Finite State Machines (9A)

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Based on

ARM System-on-Chip Architecture, 2nd ed, Steve Furber

Introduction to ARM Cortex-M Microcontrollers
– Embedded Systems, Jonathan W. Valvano

Digital Design and Computer Architecture,
D. M. Harris and S. L. Harris

Computer Organization and Design ARM Edition:
The Hardware Software Interface
By David A. Patterson, John L. Hennessy

https://thinkingeek.com/arm-assembler-raspberry-pi/

Traffic Controller Rules

(**R1**) If no cars are coming, stay in a green state, but which one doesn't matter. (00)

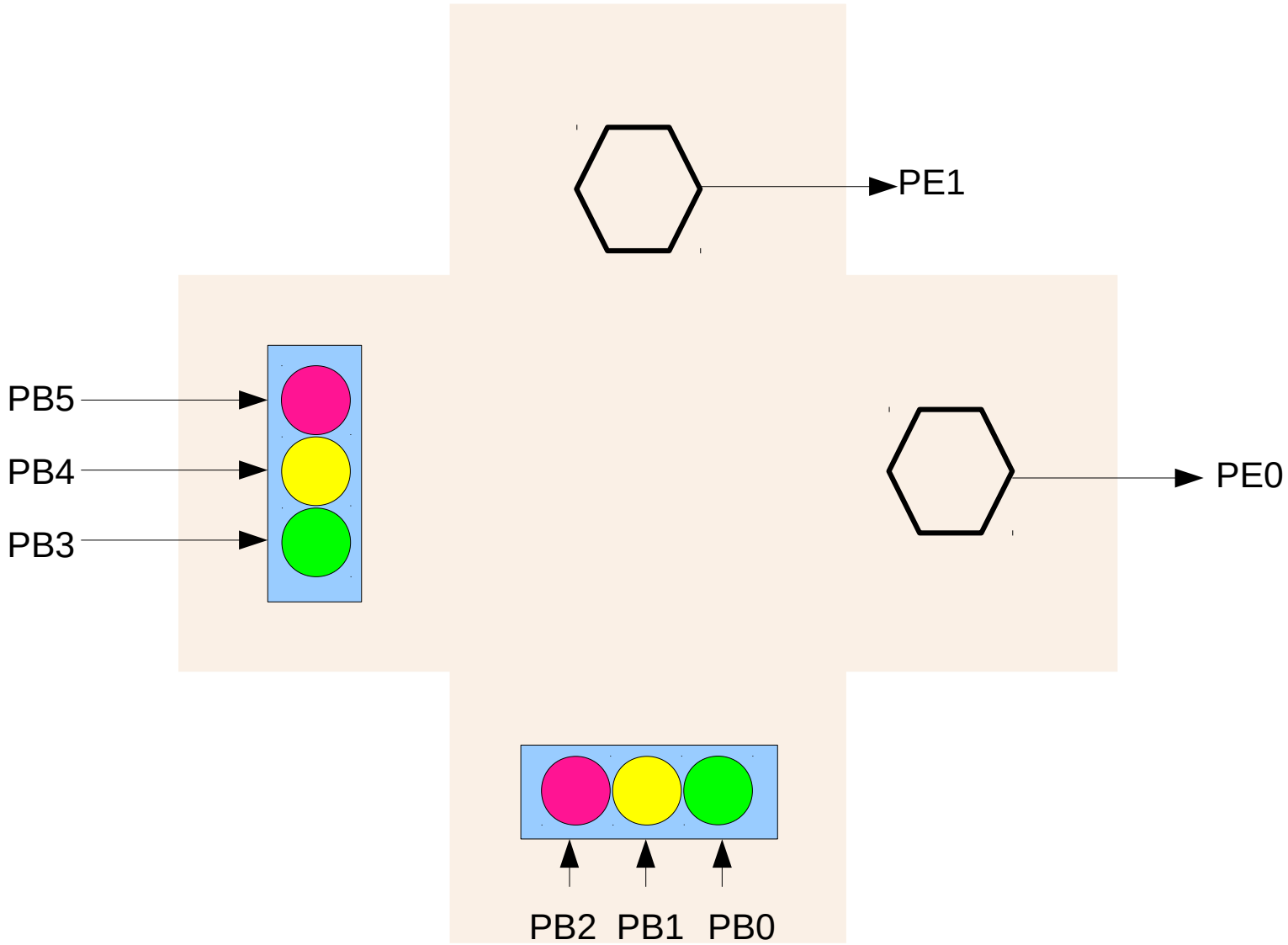
(**R2**) To change from green to red, implement a yellow light of exactly **5** seconds

(**R3**) Green lights will last at least **30** seconds

(**R4**) If cars are only coming in one direction, move to and stay green in that direction. (10, 01)

(**R5**) If cars are coming in both directions, cycle through all four states (11)

Sensor and Control Signals



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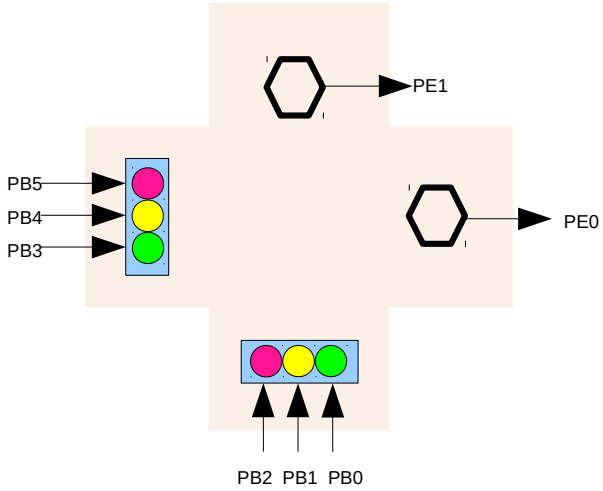
Inputs and Outputs Encoding

Inputs Encodings

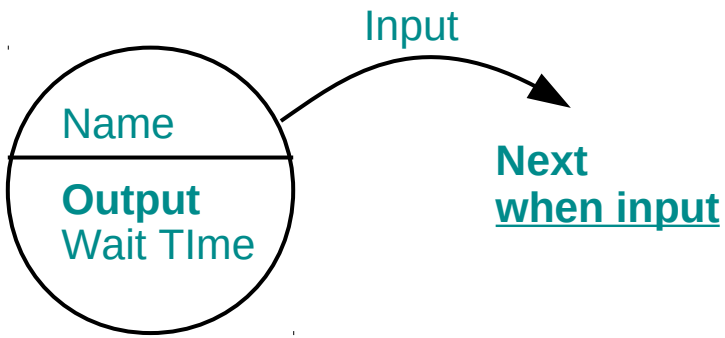
PE1	:	indicates cars on the North road
PE0	:	indicates cars on the East road

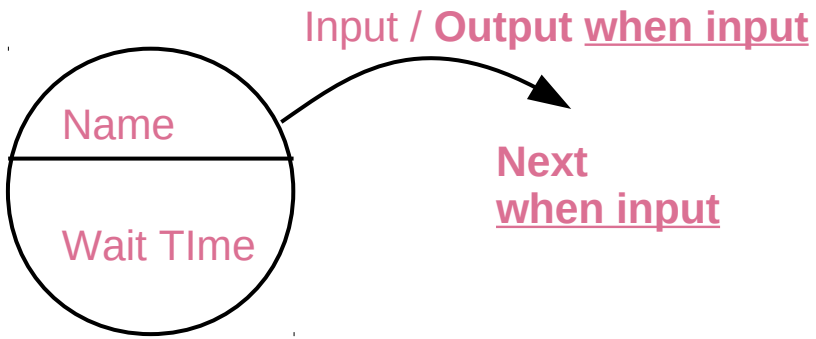
Output Encoding

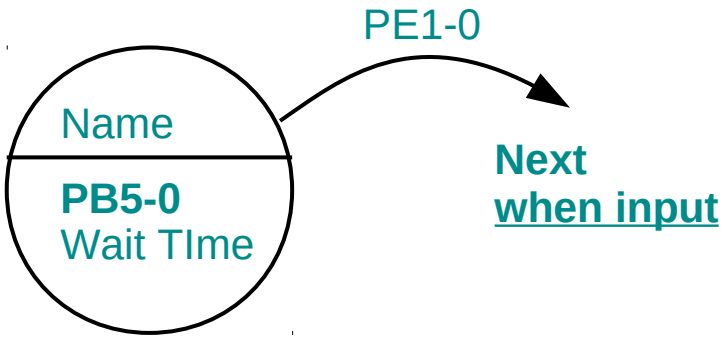
PB5	:	Red traffic lights on the East road
PB4	:	Yellow traffic lights on the East road
PB3	:	Green traffic lights on the East road
PB2	:	Red traffic lights on the North road
PB1	:	Yellow traffic lights on the North road
PB0	:	Green traffic lights on the North road



