ASTRail

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Ten Diverse Formal Models for a CBTC Automatic Train Supervision System

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Shift2Rail

Origins of the study

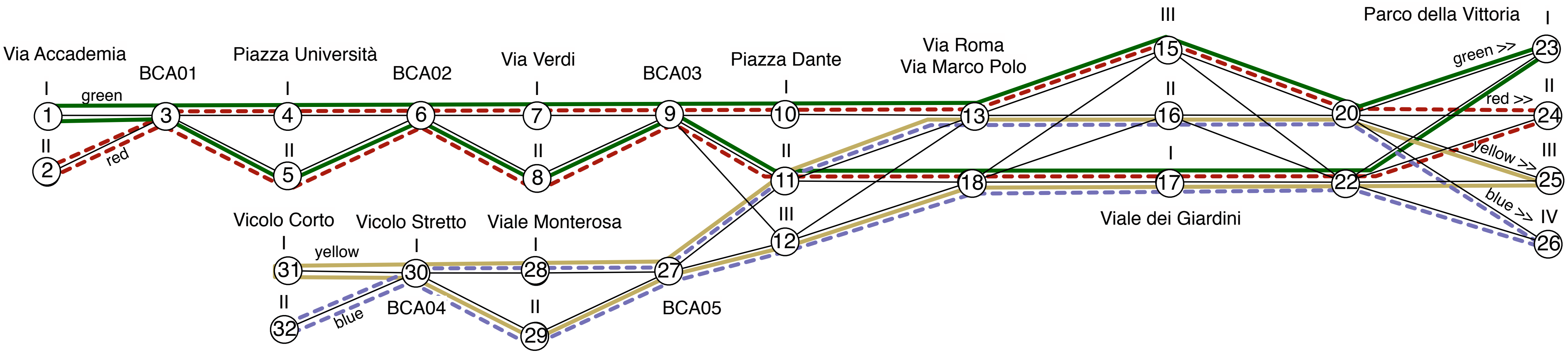
Trace-IT
- Define an ATS scheduling approach to achieve deadlock free train dispatching.
- Case Study: a project defined CBTC scenario

ASTRail
- Investigate and experiment with a rich set of formal methods an tools to compose a survey on the suggested use of formal methods in the railway field.
- Trace-IT case study re-used as one of the experiments.

The Trace-IT goal

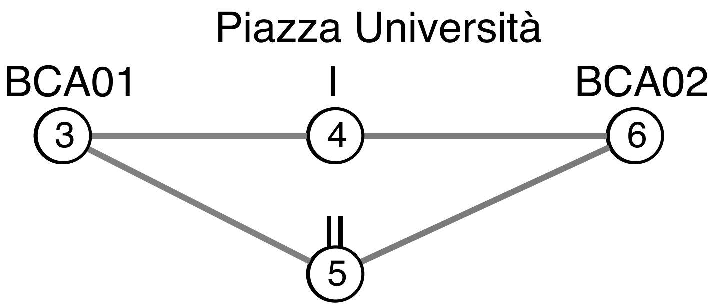
- We have a metro layout.
- We have an automatic (unmanned) metro service.
- Each train has its mission statically defined,
  provided to the ATS as static configuration data (timetable)
- We have to design the logic of the ATS scheduling kernel,
  to successfully dispatch all the trains, leading them to destination
  avoiding deadlocks (also in case of arbitrary delays)

