Your Connection to ICT Research

Building Event-B Interlocking Theories

Lessons Learned Using the Theory Plug-in

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PLUS HAUT
ET PLUS PROCHE
LE FONDS EUROPÉEN DE DÉVELOPPEMENT RÉGIONAL
ET LA WALLONIE INVESTISSENT DANS VOTRE AVENIR

FEDER
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Wallonie

Centre d'Excellence en **Technologies** de l'**Information** et de la **Communication**
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Who Am I ?

Yet another formal methods research engineer…

...with a bit of interest in the event-b method.

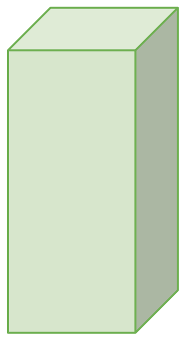
Before @ Systerel

Coded for the SMT Solvers Plug-in of Rodin

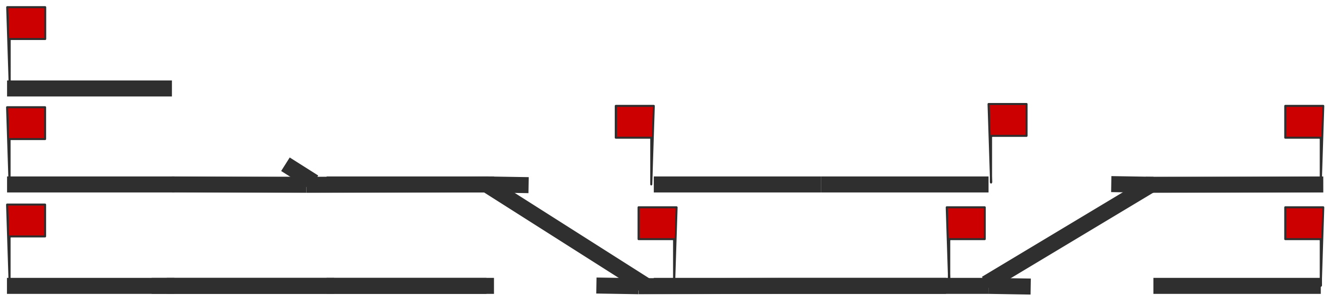
Nowadays @ **CETIC** : *Technology Transfert*

Experimenting with the Theory Plug-in of Rodin

What is an Interlocking ?



A Railway Signalling System



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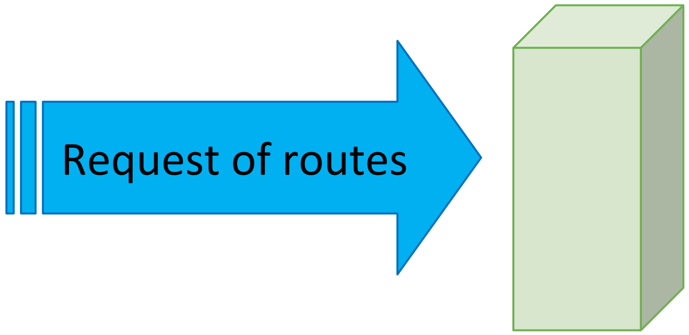

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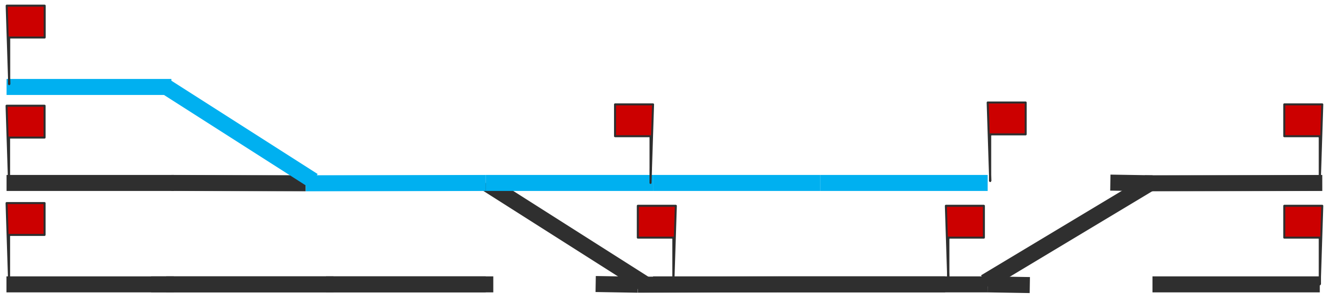

