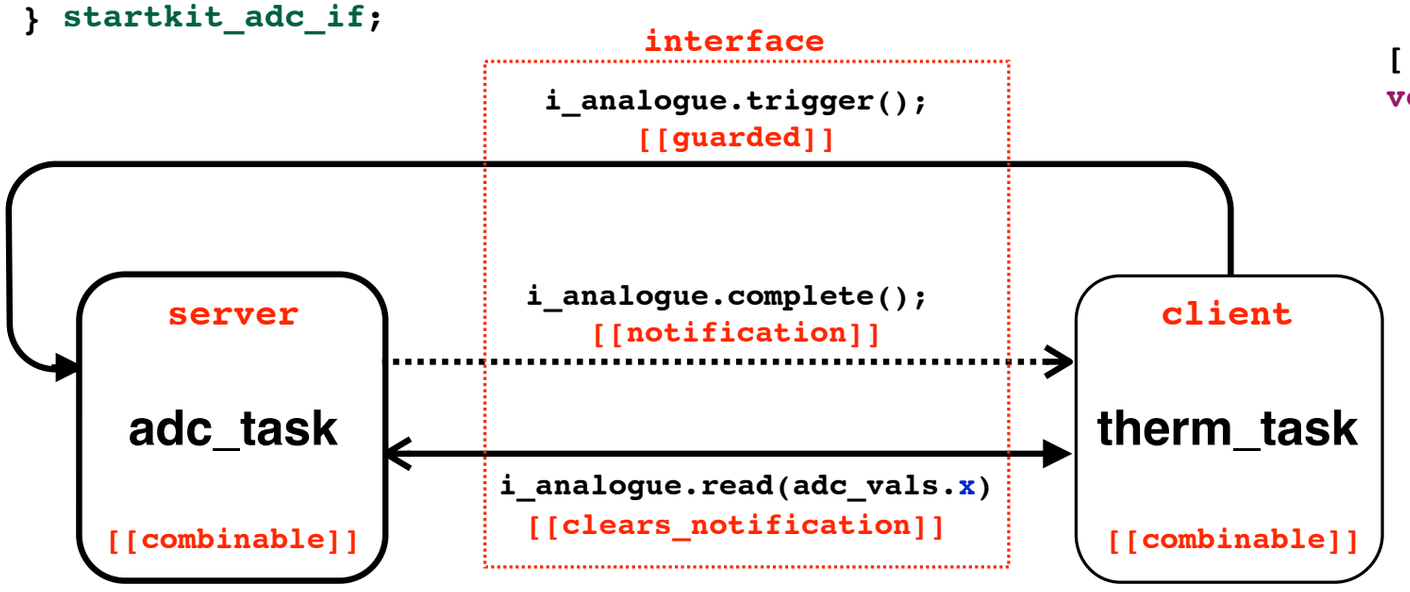

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Drawing by Øyvind Teig

This pattern is understood by the compiler and it is deadlock free

occam, too. But it didn't have `interface`

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https://en.wikipedia.org/wiki/Occam_(programming_language)

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http://www.teigfam.net/oyvind/home/technology/049-nondeterminism/

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Autronica

BS-100 fire panel (1990..)
In-house scheduler and Modula 2

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Last BS-100 for a ship (2011)
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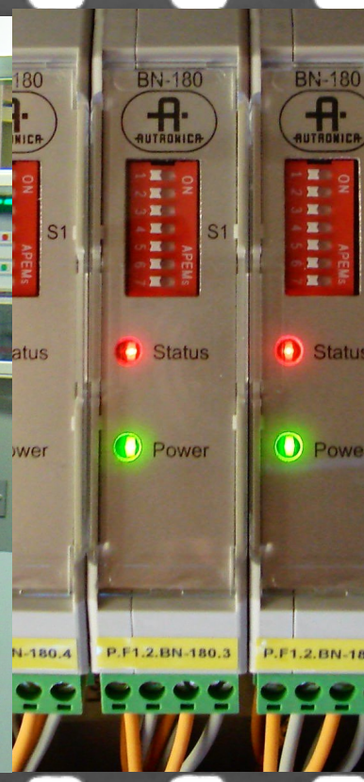
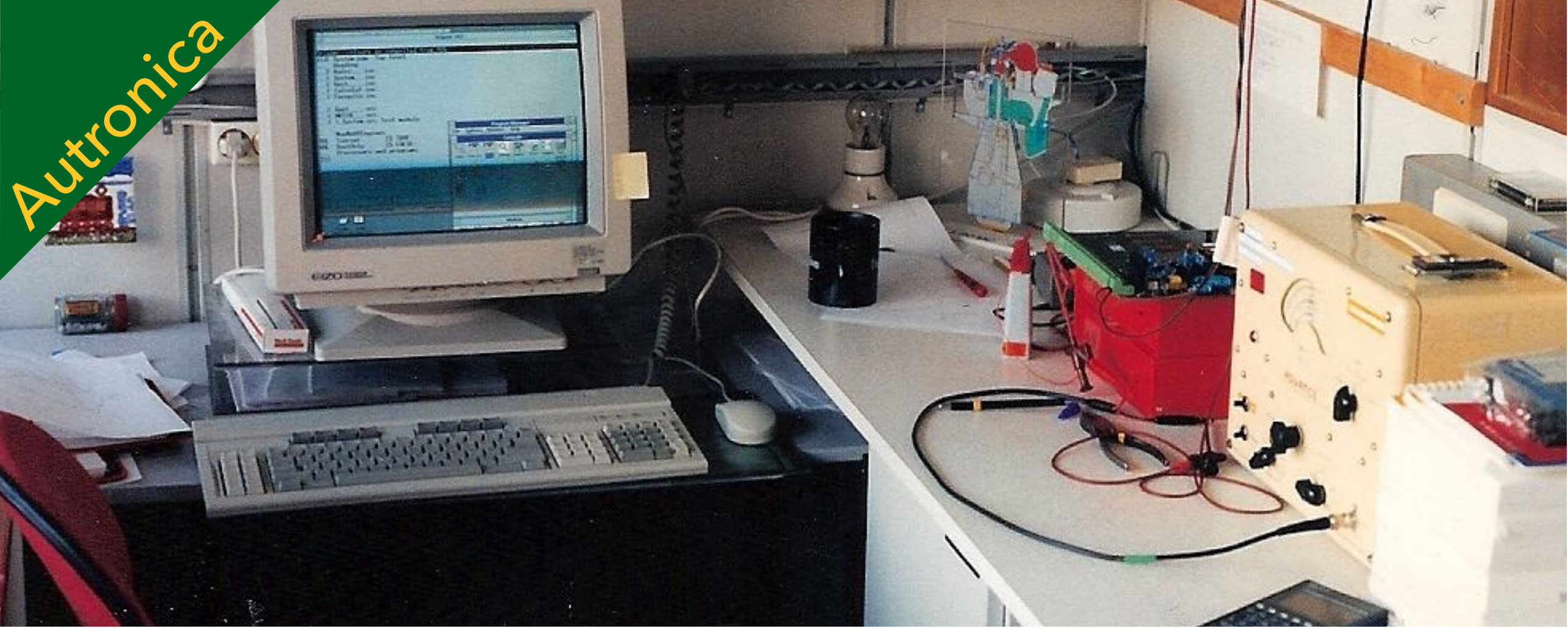
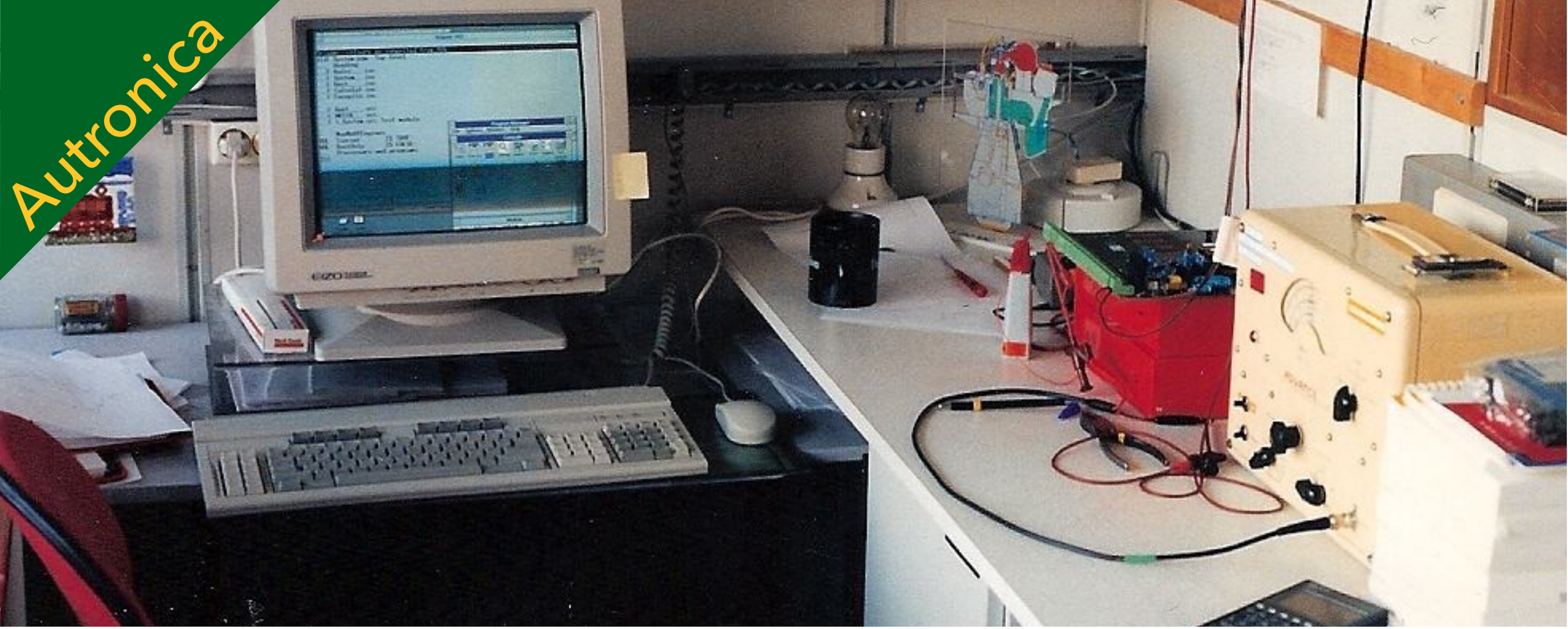
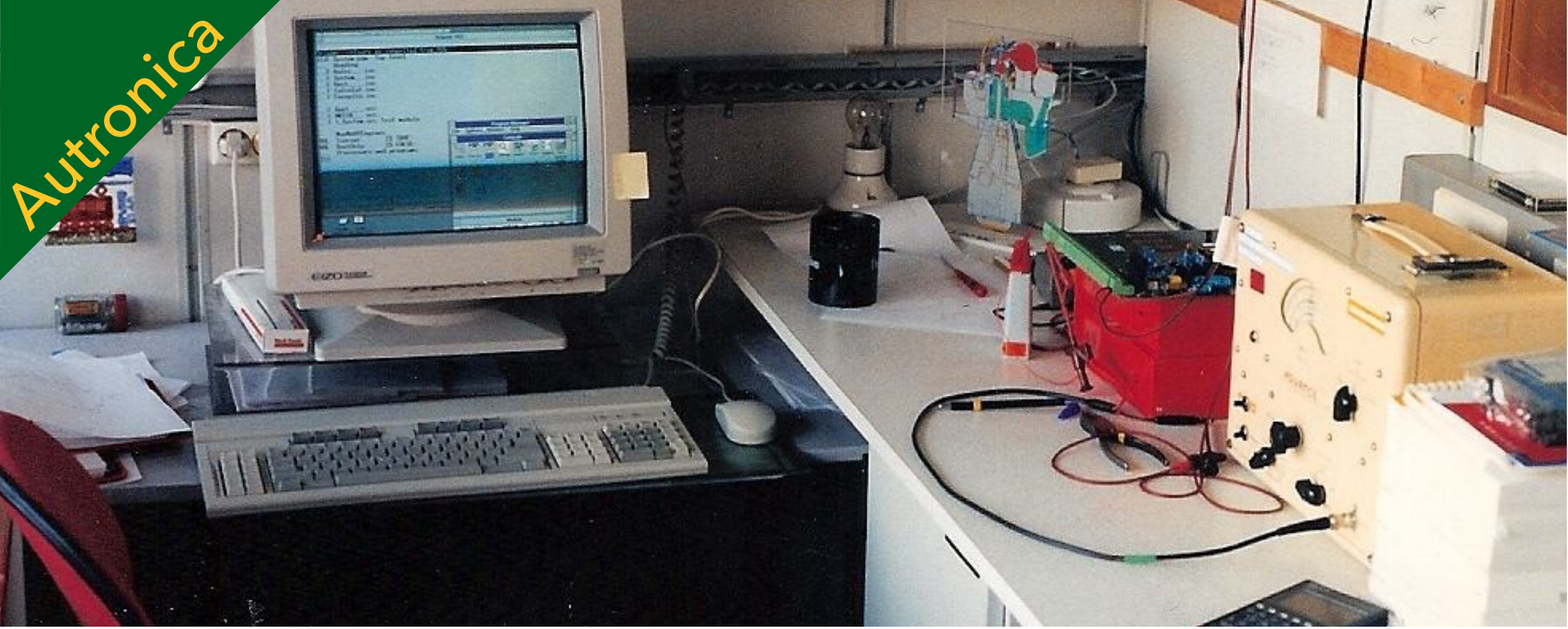


AutroKeeper (2010..)
Chansched scheduler


Autronica



1990: OCCAM WITH PROCESS AND CHANNELS.



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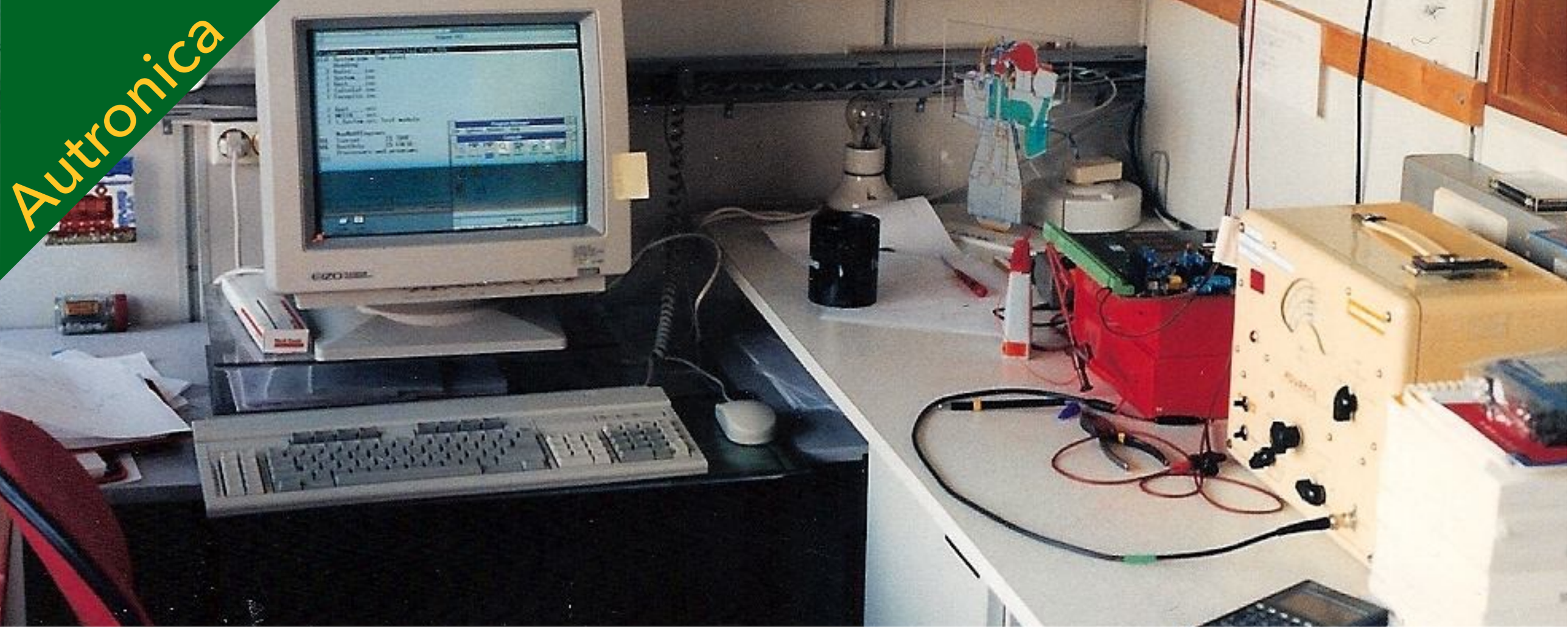

TO ME: NOTHING EVER THE SAME AFTER

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Transparent transputer links running in LON industrial network, testing a virtual channel router in my office

