TI-RSLK MAX

Texas Instruments Robotics System Learning Kit

TEXAS INSTRUMENTS

Module 7

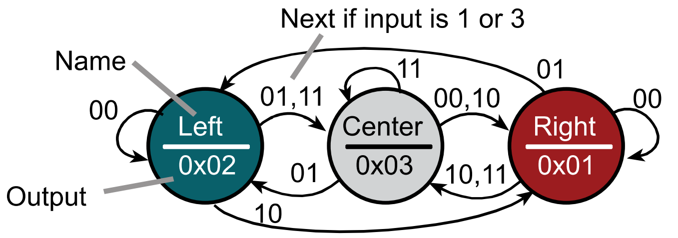
Lecture: Finite State Machines -Theory

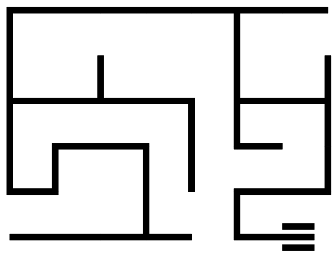
Finite State Machines - Theory

You will learn in this module

- C programming fundamentals
  - Arrays
  - Pointers
  - Structures
  - Time delays
- Develop debugging techniques such as
  - Watch windows
  - Breakpoints
  - Heart beats

- Solve problems with finite state machines
  - States, tables, graphs, input, outputs
  - Mealy versus Moore
- Design controller for a line tracking robot
  - Traffic light controller
  - Line-following robot





Abstraction

Software abstraction:

- Define a problem
  - Minimal set of basic concepts
  - Abstract principles / processes
- Separation of policy and mechanisms
  - Interfaces define what it does (policy)
  - Implementations define how it works (mechanisms)
- Straightforward, mechanical path to implementation

Three advantages of abstraction are:

- Faster to develop
- Easier to debug (prove correct) and
- Easier to change

Finite State Machine Rules

1. Simple structure: Input->Process->Output
2. Information is encoded by being in a state.
3. FSM controllers are very simple:
   e.g., output, wait, input, go to next state.
4. Complexity is captured in the state graph
5. There is a 1-1 mapping between state graph and the software implementation

Finite State Machine (FSM)

What is a Finite State Machine?

- Set of inputs, outputs, states and transitions
- State graph defines input/output relationship

What is a state?

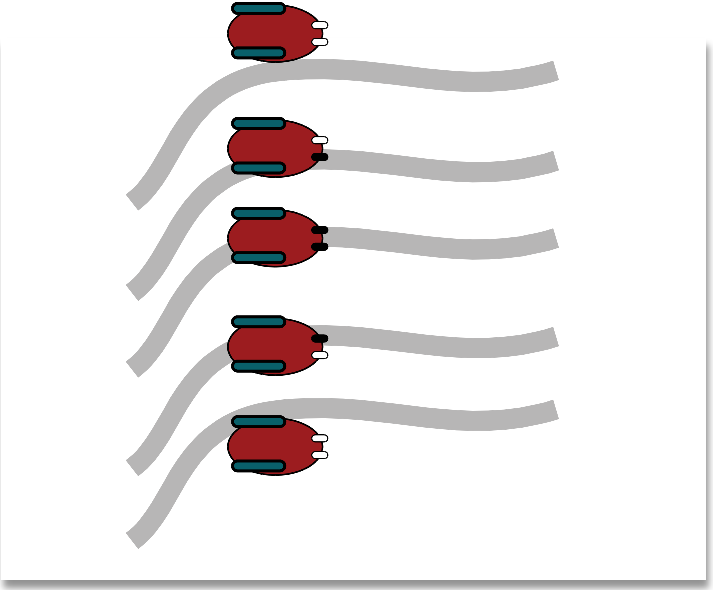
- Description of current conditions
- What you believe to be true

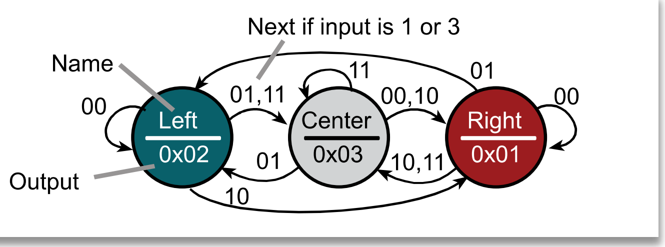
What is a state transition graph (or table)?

- Graphical interconnection between states

What is a controller?

- Software that inputs, outputs, changes state
- Accesses the state graph

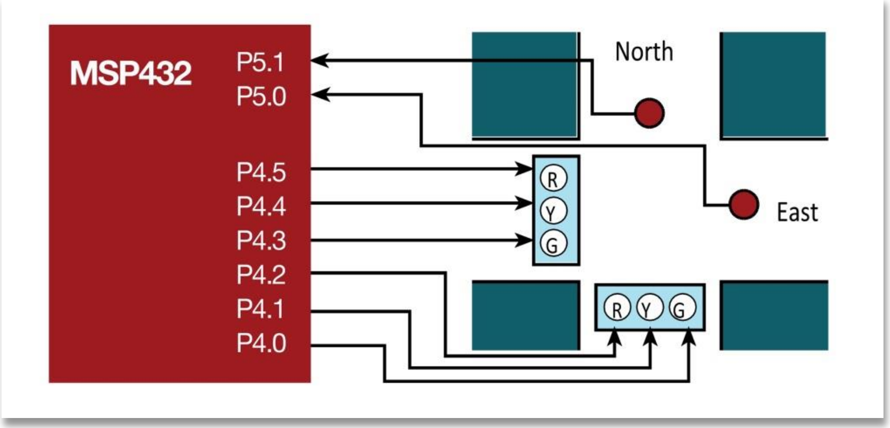


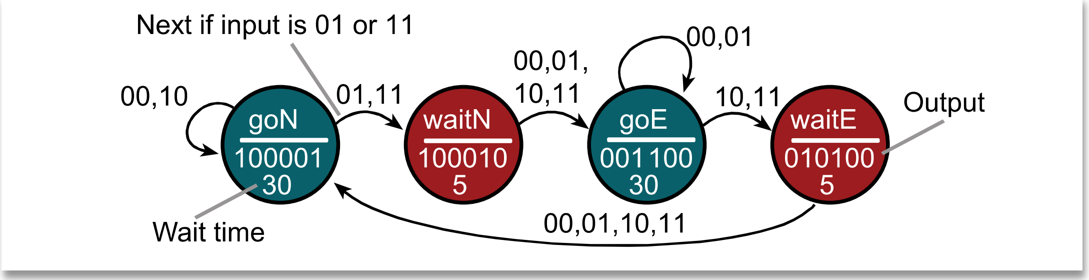


Finite State Machine (FSM)

What is a Finite State Machine (FSM)?

- Inputs (sensors)
- Outputs (actuators)
- Controller
- State transition graph



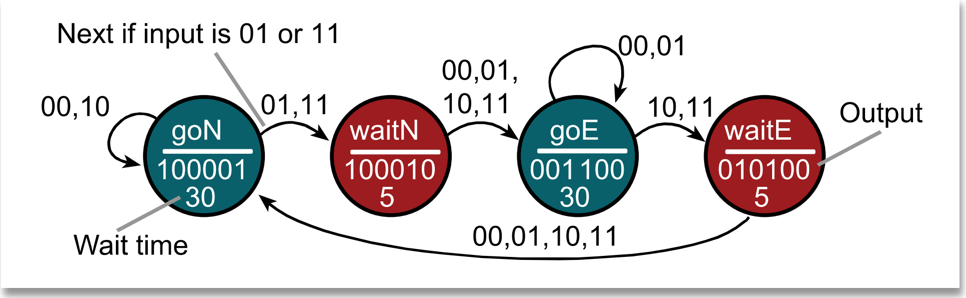


Controller loop

1. Output
2. Wait
3. Input
4. Next

Traffic Light Controller

State Transition Graph (STG)



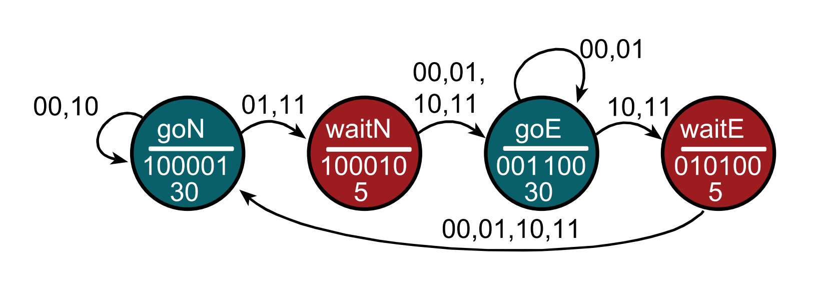
State Transition Table (STT)

State \ Input	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

FSM Data Structure in C (Index into array)

```c
const struct State {
  uint32_t Out;      // 6-bit output
  uint32_t Time;     // 1 ms units
  uint32_t Next[4]; // list of next states
};
typedef const struct State State_t;

#define goN   0
#define waitN 1
#define goE   2
#define waitE 3
State_t FSM[4] = {
 {0x21, 30000, {goN,waitN,goN,waitN}},
 {0x22,  5000, {goE,goE,goE,goE}},
 {0x0C, 30000, {goE,goE,waitE,waitE}},
 {0x14,  5000, {goN,goN,goN,goN}}
};
```



FSM Engine in C (Index into array)

```c
void main(void) {
  uint32_t cs;     // index of current state
  uint32_t input; // car sensor input
  Traffic_Init(); // initialize ports and timer
  cs = goN;        // initial state
  while(1){
// 1) set lights to current state's Out
    P4->OUT = (P4->OUT&~0x3F)|(FSM[cs].Out);
// 2) specified wait for this state
    Clock_Delay1ms(FSM[cs].Time);
// 3) input from car detectors
    input = (P5->IN&0x03);
// 4) next depends on state and input
    cs = FSM[cs].Next[input];
  }
}
```