The Trace-IT project demonstrator case study

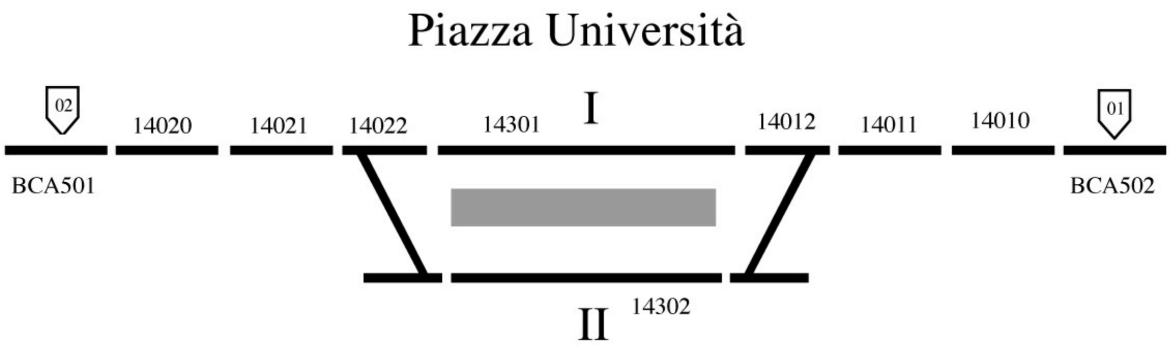


- 8 trains providing circular services

Itineraries vs circuits

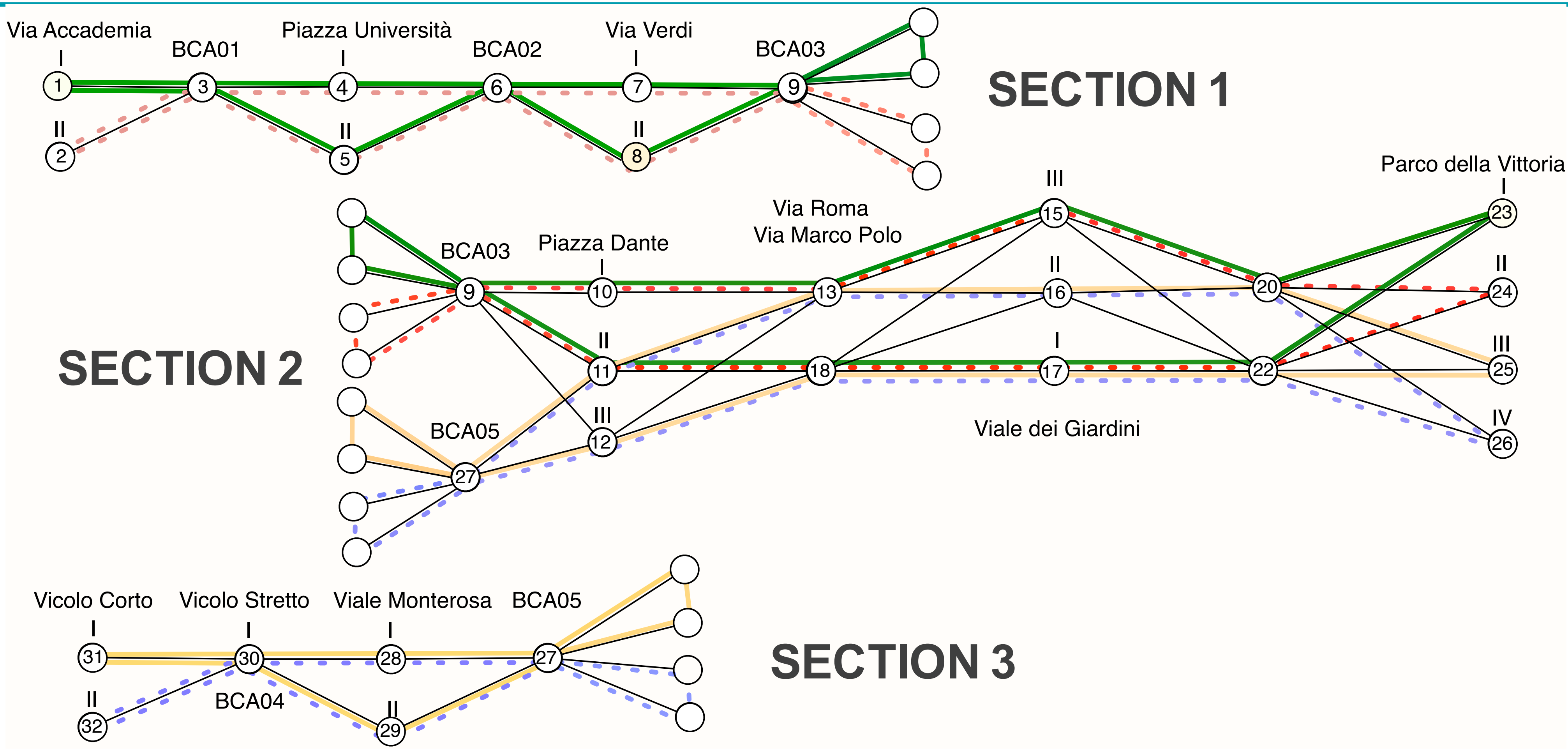


Segments correspond to entry/exit itineraries of stations

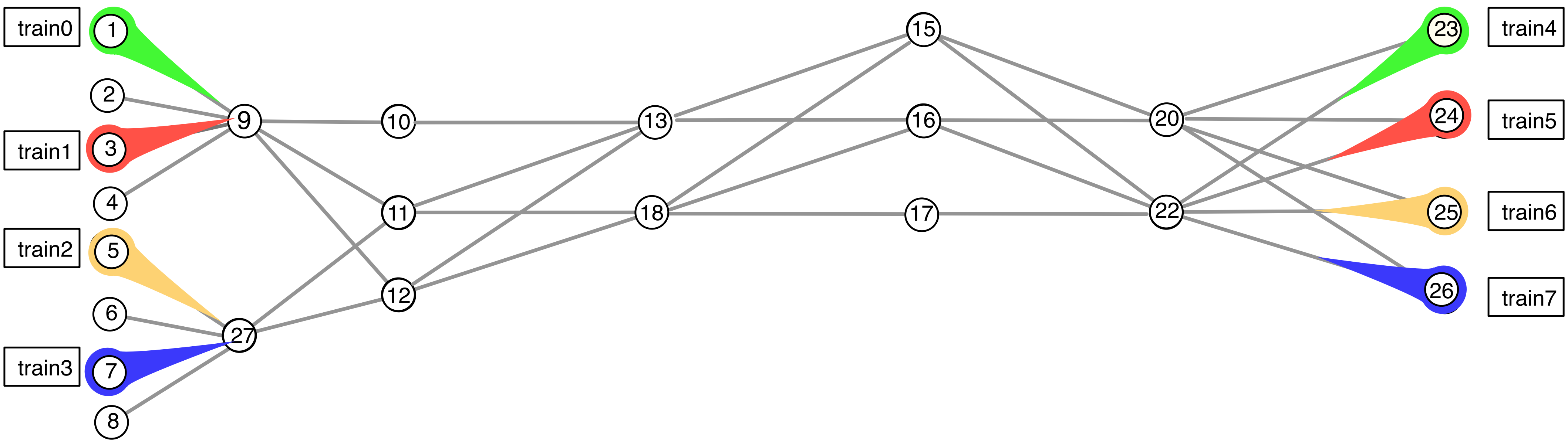


Itineraries are composed of several track circuits

Handling the problem size



The Section 2 layout and train missions.



