Model-Based Design

INF2140 Parallel Programming: Chapter 8

March 28, 2012

Design

Concepts: design process:

- requirements to models to implementations

Models: check properties of interest:

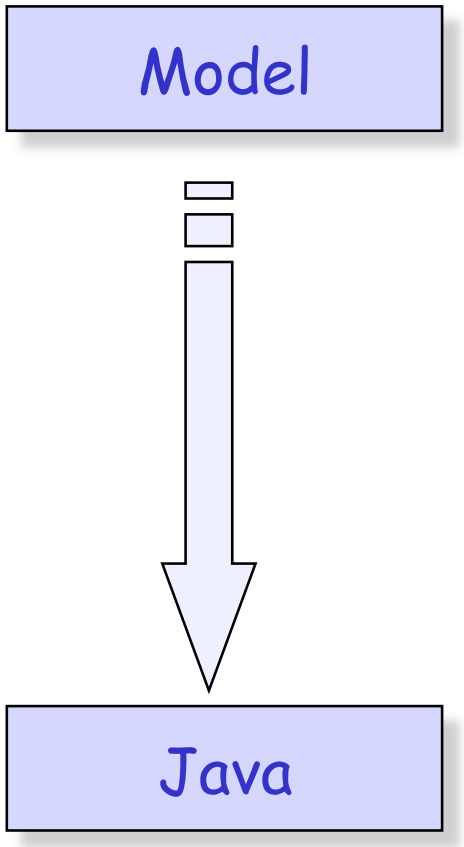
- safety on the appropriate (sub)system
- progress on the overall system

Practice: model interpretation - to infer actual system behavior

- threads and monitors

Aim: rigorous design process

8.1 from requirements to models



first *make requirements*

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

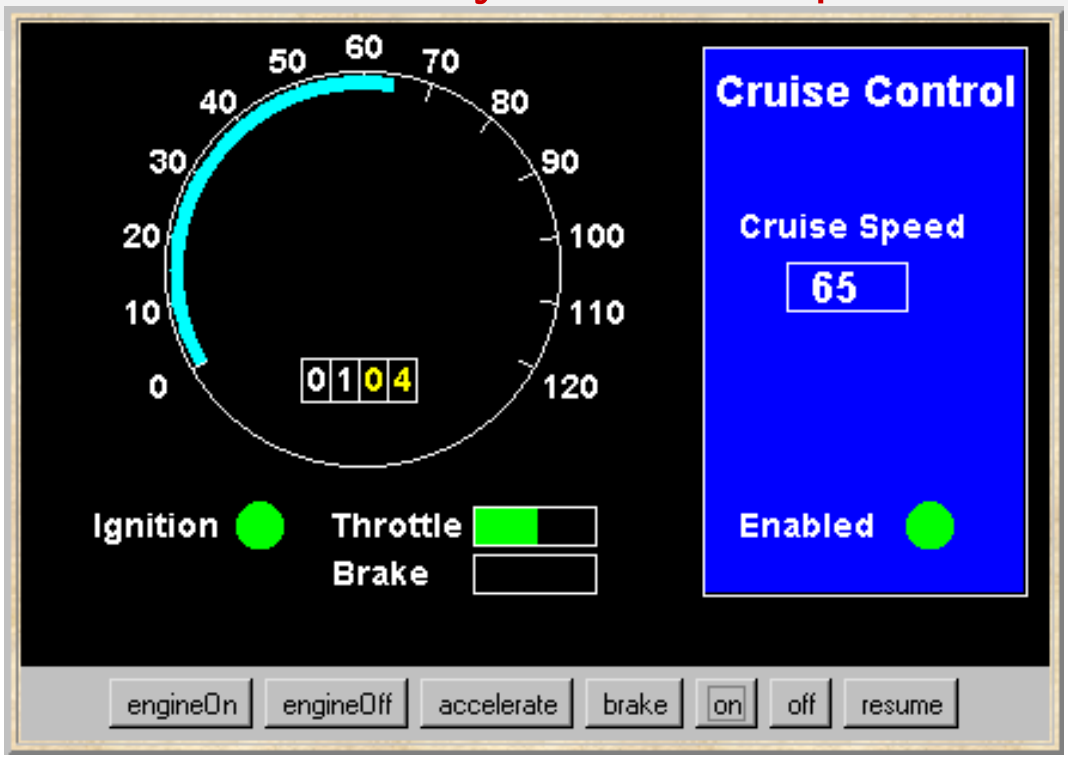
second *make the model*

1. identify the main *events*, *actions*, and *interactions*
2. identify and define the main *processes*
3. identify and define properties of interest
4. structure the processes into an **architecture**