Friendly

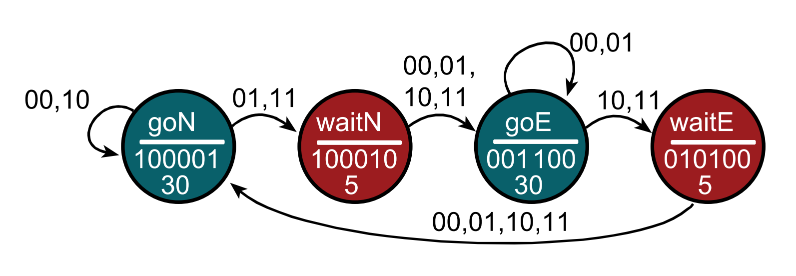
9 SysTick

Mask

FSM Data Structure in C (Pointer)

```
const struct State {
  uint32_t Out;      // 6-bit output
  uint32_t Time;     // 1 ms units
  const struct State *Next[4]; // next states
};
typedef const struct State State_t;

#define goN   &FSM[0]
#define waitN &FSM[1]
#define goE   &FSM[2]
#define waitE &FSM[3]
State_t FSM[4] = {
 {0x21,30000,{goN,waitN,goN,waitN}},
 {0x22, 5000,{goE,goE,goE,goE}},
 {0x0C,30000,{goE,goE,waitE,waitE}},
 {0x14, 5000,{goN,goN,goN,goN}}
};
```



FSM Engine in C (Pointer)

```
void main(void) {
  State_t *pt;     // pointer to current state
  uint32_t input;  // car sensor input
  Traffic_Init();  // initialize ports and timer
  pt = goN;        // initial state
  while(1){
// 1) set lights to current state's Out
    P4->OUT = (P4->OUT&~0x3F)|(pt->Out);
// 2) specified wait for this state
    Clock_Delay1ms(pt->Time);
// 3) input from car detectors
    input = (P5->IN&0x03);
// 4) next depends on state and input
    pt = pt->Next[input];
  }
}
```

Friendly

9 SysTick

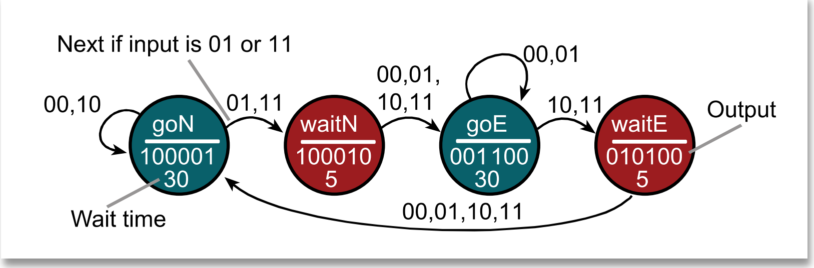
Mask

Mealy versus Moore

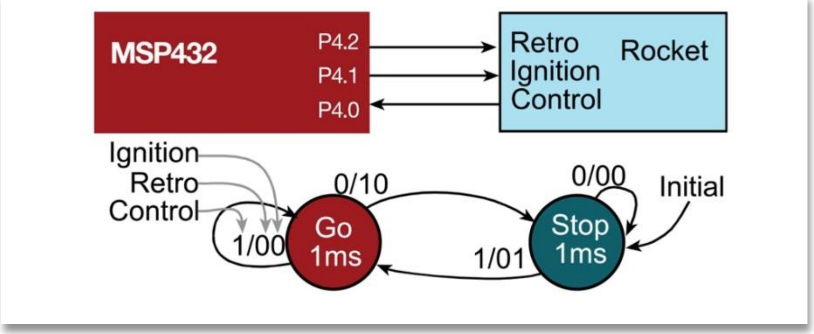
- Moore FSM
  - Output value depends on current state
  - Significance is the state
  - Input: when to change state
  - Output: how to be or what to do while in that state

- Mealy FSM
  - Output value depends on input and current state
  - Significance is the state transition
  - Input: when to change state
  - Output: how to change state

Inputs: Car sensors
Outputs: Traffic lights



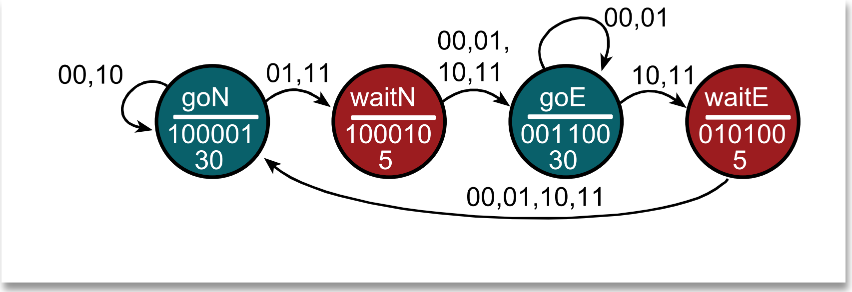
Inputs: Control
Outputs: Retro, Ignition



Summary

- Abstraction
  - Define a problem

    Concepts / principles / processes
  - Separation of policy and mechanisms
    - Interfaces define what it does (policy)
    - Implementations define how it works (mechanisms)
- Finite State Machines
  - Inputs (sensors)
  - Outputs (actuators)
  - Controller
  - State graph
    - States
    - Implementations define how it works (mechanisms)



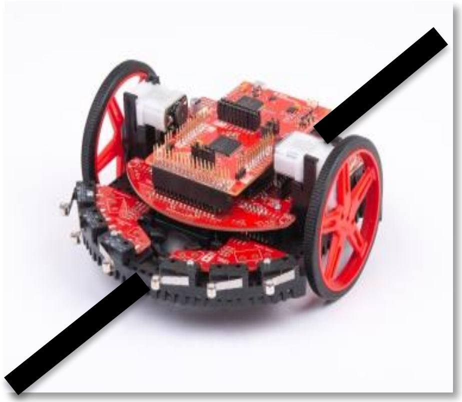
Module 7

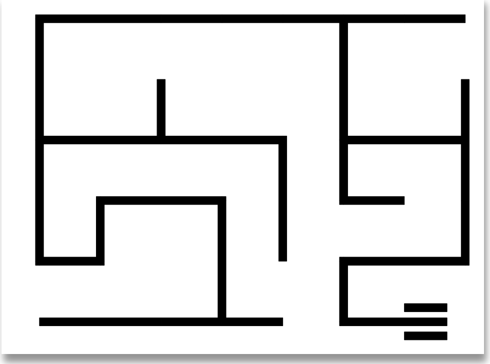
Lecture: Finite State Machines – Line Follower

Finite State Machine Example

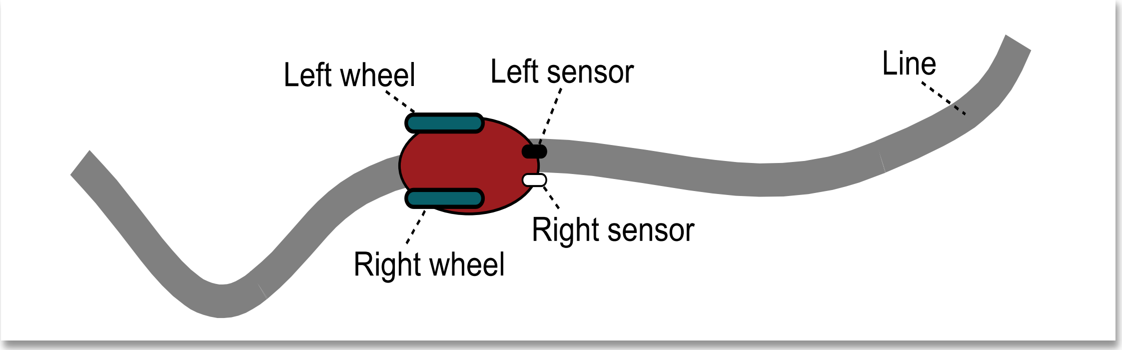
You will learn in this lecture

- Design controller for a line tracking robot
  - Two sensor inputs
  - Two motor outputs





