A systematic approach to constructing families of incremental topology control algorithms using graph transformation

Presentation at ICGT 2018
Toulouse, France, 2018-06-25

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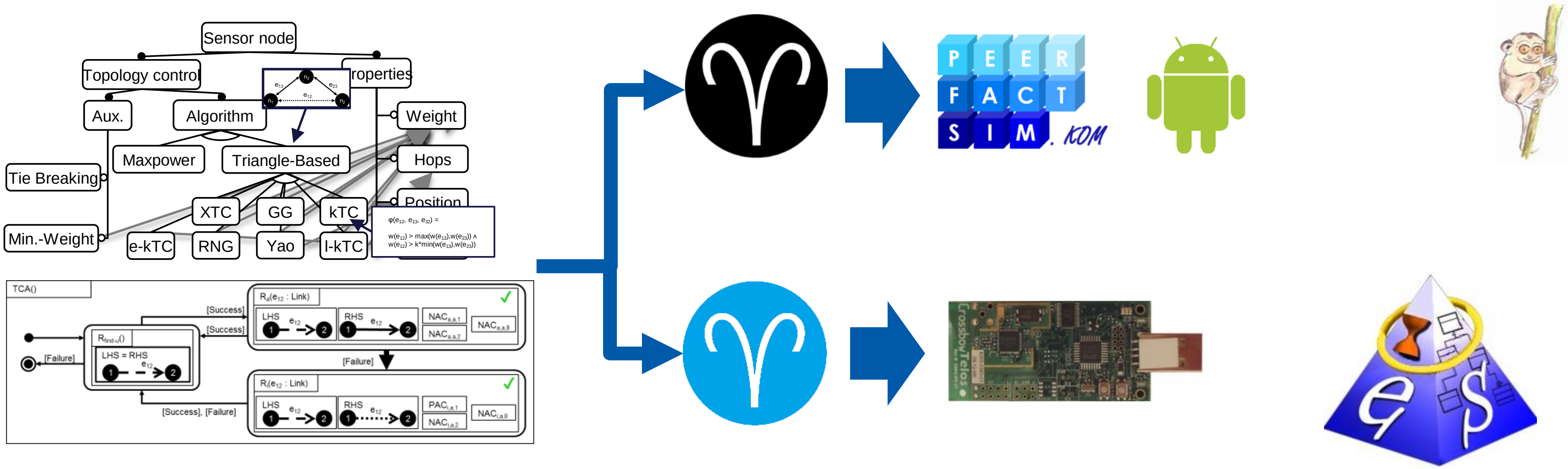
DFG Collaborative Research Centre 1053 – MAKI



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Supported by the Cooperative Research Center 1053 "MAKI" – https://tiny.cc/MAKI

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Dept. of Computer Science (adjunct Professor)

[SoSyM17] Kluge, R. et al. SoSyM 2017, DOI: 10.1007/s10270-017-0587-8

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Example: da_sense – A hybrid sensor network for Smart Cities (“Digitalstadt Darmstadt”) (I)

