A large-scale hybrid micro- and mesoscopic simulation approach for railway operation

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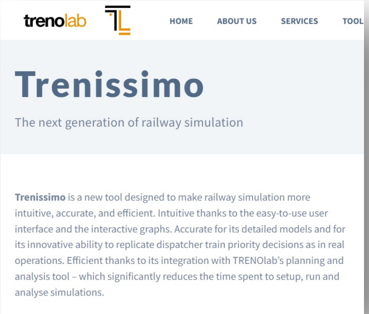
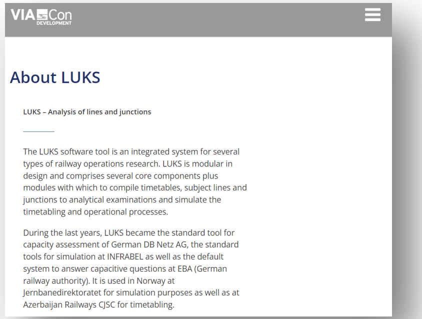
Introduction

Introduction and problem statement

- There are various railway simulation tools …





- The existing tools come with several drawbacks:
  - closed-source
  - not easily extendable
  - limited to small networks or few trains
  - missing data imports
  - no option to add control mechanisms
  - limited to the microscopic modeling resolution, …

- **Objective:** Development of a simple and flexible open-source tool …
  - to simulate the interplay of the train schedule with the infrastructure.
  - to identify conflicts and bottlenecks.
  - to investigate disturbances and control strategies.

Why MATSim?

- Open-Source-Software + active community
- Existing functionality to simulate schedule-based public transit, visualisation features, …
- Flexible and modular simulation framework
- Dynamic simulation
- Agent-based simulation approach; different train types, …

- Simulation of transport supply and demand allows for a detailed investigation of delays
- Compatible with several tools at SBB (SIMBA.MOBi, schedule editor)

MATSim
Multi-Agent Transport Simulation

Public transport simulation in MATSim

MATSim default

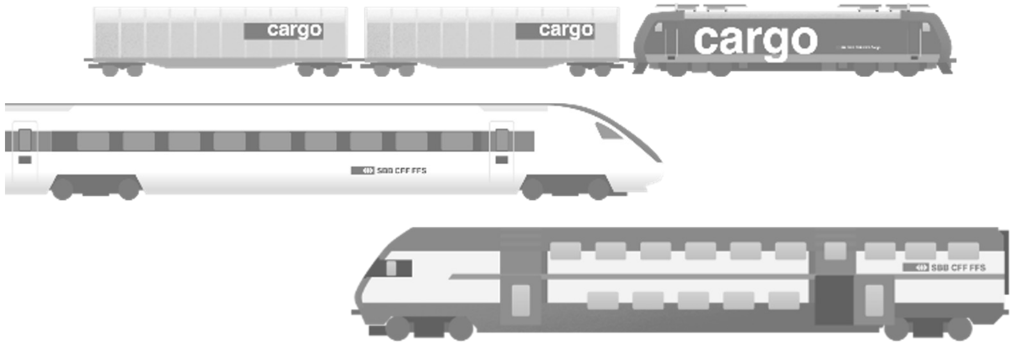
- Transit vehicles are handled as normal vehicles in the QSim engine.
- In some applications this actually makes sense: e.g. buses use the normal road network where they may face traffic congestion (e.g. bus bunching studies).
- In some applications, transit vehicles use exclusive pt links
  - capacity is sufficiently high to avoid traffic congestion
  - freespeed parameter need to be consistent with the travel times defined in the transit schedule

Recent extension: deterministic pt

- Transit vehicles strictly follow the schedule.
- Predefined modes are excluded from the default Qsim engine (no queueing dynamics, freespeed parameter is ignored, …).

Missing feature

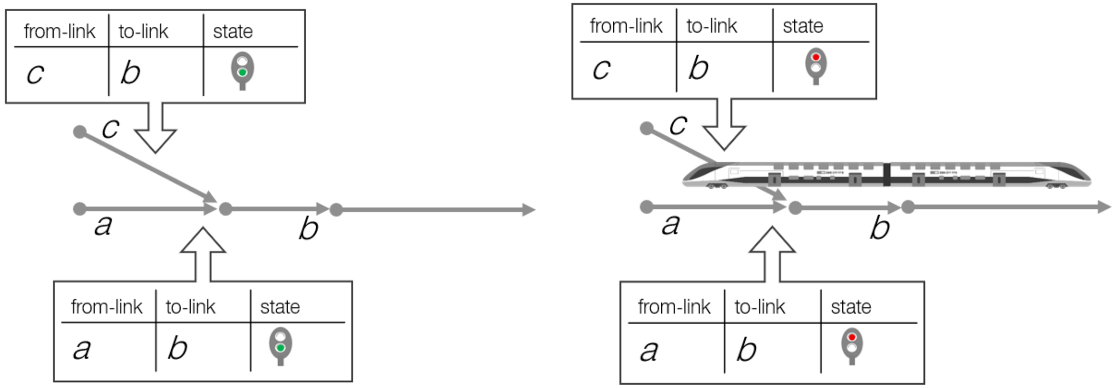
- Account for the rail-specific dynamics: moving or fixed blocks, reserved train paths, …
- Planned train movements are defined by the transit schedule. Actual train movements are the result of the physical model layer (vehicle attributes, infrastructure, available capacity).



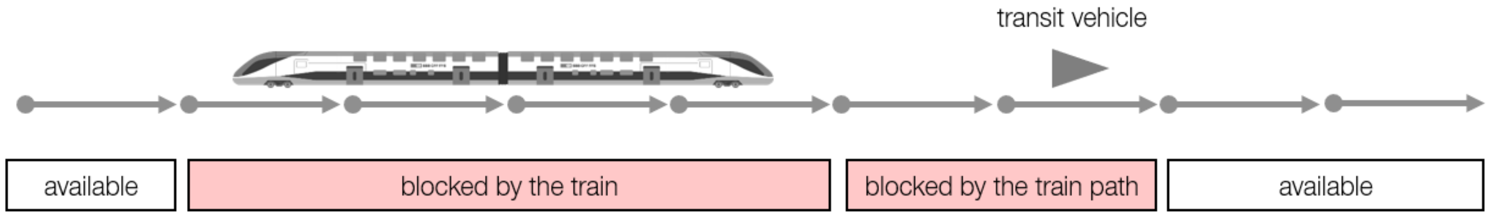
Implementation: railsim

First protoype version

- Make use of MATSim’s **signals** contribution.
  - Place a signal on each link.
  - Signals control the movement of transit vehicles, solve conflicts etc.



- Transit vehicles are **spatially expanded** along several links.
  - A train may occupy several links: reserved train path + train length
  - The MATSim vehicle itself is considered as the front of the reserved train path.