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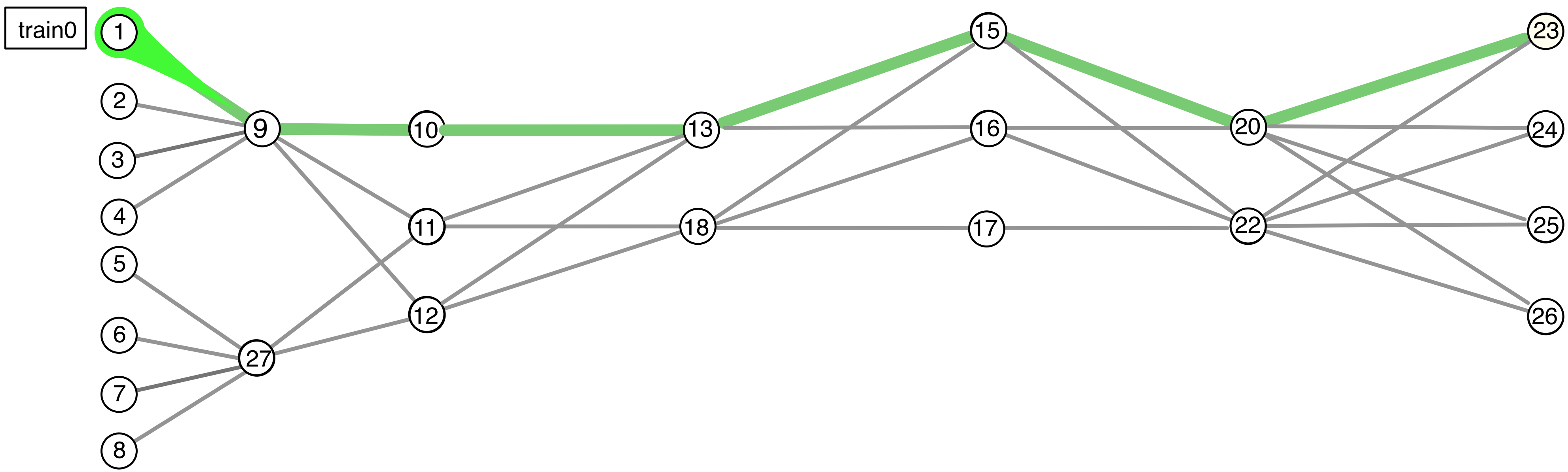

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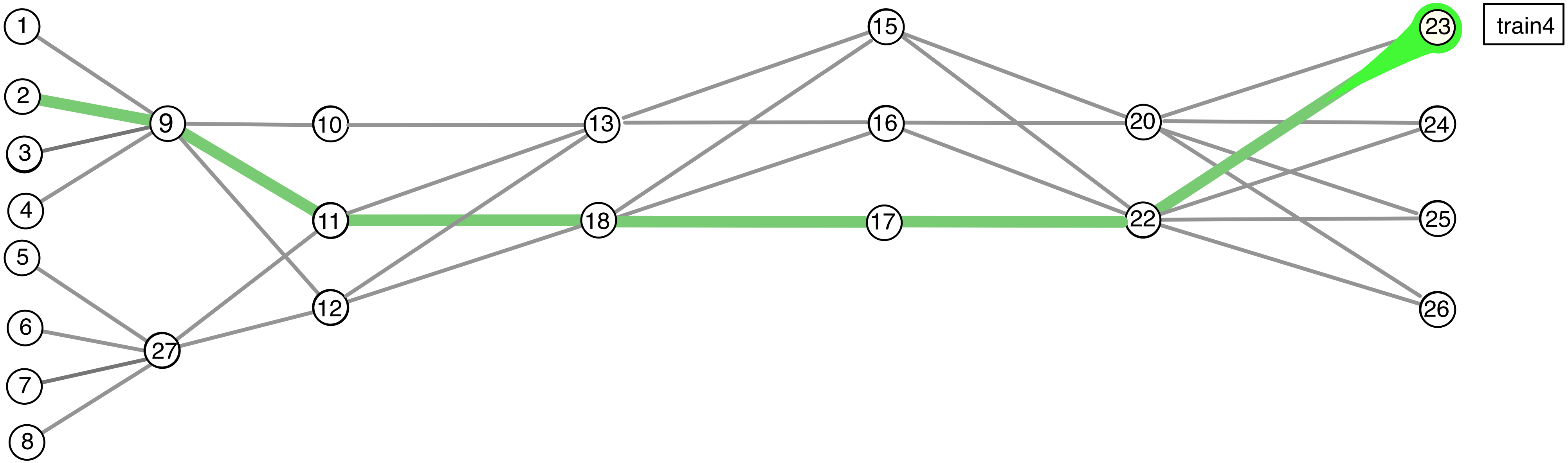