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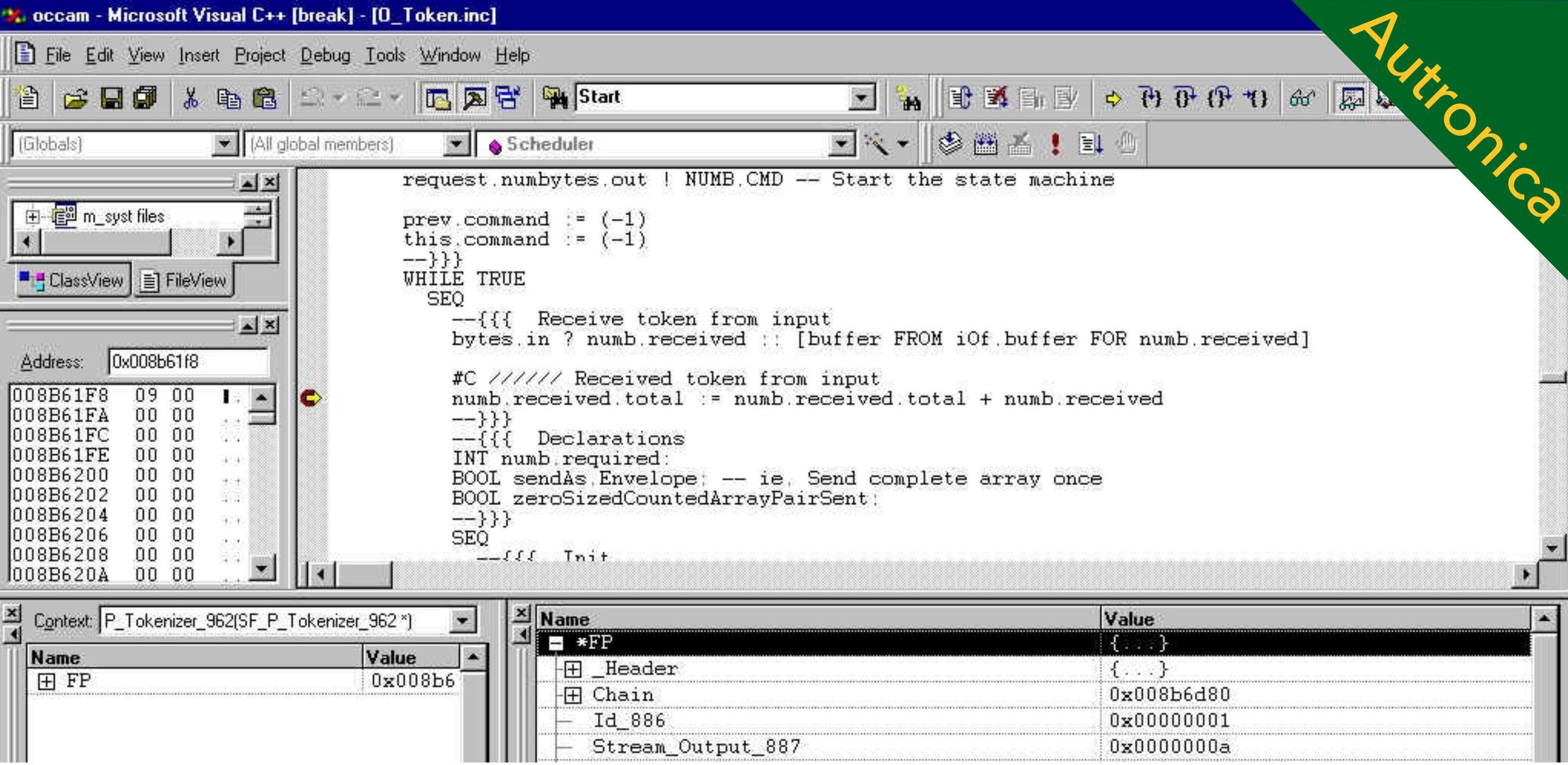

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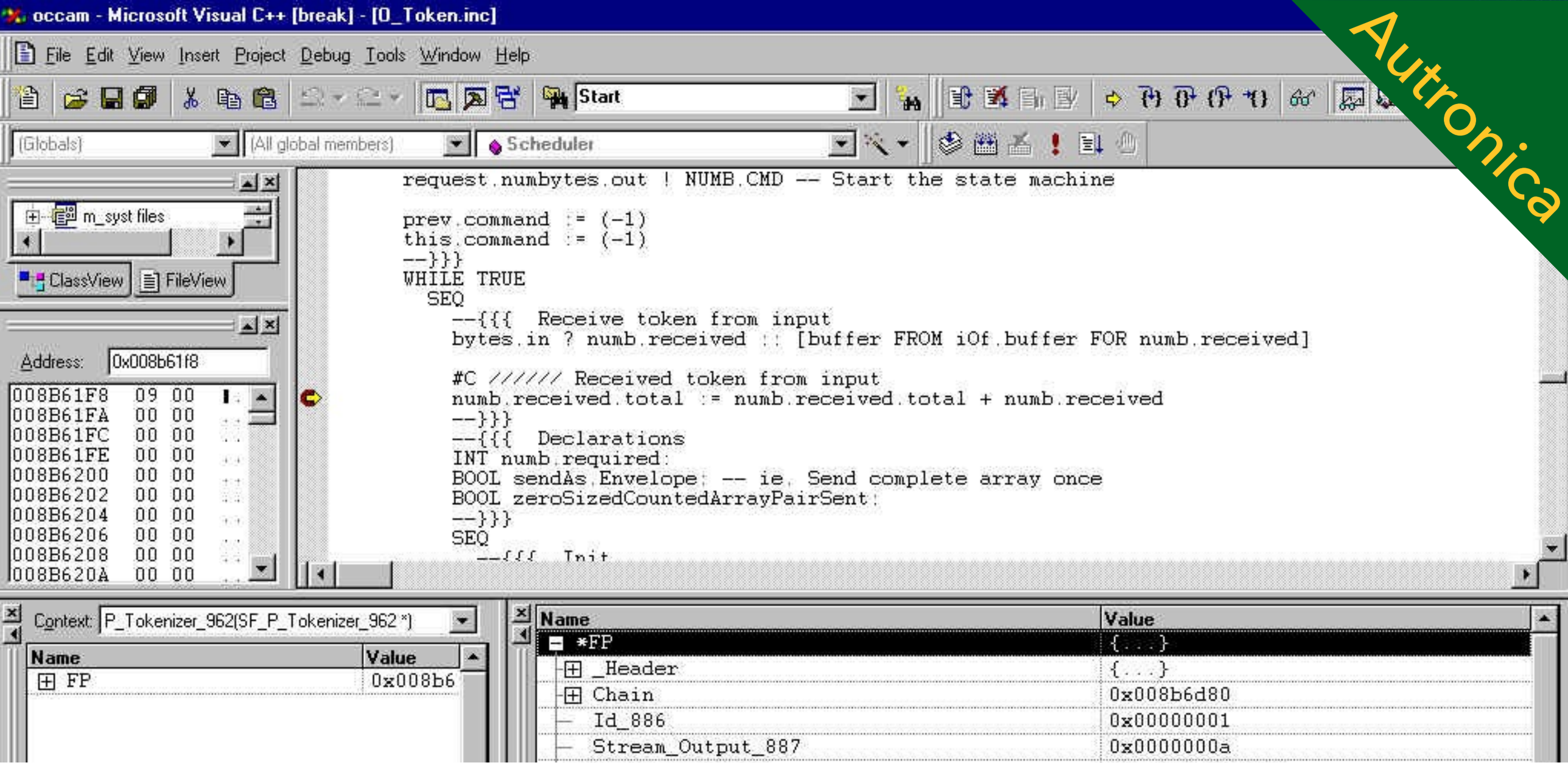

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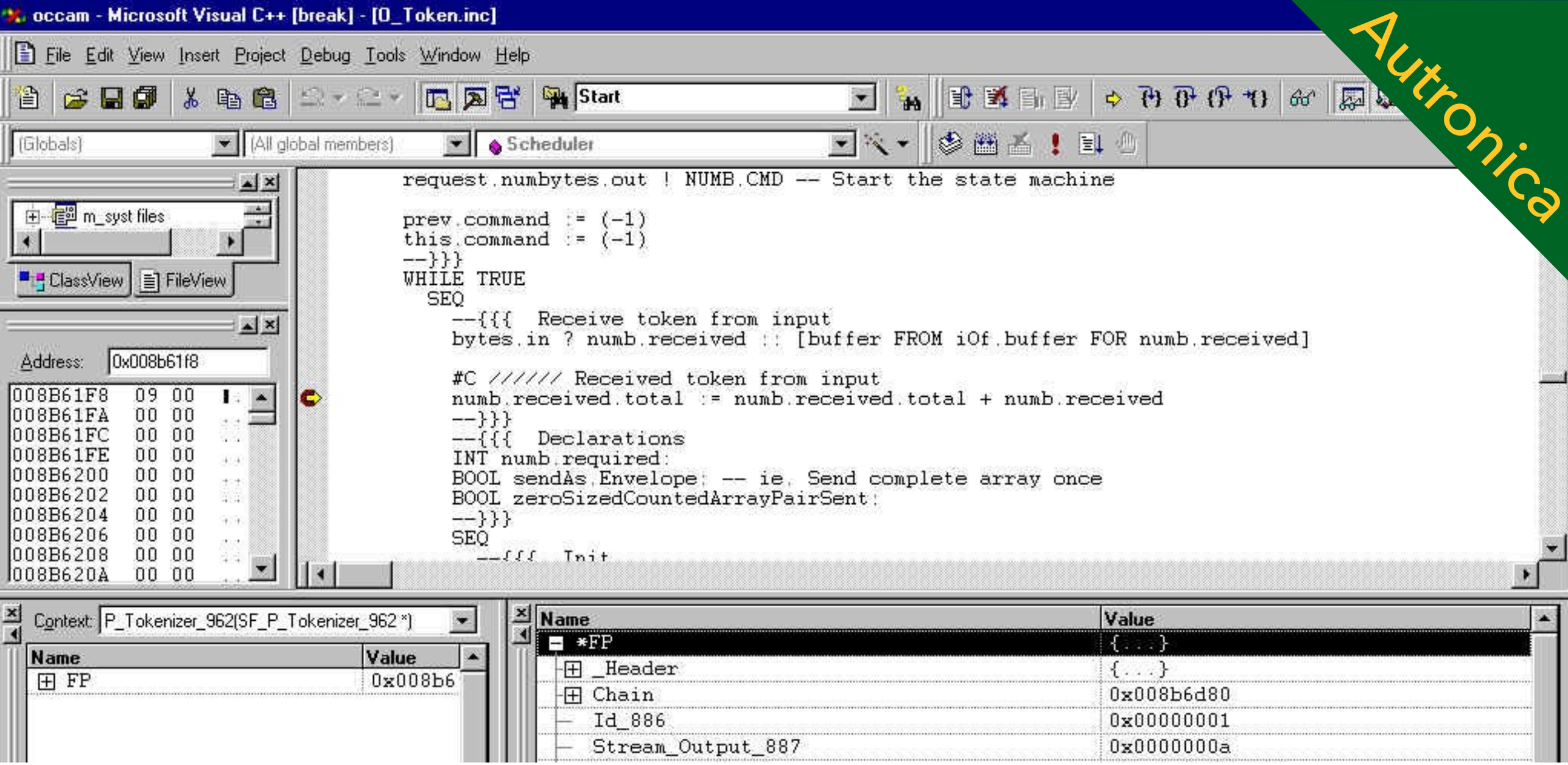
1995: OCCAM TO C ON SIGNAL PROCESSOR



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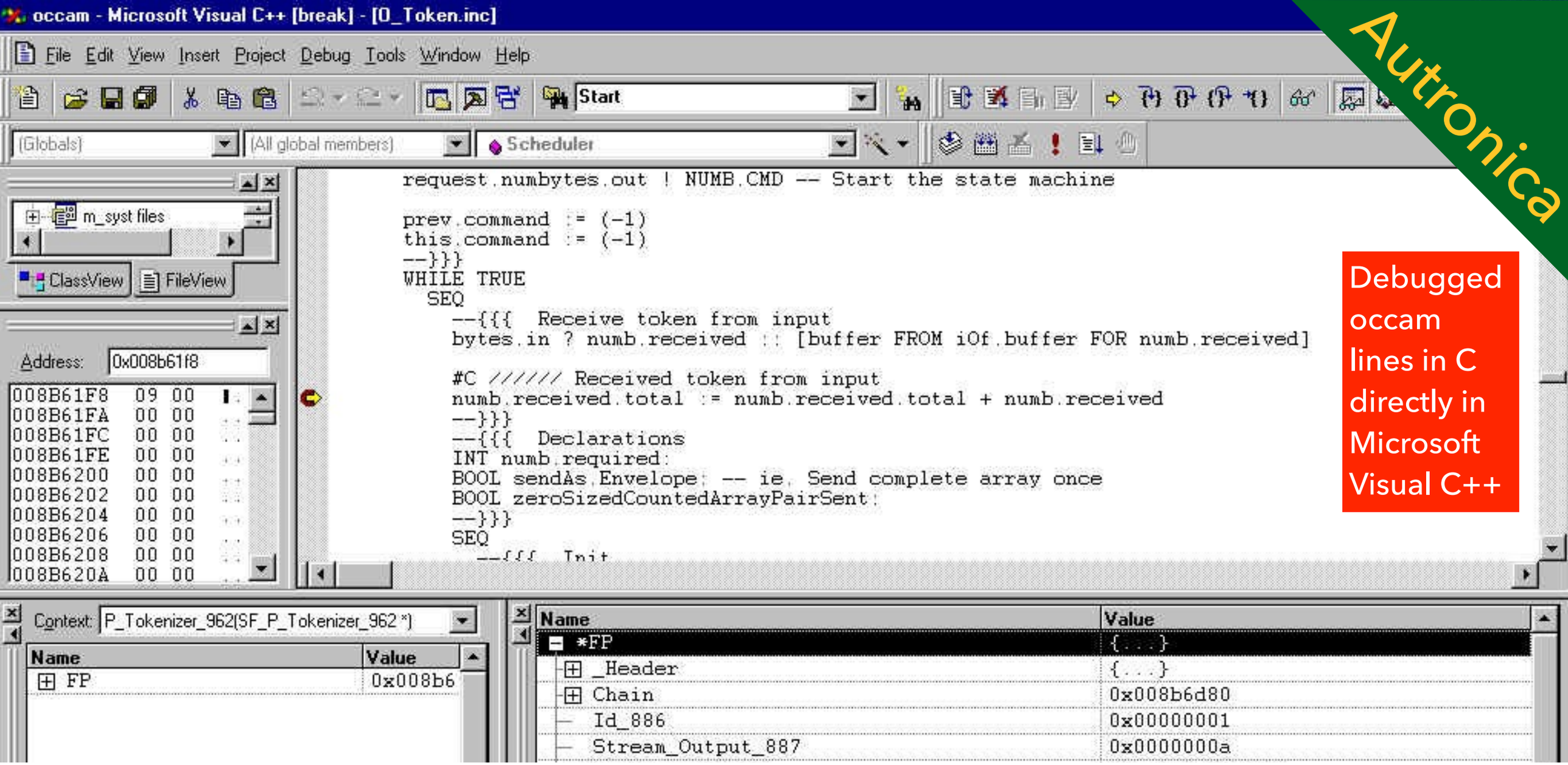
1995: OCCAM TO C ON SIGNAL PROCESSOR (MIP-CALCULATOR: NK-200) & NTH DIPLOMA