third *check the model*

- check traces of interest
- check properties of interest

a Cruise Control System - requirements

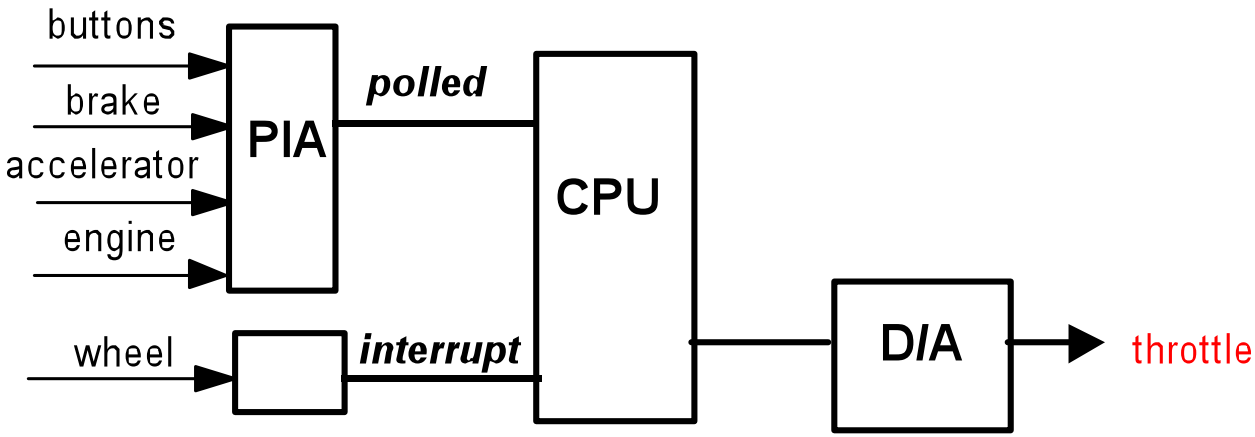


When the car ignition is switched on and the **on** button is pressed, the current speed is recorded and the system is enabled: it maintains the speed of the car at the recorded setting.

- 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:

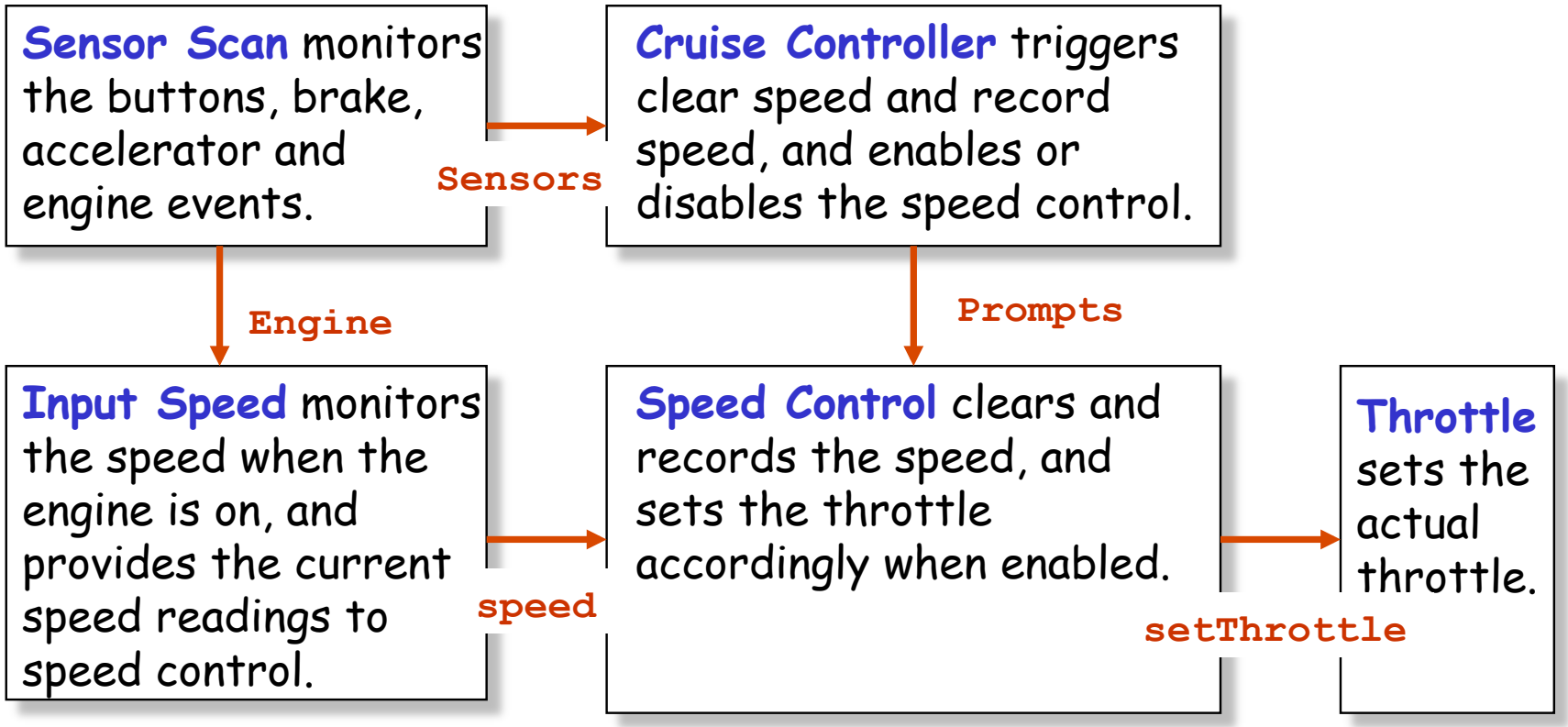


- **cruise c. buttons** (on, off, resume)
- **brake** (pressed)
- **accelerator** (pressed)
- **engine** (on, off).

- 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 – design outline

- *Outline processes and interactions:*



model - design

- Main events, actions and interactions.

sensors	• *on, off, resume*	– the Cruise Control buttons
	• *brake, accelerator*	– from driver
	• *engine on, engine off*	– from driver
	• *speed*	– from wheel sensor of car
prompts	• *clearSpeed, recordSpeed*	– from Cruise Controller
	• *enableControl, disableControl*	– from Cruise Controller
	• *setThrottle*	– from Speed Control
	• *zoom*	– from Throttle

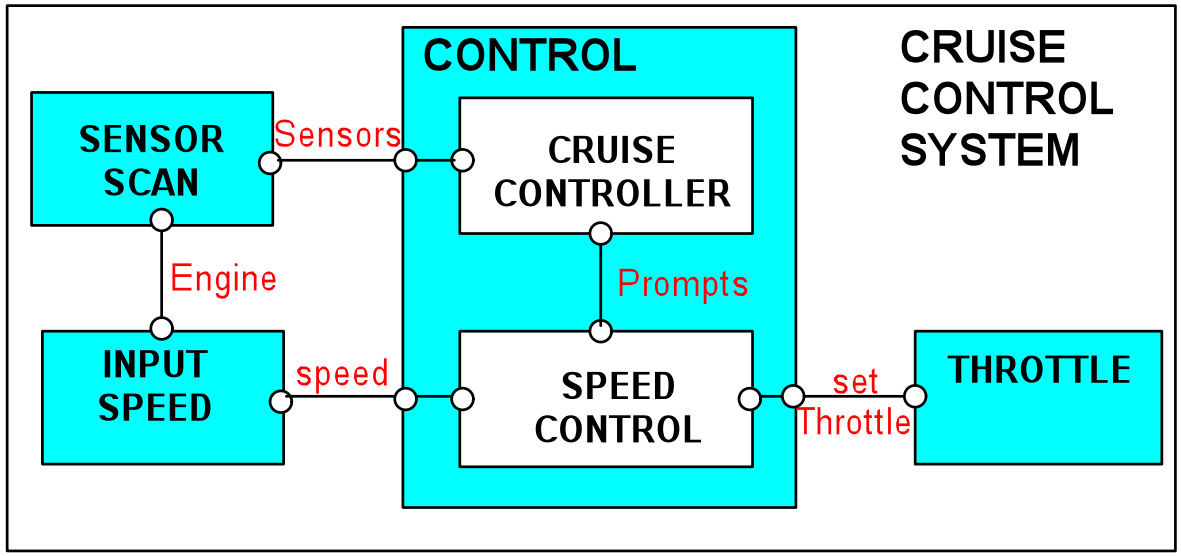
- Identify main processes.
  - *Sensor Scan, Input Speed*
  - *Cruise Controller, Speed Control and Throttle*
- Identify main properties.

