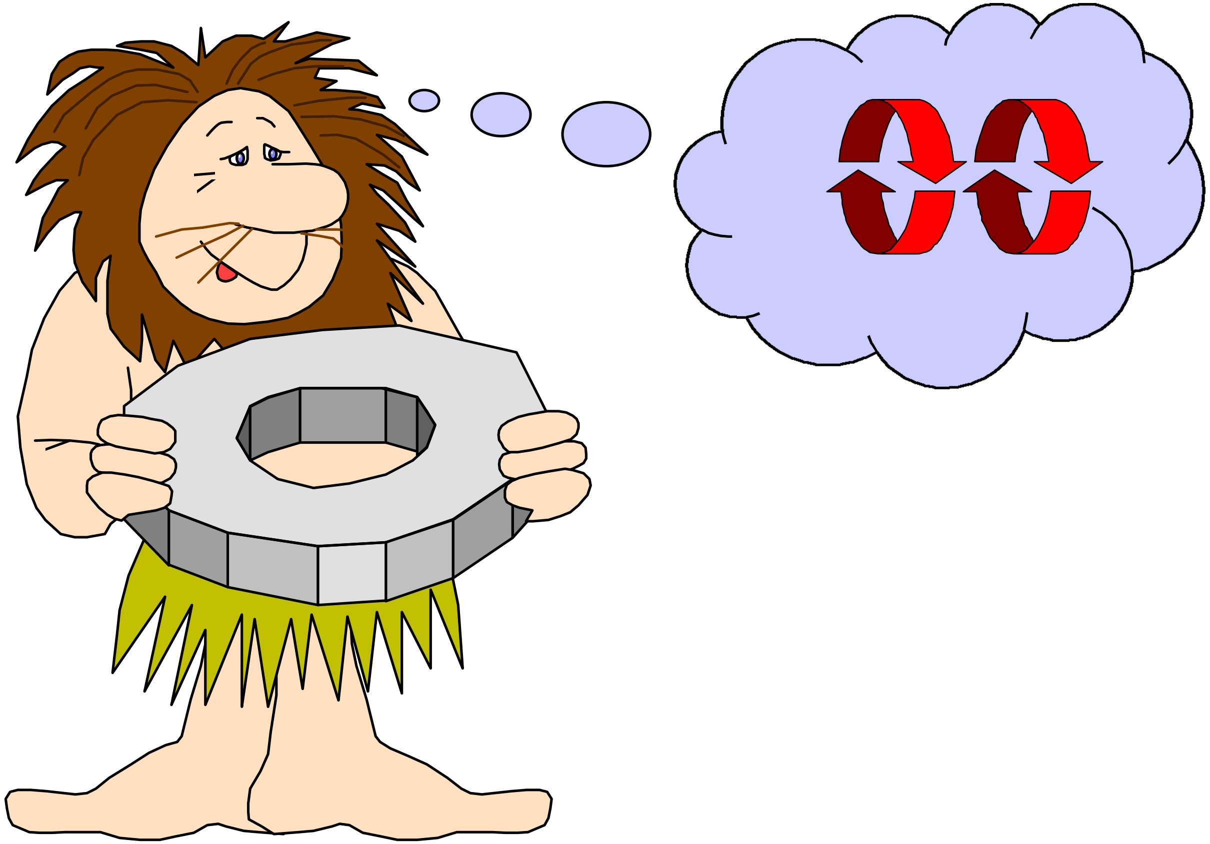
Chapter 8

Model-Based Design



Deadlock

Concepts: **design process:**

requirements to **models** to implementations

Models: check properties of interest:

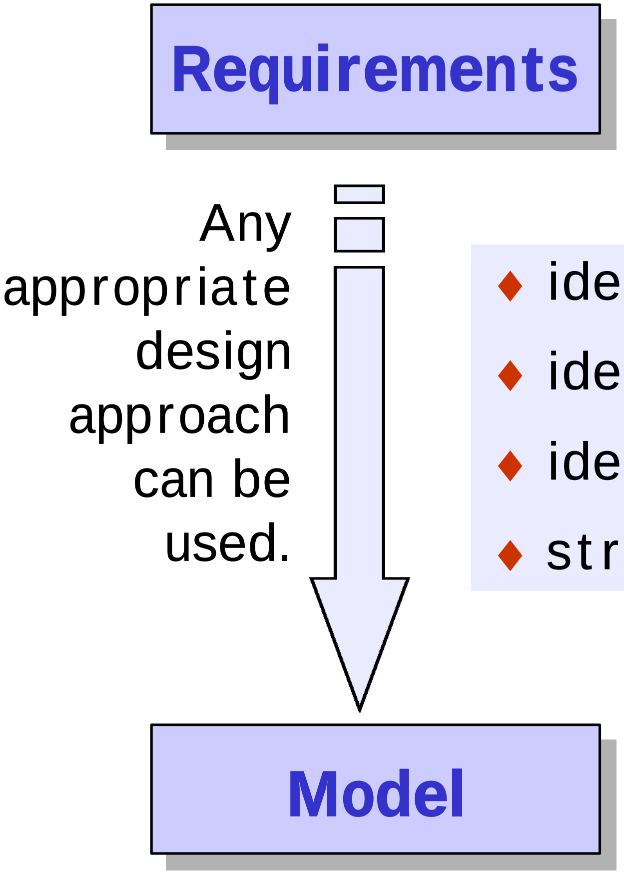
- safety on the appropriate (sub)system
- progress on the overall system

Practice: model interpretation - to infer actual system behavior

threads and monitors

Aim: rigorous design process.