Improved railway simulation approach

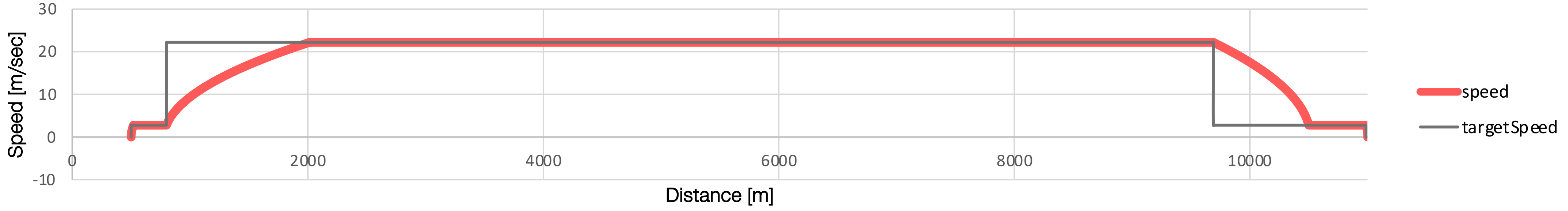
- Similar to the «deterministic pt» extension: Use a **railsim-specific QSim** engine to handle the rail mode; these vehicles are then excluded from the default QSim engine.
- Improved **computational performance** and **more flexibility** compared to the signals-based prototype.
- More **intuitive** compared to the prototype: The vehicle is no longer the head of the reserved train path.
- Implemented by Simunto GmbH (Marcel Rieser, Christian Rakow).

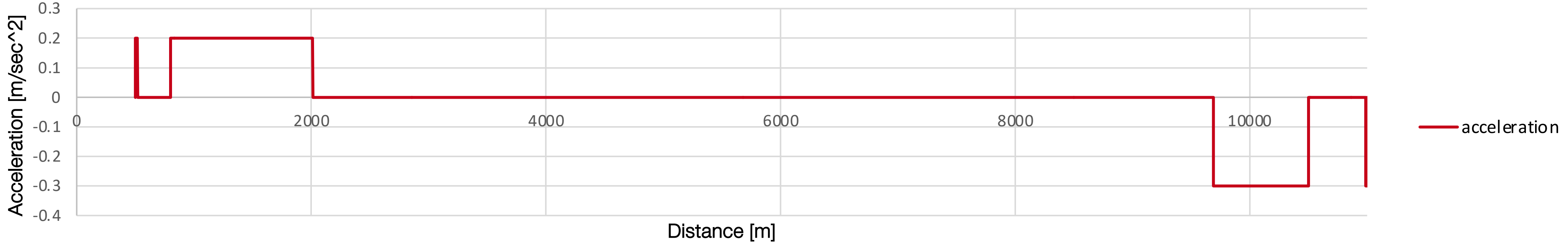
Main features:

- Trains are **spatially expanded** along several links. Additional events indicate when the end of the train leaves a link.
- Trains **accelerate and decelerate** based on predefined vehicle attributes (along a single link or along several links).
- The infrastructure ahead of each train is blocked (**reserved train path**) depending on the braking distance which is computed based on the vehicle-specific deceleration and the current speed.
- Capacity effects are modeled at the level of **resources**. A resource consists of one link or several links.
- Trains may **deviate from the network route** given in the schedule, e.g. to avoid a blocked track (dispatching, disposition).

More details will follow on the next slides …

Speed dynamics





acceleration: 0.2 m/sec^2
deceleration: 0.3 m/sec^2
vMax: 44.44 m/sec

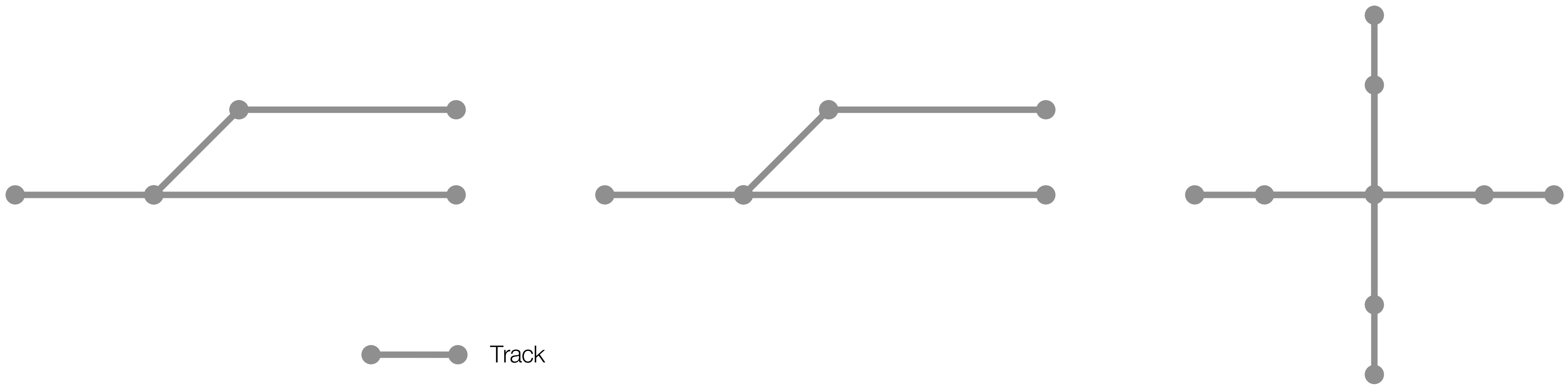
Resources concept: Microscopic scale (1)

- Single track layouts:

1) Fixed block

2) Moving block

3) Crossing



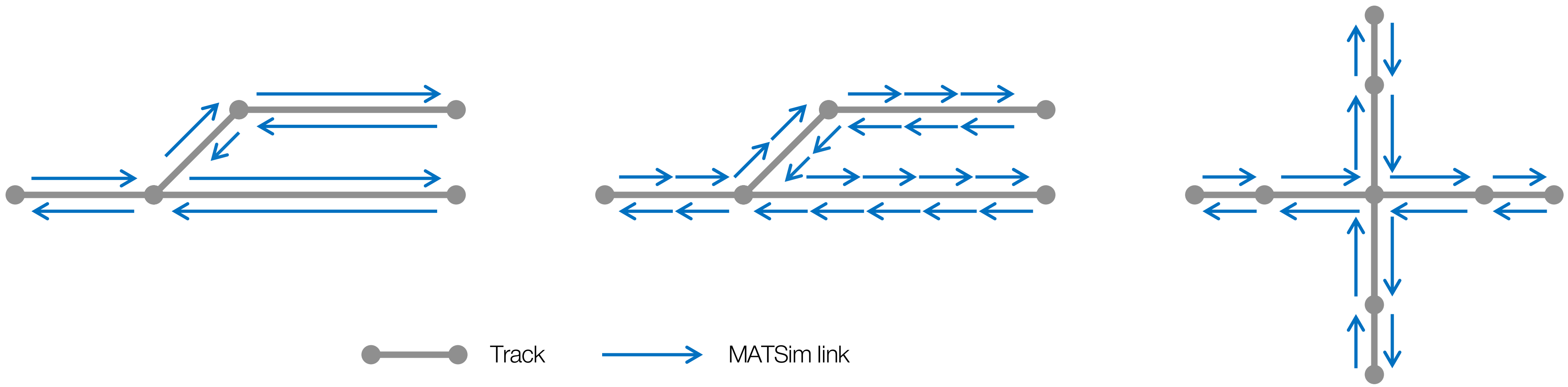
Resources concept: Microscopic scale (2)