Moore FSM v.s. Mealy FSM







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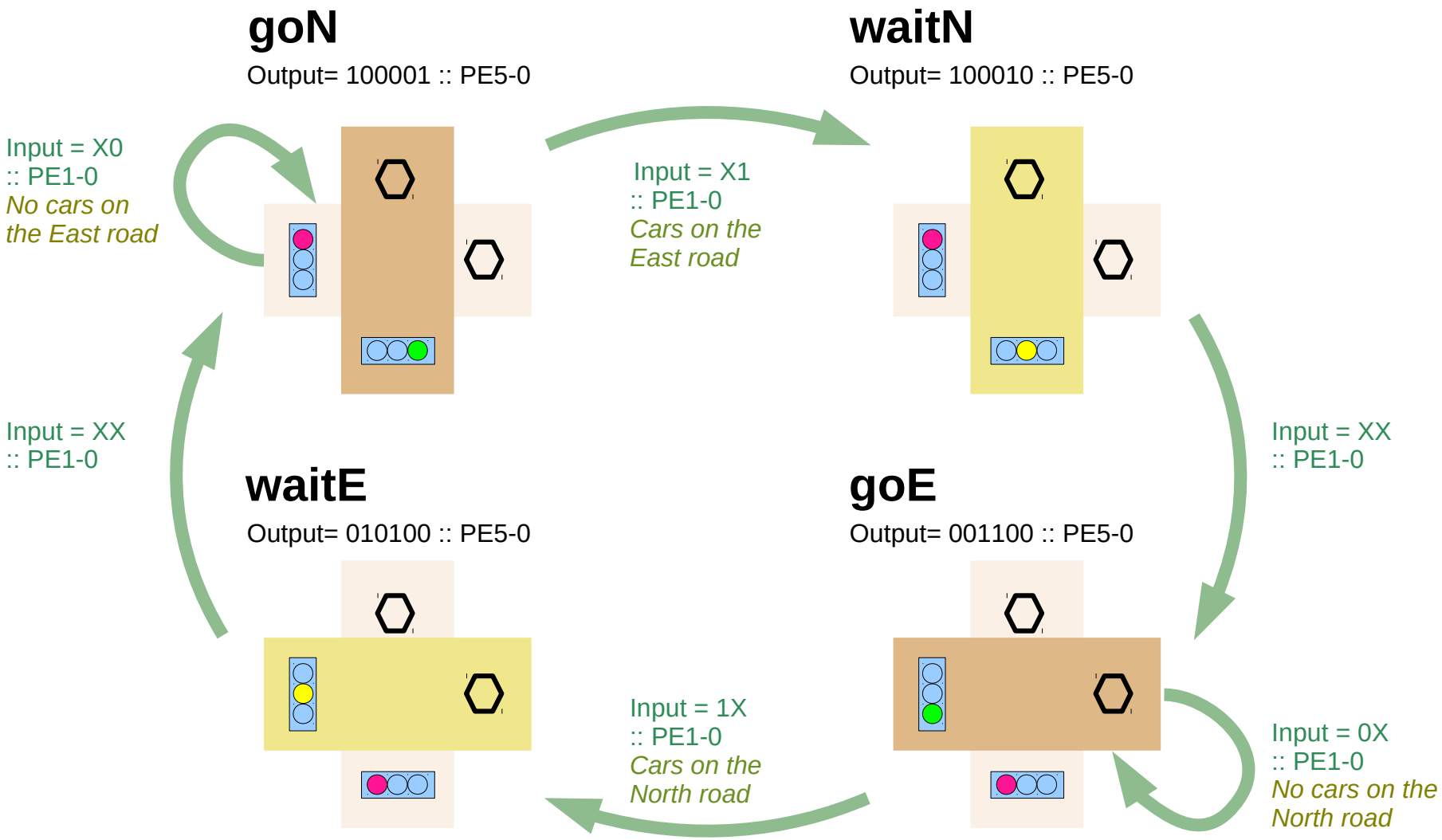
State Transition – Moore FSM



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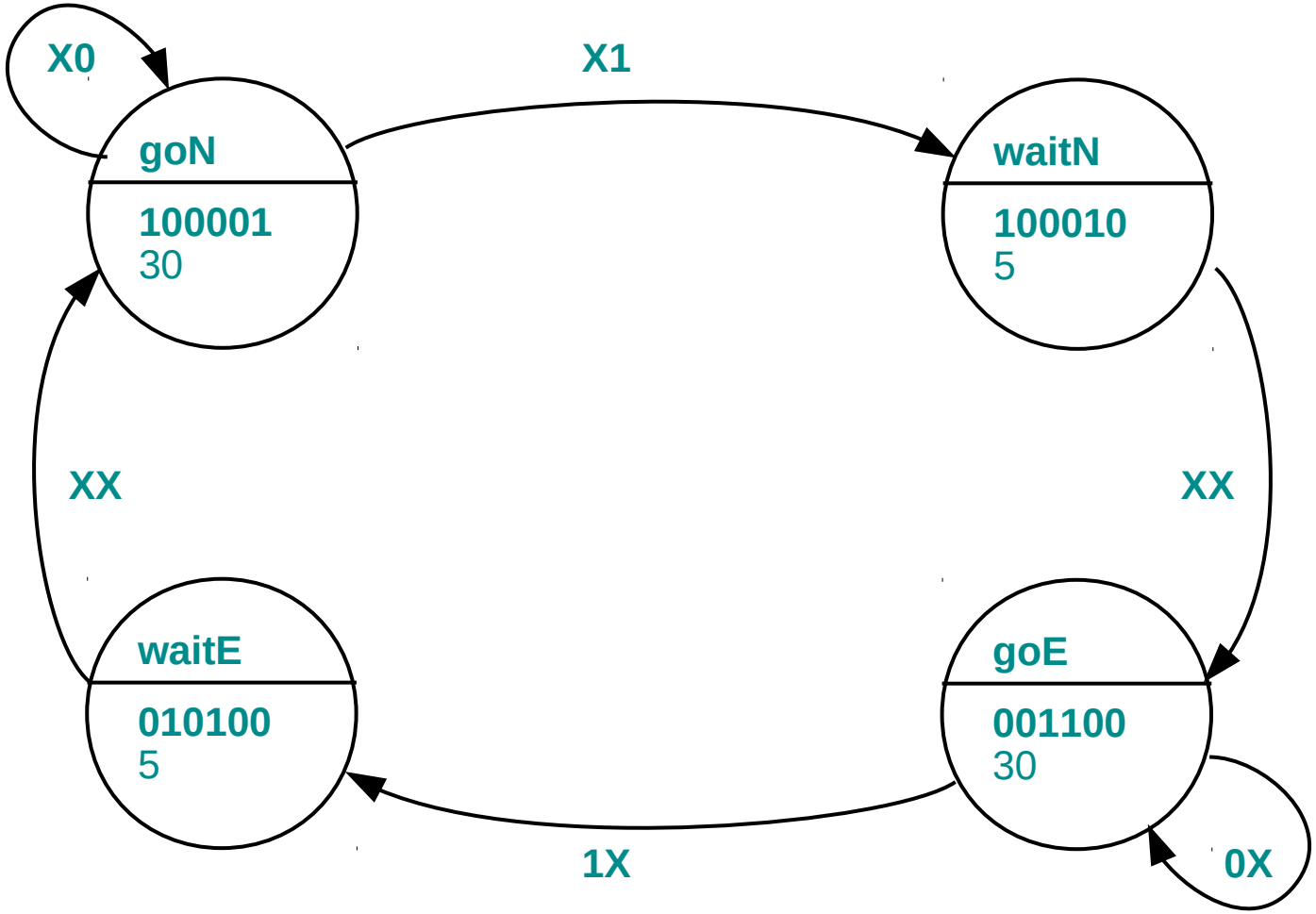
State Transition Diagram – Moore FSM



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State Transition Table – Moore FSM

PE1-0 = 00 : no cars on either road
PE1-0 = 01 : cars on the East road
PE1-0 = 10 : cars on the North road
PE1-0 = 11 : cars on both roads

	PE1-0	00	01	10	11
goN	(100001, 30)	goN	waitN	goN	waitN
waitN	(100010, 5)	goE	goE	goE	goE
goE	(001100, 30)	goE	goE	waitE	waitE
waitE	(010100, 5)	goN	goN	goN	goN

Transition Conditions – Moore FSM

	PE1-0	00	01	10	11
goN	(100001, 30)	goN	waitN	goN	waitN
waitN	(100010, 5)	goE	goE	goE	goE
goE	(001100, 30)	goE	goE	waitE	waitE
waitE	(010100, 5)	goN	goN	goN	goN

goN	00	goN	(R1)
	01	waitN	(R4)
	10	goN	(R1)
	11	waitN	(R5)
goE	00	goE	(R1)
	01	goE	(R4)
	10	waitE	(R4)
	11	waitE	(R5)

(**R1**) If no cars are coming, stay in a green state, but which one doesn't matter. (00)
(**R2**) To change from green to red, implement a yellow light of exactly **5** seconds
(**R3**) Green lights will last at least **30** seconds
(**R4**) If cars are only coming in one direction, move to and stay green in that direction. (10, 01)
(**R5**) If cars are coming in both directions, cycle through all four states (11)