8.1 from requirements to models



Requirements

- ♦ goals of the system
- ♦ scenarios (Use Case models)
- ♦ properties of interest

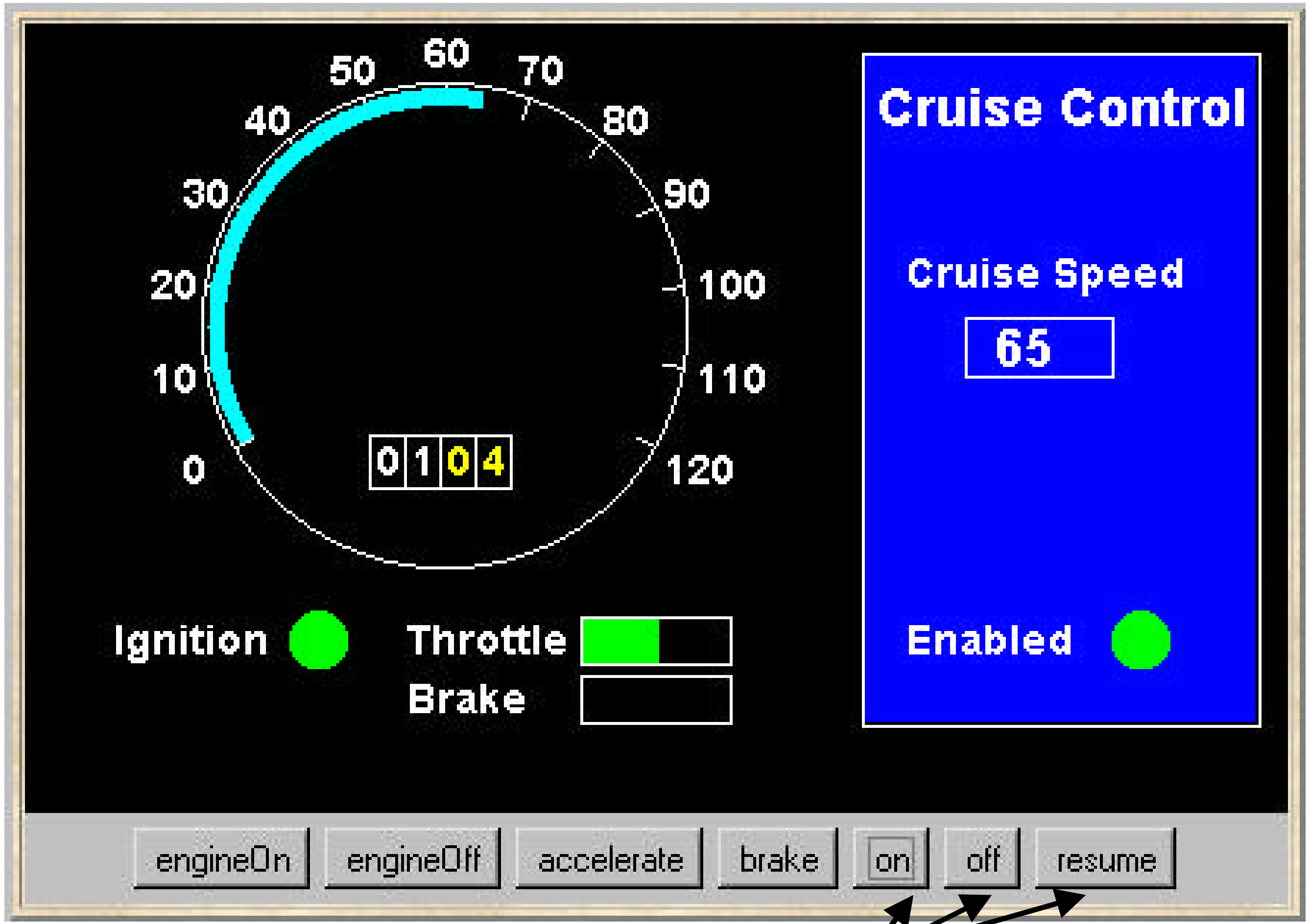
Any appropriate design approach can be used.

- ♦ identify the main events, actions, and interactions
- ♦ identify and define the main processes
- ♦ identify and define the properties of interest
- ♦ structure the processes into an **architecture**

Model

- ♦ check traces of interest
- ♦ check properties of interest

a Cruise Control System - requirements



buttons

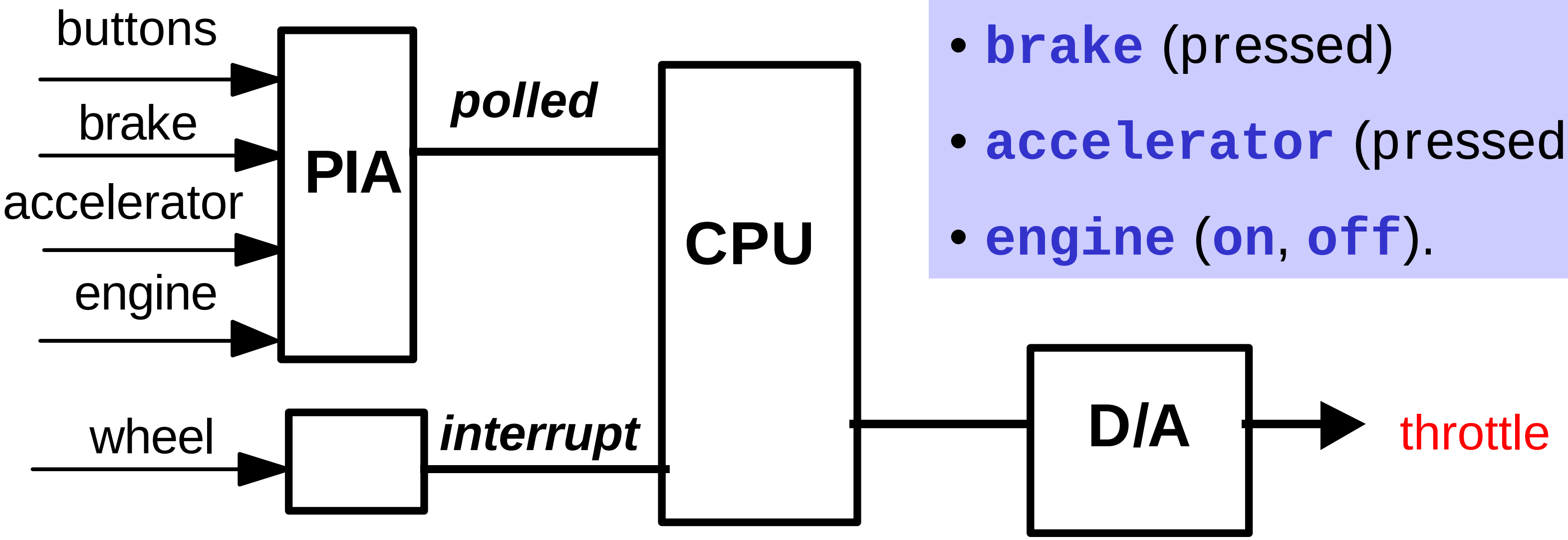
When the car ignition is switched on and the **on** button is pressed, the current speed is recorded and the system is enabled: *it maintains the speed of the car at the recorded setting*.

