Formal Development of Cyber-Physical Systems: The Event-B Approach

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The British Computer Society (FACS group)
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About Me

- Junior Research Assistant (2014-16) on the SafeCap project: formal methods for a safe and optimum railway,
- PhD work (2016-20, iCase w. Siemens Rail Automation) on formal engineering of heterogeneous railway signalling systems,
- Post-doctoral work (2020-) on the integration of hybridised Event-B and reachability analysis, real-time reachability analysis of autonomous systems and safe AI.

Cyber-Physical Systems

What are Cyber-Physical Systems (CPS)?

- integrate **computation** and **physical** processes,
- **networked** computers control physical systems.

Examples of CPS can be found in many industry sectors[1], [2]:

[1] https://www.phillymag.com/healthcare-news/2019/07/15/medcrypt-hack-proof-medical-devices/
[2] https://sites.rmit.edu.au/cyber-physical-systems/

Cyber-Physical Systems

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Importantly many of these systems are **safety-critical**.

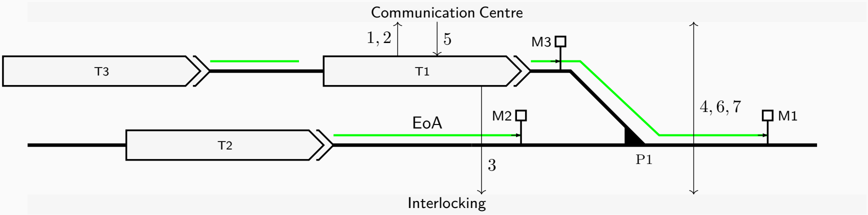
Cyber-Physical Railway Signalling Systems

2 Photo taken from https://www.networkrail-training.co.uk/media/Signaller_Training_01.jpeg

Cyber-Physical Railway Signalling Systems

Railway signalling systems are safety-critical cyber-physical systems:

- European Train Control System (ETCS L0-3, part of ERTMS), Communication-based Train Control (CBTC),

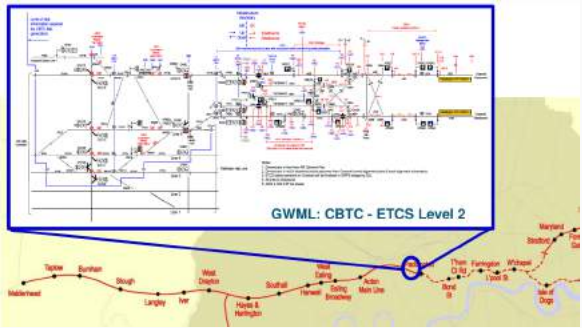


Trains are **hybrid systems** (discrete and continuous behaviour)

Cyber-Physical Railway Signalling Systems

Railway signalling systems are safety-critical cyber-physical systems:

- European Train Control System (ETCS L0-3, part of ERTMS), Communication-based Train Control (CBTC),
- **Heterogeneous** railway signalling networks (Crossrail, Thameslink).



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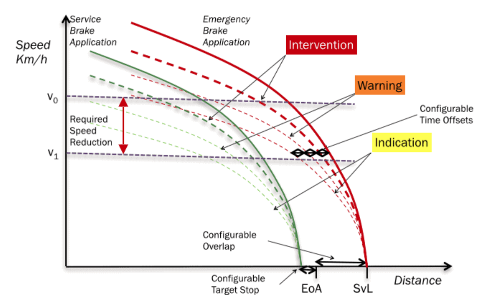
Cyber-Physical Railway Signalling Systems

Trains are **hybrid systems** (discrete and continuous behaviour)[3].

- European Vital Computed (EVC) computes braking curves and intervenes if braking curves are breached.



3 https://www.graffica.co.uk/case-studies/hermes-etcs-modelling/

Formal Methods for Railway Signalling Systems

Formal methods have been used in the railway domain, for example:

- The **B** method Paris Metro, Paris Roissy Airport shuttle.

Formal Verification of **control tables** and interlocking software (Solid State Interlocking (SSI)):

- push-button model-checking approaches.

