An Object-Oriented Modeling Language for Hybrid Systems

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Outline

1. Introduction on Hybrid Systems
2. Motivation of Our Work
3. Object-Oriented Modeling Language
4. Conclusion and Future Work

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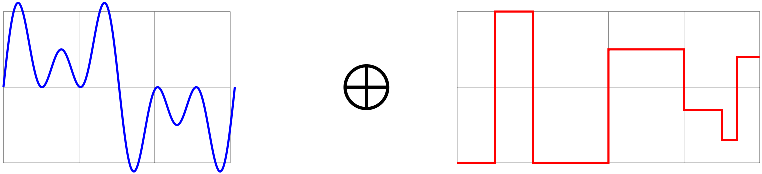
Hybrid Systems



Hybrid systems consist of discrete control programs and continuous physical behaviour, such systems exhibit both continuous and discrete dynamic behaviour.

Hybrid Automata

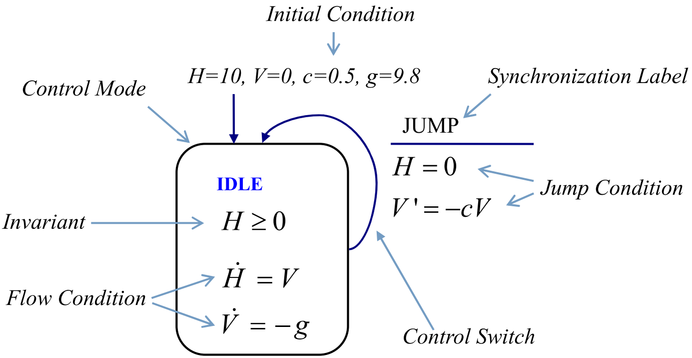


Figure : Hybrid automaton of a bouncing ball

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Motivation

Automata-Based Languages/Notations

- not the best choice for creating models from building blocks;
- the differential equations, invariants and difference equations are tightly coupled.

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Process-Algebra-Based Languages/Notations

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- not accepted widely by designers and developers due to the complicated symbols, mathematical abstractions and various concept abbreviations.

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State-Chart-Based Languages/Notations

- de facto approach for model-based development of embedded systems
- weak on model reuse as well, e.g., the continuous-time chart in Simulink/Stateflow cannot be reused

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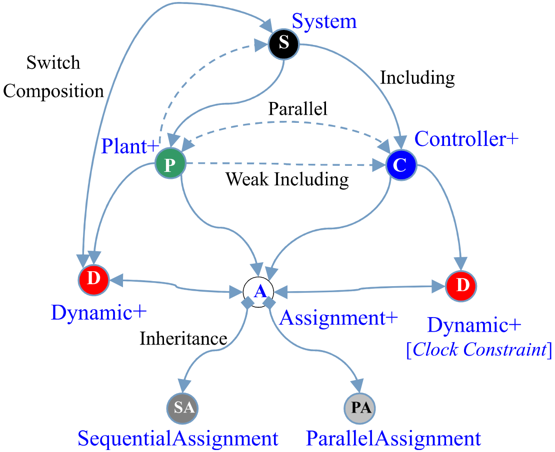
Apricot

Syntax

System	::=	$(\|\|_{i=1}^{n}$ Plant$_i$) $\|$ ($\|\|_{i=1}^{m}$ Controller$_i$);
Plant	::=	AtomComp | (AtomComp $\|$ Controller) | HierComp
		| (HierComp $\|$ Controller);
Controller	::=	AtomComp;
AtomComp	::=	*Comp*(Condition$^+$, Dynamic$^+$, Assignment$^+$);
HierComp	::=	*Comp*(Condition$^+$, Dynamic$^+$, Assignment$^+$, System);
Assignment	::=	SequentialAssignment | ParallelAssignment.

- *Dynamic*$^+$ represents a set of *Dynamic* objects used for continuous dynamics;
- *Assignment*$^+$ for *Assignment* objects denoting discrete behaviors;
- $||$ denotes parallel composition. $||_{i=1}^{n}$ *Plant*$_i$ represents the parallel composition of n plants;
- *Comp*$(\cdot)$ represents the control switch composition relation under the condition in *Condition*$^+$.

The relationship of objects in Apricot



→	Including
- - →	Weak Including
↔	Control Mode Switch Composition
← - →	Parallel Composition
◆→	Inheritance
S	System
P	Plant
C	Controller
D	Dynamic
A	Assignment

the weak include relationship, i.e., the object at starting point may not contain an object at the ending point, e.g., a plant may not contain a subsystem.

Continuous Behavior

Differential Equations:

```
void Continuous(){
    dot(Var_1, Nat_1) == MathExp_1 ;
                  ...
    dot(Var_n, Nat_n) == MathExp_n ;
}
```

where, Var_i is a continuous variable, Nat_i represents the derivative order of Var_i, $MathExp ::= Function(Vars, \dot{V}ars)$, a mathematical function, e.g., sine, cosine, log.

Discrete Behavior

Discrete Assignments:

```
void Discrete(){
    Variable_1 = MathExp_1 ;
        ...
    Variable_n = MathExp_n ;
}
```

- ParallelAssignment: the parallel composition of the assignment statements;
- SequentialAssignment: sequential composition of assignment statements. if-statement, for-loop, and method-call, etc.

Interfaces-System

```
interface System{
    Requires plants[1..*] : Plant;
    Requires controllers[1..*] : Controller;
    void Init();
}
```

- *Requires* is a keyword for the declaration of variable-requirement,
- $1..*$ denotes the amount of entities $>= 1$.
- method *Init*() indicates that the System has an initializer without any argument nor value return.

Interfaces-Plant

```
interface Plant{
   Requires dy[1..∗] : Dynamic;
   Requires ass[1..∗] : Assignment;
   Requires sy[0..1] : System;
   Requires controller[0..1] : Controller;
   void Composition(){
     Requires coms[1..∗](?|!)[0..1] : (dss[1..∗] : Dynamic|System,
                 ass[0..1] : Assignment, dsd[1..∗] : Dynamic|System)
                 { Condition{}; Discrete{}; };
   };}
```

- ! and ? behind the composition name denote the asynchronous communication between different components. ! used for asynchronous message sending;
- It is the case of synchronous communication when ? and ! are absent;
- We can define the synchronization of two compositions A and B explicitly, as $A \mid\mid B$; and $A \sim B$ denotes asynchronous communication between A and B.

Interfaces-Controller

```
interface Controller{
    Constraint clock;
    Requires dy[1..*] : Dynamic;
    Requires ass[1..*] : Assignment;
    void Composition(){
      Requires coms[1..*](?|!)[0..1] : (dys[1..*] : Dynamic,
               ass[0..1] : Assignment, dyd[1..*] : Dynamic)
               { Condition{}; Discrete{}; };
    }; }
```

- the constraint-indication *Constraint clock* denotes that: the derivative order assigned to the variables in the Dynamic object of Controller must be a constant number 1, the derivative is also a constant number.

Polymorphism

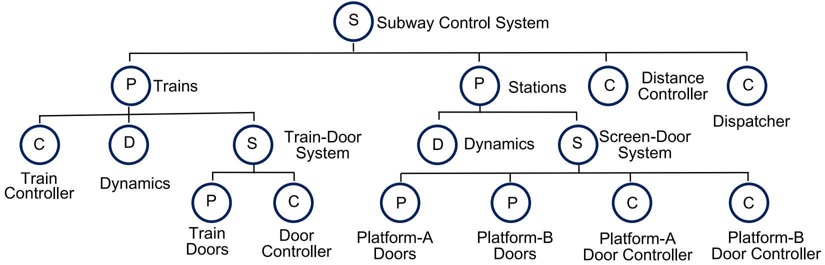


Figure : A hierarchical structure of the subway control system. The capital letters ‘S’, ‘P’, ‘C’, ‘D’ denote the entities of system, plant, controller, and dynamic, respectively

Polymorphism-Example

```
class ScreenDoorSystem extends DoorSystem{
  ...
  void Init(){
    registerComposition(PADoors,PADController);
    registerComposition(PBDoors,PBDController);
    PADoors.closed.Start();
    PBDoors.closed.Start();
    PADController.closed.Start();
    PBDController.closed.Start();
  }
}
```

```
class TrainDoorSystem extends DoorSystem{
  ...
  void Init(){
       registerComposition(doors,TDController);
       //start dynamic closed
       doors.closed.Start();
       //start controller for train doors
       TDController.closed.Start();
  }
}
```

ScreenDoorSystem and *TrainDoorSystem* have the same type of *DoorSystem*, but they can behave differently when *Init* is called.

Code-Reuse

Consider the Train Automaton:

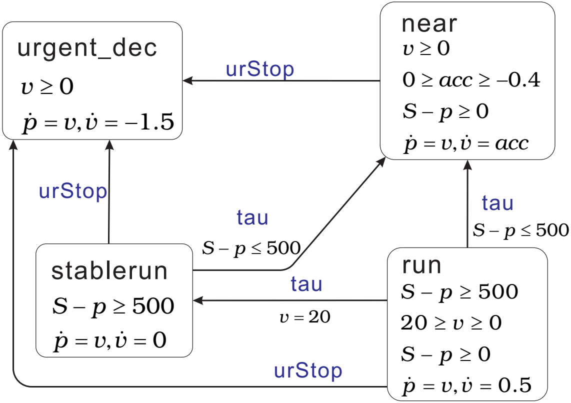


Figure : Some parts of the hybrid automaton. Variable S denotes the position of the station in front of the train. The position of the train is represented by variable p, the velocity is by v. Since $0 \geq acc \geq -0.4$ (m/s^2), variable *acc* denotes the deceleration of the train in the mode *near*

Code-Reuse

The declaration of continuous behavior of the train in Apricot.

```
class TrainBehavior implements Dynamic{
 Real p;//position
 Real v;//velocity
 Interval acc;//acceleration
 real pos1; //The lower bound of the position
 real pos2; //The upper bound of the position
 real vel1; //The lower bound of the velocity
 real vel2; //The upper bound of the velocity
  TrainBehavior(Real p, Real v, Interval acc,
   real pos1, real pos2, real vel1, real vel2){
   this.p = p; this.v = v; this.acc = acc;
   this.pos1 = pos1; this.pos2 = pos2;
   this.vel1 = vel1; this.vel2 = vel2;
  }
...//Some extra codes
 void Continuous(){
  //Declares the continuous behavior
     dot(p,1) == v;
     dot(v,1) == acc;
  }
 Invariant{
    p in [pos1, pos2];
    v in [vel1, vel2];
  };
}
```

Code-Reuse

For Mode Run

the mode *run* in Train Automaton can be declared as:

`run = new TrainBehavior(p, v, [0.5,0.5], -Inf, S-500, 0, 20).`

For Mode Near

the mode *near* can be instantiated in our language as:

`near = new TrainBehavior(p,v,[-0.4,0],-Inf,S,0,Inf).`

For Control Switches from *run* and *stablerun* to *near*:

```
tau({run,stablerun},,near){
 Condition{
    abs(S-p) <= 500;
  };
}
```

Complex in Hybrid Automaton:

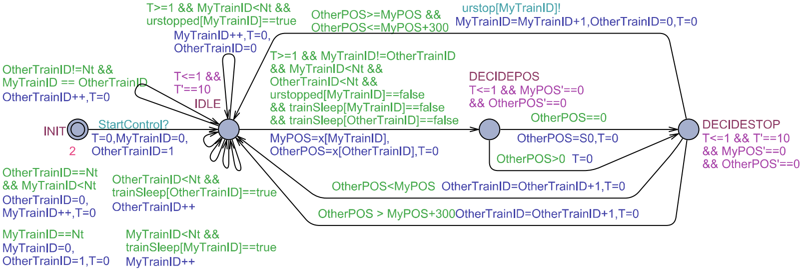


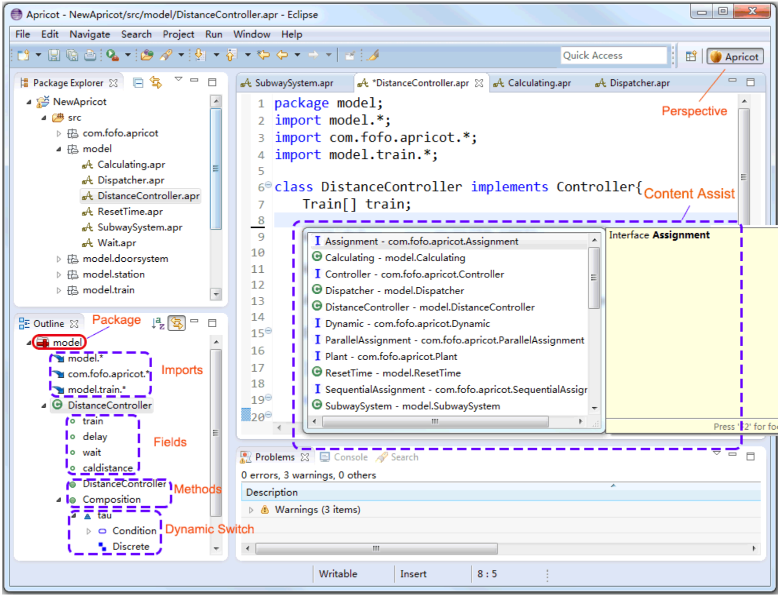
Figure : The hybrid automaton for urgent control of subway trains in UPPAAL.

Better Declaration for Control Logic

Better in Apricot with traditional control structures (for-loop, if):

```
package model;
import com.fofo.apricot.SequentialAssignment;
import model.train.Train;
class Calculating implements SequentialAssignment{
 Train[] train;  //the array of trains
 Calculating(Train[] train){ //constructed by an array of trains dynamically
   this.train = train;
 }
 void Discrete(){
   int mindis = Inf;
   for(Train currTrain : train){
     int currdir = currTrain.getCurrentDirection();
     real currpos = currTrain.getCurrentPosition();
     for(Train otherTrain : train){
       int otherdir = otherTrain.getCurrentDirection();
       real otherpos = otherTrain.getCurrentPosition();
       if(currTrain!=otherTrain and currdir == otherdir){
         //when two trains are different, but in same direction
         //calculate the distance between them
         real distance = currdir * (otherpos - currpos);
         if(distance<=300 and distance>=0 and distance < mindis){
           mindis = distance;
         }
       }//end calculate of distance
     }
     if(mindis < Inf){//the initial value of mindis is Inf
       currTrain.urStop(!);//stop currTrain
       mindis = Inf;
     }
     else if(currTrain in currTrain.urgent_stop){//currTrain can be restart
       currTrain.urStart(!);
     }
   }//end for-loop
 }//end discrete()
}//end class Calculating
```

Modeling Tool



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Conclusion and Future Work

Provide

- Object-Oriented Language for Hybrid Systems
- Code-Reuse, Better Control Logic Implementation

Future Work

- Developing Formal Verification Tool for Apricot
- Simulation and Animation with Apricot

Thanks

Thank you very much!