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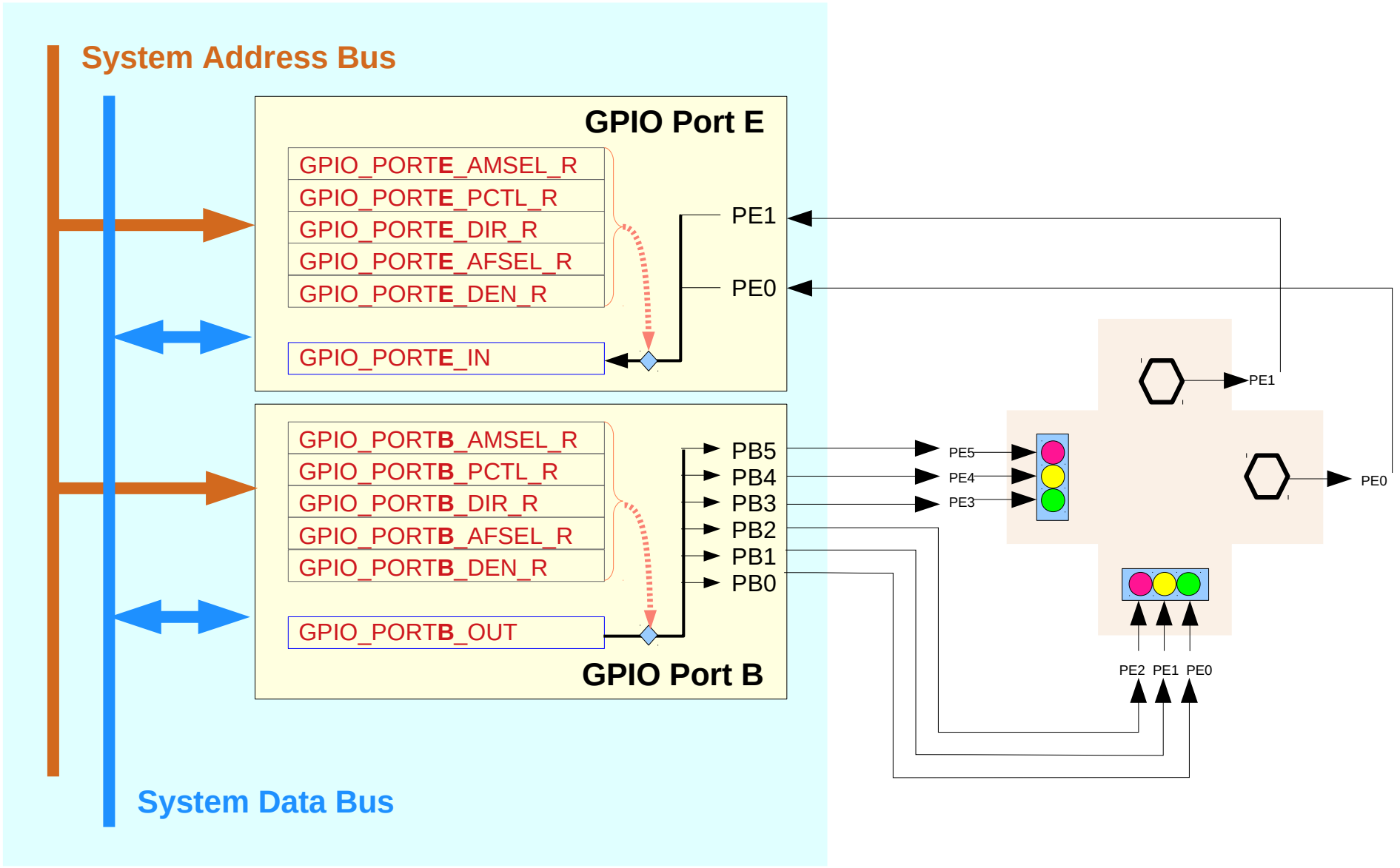
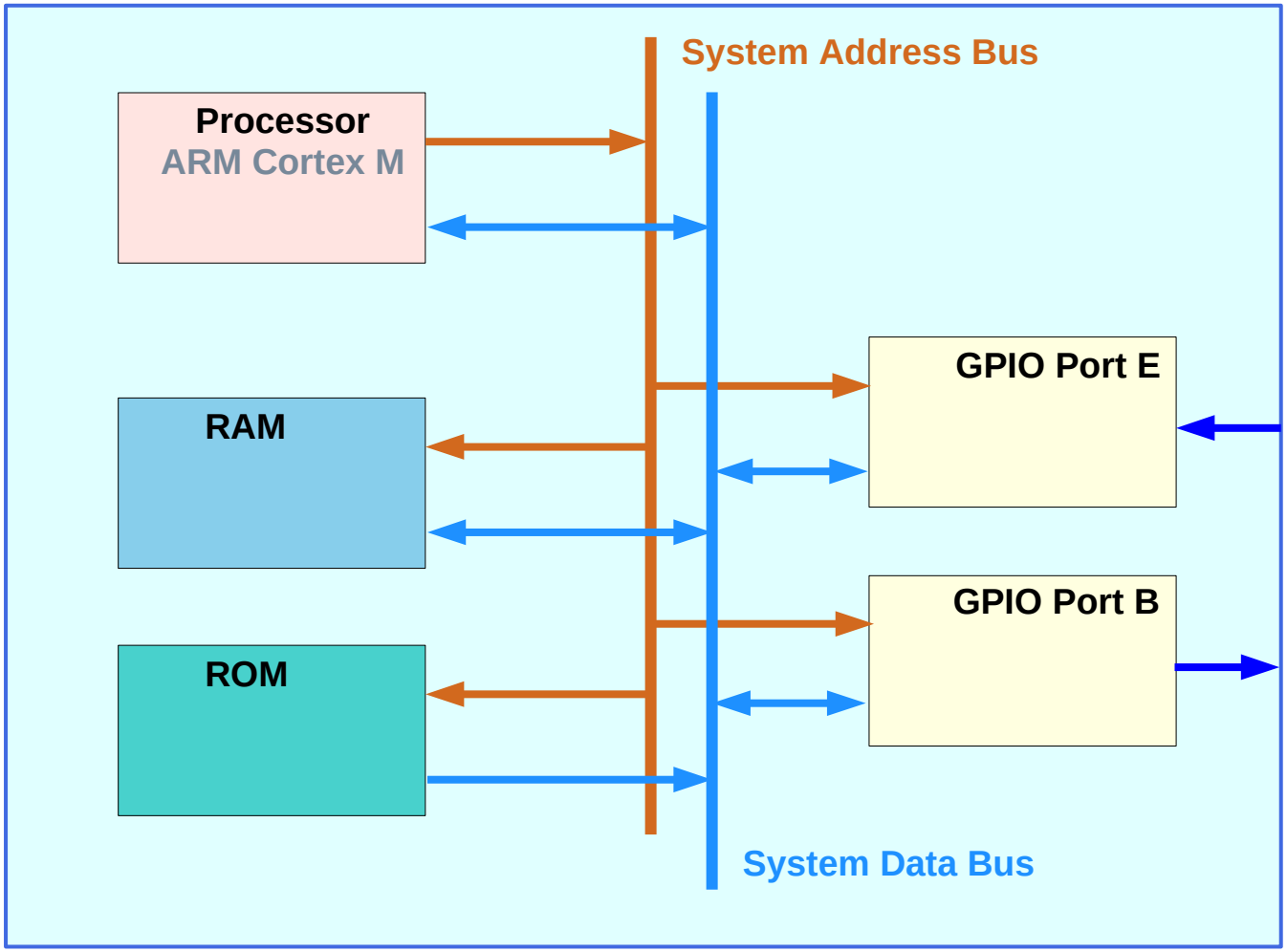
Some GPIO Control Registers

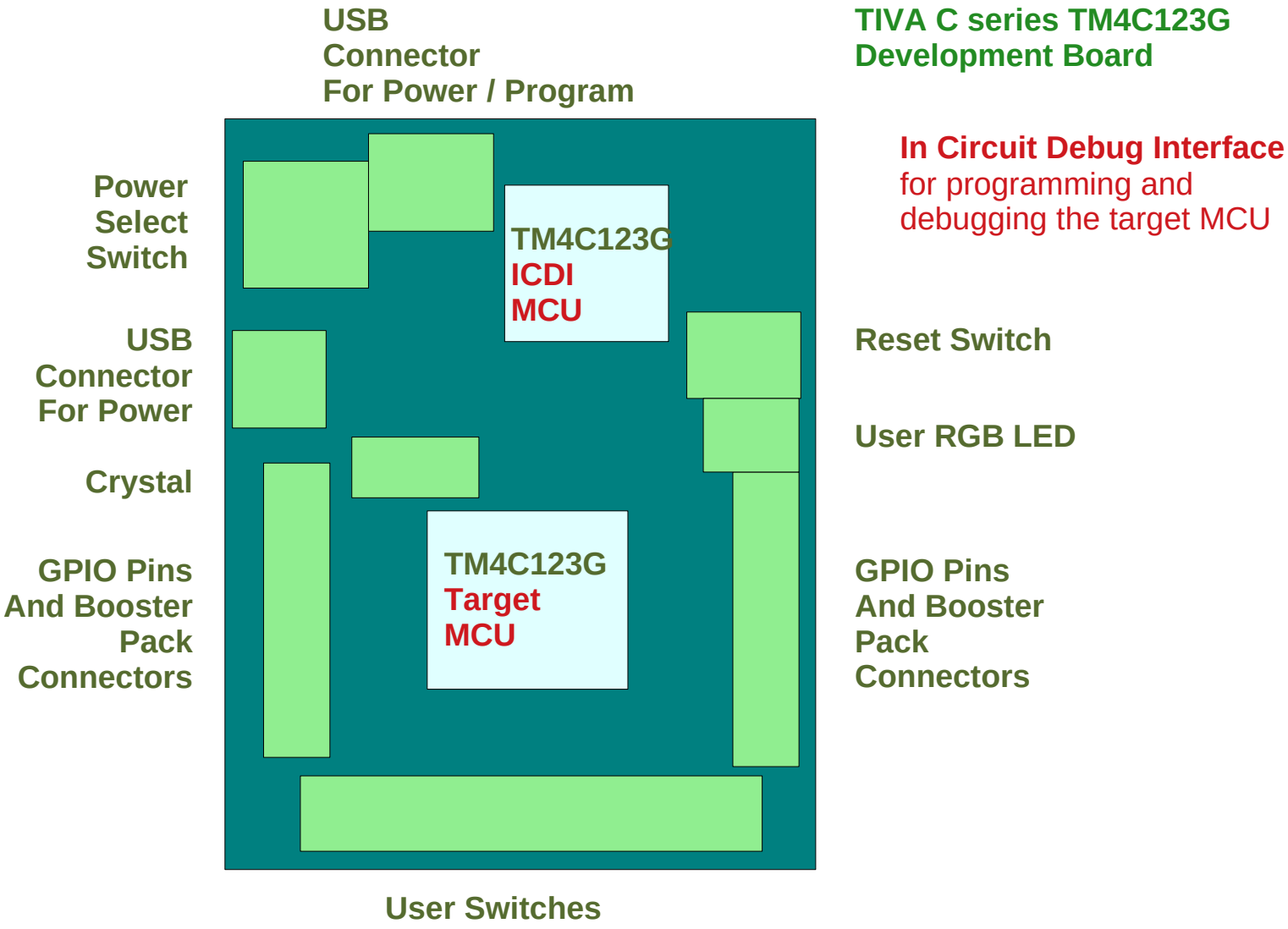


Simplified MicroController Architecture



MicroController
TI's TM4C123GH6PM

Simplified Development Board Architecture



https://circuitdigest.com/microcontroller-projects/getting-started-with-tiva-c-series-tm4c123g-launchpad-from-texas-instruments