ROUTE		INTERLOCKING				CONTROL				
		REQUIRES	SET & LOCKS POINTS		REQUIRES KEYLOCK	ASPECT	SIGNAL AHEAD	REQUIRES TC		
								CLEAR	AT TIME OF CLEARING ONLY	
From	To	ROUTE NORMAL	NORMAL	REVERSE	NORMAL				TC CLEAR OR	OCC FOR TIME
1	3					Y G	3 AT R# 3 AT Y# OR G#			
2	4					Y G	4 AT R# 4 AT Y# OR G#			
3(1)	23	16,24,4(1),4(2),3(2)		103,104	201,202, 203,204	Y+JI	23 AT R#	3T,9T,103T,24T,41T, 23T,104T,8T,4T	42	42 FOR 60 sec
3(2)	15	16,24,4(1),4(2),3(1)	103,104			Y G	15 AT R# 15 AT G#	3T,9T,103T,16T,42T, 15T,104T,8T,4T	41	41 FOR 60 sec
4(1)	16	15,23,3(1),3(2),4(2)	104,103			Y G	16 AT R# 16 AT G#	4T,8T,104T,15T,42T, 16T,103T,9T,3T	41	41 FOR 60 sec
4(2)	24	15,23,3(1),3(2),4(1)		104,103	201,202, 203,204	Y+JI	24 AT R#	4T,8T,104T,23T,41T, 24T,103T,9T,3T	42	42 FOR 60 sec
15	UP BLOCK SECTION	23,4(1),4(2)	104,103			G		15T,104T,8T,4T,2T,TOL		
23	UP BLOCK SECTION	15,4(1),4(2)		104,103		G		23T,104T,8T,4T,2T,TOL		
16	DOWN BLOCK SECTION	24,3(1),3(2)	103,104			G		16T,103T,9T,3T,1T,TOL		
24	DOWN BLOCK SECTION	16,3(1),3(2)		103,104		G		24T,103T,9T,3T,1T,TOL		

[3] Control Table example from S. Vanit-Anunchai: Verification of Railway Interlocking Tables Using Coloured Petri Nets. COORDINATION, 2010.

Formal Methods for Railway Signalling Systems

Formal methods have been used in the railway domain, for example:

– The **B** method Paris Metro, Paris Roissy Airport shuttle.

Formal Verification of control tables and the **interlocking software** (Solid State Interlocking (SSI)):

– automated theorem provers (e.g., The Formal Route company).

```
*QR117B(M)                       / route request block for route R117B(M)
  if R117B(M) a                  / route R117B(M) is available
           USD-CA f,OSC-BA f,OSV-BA f   / sub-route and sub-overlaps are free
        then if OSL-AC l,        / sub-overlap is OSL-AC locked
              P223 fr , P224 fr   / points P223, P224 free to move reverse
            then @P223QR \   / call subroutine P223QR
          if OSD-BC f         / sub-overlap is OSD-BC is free
             LTR04 xs         / latch (boolean flag) not set (false)
             P224 crf         / point P224 commanded reverse or free to move reverse
          then R117B(M) s    / set route set flag for R117B(M)
             USD-AC l , USC-AB l , USB-AB l , OSA-AB l  / set sub-routes/overlaps
             P224 cr          / command point P224 reverse
             LARR xs          / clear latch LARR
             S117 clear bpull    / clear signal button pull flag
             if P223 xcr , P223 rf then / check point states
              @P223QR    / point command subroutine
                 EP230 = 0 \ / reset timer EP230
```

[3] SSI example from Iliasov et al.: Formal Verification of Signalling Programs with SafeCap. SAFECOMP, 2018.

Framework for CPS Design and Analysis

Formal CPS development framework which utilises abstraction and refinement.

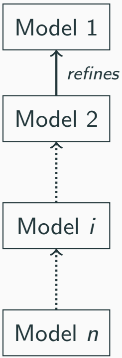
Enables a **multifaceted** CPS design:

- simulation-based system validation and analysis,
- model constraints and safe parameter values via reachability analysis.