Simple Line Tracker



Two Sensors

1,1 on line

1,0 off to the right

0,1 off to the left

0,0 lost

Two Motors

1,1 go straight

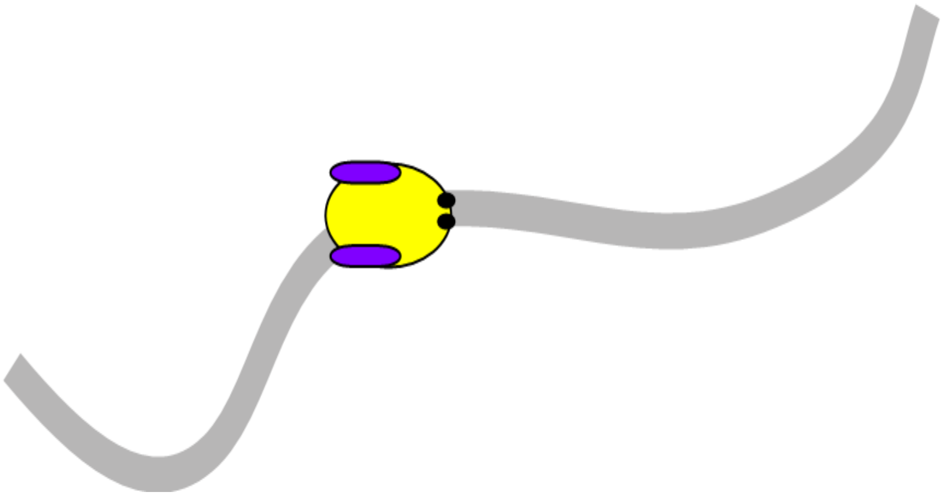
1,0 turn right

0,1 turn left

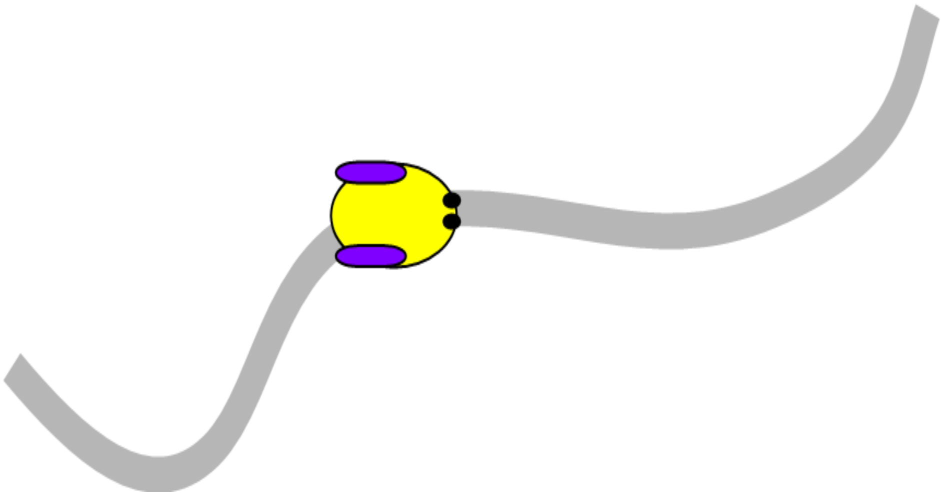
Left, Right

Left, Right

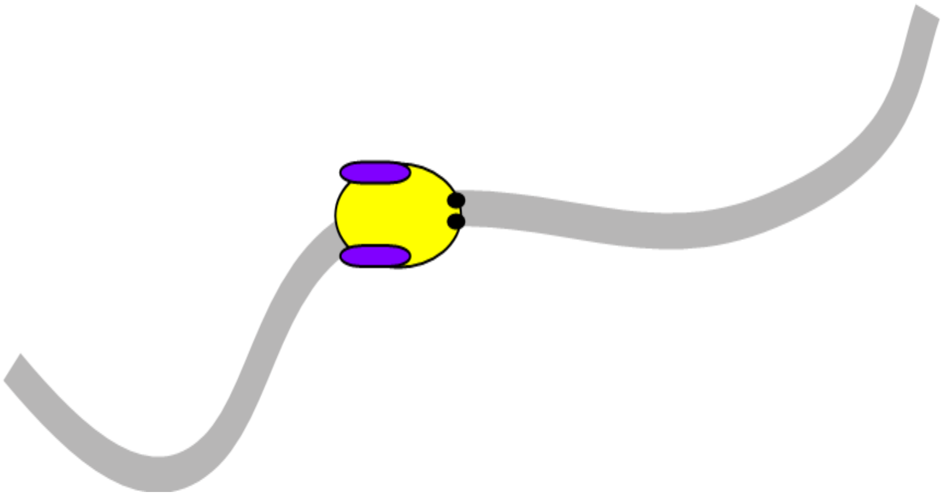
Strategy



Strategy



Strategy



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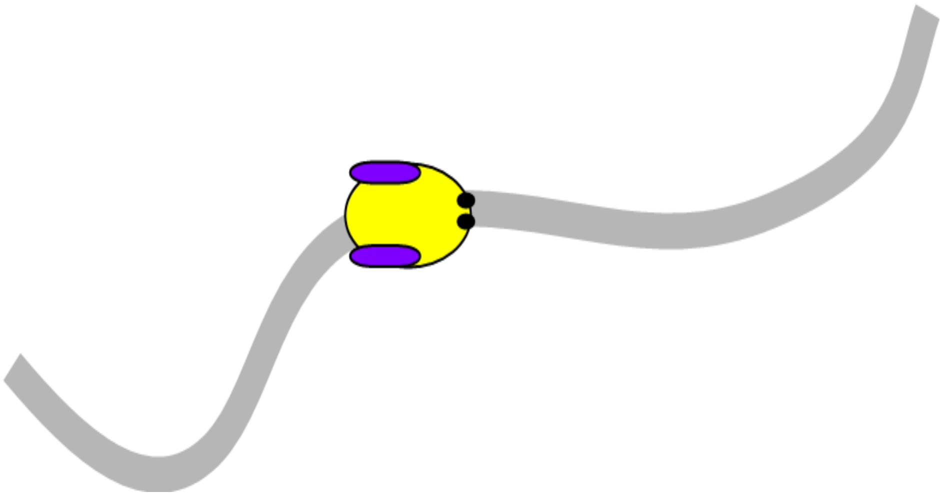

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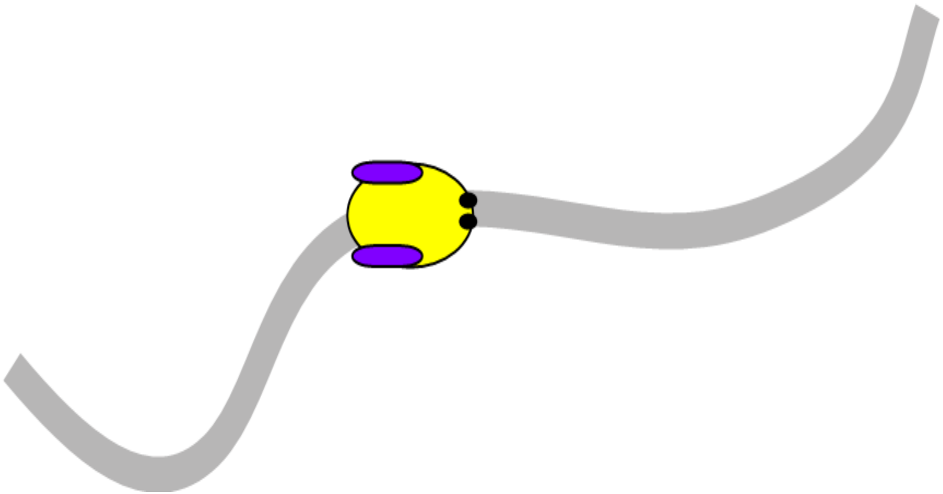

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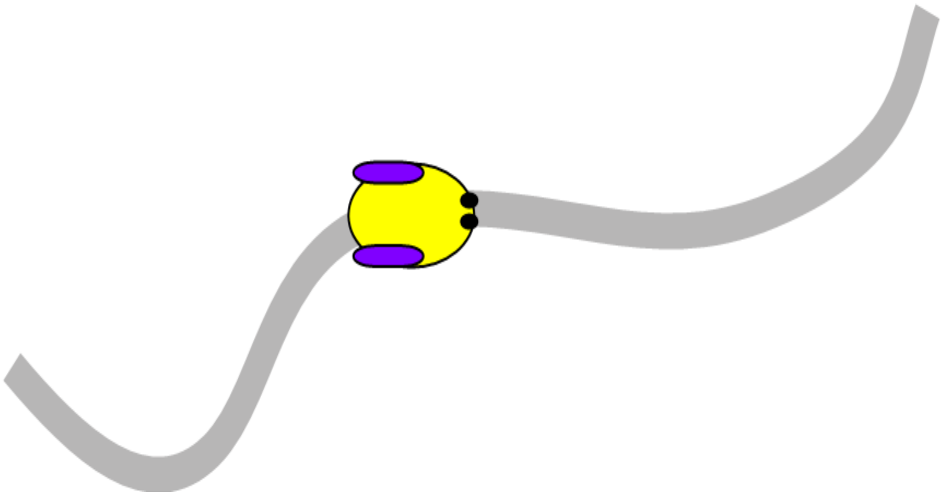
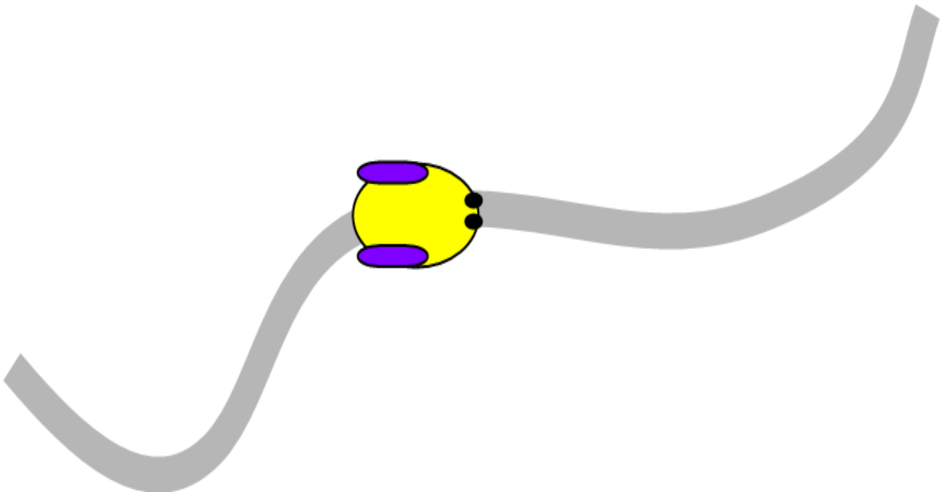
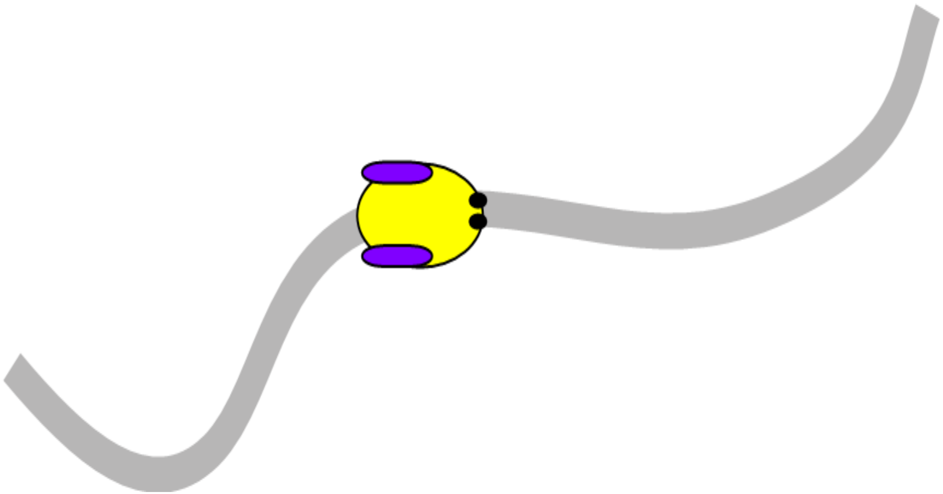