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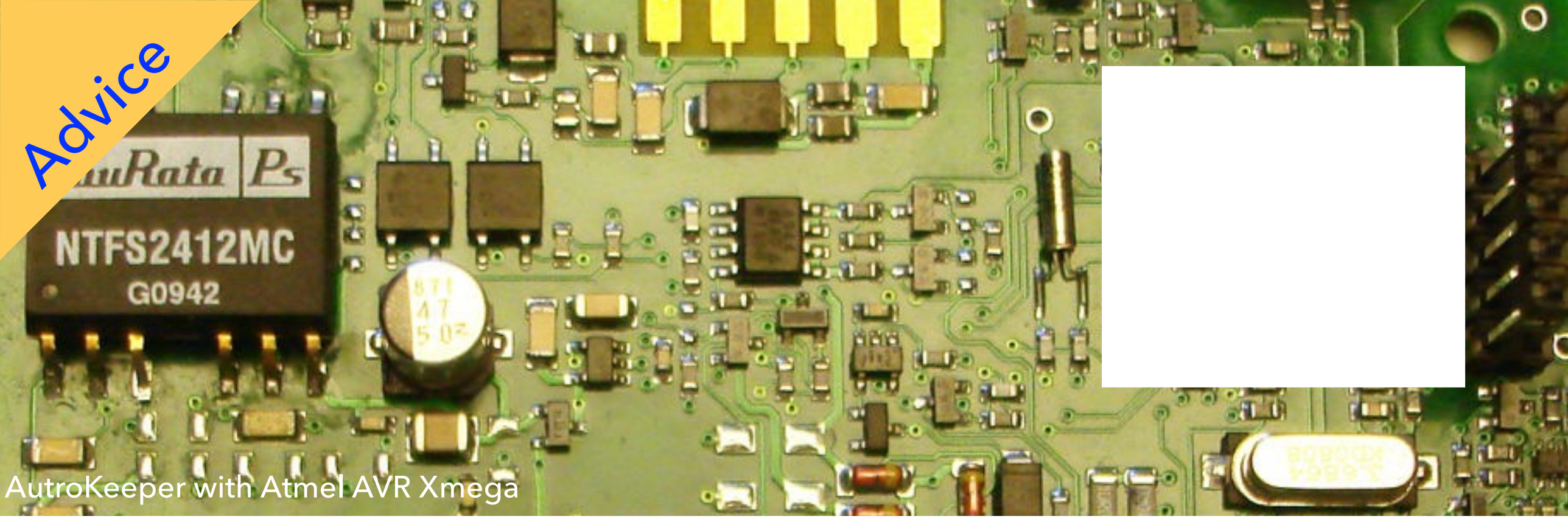
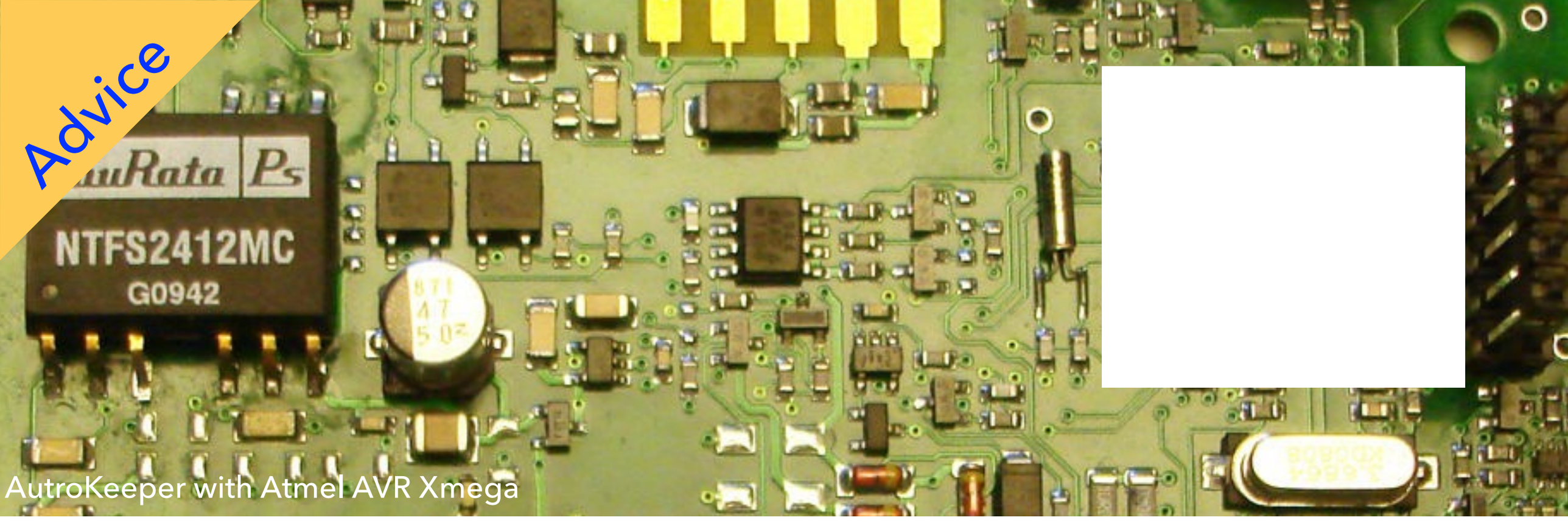


SMALL EMBEDDED SYSTEMS



SMALL EMBEDDED SYSTEMS

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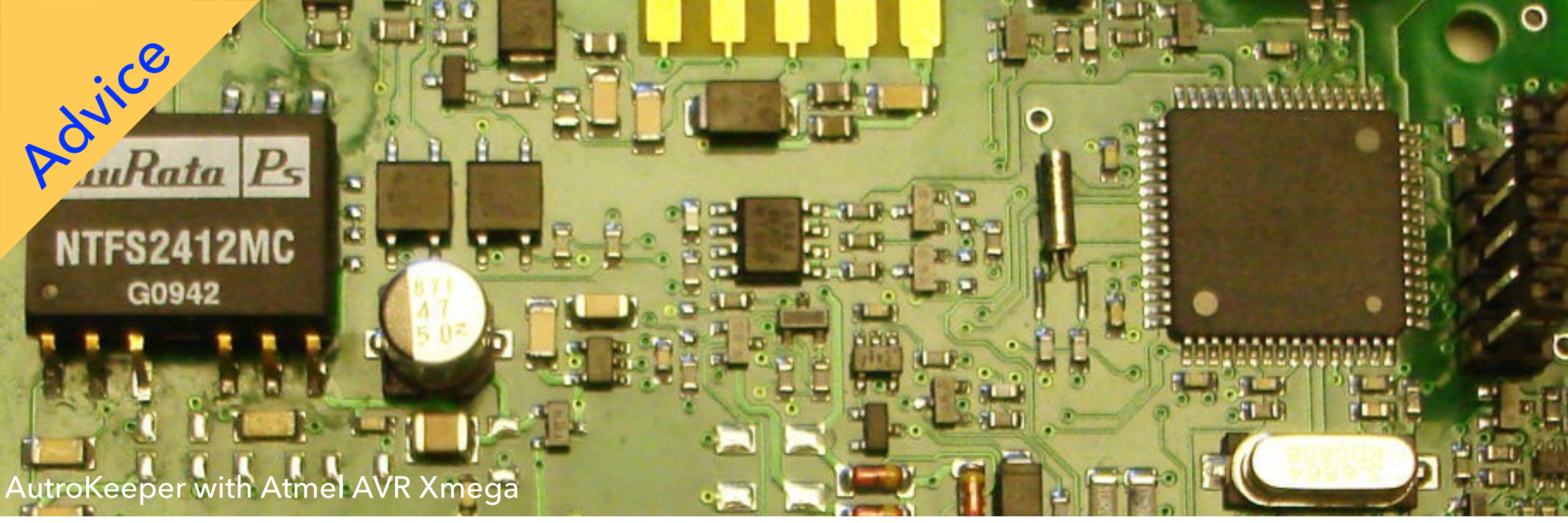

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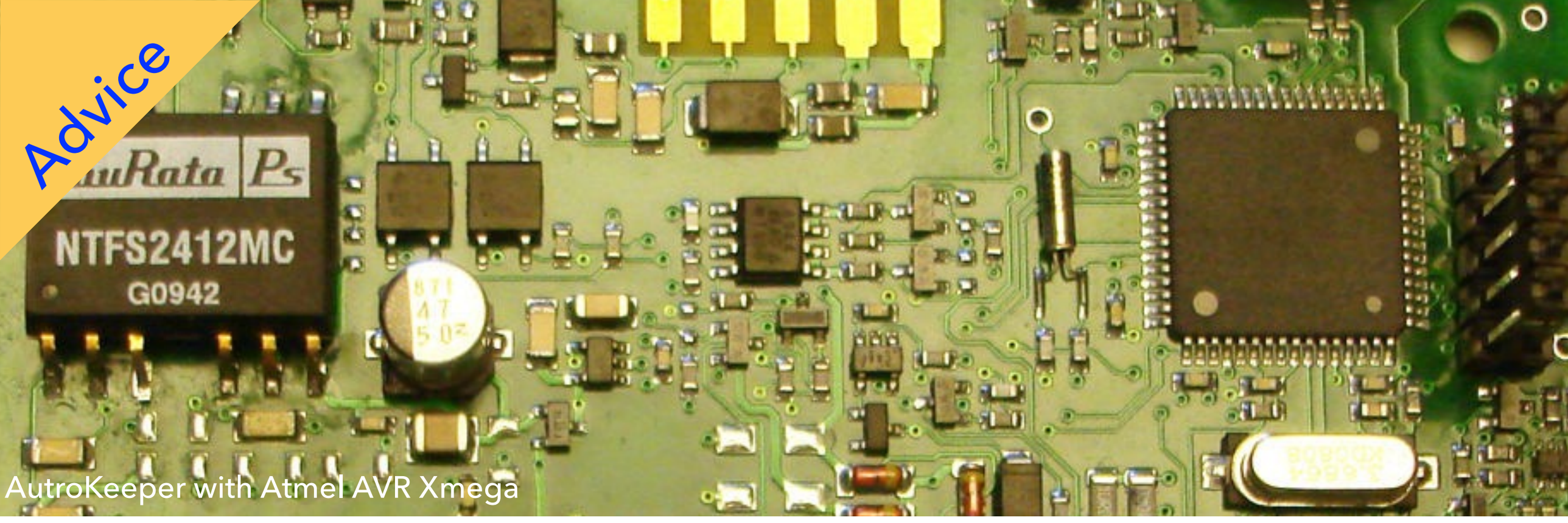

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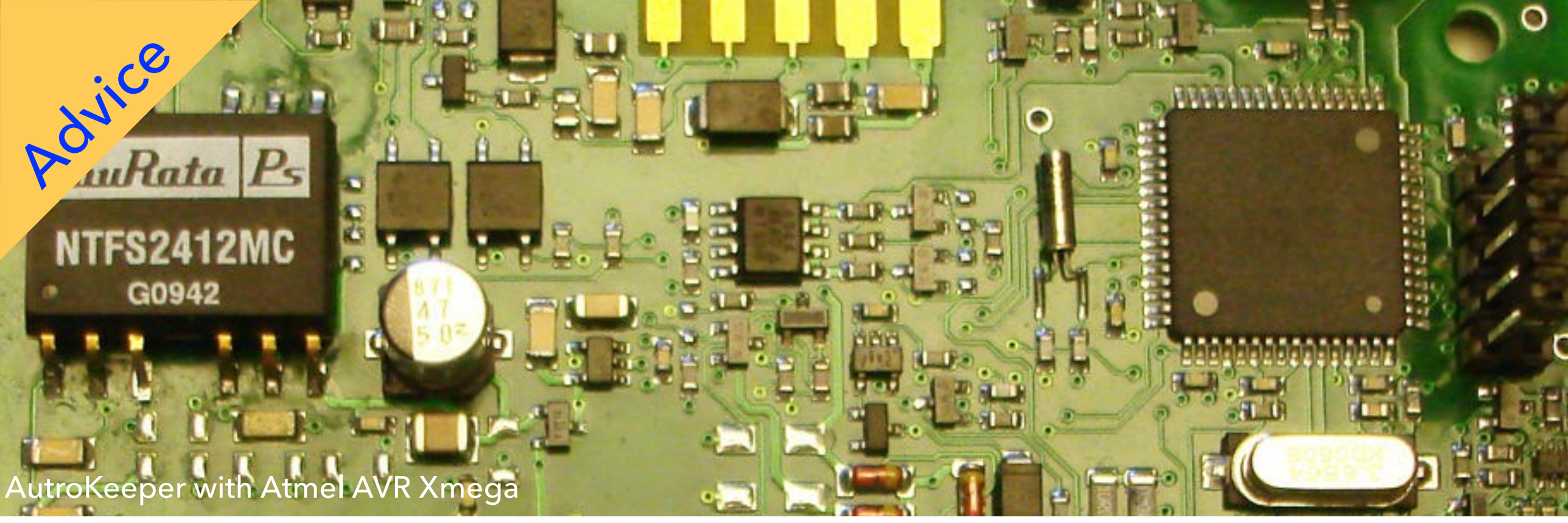

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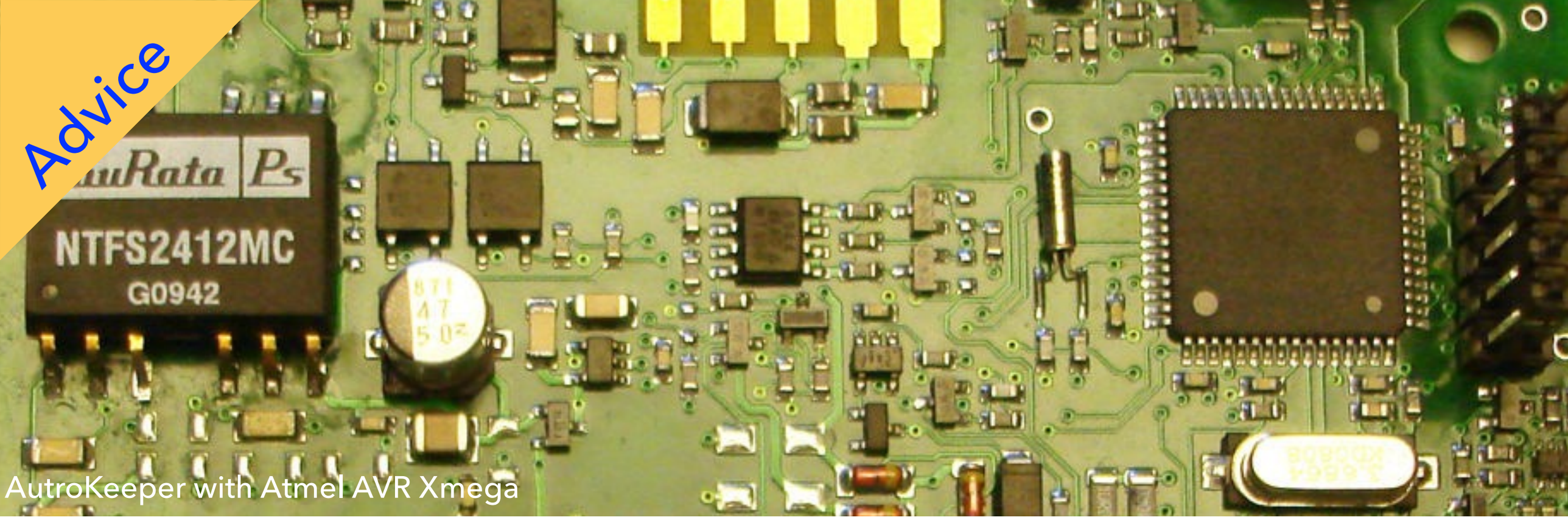

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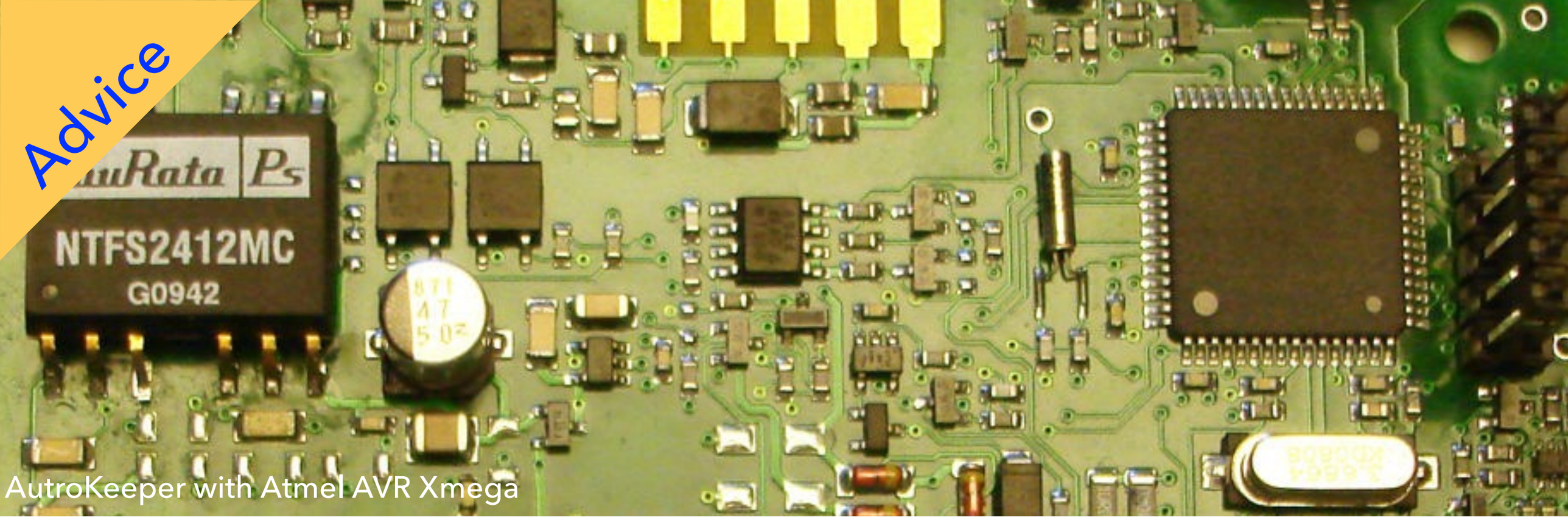

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- Project managers need to learn about the «Go potential»
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    - Even if it will be hard to C/C++ schedulers

From a blog note

Which do you mean?