Pressing the brake, accelerator or **off** button disables the system. Pressing **resume** or on re-enables the system.

a Cruise Control System - hardware

Parallel Interface Adapter (PIA) is polled every 100msec. It records the actions of the sensors:

- buttons (**`on`**, **`off`**, **`resume`**)
- **`brake`** (pressed)
- **`accelerator`** (pressed)
- **`engine`** (**`on`**, **`off`**).

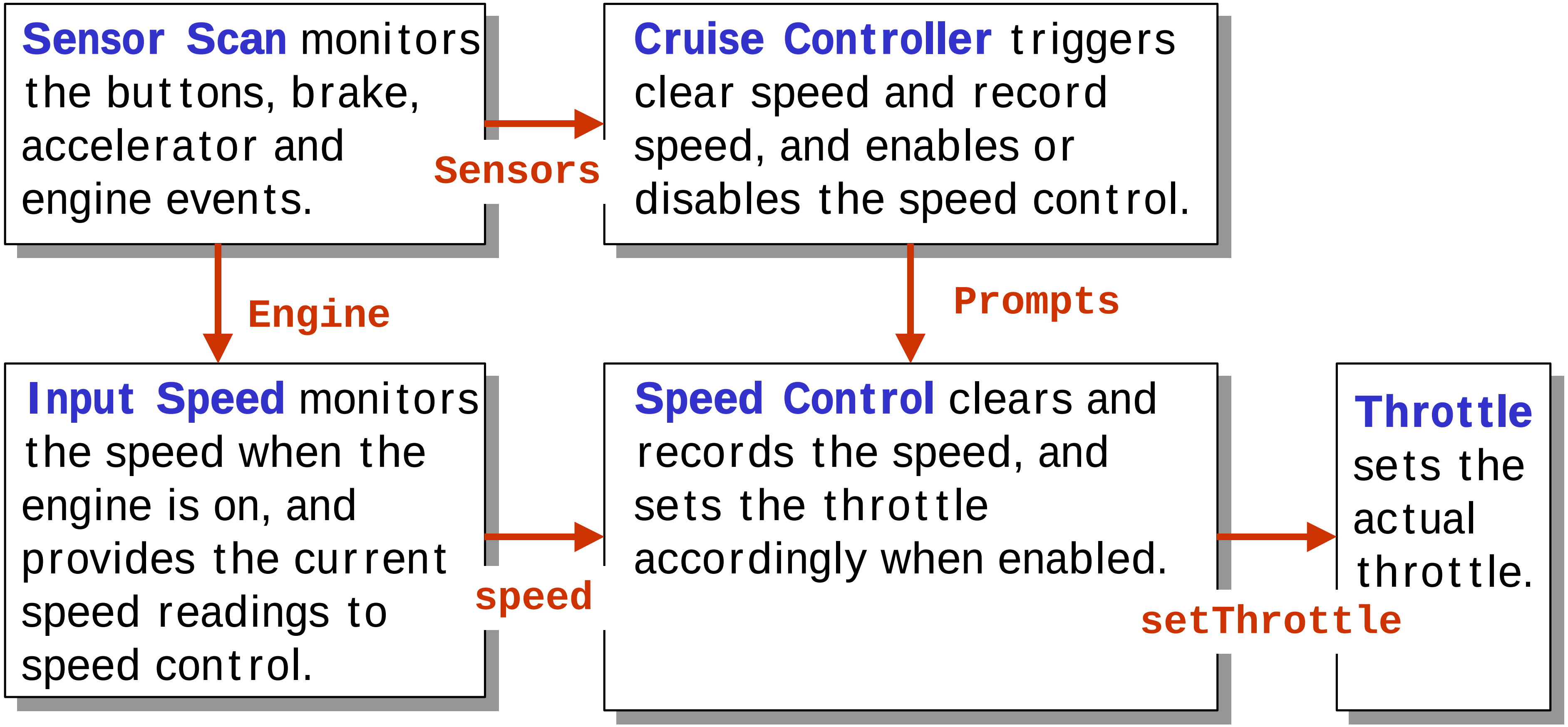


Wheel revolution sensor generates interrupts to enable the car **`speed`** to be calculated.

Output: The cruise control system controls the car speed by setting the **`throttle`** via the digital-to-analogue converter.

model - outline design

- outline processes and interactions.



Sensor Scan monitors the buttons, brake, accelerator and engine events.

Cruise Controller triggers clear speed and record speed, and enables or disables the speed control.

Input Speed monitors the speed when the engine is on, and provides the current speed readings to speed control.

Speed Control clears and records the speed, and sets the throttle accordingly when enabled.

Throttle sets the actual throttle.

model -design

- Main events, actions and interactions.

  `on`, **`off`**, **`resume`**, **`brake`**, **`accelerator`**
  `engine on`, **`engine off`**,

  `Sensors`

  `speed, setThrottle`

  `clearSpeed,recordSpeed,`
  `enableControl,disableControl`

  `Prompts`

- Identify main processes.

  `Sensor Scan, Input Speed,`
  `Cruise Controller, Speed Control and`
  `Throttle`

- Identify main properties.