- Single track layouts:

1) Fixed block

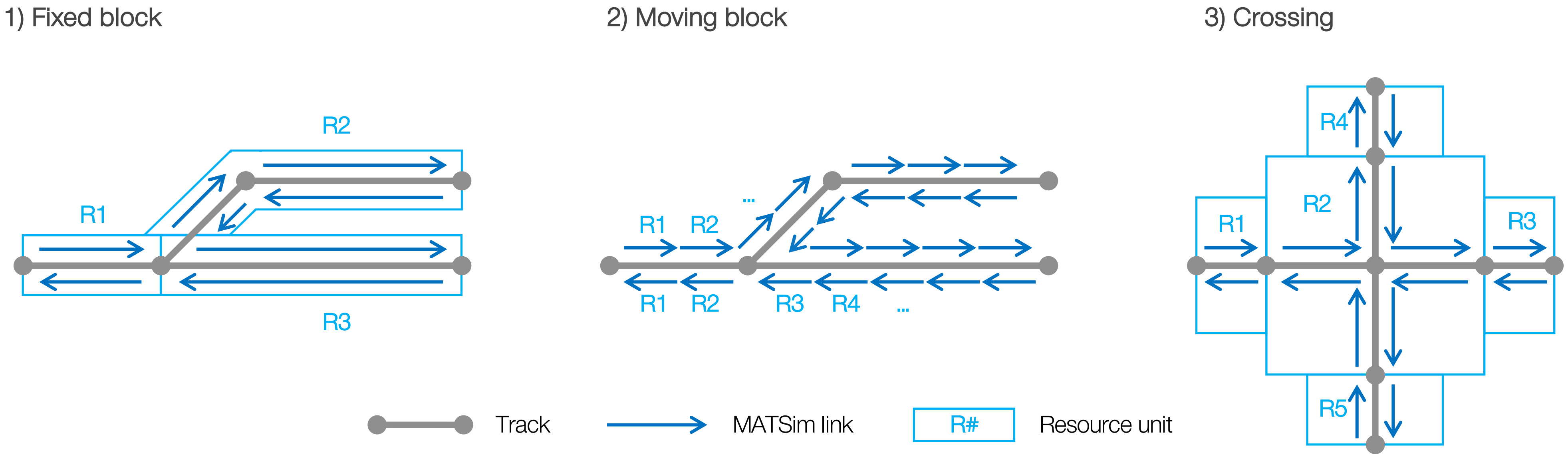
2) Moving block

3) Crossing



Resources concept: Microscopic scale (3)

- Single track layouts:

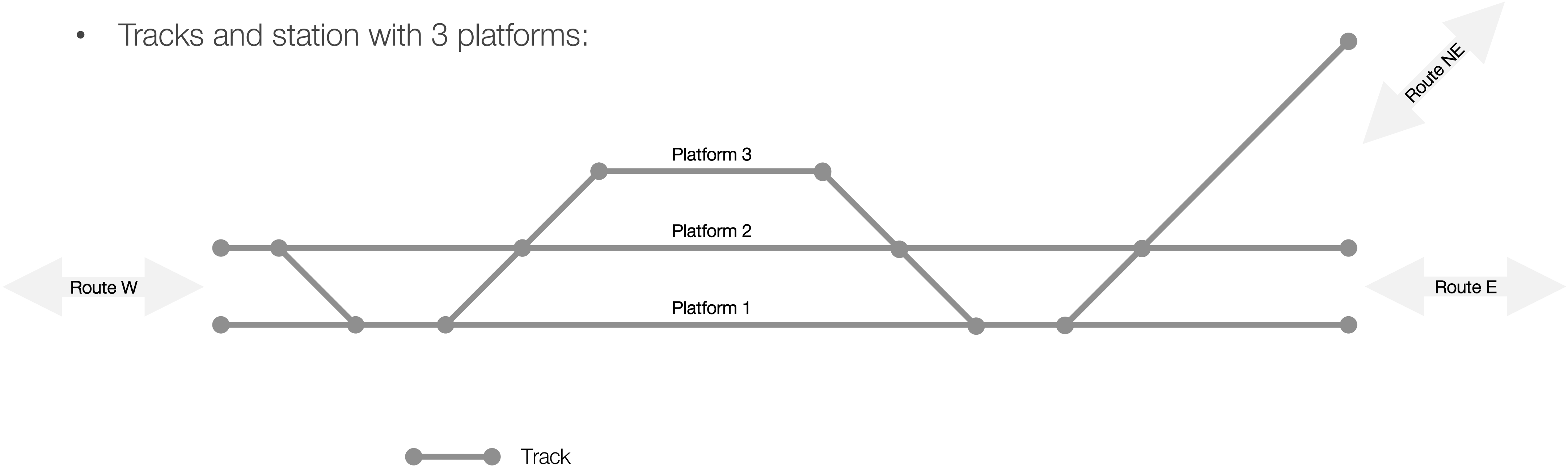


- Link attributes:
  - `railsimResourceId` determines links belonging to the same resource.
  - `railsimMinimumTime` defines the time it takes to release a resource when the train has left it
    => Minimum Headway Time / Zugfolgezeit.