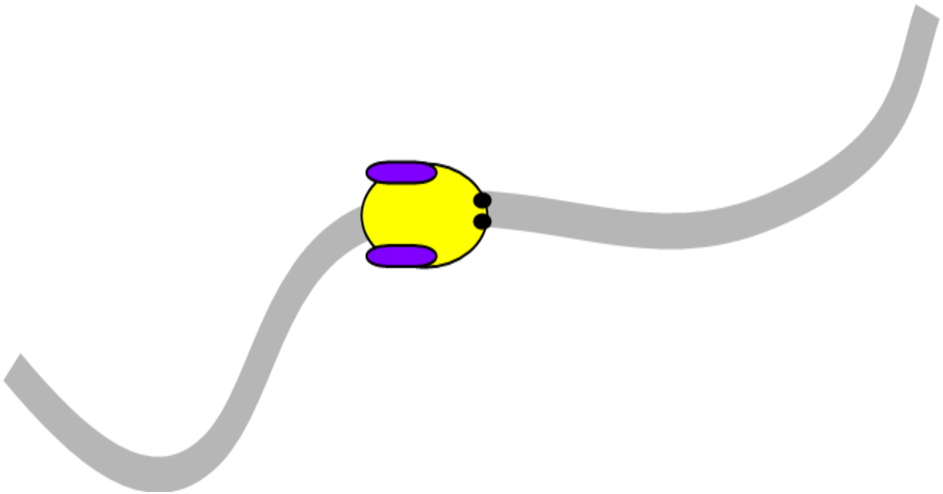
Strategy



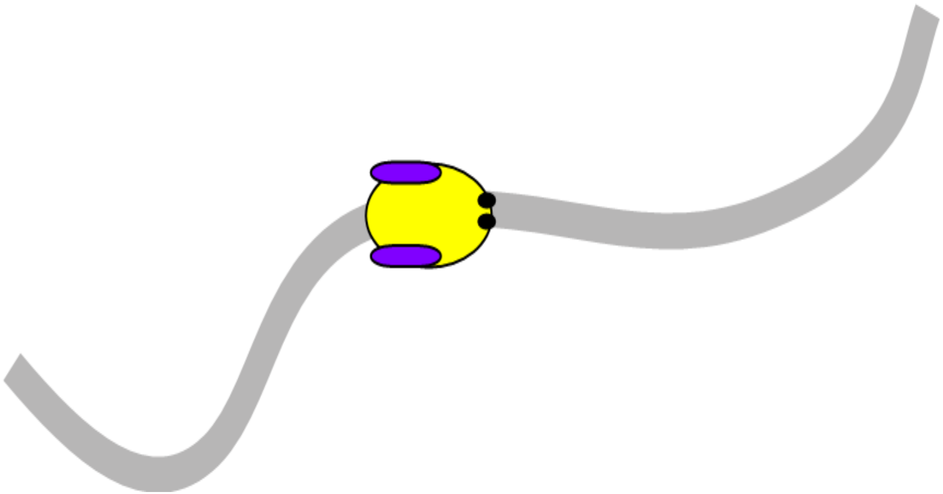
Strategy



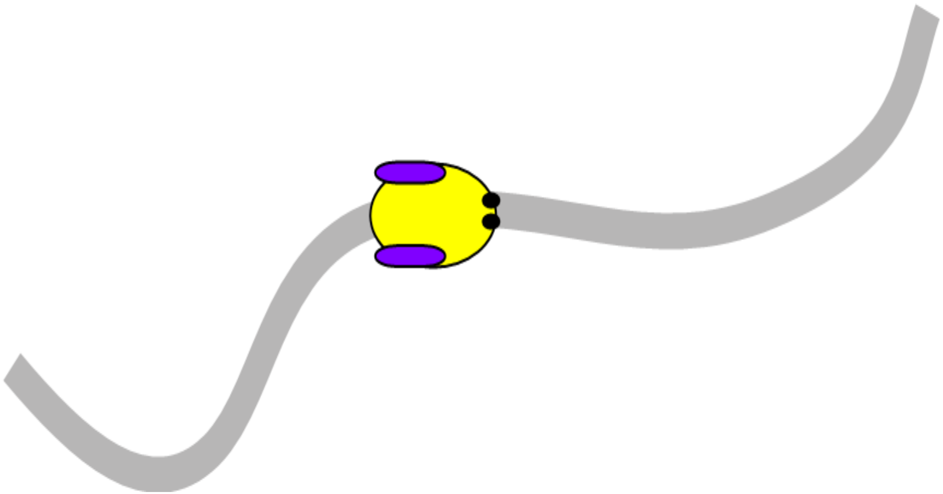
Strategy



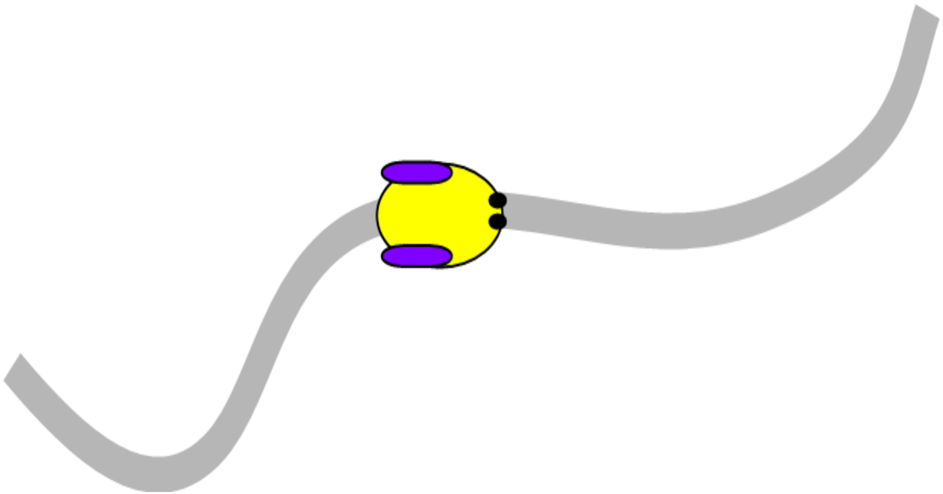
Strategy



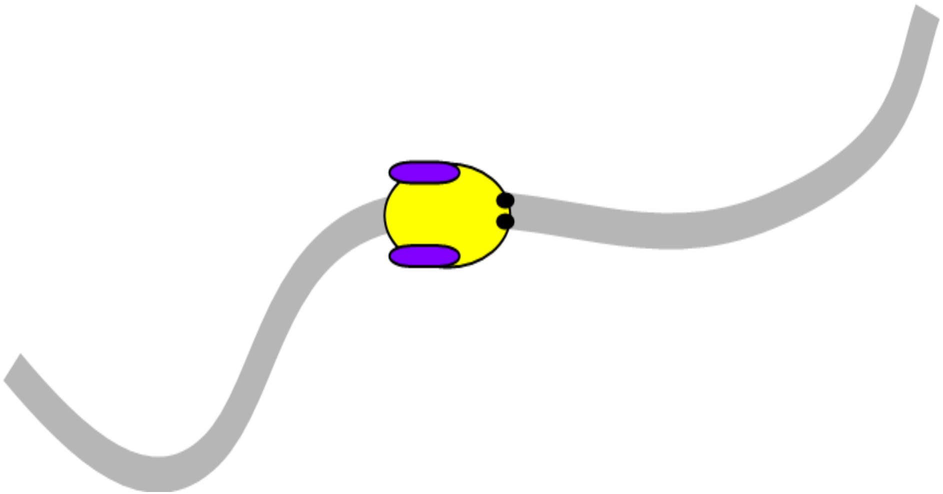
Strategy



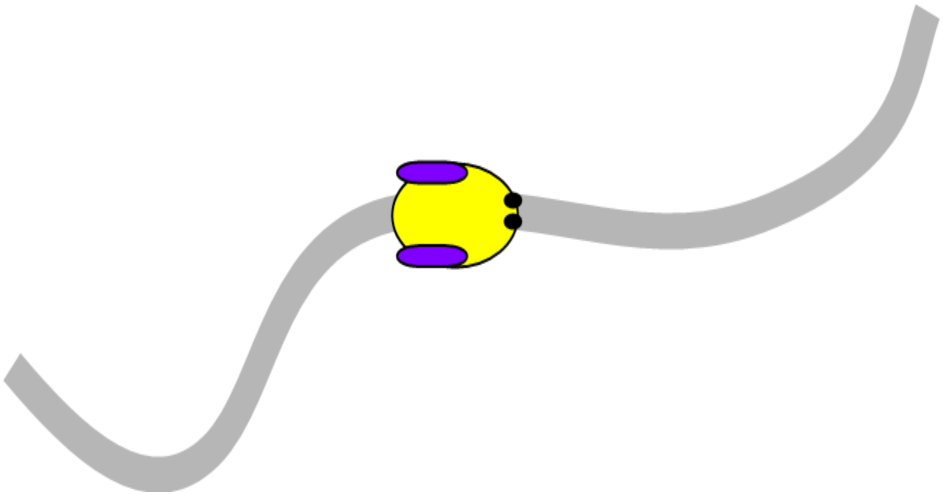
Strategy



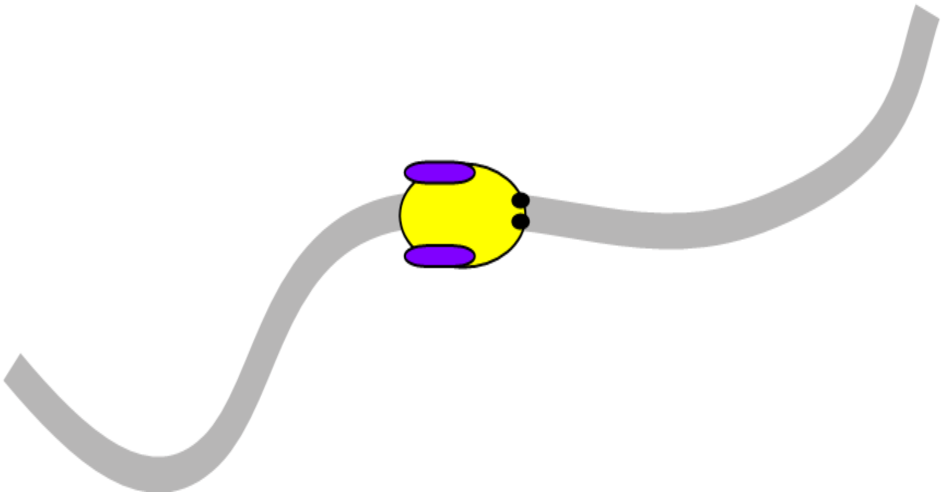
Strategy



Strategy



Strategy