Moore FSM – C code (1)

```
#define LIGHT                (*((volatile unsigned long *) 0x400050FC))
#define GPIO_PORTB_OUT       (*((volatile unsigned long *) 0x400050FC)) // bits 5-0
#define GPIO_PORTB_DIR_R     (*((volatile unsigned long *) 0x40005400))
#define GPIO_PORTB_AFSEL_R   (*((volatile unsigned long *) 0x40005420))
#define GPIO_PORTB_DEN_R     (*((volatile unsigned long *) 0x4000551C))
#define GPIO_PORTB_AMSEL_R   (*((volatile unsigned long *) 0x40005528))
#define GPIO_PORTB_PCTL_R    (*((volatile unsigned long *) 0x4000552C))

#define SENSOR               (*((volatile unsigned long *) 0x4002400C))
#define GPIO_PORTE_IN        (*((volatile unsigned long *) 0x4002400C)) // bits 1-0
#define GPIO_PORTE_DIR_R     (*((volatile unsigned long *) 0x40024400))
#define GPIO_PORTE_AFSEL_R   (*((volatile unsigned long *) 0x40024420))
#define GPIO_PORTE_DEN_R     (*((volatile unsigned long *) 0x4002451C))
#define GPIO_PORTE_AMSEL_R   (*((volatile unsigned long *) 0x40024528))
#define GPIO_PORTE_PCTL_R    (*((volatile unsigned long *) 0x4002452C))

#define SYSCTL_RCGC2_R       (*((volatile unsigned long *) 0x400FE108))
#define SYSCTL_RCGC2_GPIOE   0x00000010  // port E Clock Gating Control
#define SYSCTL_RCGC2_GPIOB   0x00000002  // port B Clock Gating Control
```

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Moore FSM – C code (2)

```
// Linked data structures
struct State {
      uint32_t              Out;
      uint32_t              Time;
      const struct State *  Next[4];
};

Typedef   struct State     Styp;

#define   goN       &FSM[0];
#define   waitN     &FSM[1];
#define   goE       &FSM[2];
#define   waitE     &FSM[3];

Styp FSM[4] = {
      {0x21, 3000,   {goN, waitN, goN,   waitN}},          // 30 sec
      {0x22, 500,    {goE, goE,   goE,   goE}},           //  5 sec
      {0x0c, 3000,   {goE, goE,   waitE, waitE}},         // 30 sec
      {0x14, 500,    {goN, goN,   goN,   goN}}     };     //  5 sec
```

Moore FSM – C code (3)

```
int main (void) {
    Styp *      Pt;                                   // state pointer
    uint32_t    Input;

    PLL_Init();                                       // 50 MHz
    SysTick_Init();
    SYSCTL_RCGCGPIO_R |= 0x12;                        // 1) B E

    while ((SYSCTl_PRGPIO_R & 0x12) != 0x12) { };     // ready?
    // 2) no need to unlock
```

Moore FSM – C code (4)

```
// 3) disable analog function on PE1-0
GPIO_PORTE_AMSEL_R &= ~0x03;
// 4) enable regular GPIO
GPIO_PORTE_PCTL_R &= ~0x000000FF;
// 5) inputs on PE1-0
GPIO_PORTE_DIR_R &= ~0x03;
// 6) regular function on PE1-0
GPIO_PORTE_AFSEL_R &= ~0x03;
// 7) enable digital on PE1-0
GPIO_PORTE_DEN_R |= 0x03;
```

```
GPIO_PORTE_AMSEL_R    &= ~0x03;
GPIO_PORTE_PCTL_R     &= ~0x000000FF;
GPIO_PORTE_DIR_R      &= ~0x03;
GPIO_PORTE_AFSEL_R    &= ~0x03;
GPIO_PORTE_DEN_R      |= 0x03;
```

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Moore FSM – C code (5)

```
// 3) disable analog function on PE5-0
GPIO_PORTB_AMSEL_R &= ~0x3F;
// 4) enable regular GPIO
GPIO_PORTB_PCTL_R &= ~0x00FFFFFF;
// 5) inputs on PE1-0
GPIO_PORTB_DIR_R  |= ~0x3F;
// 6) regular function on PE1-0
GPIO_PORTB_AFSEL_R &= ~0x3F;
// 7) enable digital on PE1-0
GPIO_PORTB_DEN_R |= 0x03;
```

```
GPIO_PORTB_AMSEL_R    &= ~0x3F;
GPIO_PORTB_PCTL_R     &= ~0x00FFFFFF;
GPIO_PORTB_DIR_R      |= ~0x3F;
GPIO_PORTB_AFSEL_R    &= ~0x3F;
GPIO_PORTB_DEN_R      |= 0x03;
```

Moore FSM – C code (6)

```
    Pt = goN;

    while (1) {
        LIGHT = Pt->Out ;                    // set lights
        SysTick_Wait10min(Pt->Time);
        Input = SENSOR;                      // read sensors
        Pt = Pt->Next[Input];                // state transition
    }
}
```

```
#define LIGHT          (*((volatile unsigned long *) 0x400050FC))
#define GPIO_PORTB_OUT (*((volatile unsigned long *) 0x400050FC)) // bits 5-0
#define SENSOR         (*((volatile unsigned long *) 0x4002400C))
#define GPIO_PORTE_IN  (*((volatile unsigned long *) 0x4002400C)) // bits 1-0
```

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Moore FSM – C code (7)

```
        Pt = goN;

        while (1) {
            LIGHT = Pt->Out ;                    // set lights
            SysTick_Wait10min(Pt->Time);
            Input = SENSOR;                      // read sensors
            Pt = Pt->Next[Input];                // state transition
        }
}
```

```
// Linked data structures
struct State {
        uint32_t              Out;
        uint32_t              Time;
        const struct State *  Next[4];
};

Typedef      struct State   Styp;

Styp * Pt;
uint32_t     Input;
```

```
#define      goN        &FSM[0];
#define      waitN      &FSM[1];
#define      goE        &FSM[2];
#define      waitE      &FSM[3];

Styp FSM[4] = {
        {0x21, 3000, {goN, waitN, goN,  waitN } },
        {0x22, 500,  {goE, goE,   goE,  goE   } },
        {0x0c, 3000, {goE, goE,   waitE, waitE } },
        {0x14, 500,  {goN, goN,   goN,  goN   } }};
```

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Moore FSM – ARM assembly (1)

```
; Linked data structure
; Put in ROM
Out     EQU   0      ; offset for output
WAIT    EQU   4      ; offset for time
NEXT    EQU   8      ; offset for next
```

```
goN     10_0001 = 0x21
waitN   10_0010 = 0x22
goE     00_1100 = 0x0c
waitE   01_0100 = 0x14
```

```
goN     DCD   0x21          ; North green, East red
        DCD   3000          ; 30 sec
        DCD   goN, waitN, goN, waitN
waitN   DCD   0x22          ; North yello, East red
        DCD   500           ; 5 sec
        DCD   goE, goE, goE, goE
goE     DCD   0x0c          ; North red, East green
        DCD   3000          ; 30 sec
        DCD   goE, goE, waitE, waitE
waitE   DCD   0x14          ; North red, East yellow
        DCD   500           ; 5 sec
        DCD   goN, goN, goN, goN
```

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Moore FSM – ARM assembly (2)

```
Start
        BL      PLL_Init                ; 50 MHz clock
        BL      SysTick_Init            ; enable SysTick
        LDR     R1, =SYSCTL_RCGCGPIO_R
        LDR     R0, [R1]
        ORR     R0, R0, #0x12           ; activate B E
        STR     R0, [R1]
        NOP
        NOP                             ; allow time to finish
```

Moore FSM – ARM assembly (3)

```
        LDR     R1, =GPIO_PORTE_AMSEL_R
        LDR     R0, [R1]
        BIC     R0, R0, #0x03           ; no analog
        STR     R0, [R1]
        LDR     R1, =GPIO_PORTE_PCTL_R
        LDR     R0, [R1]
        BIC     R0, R0, #0x000000FF     ; PE1-0
        STR     R0, [R1]
        LDR     R1, =GPIO_PORTE_DIR_R
        LDR     R0, [R1]
        BIC     R0, R0, #0x03           ; PE1-0 input
        STR     R0, [R1]
        LDR     R1, =GPIO_PORTE_AFSEL_R
        LDR     R0, [R1]
        BIC     R0, R0, #0x03           ; no alt function
        STR     R0, [R1]
        LDR     R1, =GPIO_PORTE_DEN_R
        LDR     R0, [R1]
        ORR     R0, R0, #0x03           ; enable PE1-0
        STR     R0, [R1]
```

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Moore FSM – ARM assembly (4)

```
        LDR     R1, =GPIO_PORTB_AMSEL_R
        LDR     R0, [R1]
        BIC     R0, R0, #0x3F           ; no analog
        STR     R0, [R1]
        LDR     R1, =GPIO_PORTB_PCTL_R
        LDR     R0, [R1]
        BIC     R0, R0, #0x00FFFFFF     ; PB5-0
        STR     R0, [R1]
        LDR     R1, =GPIO_PORTB_DIR_R
        LDR     R0, [R1]
        ORR     R0, R0, #0x3F           ; PB5-0 output
        STR     R0, [R1]
        LDR     R1, =GPIO_PORTB_AFSEL_R
        LDR     R0, [R1]
        BIC     R0, R0, #0x3F           ; no alt function
        STR     R0, [R1]
        LDR     R1, =GPIO_PORTB_DEN_R
        LDR     R0, [R1]
        ORR     R0, R0, #0x3F           ; enable PB5-0
        STR     R0, [R1]
```