«BLOCKING» EASY TO MISINTERPRET

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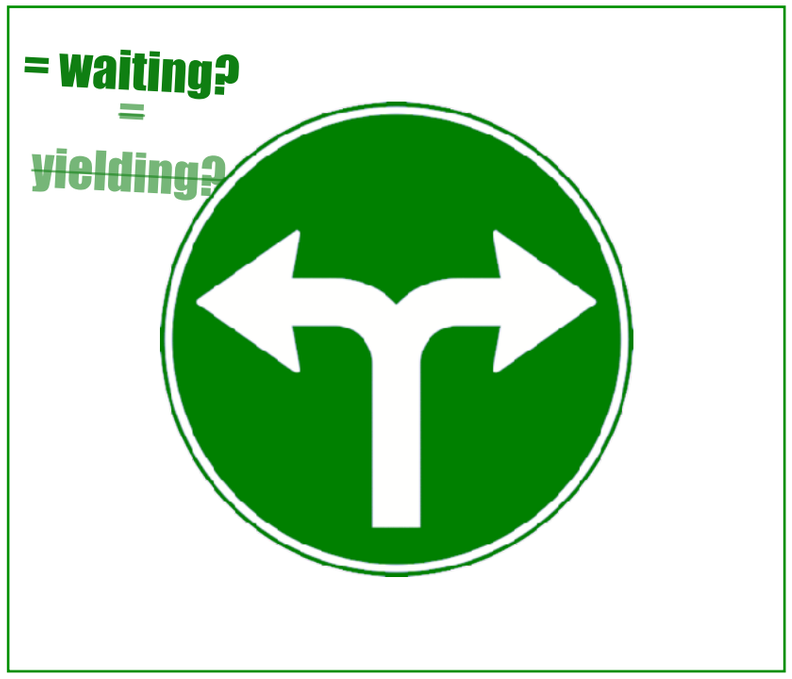

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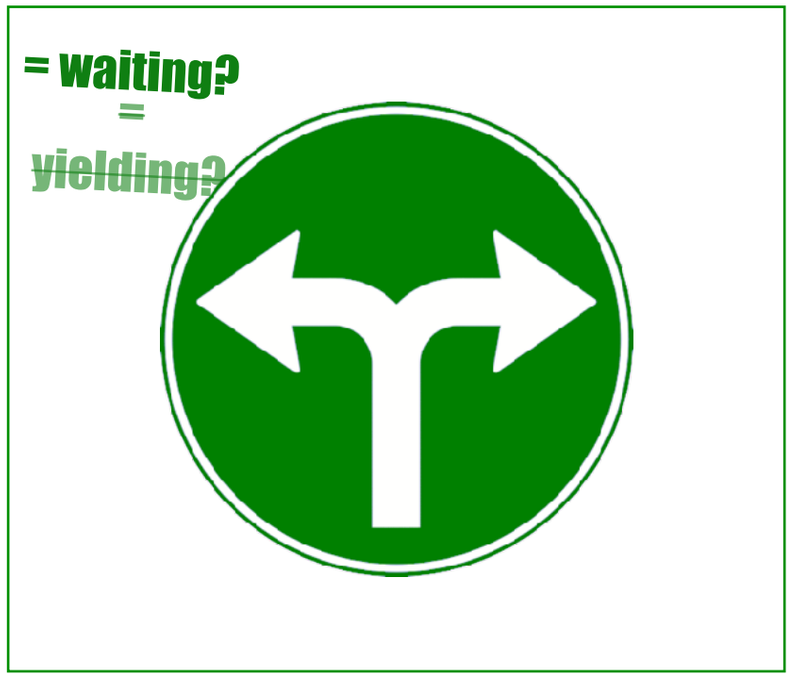

The show goes on with this blocking

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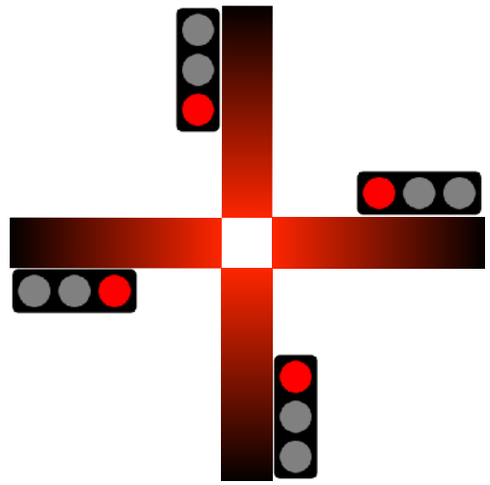

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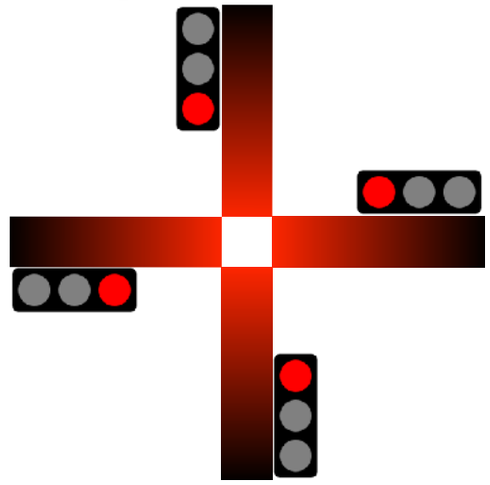

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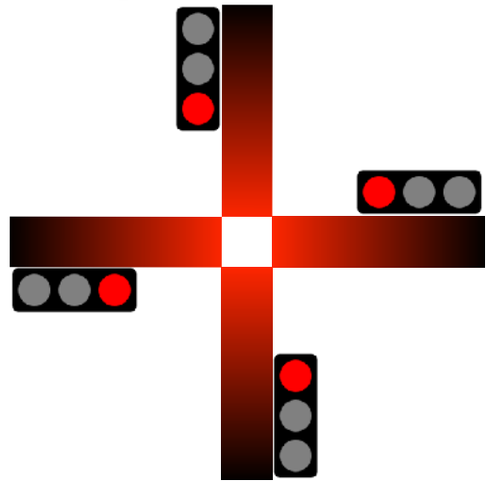

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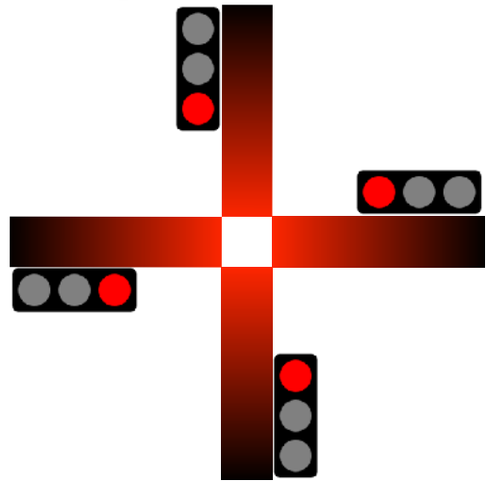

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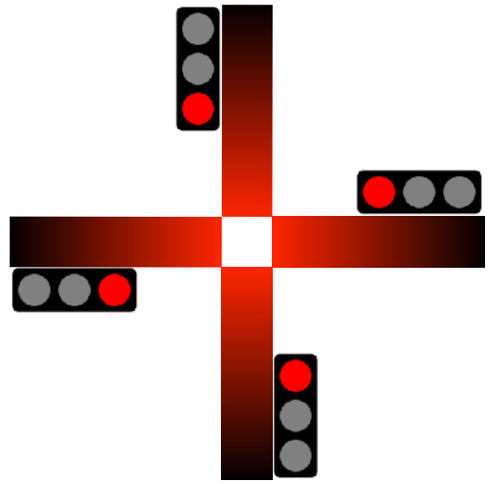

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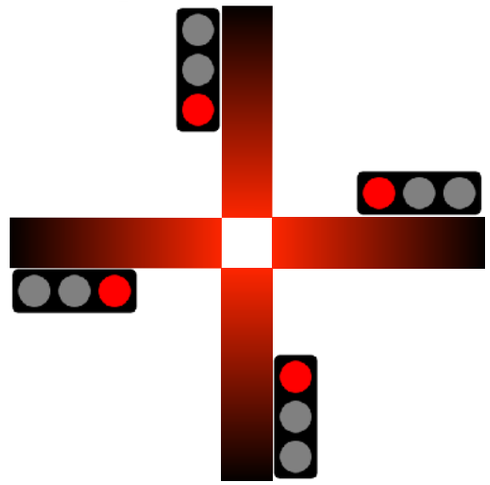

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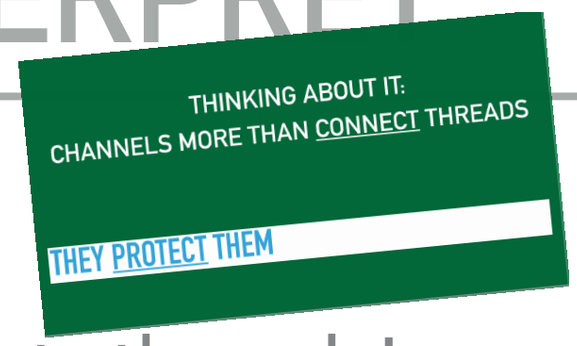

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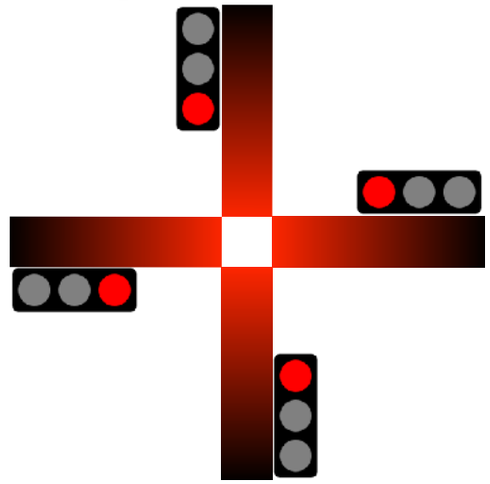

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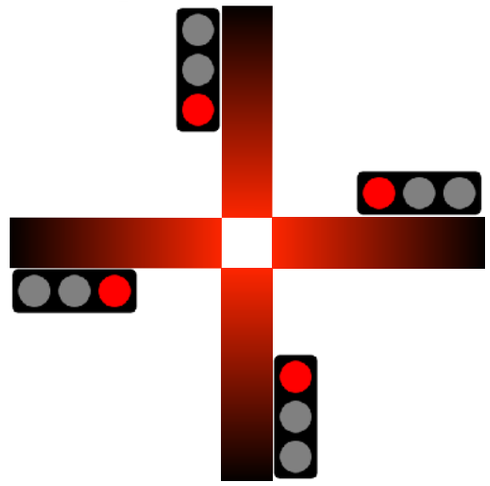

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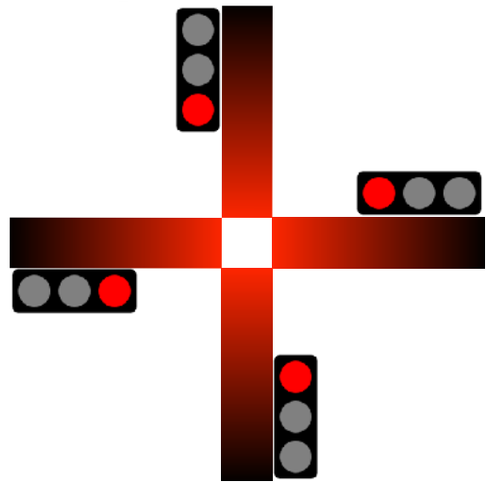

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- Event loop and callbacks

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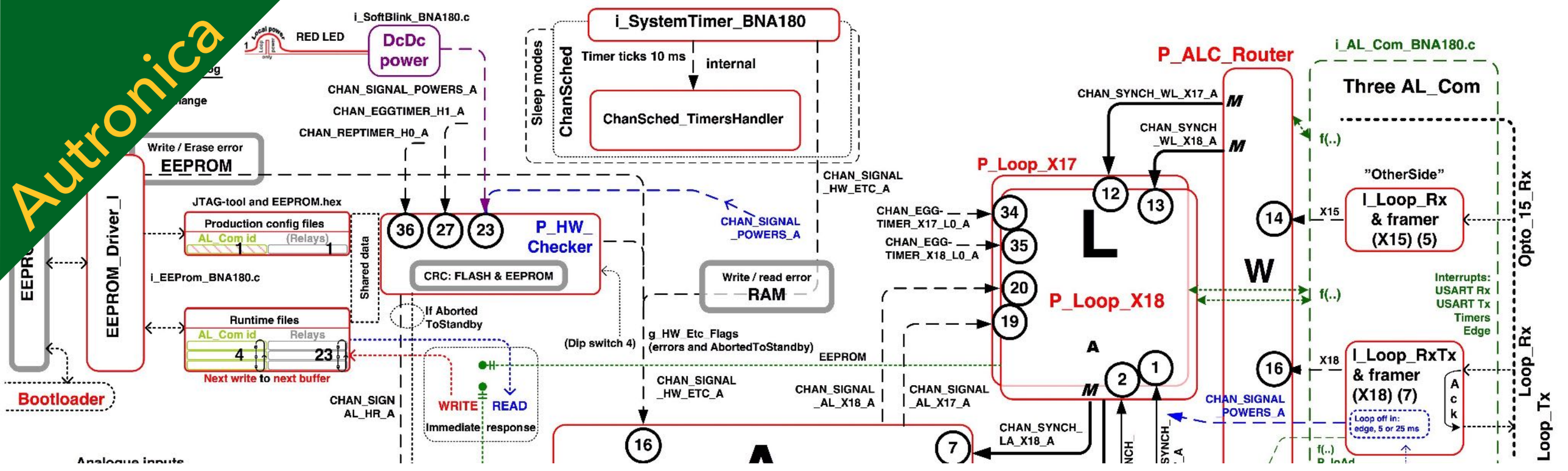
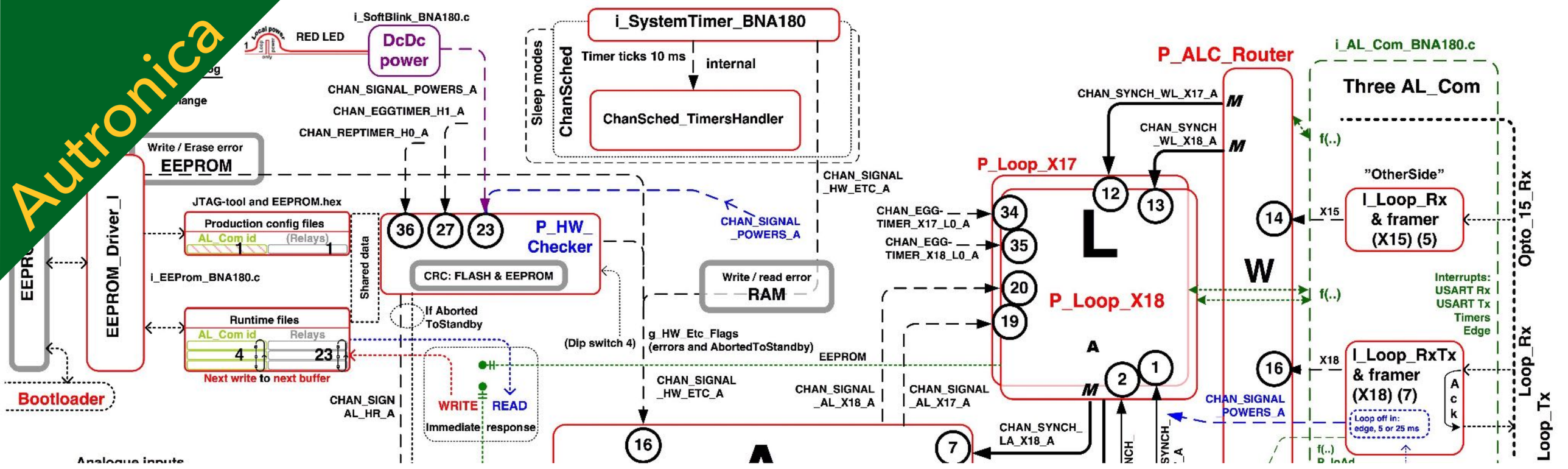
  - In proper processes, concurrency solved
- Connecting channels to event loops and callbacks when that's what you have in a library (like in Closure core.async, see Further reading)



Part of process/data flow diagram

«CHANSCHED»: CSP ON AVR XMEGA



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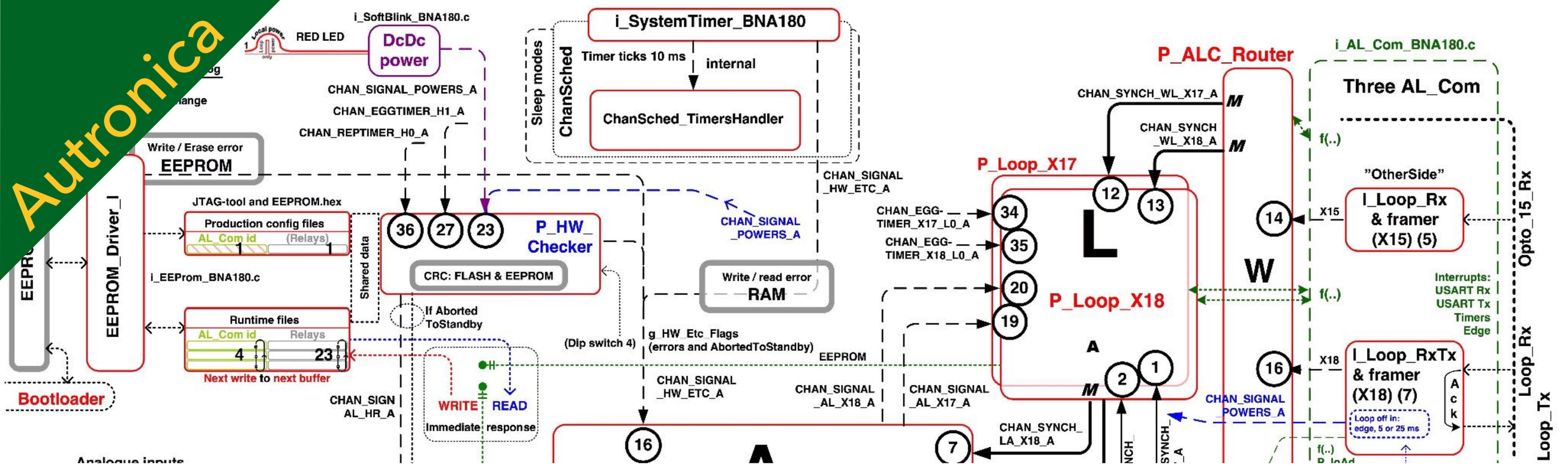
- ChanSched: finally in one of the controllers synchronous channels on top of no other runtime («naked»)