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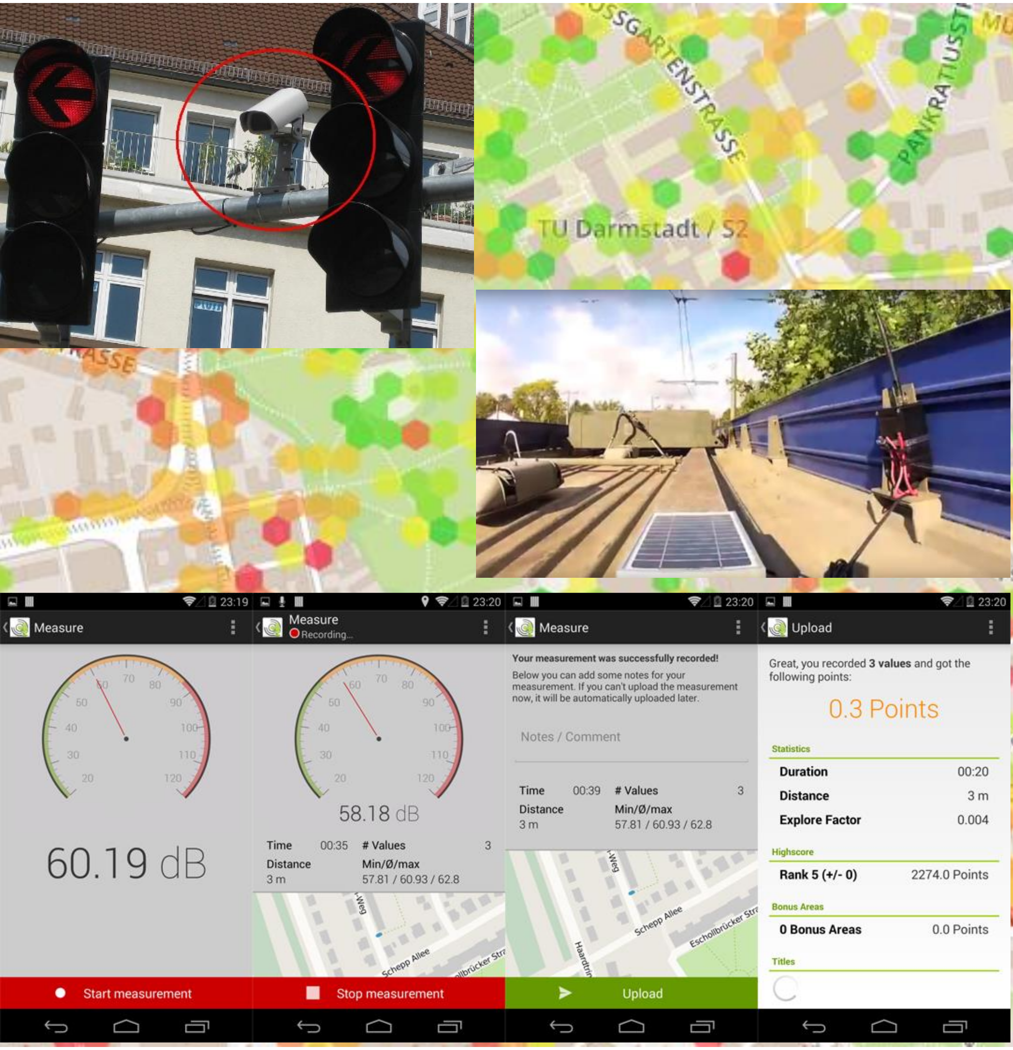

An Urban Management Platform based on heterogeneous sensor networks

- **Traffic**: static at traffic lights
- **Temperature**: mobile on trams
- **Noise**: mobile via Android app

da_sense

http://www.da-sense.de/

Image Sources: Traffic light: https://wiki.freiheitsfoo.de/pmwiki.php?n=Main.Ampel-Kameras | Tram: "Die Transparente Stadt" https://www.youtube.com/watch?v=JimyRNyLZKo | Android screenshots and map: http://www.da-sense.de/

Example: da_sense – A hybrid sensor network for Smart Cities ("Digitalstadt Darmstadt") (II)