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 (not CruiseContr.)

```
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 = (enableControl -> ENABLED
      | {speed,clearSpeed,recordSpeed} -> DISABLED ),
ENABLED = ( speed -> setThrottle -> ENABLED
      | {recordSpeed,enableControl} -> ENABLED
      |  disableControl -> DISABLED ).
```

model elaboration - process definitions of Cruise Controller

```
set DisableActions = {off,brake,accelerator}
//enable when cruising, disable when disable action
CRUISECONTROLLER = INACTIVE,
INACTIVE =(engineOn -> clearSpeed -> ACTIVE
          |DisableActions -> INACTIVE ),
ACTIVE   =(engineOff -> INACTIVE
          |on->recordSpeed->enableControl->CRUISING
          |DisableActions -> ACTIVE ),
CRUISING =(engineOff -> INACTIVE
          |DisableActions->disableControl->STANDBY
          |on->recordSpeed->enableControl->CRUISING),
STANDBY  =(engineOff -> INACTIVE
          |resume -> enableControl -> CRUISING
          |on->recordSpeed->enableControl->CRUISING
          |DisableActions -> STANDBY
          ).
```

model - overview of actions

- Driver, represented by *SensorScan*, to CRUISEC. and Car
  - *on, off, resume* – push Cruise Control buttons
  - *brake, accelerator* – press pedal
  - *engineOn, engineOff* – use key
- Car, represented by *Input Speed*, to SPEEDCONTROL
  - *speed* – by sensor on wheel
- CRUISECONTROLLER to *SPEEDCONTROL*
  - *clearSpeed, recordSpeed* – to control speeding
  - *enableControl, disableControl* – to control activity
- SPEEDCONTROL to *Throttle*
  - *setThrottle* – for adjusting speed
- THROTTLE to Car
  - *zoom* – from Throttle, to Car (internal event)

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 analysis to check exhaustively:

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 no violation at a subsystem level, then no 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 =
   ( {DisableActions,disableControl} -> CRUISESAFETY
   | {on,resume} -> SAFETYCHECK    ),

SAFETYCHECK =
   ( {on,resume} -> SAFETYCHEC
   | DisableActions -> SAFETYACTION
   | disableControl -> CRUISESAFETY    ),

SAFETYACTION =(disableControl->CRUISESAFETY).

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

- Is CRUISESAFETY violated? - **LTS**?

model - Safety properties

Safety analysis using LTSA produces the following violation:

```
Trace to property violation in CRUISESAFETY:
    engineOn
    clearSpeed
    on
    recordSpeed
    enableControl
    engineOff
    off
    off
```

Strange circumstances! If the system is enabled by switching the engine on and pressing the on button, and then the engine is switched off, it appears that the control system is not disabled.