Part of process/data flow diagram

«CHANSCHED»: CSP ON AVR XMEGA

- ChanSched: finally in one of the controllers synchronous channels on top of no other runtime («naked»)
- The runtime was more visible to the application code than I thought (next page)

C CODE ON TOP OF ASYNCH RUNTIME (LEFT) AND NAKED (RIGHT)

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Sync chan comm needs states

C CODE ON TOP OF ASYNCH RUNTIME (LEFT) AND NAKED (RIGHT)

```
void P_Standard_CHAN_CSP (void)
{
  CP_a CP = (CP_a)g_ThisExtPtr; // Application
  switch (CP->State)            // and
                                // communication
                                // state
  {
    case ST_INIT: {/*Init*/ break;}
    case ST_IN:
    {
     CHAN_IN(G_CHAN_IN,CP->Chan_val1);
      CP->State = ST_APPL1;
      break;
    }
    case ST_APPL1:
    {
      // Process val1
      CP->State = ST_OUT;
      break;
    }
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Sync chan comm needs states

Equal

```
void P_Extended_ChanSched (void)
{
  CP_a CP = (CP_a)g_ThisExtPtr; // Application
  // Init here                  // state only
  while (TRUE)
  {
    switch (CP->State)
    {
      case ST_MAIN:
      {
        CHAN_IN(G_CHAN_IN,CP->Chan_val2);

        // Process val2

        CHAN_OUT(G_CHAN_OUT,CP->Chan_val2);
        CP->State = ST_MAIN; // option1
        break;
      }
    }
  }
}
```

Synchronisation points no visible state

SAME CODE IN A LIBRARY AND OCCAM

```
void P_libcsp2 (Channel *in, Channel *out)
{
  int val3;
  for(;;)
  {
    ChanInInt (in, &val3);
    // Process val3
    ChanOutInt (out, val3);
  }
}
```

```
PROC P_occam (CHAN OF INT in, out)