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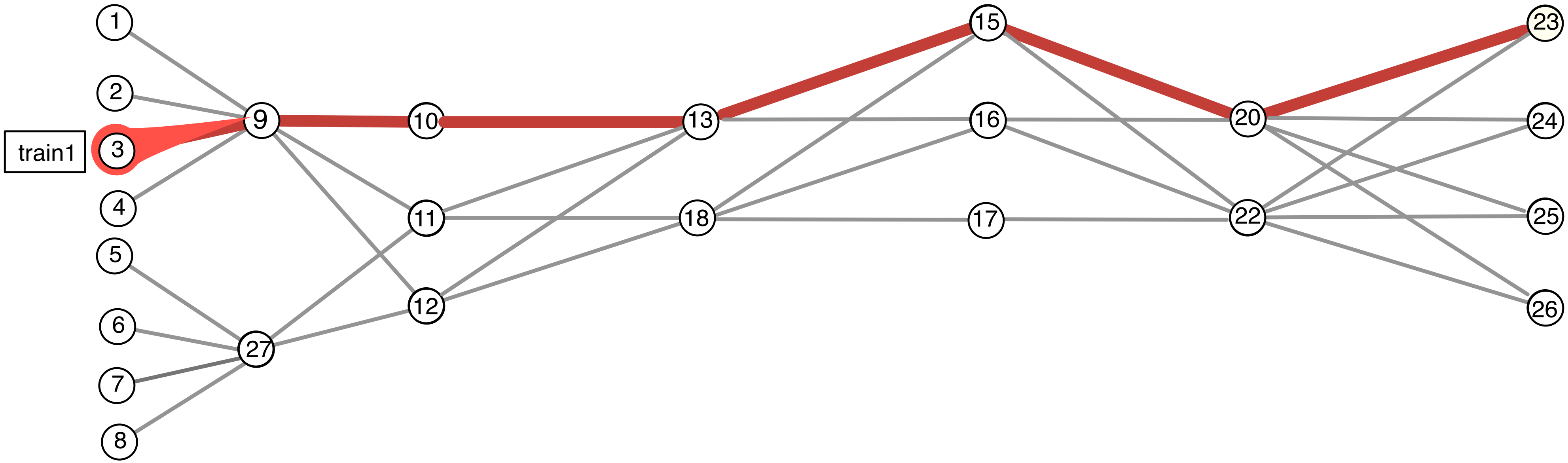
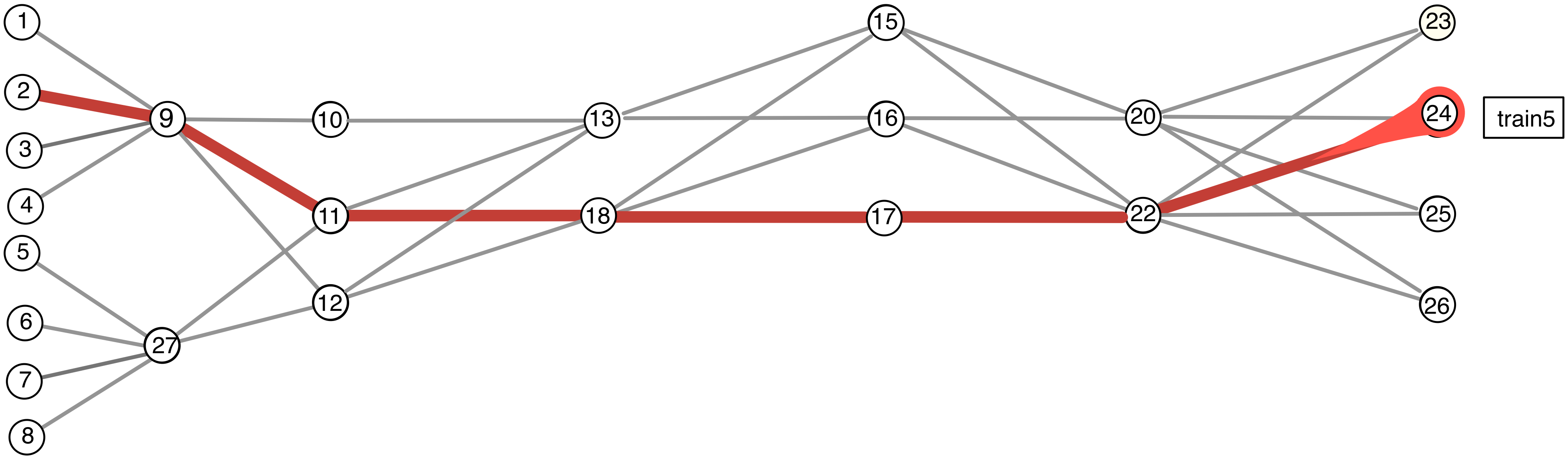