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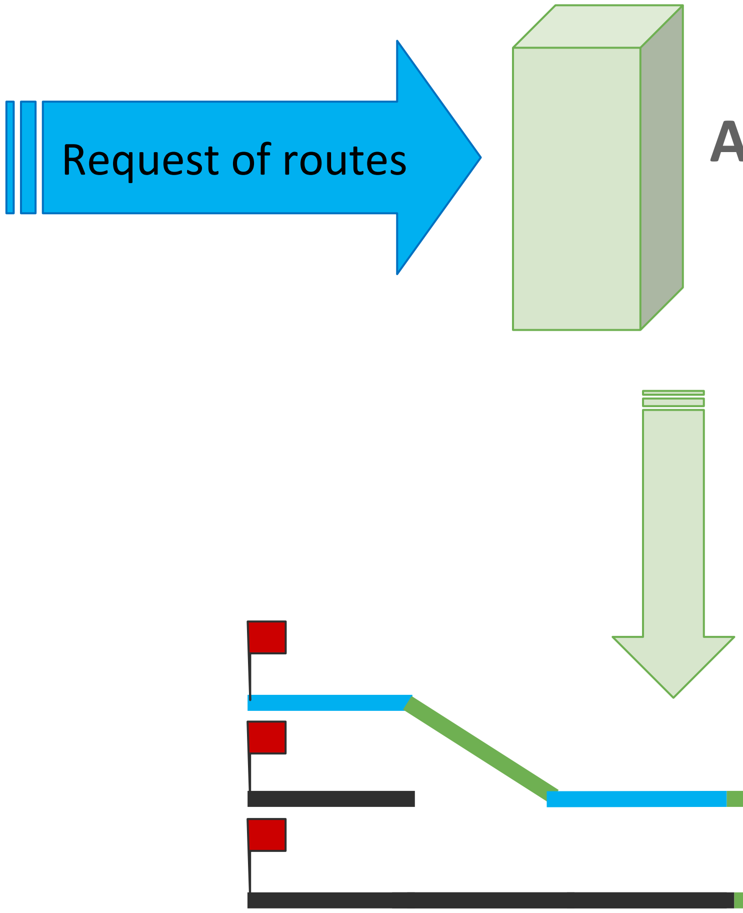
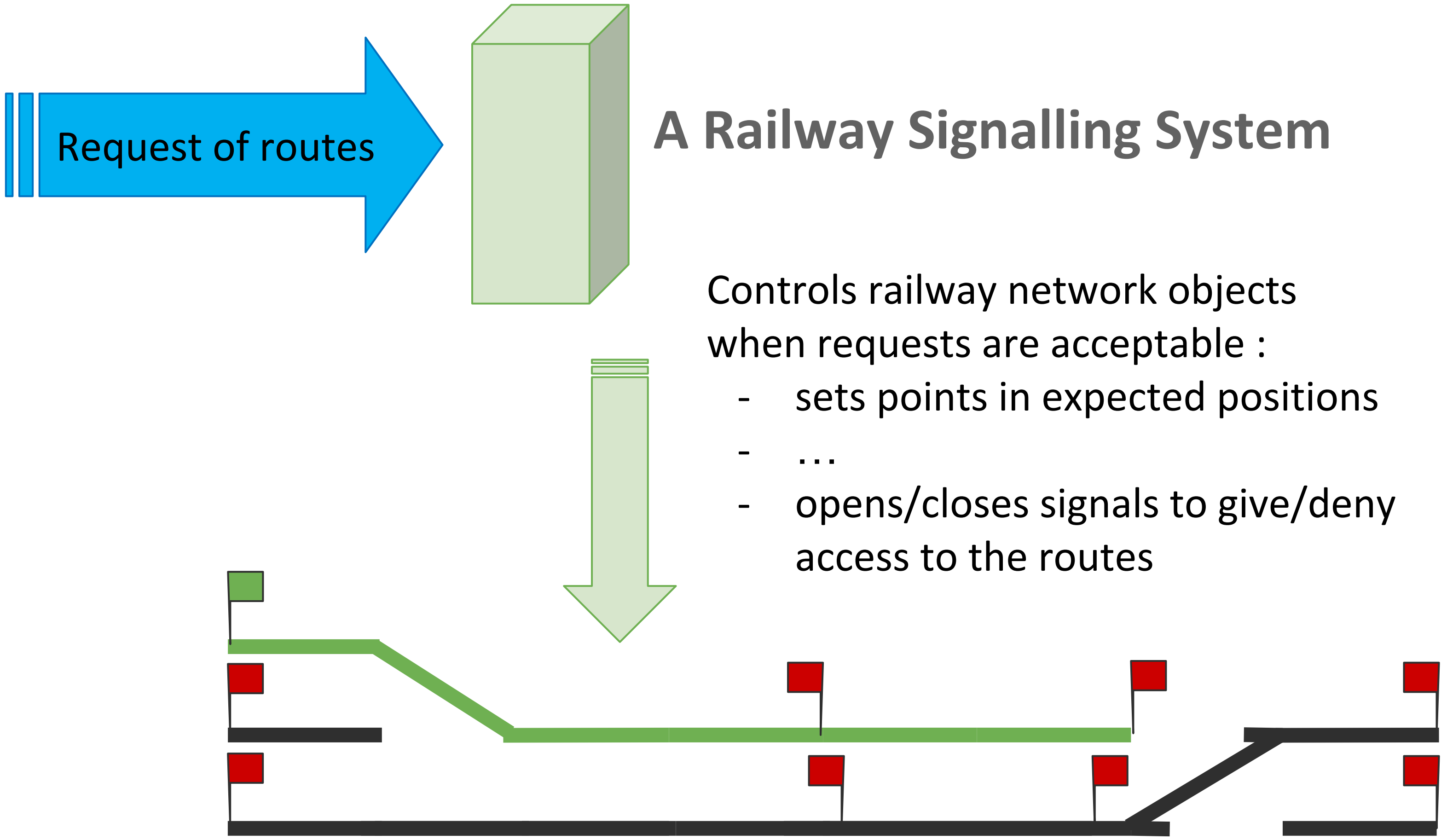