  WHILE TRUE
  INT val4:
    SEQ
      in ? val4
      -- Process val4
      out ! val4
:
```

A TYPICAL `ChanSched` PROCESS BODY (OVERVIEW)

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1.  Void P_Prefix (void)                          // extended "Prefix"
2.  {
3.    Prefix_CP_a CP = (Prefix_CP_a)g_CP; // get process Context from Scheduler
4.    PROCTOR_PREFIX()                            // jump table (see Section 2)
5.    ...  some initialisation
6.    SET_EGGTIMER (CHAN_EGGTIMER, LED_Timeout_Tick);
7.    SET_REPTIMER (CHAN_REPTIMER, ADC_TIME_TICKS);
8.    CHAN_OUT (CHAN_DATA_0, Data_0);  // first output
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    ALT();                                // this is the needed ”PRI_ALT”
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13.       ALT_EGGREPTIMER_IN (CHAN_REPTIMER);
14.       ALT_SIGNAL_CHAN_IN (CHAN_SIGNAL_AD_READY);
15.       ALT_CHAN_IN        (CHAN_DATA_2, Data_2);
16.       ALT_ALTTIMER_IN    (CHAN_ALTTIMER, TIME_TICKS_100_MSECS);
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18.     switch (g_ThisChannelId)
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20.       ...  process the guard that has been taken, e.g. CHAN_DATA_2
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http://www.teigfam.net/oyvind/pub/pub_details.html#NewALT

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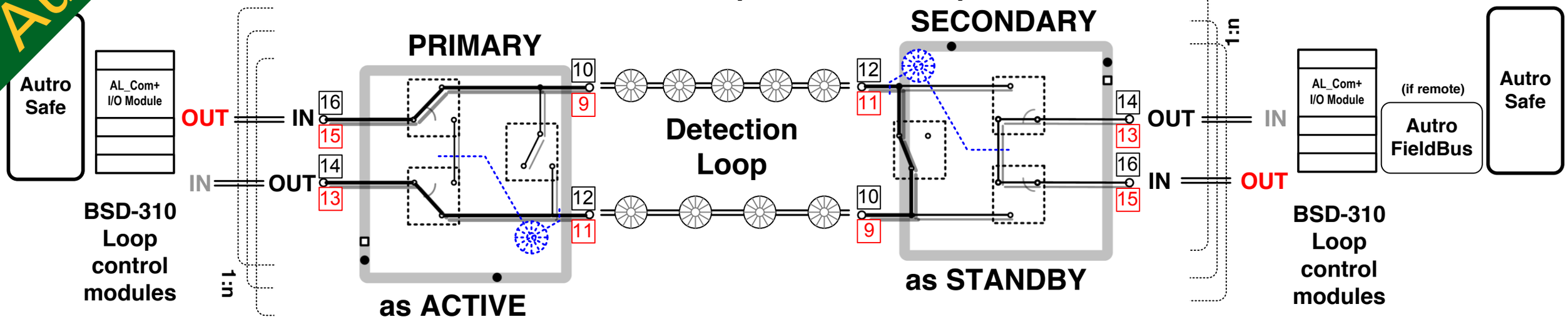
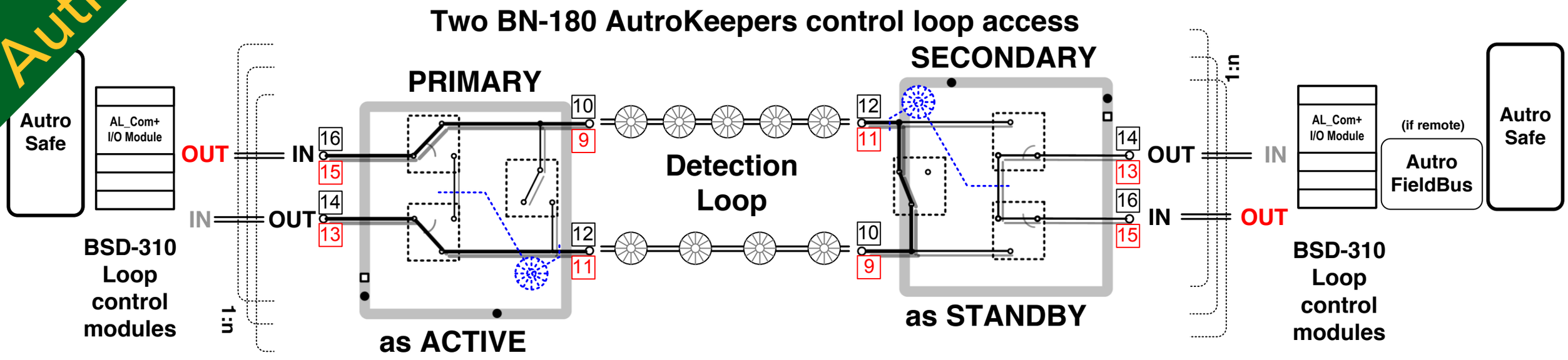
Autronica

Two BN-180 AutroKeepers control loop access