The Trace-IT case study



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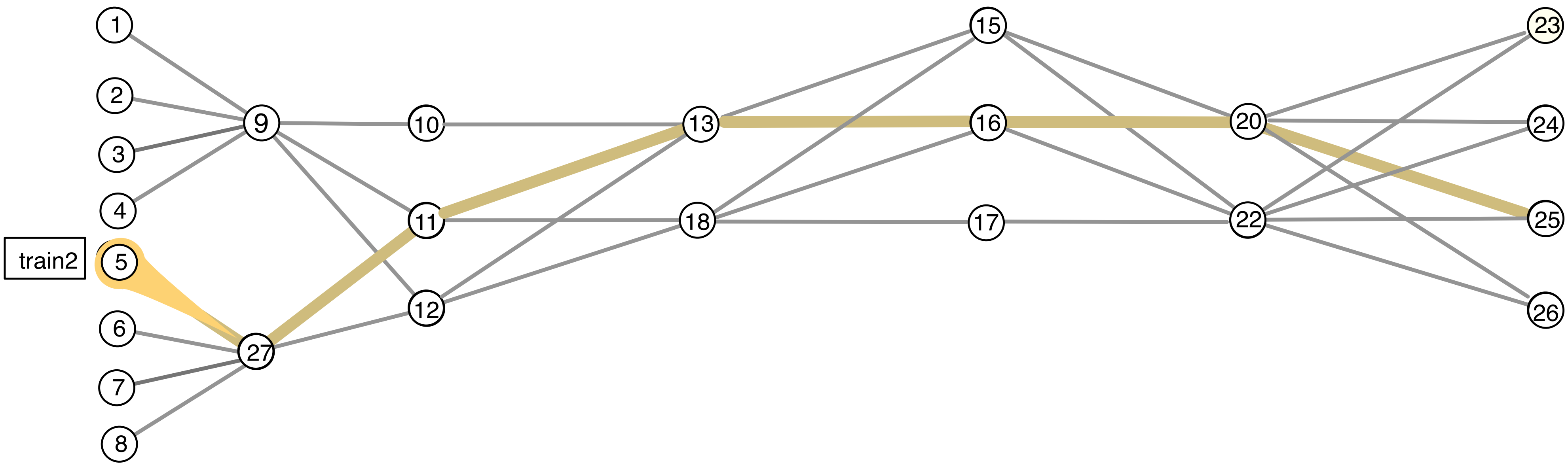

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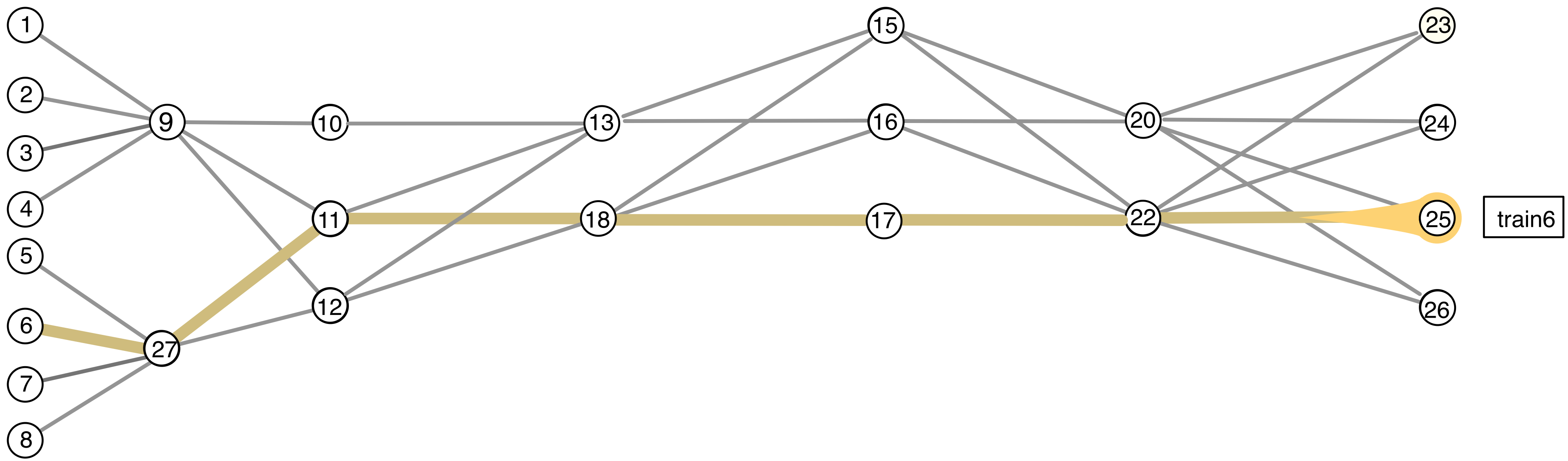