Improves **scalability** of formal verification:

- automation of formal verification of hybrid systems,
- challenge of deriving differential invariant.

State-based pivot model (A)



Framework for CPS Design and Analysis

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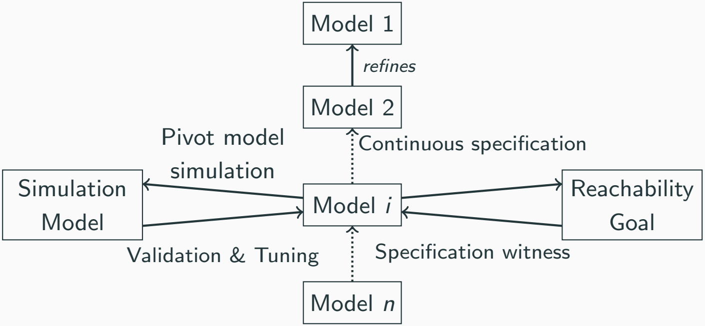
Simulation-based analysis (C)	State-based pivot model (A)	Reachability analysis (B)



Framework for CPS Design and Analysis

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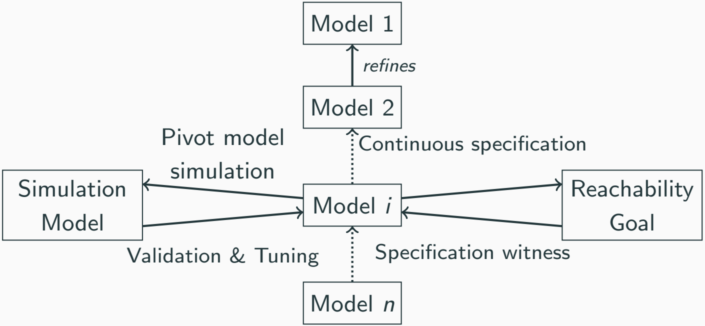
Simulation-based analysis (C) | State-based pivot model (A) | Reachability analysis (B)



From Event-B to Hybridised Event-B

From Event-B to Hybridised Event-B

The **B** method:

- formal software development method proposed by J.-R. Abrial.

The **Event-B** method:

- evolution of the **B** method for formal system-level modelling and verification.
- key features of the **Event-B** method:
  - set-theoretic modelling notation,
  - refinement- and proof- driven approach,
  - good tool support (Eclipse-based Rodin platform, ProB model checker, Theory plug-in, SMT solvers).

Both methods are used in academia and industry (e.g., Siemens Transportation, ALSTOM, CLEARSY and others)

From Event-B to Hybrid Event-B

The structure of **Event-B** models:

- a *context* holds static information about the system,
- a *machine* describes dynamic system aspects,
- properties about the system can be expressed as invariants (e.g. inv_2),
- 10 different types of possible proof obligations,
- (discrete) **Event-B** model verification automation has been significantly improved.

CONTEXT ctx0
SETS
  CRS
CONSTANTS
  m
AXIOMS
  axm_0 finite(CRS)
  axm_0 $m \in \mathbb{N}1$
  axm_0 $m \leq \text{card}(CRS)$
END

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MACHINE m0
VARIABLES
x
INVARIANTS
inv_1 $x \in \mathbb{N}$
inv_2 $\mathbf{x \leq 11}$
EVENTS
INITIALISATION
THEN
act_1 : $x := 0$
END
Increment
WHERE
grd_1 : $x \leq 10$
THEN
act_1 : $x := x + 1$
END
END

From Event-B to Hybrid Event-B

MACHINE m0
VARIABLES
x
INVARIANTS
$\text{inv}_1 \quad x \in \mathbb{N}$
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END

Invariant Preservation Rule

Axioms
Invariants
Event Guards
Event BAP
$\vdash$
Modified Specific Invariant

$x \in \mathbb{N}$	$x \in \mathbb{N}$
$x \leq 10$	$x = 0$
$\vdash$	$\vdash$
$x + 1 \leq 11$	$x \leq 11$