Autronica

Also from real life



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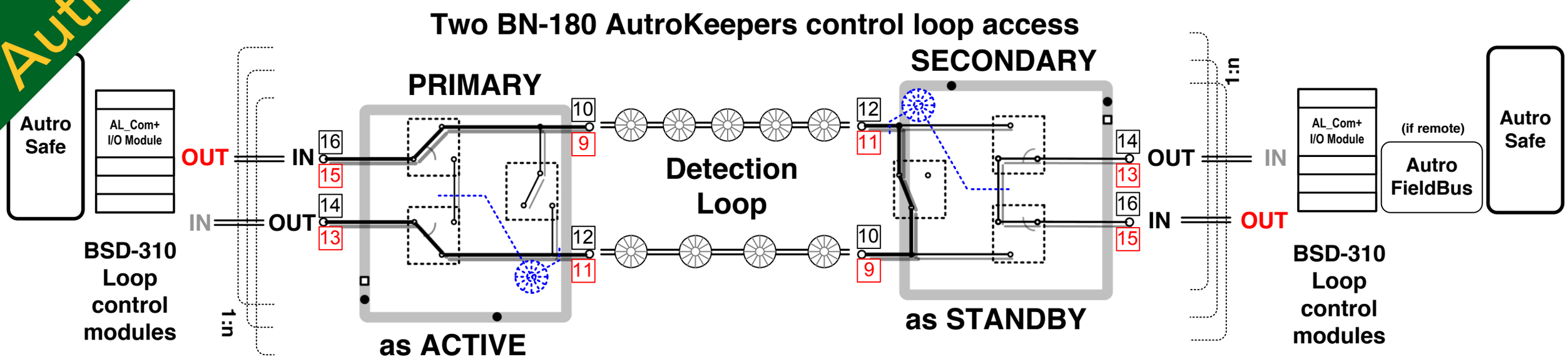

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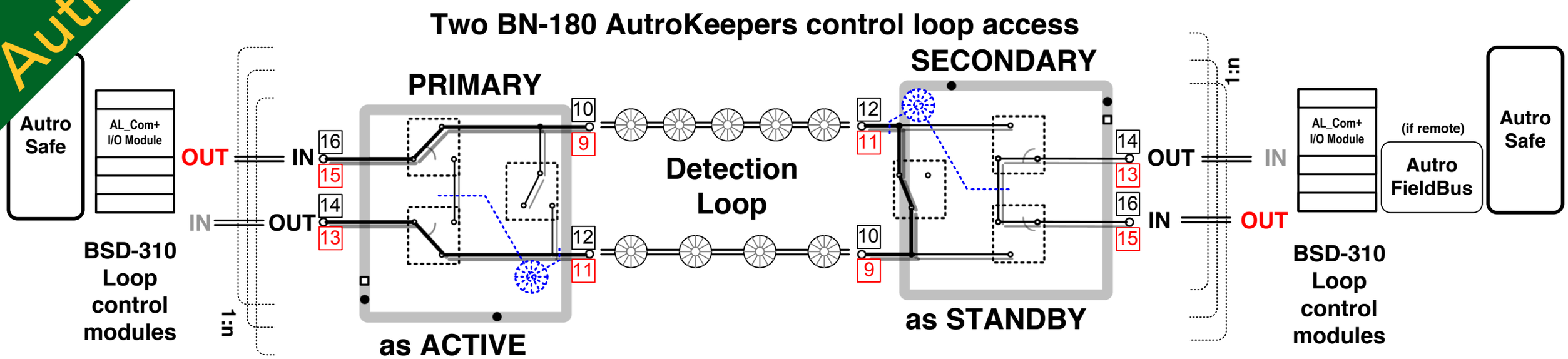

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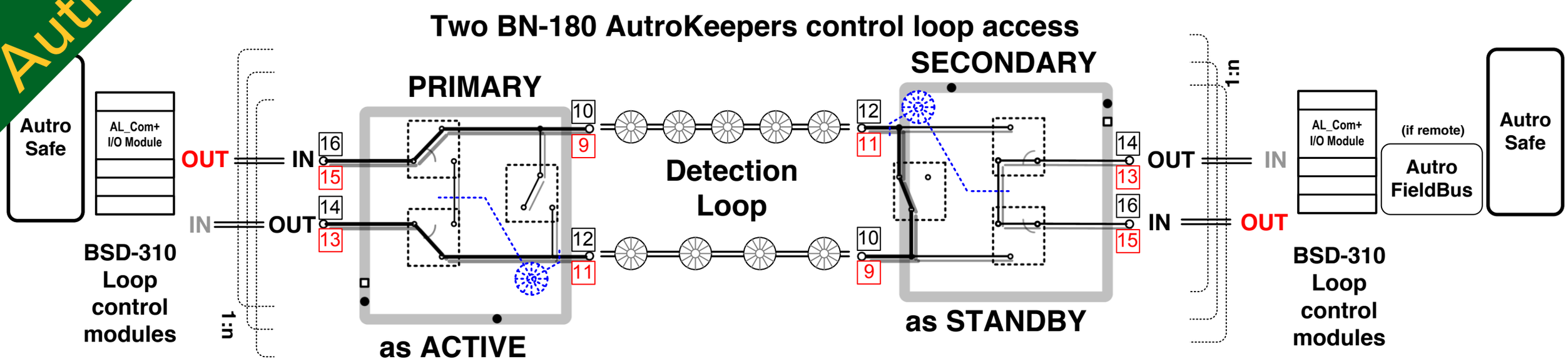

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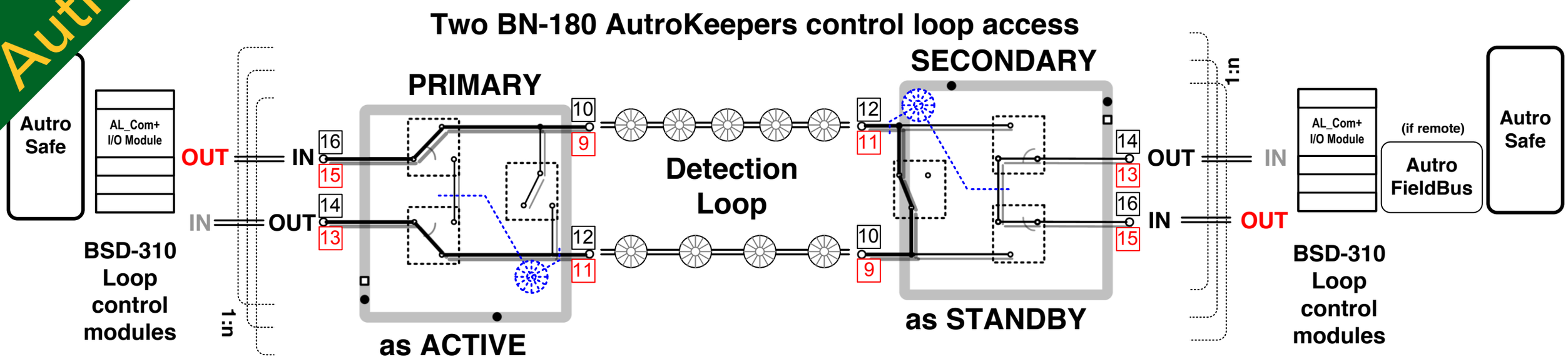

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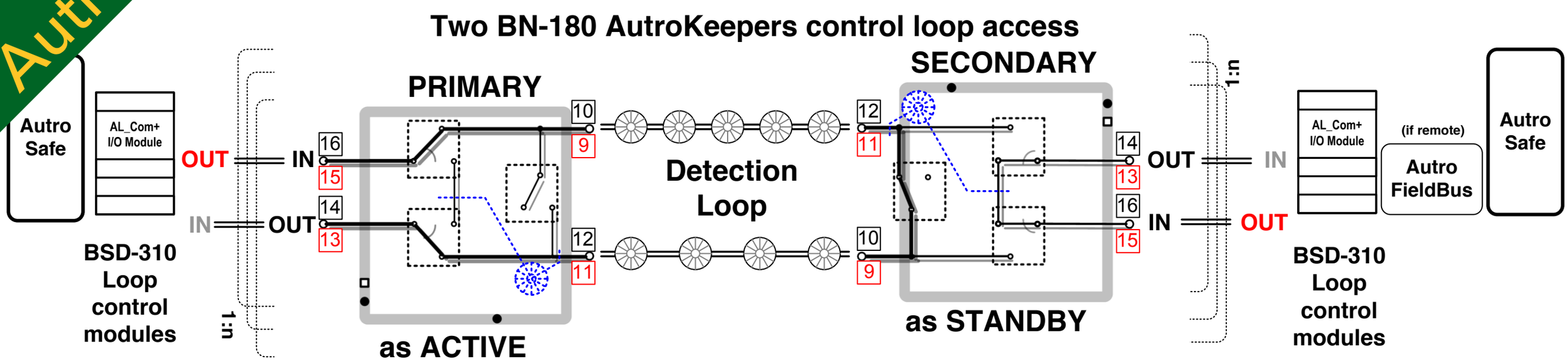

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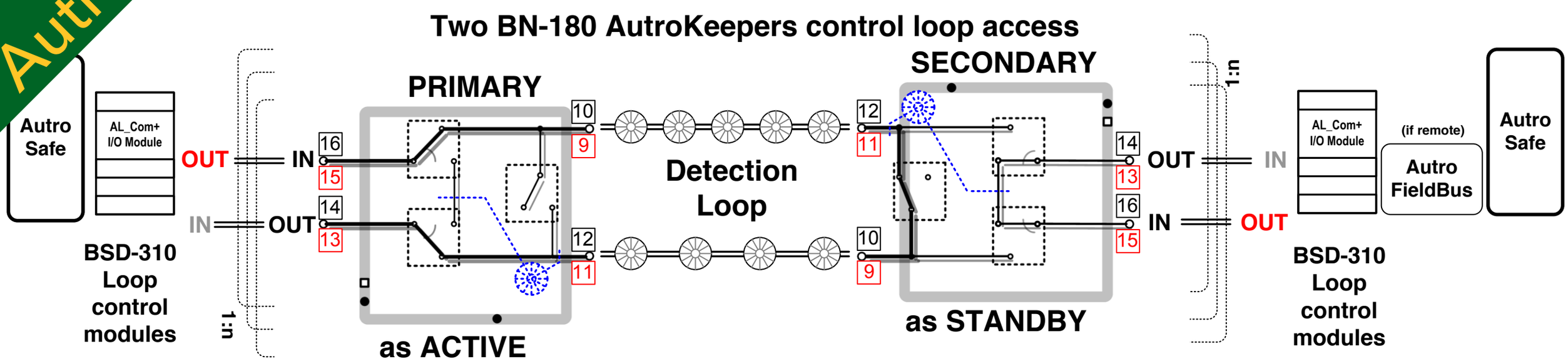

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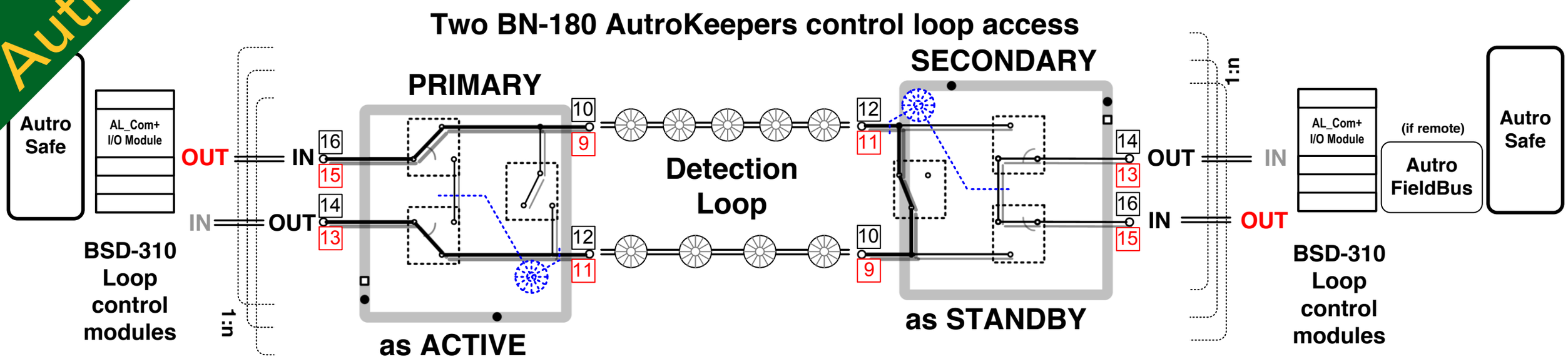

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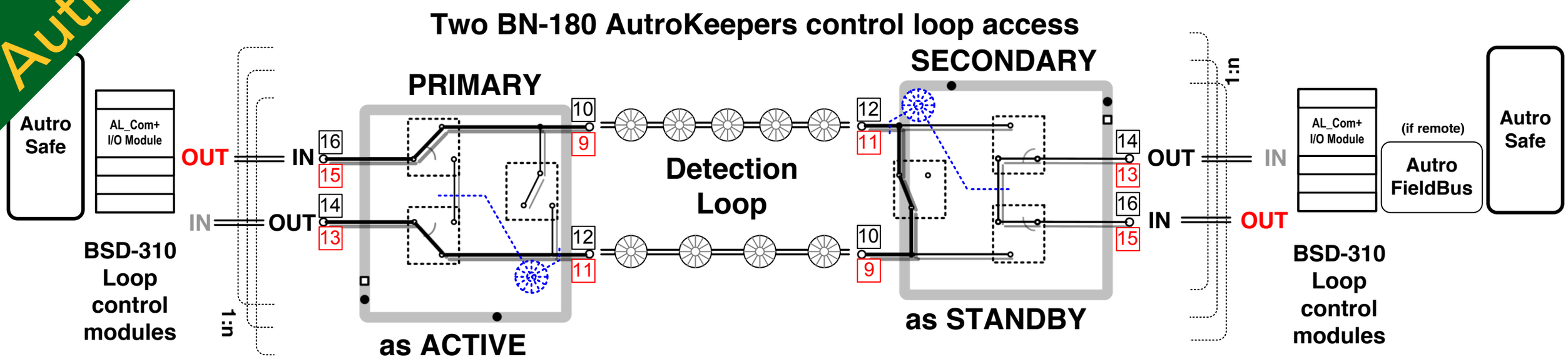

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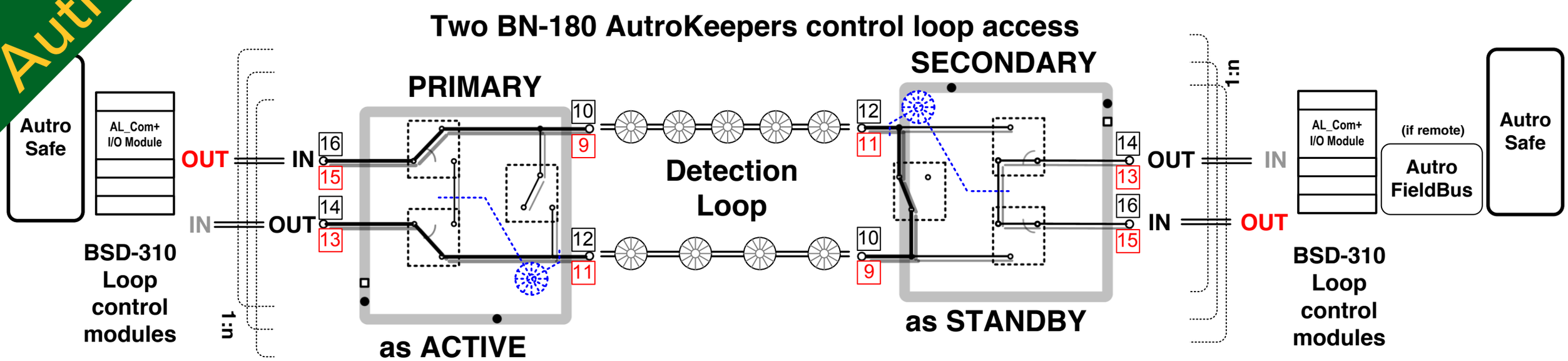

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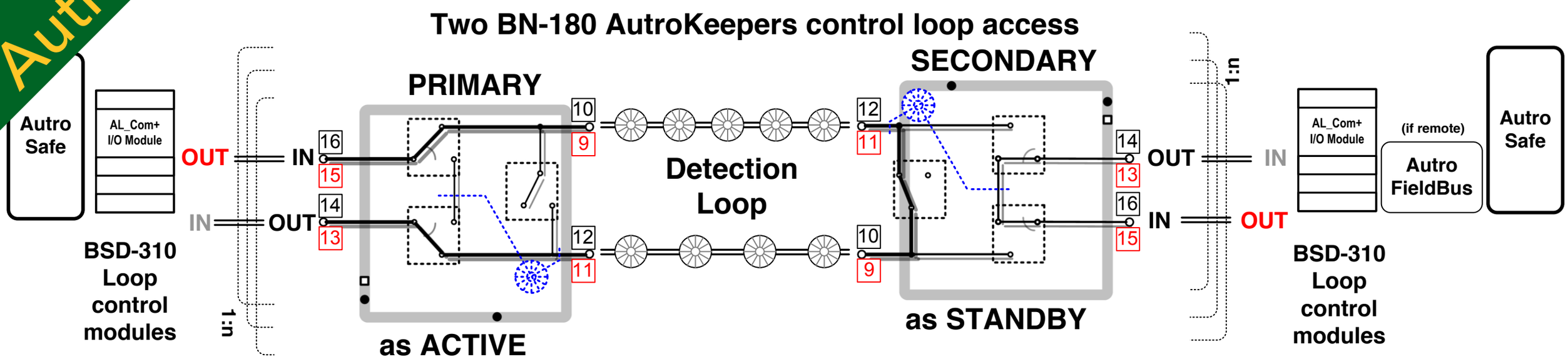

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Final advice

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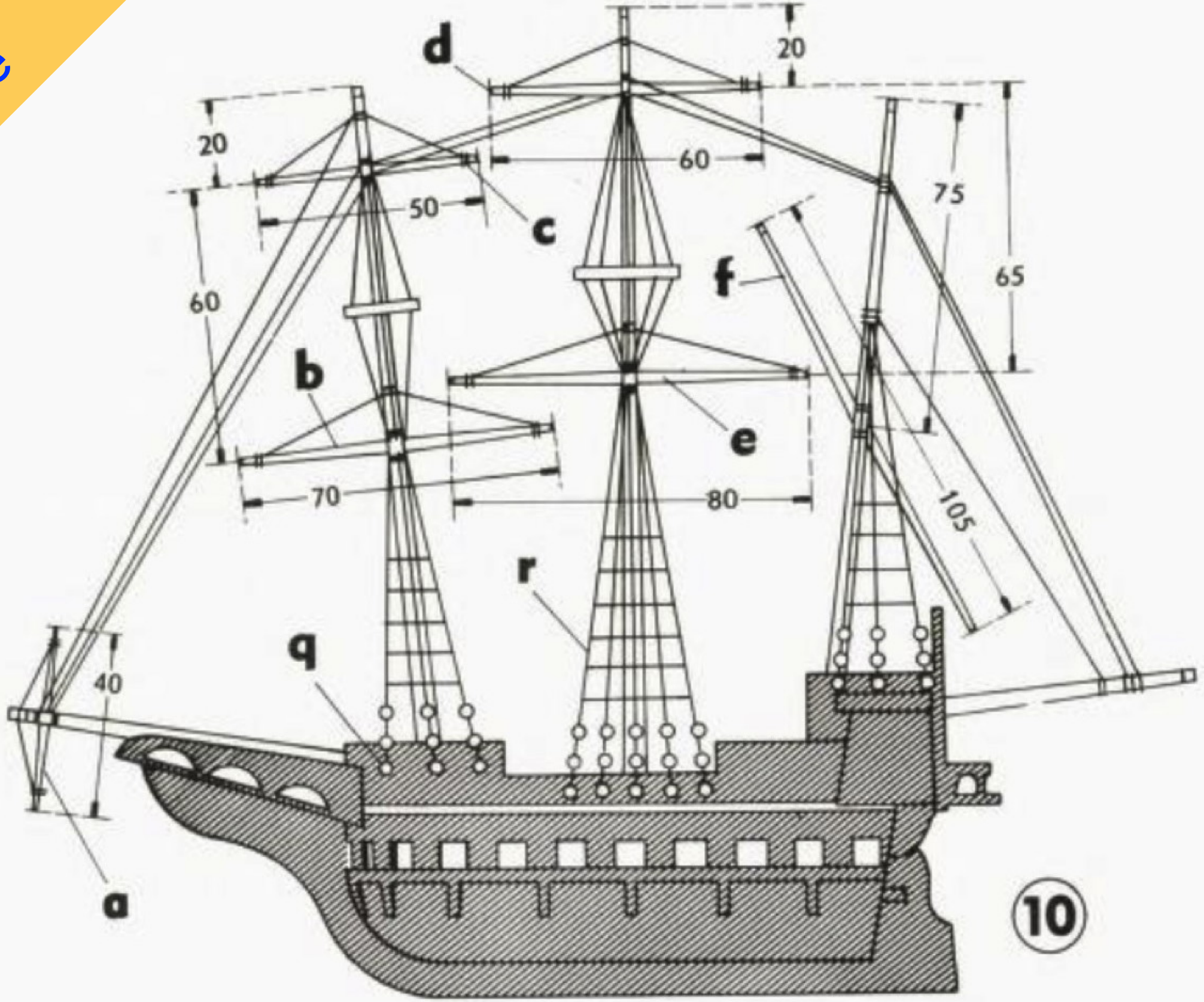

Master, spryd og rær

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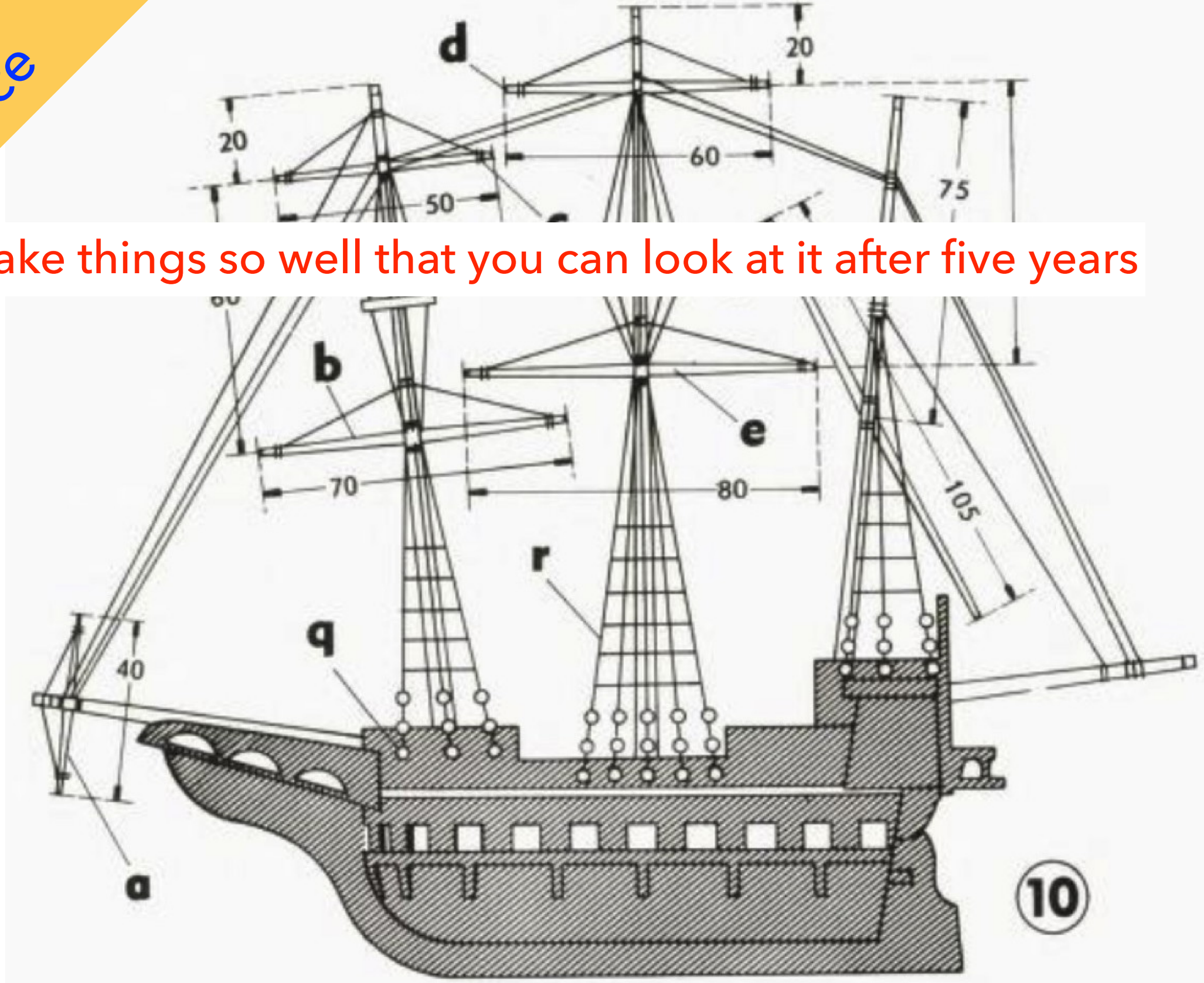
Final advice

Make things so well that you can look at it after five years



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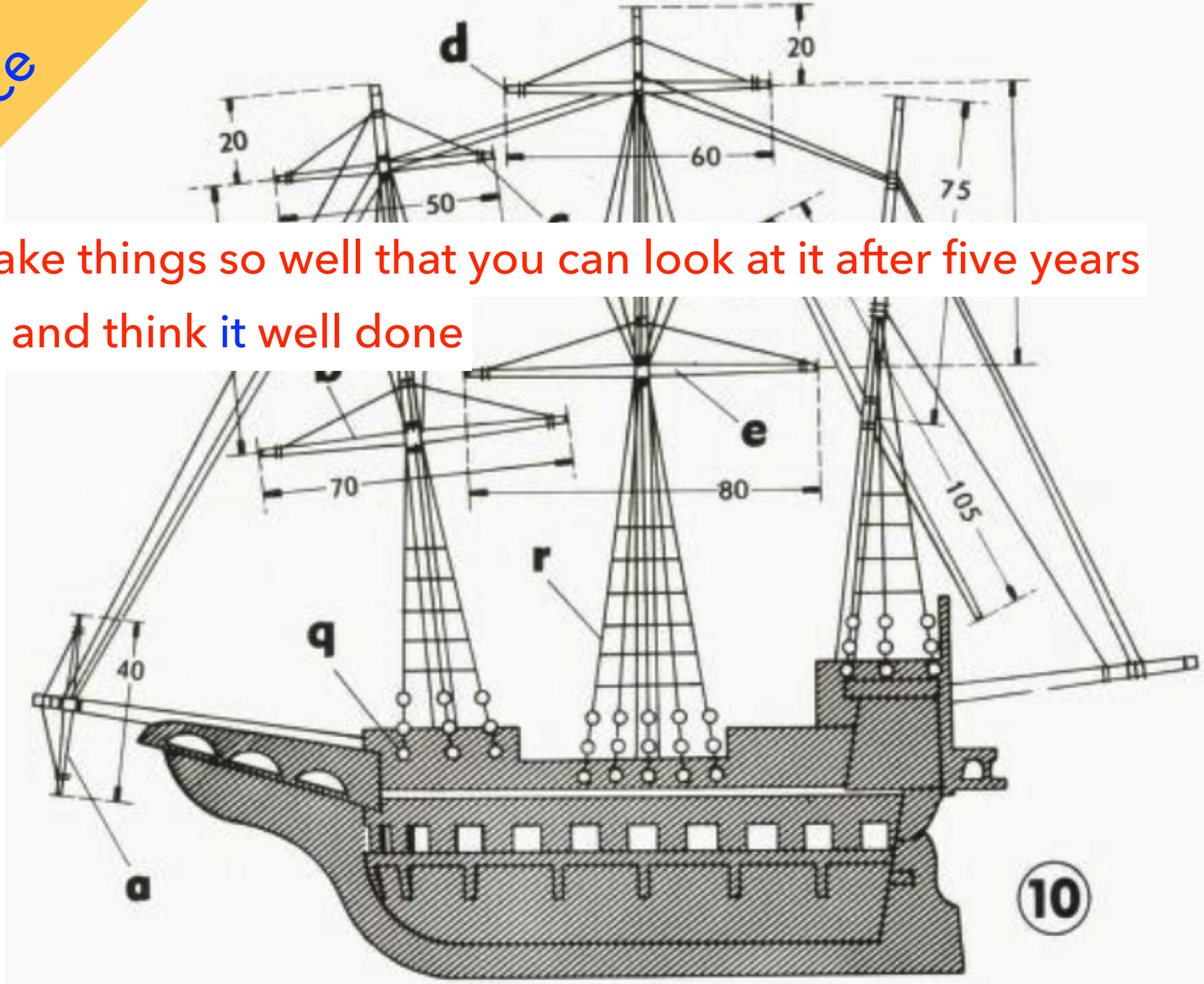

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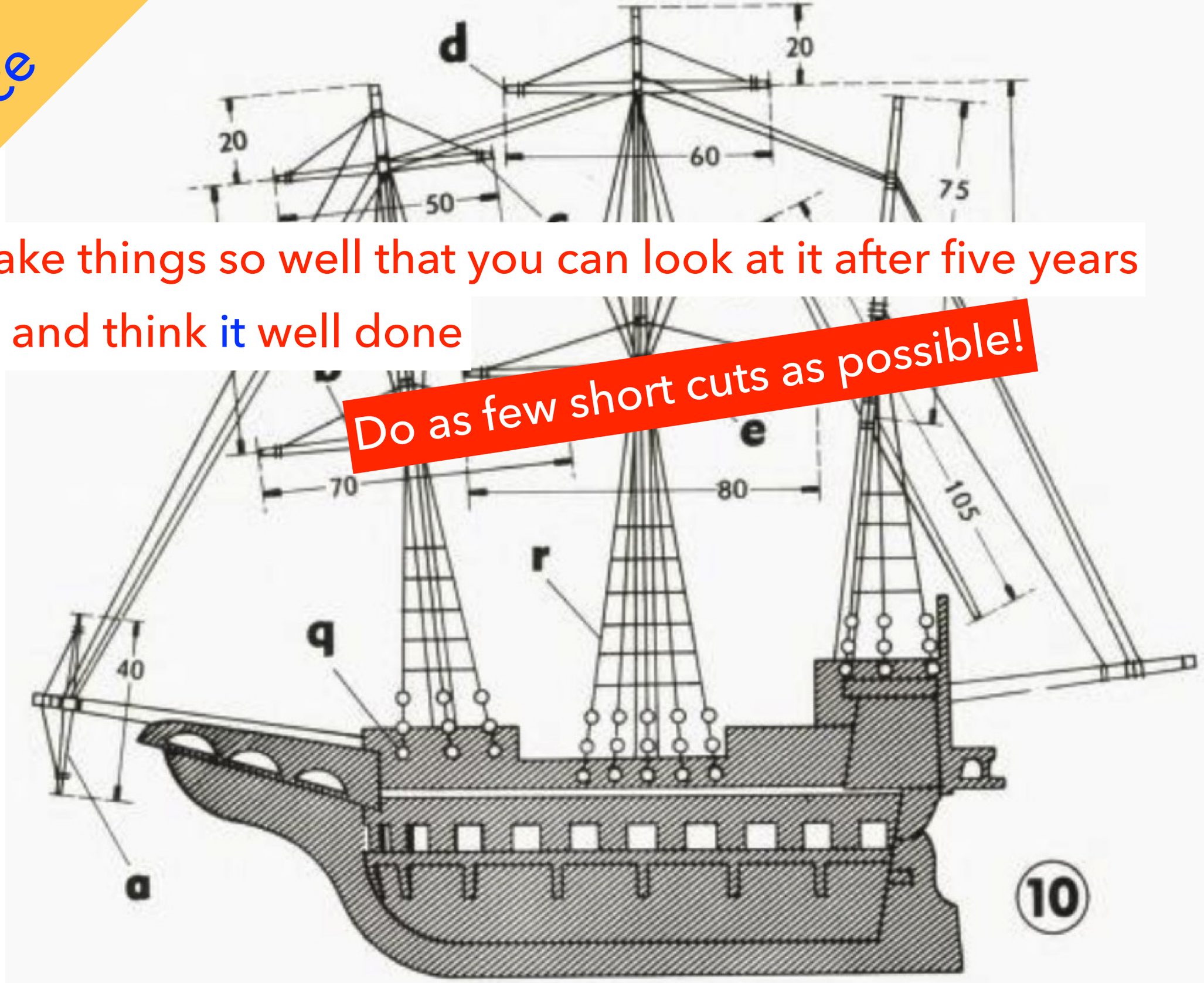