Visualization: Microscopic railway simulation

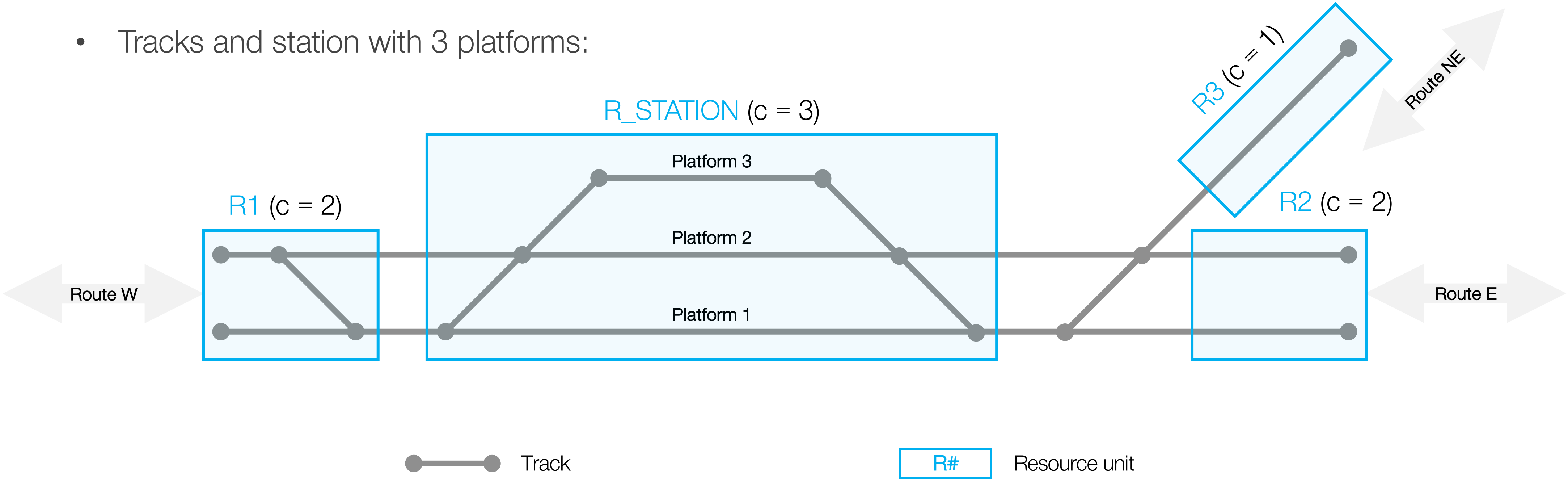
Resources concept: Mesoscopic scale (1)

- Tracks and station with 3 platforms:



Resources concept: Mesoscopic scale (2)

- Tracks and station with 3 platforms:



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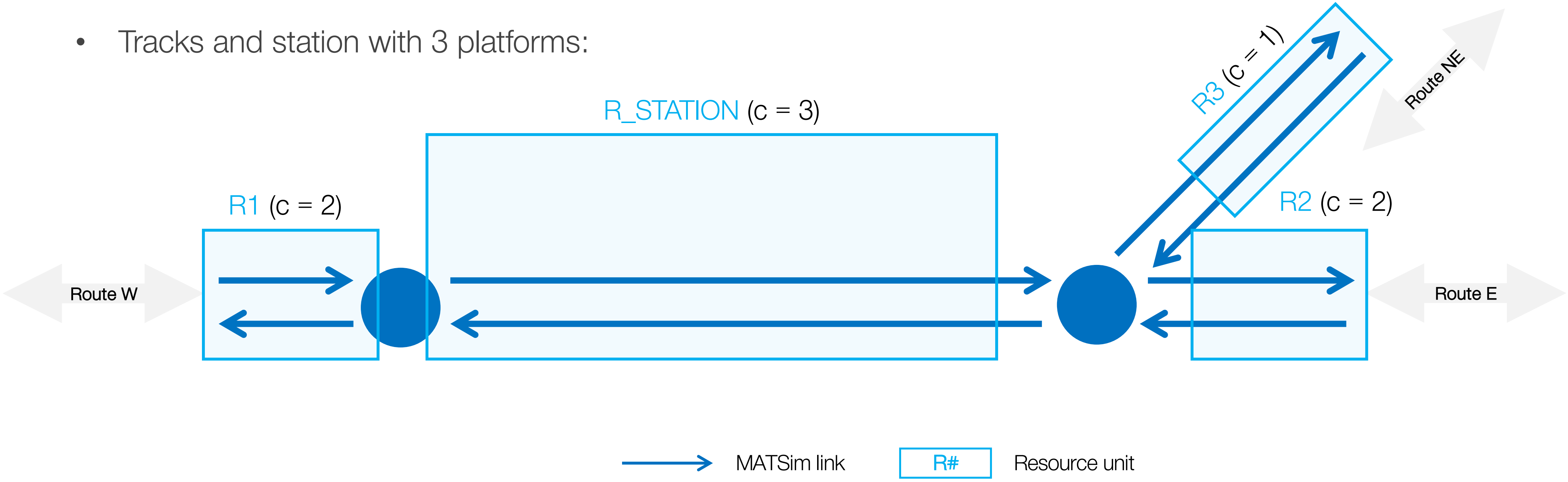
Resources concept: Mesoscopic scale (3)

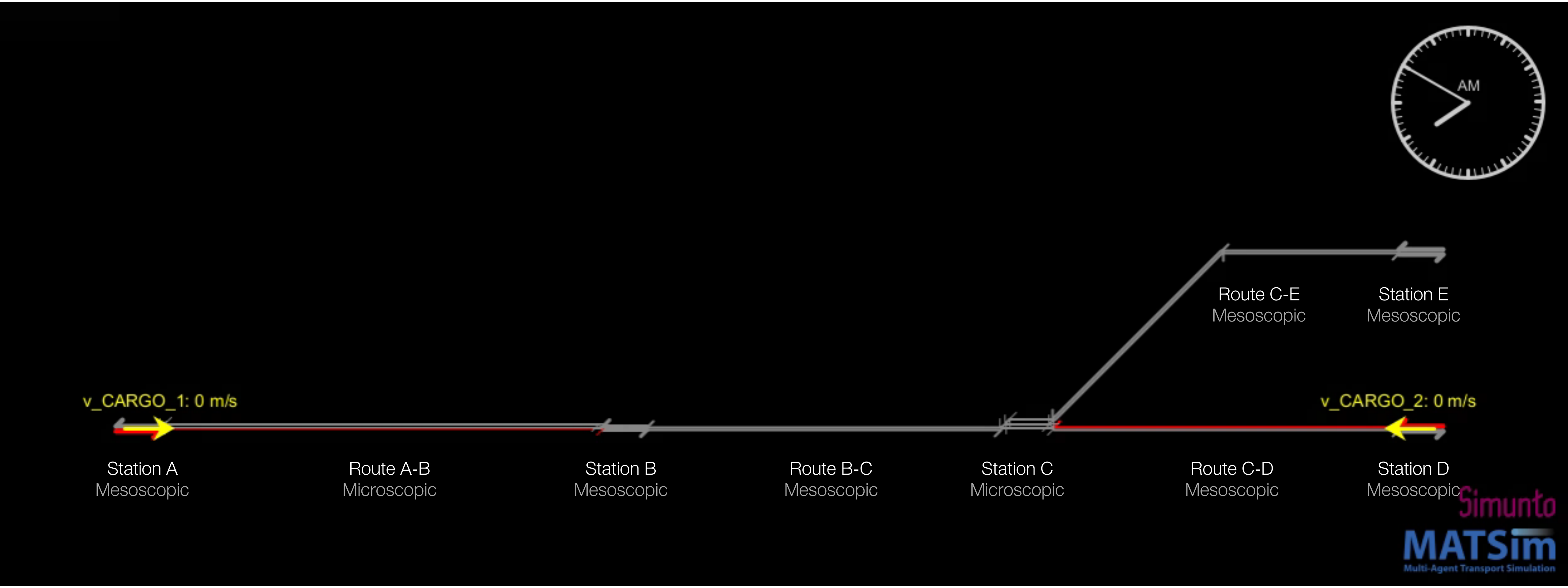
- Tracks and station with 3 platforms:



- Link attributes:
  - `railsimResourceId` determines links belonging to the same resource.
  - `railsimTrainCapacity` defines the number of tracks of a resource.