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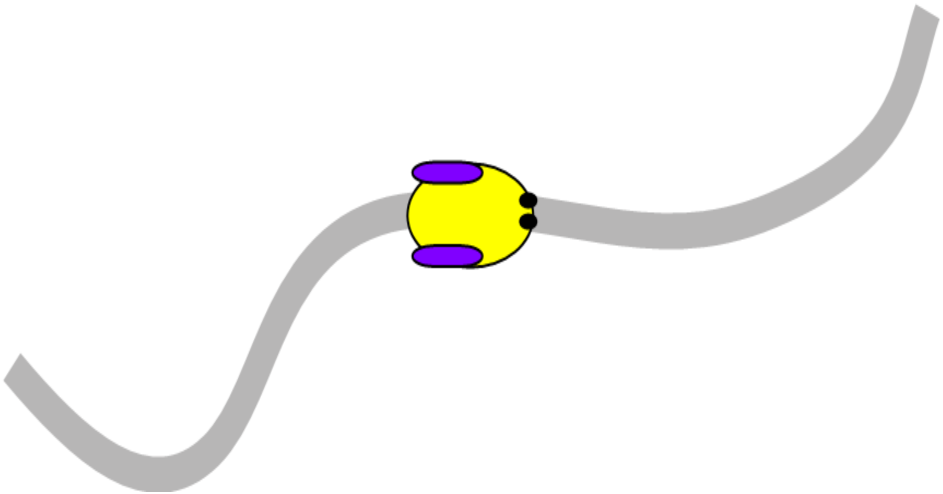

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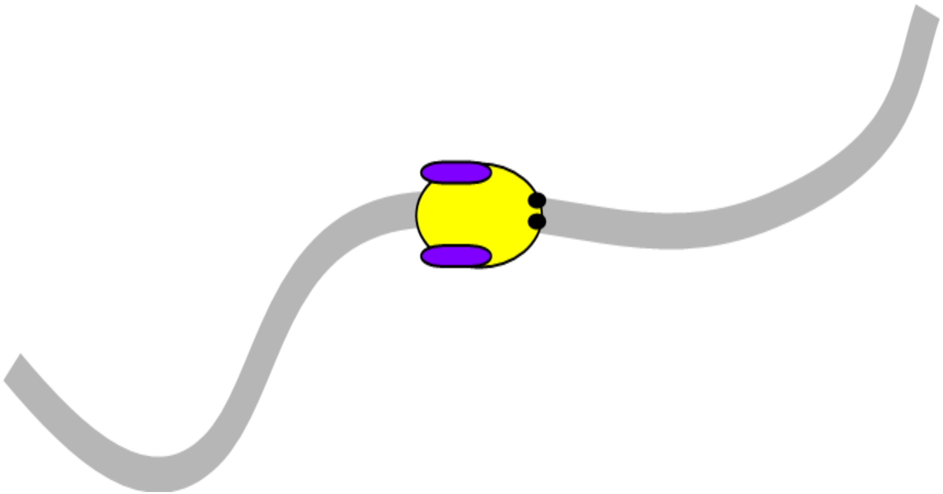

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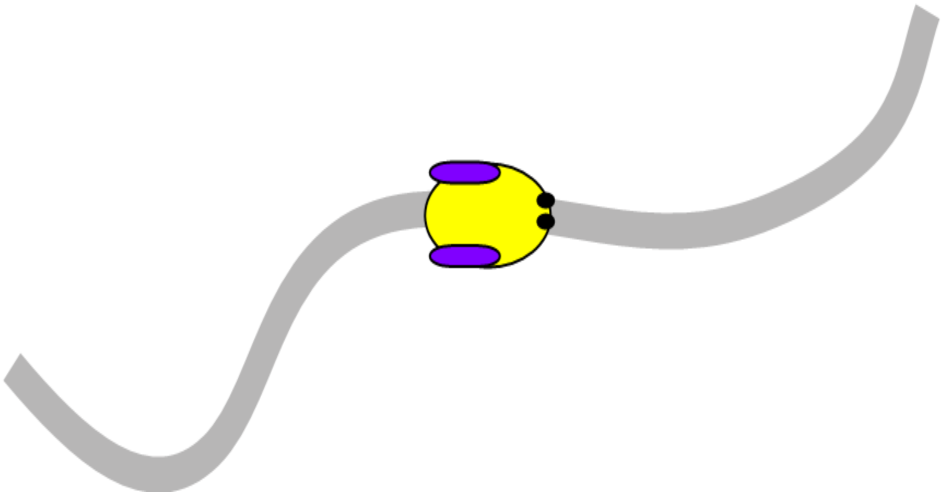

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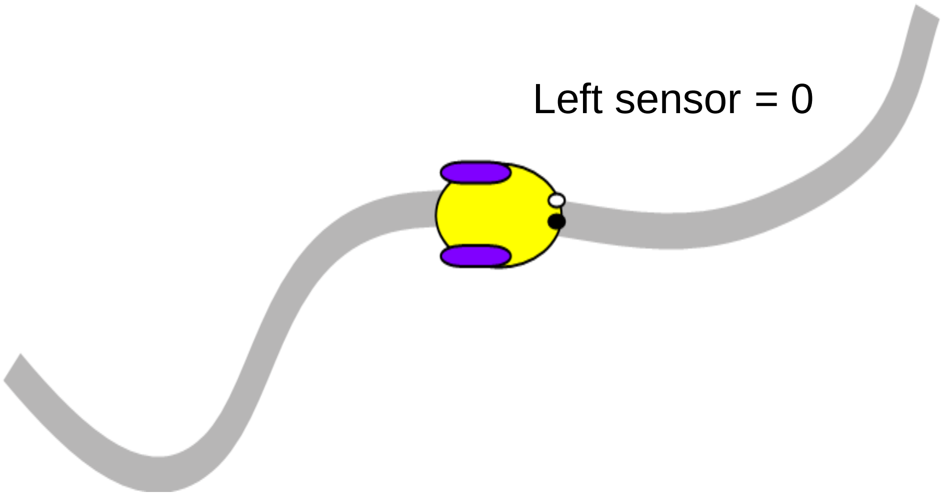
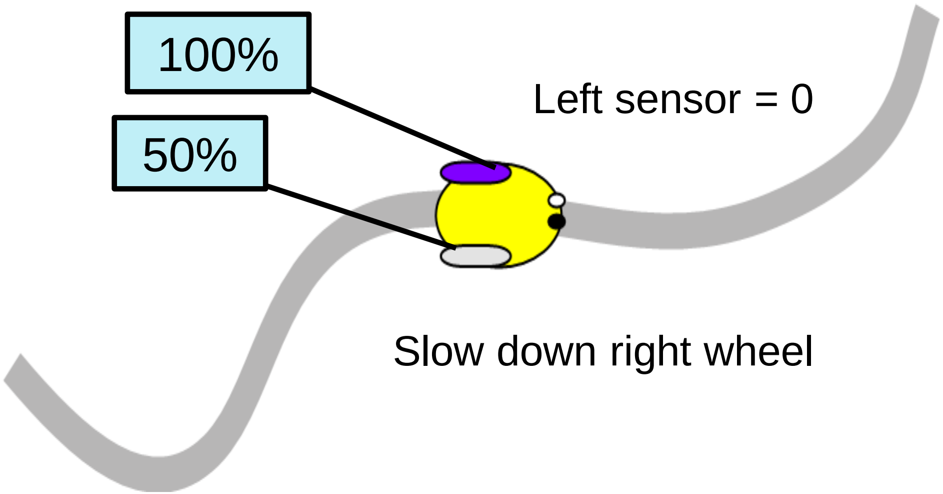
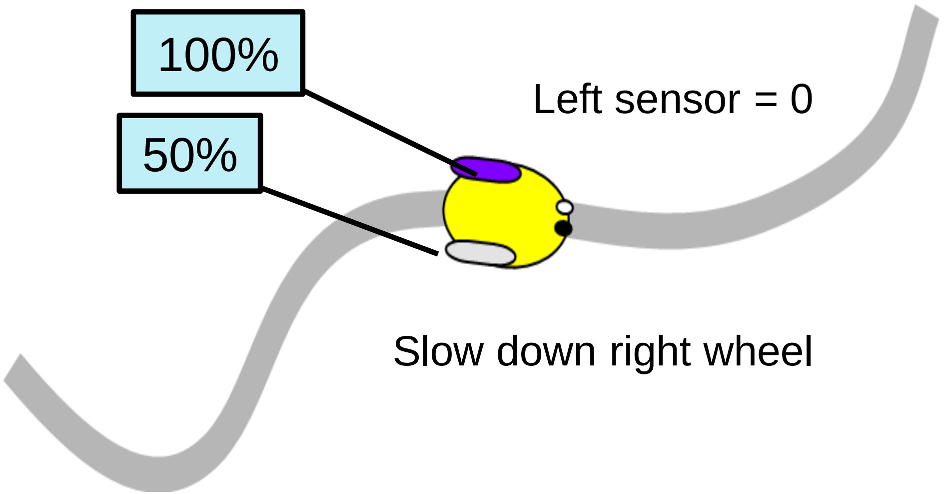