A Railway Signalling System

Controls railway network objects when requests are acceptable :

- sets points in expected positions

What is an Interlocking ?

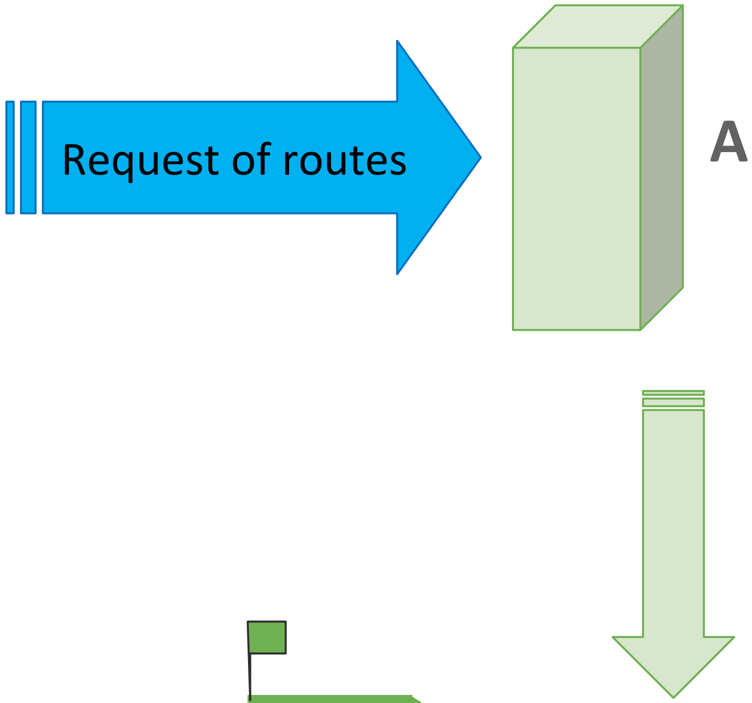


A Railway Signalling System

Controls railway network objects when requests are acceptable :

- sets points in expected positions
- …
- opens/closes signals to give/deny access to the routes

What is an Interlocking ?