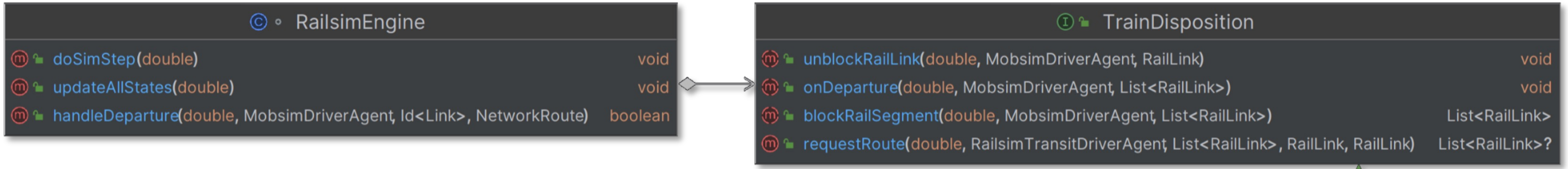
Resources concept: Mesoscopic scale (4)

- Example with micro and mesoscopic elements combined:

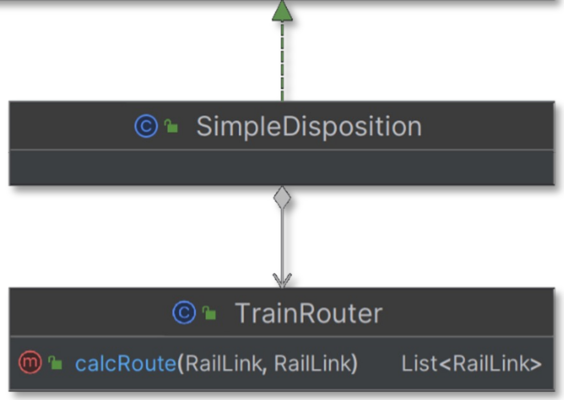


Train control: Disposition

- Interface `TrainDisposition`, can be used to implement disposition strategies
- `RailsimEngine` composes a `TrainDisposition`

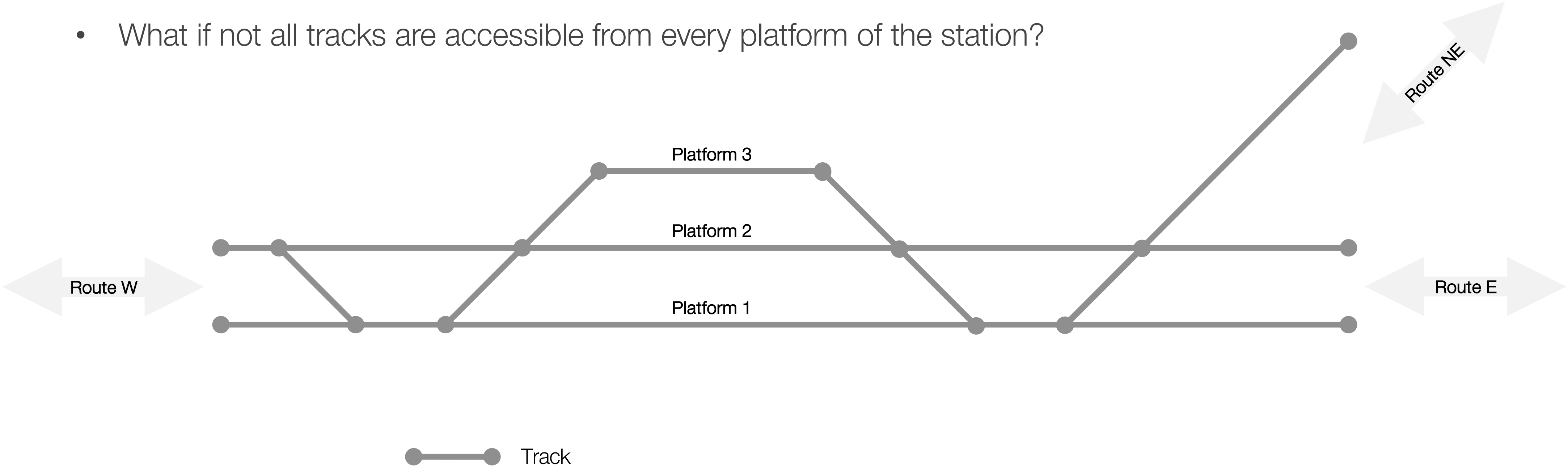


- Default: `SimpleDisposition` implements `TrainDisposition`
  - First-come, first-served approach; `onDeparture()` calls are ignored.
  - No deadlock avoidance: The simulation can experience blocking issues.
  - Local rerouting within stations/routes upon `requestRoute()` calls using `TrainRouter`.
  - Rerouting relies on standard MATSim routing: `LeastCostPathCalculator`, `FreeSpeedTravelTime`, and `TravelDisutility`, with resource capacity considerations.



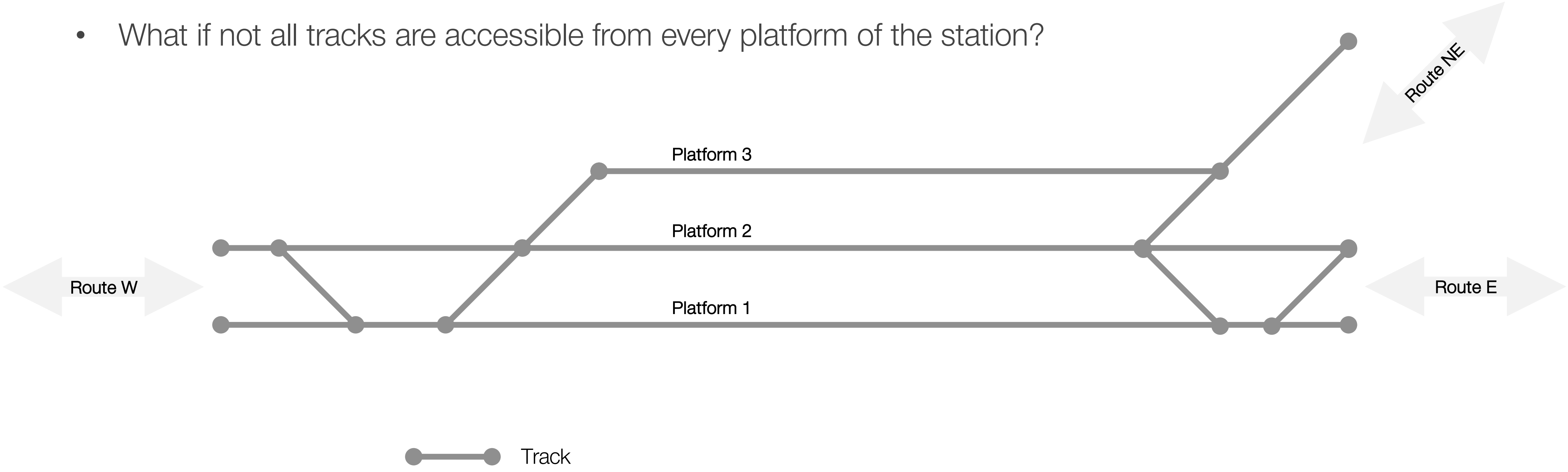
Microscopic station layout: All tracks reachable