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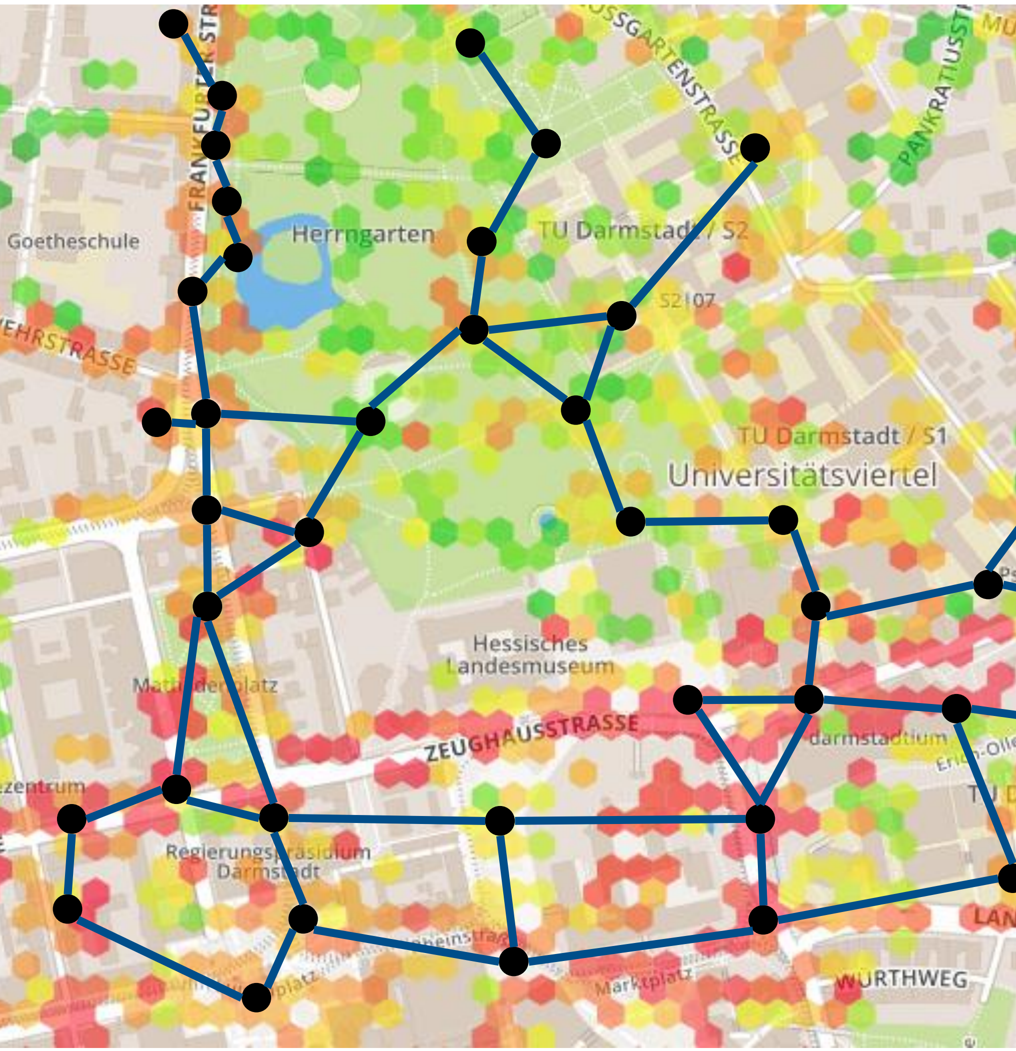

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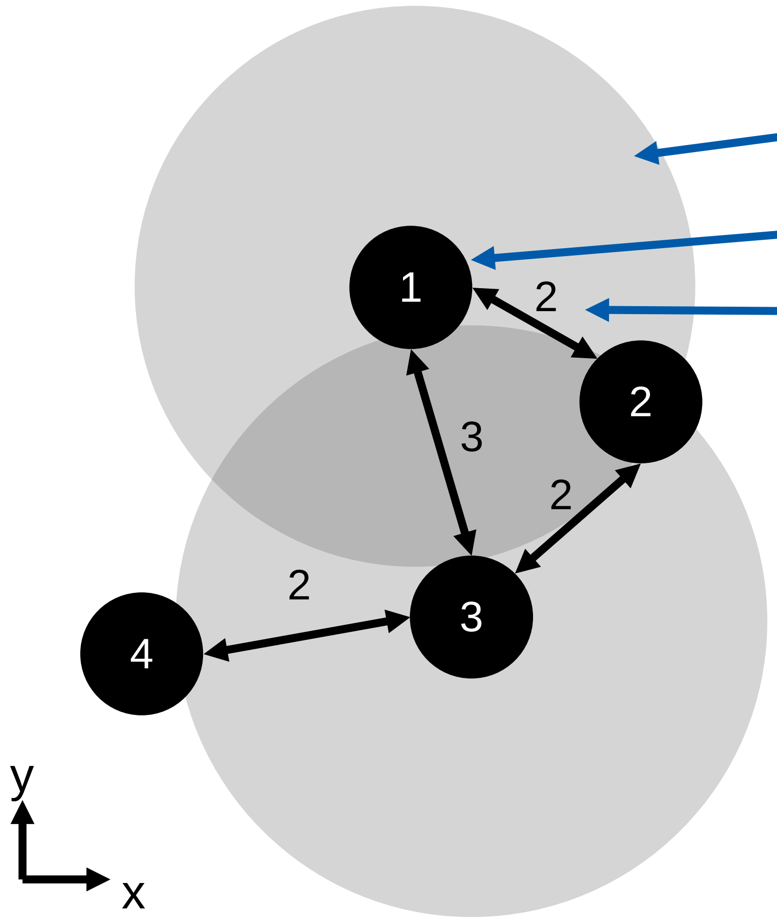
Graph-based topology model for Wireless Sensor Networks