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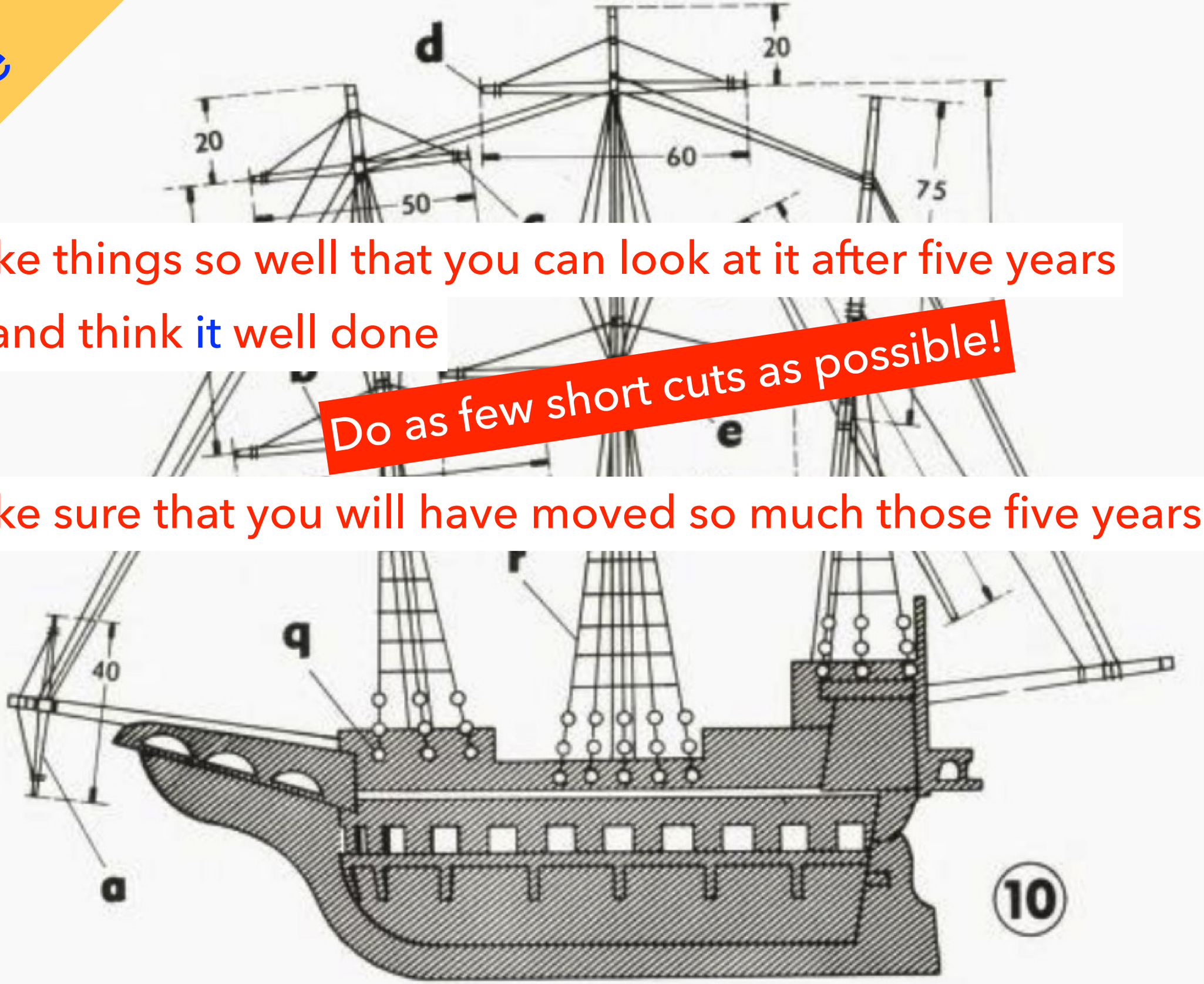

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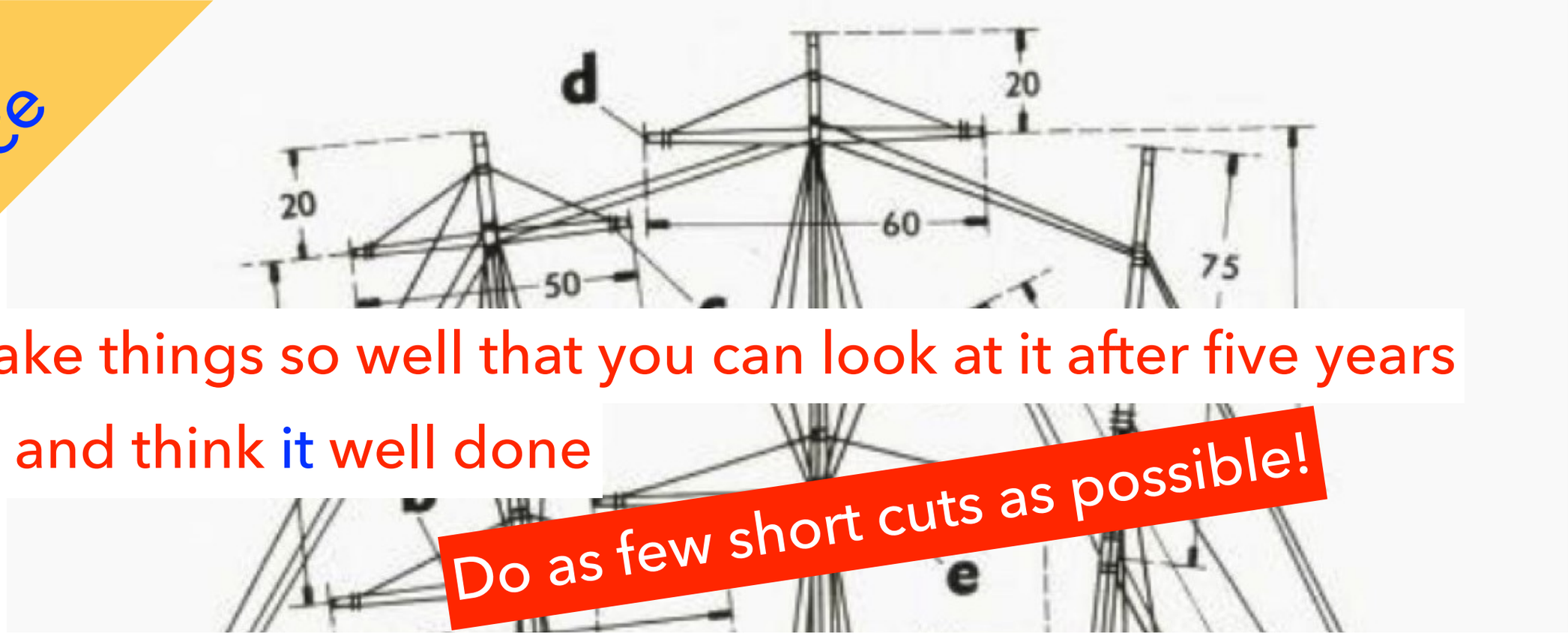

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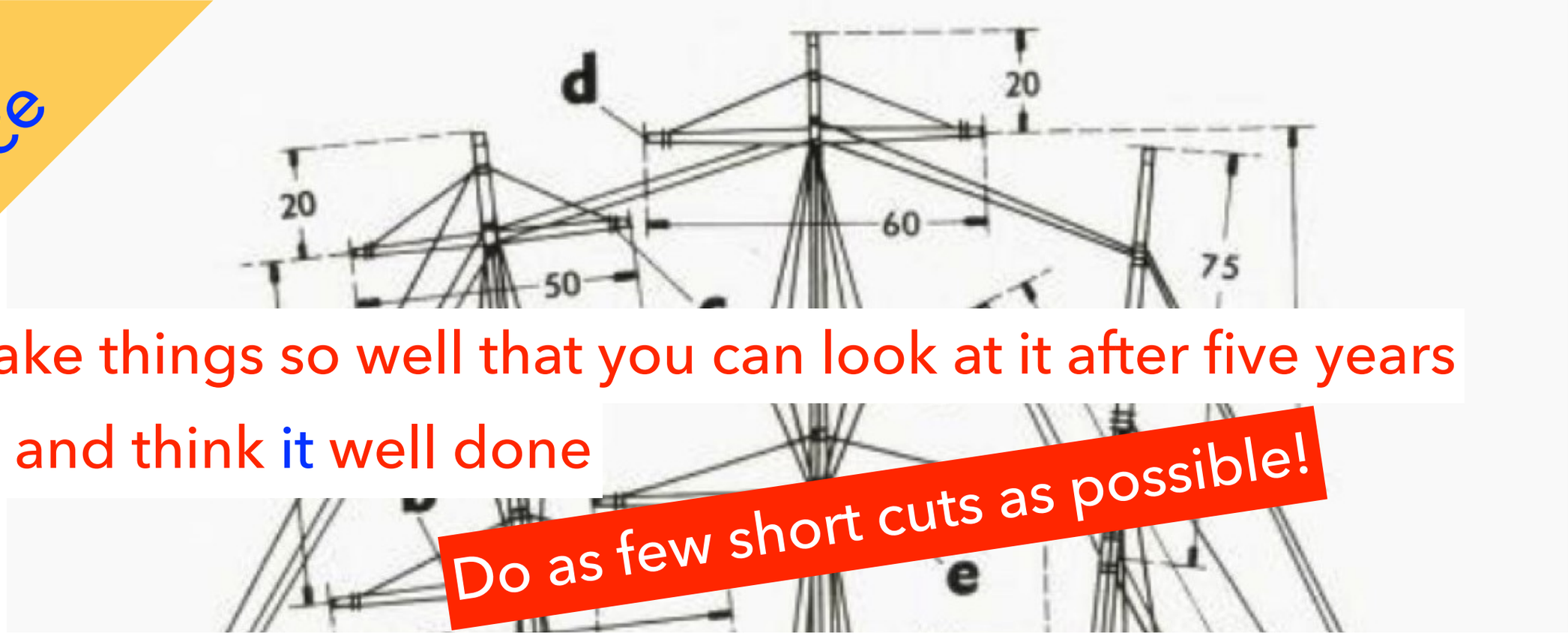

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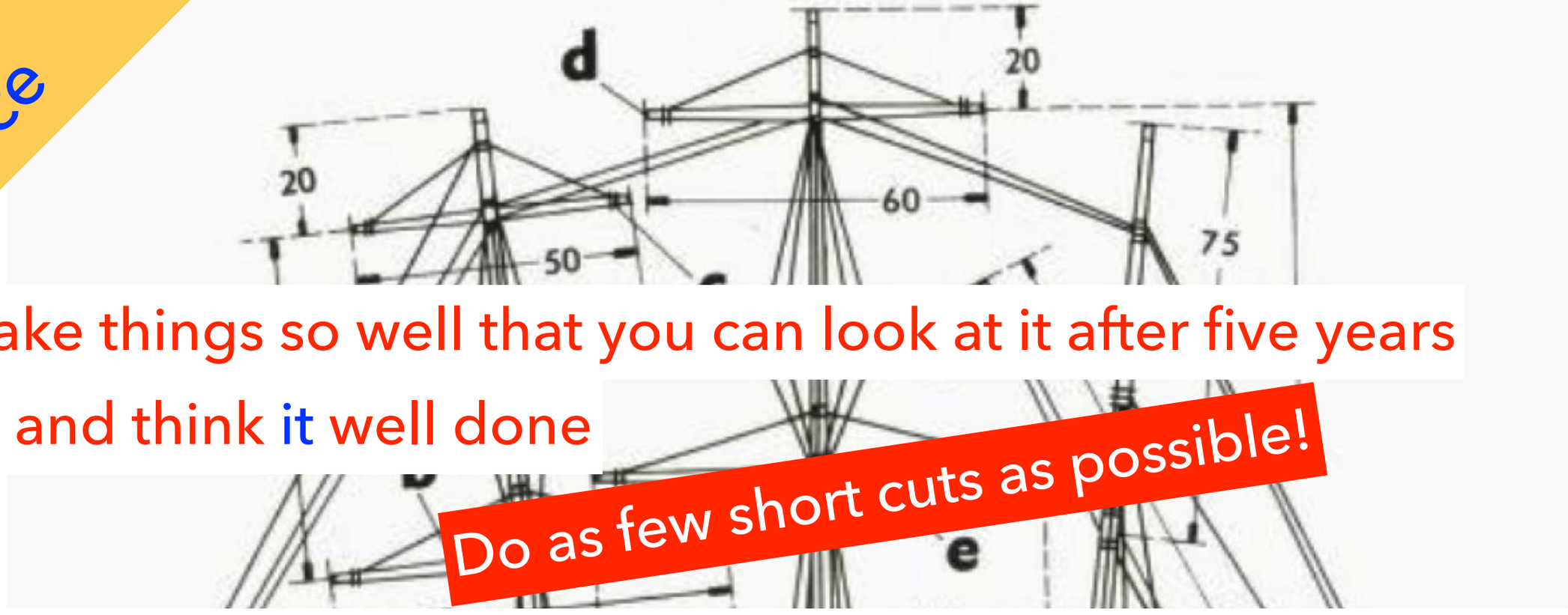

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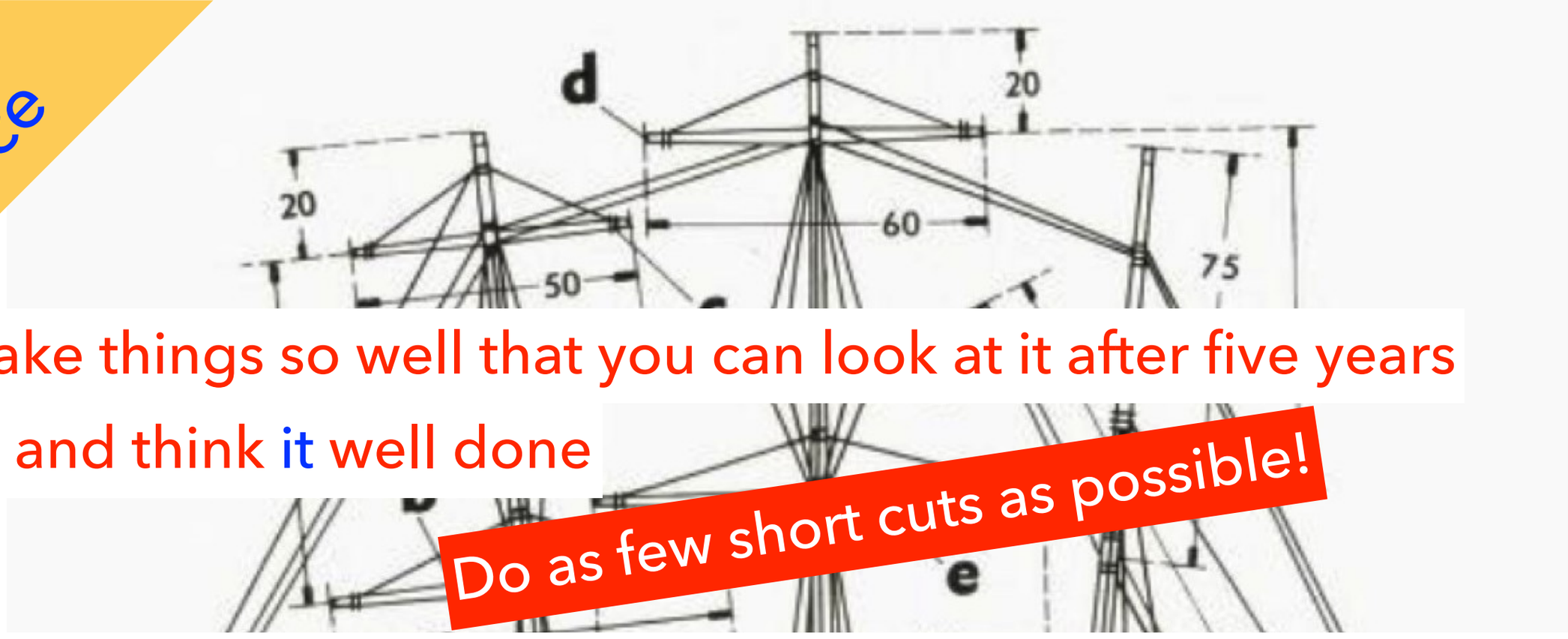

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10

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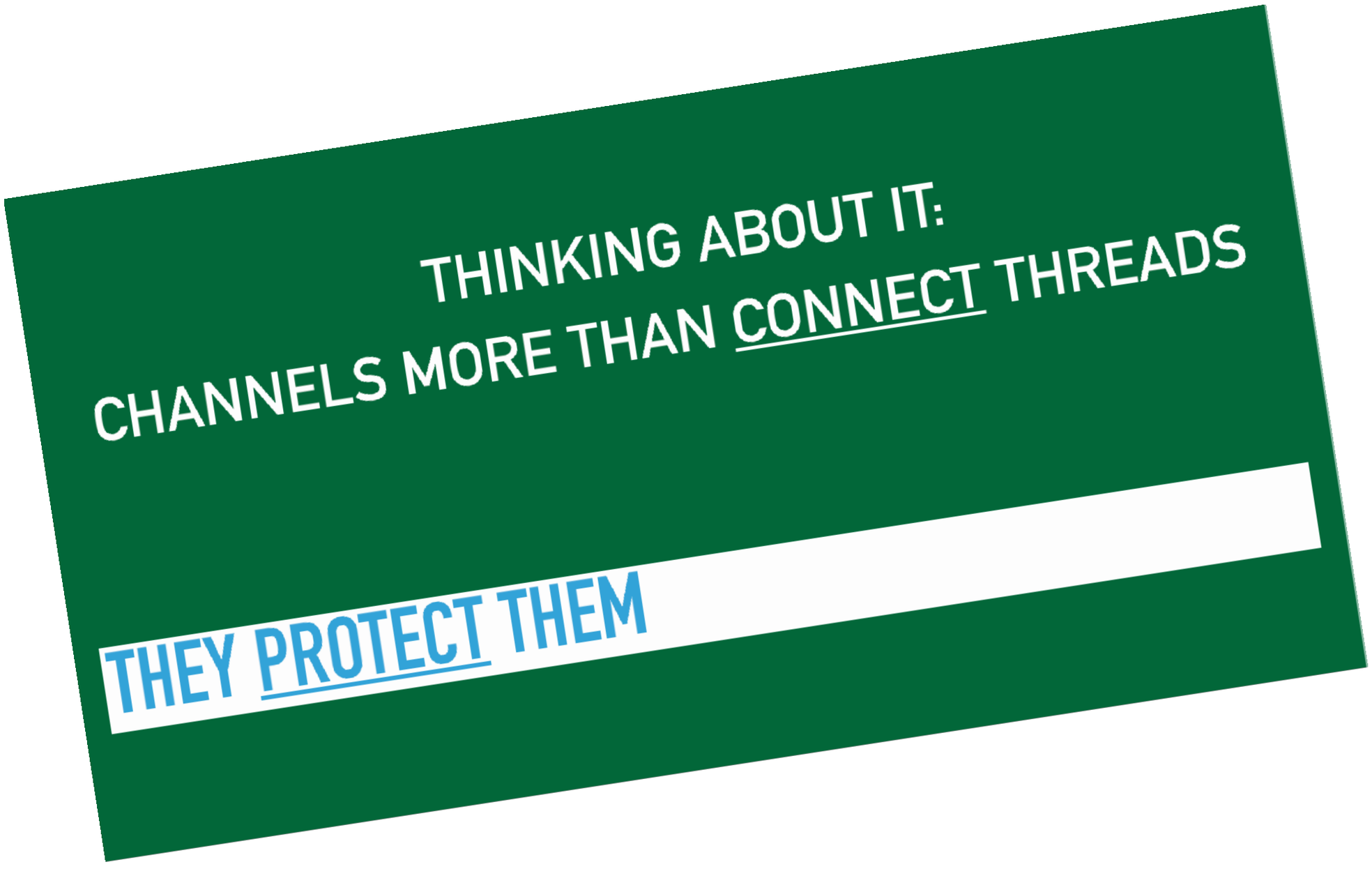
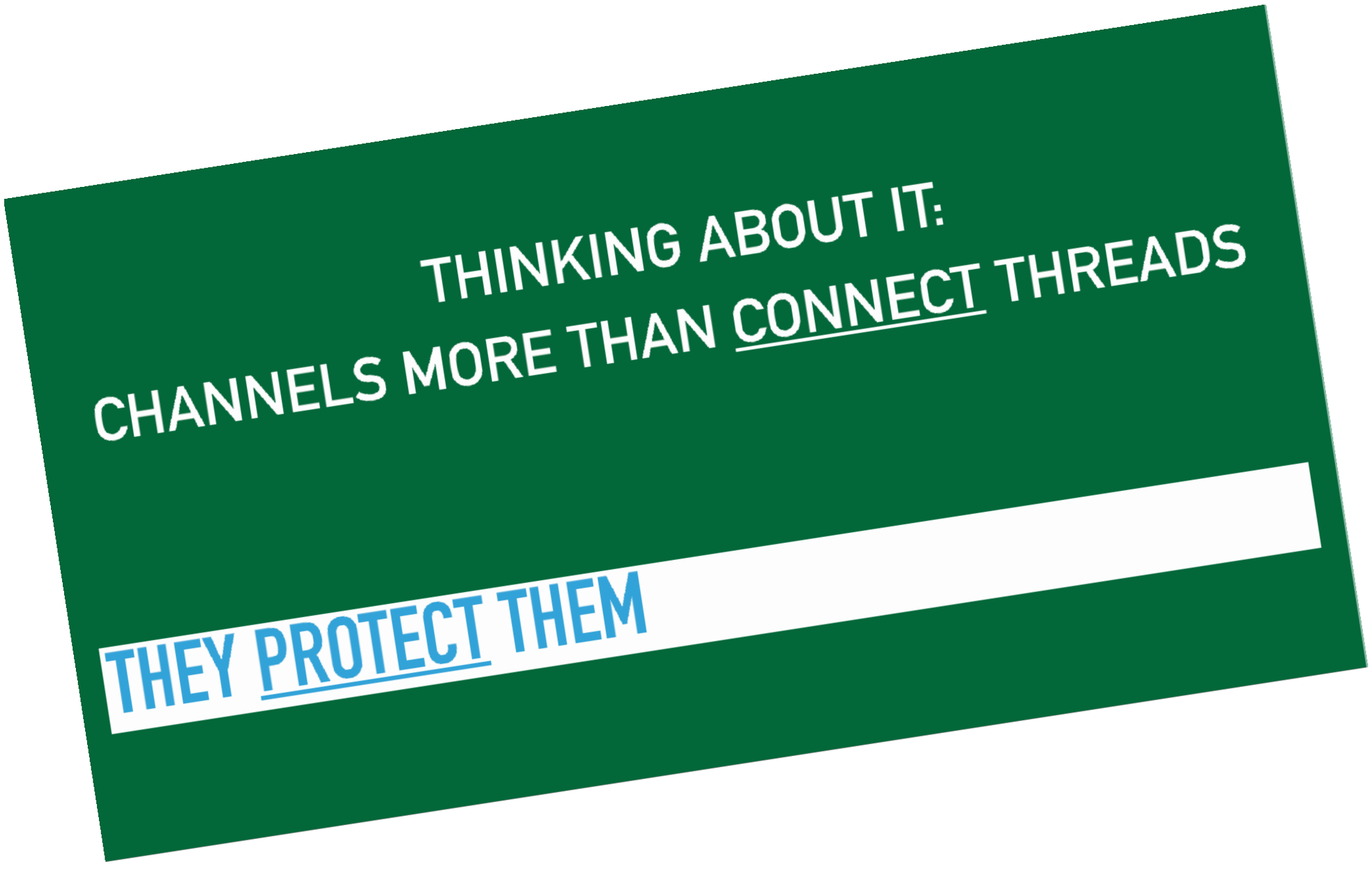
THINKING ABOUT IT:
CHANNELS MORE THAN CONNECT THREADS

THEY PROTECT THEM



HOW DO THEY PROTECT THEM?



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SUMMARY:

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CONTACT INFO ETC.

oyvind.teig@teigfam.net

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- This lecture
  - Standard picture quality, all build steps
    http://www.teigfam.net/oyvind/pub/NTNU_2018/foredrag.pdf
  - Full quality, but each page only once, no build steps (around 70 MB)
    http://www.teigfam.net/oyvind/pub/NTNU_2018/foredrag_full.pdf
- This course
  NTNU, TTK4145 Sanntidsprogrammering (Real-Time Programming) http://www.itk.ntnu.no/fag/TTK4145/information/
- My blog notes
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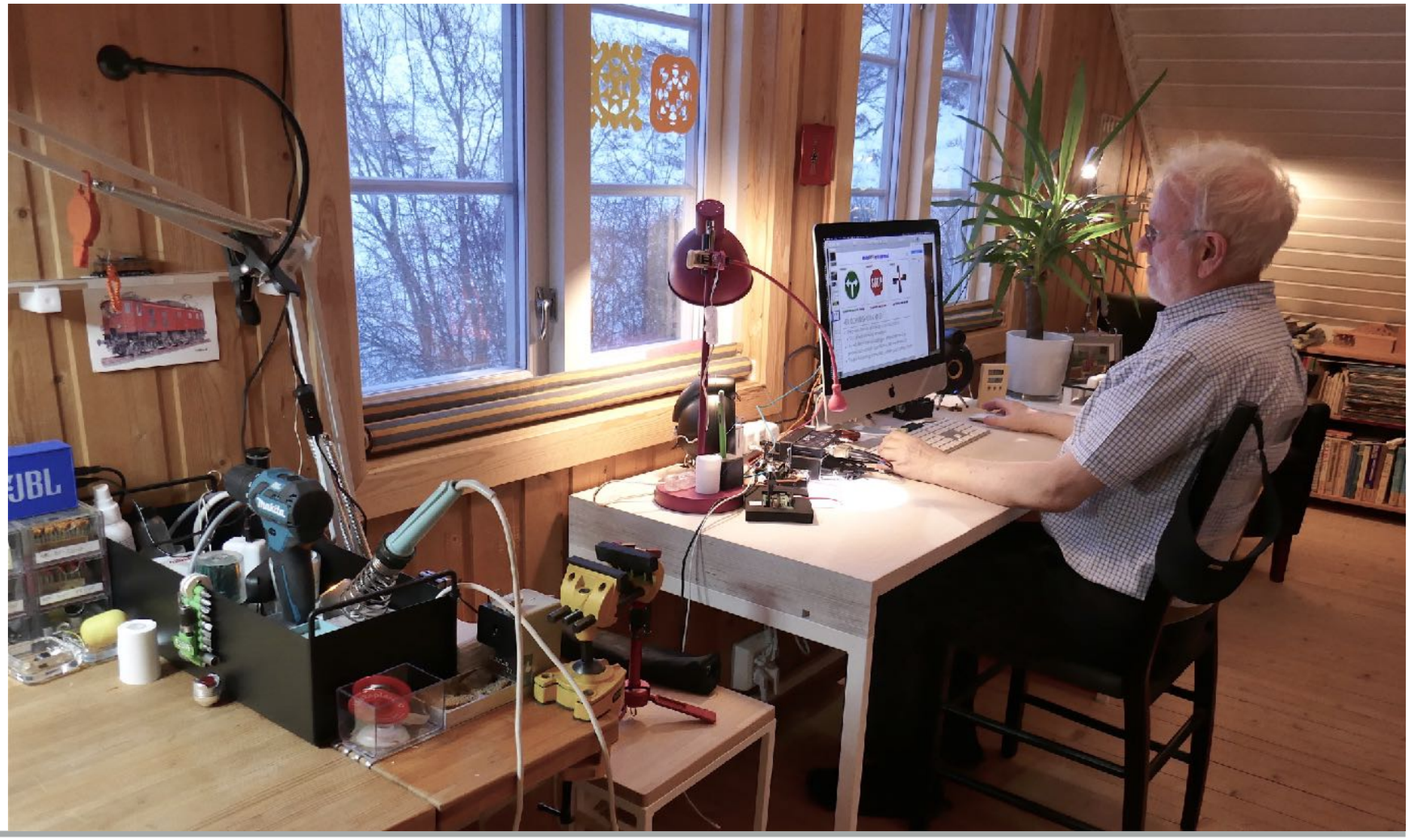
Questions?



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