- What if not all tracks are accessible from every platform of the station?



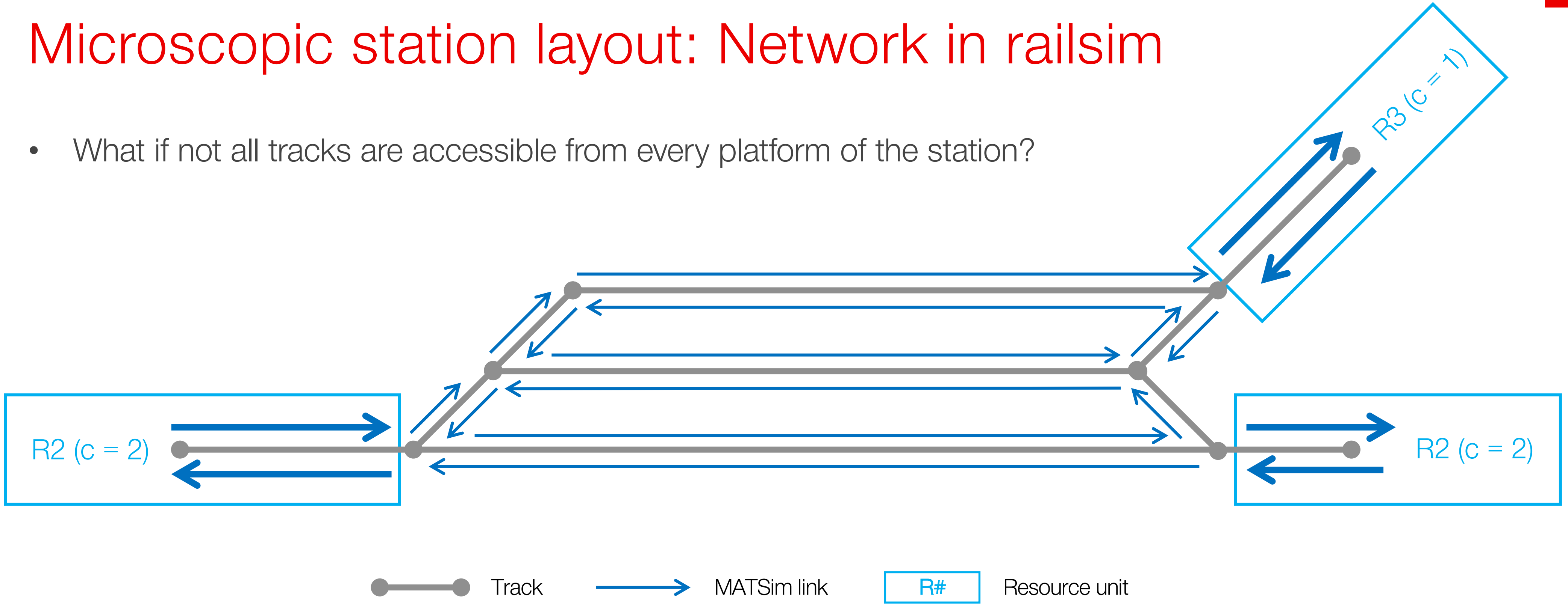
Microscopic station layout: Not all tracks reachable

- What if not all tracks are accessible from every platform of the station?



Microscopic station layout: Network in railsim

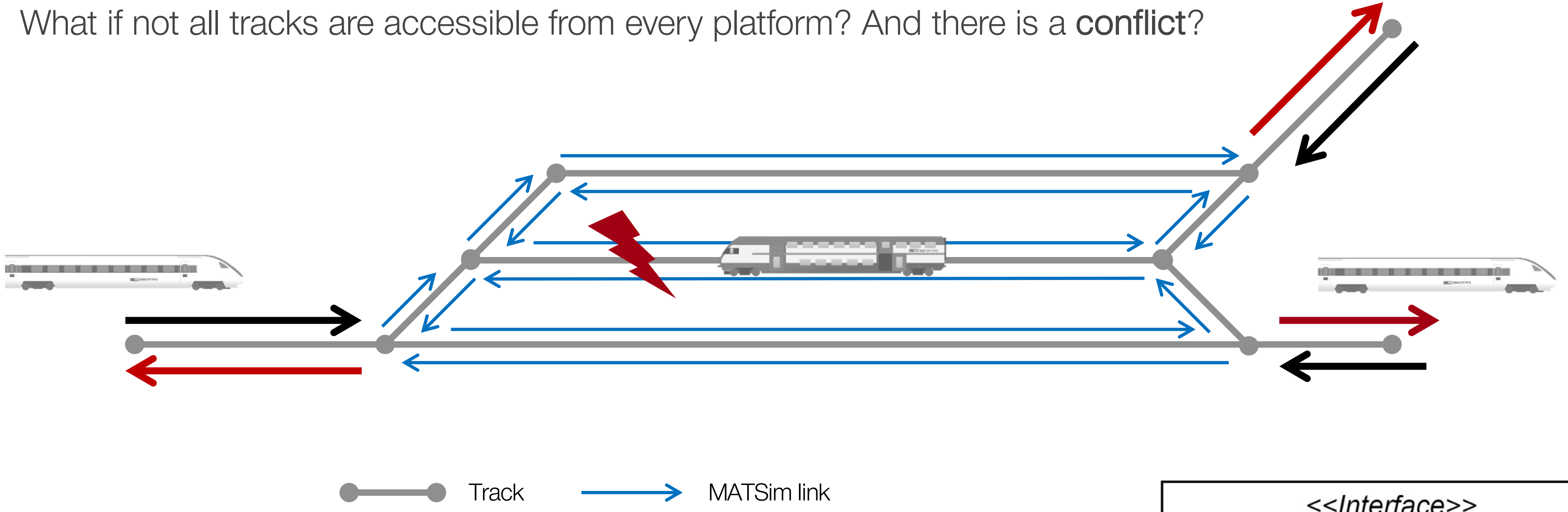
- What if not all tracks are accessible from every platform of the station?