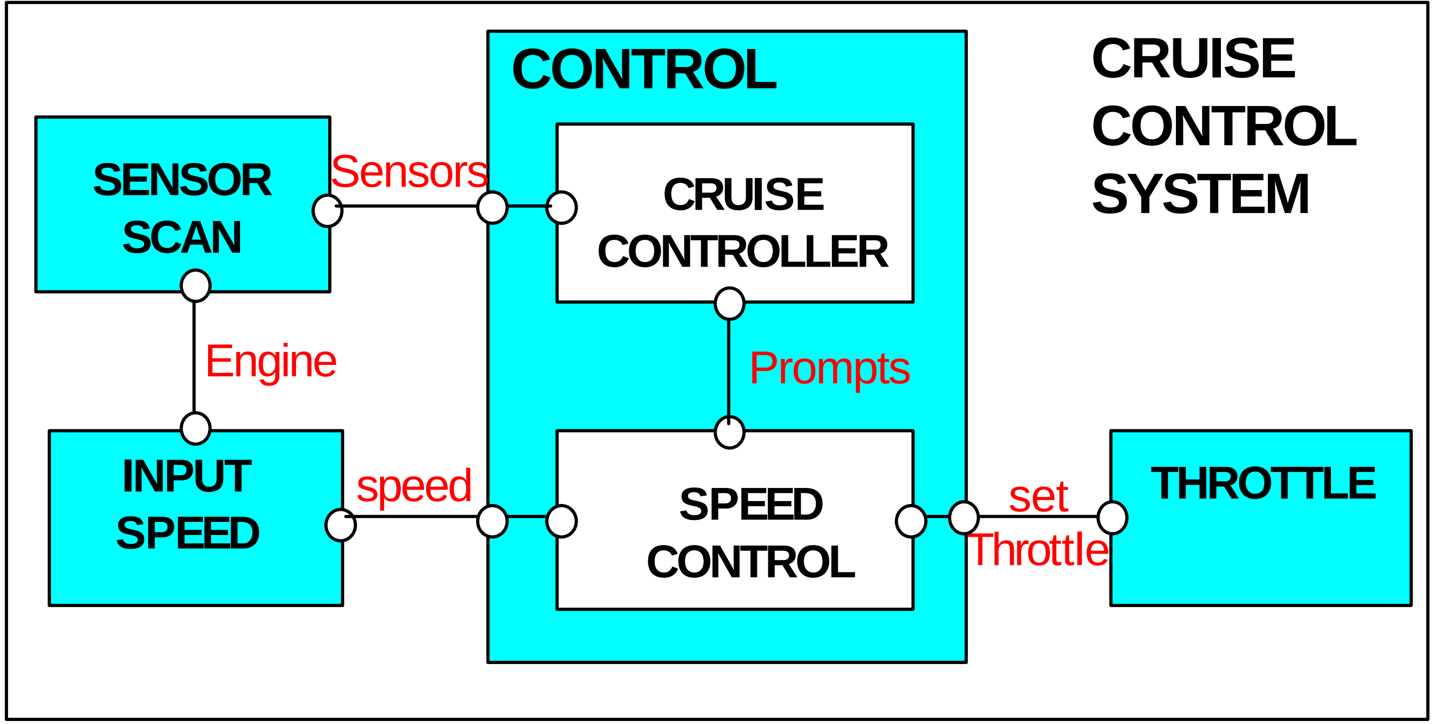
  `safety` - disabled when **`off`**, **`brake`** or **`accelerator`** pressed.

- Define and structure each process.

model - structure, actions and interactions

The CONTROL system is structured as two processes.

The main actions and interactions are as shown.



```
set Sensors = {engineOn,engineOff,on,off,
               resume,brake,accelerator}
set Engine  = {engineOn,engineOff}
set Prompts = {clearSpeed,recordSpeed,
               enableControl,disableControl}
```

model elaboration - process definitions

```
SENSORSCAN = ({Sensors} -> SENSORSCAN).
        // monitor speed when engine on
INPUTSPEED = (engineOn -> CHECKSPEED),
CHECKSPEED = (speed -> CHECKSPEED
             |engineOff -> INPUTSPEED
             ).
        // zoom when throttle set
THROTTLE =(setThrottle -> zoom -> THROTTLE).
        // perform speed control when enabled
SPEEDCONTROL = DISABLED,
DISABLED =({speed,clearSpeed,recordSpeed}->DISABLED
          | enableControl -> ENABLED
          ),
ENABLED = ( speed -> setThrottle -> ENABLED
          |{recordSpeed,enableControl} -> ENABLED
          | disableControl -> DISABLED
          ).
```

model elaboration - process definitions

// enable speed control when cruising,
// disable when off, brake or accelerator pressed

```
CRUISECONTROLLER = INACTIVE,
INACTIVE =(engineOn -> clearSpeed -> ACTIVE),
ACTIVE   =(engineOff -> INACTIVE
          |on->recordSpeed->enableControl->CRUISING
          ),
CRUISING =(engineOff -> INACTIVE
          |{ off,brake,accelerator}
                        -> disableControl -> STANDBY
          |on->recordSpeed->enableControl->CRUISING
          ),
STANDBY  =(engineOff -> INACTIVE
          |resume -> enableControl -> CRUISING
          |on->recordSpeed->enableControl->CRUISING
          ).
```

model - CONTROL subsystem

```
||CONTROL =(CRUISECONTROLLER
            ||SPEEDCONTROL
            ).
```

Animate to check particular traces:

- Is control enabled after the engine is switched on and the on button is pressed?
- Is control disabled when the brake is then pressed?
- Is control re-enabled when resume is then pressed?

However, we need to analyse to exhaustively check:

Safety: Is the control disabled when **`off`**, **`brake`** or **`accelerator`** is pressed?

Progress: Can every action eventually be selected?

model - Safety properties

Safety checks are compositional. If there is no violation at a subsystem level, then there cannot be a violation when the subsystem is composed with other subsystems.

This is because, if the **ERROR** state of a particular safety property is unreachable in the LTS of the subsystem, it remains unreachable in any subsequent parallel composition which includes the subsystem. Hence...