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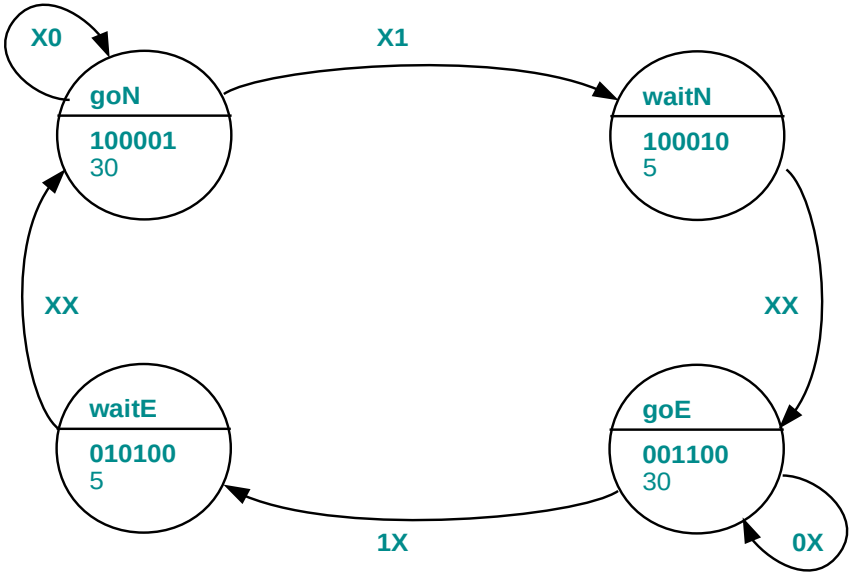
Moore FSM – ARM assembly (5)

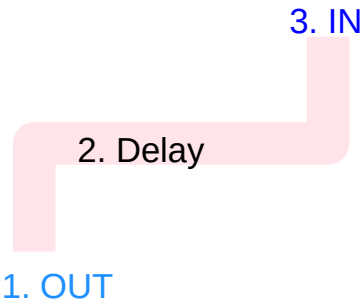
```
        LDR     R4, =goN        ; state pointer
        LDR     R5, =SENSOR     ; 0x4002400C
        LDR     R6, =LIGHT      ; 0x400050FC
FSM:    LDR     R0, [R4, #OUT]  ; output value
        STR     R0, [R6]        ; set lights
        LDR     R0, [R4, #WAIT] ; time delay
        BL      SysTick_Wait10ms
        LDR     R0, [R5]        ; read input
        LSL     R0, R0, #2      ; 4 bytes/address
        ADD     R0, R0, #NEXT   ; 8, 12, 16, 20
        LDR     R4, [R4, R0]    ; go to next state
        B       FSM
```

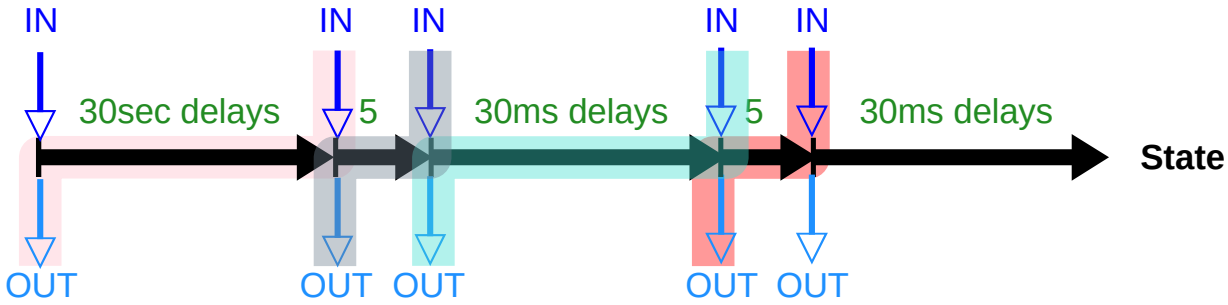
C

```
#define LIGHT          (*((volatile unsigned long *) 0x400050FC))
#define GPIO_PORTB_OUT (*((volatile unsigned long *) 0x400050FC)) // bits 5-0
#define SENSOR         (*((volatile unsigned long *) 0x4002400C))
#define GPIO_PORTE_IN  (*((volatile unsigned long *) 0x4002400C)) // bits 1-0
```

Moore FSM – ARM assembly (6)







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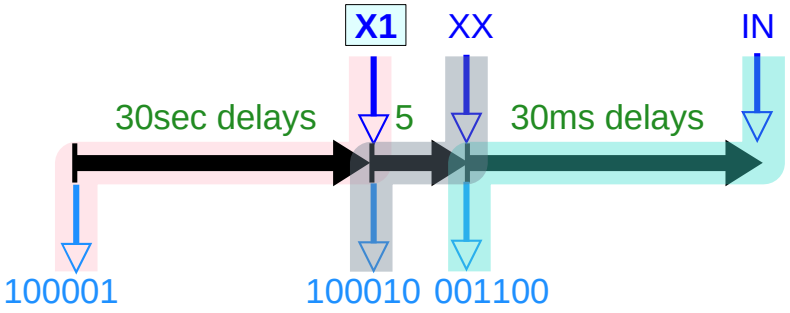
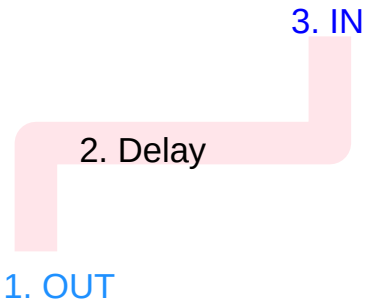
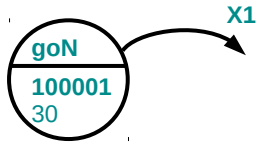
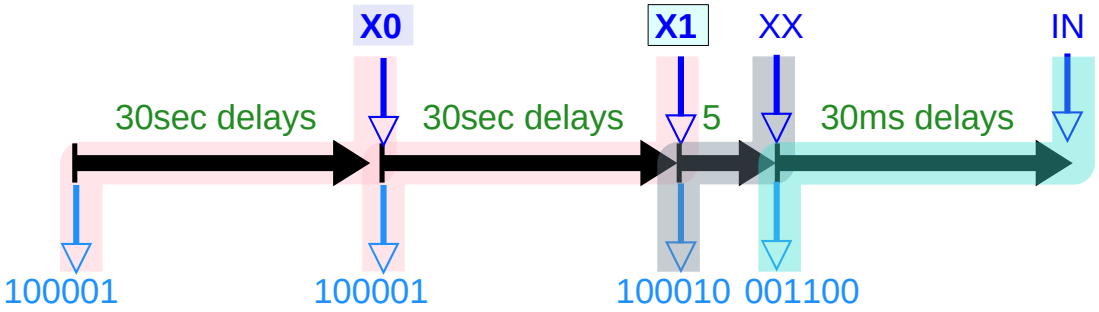
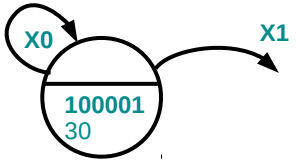
Moore FSM – ARM assembly (7)

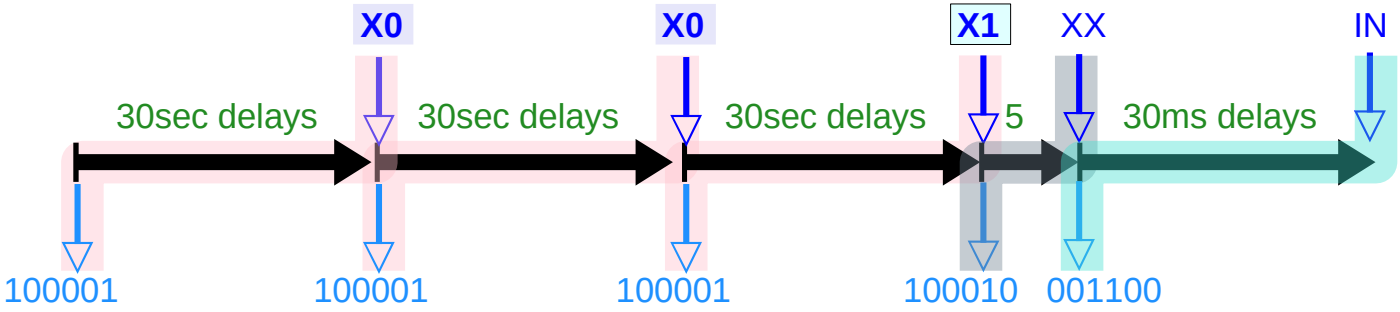


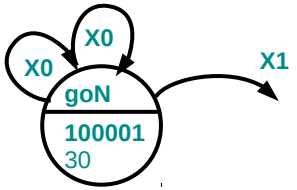












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Moore FSM – ARM assembly (8)

```
        LDR   R4, =goN          ; state pointer
        LDR   R5, =SENSOR       ; 0x4002400C
        LDR   R6, =LIGHT        ; 0x400050FC
FSM:    LDR   R0, [R4, #OUT]    ; output value
        STR   R0, [R6]          ; set lights
        LDR   R0, [R4, #WAIT]   ; time delay
        BL    SysTick_Wait10ms
        LDR   R0, [R5]          ; read input
        LSL   R0, R0, #2        ; 4 bytes/address 0, 4, 12, 16
        ADD   R0, R0, #NEXT     ; 8, 12, 16, 20
        LDR   R4, [R4, R0]      ; go to next state
        B     FSM
```

```
Out   EQU   0   ; offset for output
WAIT  EQU   4   ; offset for time
NEXT  EQU   8   ; offset for next
```

```
struct State {
uint32_t                Out;
uint32_t                Time;
const struct State *    Next[4];
};
```

R4 + #OUT	Out
R4 + #WAIT	Time
R4 + #NEXT	Next

Moore FSM – ARM assembly (9)

```
goN   DCD  0x21
      DCD  3000
      DCD  goN, waitN, goN, waitN
waitN DCD  0x22
      DCD  500
      DCD  goE, goE, goE, goE
goE   DCD  0x0c
      DCD  3000
      DCD  goE, goE, waitE, waitE
waitE DCD  0x14
      DCD  500
      DCD  goN, goN, goN, goN
```

goN	Out			
	Time			
	Next[0]	Next[1]	Next[2]	Nex[3]
waitN	Out			
	Time			
	Next[0]	Next[1]	Next[2]	Nex[3]
goE	Out			
	Time			
	Next[0]	Next[1]	Next[2]	Nex[3]
waitE	Out			
	Time			
	Next[0]	Next[1]	Next[2]	Nex[3]

```
struct State {
uint32_t              Out;
uint32_t              Time;
const struct State *  Next[4];
};
```