From Event-B to Hybrid Event-B

MACHINE m0
VARIABLES
x
INVARIANTS
inv_1 $x \in \mathbb{N}$
inv_2 $x \leq 11$
EVENTS
INITIALISATION
THEN
act_1 : $x := 0$
END
Increment
WHERE
grd_1 : $\top$
THEN
act_1 : $x :| x' = x + 1 \land \mathbf{x' + 1 \leq 11}$
END
END

Feasibility

Axioms
Invariants
Event Guards
$\vdash$
$\exists v' \cdot$ Event BAP

Note: Rewriting act_1 with *such that* and strengthening before-after predicate we can automatically prove inv_2 but need to prove feasibility.

From Event-B to Hybridised Event-B

The Rodin Theory plug-in allows extending the **Event-B** mathematical language:[4]

THEORY Seq
TYPE PARAMETERS A
OPERATORS
seq expression $seq(a : \mathbb{P}(A))$
direct definition
$seq(a : \mathbb{P}(A)) \triangleq \{n, f \cdot n \in \mathbb{N} \wedge f \in 1..n \rightarrow a | f\}$

⋮

AXIOMS
seqsIsFinite $\forall s, a \cdot a \subseteq A \wedge s \in seq(a) \Rightarrow finite(s)$

⋮

PROOF RULES

⋮

END

[4] Event-B theory example based on https://wiki.event-b.org/index.php/Theory_Plug-in

From Event-B to Hybridised Event-B

Hybrid systems are dynamical systems that exhibit discrete and continuous behaviour:

- a hybrid automaton model is used for describing hybrid systems.

The **Event-B** method for hybrid systems:

- Banach et al. Hybrid Event-B: Core Hybrid Event-B I: Single Hybrid Event-B machines
  - new *pliant* events for continuous actions,
  - approach is not tool supported.
- Dupont et al. Correct-by-Construction Design of Hybrid Systems Based on Refinement and Proof (PhD thesis)
  - new Event-B theories (Reals, continuous functions, differential equations, theory of approximations),
  - hybrid system modelling and refinement patterns (generic hybrid Event-B model).

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From Event-B to Hybridised Event-B

THEORY DiffEq **IMPORT** Functions
TYPE PARAMETERS E, F
DATATYPES
DE(F) **constructors** **ode**(f, η_0, t_0), ...
OPERATORS
solutionOf *predicate* ($D : \mathbb{P}(\mathbb{R})$, $\eta : \mathbb{R} \nrightarrow F$, $\mathcal{E}$: **DE**(F)) ...
Solvable *predicate* ($D : \mathbb{P}(\mathbb{R})$, $\mathcal{E}$: **DE**(F)) ...
CBAP *predicate* ($t, t' : \mathbb{R}^+$, $x_p, x_p' : \mathbb{R} \nrightarrow F$, $\mathcal{P} : \mathbb{P}((\mathbb{R} \nrightarrow F) \times (\mathbb{R} \nrightarrow F))$, $H : \mathbb{P}(F)$)
...
:∼ *predicate* ($t, t' : \mathbb{R}^+$, $x_p, x_p' : \mathbb{R} \nrightarrow F$, $\mathcal{E}$: **DE**(F), $H : \mathbb{P}(F)$)
well−definedness condition **Solvable**($[t, t'], \mathcal{E}$)
direct definition **solutionOf**($[t, t'], x_p', \mathcal{E}$) $\wedge \ldots$
...
AXIOMS
CauchyLipschitz: —— *external*
$\forall \mathcal{E}, D, D_F \cdot \mathcal{E} \in$ **DE**(F) $\wedge \ldots \Rightarrow$ **Solvable**($D, \mathcal{E}$)
...