Wireless Sensor Network topology



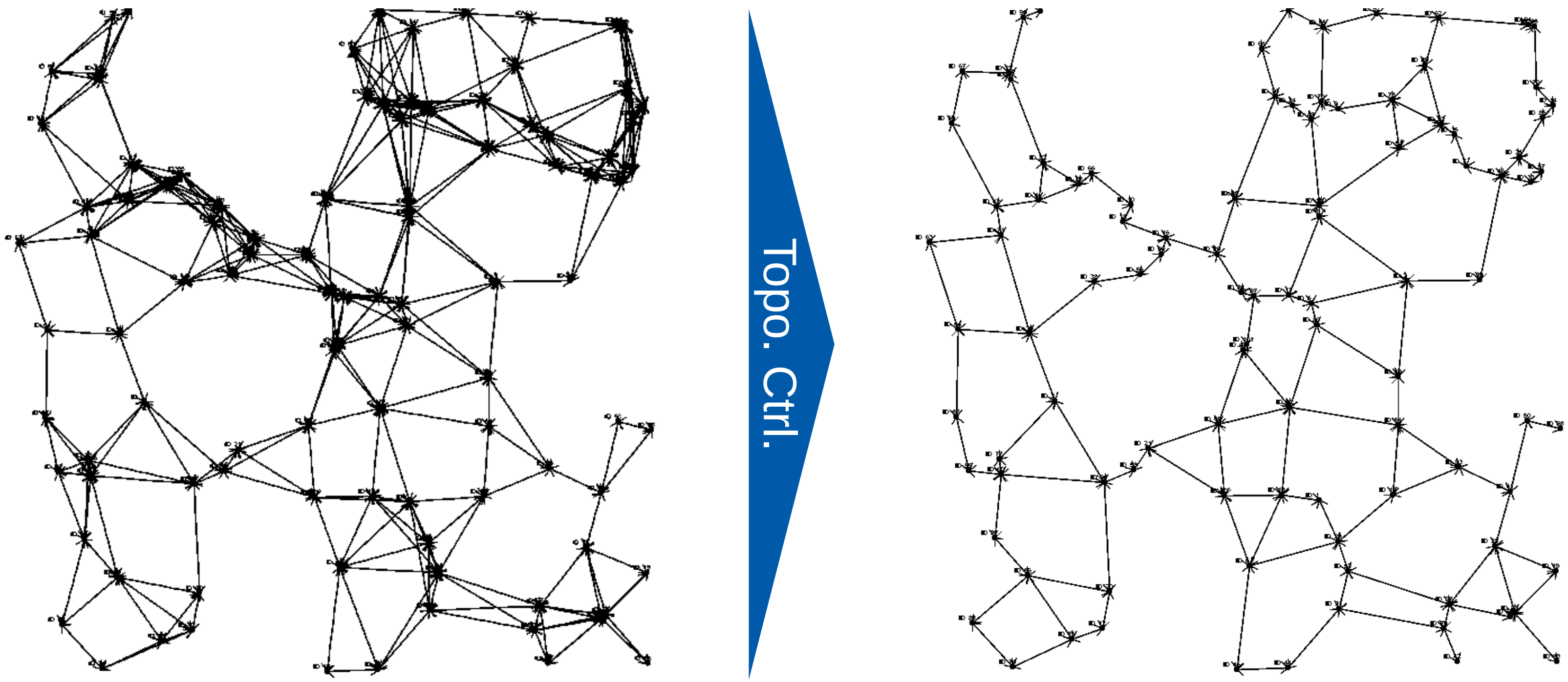
Transmission range of n_1

Wireless node n_1

Wireless link e_{12} with link weight $w(e_{12})$

TelosB sensor node
48kB ROM,
10kB RAM,
2xAAA battery

Topology control sparsens topologies to improve non-functional property