Strategy



Strategy



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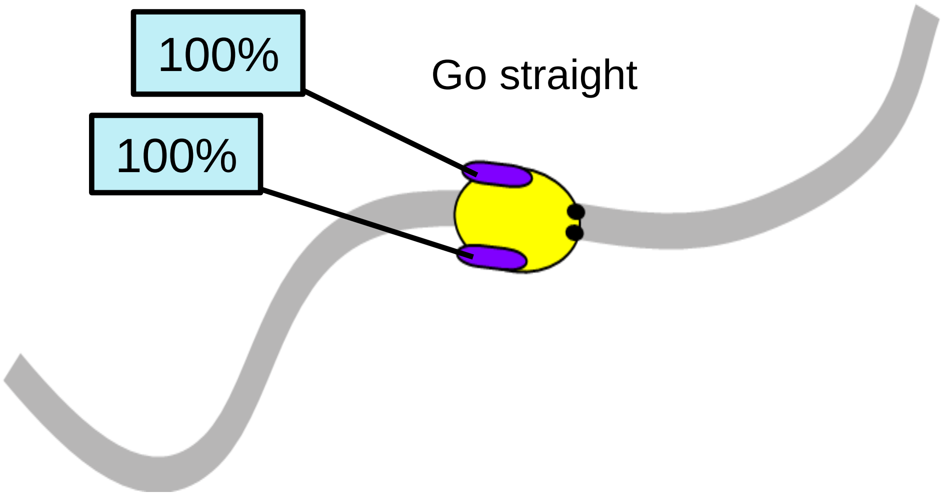
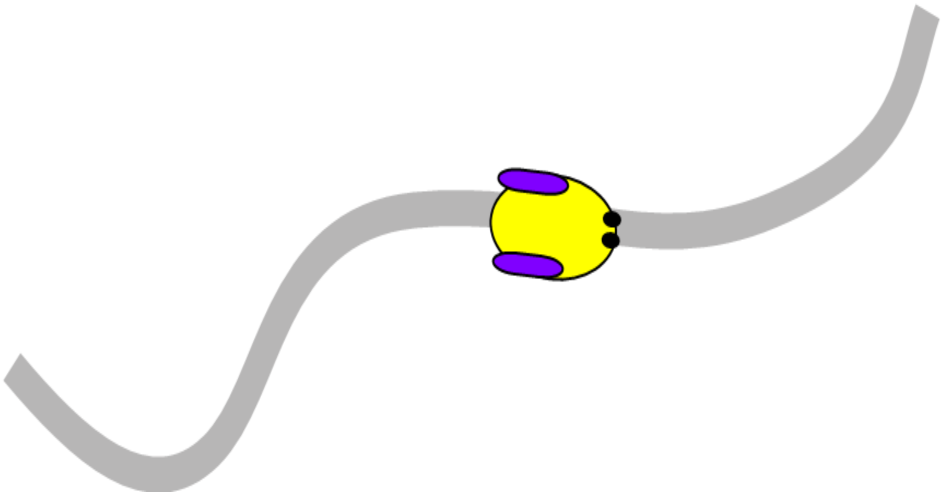
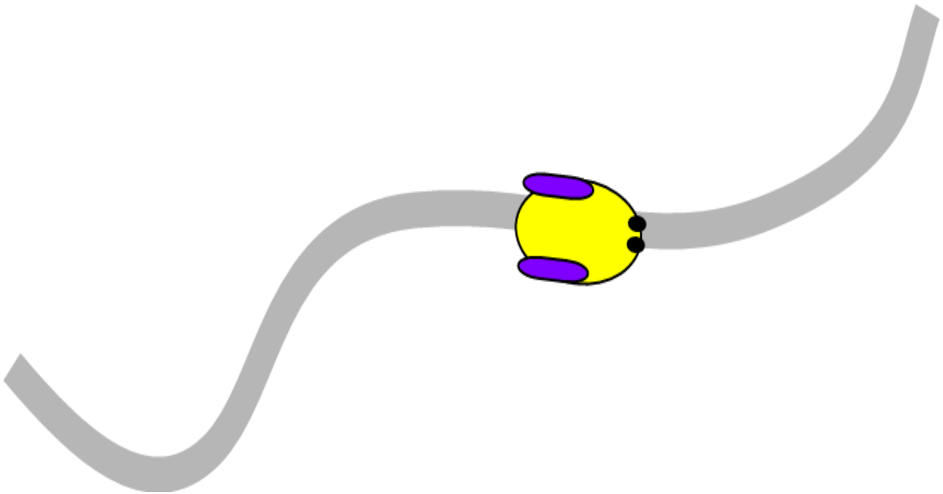
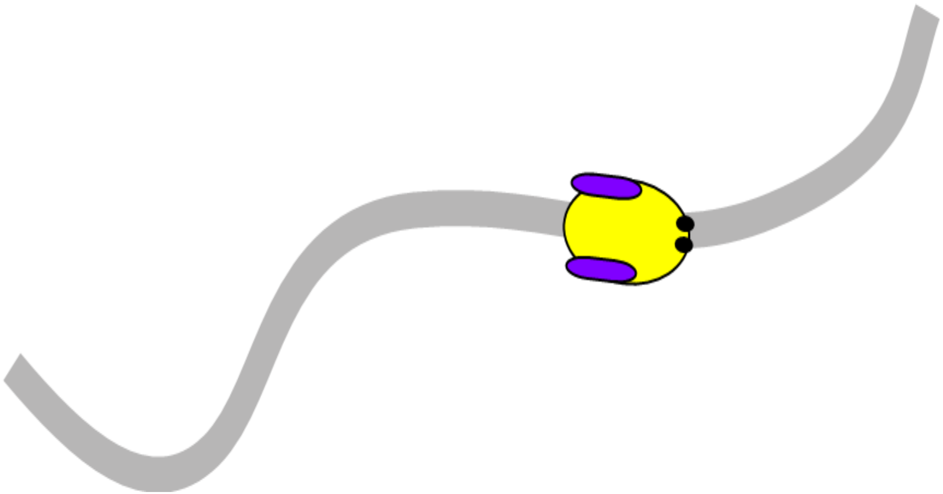