- use of theories to integrate continuous features
  $\Rightarrow$ *e.g. continuous behaviour using differential equations*
- exploit WD to ensure the correct use of operators/theorems

From Event-B to Hybridised Event-B

Continuous state variables = *functions of time* ($\in \mathbb{R} \nrightarrow S$)
$\Rightarrow$ **continuous evolution** *as CBAP*

$$\mathbf{CBAP}(t, t', x_p, x'_p, \mathcal{P}, H) \equiv$$

$$x_p \mathbin{:}|_{t \to t'} \mathcal{P}(x_p, x'_p) \,\&\, H \equiv$$

$$[0, t[\lhd x'_p = [0, t[\lhd x_p \qquad (\textit{Past Preservation})$$

$$\land \mathcal{P}([0, t] \lhd x_p, [t, t'] \lhd x'_p) \qquad (\textit{Predicate})$$

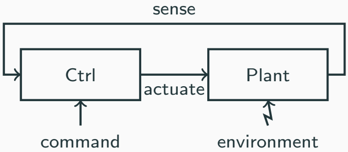
$$\land \forall t^* \in [t, t'], x_p(t^*) \in H \qquad (\textit{Evolution Dom.})$$

Note: *shorthand for differential equations:*

$$x_p \mathbin{:}\sim_{t \to t'} \mathcal{E} \,\&\, H \equiv x_p \mathbin{:}|_{t \to t'} \mathbf{solutionOf}([t, t'], \mathcal{E}, x'_p) \,\&\, H$$

From Event-B to Hybridised Event-B

Hybridised **Event-B** patterns formalise a generic controller-plant-loop hybrid system as Event-B model:



Hybridised **Event-B** machine modelling pattern:

MACHINE Generic
EXTENDS *DiffEquations*
VARIABLES t , x_s , x_p
INVARIANTS
inv$_1$: $t \in \mathbb{R}^+$
inv$_2$: $x_s \in \text{STATES}$
inv$_3$: $x_p \in \mathbb{R} \nrightarrow S$
inv$_4$: $[0, t] \subseteq \mathrm{dom}(x_p)$

- use developed theories (e.g., differential equations),
- explicit time (t),
- discrete state (x_s) + continuous state (x_p, function of time).

From Event-B to Hybridised Event-B

Generic events of hybridised **Event-B** modelling pattern:

Actuate
ANY $\mathcal{P}$, s , H , t'
WHERE
grd$_0$: $t' > t$
grd$_1$: $\mathcal{P} \in (\mathbb{R}^+ \twoheadrightarrow S) \times (\mathbb{R}^+ \twoheadrightarrow S)$
grd$_2$: $\textbf{Feasible}([t, t'], x_p, \mathcal{P}, H)$
grd$_3$: $s \subseteq \text{STATES} \wedge x_s \in s$
grd$_4$: $H \subseteq S \wedge x_p(t) \in H$
THEN
act$_1$: $x_p :|_{t \to t'} \mathcal{P}(x_p, x_p') \,\&\, H$
END

Sense
ANY s , p
WHERE
grd$_1$: $s \in \mathbb{P}1(\text{STATES})$
grd$_2$: $p \in \mathbb{P}(\text{STATES} \times \mathbb{R} \times S)$
grd$_3$: $(x_s \mapsto t \mapsto x_p(t)) \in p$
THEN
act$_1$: $x_s :\in s$
END

- discrete event **Sense** + continuous event **Actuate** (passing of time),
- **Actuate** based on **CBAP**, WD in guard (proved in refinement with guard strengthening),
- Additional generic events **Behave** and **Transition** model changes induced by environment and user.

From Event-B to Hybridised Event-B

New types of proof obligations:

– Continuous invariant preservation: if the invariant is true on $[0, t]$, then it must be true on $[t, t']$, i.e., on the whole duration of the continuous event:

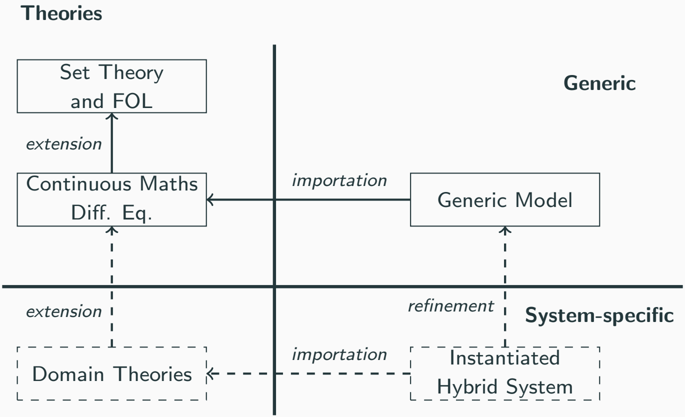
$$\Gamma, \mathcal{I}([0,t] \lhd x_p),\ CBAP(t, t', x_p, x_p', \mathcal{P}, \mathcal{H}) \quad \vdash \mathcal{I}([t,t'] \lhd x_p') \qquad \text{(CINV)}$$

– Continuous feasibility requires to prove that, if the event is triggered, then its action can be performed:

$$\Gamma \vdash \exists t' \cdot t' \in \mathbb{R}^+ \land t' > t \land \textbf{Feasible}([t,t'], x_p, \mathcal{P}, \mathcal{H}_{saf}) \qquad \text{(CFIS)}$$

Important: Proof-obligations related to continuous system behaviour of the model are generally complex and proved interactively.

Hybridised Event-B for CPS Design Framework



The following slides present the framework application for developing a cyber-physical railway signalling system.

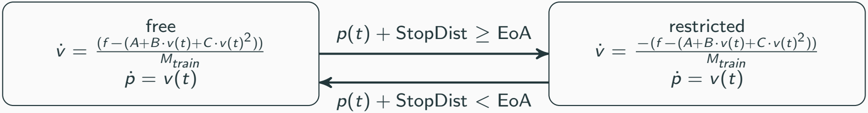
Cyber-Physical Railway Signalling System: Speed Controller

1st refinement of the generic introduces rolling stock.

- A driver (or ATO system) controls a train engine power (tractive force) - f - which yields an acceleration,
- Davis Resistance equation in Equation (1), where A, B, C are fixed parameters and $v(t)$ is the speed of a train at time t:

$$\begin{cases} \dot{v}(t) = \pm(f - (A + B \cdot v(t) + C \cdot v(t)^2))/M_{train} \\ \dot{p}(t) = v(t) \end{cases} \tag{1}$$

- The hybrid automaton model of the train speed controller:



Cyber-Physical Railway Signalling System: Speed Controller

- Properties of the train are gathered in the Train *domain theory*,
- This theory mainly defines the *Davis equation* and its properties

THEORY Trains
OPERATORS
DavisResistance *expression* $(a : \mathbb{R},\ b : \mathbb{R},\ c : \mathbb{R})$
well−definedness condition $a \geq 0,\ b \geq 0,\ c \geq 0$
direct definition $(\lambda v \cdot v \in \mathbb{R} \mid a + bv + cv^2)$
...
THEOREMS
...
END

Cyber-Physical Railway Signalling System: Speed Controller

The context defines the constants of the system:

- Davis coefficients (a, b, c), traction power limits (f_{min}, f_{max})

Also, the context introduces the stopping distance function **StopDist** and controller models.

CONTEXT TrainCtx
CONSTANTS
free_move, restricted_move
StopDist
$a, b, c, f_{min}, f_{max}, f_{dec\_min}$
AXIOMS
$\mathrm{axm}_1: \quad a, b, c \in \mathbb{R}^+$
$\mathrm{axm}_2: \quad f_{min}, f_{max}, f_{dec\_min} \in \mathbb{R}$
$\mathrm{axm}_3: \quad \mathrm{StopDist} \in (\mathbb{R} \times \mathbb{R}^+) \rightarrowtail \mathbb{R}^+$
$\mathrm{axm}_5: \quad \mathrm{partition}(\mathrm{STATES}, \{\mathrm{free\_move}\}, \{\mathrm{restricted\_move}\})$
...

Cyber-Physical Railway Signalling System: Proof Statistic

MACHINE TrainMach **REFINES** Generic
VARIABLES t , x_{st} tp , tv , ta , f , EoA
INVARIANTS

inv$_1$: $tp, tv, ta \in \mathbb{R} \nrightarrow \mathbb{R}$
inv$_2$: $[0, t] \subseteq \mathrm{dom}(tp), \ldots$
inv$_3$: $\mathsf{EoA} \in \mathbb{R}^+$
inv$_4$: $f_{min} \leq f \wedge f \leq f_{max}$
inv$_5$: $x_p = [ta\ tv\ tp]^\top$
saf$_1$: $\forall t^* \cdot t^* \in [0, t] \Rightarrow tp(t^*) \leq \mathsf{EoA}$
phy$_1$: $\forall t^* \cdot t^* \in [0, t] \Rightarrow tv(t^*) \geq 0$

Safety property as: **at all times the train must remain within the issued movement authority**:

- expressed as Event-B invariant saf$_1$,
- an additional physics property phy$_1$.

Cyber-Physical Railway Signalling System: Speed Controller

Sense_to_restricted
REFINES Sense
WHERE
grd$_1$: $tp(t) + \mathrm{StopDist}(ta(t) \mapsto tv(t))) \geq \mathrm{EoA}$
WITH
st : $st = \{\mathrm{restricted\_move}\}$
$p : p = \mathrm{STATES} \times \mathbb{R} \times \{v^* \mapsto p^* \mid p^* + \mathrm{StopDist}(f_{dec\_min} \mapsto v^*) \geq \mathrm{EoA}\}$

THEN
act$_1$: $x_{st} := \mathrm{restricted\_move}$
END

Cyber-Physical Railway Signalling System: Speed Controller

Actuate_move **REFINES** Actuate

ANY t'

WHERE

grd$_1$: $tp(t) + \text{StopDist}(ta(t) \mapsto tv(t)) \leq \text{EoA}$

grd$_2$: $t < t'$

WITH

x_p' : $x_p' = [ta\ tv\ tp]^\top$

$\mathcal{P}$: $\mathcal{P} = \ldots$

H : $H = \ldots$

st : $st = \text{STATES}$

THEN

act$_1$: $ta, tv, tp :|_{t \to t'}$

$\textbf{solutionOf}([t, t'], [tv\ tp]^\top, \text{DavisEquation}(a, b, c, f, t, tv(t), tp(t))) \wedge$

$ta = \dot{tv}$

$\& tp + \text{StopDist}(ta \mapsto tv) \leq \text{EoA} \wedge tv \geq 0$

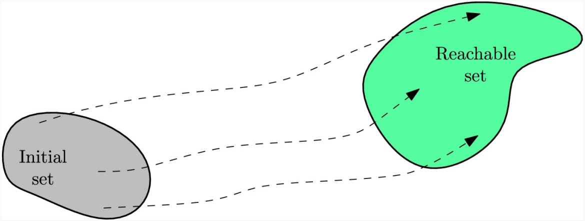
END

Cyber-Physical Railway Signalling System: Proof Statistic

Refinement	PO Type	|POs|	Auto.	Inter.
Speed Controller		55	36	19
	WD	12	12	0
	GRD	11	11	0
	INV	18	10	**8**
	FIS	8	0	**8**
	SIM	6	3	3
Communication		85	71	14
	WD	31	31	0
	GRD	12	7	5
	INV	42	33	9
	FIS	0	0	0
	SIM	0	0	0
Total		140	119	21

Reachability Analysis for Hybridised Event-B

Can **reachability analysis** help to address verification automation challenges of hybridised Event-B models (similar to how ProB model checker is used for discrete systems)?



Computing reachable states of a **hybrid automaton** requires computing *runs* of the hybrid system.

Cyber-Physical Railway Signalling System: Speed Controller

Reachability enabled verification **tactic** of **CINV**:

1. Strengthen actuation events actions such that $H \subseteq \mathcal{I}$,
2. Generating proof-obligation (automatically),
   - 2 CFIS proof obligations were generated (for the free and restricted modes).
3. Translate proof-obligations to reachability analysis tool (JuliaReach, manually),
   - translate other related functions - *StopDist*.
4. Define initial values $\mathcal{X}_0$ for the reachability problem,
5. Compute and check solution produced reachability tool,
   - check existence of an interval $[0, t']$ for which reachset $\mathcal{R}$ of continuous x_p with initial values $\mathcal{X}_0$ satisfies a strengthened local invariant $\mathcal{H}$.

Cyber-Physical Railway Signalling System: Proof Statistic

Refinement	PO Type	|POs|	Auto.	Inter.
Speed Controller		55	36 (48)	19 (7)
	WD	12	12	0
	GRD	11	11	0
	INV	18	10 (14)	8 (4)
	FIS	8	0 (8)	8 (0)
	SIM	6	3	3
Communication		85	71	14
	WD	31	31	0
	GRD	12	7	5
	INV	42	33	9
	FIS	0	0	0
	SIM	0	0	0
Total		140	119	21

To enable model animation and validation we aim to connect hybridised **Event-B** with Simulink/Stateflow.

To validate the speed controller model we (manually) translated it to Simulink/Stateflow.

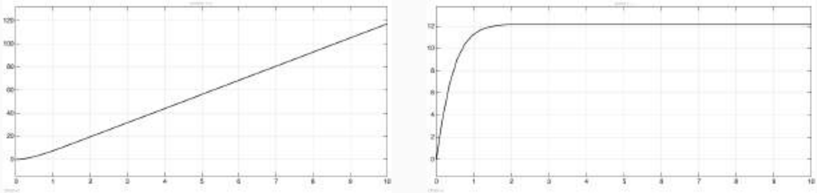


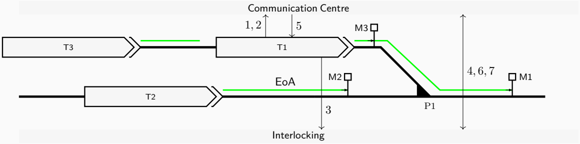
Figure 4: TGV train simulation with Davis equation coefficients for TGV: $a = 25$, $b = 1.188$ and $c = 0.0703728$

Cyber-Physical Railway Signalling System: Other Sub-Systems

2nd refinement introduces other sub-systems of the signalling system:

- communication centres, interlocking and infrastructure,
- communication protocol.

The **generic** railway signalling is based on ETCS Level 3 and CBTC systems.



Communication protocol was modelled by using developed **Event-B** communication modelling patterns.

To formally demonstrate that the generic signalling system issues **safe** movement authority and ensures safe point crossing.

Cyber-Physical Railway Signalling System: Proof Statistic

Refinement	PO Type	|POs|	Auto.	Inter.
Speed Controller		55	36 (48)	19 (7)
	WD	12	12	0
	GRD	11	11	0
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	FIS	0	0	0
	SIM	0	0	0
Total		140	119	21

Conclusions and Next Steps

In summary:

- The complexity of developing complex CPS can be reduced by using refinement and abstraction.
- Our proposed framework provides a more comprehensive formal CPS development.
- Reachability analysis can help to improve verification automation of hybridised Event-B models.

Next steps in the short-term:

- Facilitate an automatic translation of hybridised Event-B models to JuliaReach,
- develop new Event-B theories.

(Long-term) Future Work

Explore synergies between proof and reachability analysis for CPS system verification and code generation:

- proving single CINV/CFIS proof-obligations (still many open questions),
- proving CPS Event-B sub-models,
- discovering model constraints and safe parameter values,
- discretisation of continuous model and code generation (discovering t').

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Workshop on Formal Engineering of CPS

2nd International Workshop on Formal Engineering of Cyber-Physical Systems (FE-CPS) collocated with TASE 2023 (Bristol, UK), 4-6 July.

Website with CfP: https://www.irit.fr/FE-CPS-2023/

Invited talks: Ana Cavalcanti (University of York, UK) and Claudio Gomes (Aarhus University, Denmark)

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