Safety properties should be composed with the appropriate system or subsystem to which the property refers. In order that the property can check the actions in its alphabet, these actions must not be hidden in the system.

model - Safety properties

```
property CRUISESAFETY =
  ({off,accelerator,brake,disableControl} -> CRUISESAFETY
  |{on,resume} -> SAFETYCHECK
  ),
SAFETYCHECK =
  ({on,resume} -> SAFETYCHECK
  |{off,accelerator,brake} -> SAFETYACTION
  |disableControl -> CRUISESAFETY
  ),
SAFETYACTION =(disableControl->CRUISESAFETY).
```

LTS?

```
||CONTROL =(CRUISECONTROLLER
             ||SPEEDCONTROL
             ||CRUISESAFETY
             ).
```

Is **CRUISESAFETY** *violated?*

model analysis

We can now compose the whole system:

```
||CONTROL =
   (CRUISECONTROLLER||SPEEDCONTROL||CRUISESAFETY
   )@ {Sensors,speed,setThrottle}.
||CRUISECONTROLSYSTEM =
     (CONTROL||SENSORSCAN||INPUTSPEED||THROTTLE).
```

Deadlock?
Safety?

```
No deadlocks/errors
```

Progress?

model - Progress properties

Progress checks are not compositional. Even if there is no violation at a subsystem level, there may still be a violation when the subsystem is composed with other subsystems.

This is because an action in the subsystem may satisfy progress yet be unreachable when the subsystem is composed with other subsystems which constrain its behavior. Hence...

Progress checks should be conducted on the complete target system after satisfactory completion of the safety checks.

model - Progress properties

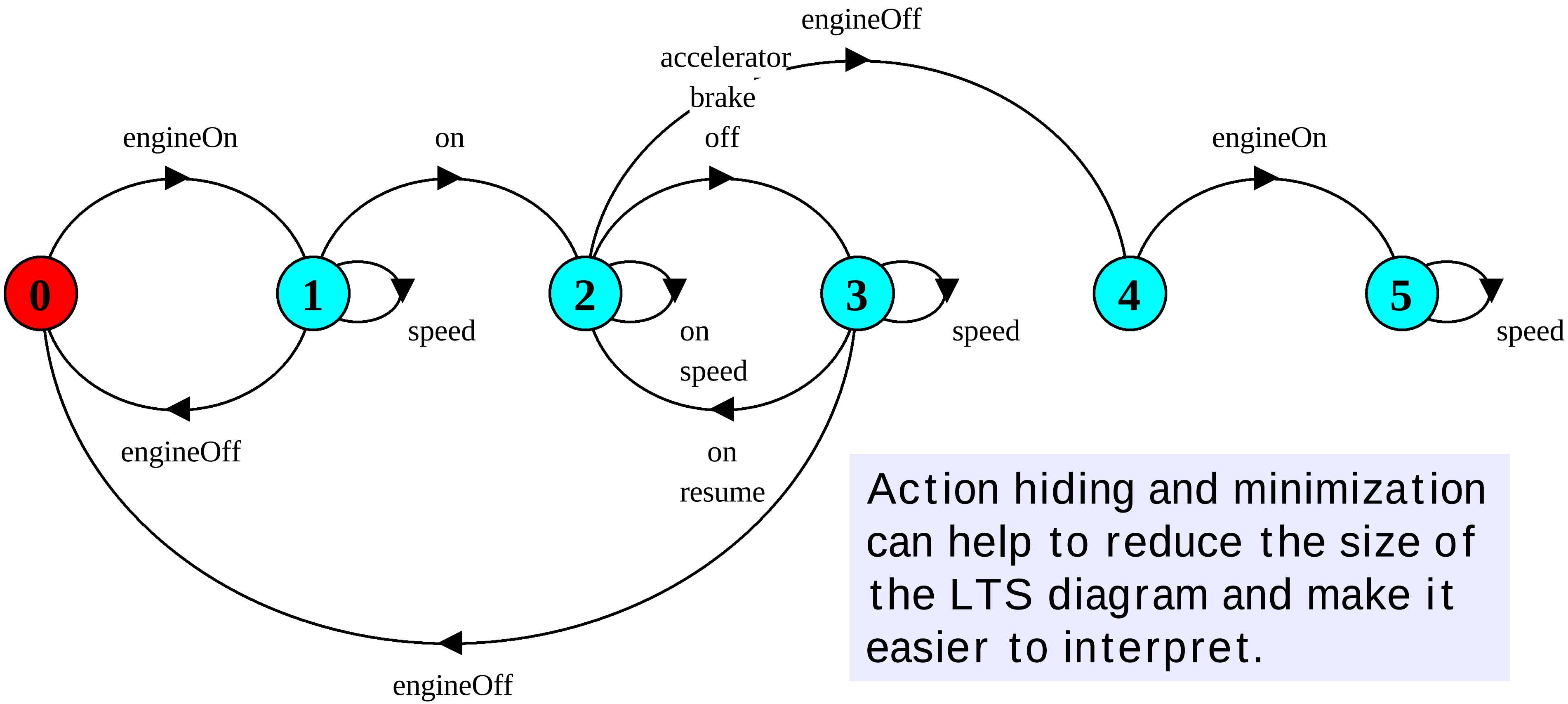
Check with no hidden actions

```
Progress violation for actions:
{engineOn, clearSpeed, engineOff, on, recordSpeed,
enableControl, off, disableControl, brake,
accelerator...........}
Path to terminal set of states:
     engineOn
     clearSpeed
     on
     recordSpeed
     enableControl
     engineOff
     engineOn
Actions in terminal set:
{speed, setThrottle, zoom}
```

Control is not disabled when the engine is switched off !

cruise control model - minimized LTS

```
||CRUISEMINIMIZED = (CRUISECONTROLSYSTEM)
                    @ {Sensors,speed}.
```



Action hiding and minimization can help to reduce the size of the LTS diagram and make it easier to interpret.

model - revised cruise control system

Modify **CRUISECONTROLLER** so that control is disabled when the engine is switched off:

```
…
CRUISING =(engineOff -> disableControl -> INACTIVE
          |{ off,brake,accelerator} -> disableControl -> STANDBY
          |on->recordSpeed->enableControl->CRUISING
          ),
…
```