Strategy

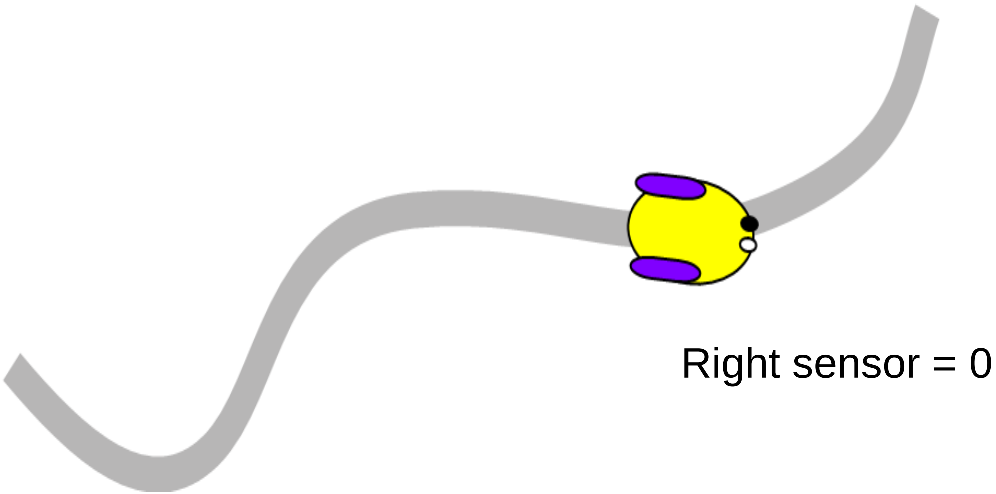




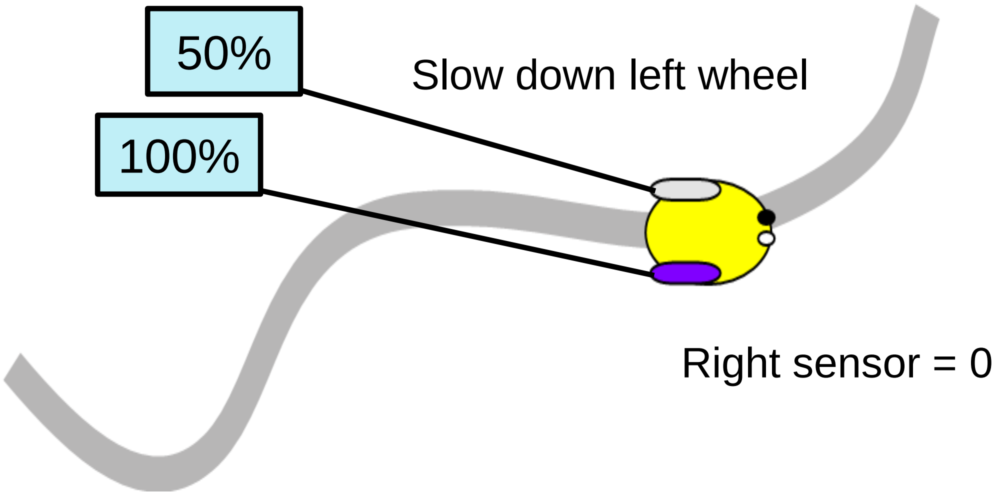
Strategy



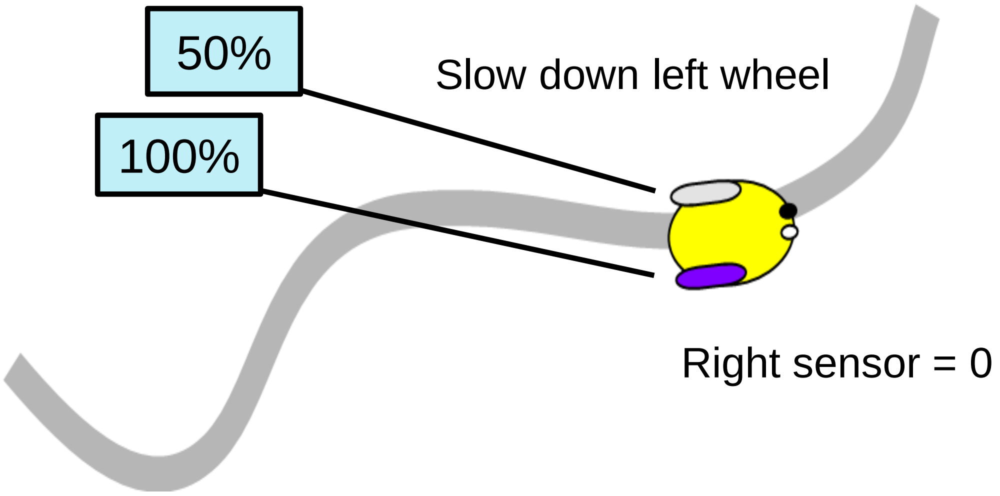
Strategy



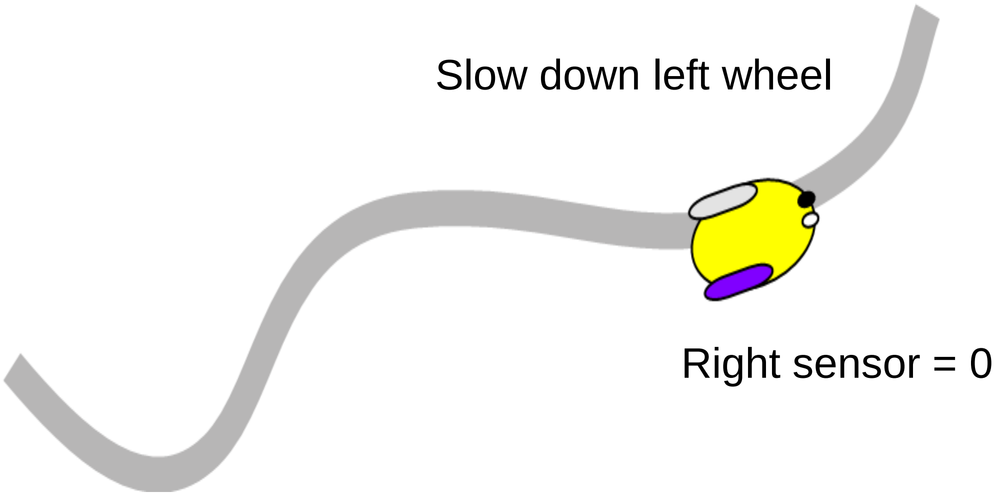
Strategy



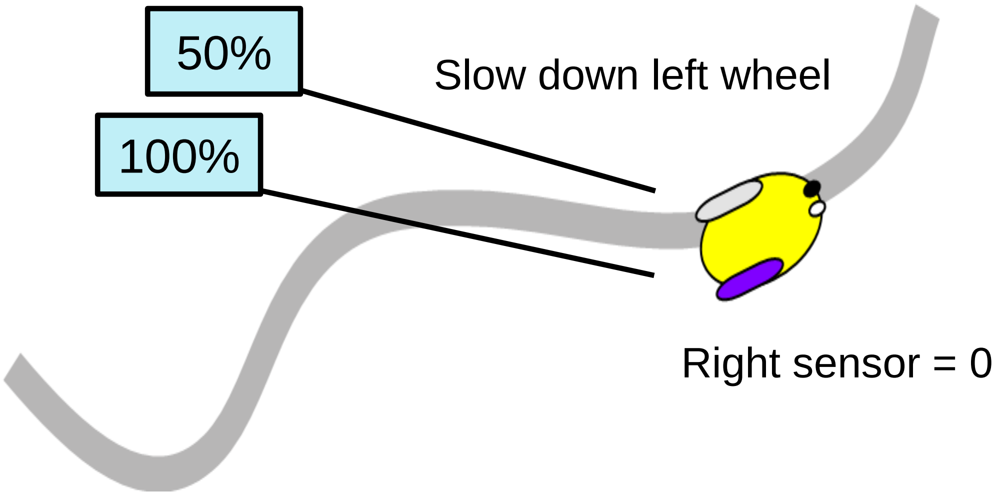
Strategy



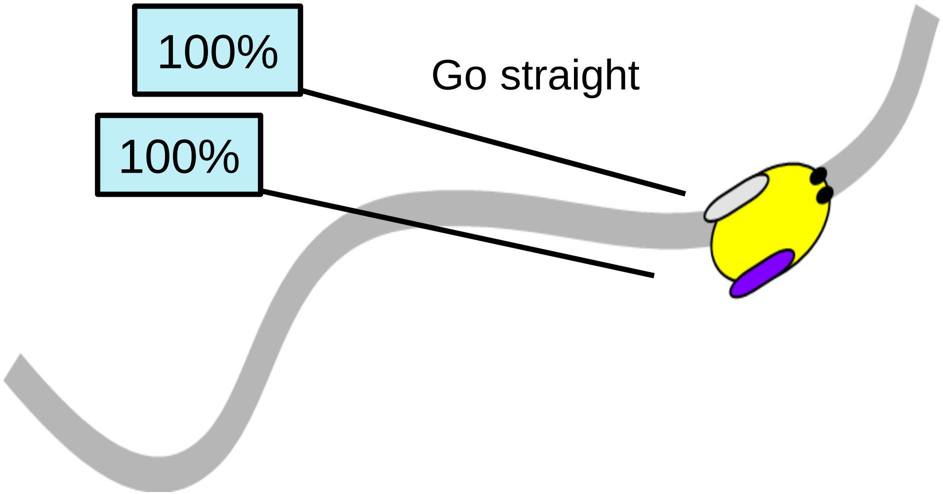
Strategy



Strategy



Strategy

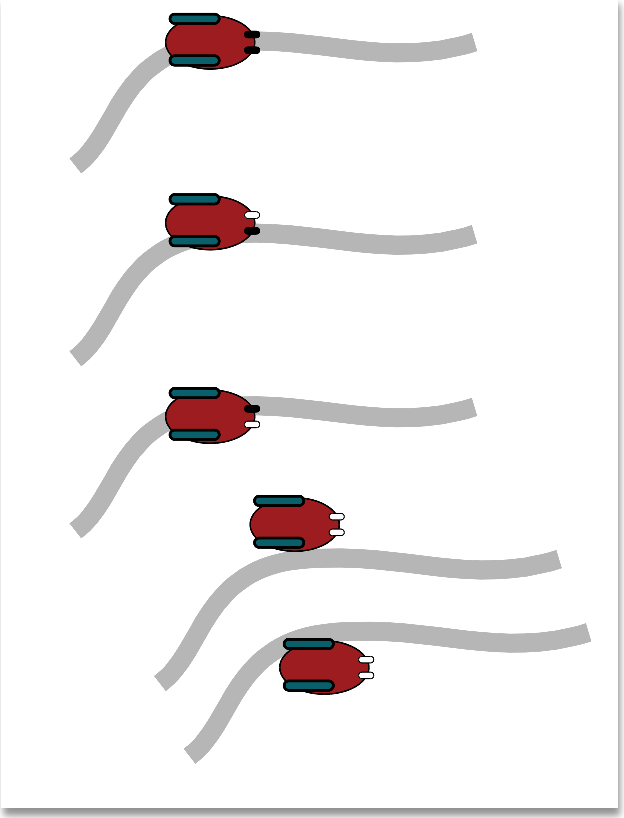


Strategy

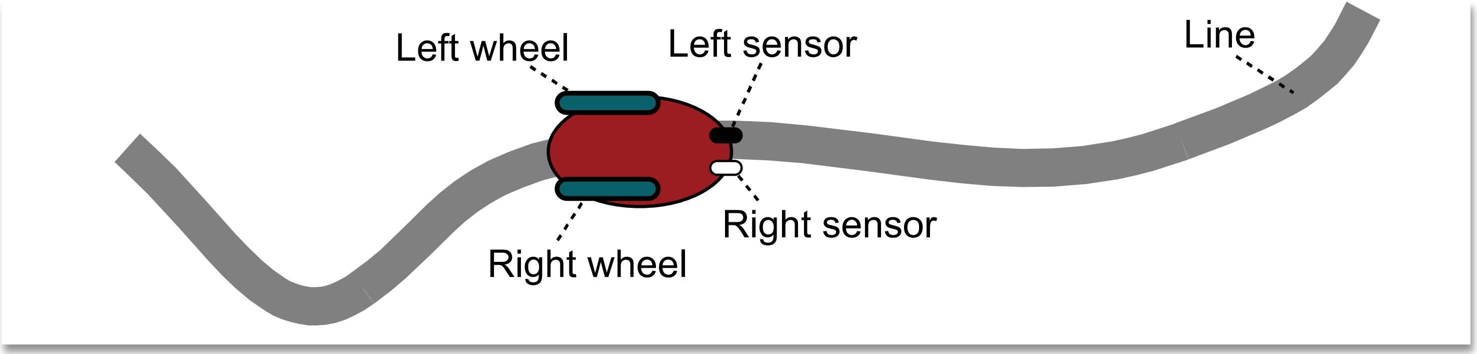
States

State	Motor
Center	1,1
Left	0,1
Right	1,0

Motors respond in 100ms,
so run FSM every 50ms



Simple Line Tracker



Two Sensors

1,1 on line

0,1 off to the left

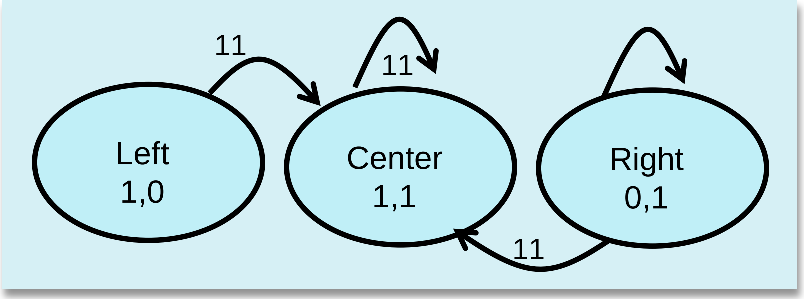
1,0 off to the right

0,0 lost

Left, Right

State Transition Table

State	Motor	In=0,0	In=0,1	In=1,0	In=1,1
Center	1,1				Center
Left	1,0				Center
Right	0,1				Center

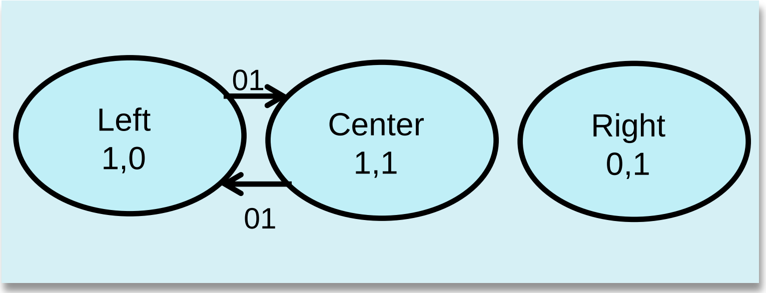



```
State_t  fsm[3]={
  {0x03, 1, {                  Center   }},
  {0x02, 1, {                  Center   }},
  {0x01, 1, {                  Center   }}
};
```