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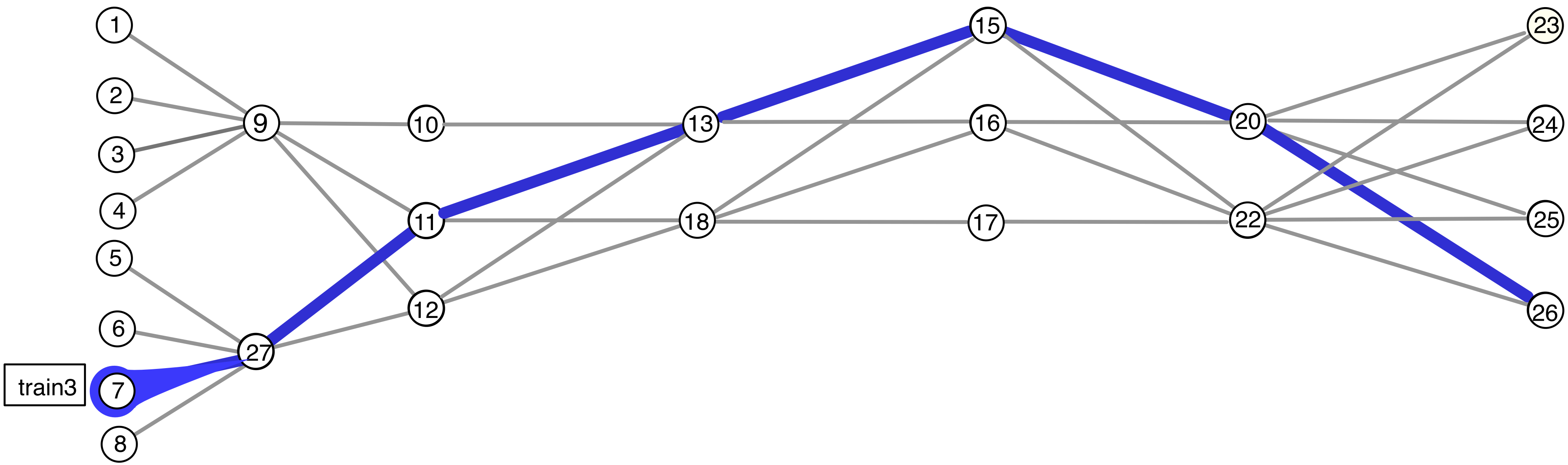

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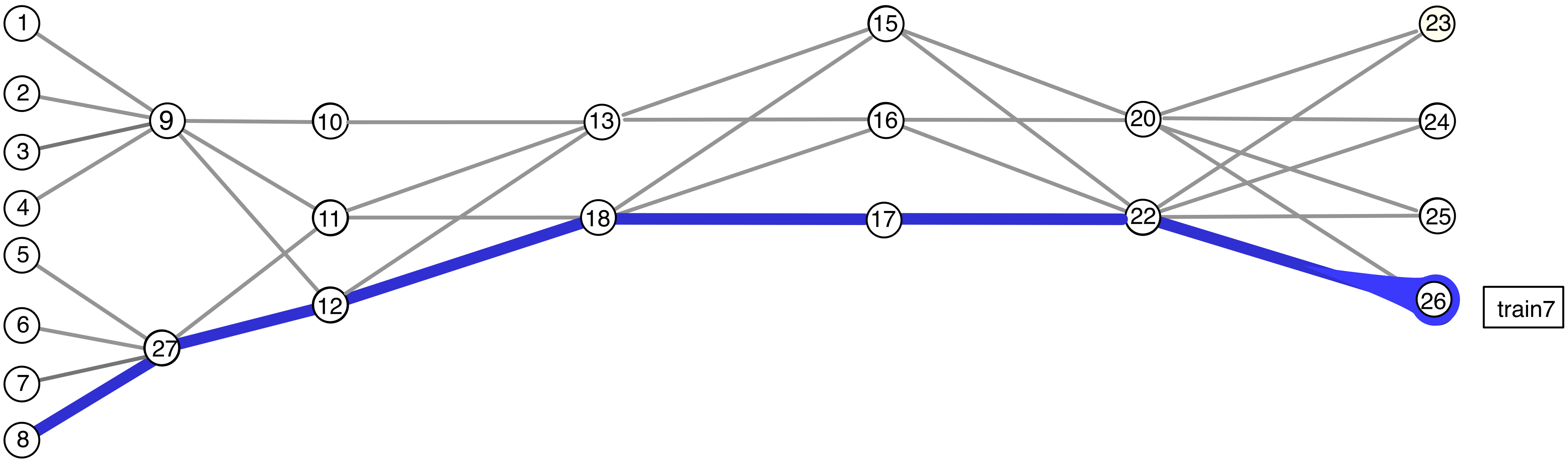
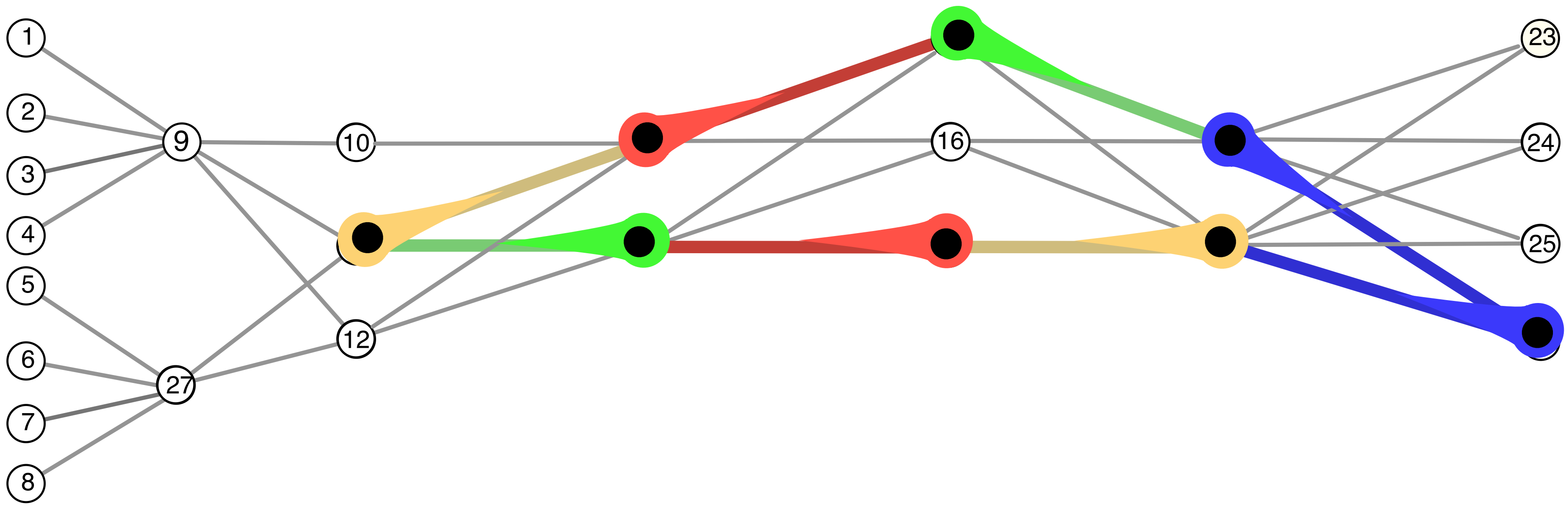
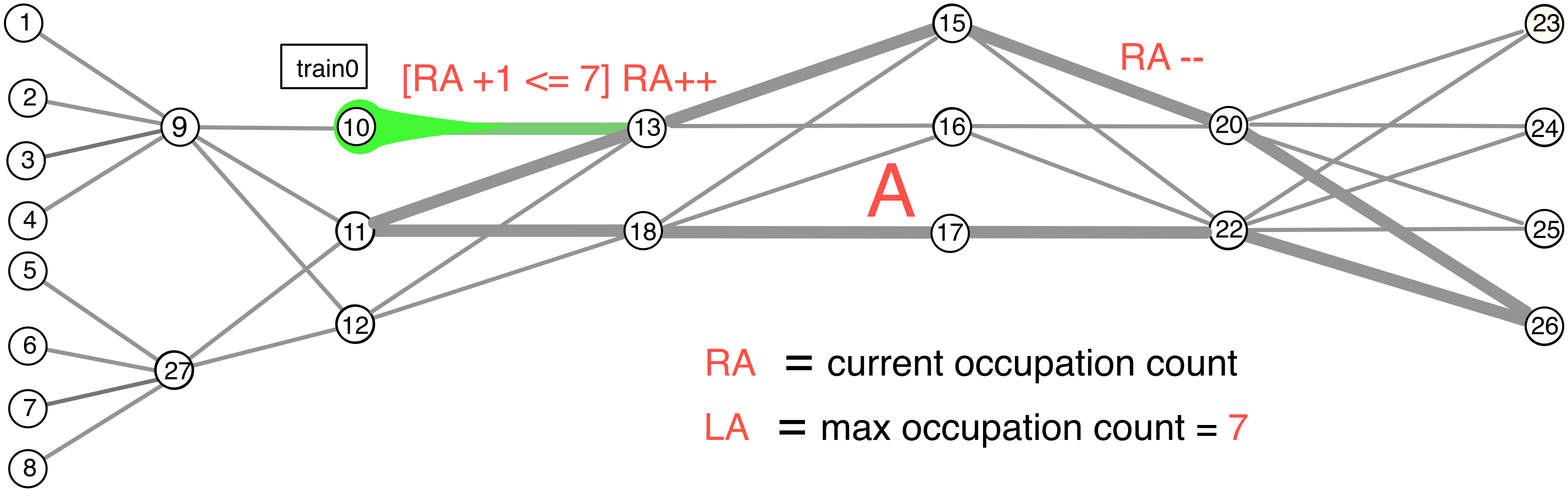