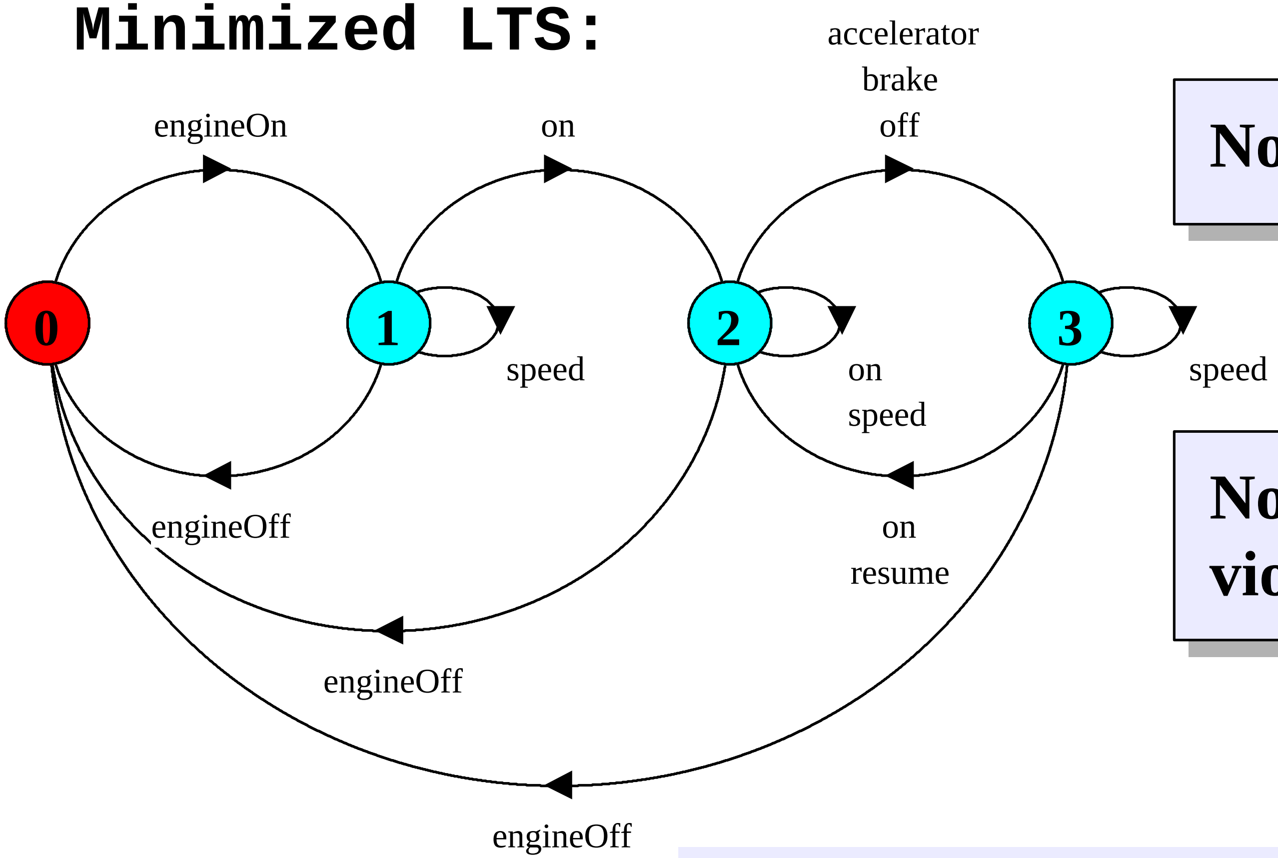
OK now?

Modify the safety property:

```
property IMPROVEDSAFETY = ({off,accelerator,brake,disableControl,
                                  engineOff} -> IMPROVEDSAFETY
                          |{on,resume}      -> SAFETYCHECK
                          ),
SAFETYCHECK = ({on,resume}  -> SAFETYCHECK
              |{off,accelerator,brake,engineOff} -> SAFETYACTION
              |disableControl    -> IMPROVEDSAFETY
              ),
SAFETYACTION =(disableControl    -> IMPROVEDSAFETY).
```

model - revised cruise control system

Minimized LTS:



No deadlocks/errors

No progress violations detected.

What about under adverse conditions? Check for system sensitivities.

model - system sensitivities

```
||SPEEDHIGH = CRUISECONTROLSYSTEM << {speed}.
```

```
Progress violation for actions:
{engineOn, engineOff, on, off, brake, accelerator,
resume, setThrottle, zoom}
Path to terminal set of states:
     engineOn
     tau
Actions in terminal set:
{speed}
```

The system may be sensitive to the priority of the action **speed**.

model interpretation

Models can be used to indicate system sensitivities.

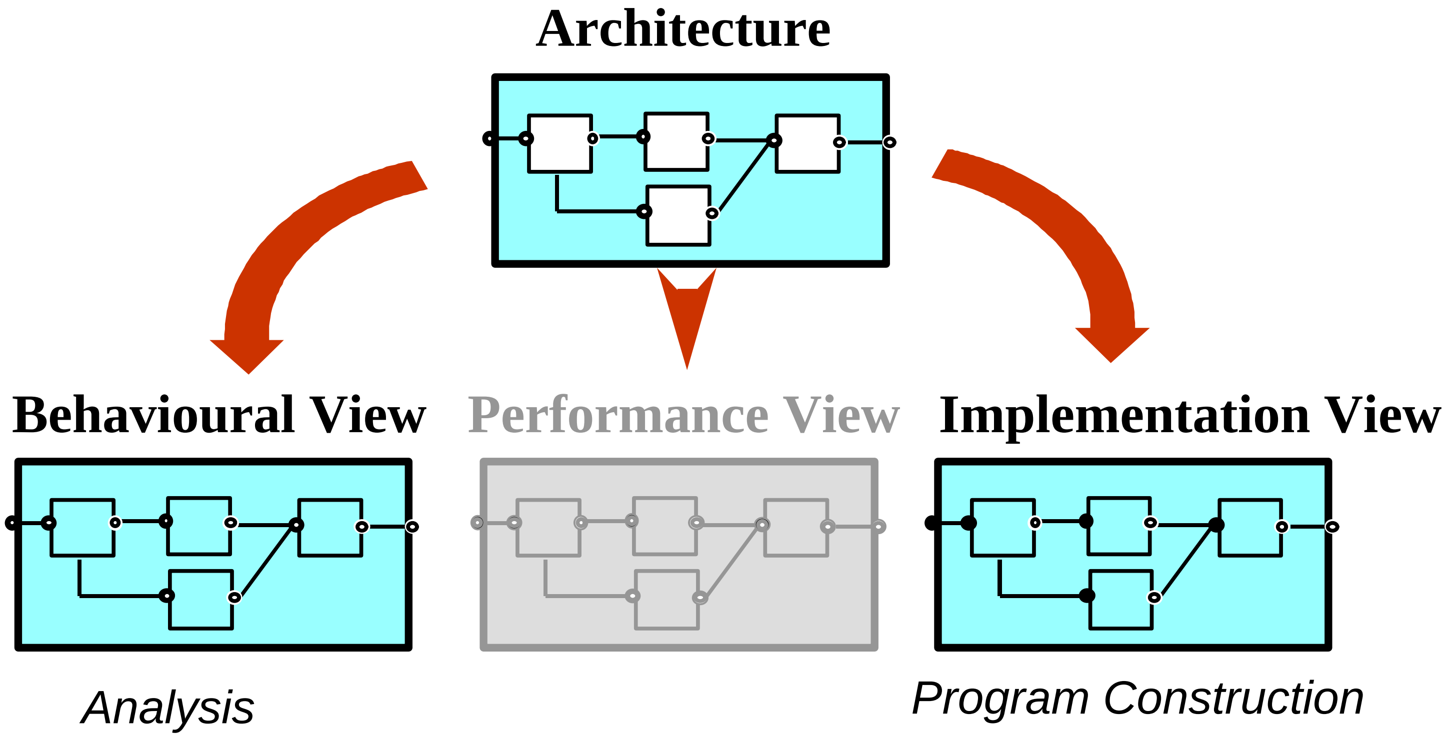
If it is possible that erroneous situations detected in the model may occur in the implemented system, then the model should be revised to find a design which ensures that those violations are avoided.

However, if it is considered that the real system will not exhibit this behavior, then no further model revisions are necessary.

Model interpretation and correspondence to the implementation are important in determining the relevance and adequacy of the model design and its analysis.

The central role of design architecture

Design architecture describes the gross organization and global structure of the system in terms of its constituent components.



Architecture

Behavioural View

Performance View

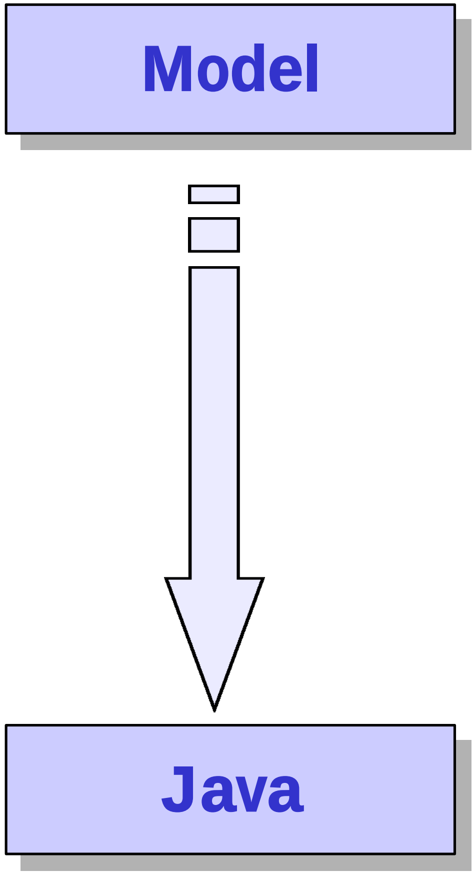
Implementation View

Analysis

Program Construction

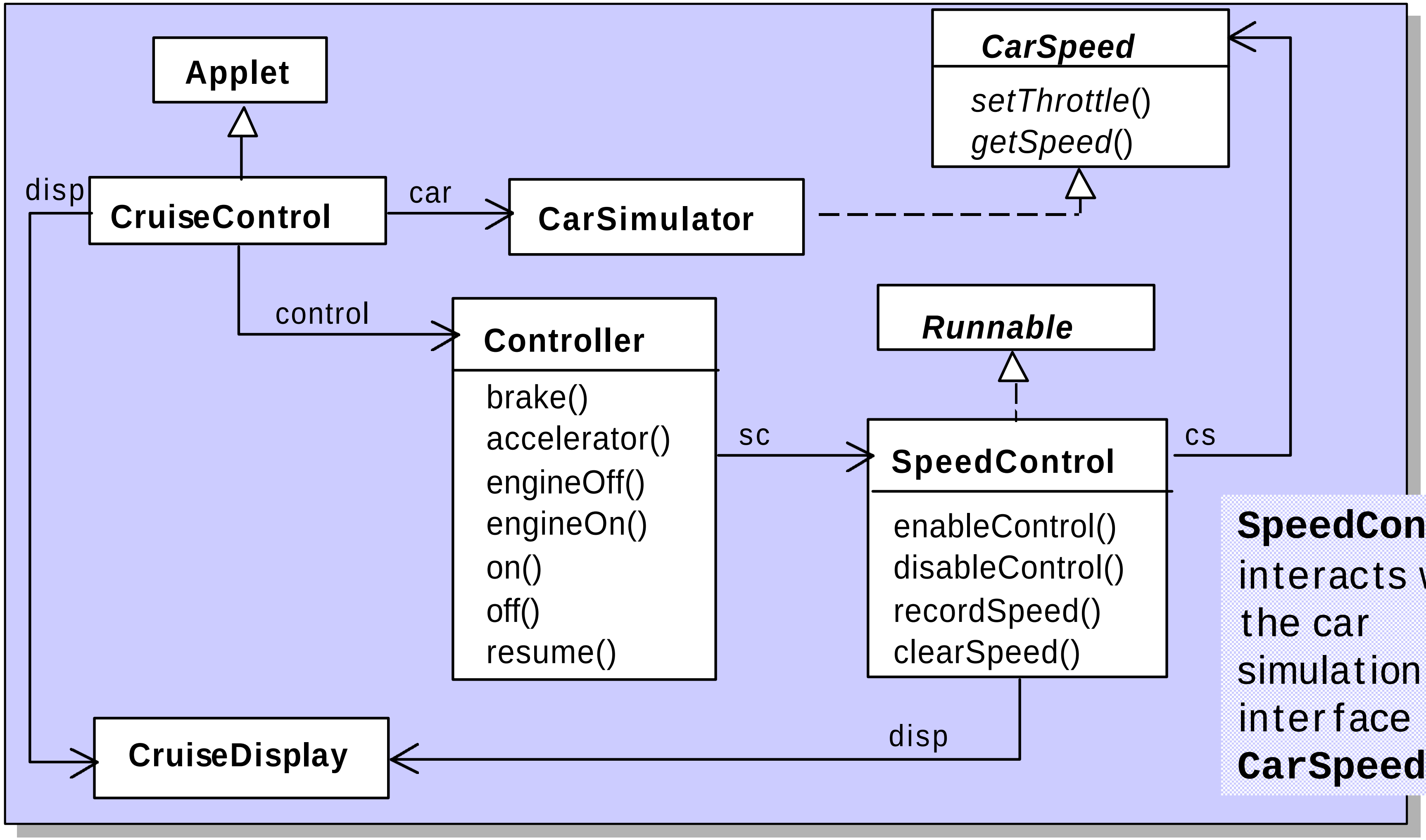
We consider that the models for analysis and the implementation should be considered as elaborated views of this basic design structure.

8.2 from models to implementations



- identify the main active entities
  - to be implemented as threads
- identify the main (shared) passive entities
  - to be implemented as monitors
- identify the interactive display environment
  - to be implemented as associated classes
- structure the classes as a class diagram

cruise control system - class diagram



`SpeedControl` interacts with the car simulation via interface **`CarSpeed`**.

`CRUISECONTROLLER`

`SPEEDCONTROL`

cruise control system - class Controller

```
class Controller {
  final static int INACTIVE = 0; // cruise controller states
  final static int ACTIVE   = 1;
  final static int CRUISING = 2;
  final static int STANDBY  = 3;
  private int controlState  = INACTIVE; //initial state
  private SpeedControl sc;

  Controller(CarSpeed cs, CruiseDisplay disp)
    {sc=new SpeedControl(cs,disp);}

  synchronized void brake(){
    if (controlState==CRUISING )
      {sc.disableControl(); controlState=STANDBY; }
  }

  synchronized void accelerator(){
    if (controlState==CRUISING )
      {sc.disableControl(); controlState=STANDBY; }
  }
 synchronized void engineOff(){
    if(controlState!=INACTIVE) {
      if (controlState==CRUISING) sc.disableControl();
      controlState=INACTIVE;
    }
  }
```

Controller is a passive entity - it reacts to events. Hence we implement it as a **monitor**

cruise control system - class `Controller`

```
synchronized void engineOn(){
    if(controlState==INACTIVE)
      {sc.clearSpeed(); controlState=ACTIVE;}
  }
  synchronized void on(){
    if(controlState!=INACTIVE){
      sc.recordSpeed(); sc.enableControl();
      controlState=CRUISING;
    }
  }
  synchronized void off(){
    if(controlState==CRUISING )
      {sc.disableControl(); controlState=STANDBY;}
  }
  synchronized void resume(){
    if(controlState==STANDBY)
     {sc.enableControl(); controlState=CRUISING;}
  }
}
```

This is a direct translation from the model.

cruise control system - class SpeedControl

```
class SpeedControl implements Runnable {
  final static int DISABLED = 0; //speed control states
  final static int ENABLED  = 1;
  private int state = DISABLED;  //initial state
  private int setSpeed = 0;      //target speed
  private Thread speedController;
  private CarSpeed cs;      //interface to control speed
  private CruiseDisplay disp;
  SpeedControl(CarSpeed cs, CruiseDisplay disp){
    this.cs=cs; this.disp=disp;
    disp.disable(); disp.record(0);
  }
  synchronized void recordSpeed(){
    setSpeed=cs.getSpeed(); disp.record(setSpeed);
  }
  synchronized void clearSpeed(){
    if (state==DISABLED) {setSpeed=0;disp.record(setSpeed);}
  }
  synchronized void enableControl(){
    if (state==DISABLED) {
      disp.enable(); speedController= new Thread(this);
      speedController.start(); state=ENABLED;
    }
  }
```

SpeedControl is an active entity - when enabled, a **new thread** is created which periodically obtains car speed and sets the throttle.

cruise control system - class **SpeedControl**

```
  synchronized void disableControl(){
     if (state==ENABLED)  {disp.disable(); state=DISABLED;}
   }

   public void run() {     // the speed controller thread
     try {
       while (state==ENABLED) {
         Thread.sleep(500);
         if (state==ENABLED) synchronized(this) {
           double error = (float)(setSpeed-cs.getSpeed())/6.0;
           double steady = (double)setSpeed/12.0;
           cs.setThrottle(steady+error); //simplified feed back control
         }
       }
     } catch (InterruptedException e) {}
     speedController=null;
   }
 }
```

`SpeedControl` is an example of a class that combines both synchronized access methods (to update local variables) and a thread.

Summary

- Concepts
  - **design process:**

    from requirements to models to implementations
  - **design architecture**
- Models
  - **check properties of interest**

    safety: ***compose safety properties at appropriate (sub)system***

    progress: ***apply progress check on the final target system model***
- **Practice**
  - **model interpretation - to infer actual system behavior**
  - **threads and monitors**

Aim: rigorous design process.

Course Outline

- **Processes and Threads**
- **Concurrent Execution**
- **Shared Objects & Interference**
- **Monitors & Condition Synchronization**
- **Deadlock**
- **Safety and Liveness Properties**
- **Model-based Design**

Concepts

Models

Practice

- Dynamic systems
- Concurrent Software Architectures
- Message Passing
- Timed Systems