A Railway Signalling System

Controls railway network objects when requests are acceptable :

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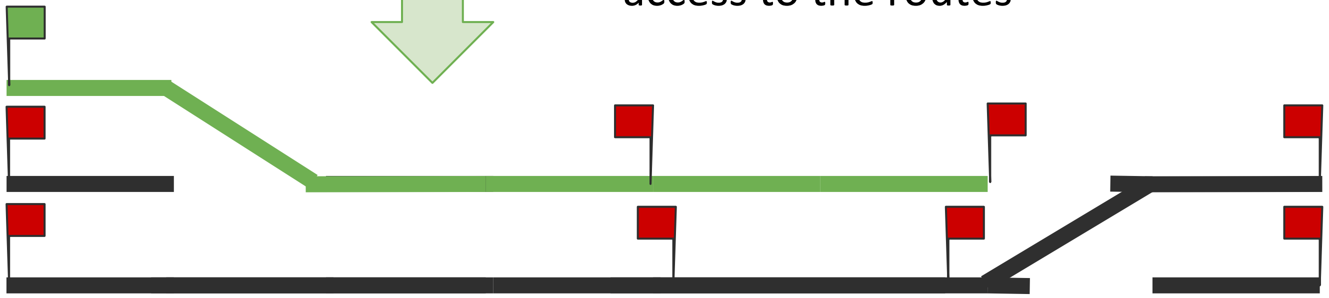

Trains move on the network without colliding with each others nor derailing…

Who Makes Interlockings ?

Signalling engineers…

- possess the historical knowledge
- incrementally design new interlockings
- directly produce specific code
  based on generic programming rules
- *validate by reviewing and testing*

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What about mathematical
proof of safety ?

- are generally *not* fluent in formal methods
- are especially *not* event-b lovers

Outline

How to Bring These Worlds Together

Use the Theory Plug-in of Rodin[1]

"Cover up those mathematical expressions which I cannot endure…"[2]

Defining Interlocking Theories

Reducing the Proof Effort

[1]Modeling a Safe Interlocking Using the Event-B Theory Plug-in, M-T. Khuu, L. Voisin and F. Mejia

[2](almost) Molière's Tartuffe

Covering Mathematical Expressions

The Famous Train Example First Context

axm1: blocks_routes ∈ BLOCKS ↔ ROUTES

axm2: dom(blocks_routes) = BLOCKS

axm3: ran(blocks_routes) = ROUTES

axm4: next ∈ ROUTES → (BLOCKS □ BLOCKS)

axm5: fst ∈ ROUTES → BLOCKS

axm6: last ∈ ROUTES → BLOCKS

axm7: fst~ ⊆ blocks_routes

axm8: last~ ⊆ blocks_routes

axm9: ∀r · r ∈ ROUTES ⇒ fst(r) ≠ last(r)

axm10: ∀r · r ∈ ROUTES ⇒ next(r) ∈ blocks_routes~[{r}] ∖ {last(r)} □ blocks_routes~[{r}] ∖ {fst(r)}

axm11: ∀r · r ∈ ROUTES ⇒ (∀S · S ⊆ next(r)[S] ⇒ S = ∅)

axm12: ∀r1, r2 · r1 ∈ ROUTES ∧ r2 ∈ ROUTES ∧ r1 ≠ r2
⇒ fst(r1) ∉ blocks_routes~[{r2}] ∖ {fst(r2), last(r2)}

axm13: ∀r1, r2 · r1 ∈ ROUTES ∧ r2 ∈ ROUTES ∧ r1 ≠ r2
⇒ last(r1) ∉ blocks_routes~[{r2}] ∖ {fst(r2), last(r2)}

The Famous Train Example First Context

axm1: $blocks\_routes \in BLOCKS \leftrightarrow ROUTES$

axm2: $dom(blocks\_routes) = BLOCKS$

axm3: $ran(blocks\_routes) = ROUTES$

Objects definitions

axm4: $next \in ROUTES \rightarrow (BLOCKS\ \square\ BLOCKS)$

axm5: $fst \in ROUTES \rightarrow BLOCKS$

axm6: $last \in ROUTES \rightarrow BLOCKS$

axm7: $fst^{\sim} \subseteq blocks\_routes$

axm8: $last^{\sim} \subseteq blocks\_routes$

Operators for manipulating the objects

Expected properties of the objects

axm9: $\forall r \cdot r \in ROUTES \Rightarrow fst(r) \neq last(r)$

axm10: $\forall r \cdot r \in ROUTES \Rightarrow next(r) \in blocks\_routes^{\sim}[\{r\}] \setminus \{last(r)\}\ \square\ blocks\_routes^{\sim}[\{r\}] \setminus \{fst(r)\}$

axm11: $\forall r \cdot r \in ROUTES \Rightarrow (\forall S \cdot S \subseteq next(r)[S] \Rightarrow S = \varnothing)$

axm12: $\forall r1, r2 \cdot r1 \in ROUTES \land r2 \in ROUTES \land r1 \neq r2$
$\Rightarrow fst(r1) \notin blocks\_routes^{\sim}[\{r2\}] \setminus \{fst(r2), last(r2)\}$

axm13: $\forall r1, r2 \cdot r1 \in ROUTES \land r2 \in ROUTES \land r1 \neq r2$
$\Rightarrow last(r1) \notin blocks\_routes^{\sim}[\{r2\}] \setminus \{fst(r2), last(r2)\}$

What Is Our Goal ?