A sample deadlock occurrence



The Trace-IT solution



T0 = [1 , 9, 10, 13, 15, 20, 23] Mission for train0

A0 = [0, 0, 0, 1, 0, -1, 0] Region-A Constraints for train0

The progression rule (e.g. for train0)

T0	=	[1 , 9, 10, 13, 15, 20, 23]	Mission for train0
A0	=	[0, 0, 0, 1, 0, -1, 0]	Region-A Increments/Decr. for train0
P0	=	n	current progress point of train0 (index in T0)
RA	=	n	current degree of occupancy of region A
LA	=	7	maximum degree of occupancy for region A

when <next endpoint of train0 is free>
i.e. for all i: T0[P0+1] !=Ti[Pi]

and <train0 move does not saturate any region>
i.e. for all regions A, … : RA + A0[P0+1] <= LA

the train can advance: i.e. P0 = P0+1, RA = RA+A0[P0]

The reference structure of the model

Global Constants

T0 = [1 , 9, 10, 13, 15, 20, 23];
A0 = [0, 0, 0, 1, 0, -1, 0];
B0 = [0, 0, 0, 1, 0, -1, 0];
…
T7 = [26, 22, 17, 18, 12, 27, 7];
A7 = [1, 0, 0, -1, 0, 0, 0];
B7 = [1, 0, 0, -1, 0, 0, 0];
LA = 7; LB =7

Global Variables

P0, P1, ..., P7 := 0;
RA:=1, RB :=1

Train Rules

Train0: [guard train0] / actions train0
…
Train7: [guard train7] / actions train7

The encoding of the model: UMC

```
train0: s1 -> s1
        {- [P0<6   &  T0[P0+1] !=T5[P5]   &…&   T0[P0+1] !=T7[P7]   &
           RA+A0[P0+1]<=LA   &   RB+B0[P0+1]<=LB] /
          P0 := P0+1;
          RA := RA+A0[P0];   RB := RB+B0[P0];
        }
   …
train7: s1 -> s1
        {…}
```