model - Safety properties

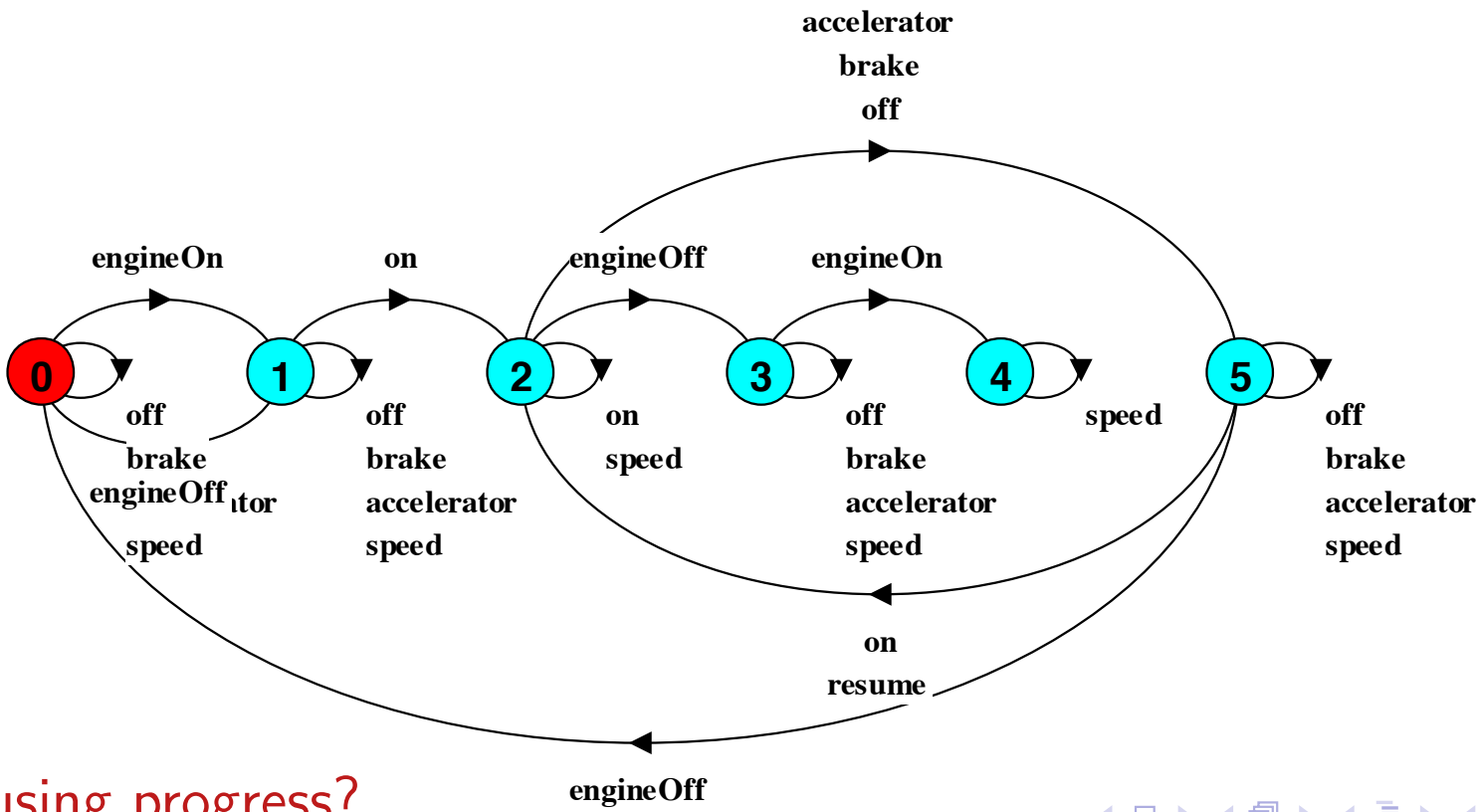
What if the engine is switched on again?
We can investigate further using animation ..

```
engineOn
clearSpeed
on
recordSpeed
enableControl
engineOff
engineOn
speed
setThrottle
speed
setThrottle
...
```

- The car will accelerate and zoom off when the engine is switched on again!
- .. using LTS? Action hiding and minimization can help to reduce the size of an LTS diagram and make it easier to interpret ..

Model LTS for CONTROLMINIMIZED

```
minimal
||CONTROLMINIMIZED =
(CRUISECONTROLLER||SPEEDCONTROL) @ {Sensors,speed}.
```



using progress?

model - Progress properties

Check the model for progress properties with no safety property and no hidden actions:

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

model - revised cruise controller

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

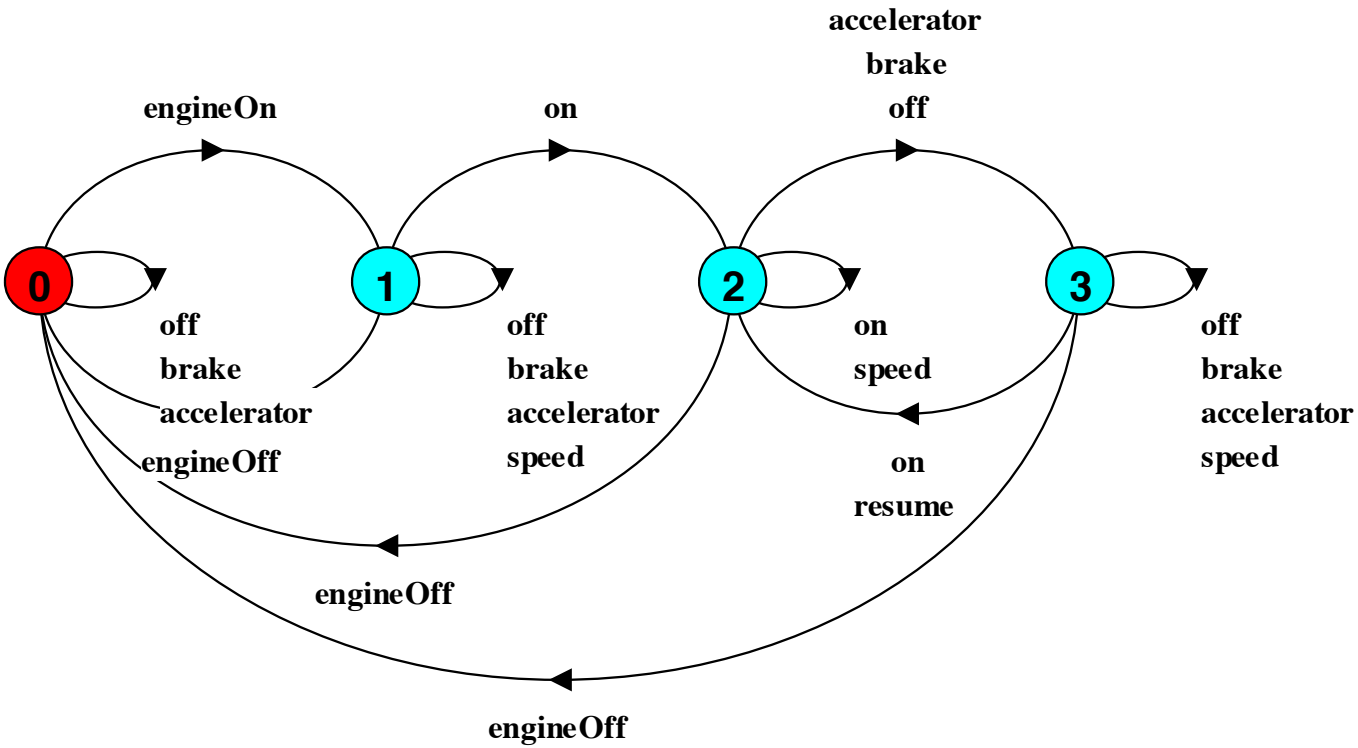
```
CRUISING = (engineOff -> disableControl -> INACTIVE
        | DisableActions -> disableControl -> STANDBY
        | on -> recordSpeed->enableControl->CRUISING ),
```

Modify the safety property:

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

OK now?

revised CONTROLMINIMIZED



No deadlocks/errors

model analysis

We can now proceed to compose the whole system:

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

||CRUISECONTROLSYSTEM =
        (CONTROL||SENSORSCAN||INPUTSPEED||THROTTLE).
```

No deadlocks/errors

- Deadlock?
- Safety?
- 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.
Progress? No progress violations detected

model - system sensitivities

What about progress under adverse conditions? Check for 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**.

Further safety checks

We test the revised system with all relevant driver actions visible.

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

We may now obtain the following trace (ignoring *tau* actions):

```
engineOn, on, speed, off, setThrottle, zoom
```

So the revised model may **zoom** the car after the **off** button is pressed! Not safe!

- We need a safety proerty to test this!

model - stronger safety specification

The system should not change the speed when the system is disabled, i.e. no zoom when disabled.

```
property SAFE =
        (zoom -> ERROR
        | enableControl -> SF ),
 SF =  (zoom -> SF
        | disableControl -> SAFE
        | enableControl -> SF ).
```

This safety property is **not** satisfied!

- Exercise: revise the model.

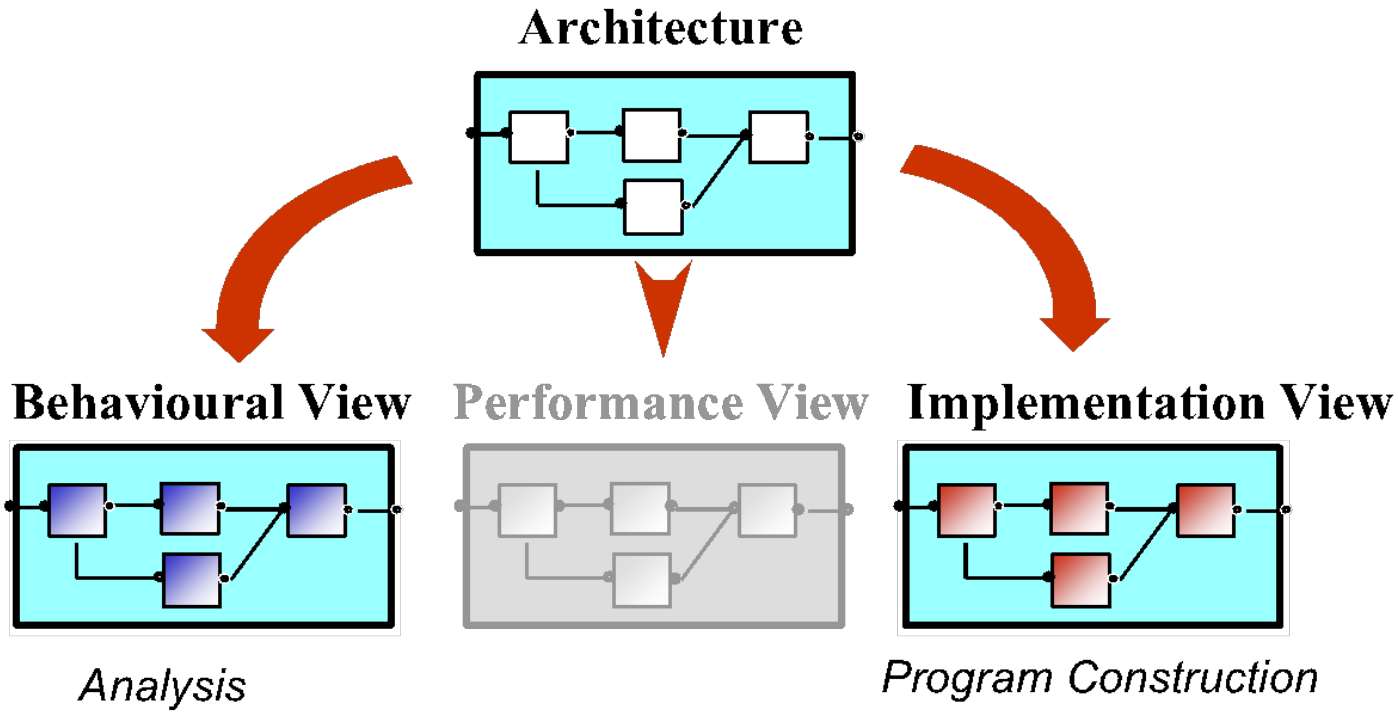
model interpretation

- 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.

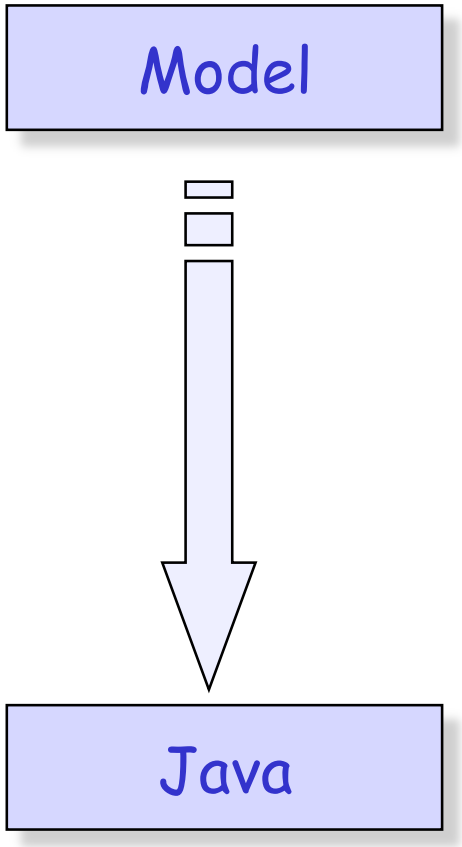
The central role of design architecture

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



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

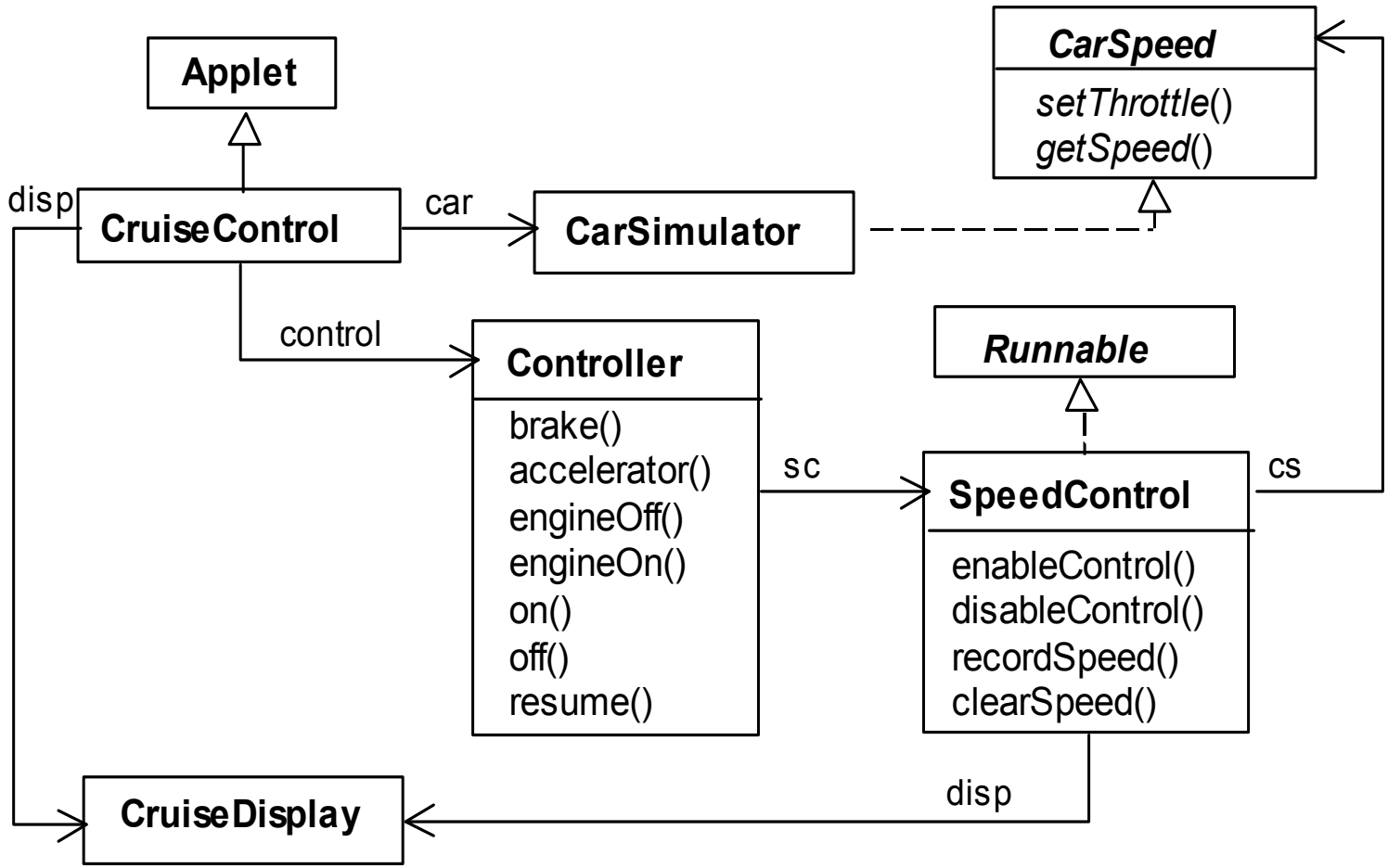
8.2 from model to implementation



- 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

cruisecontroller & speedcontrol:



SpeedControl interacts with the car simulation via interf. CarSpeed.

cruise control system - class controller

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

Controller is a passive entity. Hence we implement it as a monitor.

cruise control system - class controller (part 2)

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

cruise control system - class SpeedControl (Part 2)

```
synchronized void enableControl(){
 if(state==DISABLED)
  {disp.enable(); speedController= new Thread(this);
   speedController.start(); state=ENABLED; }
}
synchronized void disableControl(){
  if(state==ENABLED)
   {disp.disable();state=DISABLED;}}
```

- 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 (Part 3)

```
synchronized public void run() {
 try {                          //the speed controller thread
  while (state==ENABLED) {
   double error=(float)(setSpeed-cs.getSpeed())/6.0;
   double steady = (double)setSpeed/12.0;
   cs.setThrottle(steady+error);
                          // simplified feedback control
   wait(500);
   } 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.
- run also synchronized

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

- basic topics
  - 2. Processes and Threads
  - 3. Concurrent Execution
  - 4. Shared Objects & Interference
  - 5. Monitors & Condition Synchronization
  - 6. Deadlock
  - 7. Safety and Liveness Properties
  - 8. Model-based Design
- advanced topics
  - 9. Dynamic systems
  - 10. Message Passing
  - 11. Concurrent Software Architectures
  - 12. Timed Systems
  - 13. Program Verification
  - 14. Logical Properties