Be as close as possible to the signaling engineers usage:

- Implicit objects definitions (blocks, routes, signals…)
- Implicit operators definitions (reserve, lock, open...)
- Rich DSL
- Implicit objects basic properties

Just model *this* interlocking.

The Famous Train Example First Context

axm1: $\text{blocks\_routes} \in \text{BLOCKS} \leftrightarrow \text{ROUTES}$

axm2: $\text{dom}(\text{blocks\_routes}) = \text{BLOCKS}$

axm3: $\text{ran}(\text{blocks\_routes}) = \text{ROUTES}$

axm4: $\text{next} \in \text{ROUTES} \rightarrow (\text{BLOCKS} \;\square\; \text{BLOCKS})$

axm5: $\text{fst} \in \text{ROUTES} \rightarrow \text{BLOCKS}$

axm6: $\text{last} \in \text{ROUTES} \rightarrow \text{BLOCKS}$

axm7: $\text{fst}^{\sim} \subseteq \text{blocks\_routes}$

axm8: $\text{last}^{\sim} \subseteq \text{blocks\_routes}$

axm9: $\forall r \cdot r \in \text{ROUTES} \Rightarrow \text{fst}(r) \neq \text{last}(r)$

axm10: $\forall r \cdot r \in \text{ROUTES} \Rightarrow \text{next}(r) \in \text{blocks\_routes}^{\sim}[\{r\}] \setminus \{\text{last}(r)\} \;\square\; \text{blocks\_routes}^{\sim}[\{r\}] \setminus \{\text{fst}(r)\}$

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$\Rightarrow \text{last}(r1) \notin \text{blocks\_routes}^{\sim}[\{r2\}] \setminus \{\text{fst}(r2), \text{last}(r2)\}$

Using Our Theories

axm1:	ROUTES $\subseteq$ routes(BLOCKS)
axm2:	wellFormedRoutes(ROUTES)

Using Our Theories

Concrete set of routes (event-b constant)

Definition of *routes* constructor is hidden in the theories

Concrete set of blocks (event-b constant)

axm1: ROUTES ⊆ routes(BLOCKS)

axm2: wellFormedRoutes(ROUTES)

Additional properties of routes

- routes don’t start in the middle of others
- routes don’t end in the middle of others

The Famous Train Example First Machine

Without Theories

```
route_reservation:
ANY r WHERE
   r ∉ res_routes

   blocks_routes~[{r}] ∩ res_blocks = ∅
THEN
   res_routes ≔ res_routes ∪ {r}
   resbl_resrt ≔ resbl_resrt ∪ (blocks_routes ▷ {r})
   res_blocks ≔ res_blocks ∪ blocks_routes~[{r}]
END
```

Using Our Theories

```
route_reservation:
ANY r WHERE
   r ∈ ROUTES
   ¬ isReserved(r, res_routes)
   noReservedBlocks(r, res_routes)
THEN
   res_routes ≔ res_routes ∪ completeRes(r)


END
```

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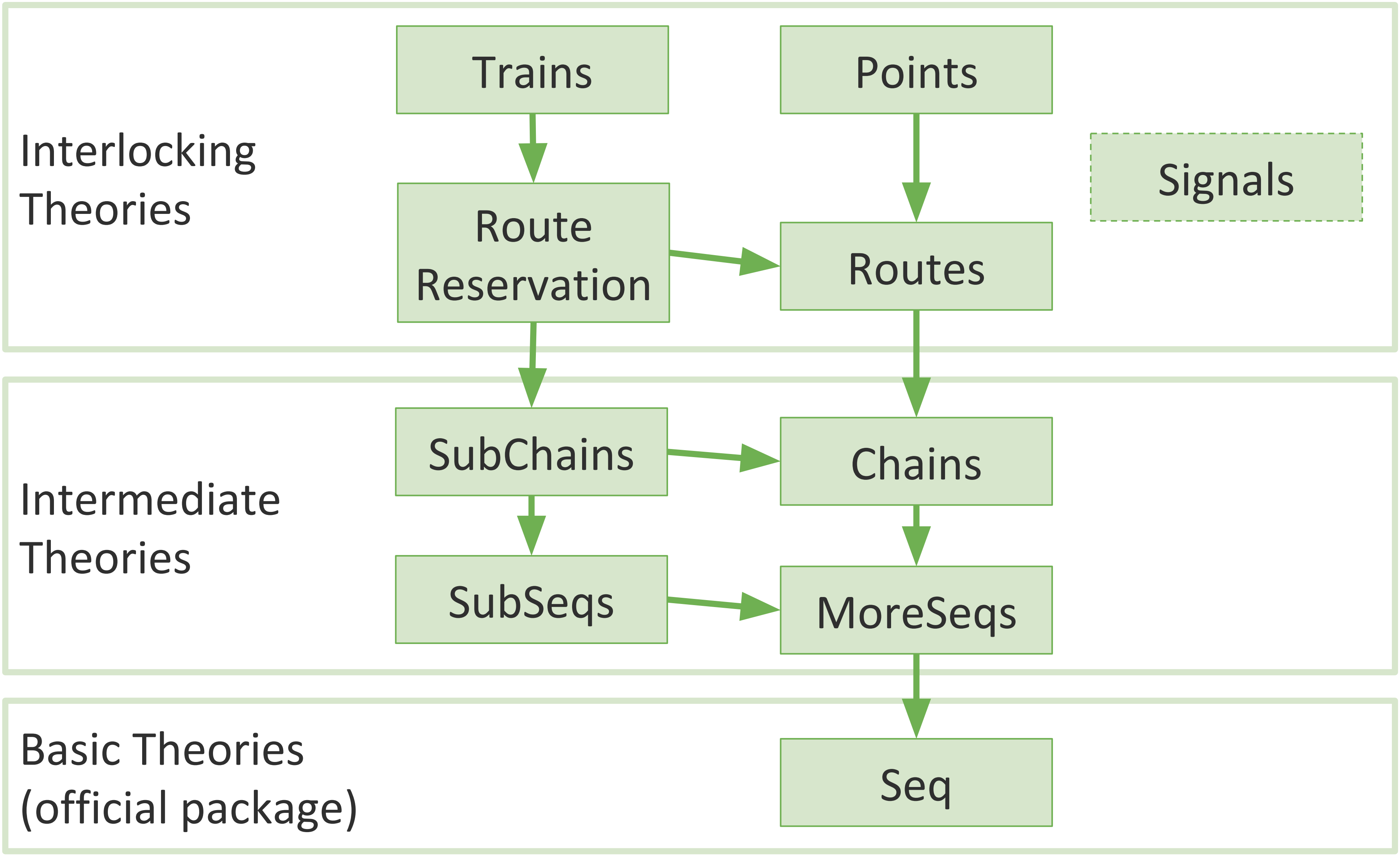
Defining Interlocking Theories

Interlocking Theories Dependencies



Chains

Railway network is made of chains of blocks.

$\{ c \mid c \in seq(S) \land c^{\sim} \in T \mathrel{+\!\!\!\rightarrow} \mathbb{Z} \}$

equivalent to iseq
garantees that there is no cycle

Operators:

- chains (constructor)
- chainSize
- emptyChain
- chainFst / Last / Tail
- chainPrev / Next
- chainPrepend / Append
- …

Theorems:

- chainIsFinite
- chainIsMonotonic
- nextIsInRange
- chainTailIsChain
- chainPrependIsChain
- …

Routes

Routes are chains of at least two blocks.

$\{ c \mid c \in \text{chains(blocks)} \wedge \text{card}(c) > 1 \}$

Operators:

- routes (constructor)
- blcks
- routeLength
- routeFst / Last / Tail
- routePrev / Next
- starts / endsInTheMiddle
- wellFormedRoutes
- ...

Theorems:

- routeIsFinite
- routeIsMonotonic
- routeIsFunc
- routeDomain
- routeIsChain
- ...

Routes (How To Use It ?)

Routes are chains of at least two blocks.

$\{ c \mid c \in \text{chains}(\text{blocks}) \land \text{card}(c) > 1 \}$

• r is a route	$r \in \text{routes}(\text{BLOCKS})$
• b is a block of r	$b \in \text{blcks}(r)$
• first block of r	routeFst(r)
• block after b on r	routeNext({b}, r)
• r1 starts in the middle of r2	startsInTheMiddle(r1, r2)
• R is a set of routes	$R \subseteq \text{routes}(\text{BLOCKS})$
• no route in R ends in the middle of another	routesDontEndInTheMiddle(R)

Subchains

Routes reservations and trains are subchains of routes.

$\{ sub \mid sub \in chains(T) \land subChain(sub, c) \}$

Operators:

- subChain (constructor)
- subChains (constructor)
- frontSubChains (constructor)
- backSubChains (constructor)

Theorems:

- subChainIsChain
- frontSubChainIsSubChain
- backSubChainIsSubChain
- chainTailIsABackSubChain
- chainTail
- ...

Subchains (How To Use It ?)

Routes reservations and trains (routes occupation) are subchains of routes.

$\{ \text{sub} \mid \text{sub} \in \text{chains}(T) \land \text{subChain}(\text{sub}, c) \}$

• r1 is a subchain of r2	subChain(r1, r2)
• set of subchains of r	subChains(r)
• set of “front subchains” of r	frontSubChains(r)
• set of “back subchains” of r	backSubChains(r)

Routes Reservations

A theory for maintaining the set of routes reservations.

$\{ r \mapsto b \mid r \in routes(blocks) \land b \in backSubChains(r) \}$

Operators:

- allRouteRes (constructor)
- validRouteRes (constructor)
- onlyOneResByRoute
- compatibleRoutesOnly
- wellFormedRouteRes
- blocksResForThisRoute
- isReserved
- addToRouteRes
- freeResHeadBlock
- …

Theorems:

- routeReservationIsAFunction
- routeResAreBackSubChains
- addRouteResStillOnlyOne
- addRouteResStillCompatible
- onlyOneResByRouteTrans
- filterResUnion
- …

Routes Reservations (How To Use It ?)

A theory for maintaining the set of routes reservations.

$\{ r \mapsto b \mid r \in routes(blocks) \land b \in backSubChains(r) \}$

• the set of route reservations on the track	res ∈ validRouteRes(BLOCKS, ROUTES)
• only one reservation can be made for each route	onlyOneResByRoute(res)
• a block cannot be reserved twice	compatibleRoutesOnly(res)

Routes Reservations (How To Use It ?)

A theory for maintaining the set of routes reservations.

$\{ r \mapsto b \mid r \in routes(blocks) \land b \in backSubChains(r) \}$

$r = \{b1; b2; \ldots; bn\}$

Events	**Route Reservations**
Initialisation	$\{\}$
Reserve r	$\{ r \mapsto \{ b1; b2; \ldots; bn \}\}$
Enter route; Front moves...	$\{ r \mapsto \{ b1; b2; \ldots; bn \}\}$
Back move	$\{ r \mapsto \{ b2; \ldots; bn \}\}$
Back moves…	$\{ r \mapsto \{\}\}$
Free r	$\{\}$

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Reducing the Proof Effort ?

Conclusion

Current Status

Theorems defined = proof factorized.

Manual proof is easier, sometimes even trivial.

But only 40% POs automatically discharged in our theories and models.

Defining theories does not naturally simplify the proof.

The Right Theorems… (future work)

How to define the right theorems ?

Suggestion:

1. define more theorems… a lot of them !
2. generalization of the theorems
3. simplification of the theorems

Proof Strategies? (future work)

Theorems not automatically applied: use strategies ?

How to define them ?

Discussion (1/2)

- Infix predicates ?
  - startsInTheMiddle(r1, r2) => r1 startsInTheMiddle r2

- Type inference ?
  - r ∈ ROUTES
    ¬ isReserved(r, res_routes)

- Local theories ? Using symbols that are local for a given project.
  - ¬ isReserved(r, res_routes)

- Assignment operators ?
  - res_routes ≔ res_routes ∪ completeRes(r)

Discussion (2/2)

- Theory instanciation?
  - ex: Instantiate the Routes theory with the constant BLOCKS

- What about a Rodin plug-in for generating *Domain Specific Platforms* (DSP) ?
  1. Define the DSL using the Theory plug-in
  2. Validate the DSL with signaling engineers
  3. Generate the DSP
  4. Let signaling engineers model their system

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Thanks

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