The encoding of the model: SPIN

```
do :: atomic {
        (P0<6   &&   T0[P0+1] !=T1[P1]   && … &&   T0[P0+1] !=T7[P7]  &&
            (RA+A0[P0+1])<=LA   &&  (RB+B0[P0+1]<=LB)
        ) ->
        P0 = (P0+1);
        RA = RA+A0[P0];  RB = RB+B0[P0];
       };

    :: atomic {
     };
od;
```

The encoding of the model: CADP/LNT

```
loop
  select
    only if
      P0<6  and T0[P0+1] !=T1[P1]   and … and   T0[P0+1] !=T7[P7] and
          (RA+A0[P0+1])<=LA   and  (RB+B0[P0+1]<=LB)
    then
      MOVE (0 of Train_Number);
      P0 := (P0+1);
      RA := RA+A0[P0];  RB := RB+B0[P0];
    end if
  [ ]
    only if
      …
  end select
end loop
```

The encoding of the model: ProB

```
OPERATIONS

  move0 =
     PRE
        P0<6   &  T0(P0+1) /=T1(P1)   &…&  T0(P0+1) /=T7(P7)   &
           RA+A0(P0+1)<=LA   &   RB+B0(P0+1)<=LB
    THEN
       P0 := P0+1;
       RA := RA+A0(P0);      RB := RB+B0(P0);
    END;

  move1 =   …
```

The encoding of the model: NuSMV/ nuXmv

```
TRANS
   RUNNING=0  ->
      P0<6  &&  T0[P0+1] !=T1[P1]  &…&  T0[P0+1] !=T7[P7]  &
          (RA+A0[P0+1])<=LA   &  (RB+B0[P0+1])<=LB

      ? next(P0)=(P0+1)  &   next(P1)=P1  &…&  next(P7)=P7  &
         next(RA)= RA+A0[P0;   next(RB)=RB+B0[P0];

      :  next(P0)=P0  &…&  next(P7)=P7  &  next(RA)=RA  &  next(RB)=RB

 …

TRANS
   RUNNING=7  ->
```

The encoding of the model: FDR4 / CSPm

```
AllTrains (P0, P1, P2, P3, P4, P5, P6, P7, RA, RB) =

  (   P0 < 6 and
      el(T0,P0+1) != el(T1,P1)    and … and     el(T0,P0+1) != el(T7,P7)  and
       RA + el(A0,P0+1) <= LA    and     RB + el(B0,P0+1) <= LB
  ) &
     move0  ->
        AllTrains(P0+1,P1,P2,P3,P4,P5,P6,P7,  RA+el(A0,P0+1),  RB+el(B0,P0+1))

[ ]
  (  P1 < 6  and
       …
```

The encoding of the model: mCRL2

```
proc AllTrains(P0,P1,P2,P3,P4,P5,P6,P7:Nat,  RA,RB: Int) =

   (   P0 < 6 &&
       T0(P0+1) != T1(P1)    &&… &&   T0(P0+1) != T7(P7)  &&
        RA+A0(P0+1) <= LA    &&   RB+ B0(P0+1)<=LB
   ) &
     move(0)  ->
        AllTrains(P0+1,P1,P2,P3,P4,P5,P6,P7,  RA+A0(P0+1), RB+B0(P0+1))

 [ ]
  (  P1 < 6  &&
       …
```

The encoding of the model: TLAplus

```
Move0 ==  /\
    P0 < 6   /\   T0[P0+2] /=T1[P1+1]   /\ … /\   T0[P0+2] /=T7[P7+1]   /\
    RA + A0[P0+2] <= LA    /\     RB + B0[P0+2] <= LB   /\
    P0' = (P0+1)   /\
    RA' = RA+A0[P0+2]   /\   RB' = RB+B0[P0+2]   /\
    UNCHANGED  <<P1,P2,P3,P4,P5,P6,P7>>

Move1 ==
  …

Next  ==   Move0 \/  Move1 \/  Move2 \/  Move3  \/
           Move4 \/  Move5 \/  Move6 \/  Move7
```

Considerations:

So what ????

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Blackboard models /
Event-Condition-Action models /
Guard-Transition models /

can have a common reference baseline

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Diversity in tool selection / model encoding

→ more trustable verification results

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Event Condition Action models / can have a common baseline
Guard Transition models /

Diversity in tool selection / model encoding

more trustable verification results

better exploitation of the verification features of multiple existing frameworks.

e.g. Branching vs. Linear vs. Refinements vs. Compositional

e.g. tool. friendliness vs. ability to deal with very large models

e.g. timed vs untimed

Further Works:

***More frameworks taken into consideration**:*
Simulink / SCADE / SAL / UPPAAL / ….

More features compared:

Customer Support

Code Generation?

Simulation?

Language Expressiveness

Cost

Maturity

Documentation

Report Generation?

Model-based Testing?

Industrial Diffusion

Standard input format?

Time Retated Aspects?

Modularity

Inport/Export

Probability?

Certification

Official Formal Disclaimer:

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ASTRail

SAtellite-based Signalling and Automation SysTems on Railways along with Formal Method and Moving Block validation

THANK YOU!

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The incremental design/verification approach: