Applications of Program analysis in Model-Based Design

Prahlad Sampath (Prahlad.Sampath@mathworks.com)

Outline

- Model-Based Design overview and role of program analysis (20 mins)
- Data flow analysis (20 mins)
- Abstract interpretation (20 mins)
- Software model checking (20 mins)

Model-Based Design Overview

Model-Based Design

- Design activities
  - Specification, prototyping (at different levels of fidelity), design space exploration, code-generation, verification

- Use of appropriate abstractions for modelling – from algorithms to systems
  - Graphical languages where appropriate
  - Textual languages where appropriate
  - Provide a framework where these can be combined and analysed

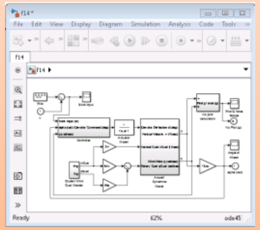
- Analysis is the corner stone of Model-Based Design
  - Different levels of adoption of Model-Based Design will use different kinds of analysis

Simulink Workflow

Dynamical System

Graphically model the system in Simulink

Simulink Block Diagram



Compilation: Convert from graphical model to some internal representation

Compiled Information (CI)

$$\begin{cases} X = [x_c, x_d] \\ \dot{x}_c = f_c(X, U, t) \\ x_d[n+1] = f_d(X, U, t) \\ y = g(X, U, t) \\ X(t_0) = X_0 \end{cases}$$

Execution Phase

Simulate

CI

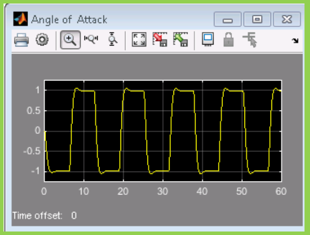
$$\begin{cases} X = [xc, xd] \\ \dot{x}_c = f(X, u_1, u_2, t) \\ x_d[n+1] = g(X, u_1, u_2, t) \\ y = h(X, u_1, u_2, t) \\ X(t_0) = X_0 \end{cases}$$

Solver Info

$t(n+1) = \ ...$

Present the solution (logging, scopes)

Analyze Results



Modelling Formalisms

- Linear systems (ODEs)

$$\frac{dv}{dt} = -g,$$

$$\frac{dx}{dt} = v,$$

$$v_0 = 15 \text{ m/s} \qquad x_0 = 10 \text{ m}$$

$$v^+ = -\kappa v^-, \qquad x = 0$$

```
>>sldemo_bounce_two_integrators
```

Modelling Formalisms

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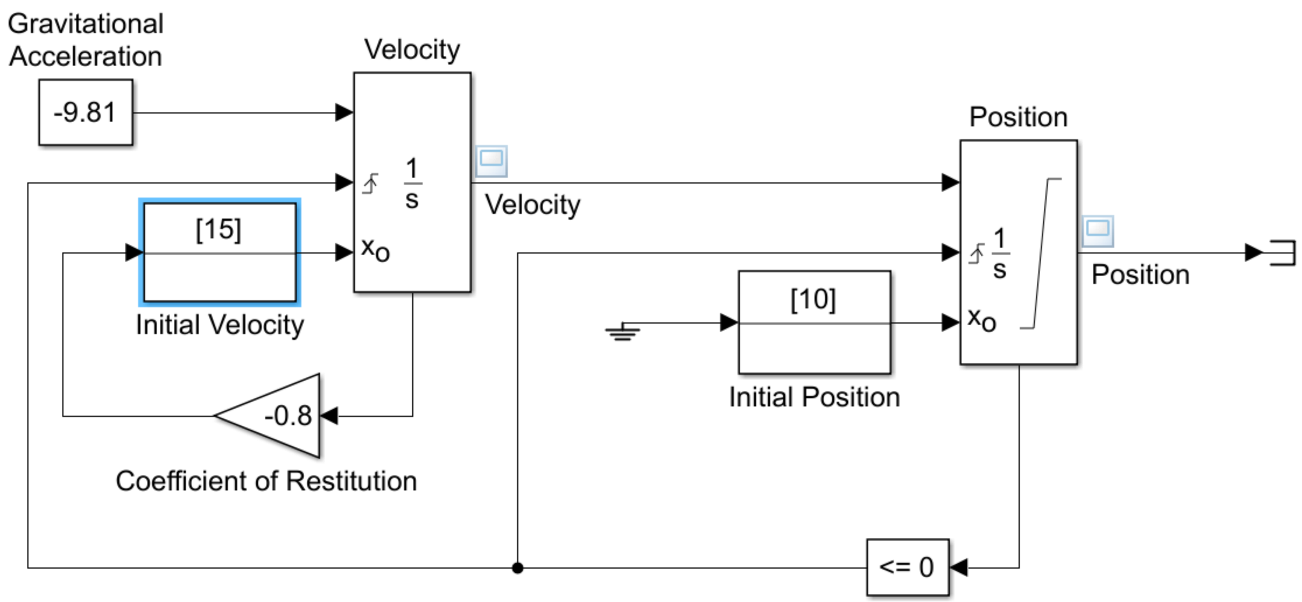


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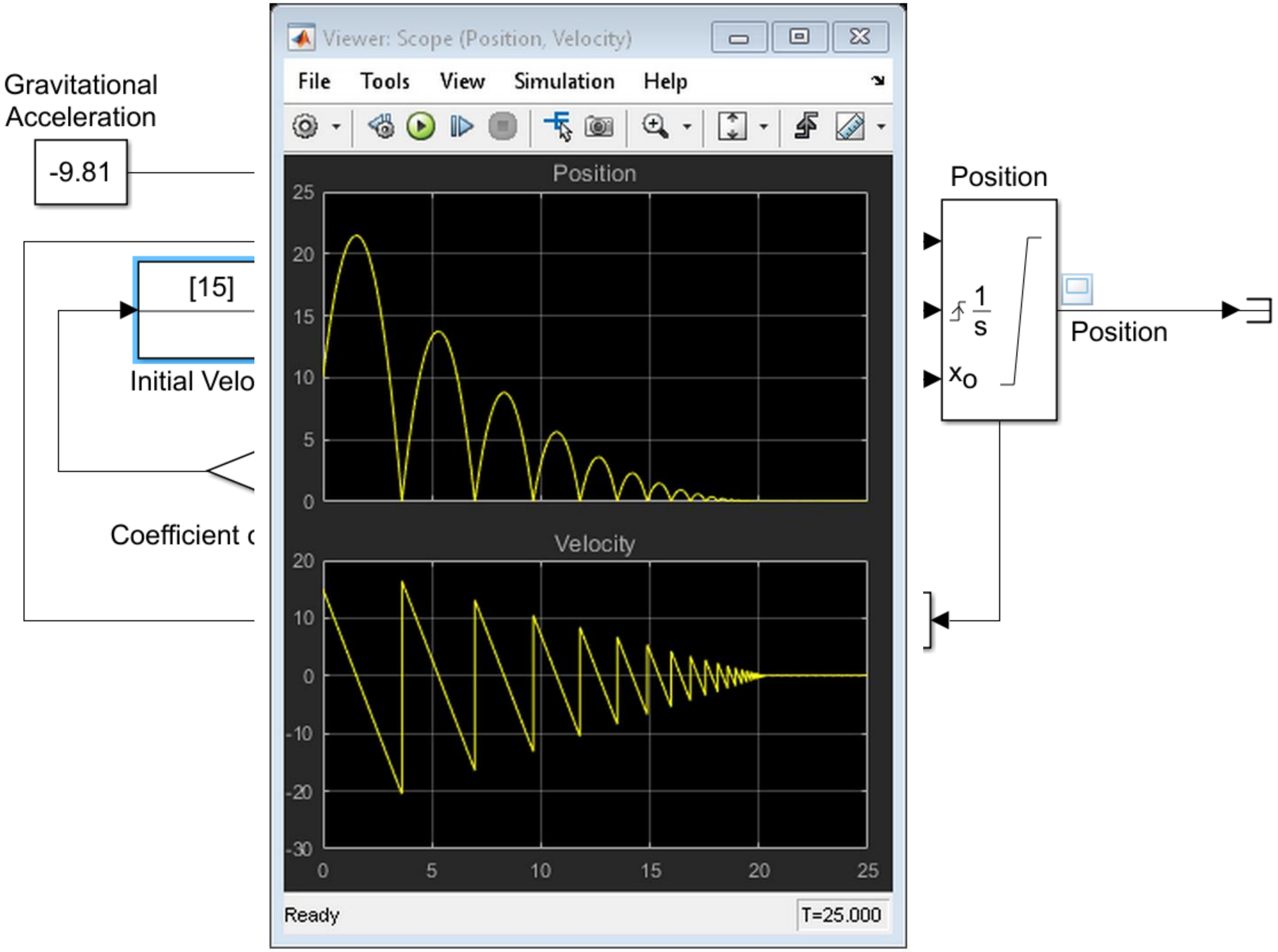


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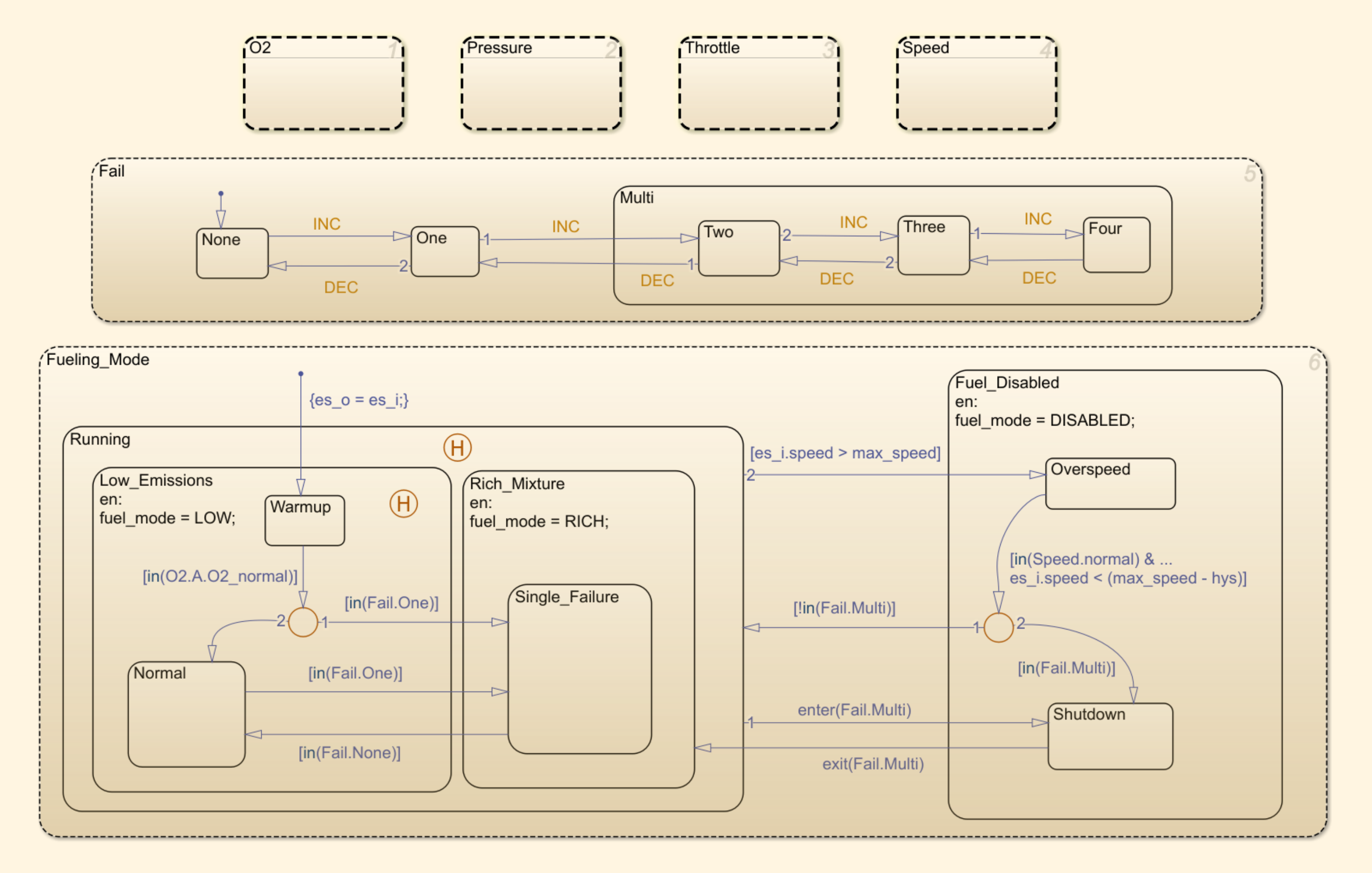
Modelling Formalisms

- Linear systems (ODEs)
- Hierarchical state machines



\>>sldemo_fuelsys

Modelling Formalisms

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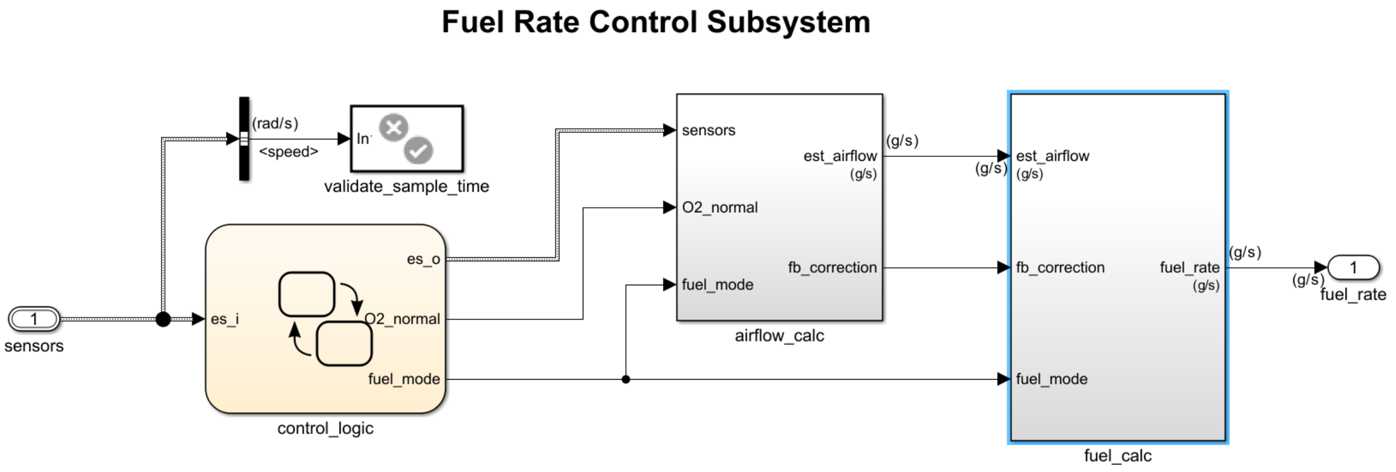


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```

Modelling Formalisms

- Linear systems (ODEs)
- Hierarchical state machines
- Tabular specifications

STATES	TRANSITIONS: IF	TRANSITIONS: ELSE-IF(2)
Normal	[ALARM] Alarm	

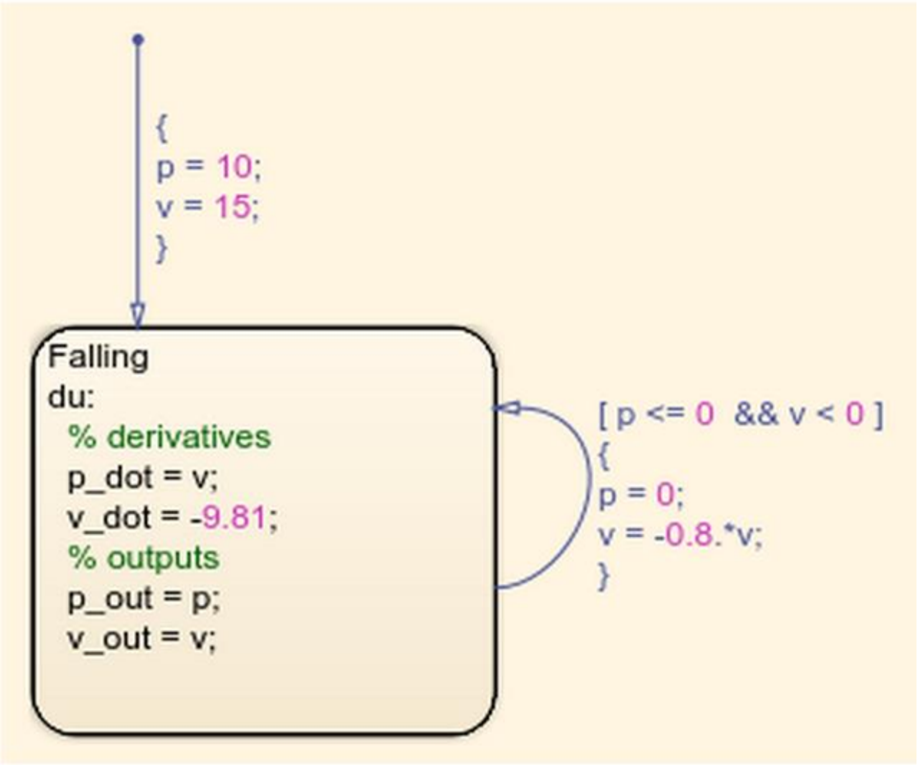
Off
entry:
boiler_cmd = 0;
doneWarmup = false;
	[temp <= reference_low]
	
	Warmup	

Warmup entry: boiler_cmd = 2;	[doneWarmup] On	[after(10, sec)] {doneWarmup = true;} On
On entry: boiler_cmd = 1;	[temp >= reference_high] Off	
Alarm entry: boiler_cmd = 0;	[CLEAR] Normal	

```
>>ex_stt_boiler
```

Modelling Formalisms

- Linear systems (ODEs)
- Hierarchical state machines
- Tabular specifications
- Hybrid automata

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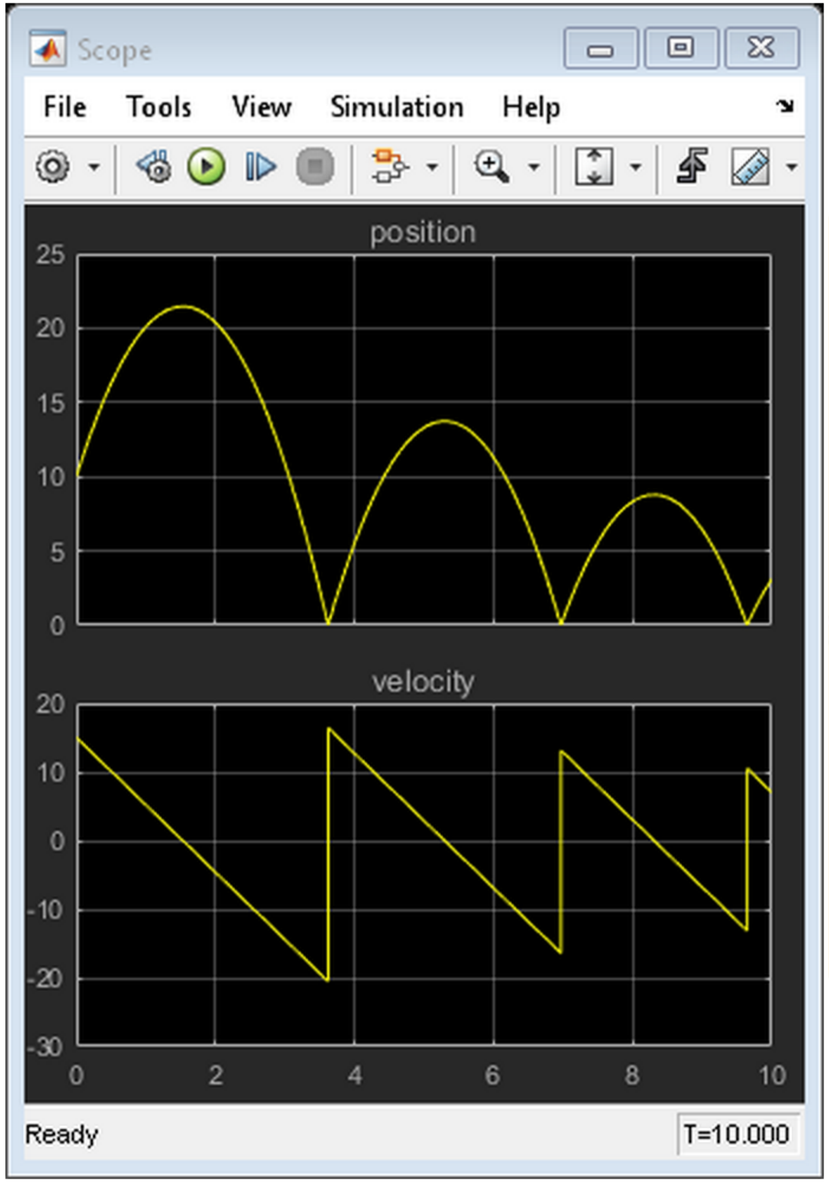


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Modelling Formalisms

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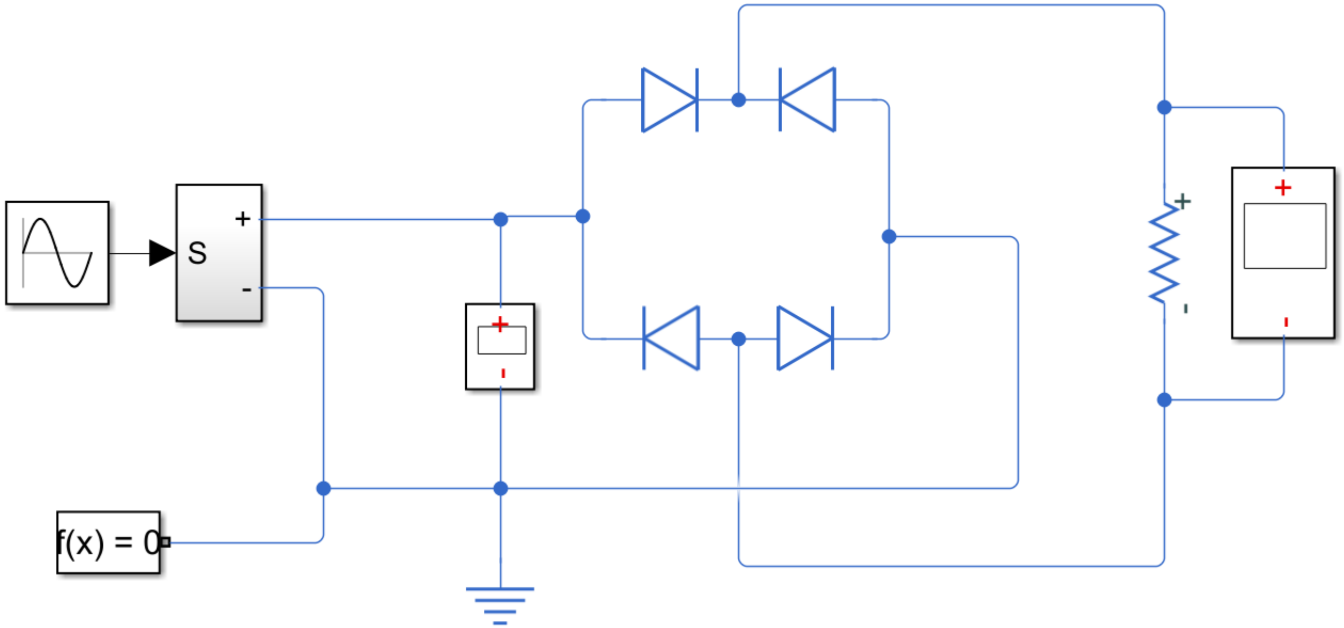
- Differential algebraic system (acausal models for physical systems)



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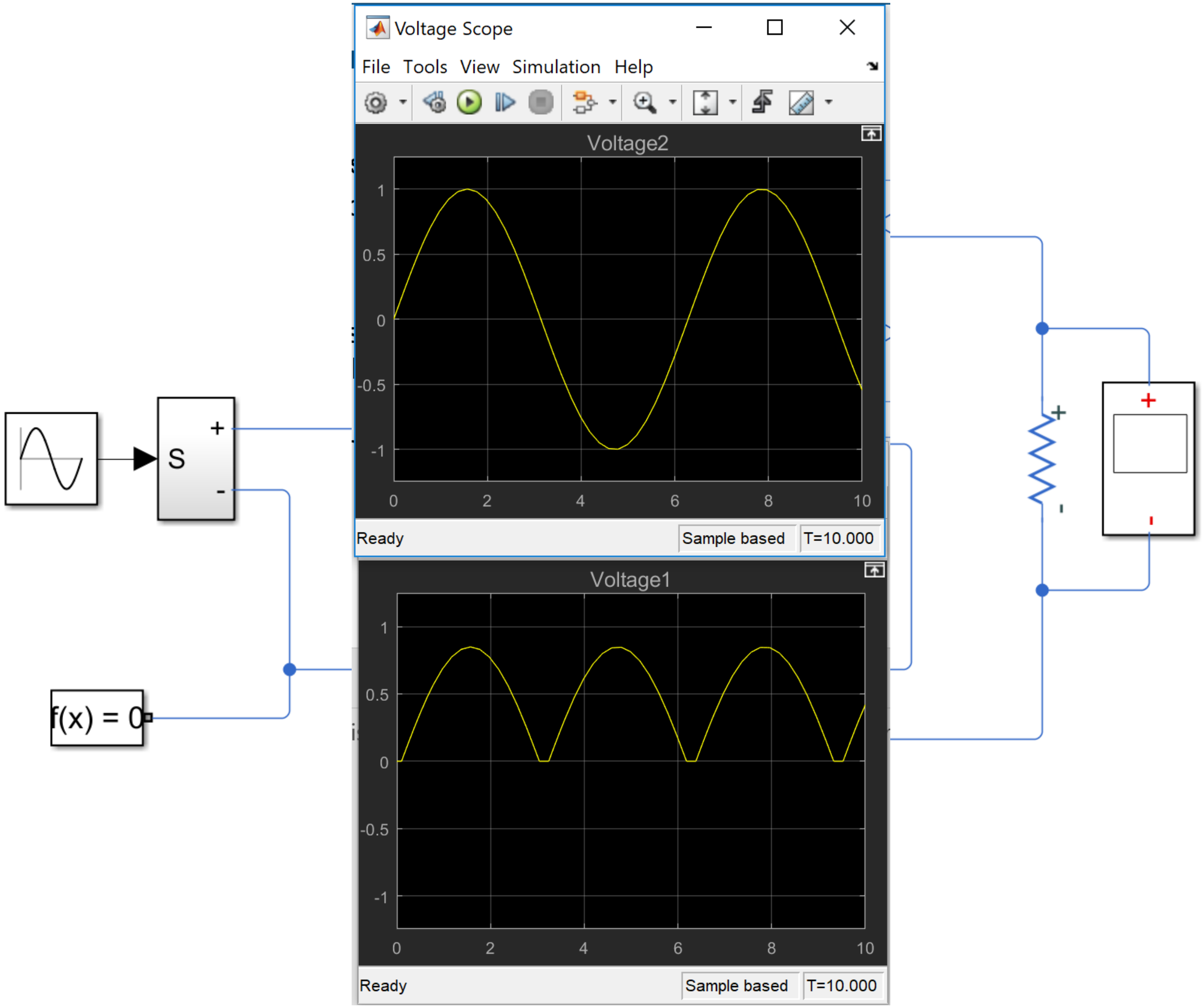
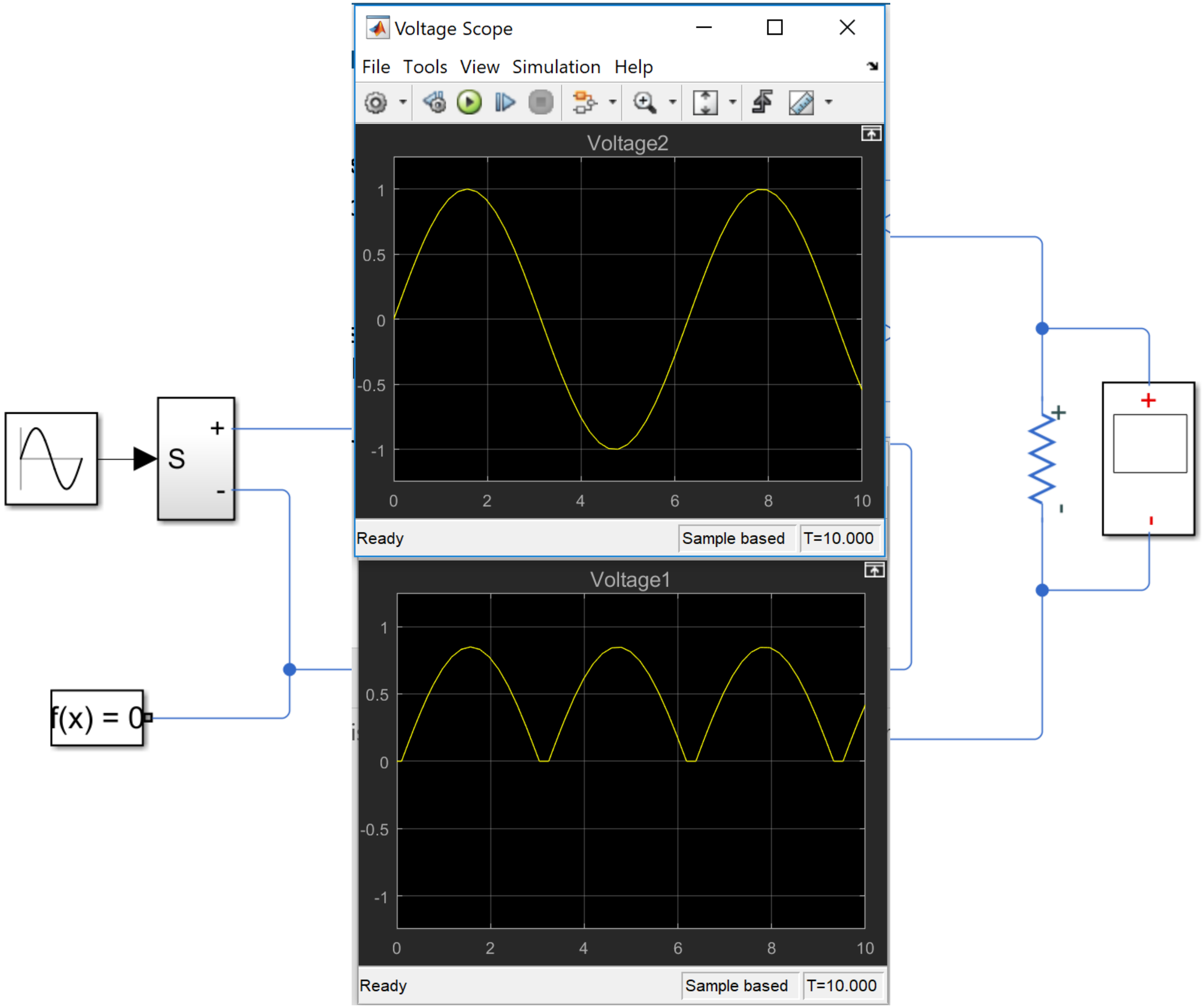


Modelling Formalisms

- Linear systems (ODEs)
- Hierarchical state machines
- Tabular specifications
- Hybrid automata
- Differential algebraic system (acausal models for physical systems)
- Discrete event systems
- Procedural code



Model-Based Design – Hardware

- Hardware connectivity
- Real time simulation

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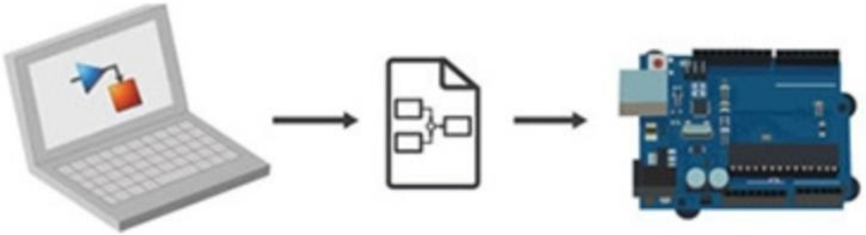
- Real time simulation

With MATLAB support package for Arduino, the Arduino is connected to a computer running MATLAB. Processing is done on the computer with MATLAB.

Model-Based Design – Hardware

- Hardware connectivity
- Real time simulation

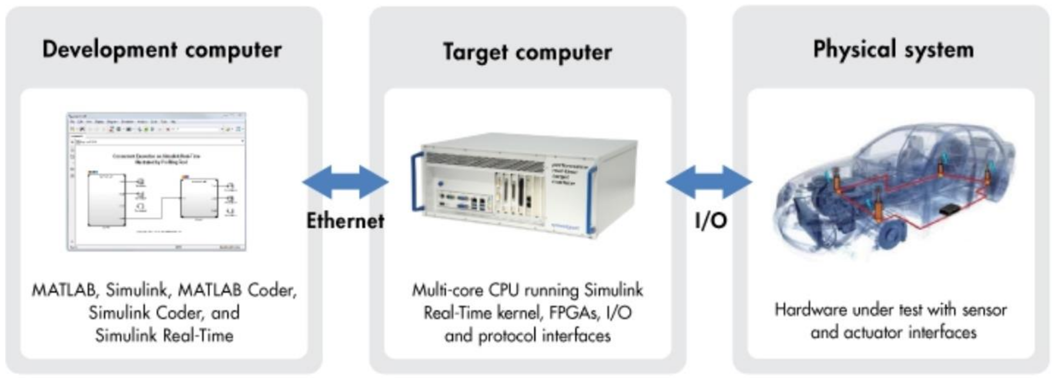


With Simulink support package for Arduino, you develop the algorithm in Simulink and deploy to the Arduino using automatic code generation. Processing is then done on the Arduino.

Model-Based Design – Hardware

- Hardware connectivity
- Real time simulation

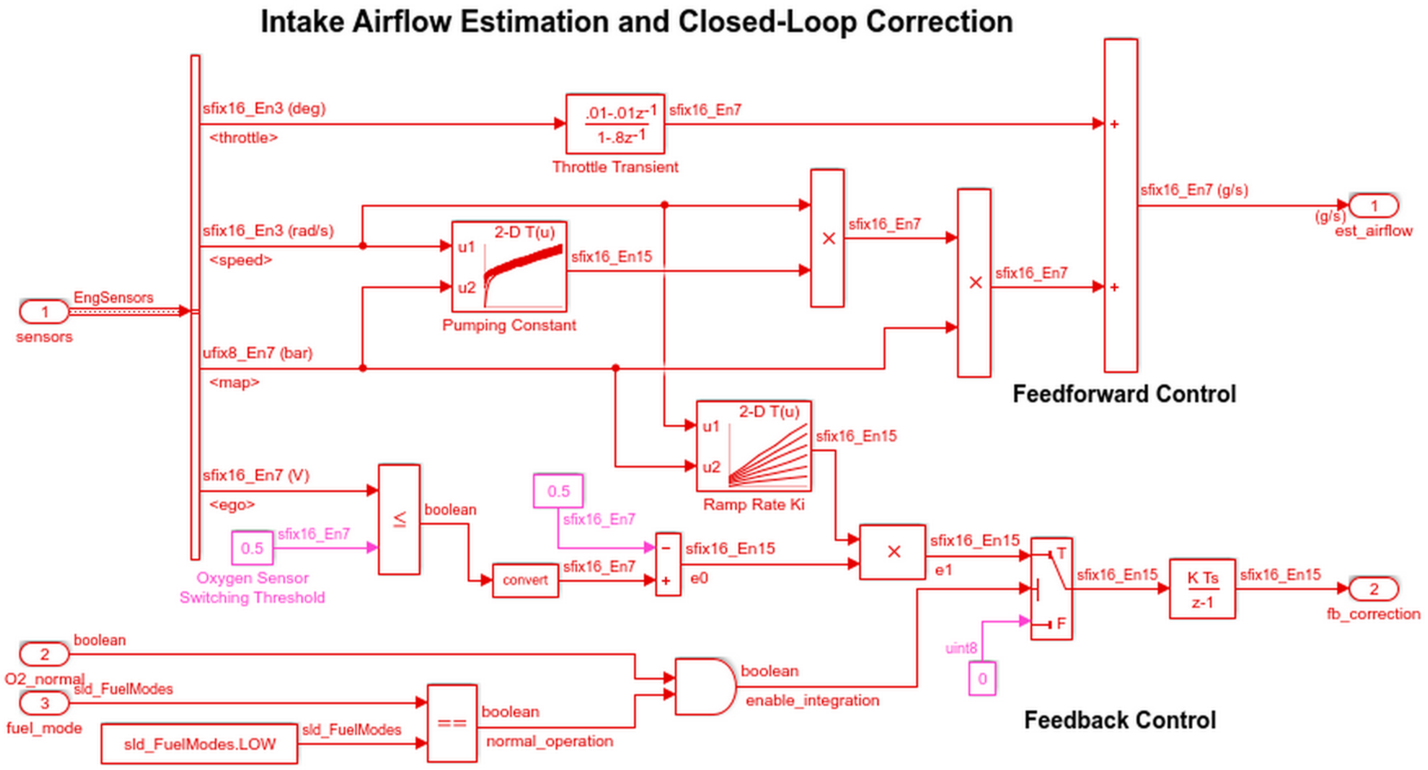
Typical real-time simulation and testing environment using Simulink Real-Time.



Typical real-time simulation and testing environment using Simulink Real-Time.

Model-Based Design – Code generation

- Programming
  - Code generation
  - Design optimizations
  - Verification



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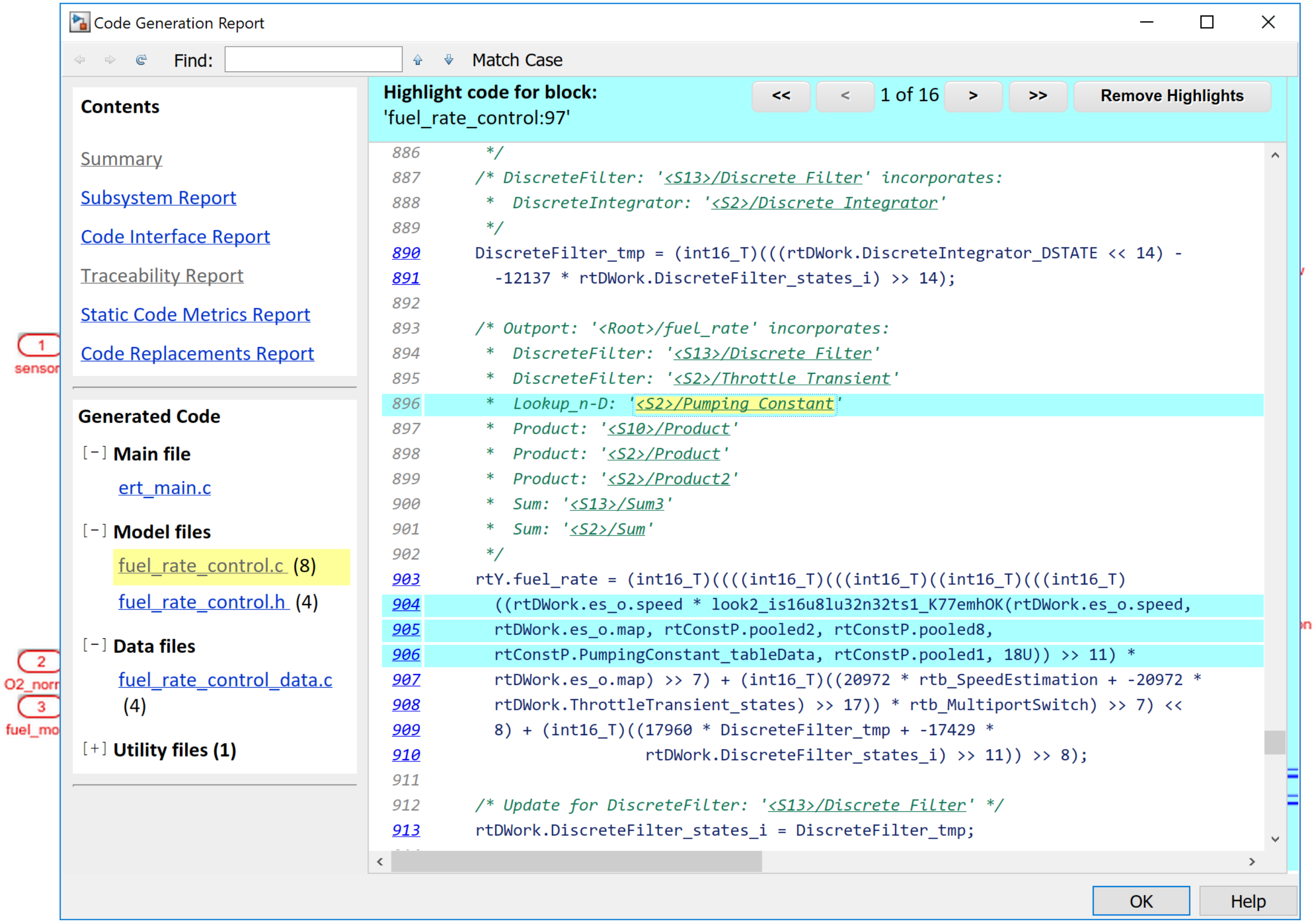

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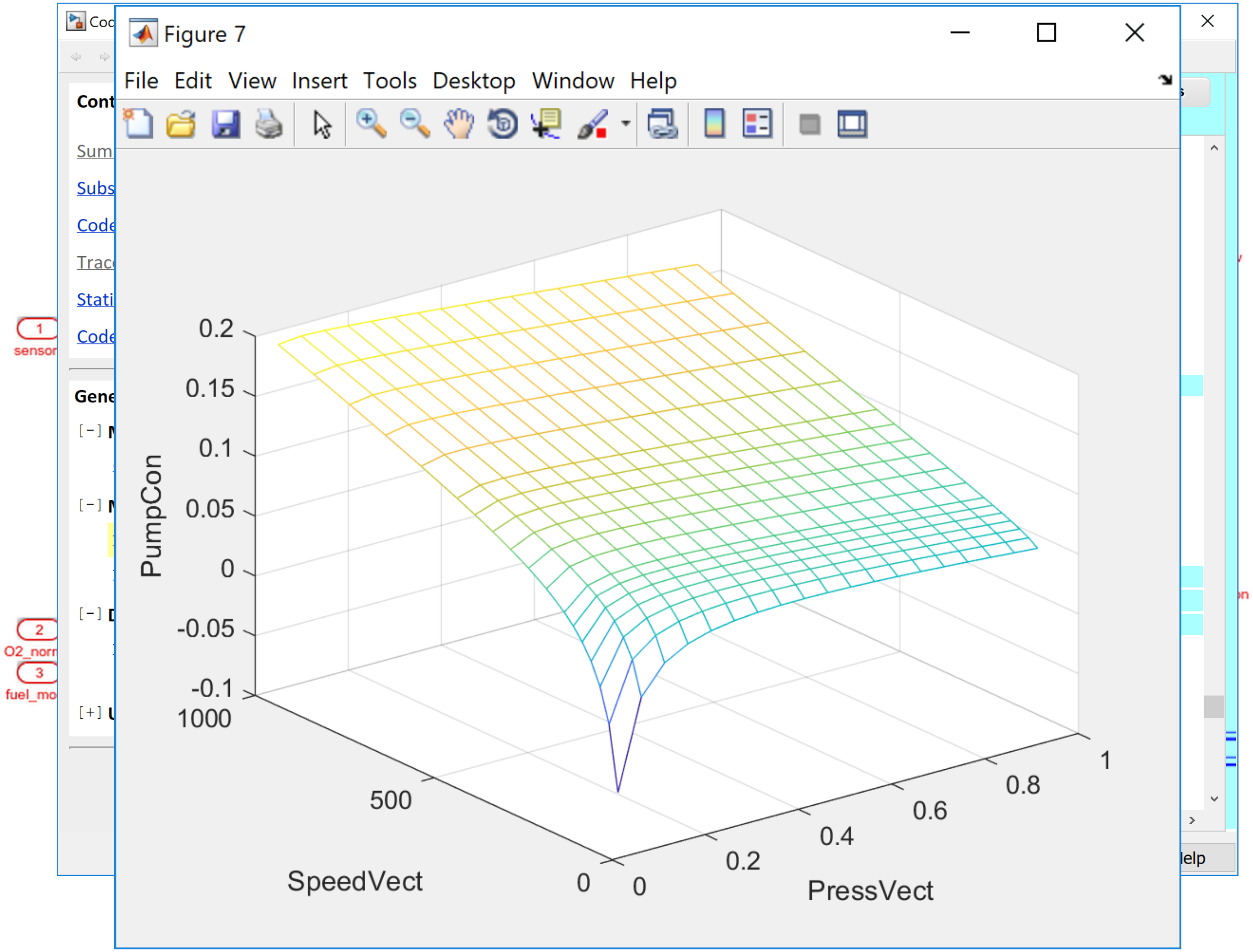

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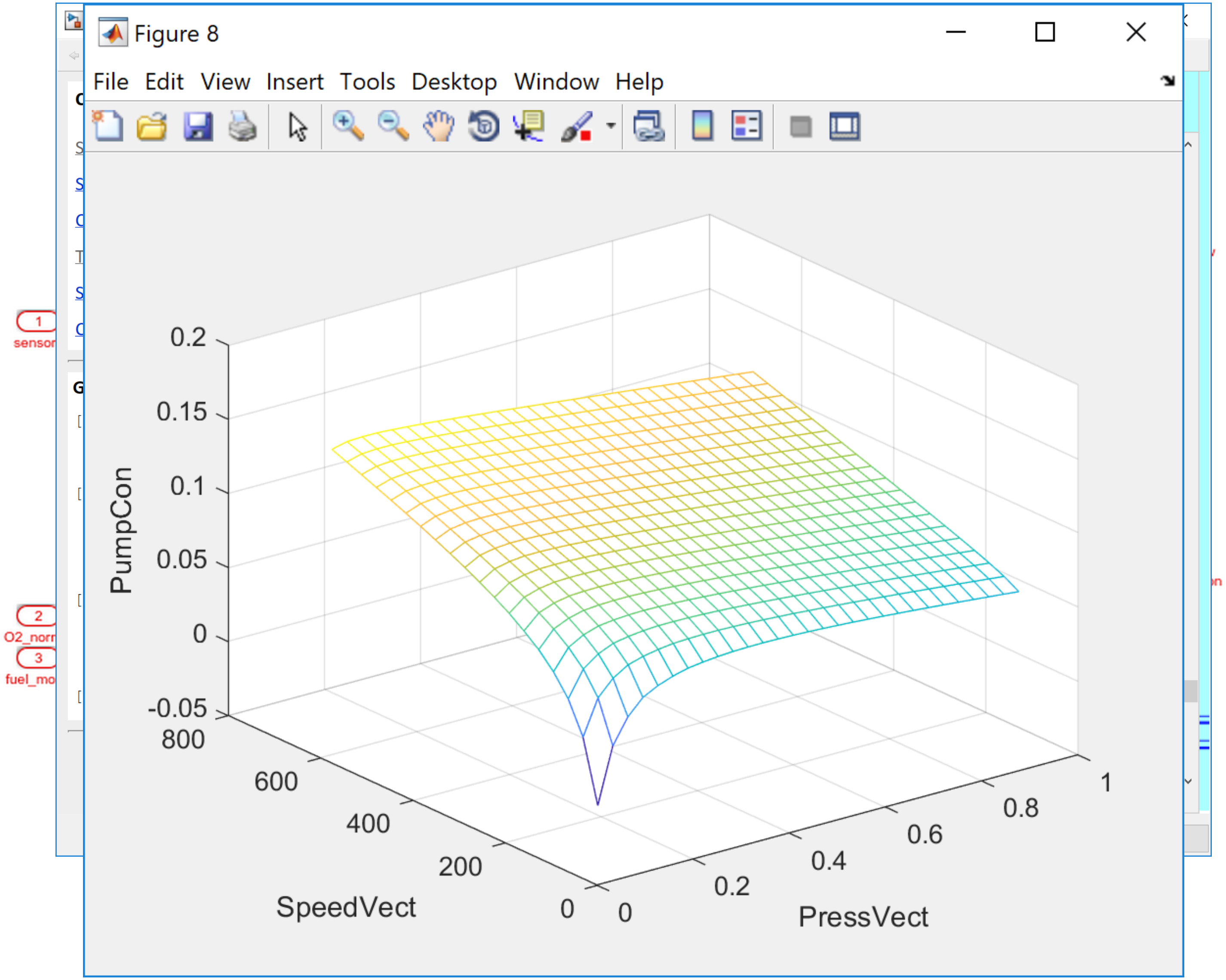

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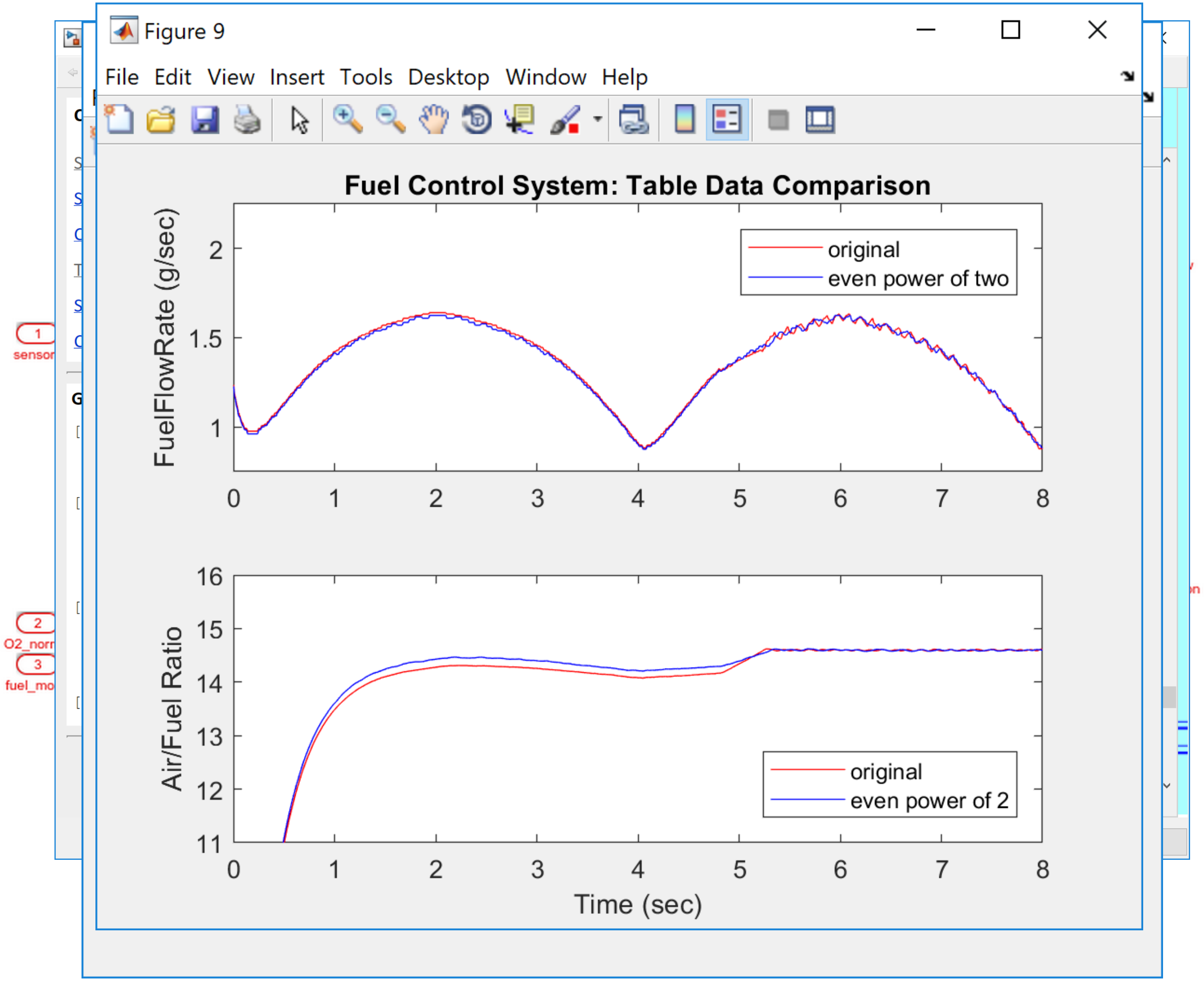

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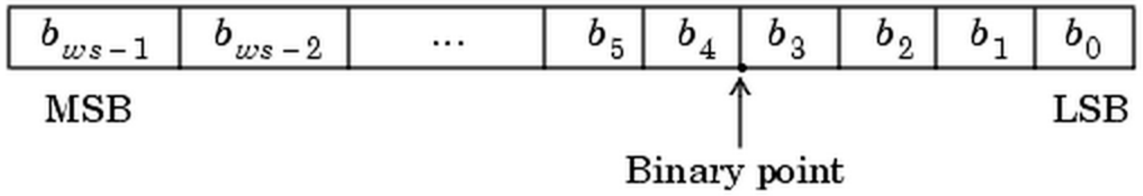

- Data-type design

Model-Based Design – Code generation

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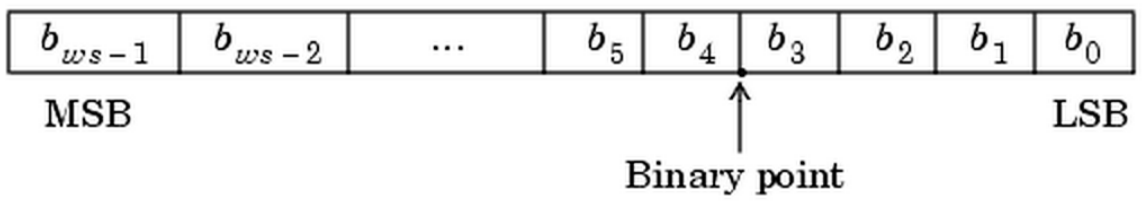
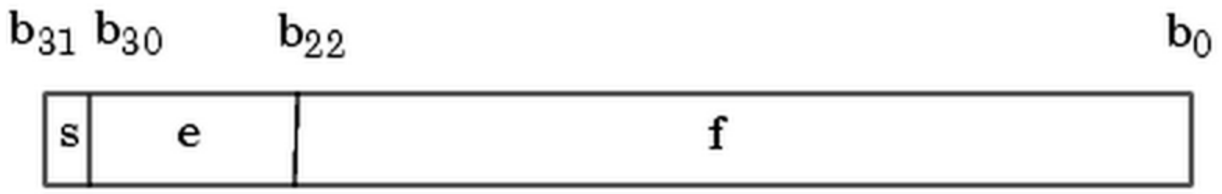


- Data-type design



- Systematic verification
  - Coverage analysis
  - Detect run-time error
  - Property proving

Where does Program Analysis fit into this picture?

- Techniques for reasoning about behaviour
  - Spanning many programming paradigms

- Well developed abstraction techniques
  - Abstraction vs. approximation!

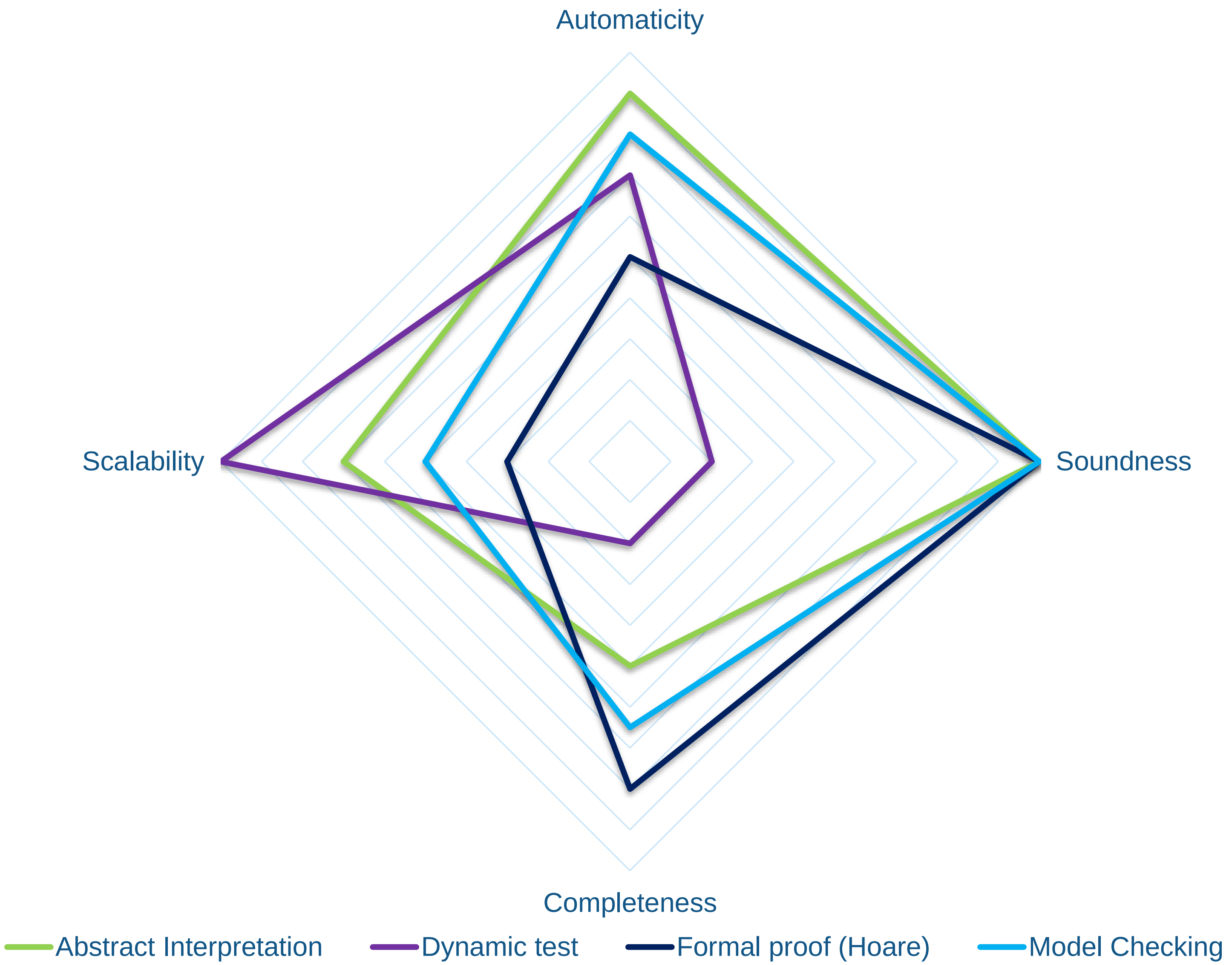
- Scalable algorithms
  - Algorithms that scale to millions of lines of code

- Active area of research
  - New techniques and algorithms

Four properties for a tool

- Automaticity
  - Is the tool press-button or does it require user interaction ?
- Soundness
  - Are results trustable ?
- Completeness
  - Will the tool find all my bugs ?
- Scalability
  - How does the tool react to large programs ?

Comparison of formal methods properties

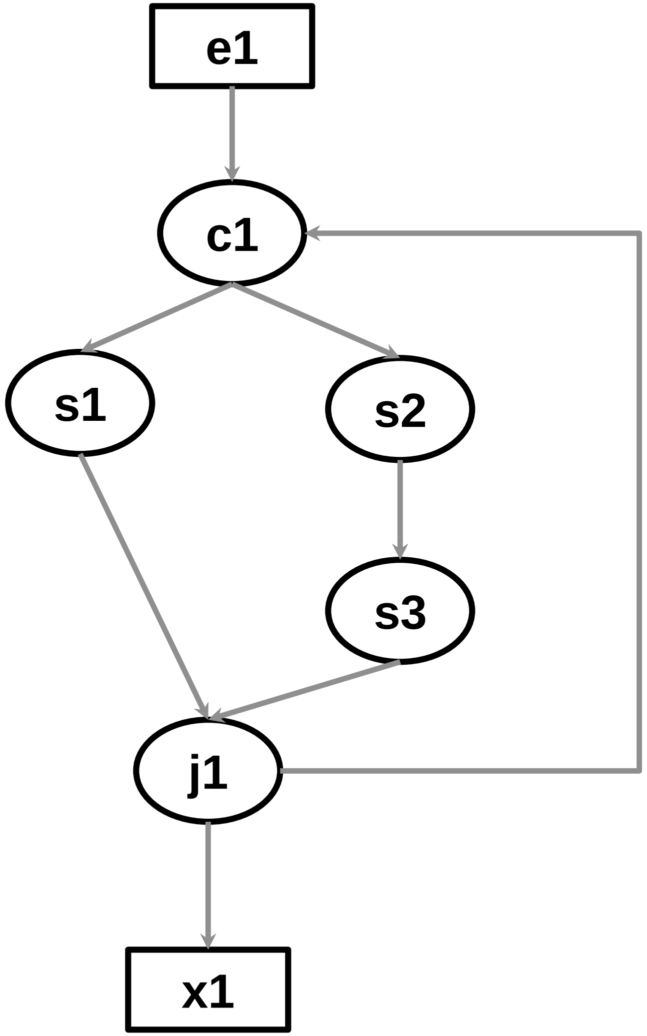


It’s all about the Workflow!

Data Flow Analysis

A Refresher

- Infer “flows” in programs
  - Reason about program statements
  - System of equations that capture the “flow” across statements in a program
  - Algorithms well suited for program graphs
  - Basis for compiler optimizations



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- Generate a set of equations
  - Over a lattice domain
  - Solution calculated by using fixpoint iteration

$$entry(s1) = exit(e1)$$

$$\ldots$$

$$entry(c1) = entry(e1) \cup exit(j1)$$

$$exit(c1) = entry(c1) - kill(c1) \cup gen(c1)$$

$$\ldots$$

$$entry(j1) = exit(s3) \cup exit(s3)$$

A Refresher

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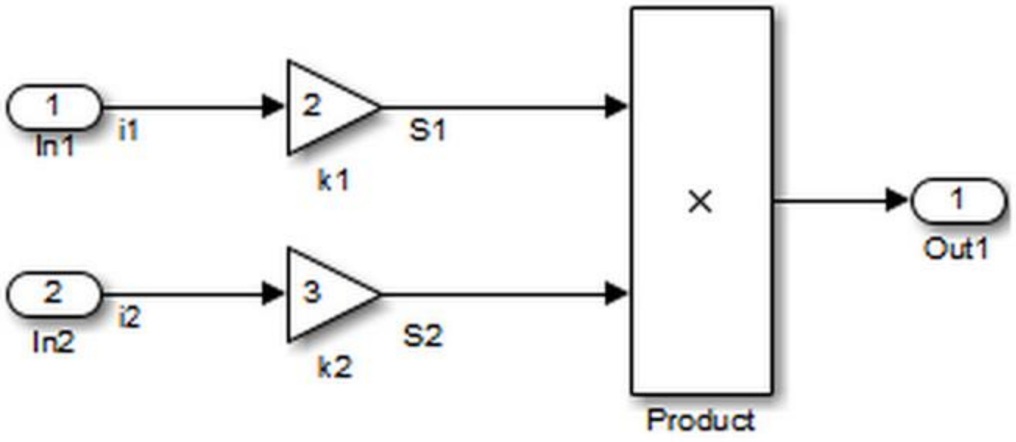
- Forward vs. Backward analysis
- Context sensitivity
- Flow sensitivity
- Inter vs. Intra procedural analysis
- …

Applications of data-flow analysis

- Compiler optimizations
  - Expression folding
  - Variable reuse (RAM)
  - Constant folding
  - Strength reduction



Applications of data-flow analysis

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```
/* Model step function */
void exprfld_step(void)
{
  /* Gain: '<Root>/Gain' incorporates:
   *  Inport: '<Root>/In1'
   */
  exprfld_B.S1 = exprfld_P.Gain_Gain * exprfld_U.i1;

  /* Gain: '<Root>/Gain1' incorporates:
   *  Inport: '<Root>/In2'
   */
  exprfld_B.S2 = exprfld_P.Gain1_Gain * exprfld_U.i2;

  /* Outport: '<Root>/Out1' incorporates:
   *  Product: '<Root>/Product'
   */
  exprfld_Y.Out1 = exprfld_B.S1 * exprfld_B.S2;
}
```

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void exprfld_step(void)
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   *  Gain: '<Root>/Gain1'
   *  Inport: '<Root>/In1'
   *  Inport: '<Root>/In2'
   *  Product: '<Root>/Product'
   */
  exprfld_Y.Out1 =
     exprfld_P.Gain_Gain *
     exprfld_U.i1 *
     (exprfld_P.Gain1_Gain * exprfld_U.i2);
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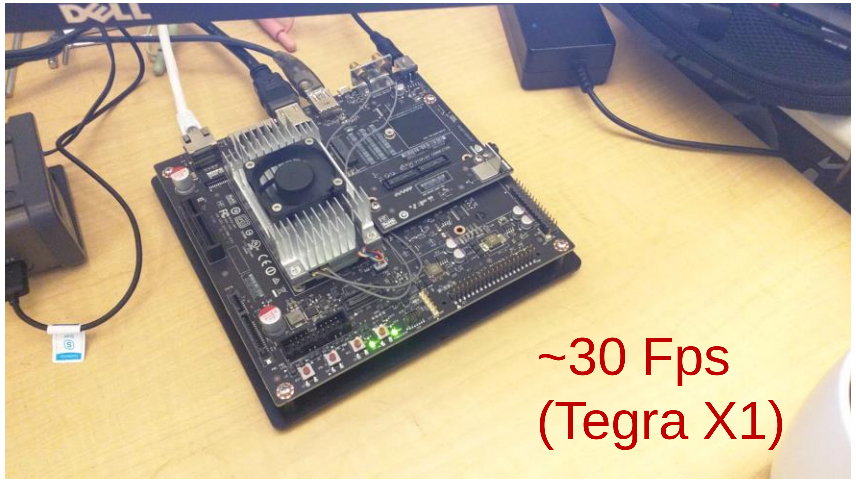
```

Applications of data-flow analysis

- Compiler optimizations
  - Expression folding
  - Variable reuse (RAM)
  - Constant folding
  - Strength reduction
- Parallelization
  - GPU Coder™

Deploy with GPU Coder™

Alexnet



Vehicle Detection

People detection

Lane detection

Debugging Workflow

- Problem:

Debugging Workflow

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  - You have a large model, with an error. How should you go about localizing the error?

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    - Simulate the model
    - Insert break-points
    - Visualize signals/outputs

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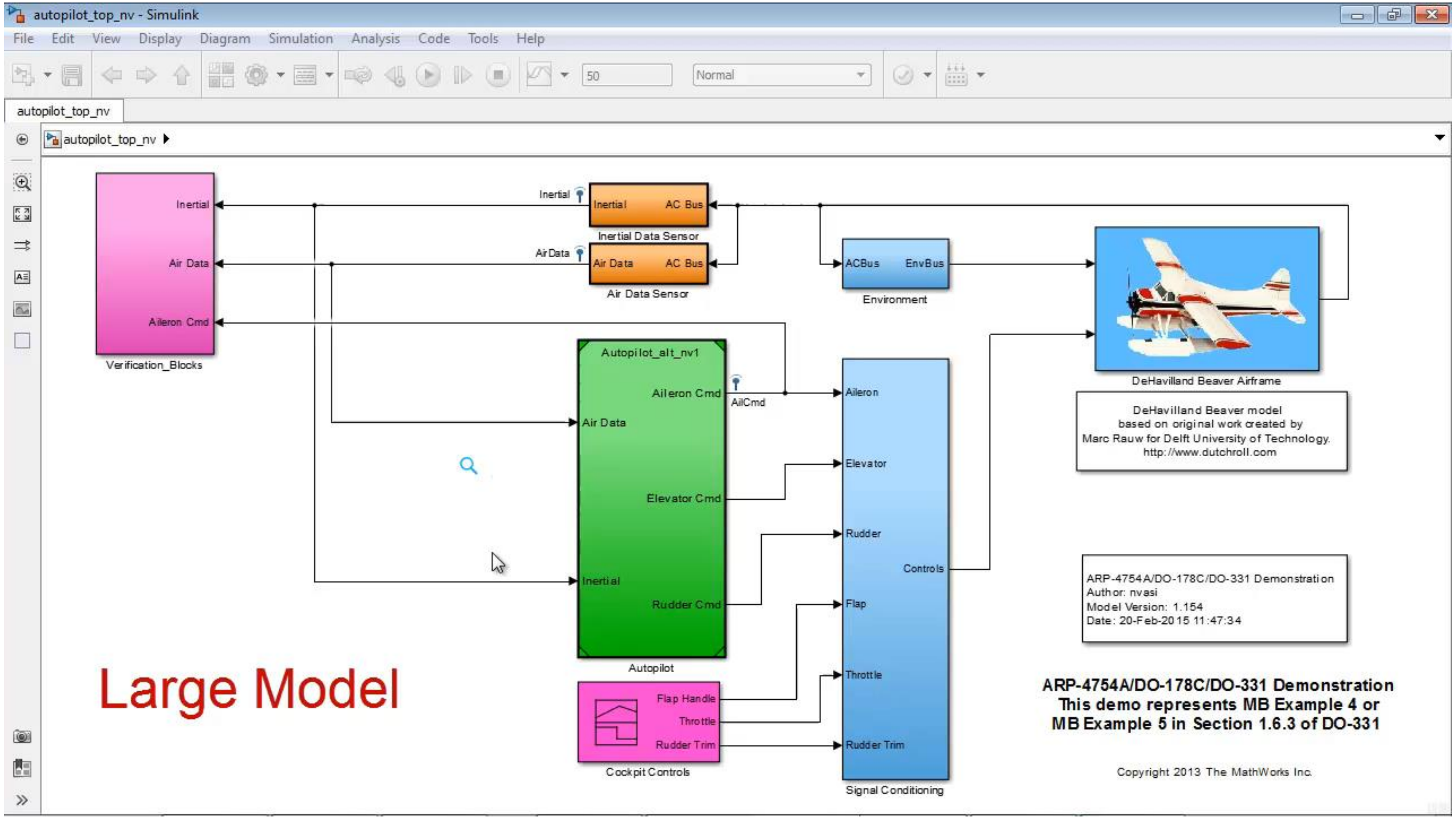
Google search: “simulink model slicer youtube”
https://www.youtube.com/watch?v=48EAr508mmw

Slicing Models to Reduce Complexity



Abstract Interpretation

Prove that no division by zero occurs here

```
// x is an unknown parameter
float runTheLoop(int x)
{
  if (x<0 || x>100)
    return 1.0;
  float in = input();
  float current_out = 0.0;
  float prev_out = 0.0;
  int i;
  for (i=0;i<=x;i++)
    {
      current_out = in*0.1 + prev_out*0.9;
      prev_out = current_out;
      if (random())
    prev_out = 0.0;
      in = input();
    }

  current_out = current_out + 3.0;

  return 1/current_out;
}
```

Prove that no division by zero occurs here

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Clearly testing is not practicable

- Too many unknown

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Philosophy of AI to prove correctness:

- You don't need the exact value of `current_out` to prove absence of ZDIV
- Having a *less precise* information
  e.g. `current_out >= 0.2`
  is sufficient

Formalization of the concrete semantics of the program

States of the program

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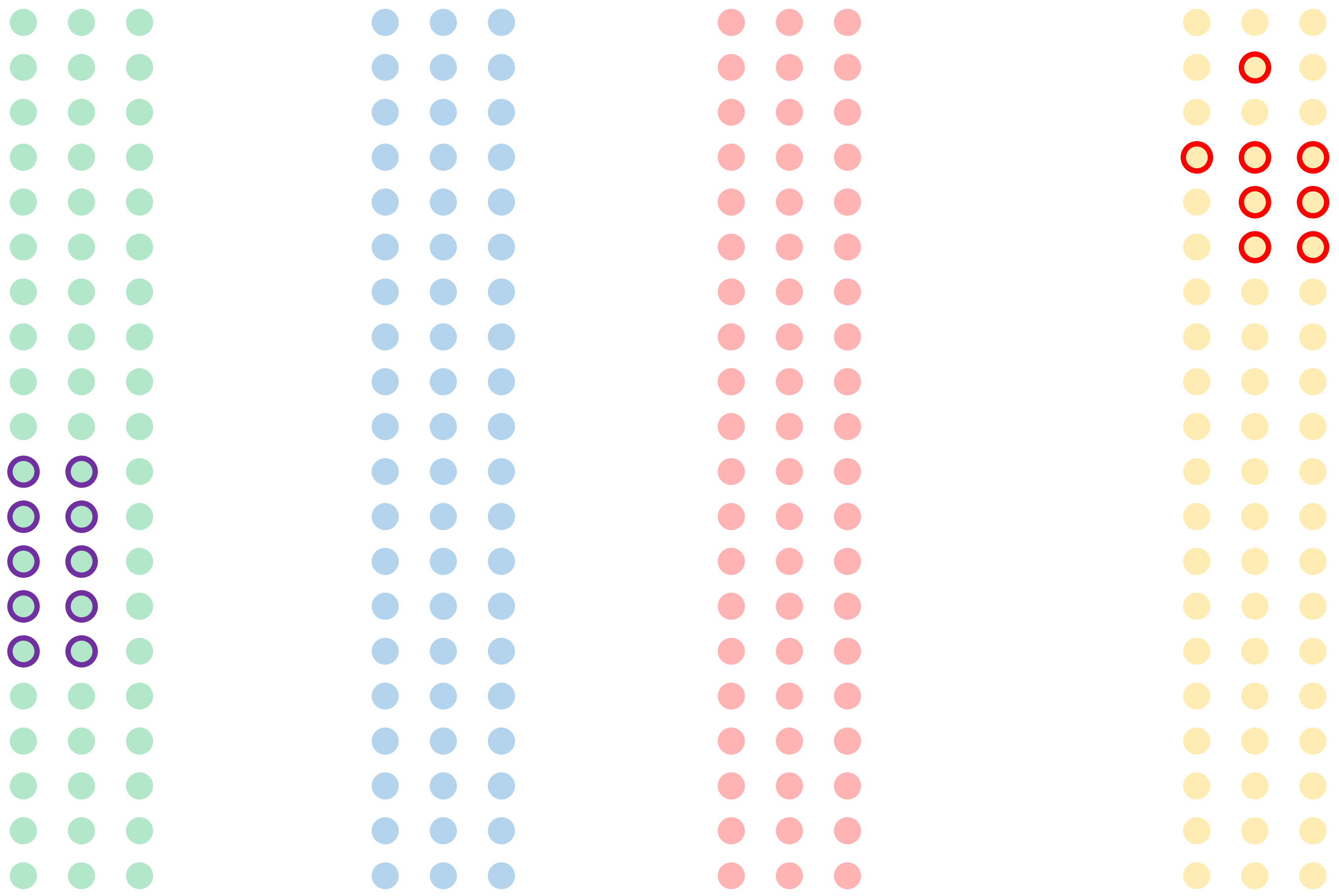

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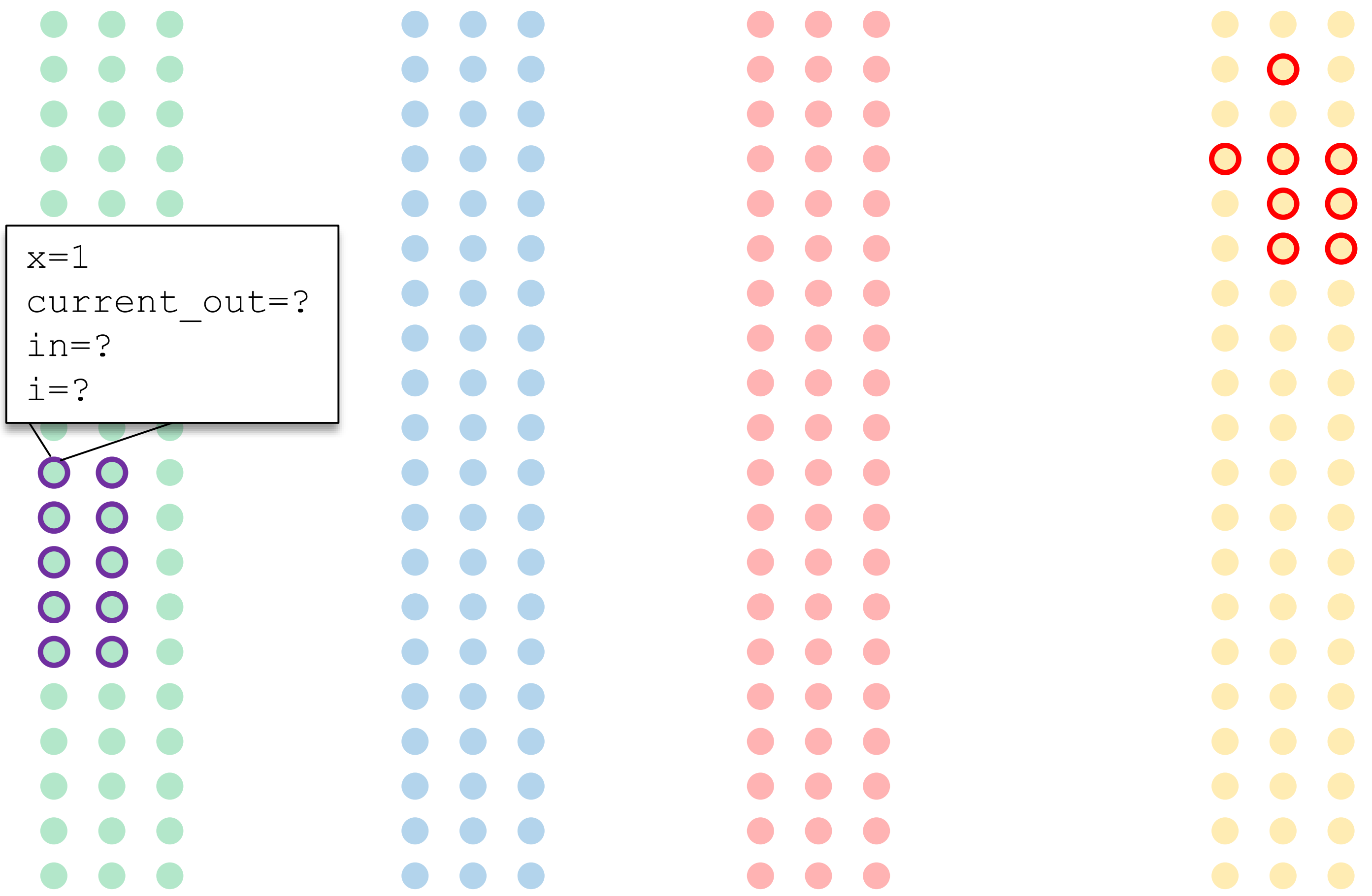

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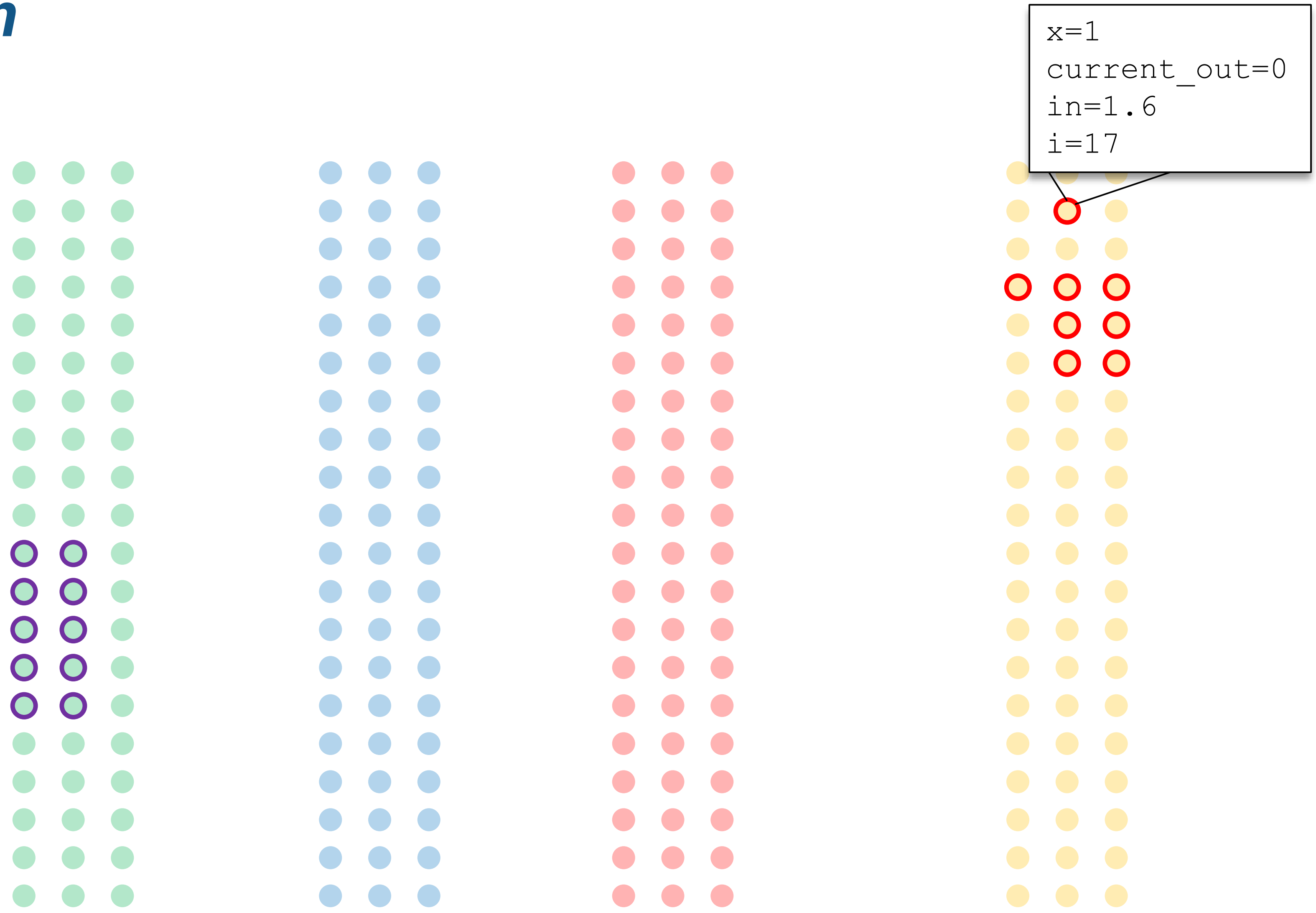

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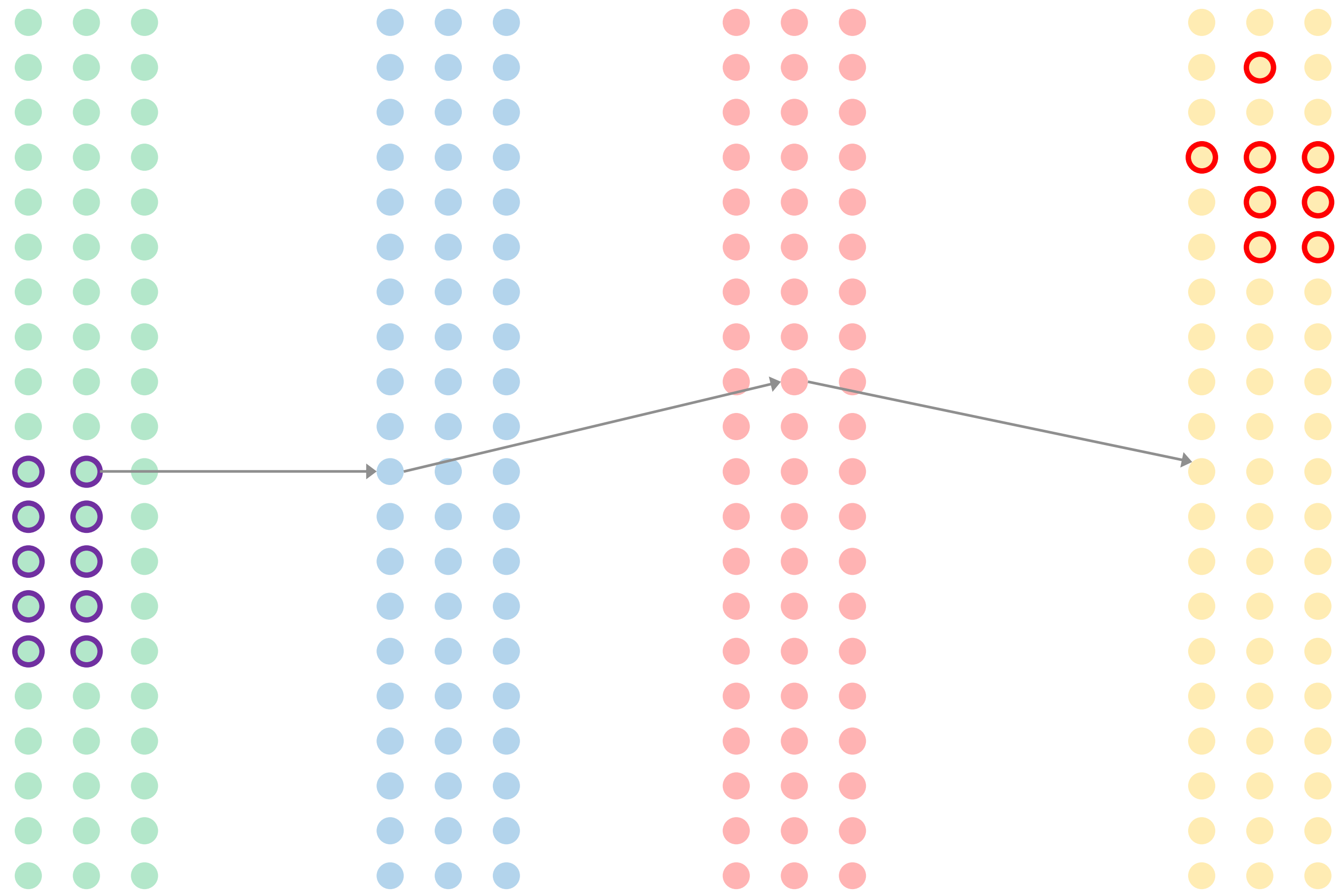

Infinite state machine that simulates program execution

Formalization of the concrete semantics of the program

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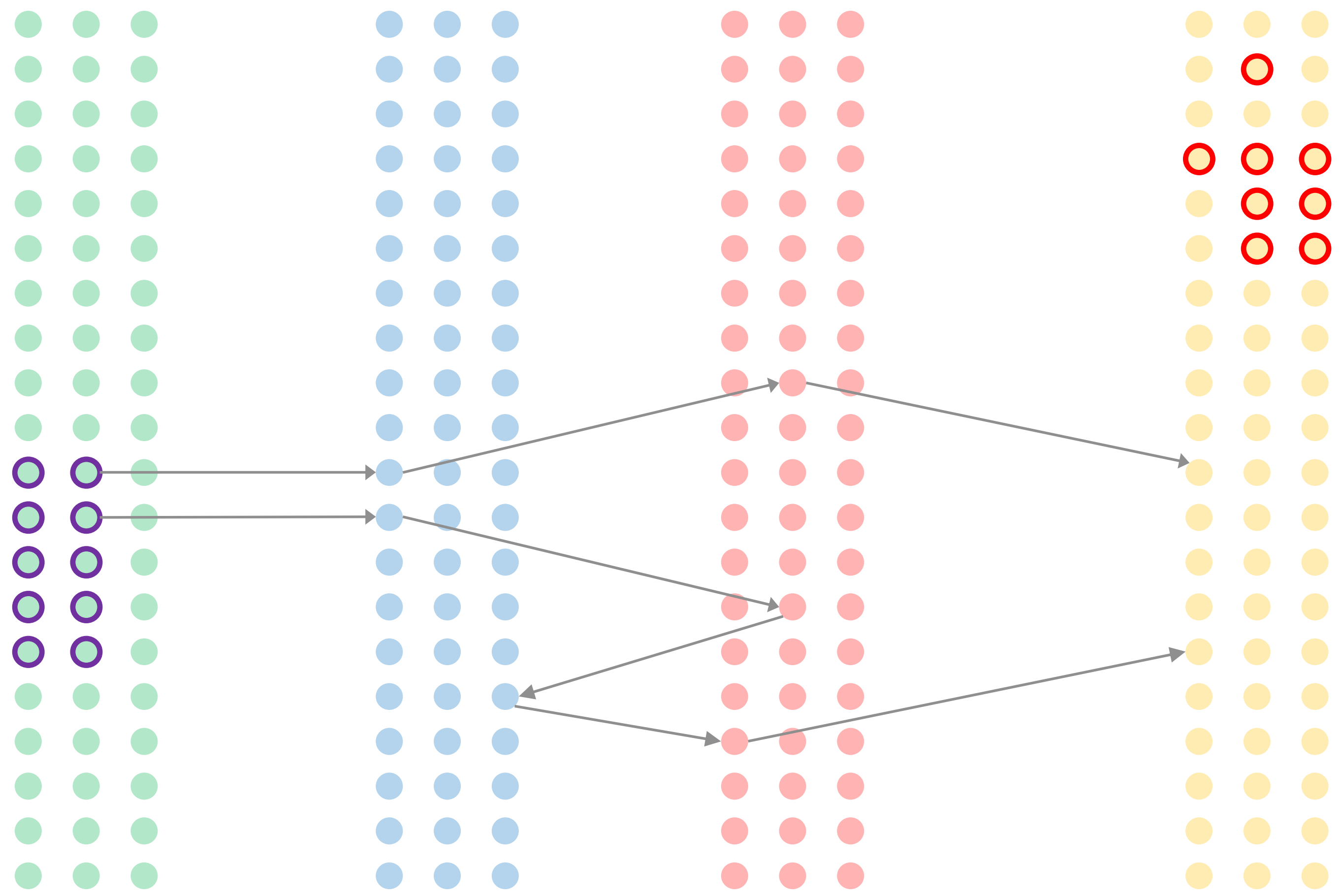
   return 1/current_out;
}
```



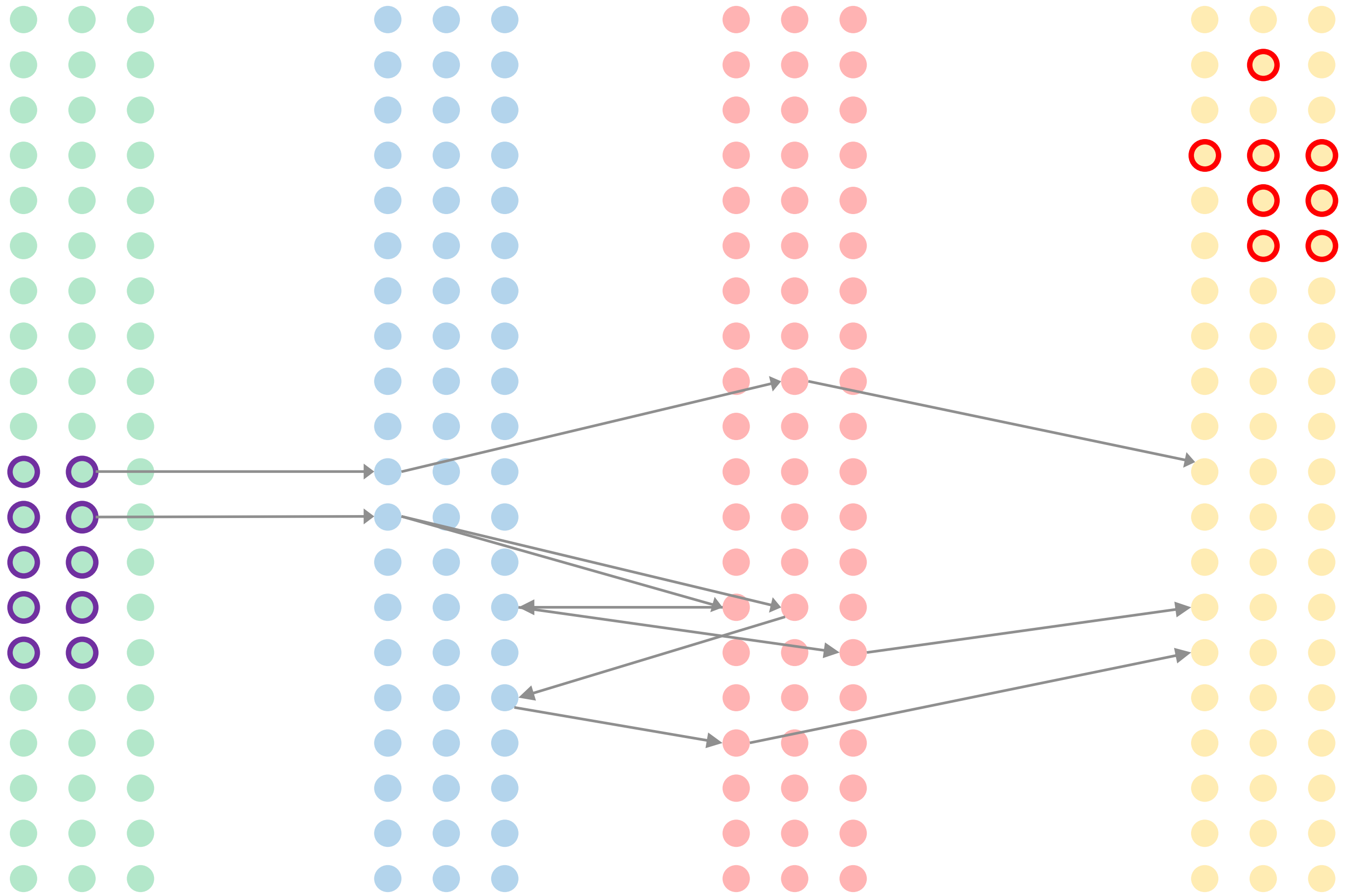
Infinite state machine that simulates program execution

Formalization of the concrete semantics of the program
Traces semantics

```
// x is an unknown parameter
float runTheLoop(int x)
{
  if (x<0 || x>100)
    return 1.0;
  float in = input();
  float current_out = 0.0;
  float prev_out = 0.0;
  int i;
  for (i=0;i<=x;i++)
    {
    current_out = in*0.1 + prev_out*0.9;
    prev_out = current_out;
    if (random())
  prev_out = 0.0;
    in = input();
    }

  current_out = current_out + 3.0;

  return 1/current_out;
}
```



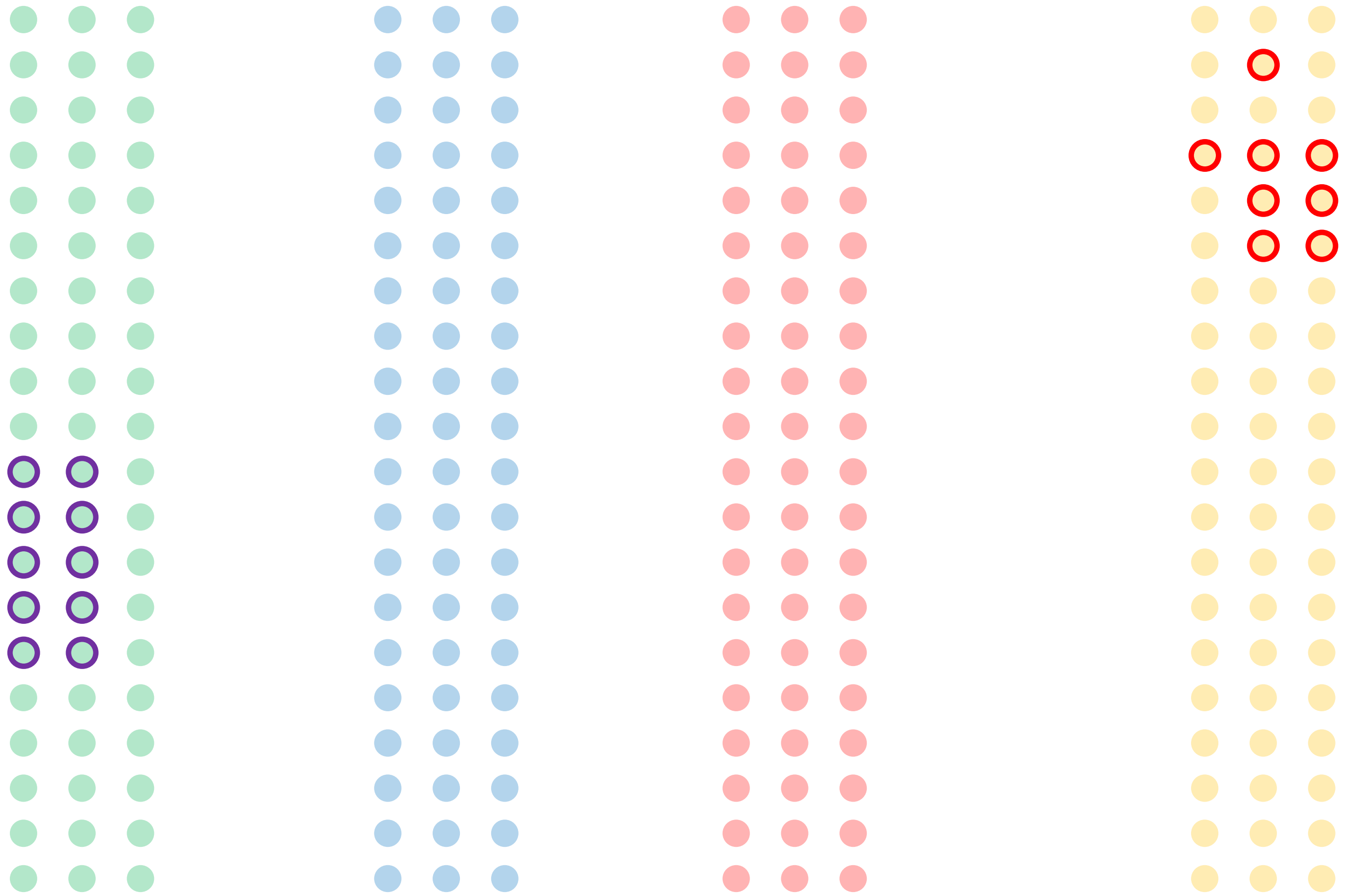
Infinite state machine that simulates program execution

Formalization of the collecting semantics of the program
Invariants semantics

```
// x is an unknown parameter
float runTheLoop(int x)
{
  if (x<0 || x>100)
    return 1.0;
  float in = input();
  float current_out = 0.0;
  float prev_out = 0.0;
  int i;
  for (i=0;i<=x;i++)
    {
      current_out = in*0.1 + prev_out*0.9;
      prev_out = current_out;
      if (random())
    prev_out = 0.0;
      in = input();
    }

  current_out = current_out + 3.0;

  return 1/current_out;
}
```



Interate until no new states are reached

Formalization of the collecting semantics of the program
Invariants semantics

```
// x is an unknown parameter
float runTheLoop(int x)
{
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    return 1.0;
  float in = input();
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  float prev_out = 0.0;
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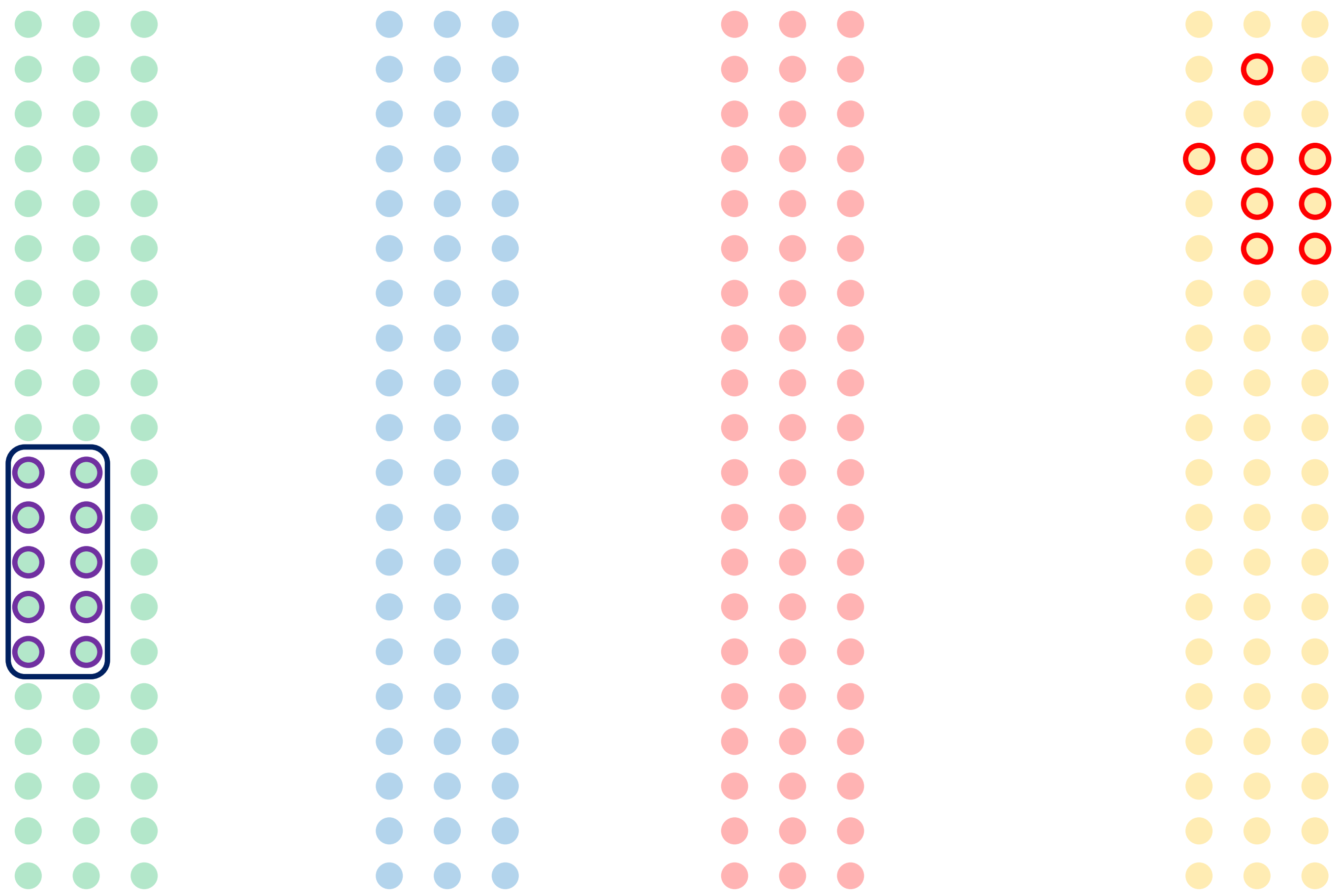
    {
      current_out = in*0.1 + prev_out*0.9;
      prev_out = current_out;
      if (random())
    prev_out = 0.0;
      in = input();
    }

  current_out = current_out + 3.0;

  return 1/current_out;
}
```



Interate until no new states are reached

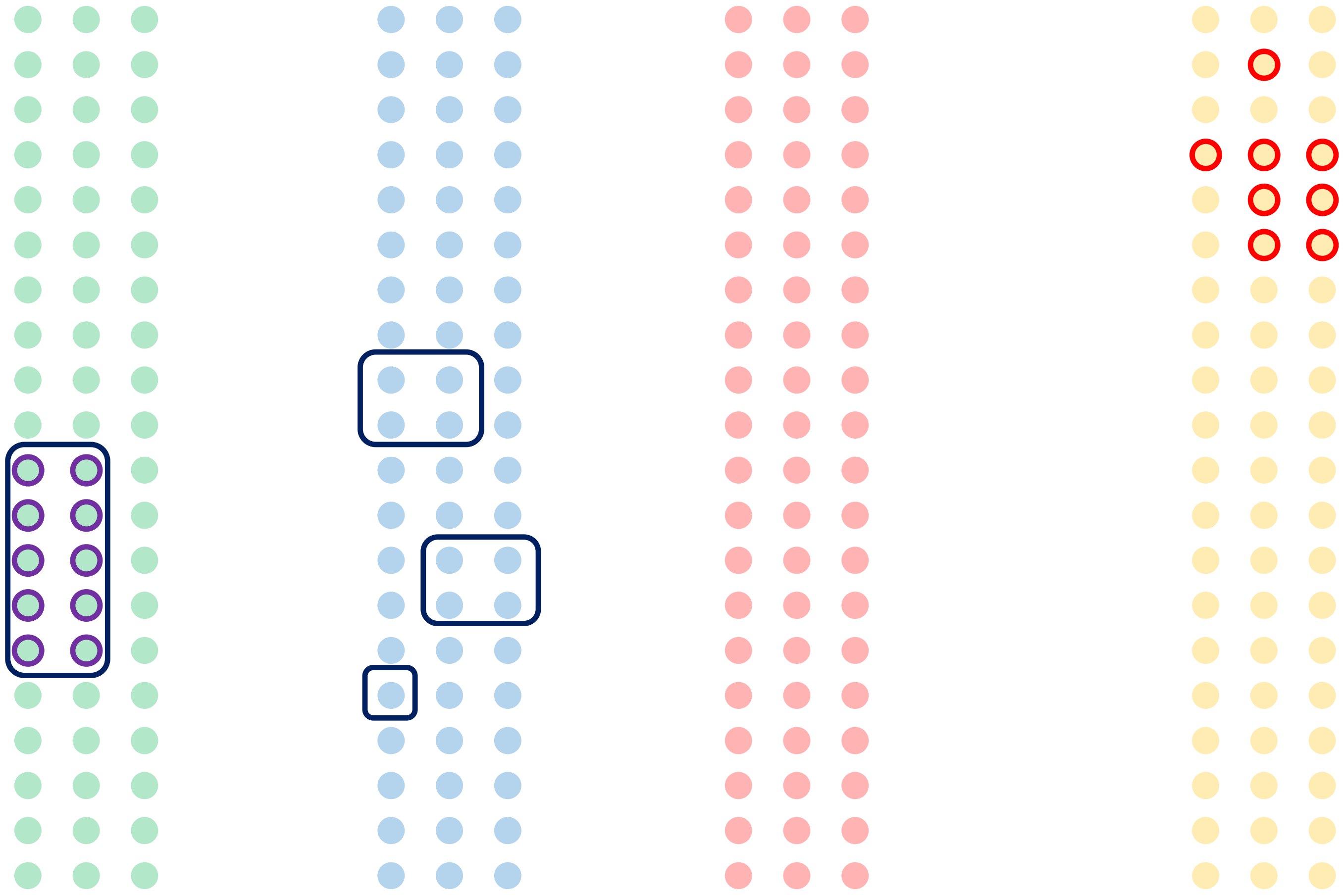
Formalization of the **collecting** semantics of the program

Invariants semantics

```
// x is an unknown parameter
float runTheLoop(int x)
{
   if (x<0 || x>100)
     return 1.0;
   float in = input();
   float current_out = 0.0;
   float prev_out = 0.0;
   int i;
   for (i=0;i<=x;i++)
     {
       current_out = in*0.1 + prev_out*0.9;
       prev_out = current_out;
       if (random())
     prev_out = 0.0;
       in = input();
     }

   current_out = current_out + 3.0;

   return 1/current_out;
}
```



Interate until no new states are reached

Formalization of the collecting semantics of the program
Invariants semantics

```
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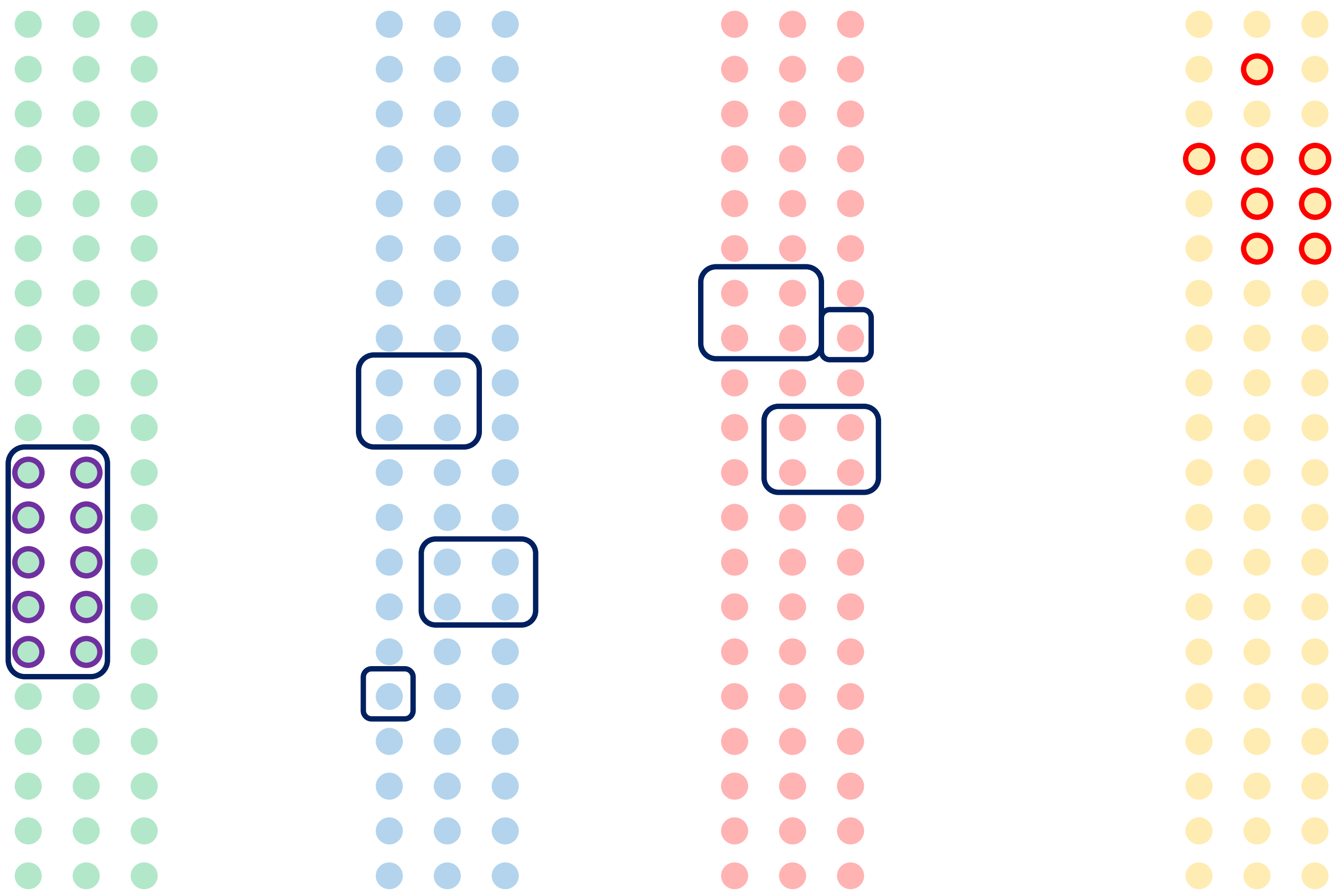
    {
      current_out = in*0.1 + prev_out*0.9;
      prev_out = current_out;
      if (random())
    prev_out = 0.0;
      in = input();
    }

  current_out = current_out + 3.0;

  return 1/current_out;
}
```



Interate until no new states are reached

Formalization of the collecting semantics of the program
Invariants semantics

```
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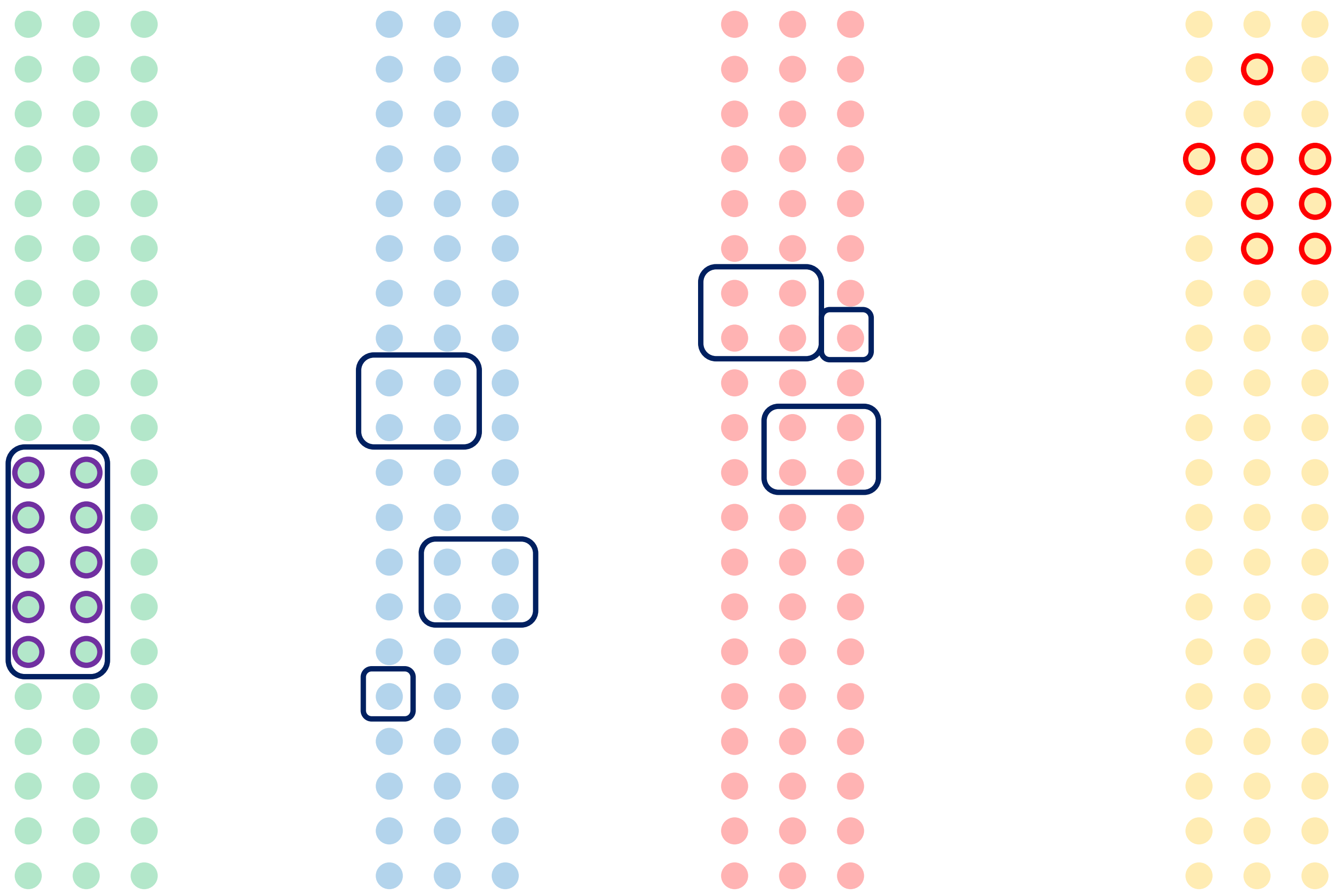
      if (random())
    prev_out = 0.0;
      in = input();
    }

  current_out = current_out + 3.0;

  return 1/current_out;
}
```



Interate until no new states are reached

Formalization of the collecting semantics of the program

Invariants semantics

```
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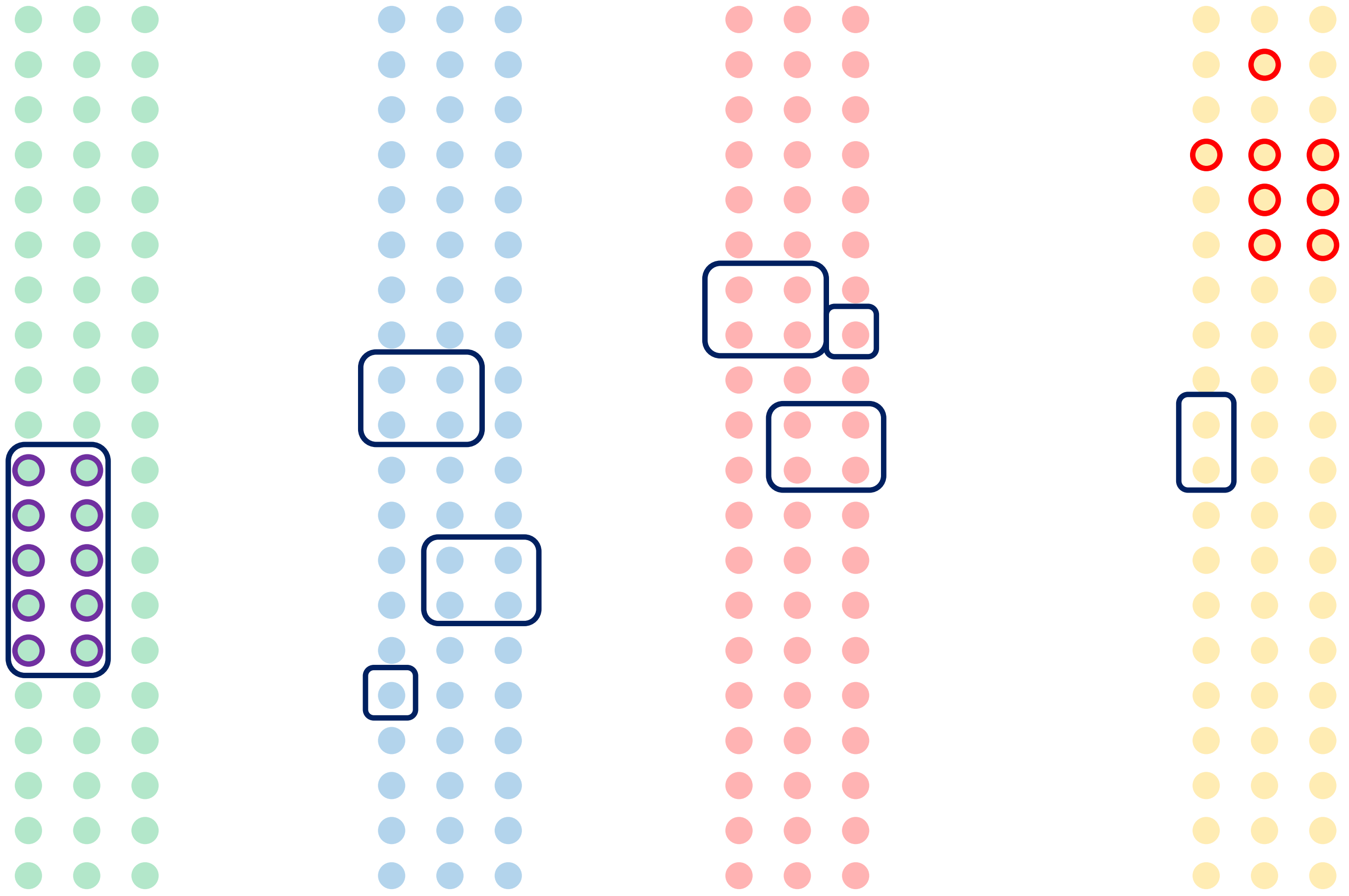
      if (random())
    prev_out = 0.0;
      in = input();
    }

  current_out = current_out + 3.0;

  return 1/current_out;
}
```



Interate until no new states are reached

Formalization of the collecting semantics of the program

Invariants semantics

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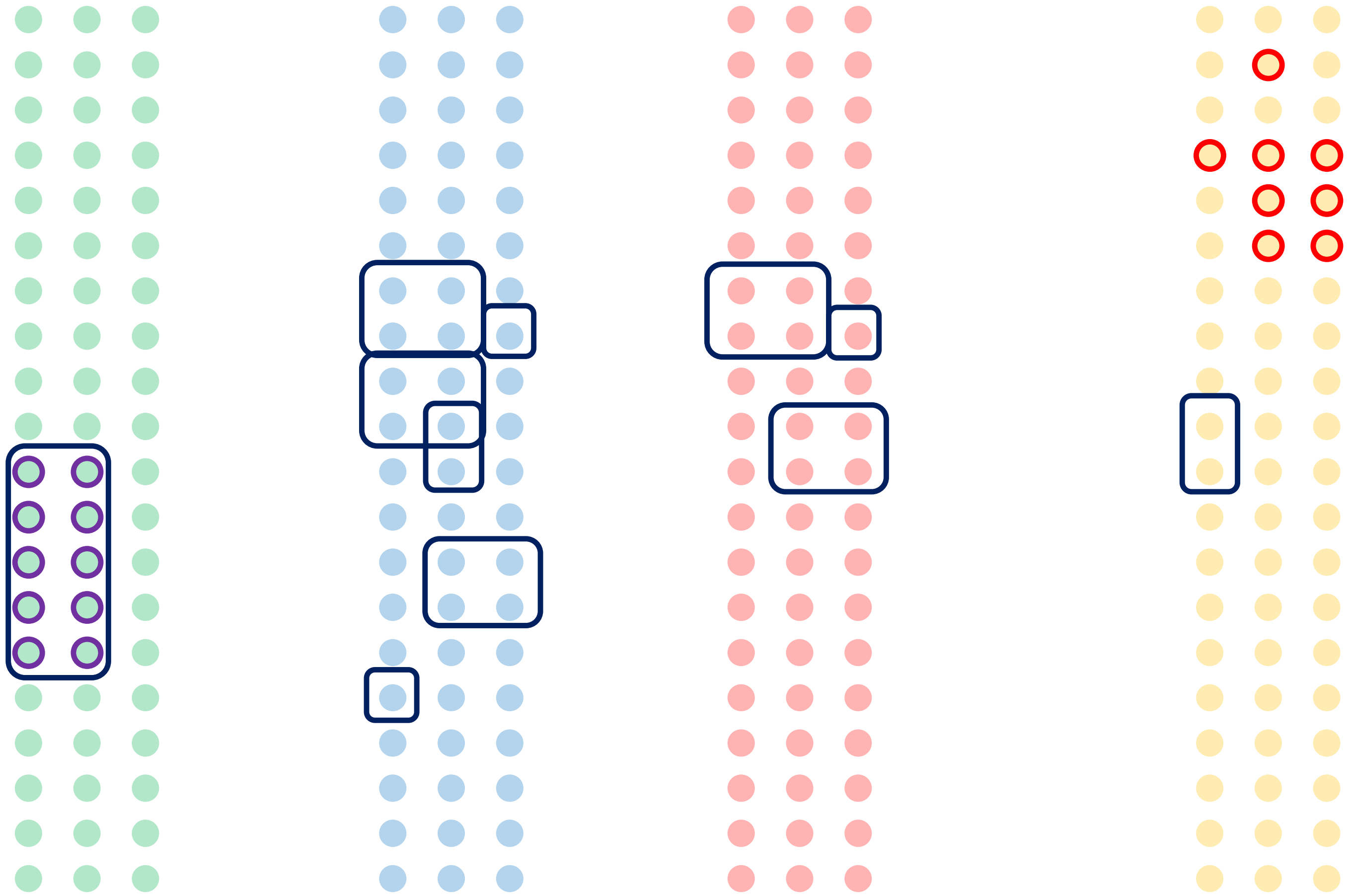
      if (random())
    prev_out = 0.0;
      in = input();
    }

  current_out = current_out + 3.0;

  return 1/current_out;
}
```



Interate until no new states are reached

Formalization of the collecting semantics of the program

Invariants semantics

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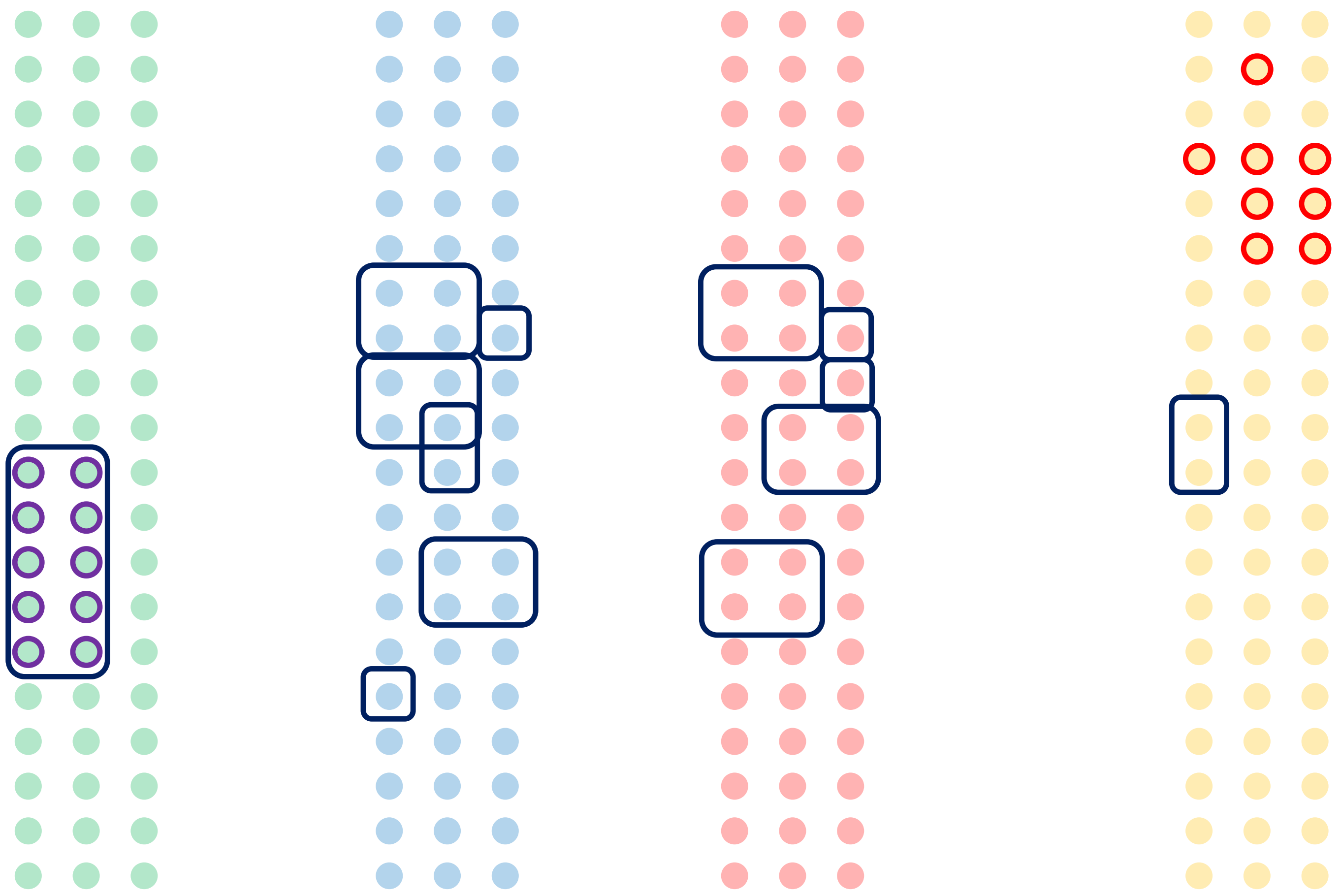
       if (random())
     prev_out = 0.0;
       in = input();
     }

   current_out = current_out + 3.0;

   return 1/current_out;
}
```



Interate until no new states are reached

Formalization of the collecting semantics of the program
Invariants semantics

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    {
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     if (random())
    prev_out = 0.0;
     in = input();
    }

  current_out = current_out + 3.0;

  return 1/current_out;
}
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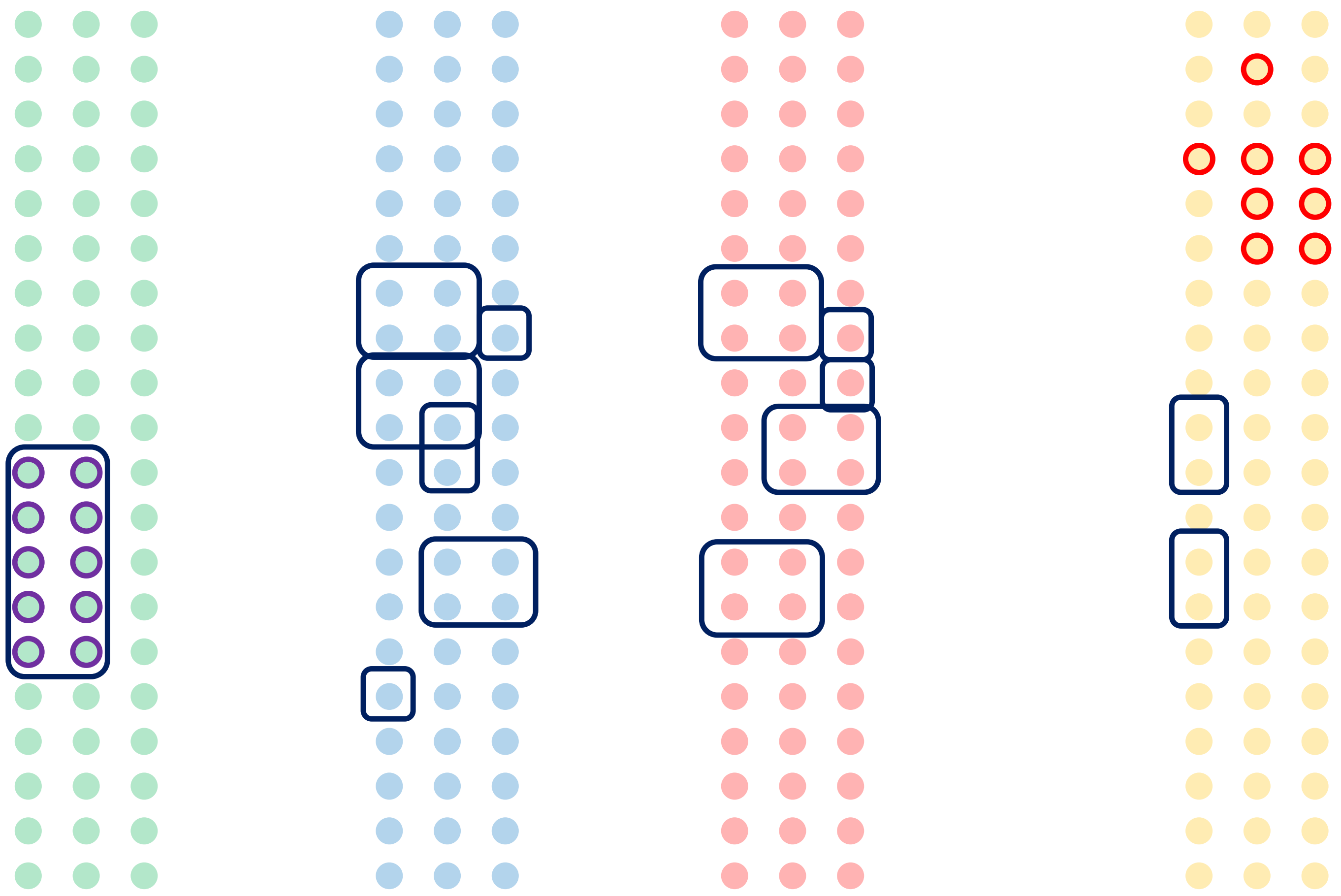

Interate until no new states are reached

Formalization of the collecting semantics of the program
Invariants semantics

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    prev_out = 0.0;
      in = input();
    }

  current_out = current_out + 3.0;

  return 1/current_out;
}
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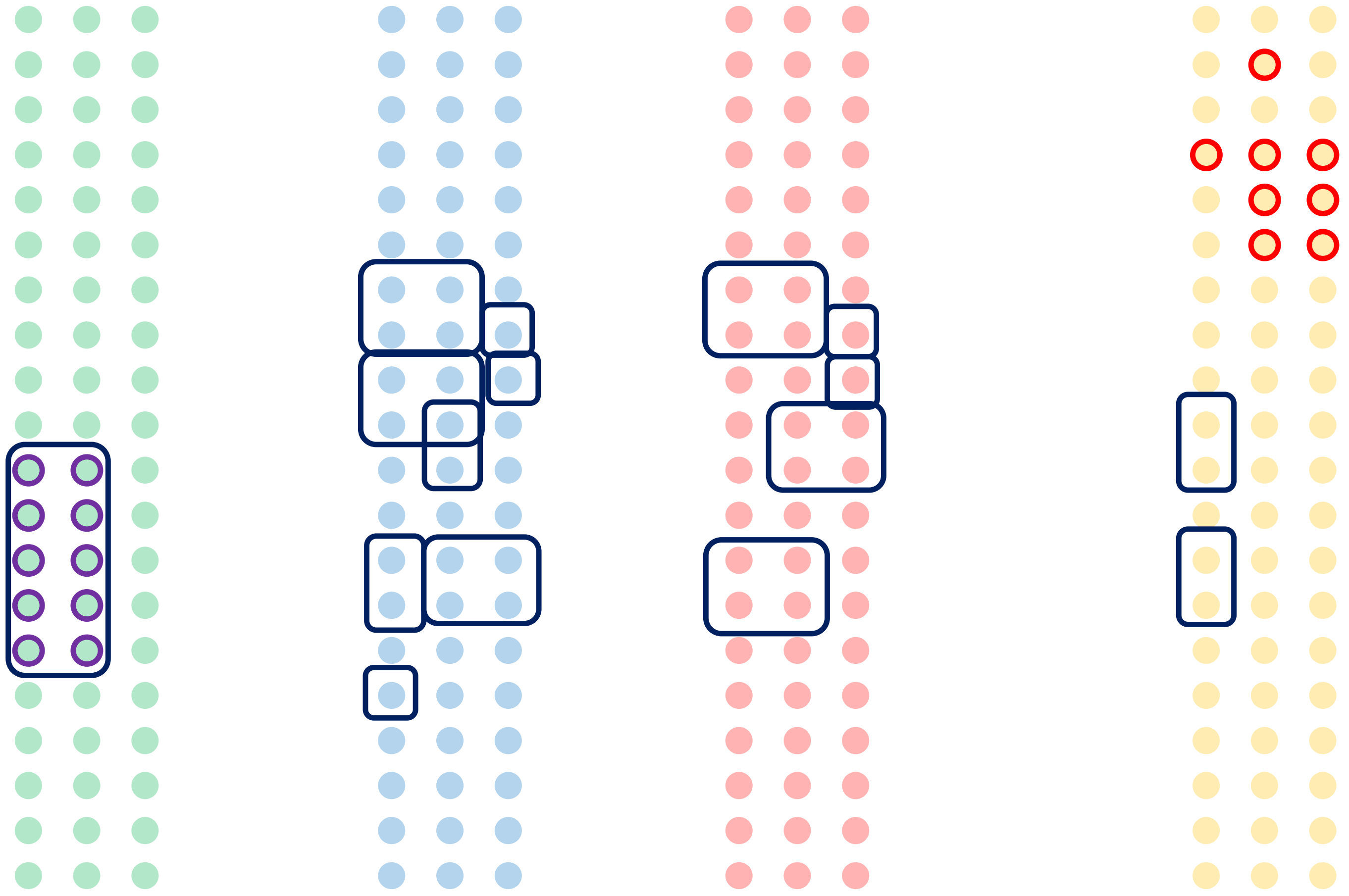

Interate until no new states are reached

Formalization of the collecting semantics of the program

Invariants semantics

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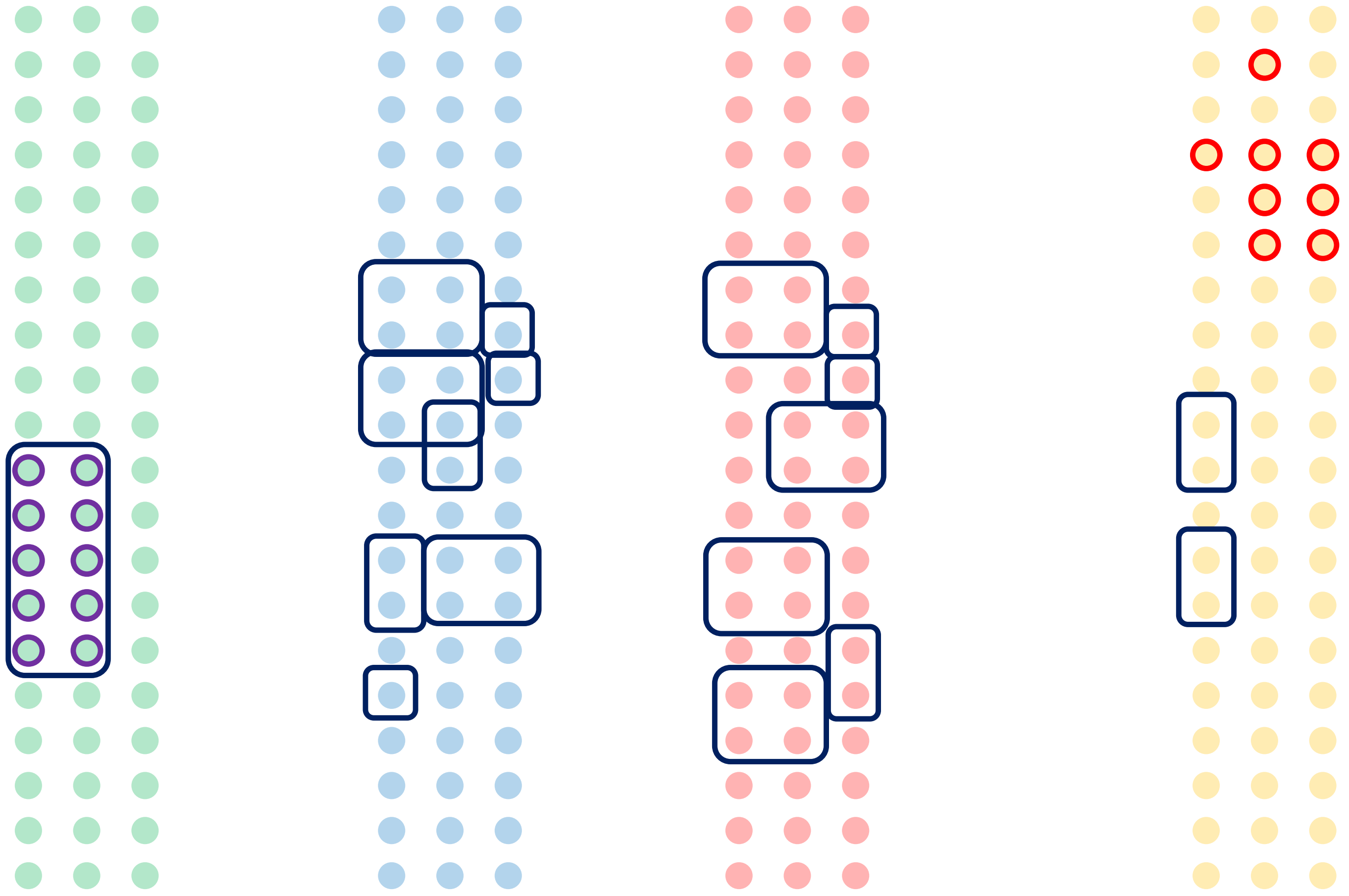
      if (random())
    prev_out = 0.0;
      in = input();
    }

  current_out = current_out + 3.0;

  return 1/current_out;
}
```



Interate until no new states are reached

Formalization of the collecting semantics of the program
Invariants semantics

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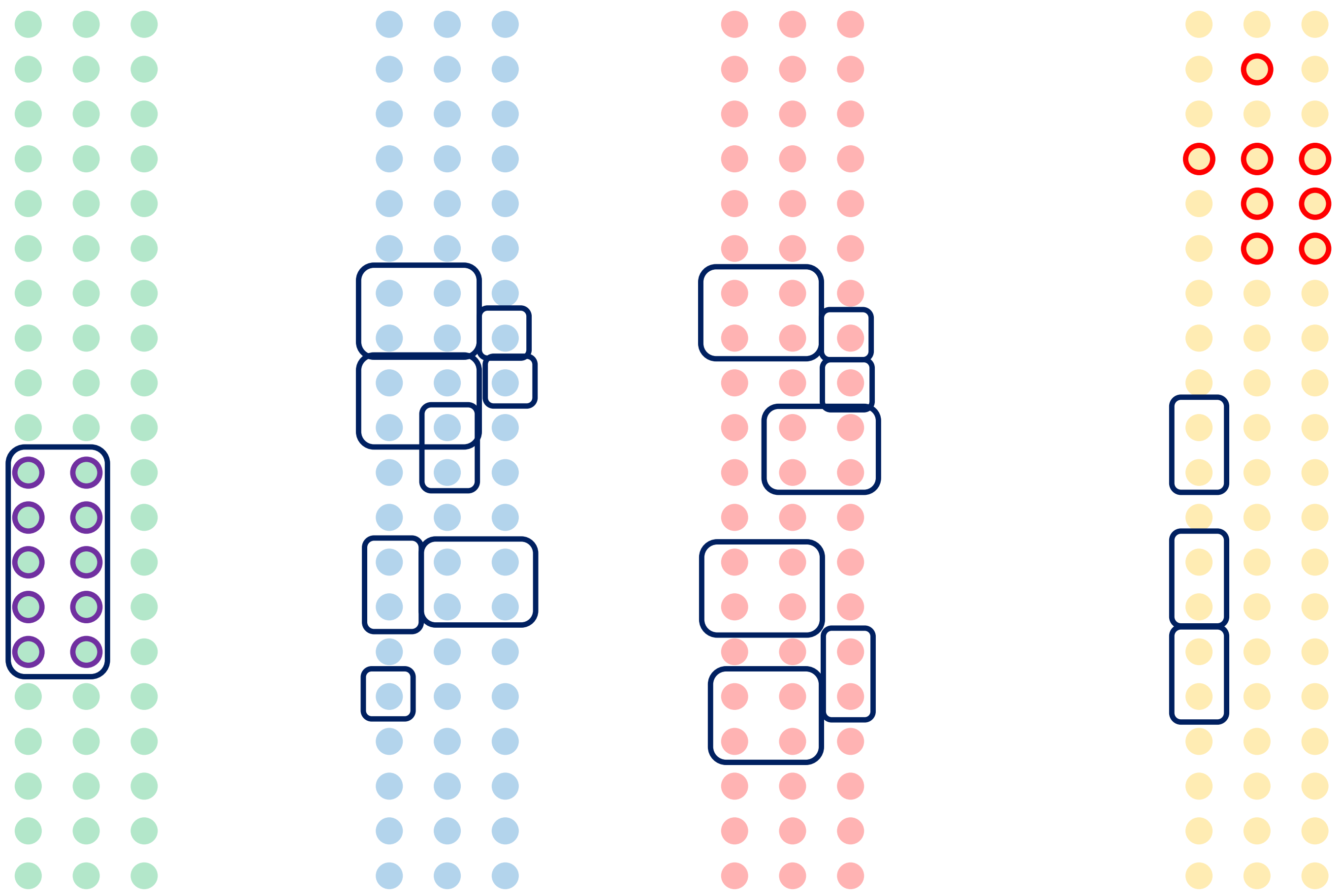
     }

   current_out = current_out + 3.0;

   return 1/current_out;
}
```



Interate until no new states are reached

Formalization of the collecting semantics of the program

Invariants semantics

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    prev_out = 0.0;
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    }

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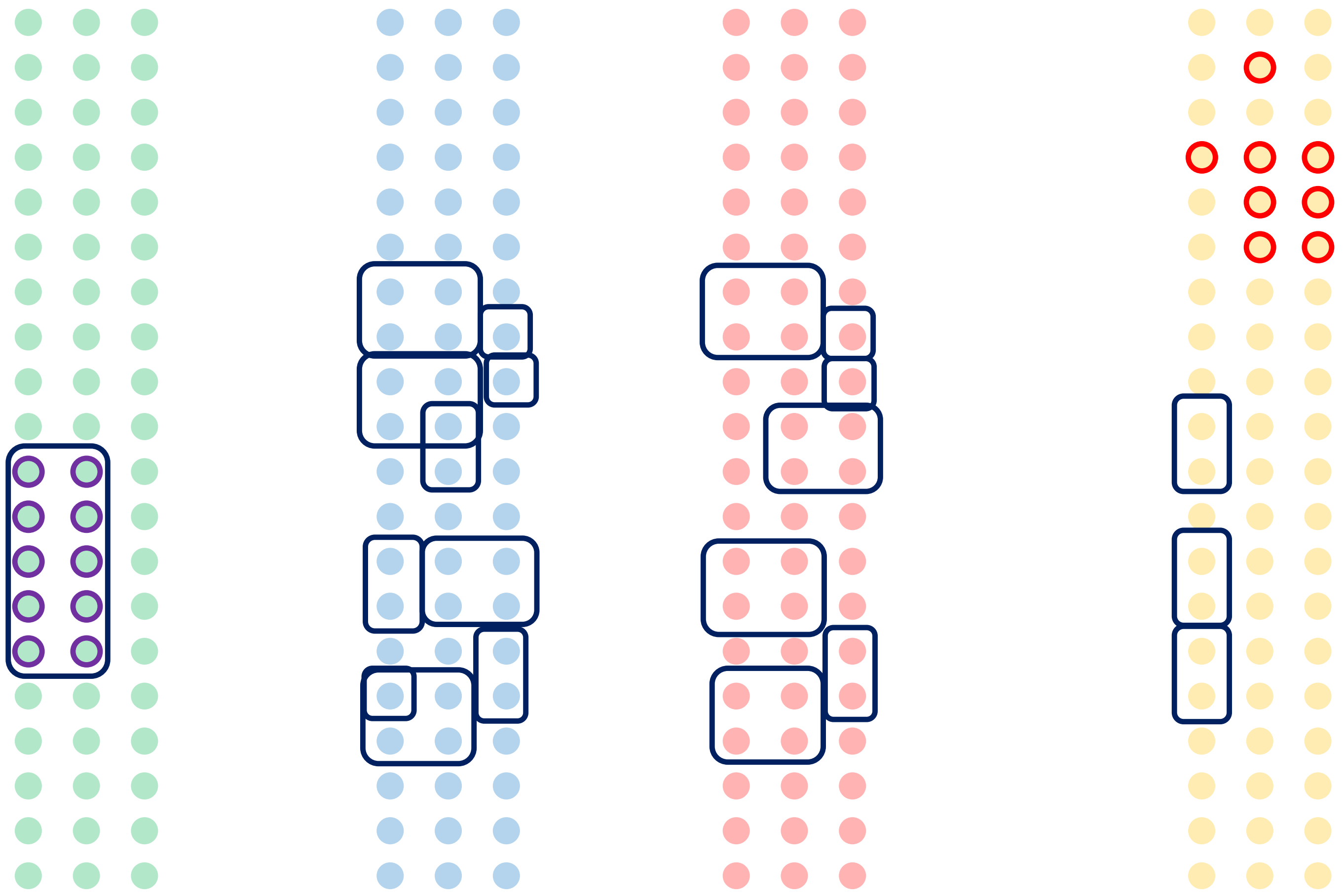
  return 1/current_out;
}
```



Interate until no new states are reached

Formalization of the abstract semantics of the program
Properties semantics – Loss of expressivity

```
// x is an unknown parameter
float runTheLoop(int x)
{
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    return 1.0;
  float in = input();
  float current_out = 0.0;
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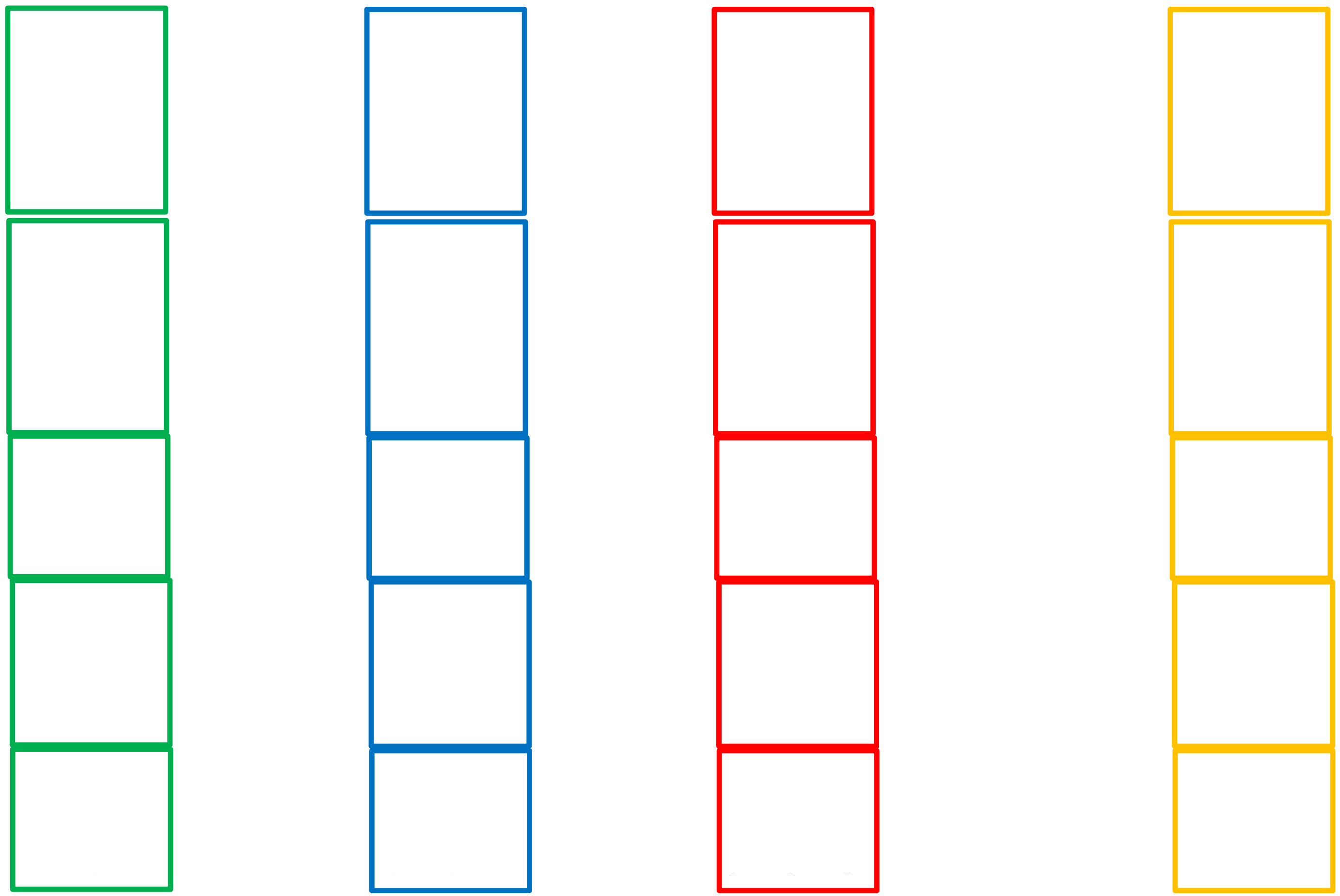
  int i;
  for (i=0;i<=x;i++)
    {
      current_out = in*0.1 + prev_out*0.9;
      prev_out = current_out;
      if (random())
    prev_out = 0.0;
      in = input();
    }

  current_out = current_out + 3.0;

  return 1/current_out;
}
```



Finite state machine that over-approximates program execution

Formalization of the abstract semantics of the program

Properties semantics – Loss of expressivity

```
// x is an unknown parameter
float runTheLoop(int x)
{
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    return 1.0;
  float in = input();
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  int i;
  for (i=0;i<=x;i++)
    {
      current_out = in*0.1 + prev_out*0.9;
      prev_out = current_out;
      if (random())
    prev_out = 0.0;
      in = input();
    }

  current_out = current_out + 3.0;

  return 1/current_out;
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```

Finite state machine that over-approximates program execution

Formalization of the abstract semantics of the program
Properties semantics – Loss of expressivity

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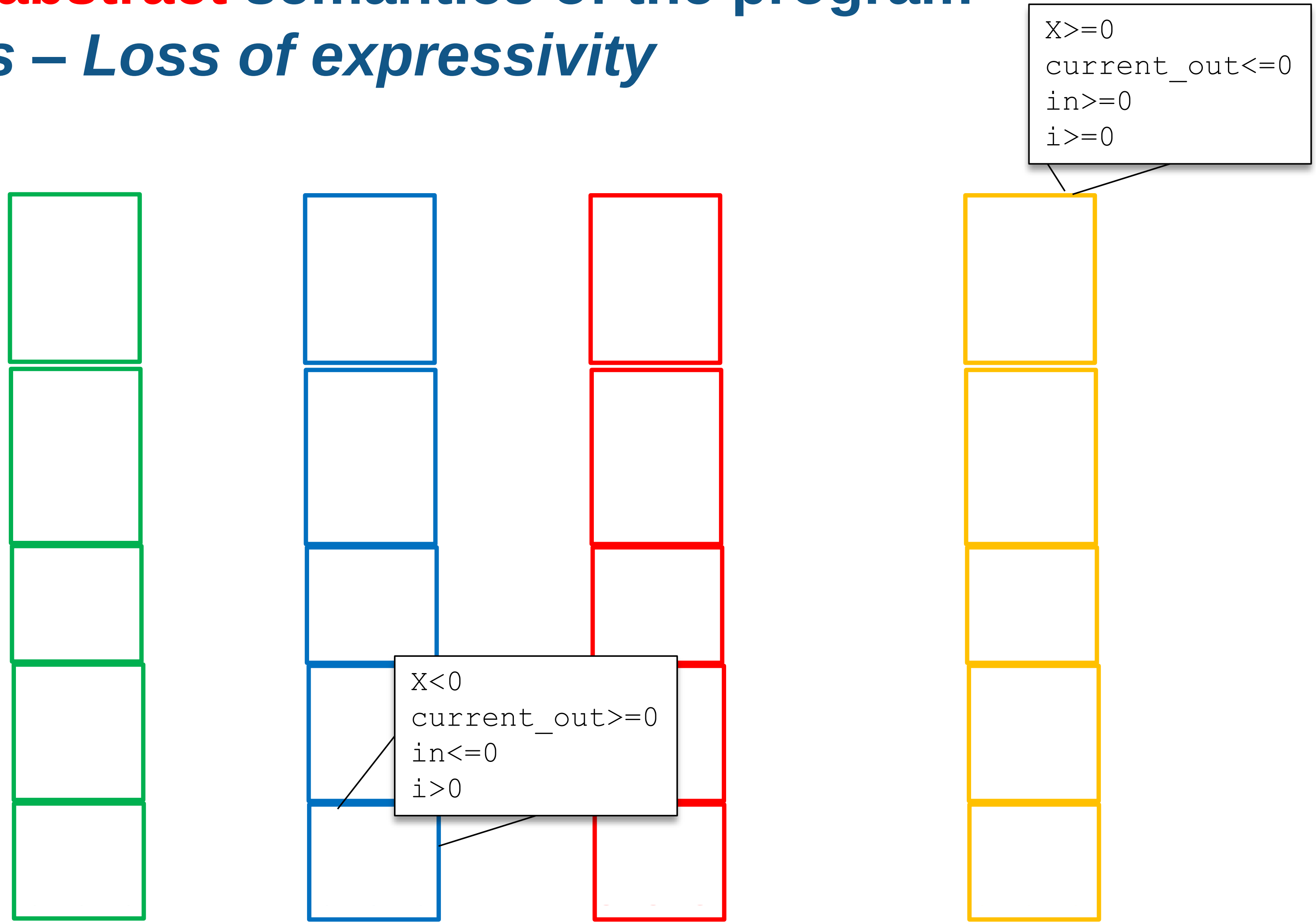
      if (random())
    prev_out = 0.0;
      in = input();
    }

  current_out = current_out + 3.0;

  return 1/current_out;
}
```



Finite state machine that over-approximates program execution

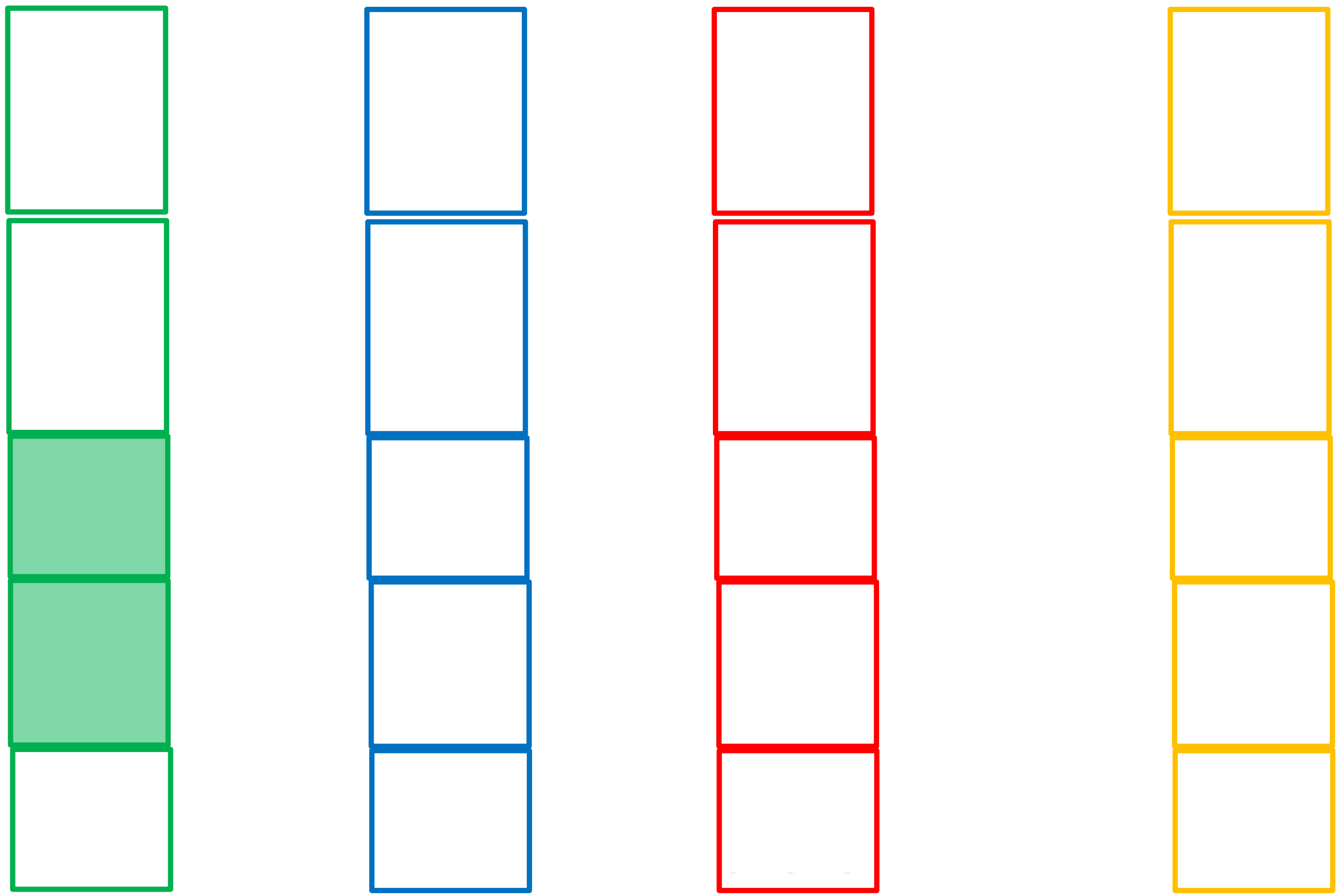
Formalization of the abstract semantics of the program

Properties semantics – Fixpoint computation

```
// x is an unknown parameter
float runTheLoop(int x)
{
  if (x<0 || x>100)
    return 1.0;
  float in = input();
  float current_out = 0.0;
  float prev_out = 0.0;
  int i;
  for (i=0;i<=x;i++)
    {
      current_out = in*0.1 + prev_out*0.9;
      prev_out = current_out;
      if (random())
    prev_out = 0.0;
      in = input();
    }

  current_out = current_out + 3.0;

  return 1/current_out;
}
```



Finite state machine that over-approximates program execution

Formalization of the abstract semantics of the program

Properties semantics – Fixpoint computation

```
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      if (random())
    prev_out = 0.0;
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    }

  current_out = current_out + 3.0;

  return 1/current_out;
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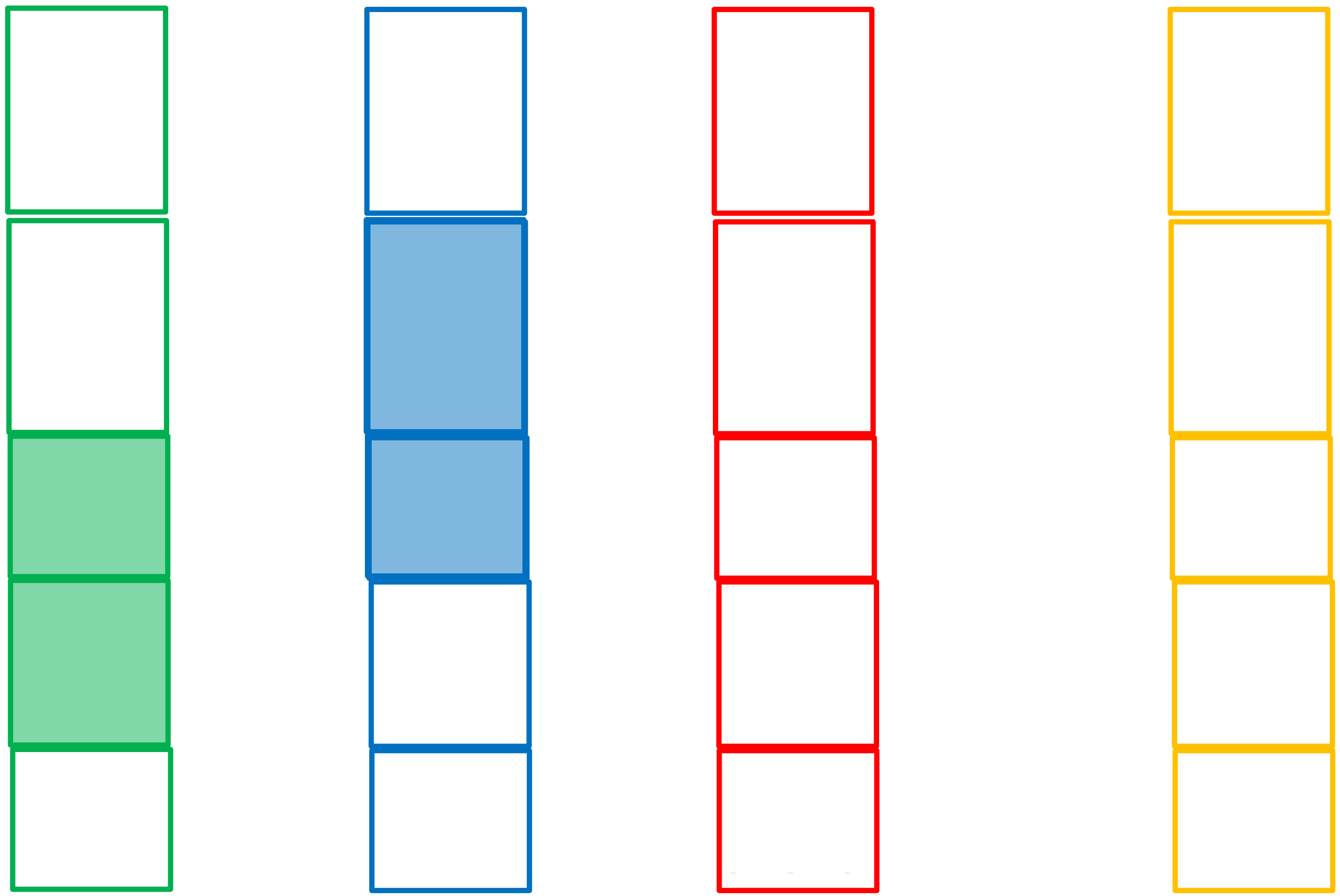
```



Finite state machine that over-approximates program execution

Formalization of the **abstract** semantics of the program
Properties semantics – Fixpoint computation

```
// x is an unknown parameter
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      current_out = in*0.1 + prev_out*0.9;
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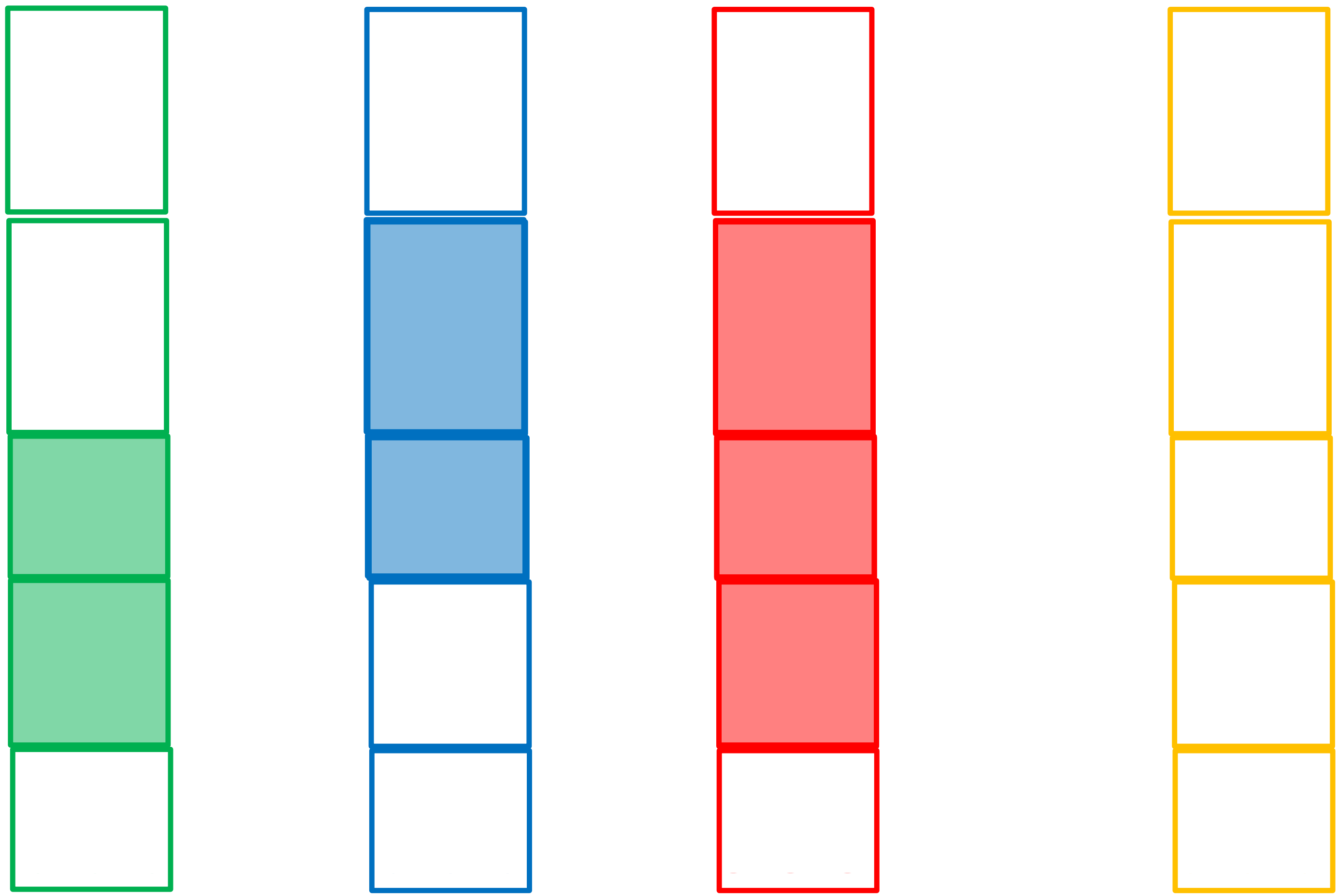
      if (random())
    prev_out = 0.0;
      in = input();
    }

  current_out = current_out + 3.0;

  return 1/current_out;
}
```



Finite state machine that over-approximates program execution

Formalization of the abstract semantics of the program

Properties semantics – Fixpoint computation

```
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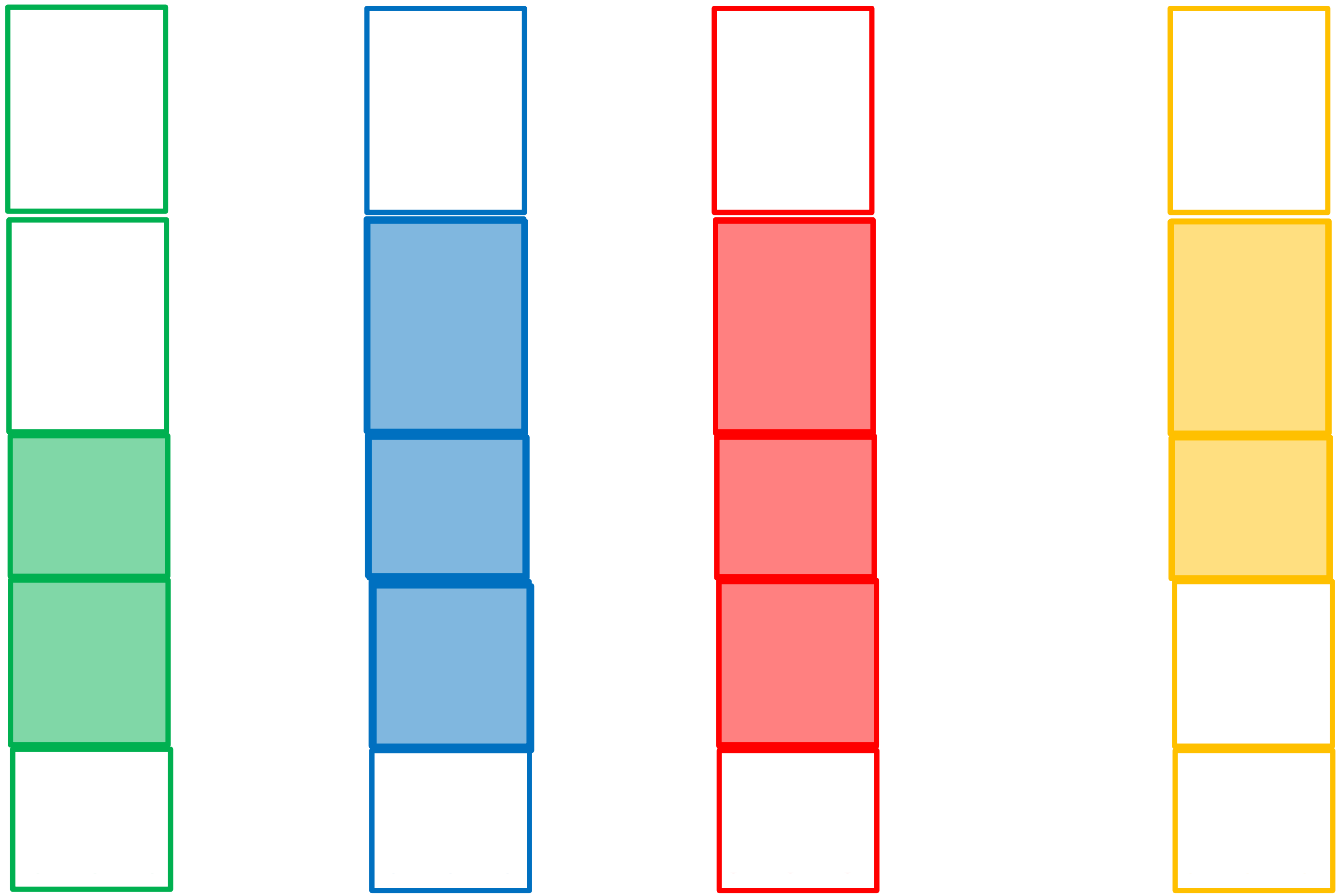
      if (random())
    prev_out = 0.0;
      in = input();
    }

  current_out = current_out + 3.0;

  return 1/current_out;
}
```



Finite state machine that over-approximates program execution

Formalization of the abstract semantics of the program

Properties semantics – Fixpoint computation

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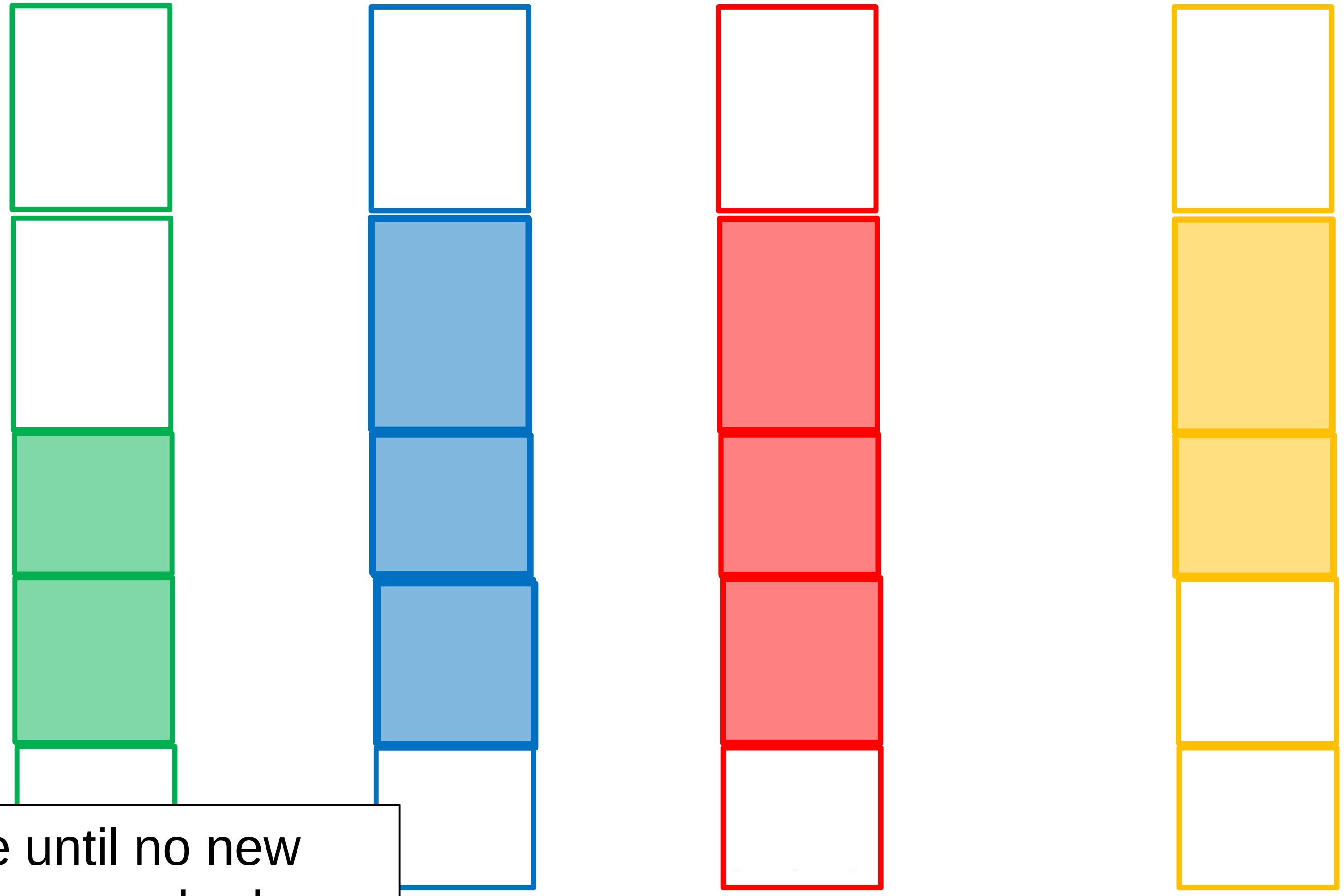
      if (random())
    prev_out = 0.0;
      in = input();
    }

  current_out = current_out + 3.0;

  return 1/current_out;
}
```



Finite state machine that over-approximates program execution

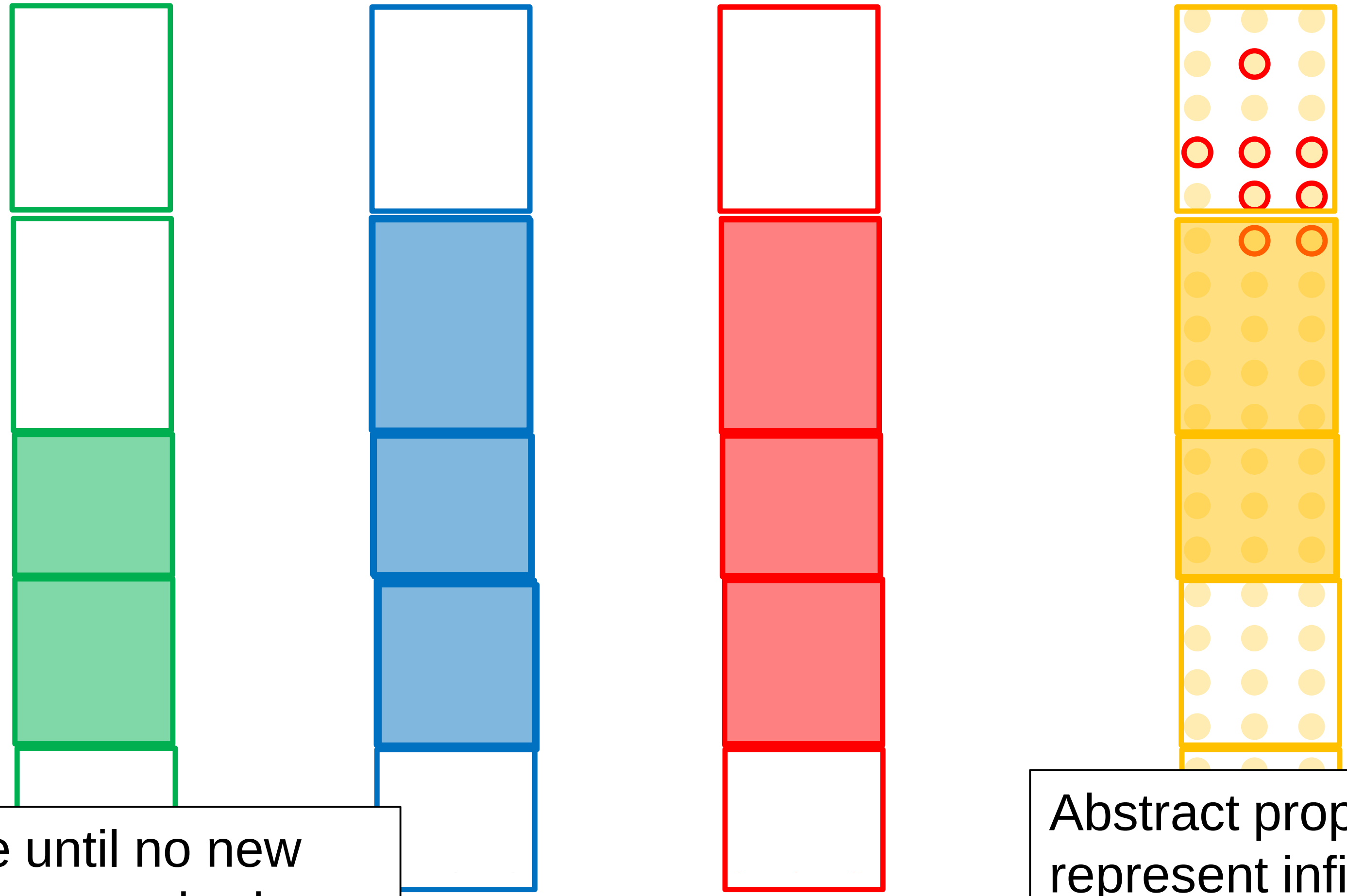
Interate until no new states are reached

Formalization of the abstract semantics of the program
Properties semantics – Fixpoint computation

```
// x is an unknown parameter
float runTheLoop(int x)
{
   if (x<0 || x>100)
      return 1.0;
   float in = input();
   float current_out = 0.0;
   float prev_out = 0.0;
   int i;
   for (i=0;i<=x;i++)
      {
        current_out = in*0.1 + prev_out*0.9;
        prev_out = current_out;
        if (random())
      prev_out = 0.0;
        in = input();
      }

   current_out = current_out + 3.0;

   return 1/current_out;
}
```



Finite state machine that over-approximates program execution

Interate until no new states are reached

Abstract properties represent infinitely many states

Formalization of the abstract semantics of the program

Properties semantics – Fixpoint computation

```
// x is an unknown parameter
float runTheLoop(int x)
{
   if (x<0 || x>100)
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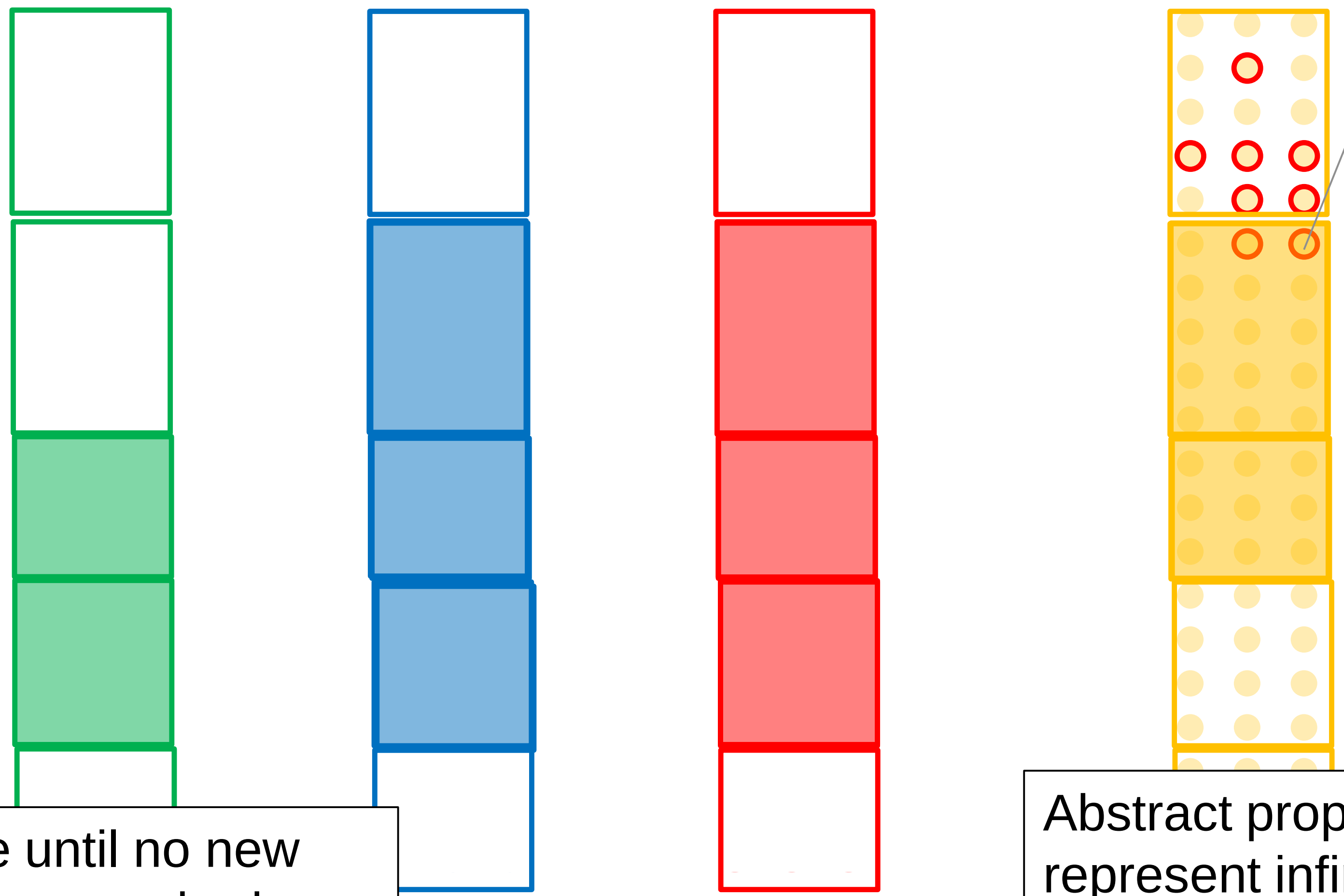
   float in = input();
   float current_out = 0.0;
   float prev_out = 0.0;
   int i;
   for (i=0;i<=x;i++)
      {
        current_out = in*0.1 + prev_out*0.9;
        prev_out = current_out;
        if (random())
      prev_out = 0.0;
        in = input();
      }

   current_out = current_out + 3.0;

   return 1/current_out;
}
```



False alarm

Finite state machine that over-approximates program execution

Interate until no new states are reached

Abstract properties represent infinitely many states

Applications of Abstract Interpretation

- Analysis of C Code
  - Code prover
  - Bug finder

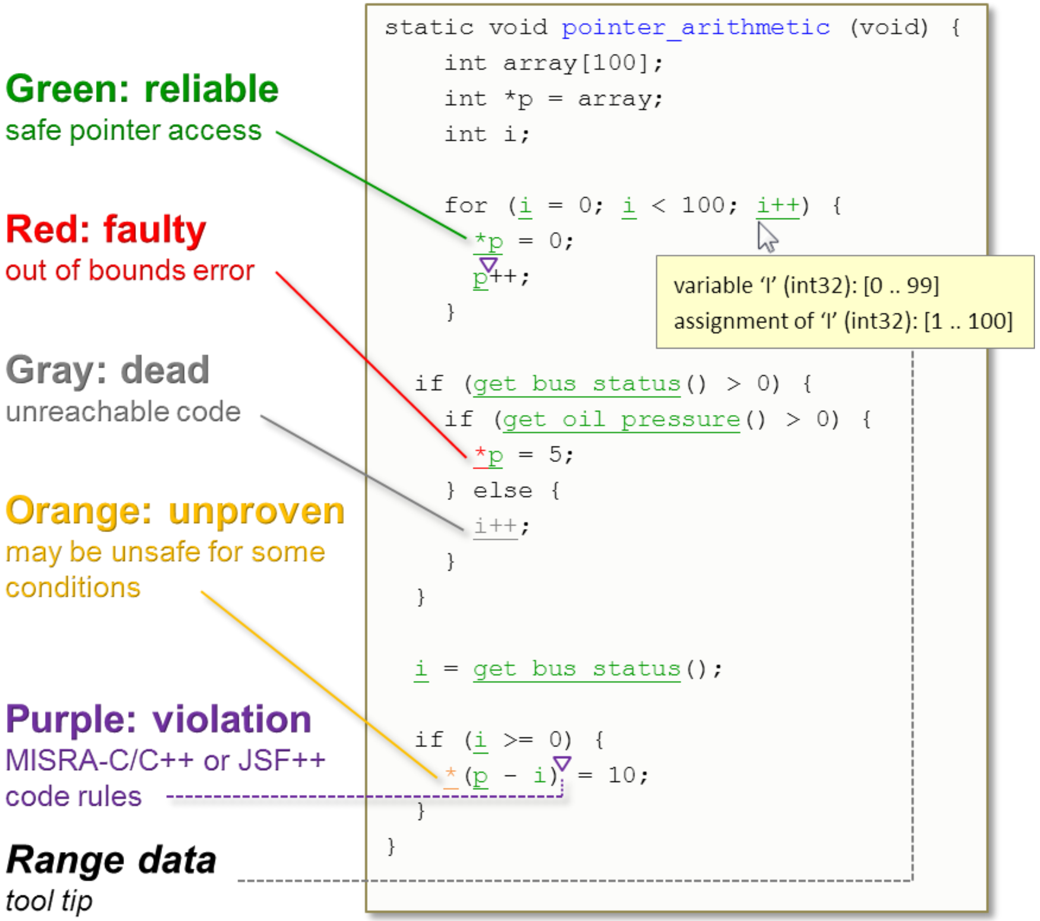
Code Prover

- Performs abstract invariants computation on C/C++/ADA programs
  - With pointers
  - With floating points
  - With function calls
  - With multi-tasking
- Zero False Positives
- Computes many properties on program variables
  - Ranges (interval domains) with holes
  - Multiplicity (both integer and floating point)
  - Linear relations between program variables

    e.g. $3x - 2y + 4z \leq 32 \wedge y + 3z - t \leq 1$

```
Local variable 'z' (unsigned int 32): multiples of 16 in [0 .. 15984] or [32000 .. 65520]
```

Simple color code for presenting the information

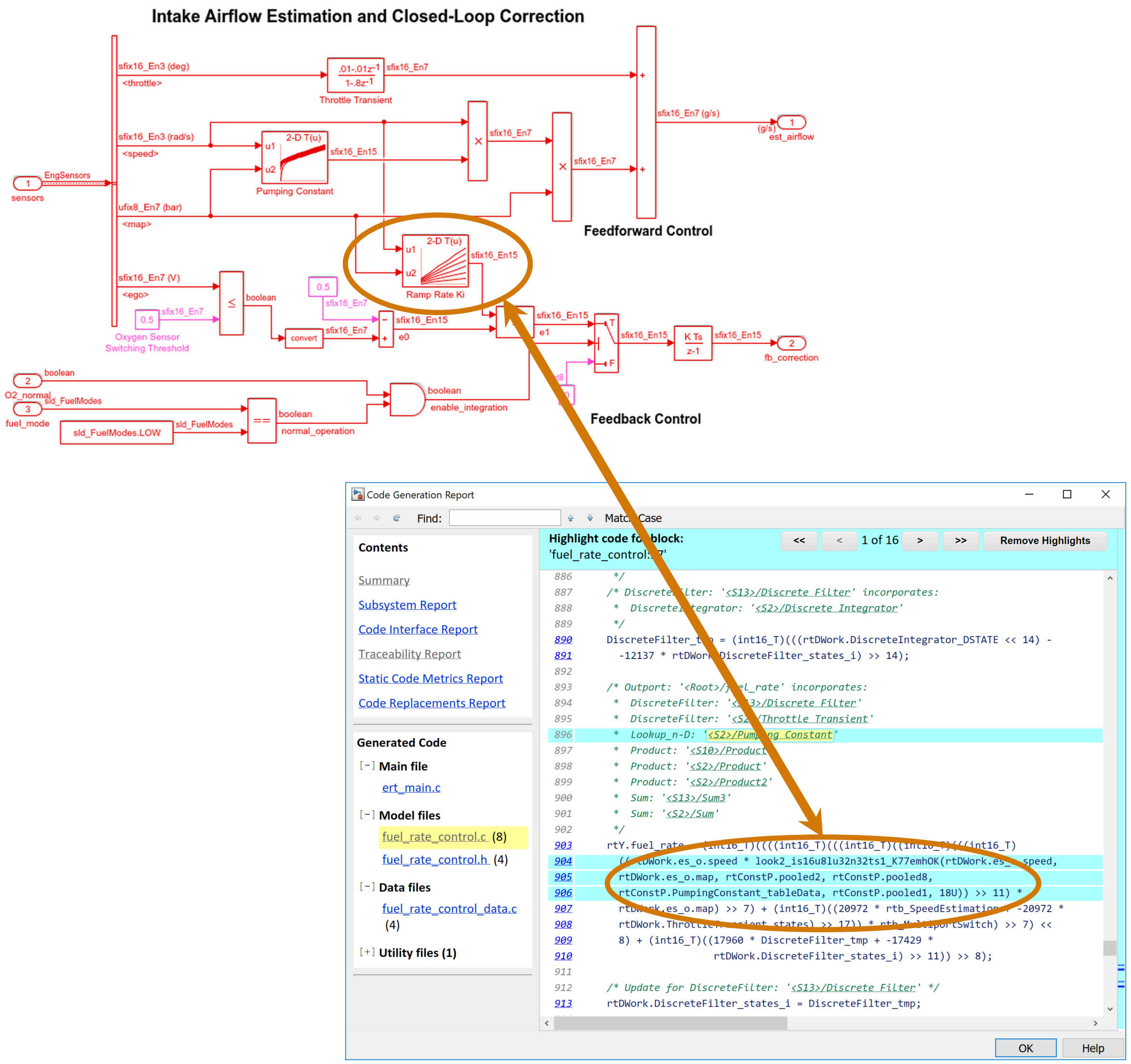


Bug Finder

- Bug Finder uses abstract interpretation techniques to find bugs
  - Does not claim to be exhaustive
    Cannot prove abscence of bugs
  - May find a broader set of bugs
    Some are hard to deal with in Code Prover
- Few False Positives

Applications of Abstract Interpretation

- Analysis of C Code
  - Code prover
  - Bug finder
- Analysis of code generated from models
  - Opportunities for using model semantics to improve precision of code-based analysis



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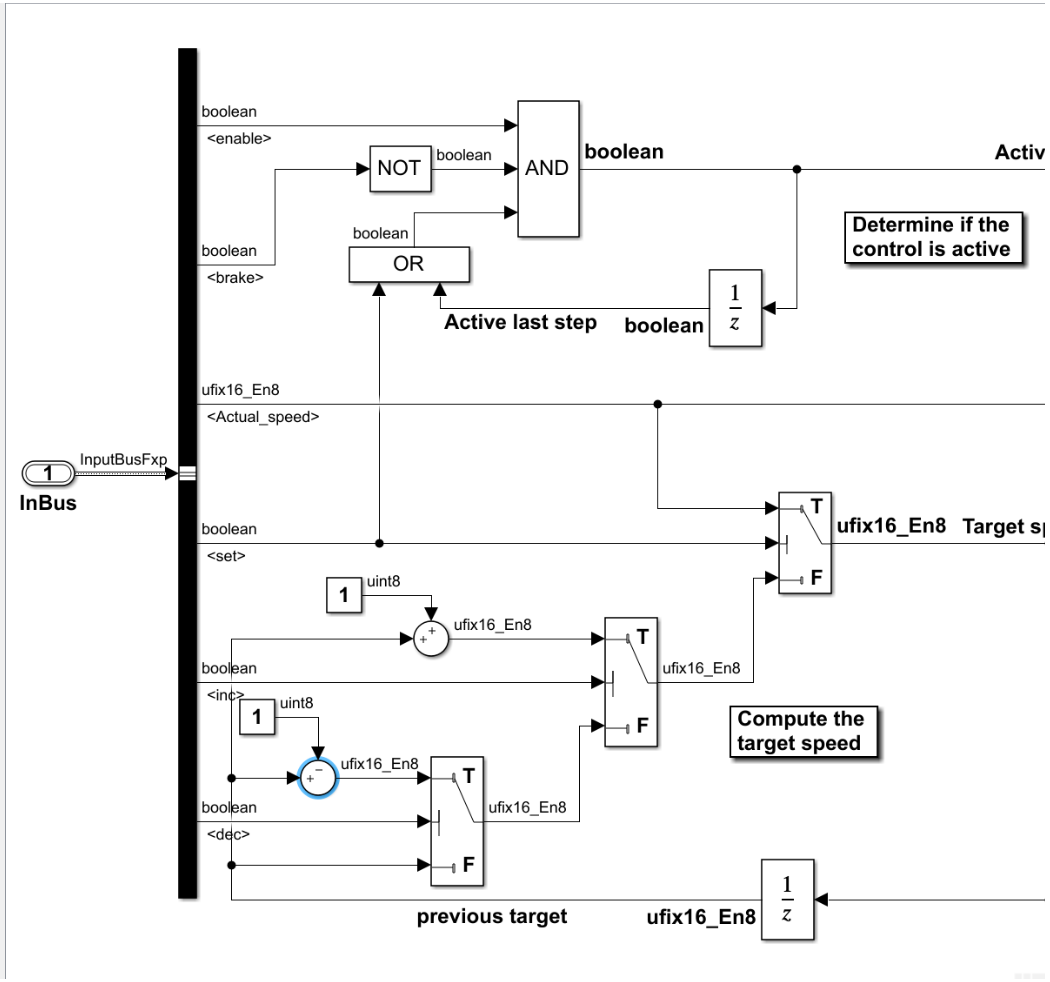

Applications of Abstract Interpretation

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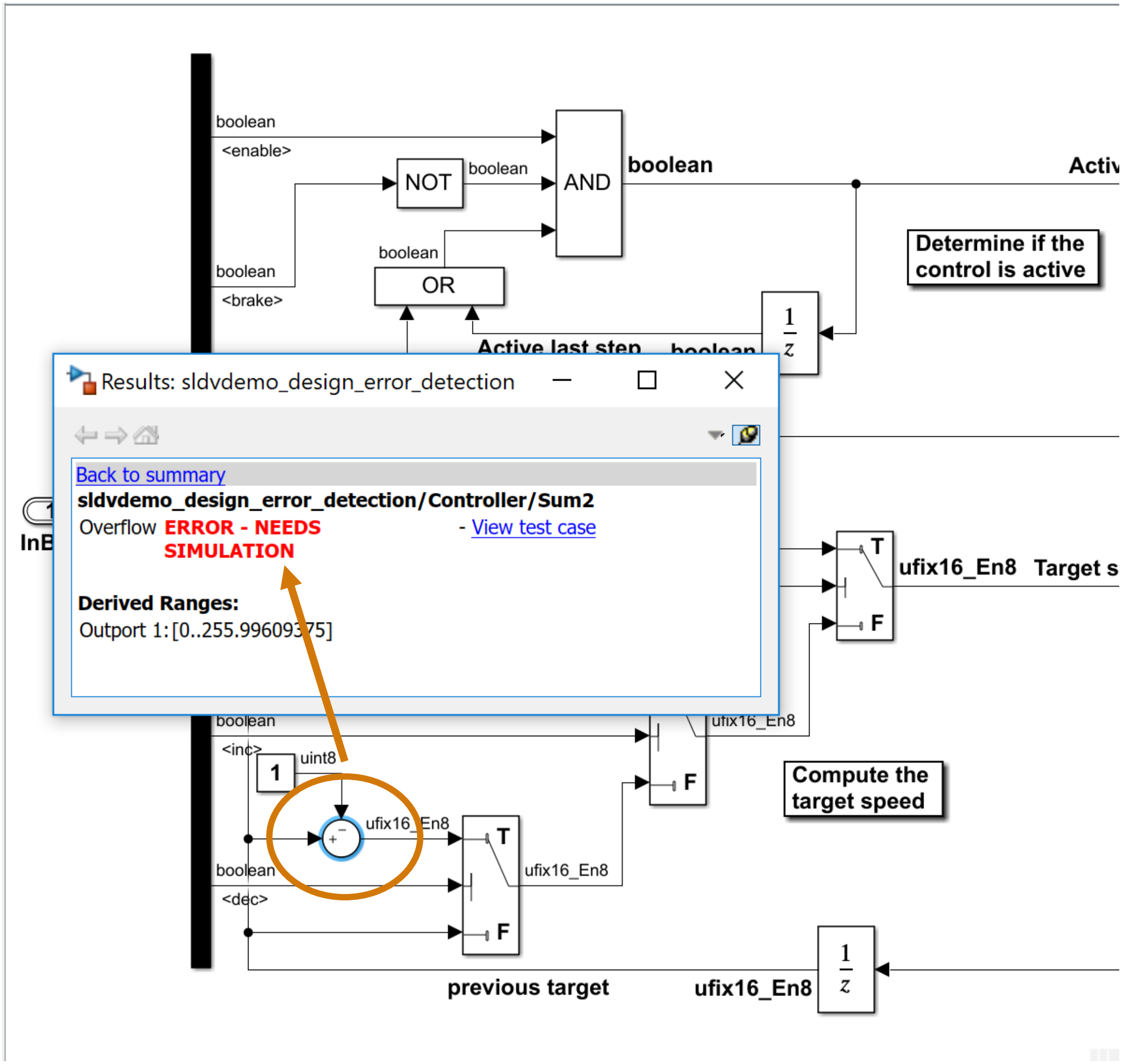

Detailed design – Data-type design

From Specification to Code

- High level design focuses on maximum flexibility in design space exploration
  - Use doubles
  - Let Simulink choose appropriate data-types
- Code generation focuses on designs that are quite precisely specified and optimised
  - Cost of computation
  - Cost of memory
  - Precision requirements

Data type design

- Start with MATLAB algorithm (uses doubles)

```
% Compute Output
if (u_state > limit_upper)
    y = limit_upper;
    clip_status = -2;
elseif (u_state >= limit_upper)
    y = limit_upper;
    clip_status = -1;
elseif (u_state < limit_lower)
    y = limit_lower;
    clip_status = 2;
elseif (u_state <= limit_lower)
    y = limit_lower;
    clip_status = 1;
else
    y = u_state;
    clip_status = 0;
end
```

Data type design

- Start with MATLAB algorithm (uses doubles)
- Convert all computations to use fixed-point calculations

```
% Compute Output
if (u_state > limit_upper)
    %F2F: No information found for converting the following block of code
    %F2F: Start block
    y = fi(limit_upper, 0, 16, 7, fm);
    clip_status = fi(-2, 0, 1, 0, fm);
    %F2F: End block
elseif (u_state >= limit_upper)
    %F2F: No information found for converting the following block of code
    %F2F: Start block
    y = fi(limit_upper, 0, 16, 7, fm);
    clip_status = fi(-1, 0, 1, 0, fm);
    %F2F: End block
elseif (u_state < limit_lower)
    %F2F: No information found for converting the following block of code
    %F2F: Start block
    y = fi(limit_lower, 0, 16, 7, fm);
    clip_status = fi(2, 0, 1, 0, fm);
    %F2F: End block
elseif (u_state <= limit_lower)
    %F2F: No information found for converting the following block of code
    %F2F: Start block
    y = fi(limit_lower, 0, 16, 7, fm);
    clip_status = fi(1, 0, 1, 0, fm);
    %F2F: End block
else
    y = fi(u_state, 0, 16, 7, fm);
    clip_status = fi(0, 0, 1, 0, fm);
end
```

Data type design

- Start with MATLAB algorithm (uses doubles)

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% Compute Output
if (u_state > limit_upper)
    y = limit_upper;
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Data type design

- Start with MATLAB algorithm (uses doubles)
- Execute test-bench with sample inputs

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if (u_state > limit_upper)
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Data type design

- Start with MATLAB algorithm (uses doubles)
- Execute test-bench with sample inputs
- Instrument MATLAB to monitor min/max for each variable

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% Compute Output
if (u_state > limit_upper)
    y = limit_upper;
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Data type design

- Start with MATLAB algorithm (uses doubles)
- Execute test-bench with sample inputs
- Instrument MATLAB to monitor min/max for each variable
- Propose fixpoint types based on observed ranges

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else
    y = u_state;
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```

Variable	Type	Sim Min	Sim Max	Whole Num...	Proposed Type
Input					
u_in	double	-1	1	No	numerictype(1, 16, 14)
Output					
y	double	2	320.31	No	numerictype(0, 16, 7)
clip_status	double	0	0	Yes	numerictype(0, 1, 0)
Persistent					
u_state	double	2	320.31	No	numerictype(0, 16, 7)
Local					
init_val	double	1	1	Yes	numerictype(0, 1, 0)
gain_val	double	1	1	Yes	numerictype(0, 1, 0)
limit_upper	double	500	500	Yes	numerictype(0, 9, 0)
limit_lower	double	-500	-500	Yes	numerictype(1, 10, 0)
tprod	double	-1	1	No	numerictype(1, 16, 14)

Data type design

- Start with MATLAB algorithm (uses doubles)
- Execute test-bench with sample inputs
- Instrument MATLAB to monitor min/max for each variable
- Propose fixpoint types based on observed ranges
- Change algorithm to use the proposed types

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Data type design

- Start with MATLAB algorithm (uses doubles)
- Execute test-bench with sample inputs
- Instrument MATLAB to monitor min/max for each variable
- Propose fixpoint types based on observed ranges
- Change algorithm to use the proposed types
- Verify behaviour on test-bench

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Data type design

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- Propose fixed-point types based on Abstract Interpretation

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Output						
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Persistent						
u_state	double	2	320.31	-501	501	No
Local						
init_val	double	1	1	1	1	Yes
gain_val	double	1	1	1	1	Yes
limit_upper	double	500	500	500	500	Yes
limit_lower	double	-500	-500	-500	-500	Yes
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Software Model Checking

Model Checking

- Start with a model
  - Various forms of state machines/transition systems
  - Represents a system
- Add a property
  - Various forms of logic – temporal, modal etc.
  - Represents a property
- Algorithms to check the satisfiability/validity of the property on the model

Software Model Checking

- Model is software
  - Complex control-flow
  - Functions/procedures
  - Data-structures, pointers
  - Libraries
  - …

Software Model Checking

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  - Complex control-flow
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- Some properties can also be encoded in the software
  - ASSERT statements

Software Model Checking

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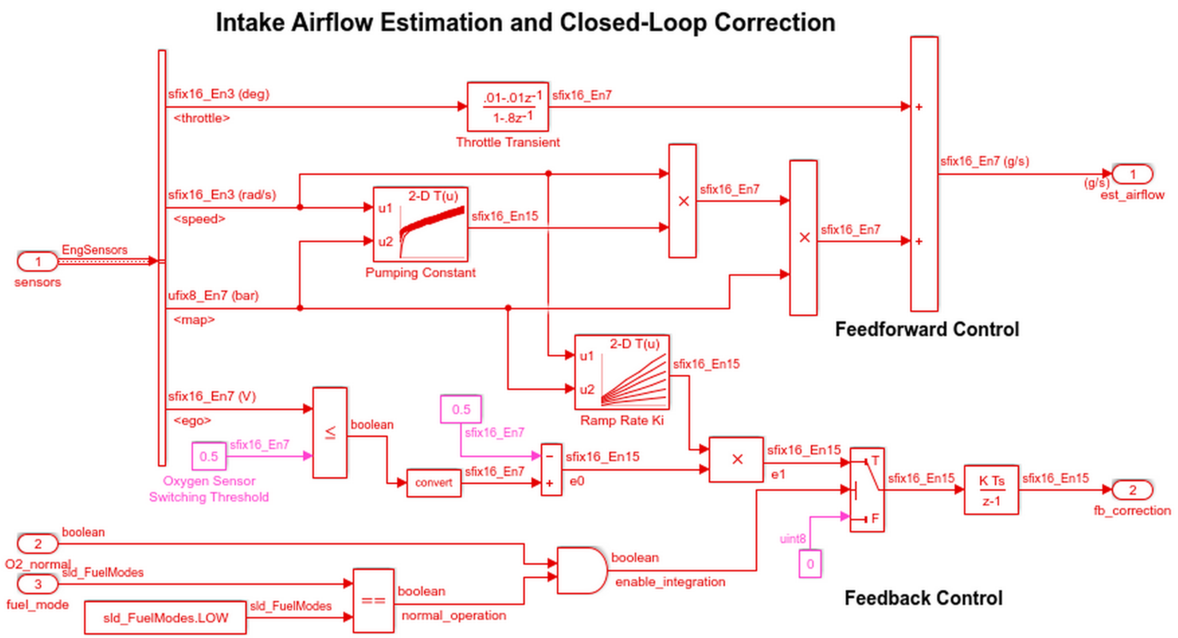
  - Libraries
  - …
- Some properties can also be encoded in the software
  - ASSERT statements
- Prove that the ASSERT statements cannot be hit or provide evidence of reachability

Model-Based Software Model Checking

- Model is the software (is the model)!



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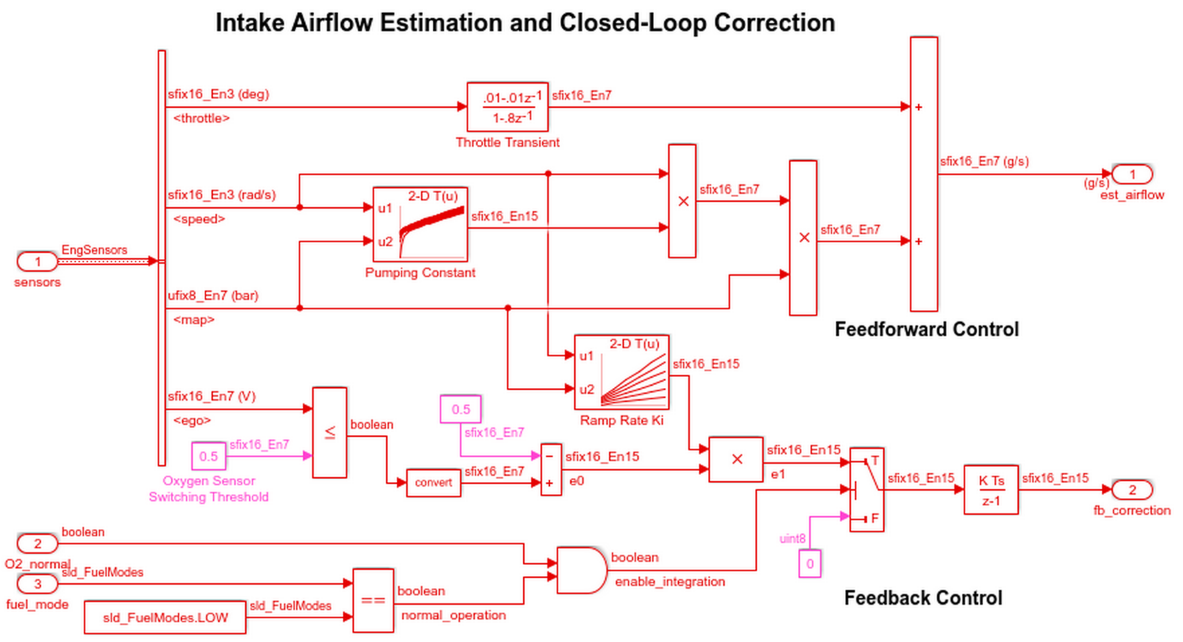

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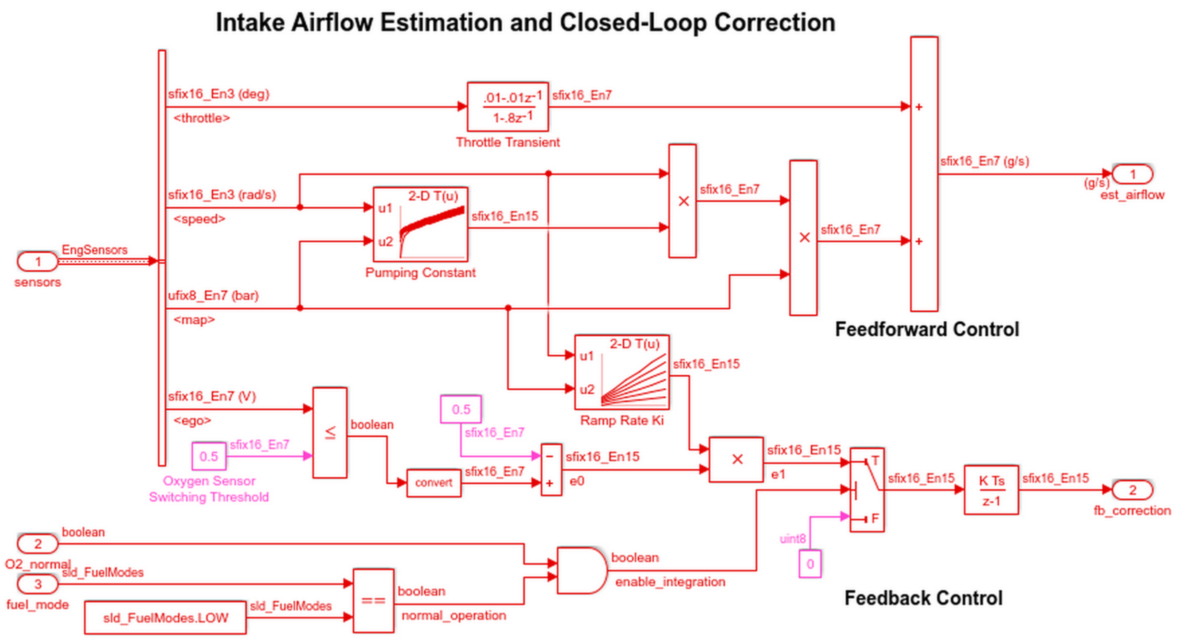

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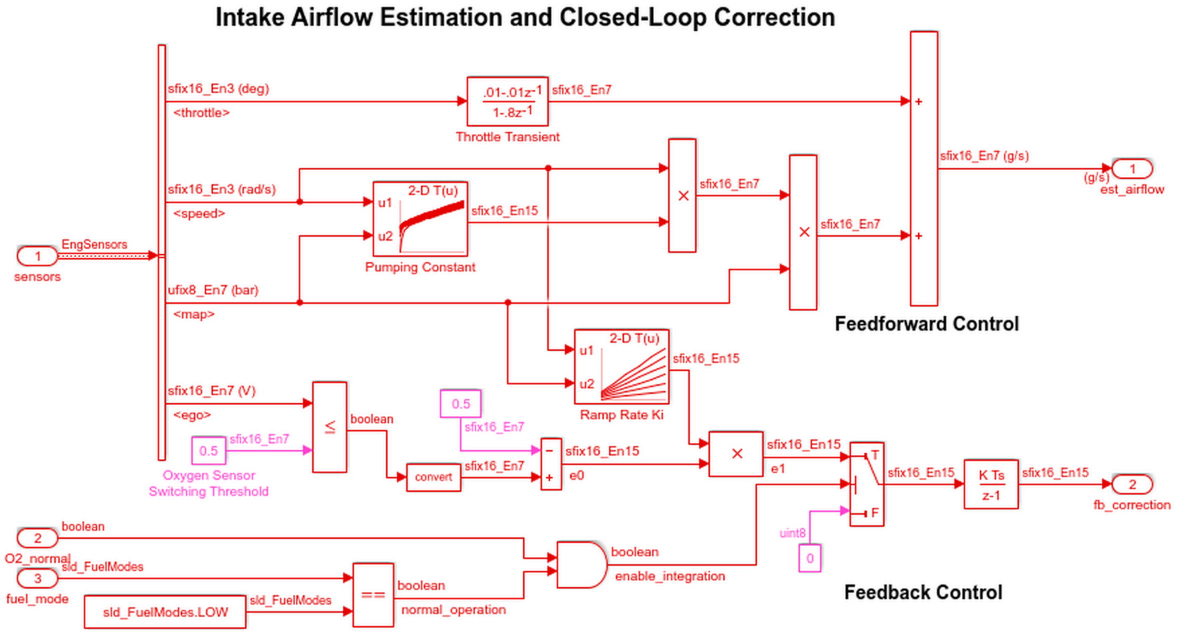

Model-Based Software Model Checking

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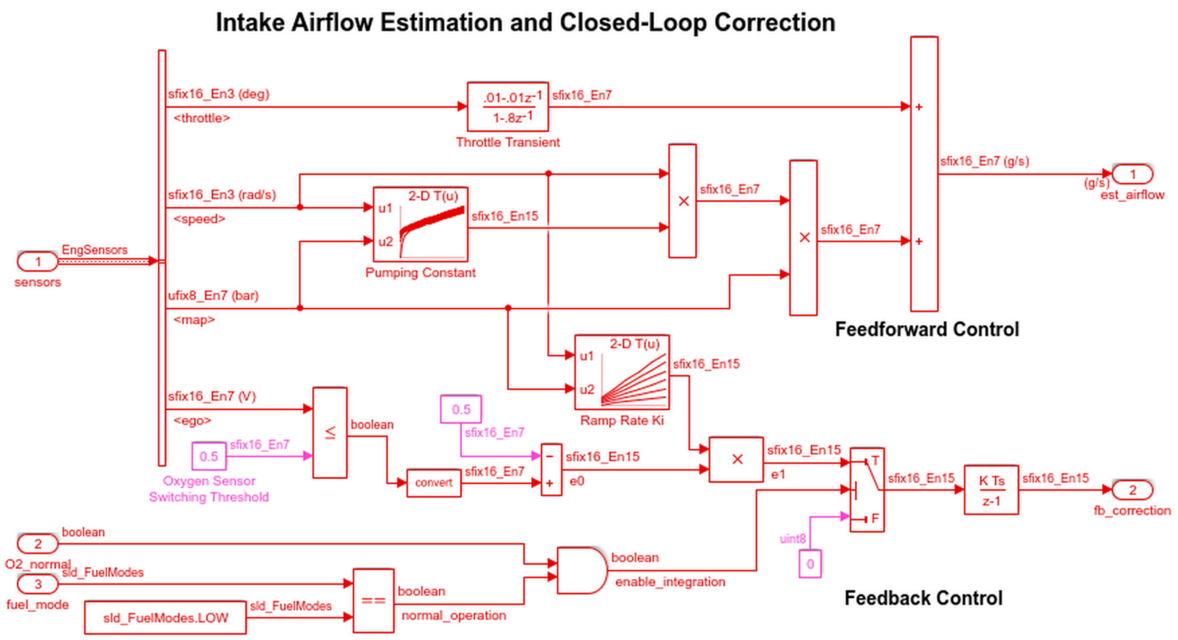

Model-Based Software Model Checking

- Model is the software (is the model)!
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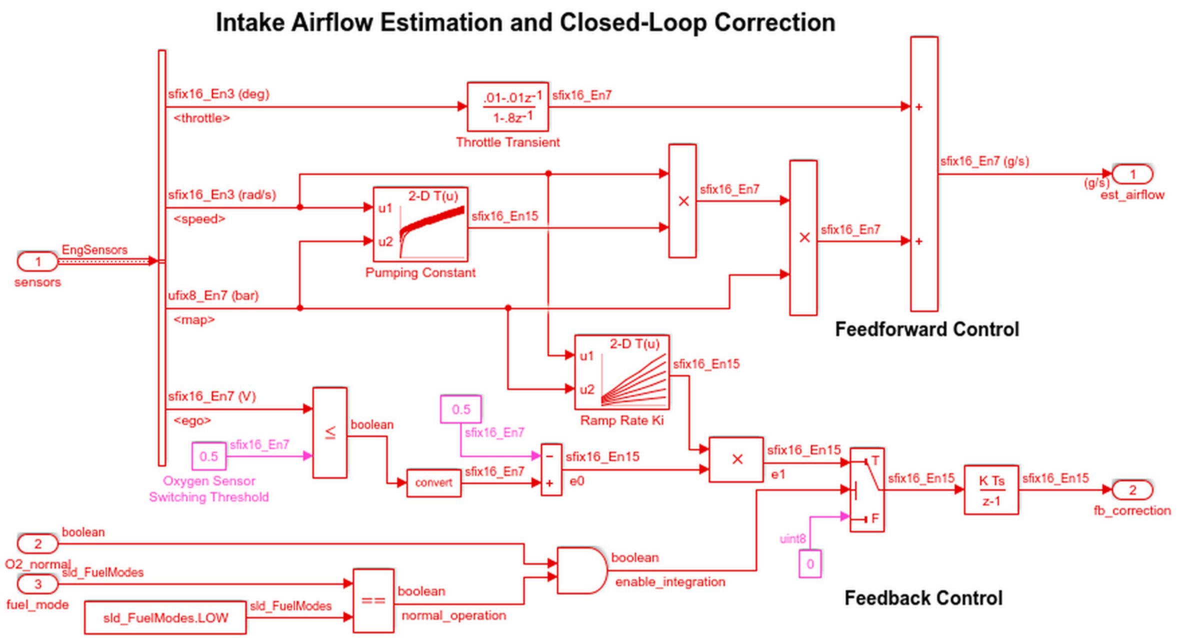

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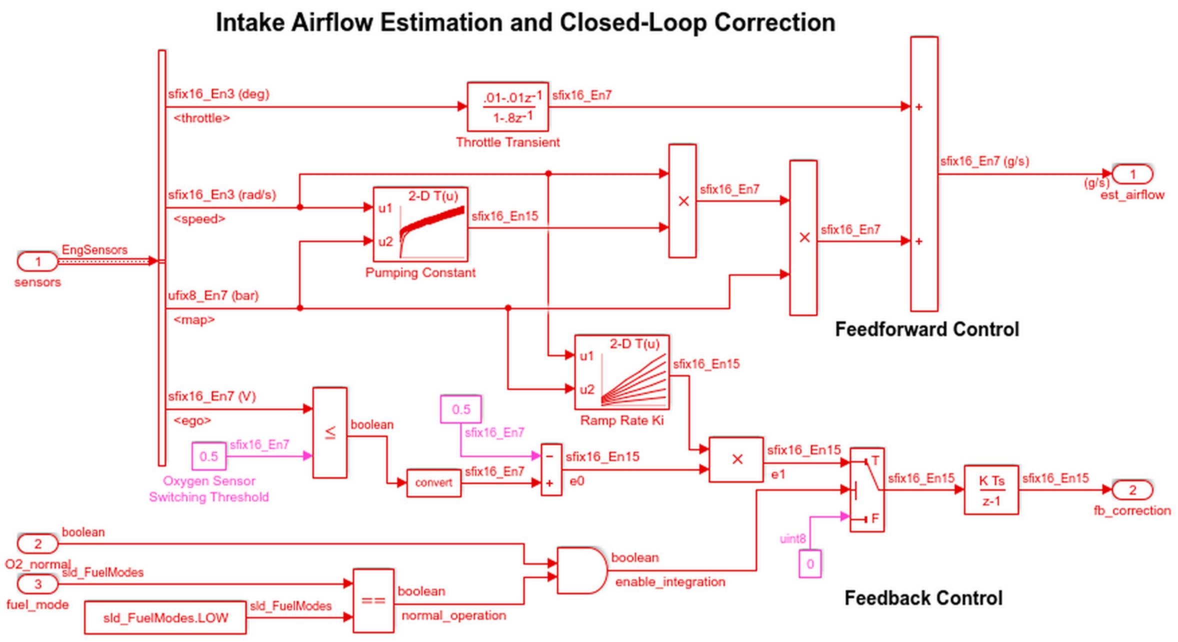
  - Arrays of signals, Buses (structures) of signals



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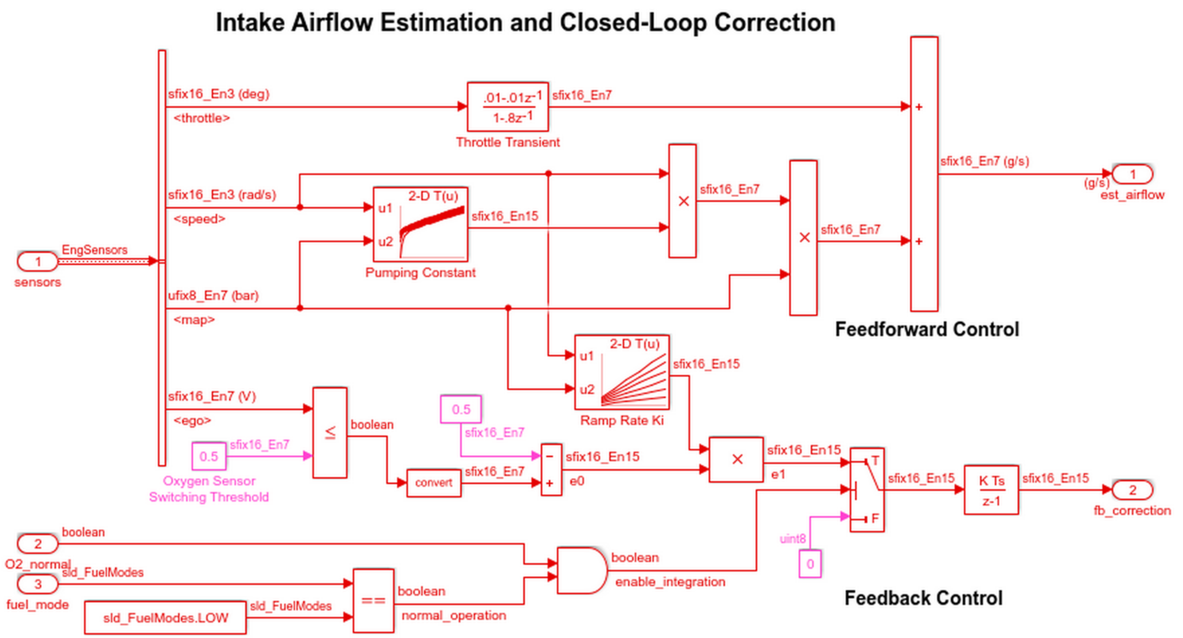
  - MATLAB code



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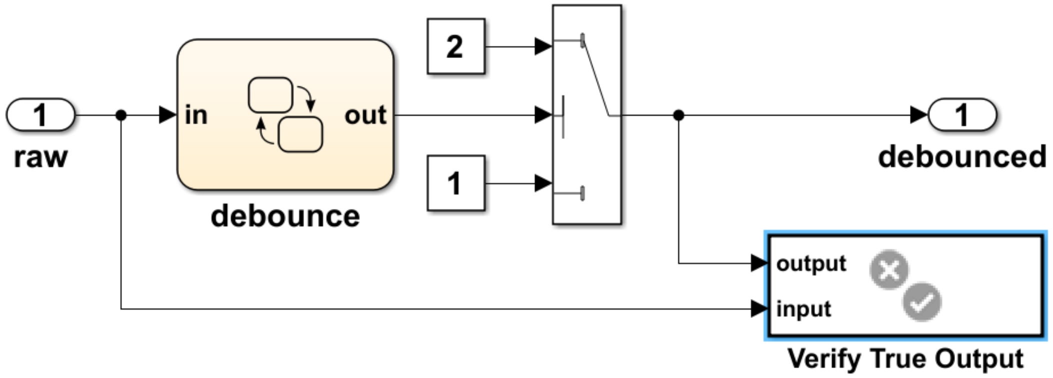
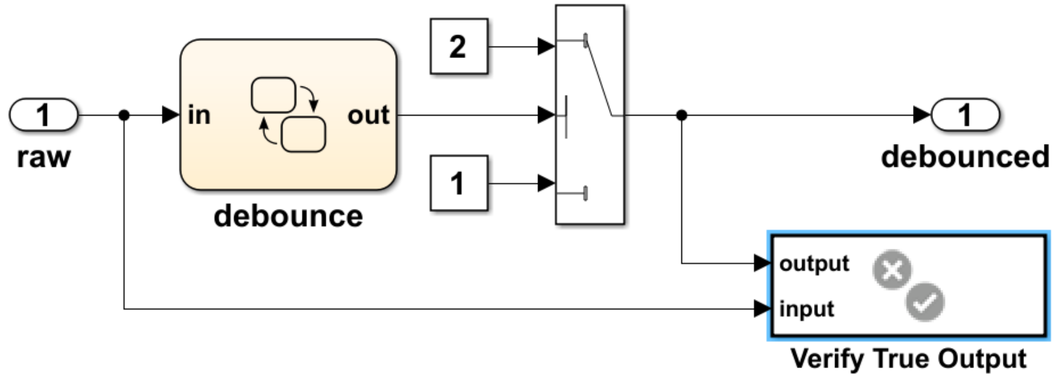


Model-Based Software Model Checking

- Model is the software (is the model!)
- Property is also modelled
  - Assertion blocks
  - Assumption blocks



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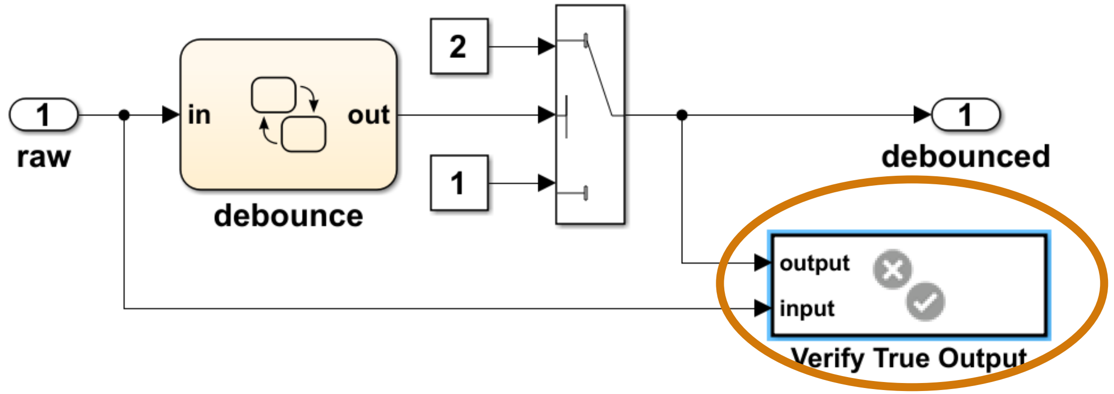
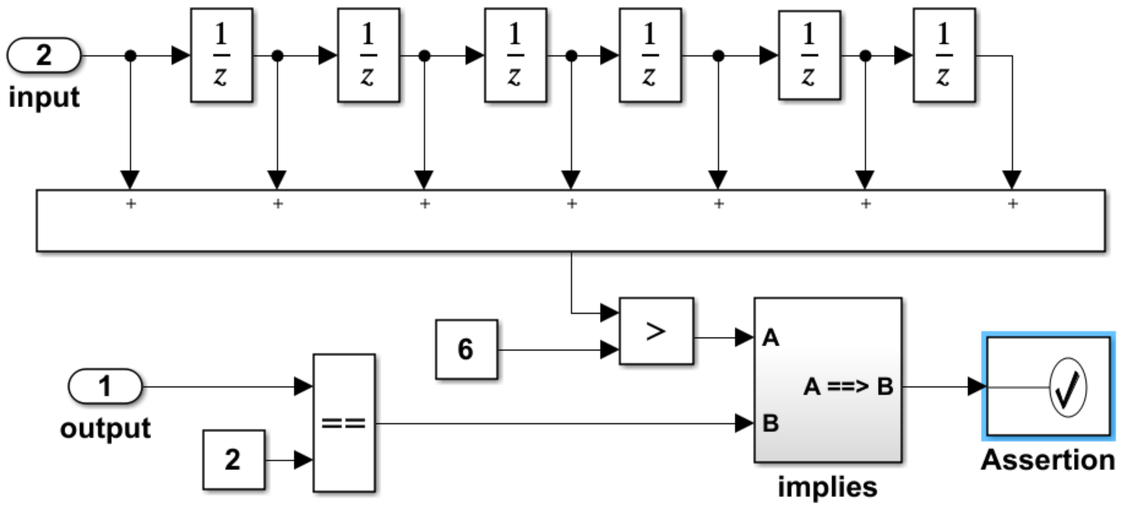
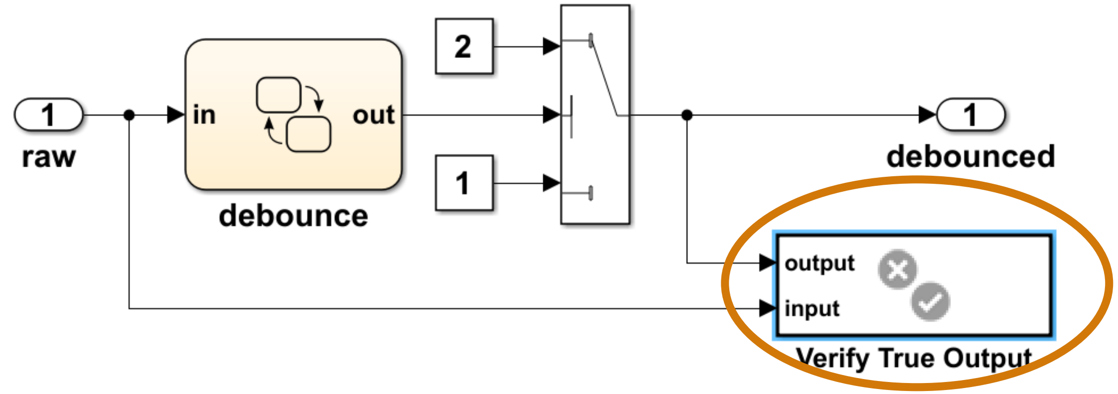
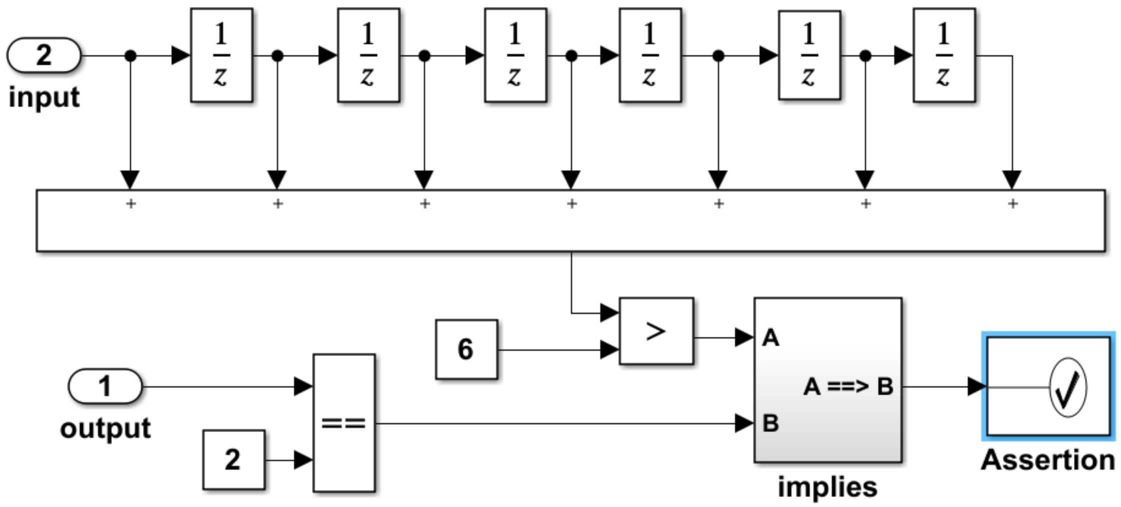




Model-Based Software Model Checking

- Model is the software (is the model!)
- Property is also modelled
  - Assertion blocks
  - Assumption blocks
  - Special statements in MATLAB code





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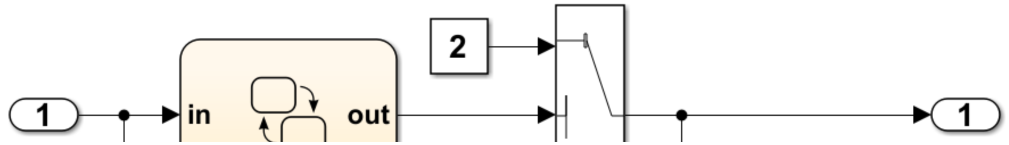
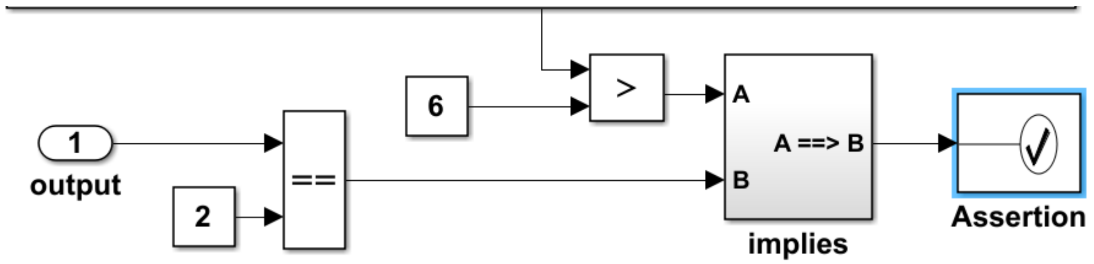



```matlab
function check_reminder(SeatBeltIcon,Inputs) %#codegen
    % The seat belt light should be active whenever the key is turned on
    % and speed is less than 15 and the seatbelt is not fastened
    activeCond = ((Inputs.KEY ~= 0) && (Inputs.SeatBeltFasten == 0) && ...
                  (Inputs.Speed < 15));

    sldv.prove(implies(activeCond,SeatBeltIcon));

function out = implies(cond, result)
    if (cond)
        out = result;
    else
        out = true;
    end
```



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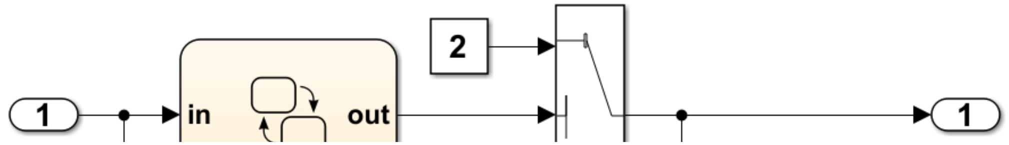
  - Special statements in MATLAB code
- Prove properties valid

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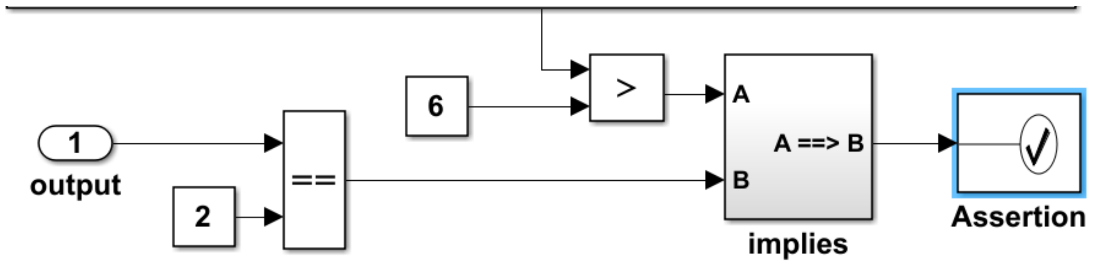
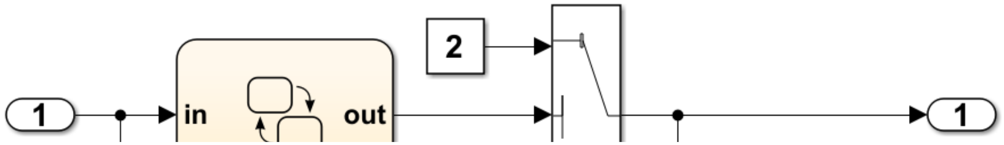
    end
```



Model-Based Software Model Checking

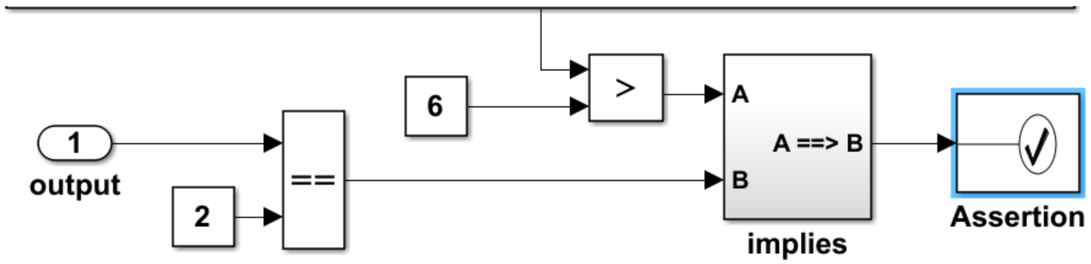
- Model is the software (is the model!)
- Property is also modelled
  - Assertion blocks
  - Assumption blocks
  - Special statements in MATLAB code
- Prove properties valid
- Provide evidence of invalidity



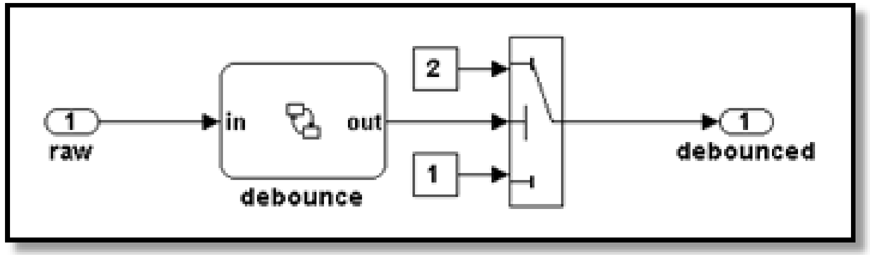

```
function check_reminder(SeatBeltIcon,Inputs) %#codegen
    % The seat belt light should be active whenever the key is turned on
    % and speed is less than 15 and the seatbelt is not fastened
    activeCond = ((Inputs.KEY ~= 0) && (Inputs.SeatBeltFasten == 0) && ...
                  (Inputs.Speed < 15));

    sldv.prove(implies(activeCond,SeatBeltIcon));

function out = implies(cond, result)
    if (cond)
        out = result;
    else
        out = true;
    end
```

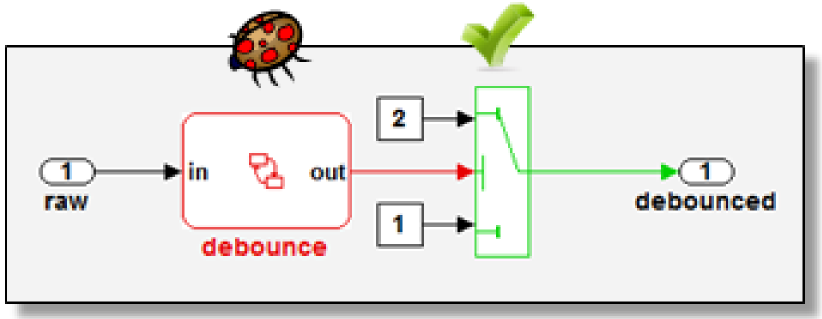


Run-time Error Check

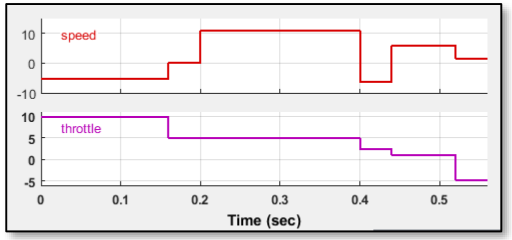


Design Model

- Integer overflow
- Division by zero
- Array out-of-bounds
- Range violations
- Dead Logic

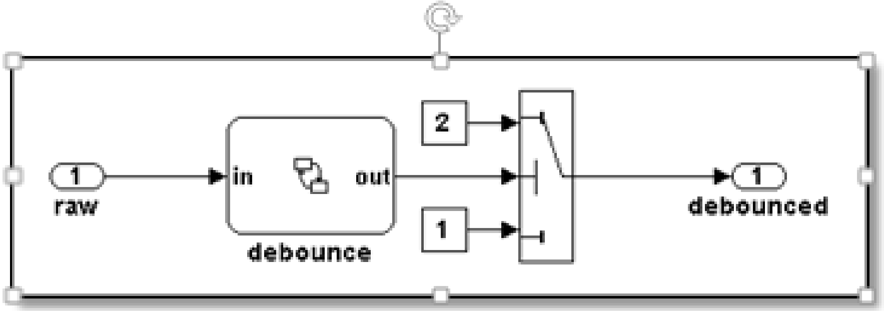


Highlighted Model

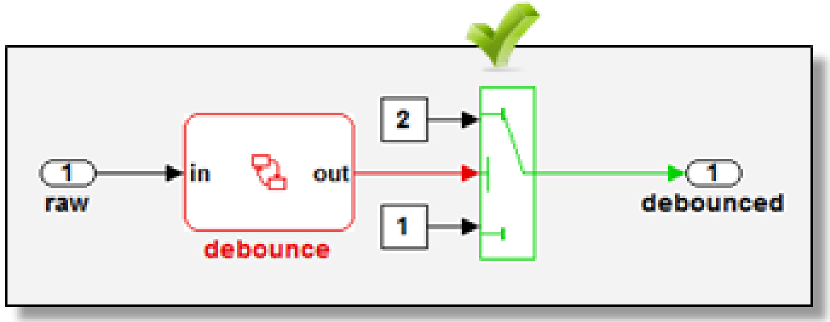


Counter-example

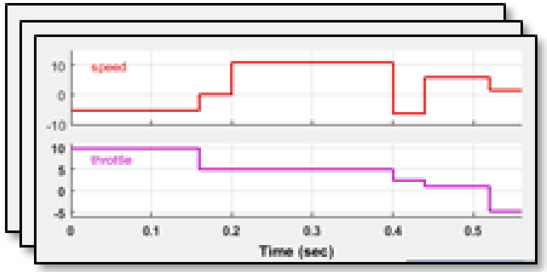
Test Generation Analysis



Design Model



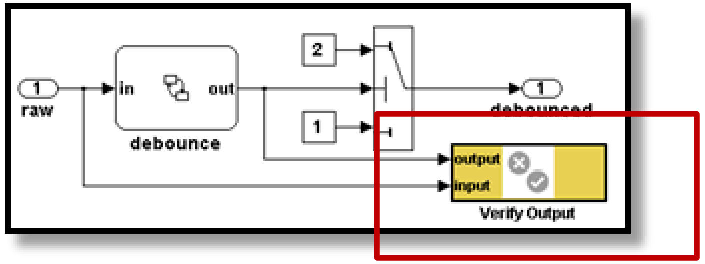
Highlighted Model



Test Cases

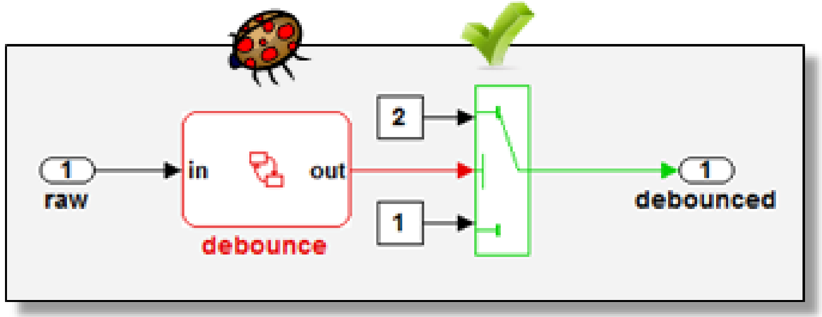
- Time varying inputs to satisfy coverage conditions
- Generate tests for missing coverage
- Special heuristics to satisfy timers/counters

Property Proving



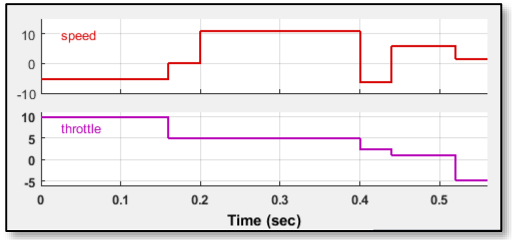
Design augmented with
modeled requirements

Property proving



Highlighted Model

- Functional verification and witness generation for safety properties
- Check for bounded depth validation or for full guarantees



Counter-example

It’s all about the Workflow!

Opportunities at MathWorks Bangalore

- Teams working on multiple areas of MATLAB and Simulink
- IN-SLVnV team
  - Simulink Design Verifier
  - Simulink Solvers and Execution Engine
  - HDL Code Generation and optimizations
  - Simulink Model Advisor
  - Simulink Test
  - Simulink Coder and optimizations
  - MATLAB Coder and optimizations
- Masters with some industry experience or PhD
  - Passion for developing software