On the line, so go straight

State Transition Table

State	Motor	In=0,0	In=0,1	In=1,0	In=1,1
Center	1,1		Left		
Left	1,0		Center		
Right	0,1				

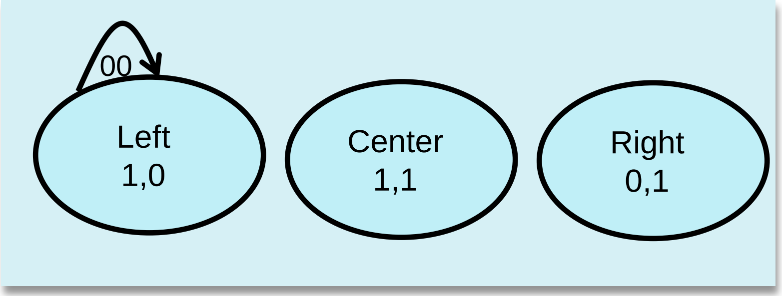



```
State_t  fsm[3]={
  {0x03, 1, {          Left,                 }},
  {0x02, 1, {        Center,                 }},
  {0x01, 1, {                                }}
};
```

Off to left, so toggle right motor, turn right

State Transition Table

State	Motor	In=0,0	In=0,1	In=1,0	In=1,1
Center	1,1				
Left	1,0	Left			
Right	0,1				

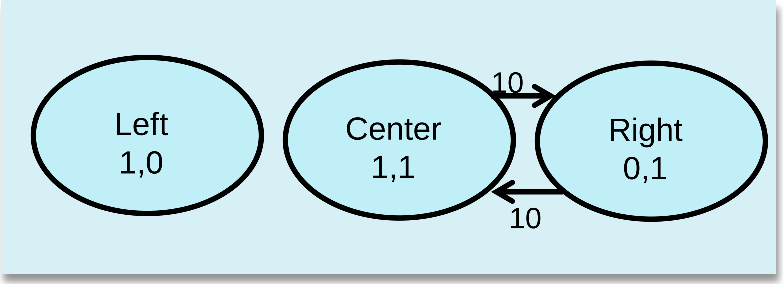



```
State_t  fsm[3]={
  {0x03, 1, {                               Center  }},
  {0x02, 1, {  Left,                        Center  }},
  {0x01, 1, {                               Center  }}
};
```

Way off to left, so stop right motor, turn right

State Transition Table

State	Motor	In=0,0	In=0,1	In=1,0	In=1,1
Center	1,1			Right	
Left	1,0				
Right	0,1			Center	

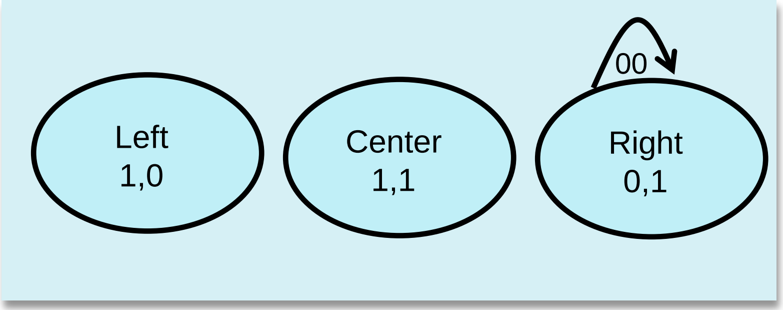



```
State_t  fsm[3]={
  {0x03, 1, {          Right          }},
  {0x02, 1, {                         }},
  {0x01, 1, {          Center         }}
};
```

Off to right, so toggle left motor, turn left

State Transition Table

State	Motor	In=0,0	In=0,1	In=1,0	In=1,1
Center	1,1				
Left	1,0				
Right	0,1	Right			

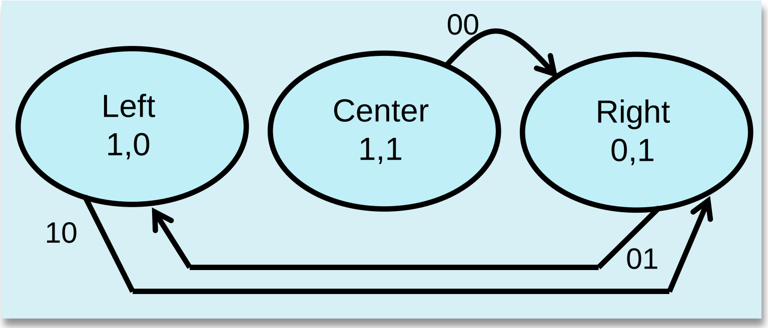



```
State_t  fsm[3]={
  {0x03, 1, {                                   }},
  {0x02, 1, {                                   }},
  {0x01, 1, {  Right,                           }}
};
```

Way off to right, so stop left motor, turn left

State Transition Table

State	Motor	In=0,0	In=0,1	In=1,0	In=1,1
Center	1,1	Right			
Left	1,0			Right	
Right	0,1		Left		

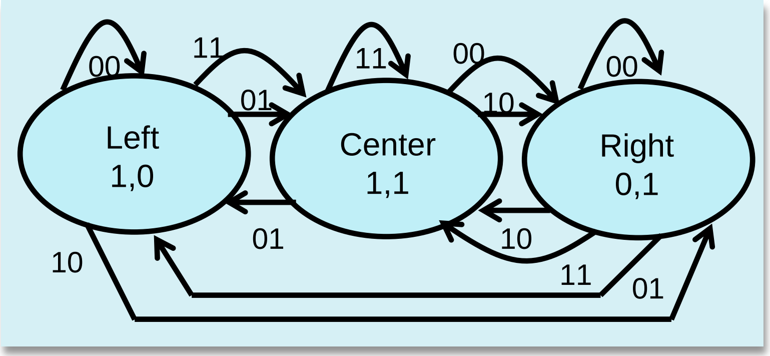



```
State_t  fsm[3]={
  {0x03, 1, {  Right,                    }},
  {0x02, 1, {              Right         }},
  {0x01, 1, {        Left,               }}
};
```

Weird things that shouldn't happen

State Transition Table

State	Motor	In=0,0	In=0,1	In=1,0	In=1,1
Center	1,1	Right	Left	Right	Center
Left	1,0	Left	Center	Right	Center
Right	0,1	Right	Left	Center	Center



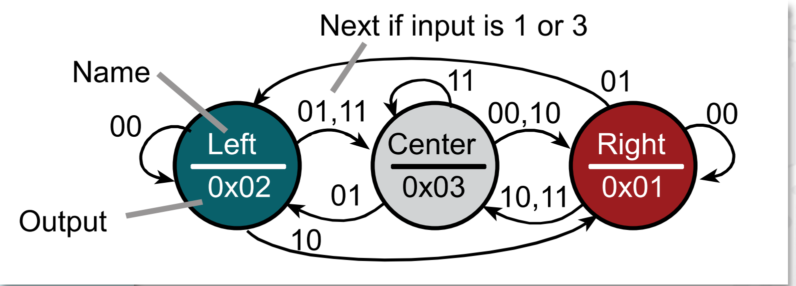

```
State_t  fsm[3]={
  {0x03, 1, {Right, Left, Right,    Center }},
  {0x02, 1, {Left, Center, Right,  Center }},
  {0x01, 1, {Right, Left, Center,  Center }}
};
```

Motors respond in 100ms, so run FSM every 10ms

Robot Implementation

```
struct State {
  uint32_t out;                // 2-bit output
  uint32_t delay;              // time to delay in 1ms
  const struct State *next[4]; // Next if 2-bit input is 0-3
};
typedef const struct State State_t;

#define Center &fsm[0]
#define Left   &fsm[1]
#define Right  &fsm[2]
State_t fsm[3]={
  {0x03, 50, { Right, Left,   Right,  Center }},  // Center
  {0x02, 50, { Left,  Center, Right,  Center }},  // Left
  {0x01, 50, { Right, Left,   Center, Center }}   // Right
};
State_t *Spt;      // pointer to the current state
uint32_t Input;    // 00=off, 01=right, 10=left, 11=on
uint32_t Output;   // 3=straight, 2=turn right, 1=turn left
int main(void){
  Clock_Init48MHz();
  Motor_Stop();  // initialize DC motors
  Spt = Center;
  while(1){
    Output = Spt->out;                 // set output from FSM
    Motor_Output(Output);              // do output to two motors
    Clock_Delay1ms(Spt->delay);        // wait
    Input = Reflectance_Center(1000); // read sensors
    Spt = Spt->next[Input];            // next depends on input and state
  }
}
```



12 Motors

13 Timers

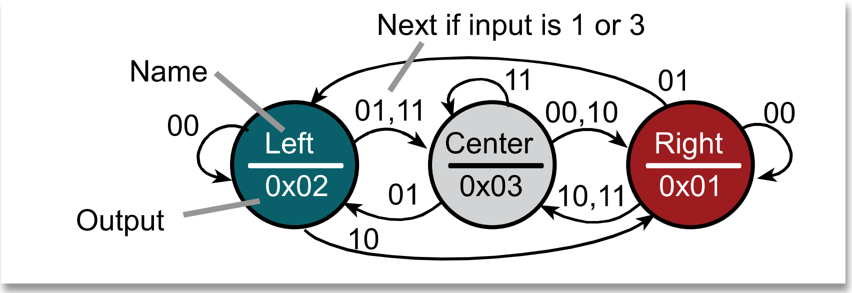
9 SysTick

6 GPIO

Summary

- Abstraction
  - Define a problem

    Concepts / principles / processes
  - Separation of policy and mechanisms
    - Interfaces define what it does (policy)
    - Implementations define how it works (mechanisms)
- Finite State Machines
  - Inputs (sensors)
  - Outputs (actuators)
  - Controller
  - State graph
    - States
    - Implementations define how it works (mechanisms)



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