- Combine mesoscpoic and microscopic network elements!

Microscopic station layout: Rerouting in station

- What if not all tracks are accessible from every platform? And there is a **conflict**?



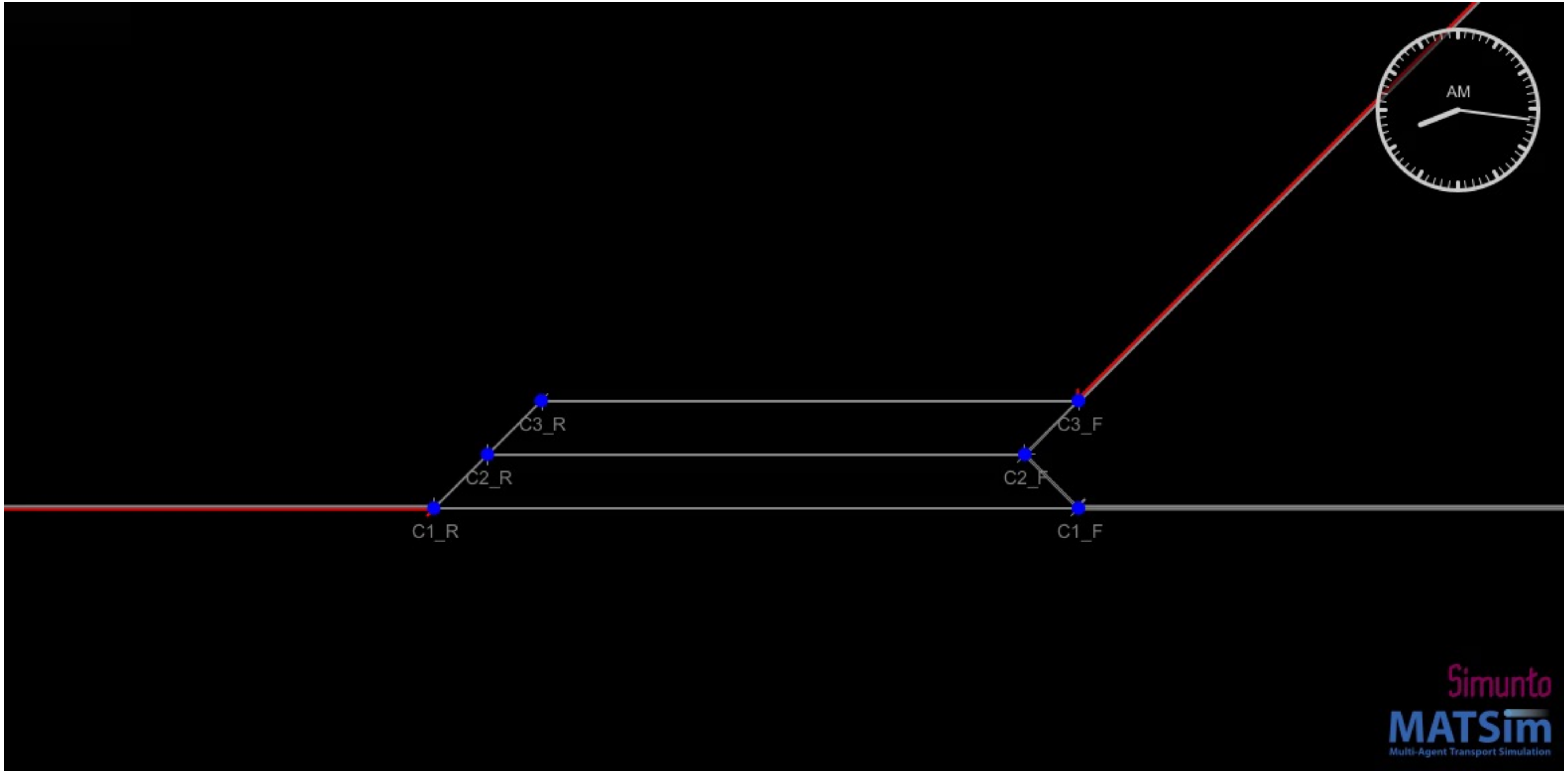
- Combine mesoscpoic and microscopic network elements!
- Link attributes:
  - `railsimEntry` flags link as origins for re-routing.
  - `railsimExit` flags link as desitination for re-routing.
- Traversing an EntryLink triggers a rerouting, engine calls `requestRoute()` on Disposition

<<*Interface*>>
TrainDisposition

+ onDeparture(...): List<RailLink>?
+ requestRoute(...): List<RailLink>
+ blockRailSegment(...): void
+ unblockRailLink(...): void

Disposition: Rerouting in microscopic station (3)

- Rerouting using entry and exits links in a station with 3 platforms:



Discussion

Microscopic vs. mesoscopic modeling approach

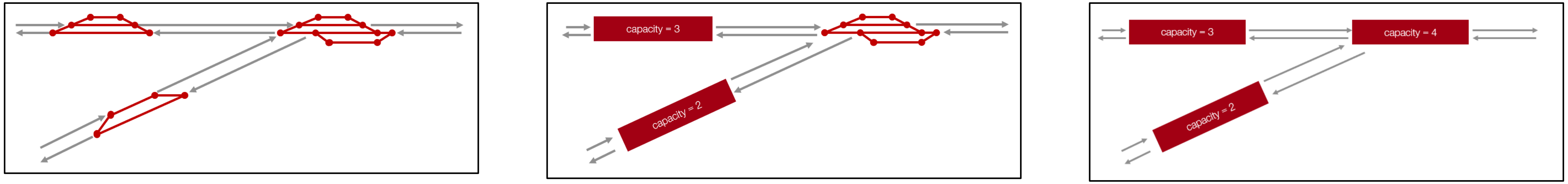
- The behavior of railsim is defined by the input rail network.
- No configurations related to mesoscopic or microscopic simulations.
- Seamless transition from mesoscopic to microscopic network elements in the simulation.

	Microscopic	Mesoscopic
Fixed Block	Model blocks of links with a capacity of 1 each and identical resource IDs.	Model routes consisting of links with capacities exceeding 1. Opposite links share the same resource ID. There is no differentiation between moving block and fixed block. A mesoscopic link can only initiate or terminate at points where a physical track change is feasible.
Moving Block	Model tracks consisting of short links. Each link, except for the opposite link, has a unique resource ID and a capacity of 1.	
Station	Each platform link has a distinct resource ID, except for the opposite link, and a capacity of 1. Each platform link has a transit stop facility, which belongs to the same stop area id. Ingoing and outgoing links of the station have entry and exit attributes.	The station consists of one or several links, including the opposite links, with the same resource ID. The capacity is larger than 1 and corresponds to the number of tracks.