R4 = goN / waitN / goE / waitE

R4 + #OUT	Out	R4 + #0
R4 + #WAIT	Time	R4 + #4
R4 + #NEXT	Next[0]	R4 + #8

R4 + #NEXT	Next[0]	Next[1]	Next[2]	Nex[3]
	Input=00	Input=01	Input=10	Input=11
	4*R5=0	4*R5=4	4*R5=8	4*R5=12

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Engine Controller Rules

(**R1**) if we are stopped, and the control is low, we press the brake and remain stopped

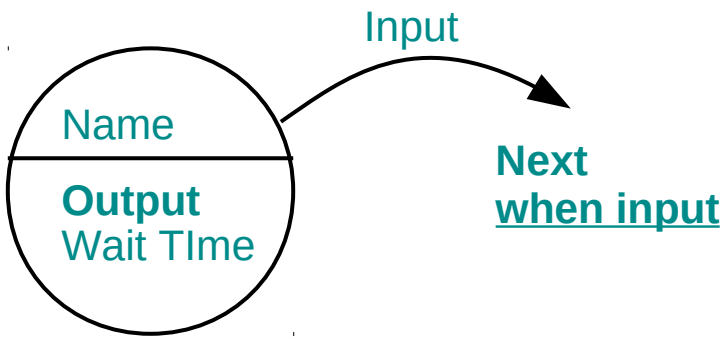
(**R2**) if we are stopped, and the control is high, we release the brake and begin to go.

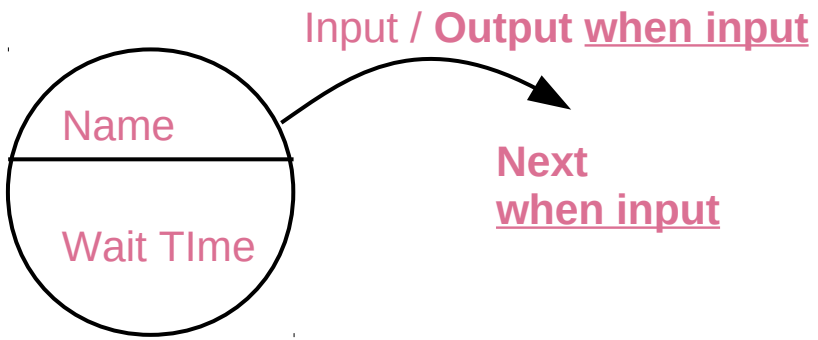
(**R3**) If we are going, and the control is low, we release the gas and begin to stop

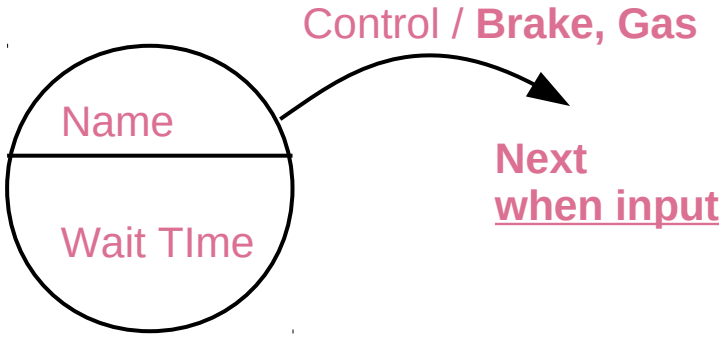
(**R4**) If we are going, and the control is high, we press the gas and continue to go

(**R5**) There must be **at least 1 ms** of no brake, no gas it switches between go and stop.

Moore FSM v.s. Mealy FSM







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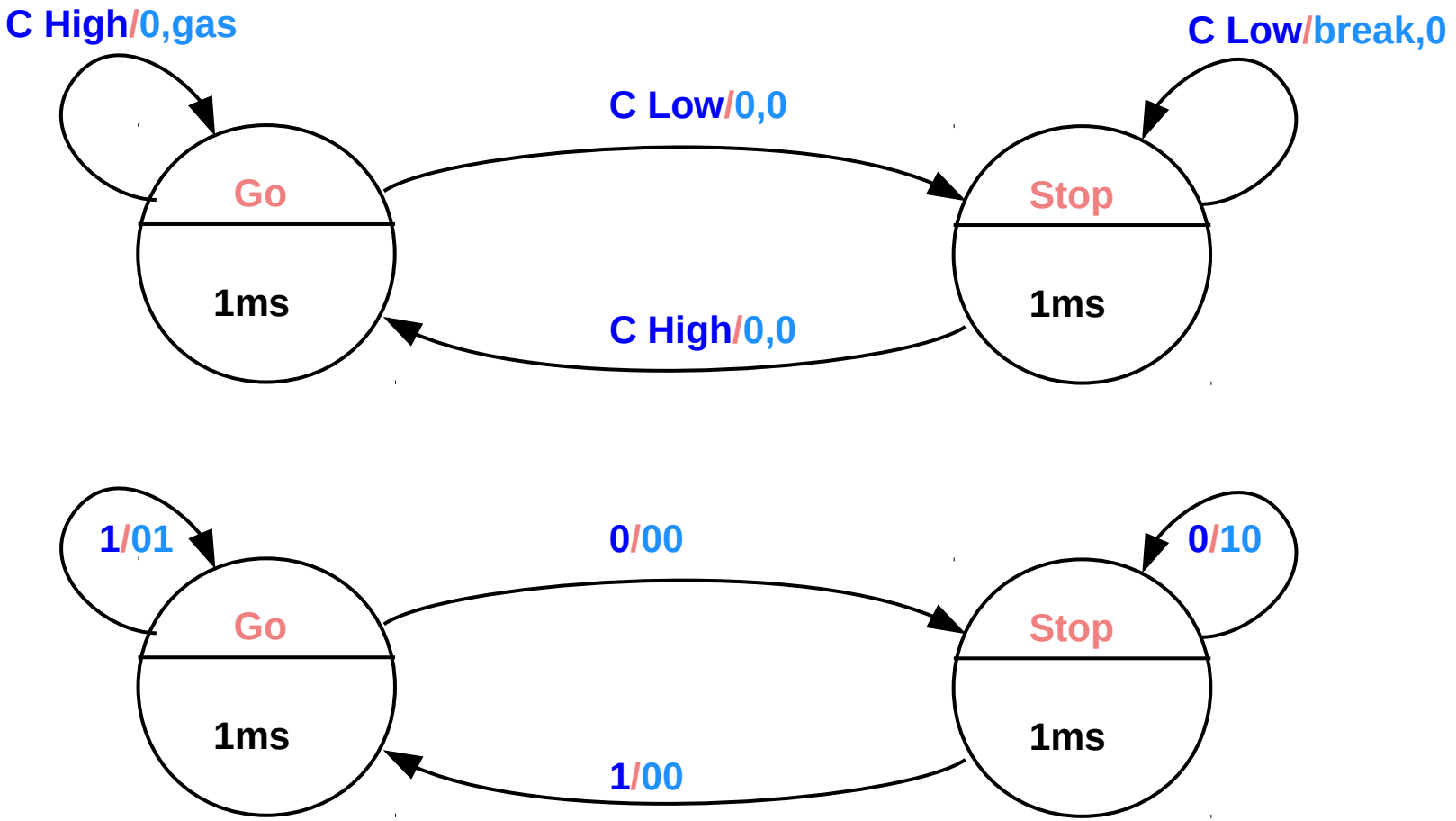
State Transition Diagram – Mealy FSM



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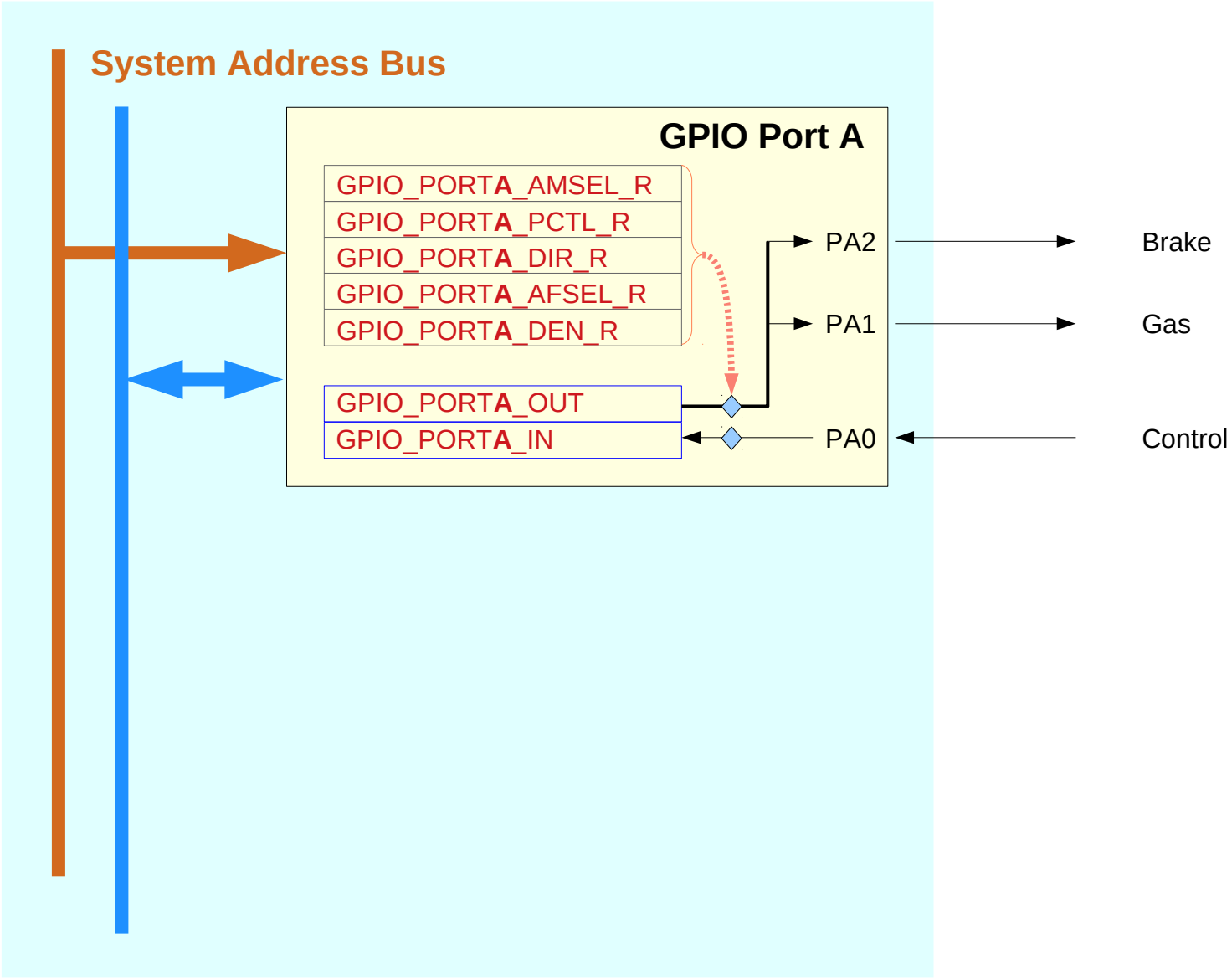
Some GPIO Control Registers



Mealy FSM – C code (1)

```
// linked list data structure
struct State {
      uint32_t                Out[2];
      uint32_t                Delay;
      const struct State *    Next[2];
};

typedef   const struct    State Styp;

#define   Stop      &FSM[0]
#define   Go        &FSM[1]

Styp      FSM[2] = {
          { {2, 0}, 50000, {Stop, Go} },
          { {0,1},  50000, {Stop, Go} }    };
```

Mealy FSM – C code (2)

```
int main(void) {
    Styp      *Pt;                  // state pointer
    uint32_t  Input;

    PLL_Init();                     // 50 MHz
    SysTick_Init();

    // 1) activate port A
    SYSCTL_RCGCGPIO_R |= 0x01;
    while ((SYSCTL_PRGPIC_R & 0x01) == 0) { );

    // 2) no need to unlock Port A
```

Mealy FSM – C code (3)

```
// 3) disable analog on PA2-0
GPIO_PORTA_AMSEL_R &= ~0x000000FF;
// 4) configure PA20 as GPIO
GPIO_PORTA_PCTL_R &= ~0x00000FFF;
// 5) make PA0 in and PA2-1 out
GPIO_PORTA_DIR_R &= ~0x01;
GPIO_PORTA_DIR_R |= 0x06;
// 6) disable all func on PA2-0
GPIO_PORTA_AFSEL_R &= ~ox07;
```

```
GPIO_PORTA_AMSEL_R    &= ~0x000000FF;
GPIO_PORTA_PCTL_R     &= ~0x00000FFF;
GPIO_PORTA_DIR_R      &= ~0x01;
GPIO_PORTA_DIR_R      |=    0x06;
GPIO_PORTA_AFSEL_R    &= ~0x07;
```

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Mealy FSM – C code (4)

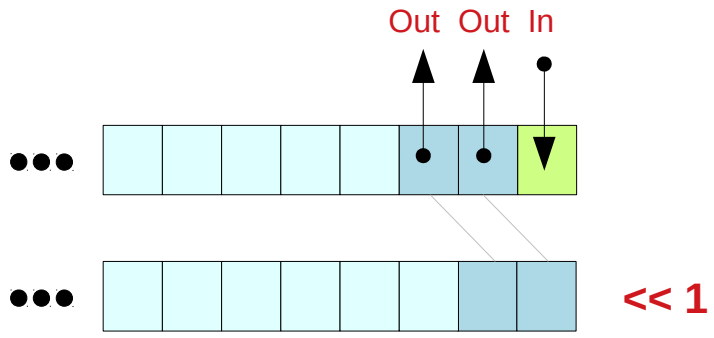
```
        Pt = Stop;                  // initial state: stopped

        while (1) {
            Input = INPUT;
            // get new input from Control
            OUTPUT = Pt->Out[Input] << 1;
            SysTick_Wait(Pt->Delay);            // wait
            Pt = Pt->Next[Input];               // next
        }
}
```

Operator Precedence

(Pt->(Out[Input])) << 1;
(Pt->(Next[Input]))

1. **[ ]**
2. **->**
3. **<<**

Port A IO Direction



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Mealy FSM – C code (5)

```
        Pt = Stop;                  // initial state: stopped

        while (1) {
            Input = INPUT;
            // get new input from Control
            OUTPUT = Pt->Out[Input] << 1;      // Mealy Machine : outputs depend on inputs
            SysTick_Wait(Pt->Delay);           // wait
            Pt = Pt->Next[Input];              // next
        }
}
```

```
Styp        *Pt;                // state pointer

Styp        FSM[2] = {
            { {2, 0}, 50000, {Stop, Go} },
            { {0, 1}, 50000, {Stop, Go} }    };
```

Input=1 input=0 Input=1 input=0

```
// linked list data structure

struct State {
        uint32_t                Out[2];
        uint32_t                Delay;
        const struct State *    Next[2];
};
```

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Mealy FSM – ARM assembly (1)

```
; Linked data structure
; Put in ROM
OUT     EQU     0       ; offset for output
DELAY   EQU     8       ; offset for delay
NEXT    EQU     12      ; offset for next

Stop    DCD     2, 0            ; Outputs for 0, 1
        DCD     50000           ; 1 ms
        DCD     Stop, Go        ; Next for 0, 1
Go      DCD     0, 1            ; outputs for 0, 1
        DCD     50000           ; 1 ms
        DCD     Stop, Go        ; Next for 0, 1
```

Mealy FSM – ARM assembly (2)

```
Start
        BL      PLL_Init                ; 50 MHz clock
        BL      SysTick_Init            ; enable SysTick
        LDR     R1, =SYSCTL_RCGCGPIO_R
        LDR     R0, [R1]
        ORR     R0, R0, #0x01           ; activate A
        STR     R0, [R1]
        NOP
        NOP                             ; allow time to finish
```

Mealy FSM – ARM assembly (3)

```
        LDR     R1, =GPIO_PORTA_AMSEL_R
        LDR     R0, [R1]
        BIC     R0, #0x07               ; no analog
        STR     R0, [R1]
        LDR     R1, =GPIO_PORTA_PCTL_AMSEL_R
        LDR     R0, [R1]
        MOV     R2, #0x00000FFF
        BIC     R0, R0, R2              ; GPIO PA2-0
        STR     R0, [R1]
        LDR     R1, =GPIO_PORTA_DIR_R
        LDR     R0, [R1]
        BIC     R0, R0, #0x01           ; PA0 input
        ORR     R0, R0, #0x06           ; PA2-1 output
        STR     R0, [R1]
        LDR     R1, =GPIO_PORTA_AFSEL_R
        LDR     R0, [R1]
        BIC     R0, R0, #0x07           ; no alt function
        STR     R0, [R1]
```

Mealy FSM – ARM assembly (4)

```
LDR     R1, =GPIO_PORTA_DEN_R
LDR     R0, [R1]
ORR     R0, R0, #0x07           ; enable PA2-0
STR     R0, [R1]
```

Mealy FSM – ARM assembly (5)

```
        LDR     R4, =Stop       ; State pointer
        LDR     R5, =INPUT      ; 0x40004004
        LDR     R6, =OUTPUT     ; 0x40004018
FSM     LDR     R3, [R5]        ; Read input
        LSL     R3, R3, #2      ; 4 bytes each
        ADD     R1, R3, #OUT    ; R1 is 0 or 4
        LDR     R2, [R4, R1]    ; Output value
        LSL     R2, R2, #1      ; into bits 2, 1
        STR     R2, [R6]        ; set outputs
        LDR     R0, [R4, #DELAY] ; 1ms delays
        ADD     R1, R3, #NEXT   ; R1 is 12 or 16
        LDR     R4, [R4, R1]    ; find next state
        BL      SysTick_Wait
        B       FSM
```

```
#define OUTPUT          (*((volatile unsigned long *) 0x40004018))
#define GPIO_PORTA_OUT  (*((volatile unsigned long *) 0x40004018)) // bits 5-0
#define INPUT           (*((volatile unsigned long *) 0x40004004))
#define GPIO_PORTA_IN   (*((volatile unsigned long *) 0x40004004)) // bits 1-0
```

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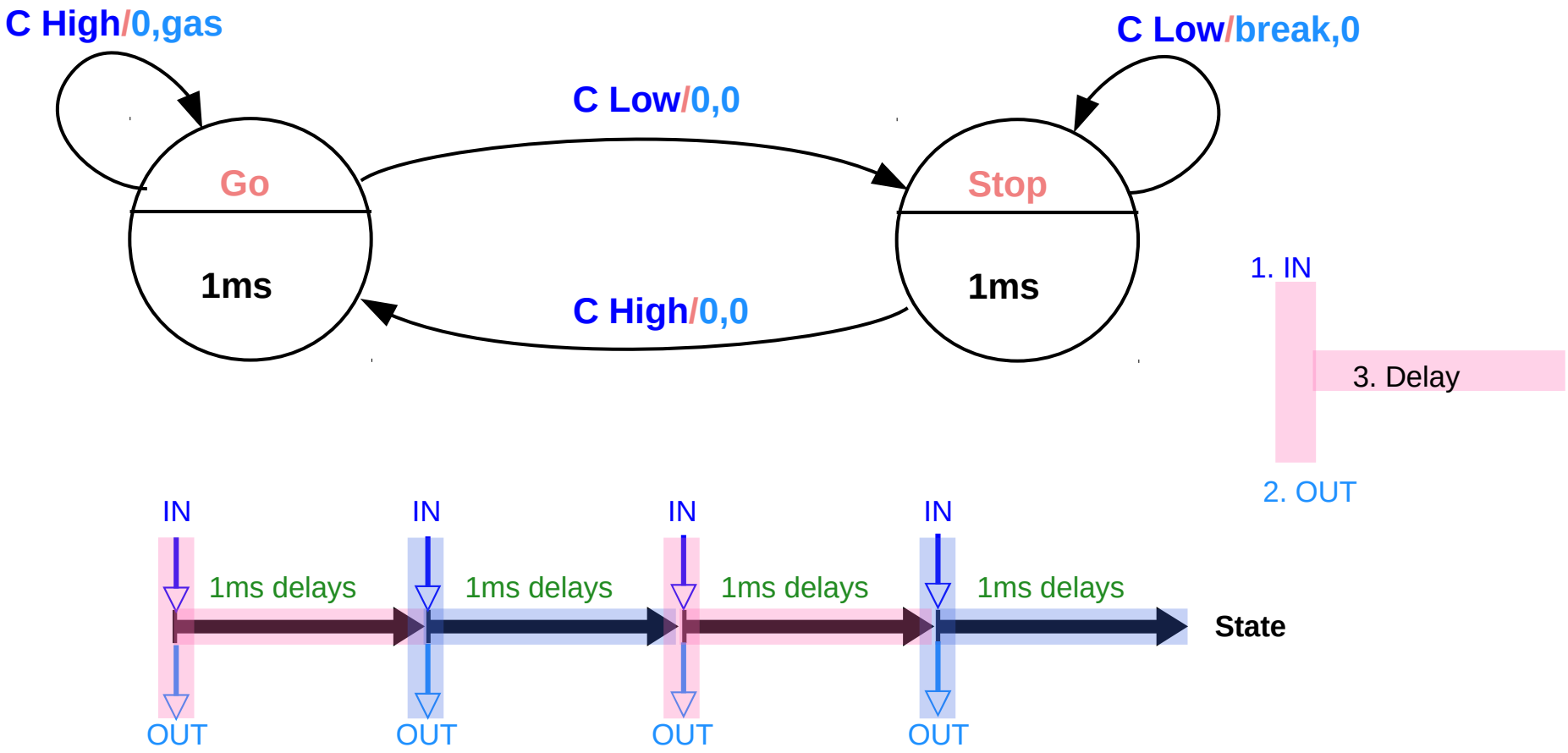
Mealy FSM – ARM assembly (6)



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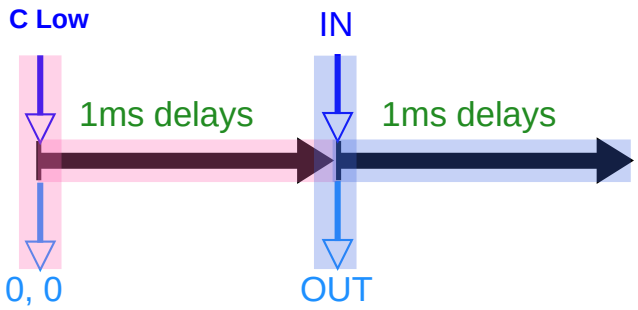
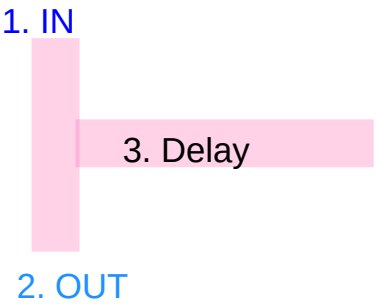
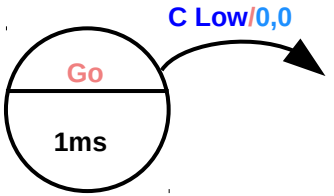
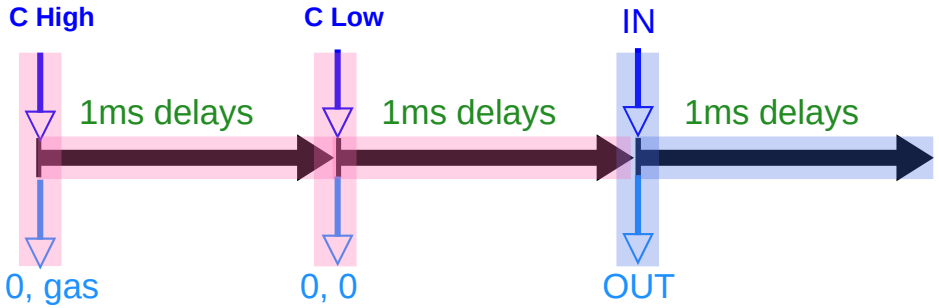
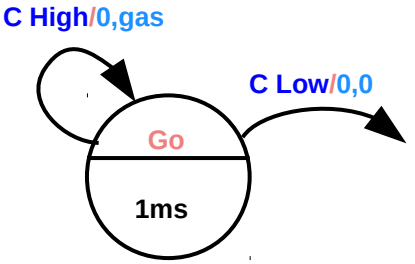
Mealy FSM – ARM assembly (7)

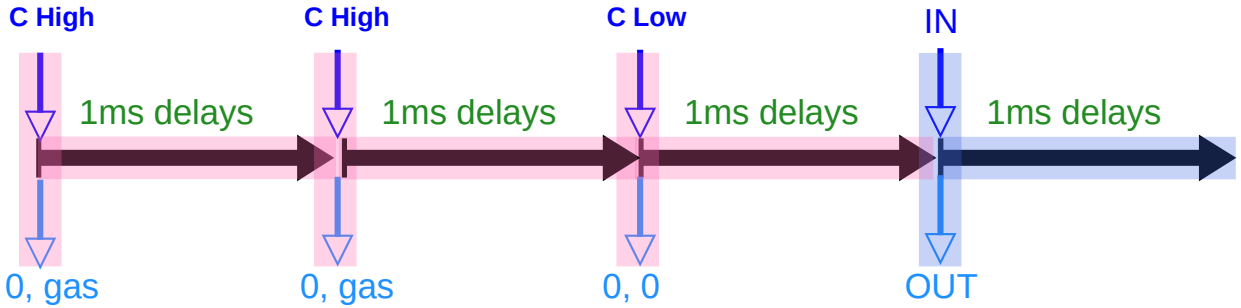


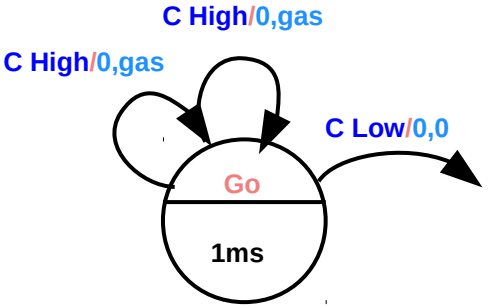












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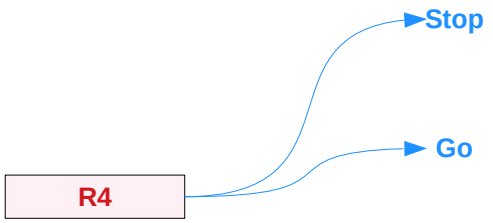
Mealy FSM – ARM assembly (8)

```
        LDR   R4, =Stop      ; State pointer
        LDR   R5, =INPUT     ; 0x40004004
        LDR   R6, =OUTPUT    ; 0x40004018
FSM     LDR   R3, [R5]       ; Read input          R3 ← Input
        LSL   R3, R3, #2     ; 4 bytes each        R3 ← Input *4
        ADD   R1, R3, #OUT   ; R1 is 0 or 4        R1 ← Input *4 + 0
        LDR   R2, [R4, R1]   ; Output value        R2 ← [R4 + Input *4 + 0]
        LSL   R2, R2, #1     ; into bits 2, 1      R2 ← [R4 + Input *4 + 0] *2
        STR   R2, [R6]       ; set outputs
        LDR   R0, [R4, #DELAY] ; 20ns delays       R0 ← [R4 + 8]
        ADD   R1, R3, #NEXT  ; R1 is 12 or 16
        LDR   R4, [R4, R1]   ; find next state     R4 ← [R4 + Input *4 + 12]
        BL    SysTick_Wait
        B     FSM
```

```
OUT     EQU  0
DELAY   EQU  8
NEXT    EQU  12
```

0 byte offset
2 byte offset
3 byte offset



Out[0]	Out[1]
Delay	
Next[0]	Next[1]
Out[0]	Out[1]
Delay	
Next[0]	Next[1]

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Mealy FSM – ARM assembly (9)

```
Stop   DCD   2, 0
       DCD   50000
       DCD   Stop, Go
Go     DCD   0, 1
       DCD   50000
       DCD   Stop, Go
```

Stop	**Out[0]**	**Out[1]**
	Delay	
	Next[0]	**Next[1]**
Go	**Out[0]**	**Out[1]**
	Delay	
	Next[0]	**Next[1]**

```
struct State {
uint32_t              Out[2];
uint32_t              Delay;
const struct State *  Next[2];
};
```

R4 = goN / waitN / goE / waitE

R4 + #OUT	**Out[0]**	**Out[1]**
R4 + #WAIT	**Delay**	
R4 + #NEXT	**Next[0]**	**Next[1]**

```
OUT     EQU   0
DELAY   EQU   8
NEXT    EQU   12
```

R4 + #0
R4 + #8
R4 + #12

R4 + #OUT	**Out[0]**	**Out[1]**
R4 + #NEXT	**Next[0]**	**Next[1]**

Input=0 **Input=1**

4*R5=0 **4*R5=4**

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Pointer access to an array

References

[1] ftp://ftp.geoinfo.tuwien.ac.at/navratil/HaskellTutorial.pdf
[2] https://www.umiacs.umd.edu/~hal/docs/daume02yaht.pdf