Microscopic and mesoscopic combination

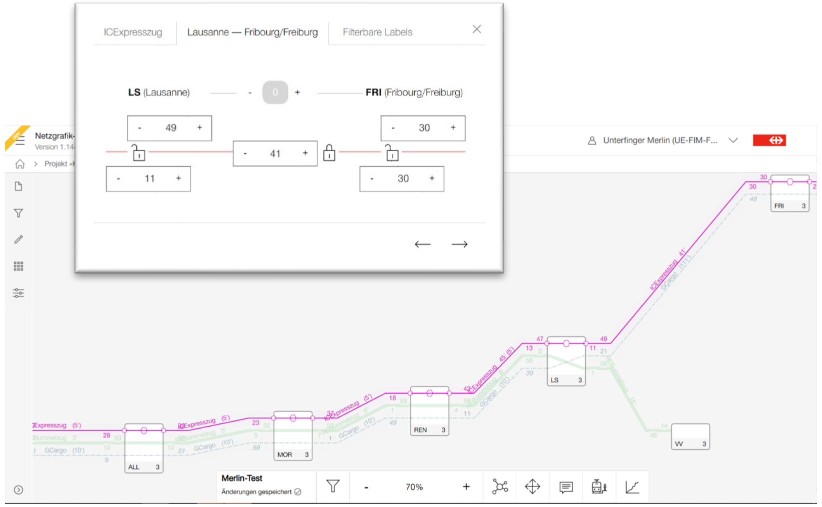
- Currently **not all combinations** of network elements are **possible**:
  - Joining microscopic stations on microscopic tracks pose challenges.
  - Entry and exit link attribute logic fails on the incoming and outgoing edges of the station, as they are not unambiguous.
- Mesoscopic level, **no moving block vs. fixed block distinction**:
  - A mesoscopic fixed block lacks clarity.
  - Moving blocks imply a potential track change after each resource → Capacity inaccuracies.
  - Conclusion: Detailed examination requires microscopic modeling.

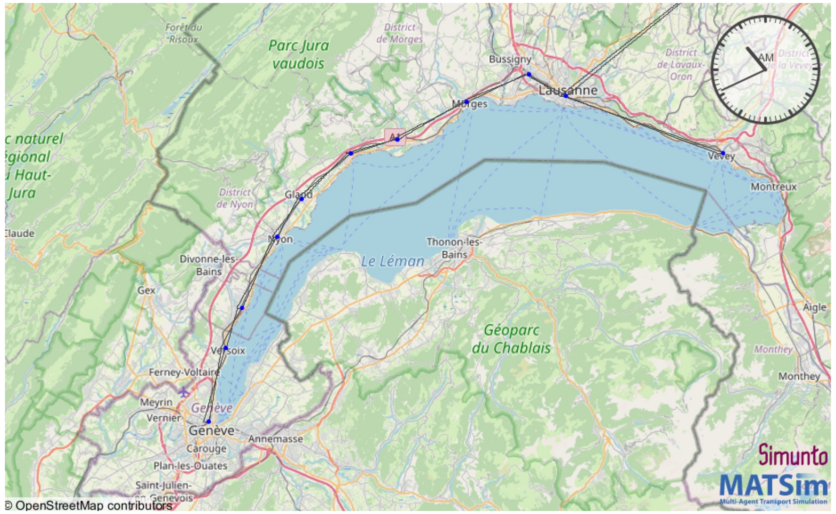
Track / Route \ Station	Meso	Micro
Meso	✓	✓
Micro	✓	✗



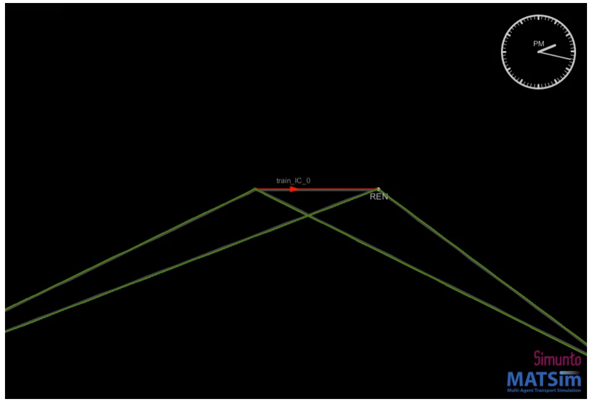
Application

Application: Rail train schedule editor + Railsim

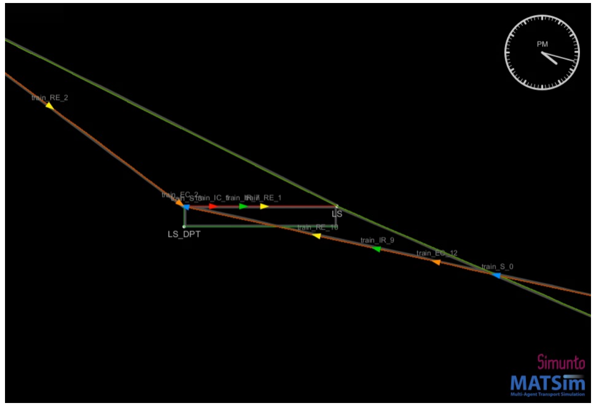




- A train schedule concept for the year 2050 is developed using a train schedule editor (SBB internal tool).
- The schedule concept is converted into the MATSim format.
- The network is modeled for different assumptions about the infrastructure. Modeling approach: mesoscopic stations, microscopic connections.
- The schedule is simulated for an entire day. The dynamics are visualized and bottlenecks identified.



Renens: Capacity sufficiently high



Lausanne: Capacity not sufficient, queuing on the ingoing links

Conclusion & Outlook

Conclusion and outlook

Conclusion

- MATSim was successfully extended to simulate the railway-specific dynamics.
- Pull request into the matsim-libs planned for this week.
- Some first experiments have been conducted for the corridor Geneva-Lausanne: Schedule concepts have been evaluated and visualized in the long-term planning context.

Outlook

- Train **control** strategies:
  - deadlock avoidance: implement conventional algorithms …
  - delay minimization: Multi-agent path finding: planning collision-free paths for multiple agents on a given graph, e.g., by scoring and replanning transit schedules
- More sophisticated modeling of the **physics**
  - Acceleration/deceleration based on the engine power
  - Tunnels, track gradients, …
- Improved **mesoscopic modeling**
  - Definition of mesoscopic capacity parameters for different track layouts.
  - Integrated micro- and mesoscopic modeling
- Integrated case study with focus on the interplay of supply and **demand**
- **Large-scale application** for Switzerland; microscopic/mesoscopic representation of the infrastructure based on available data


SBB CFF FFS
Danke, merci
& grazie.

Backup