Input topology

Maintain connectivity

Output topology

— Communication link

ID: 3 ● Sensor node

Topology control by example: kTC algorithm

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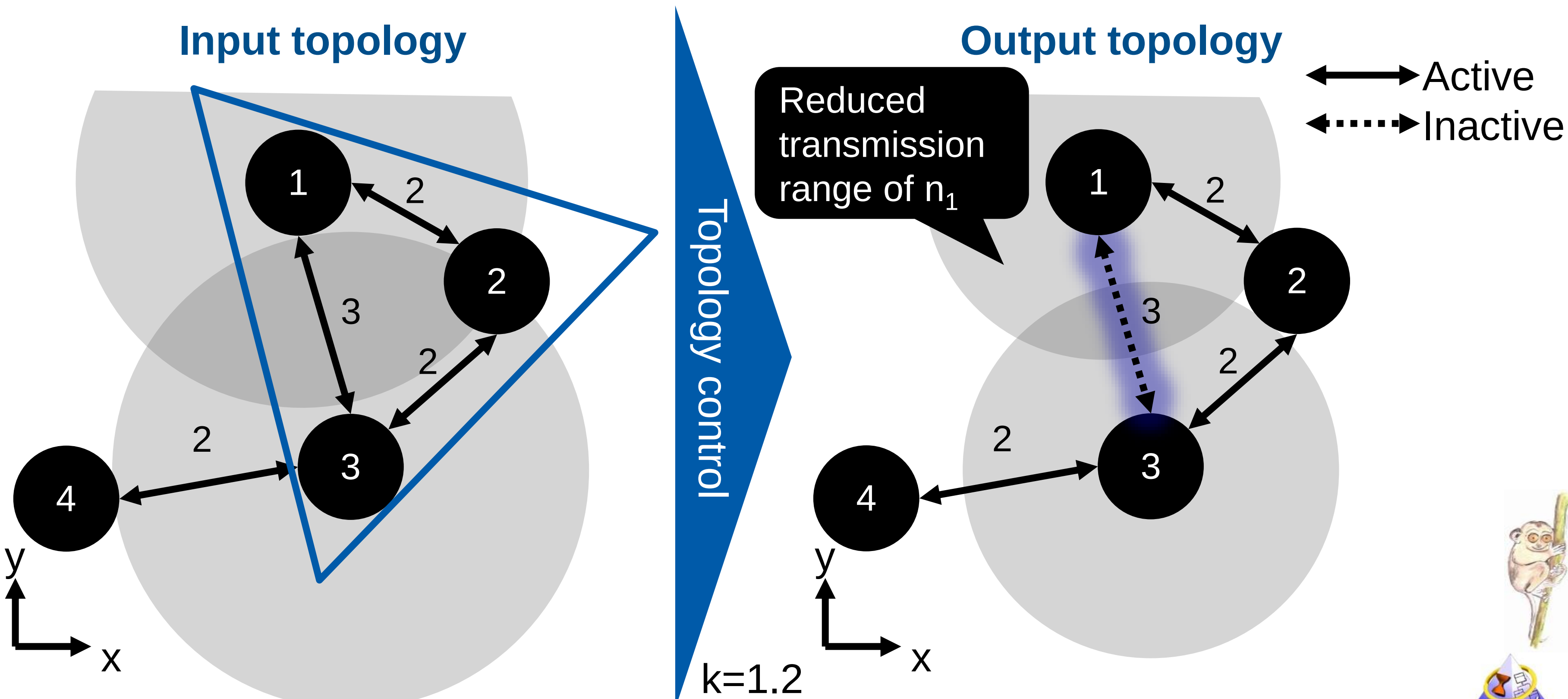
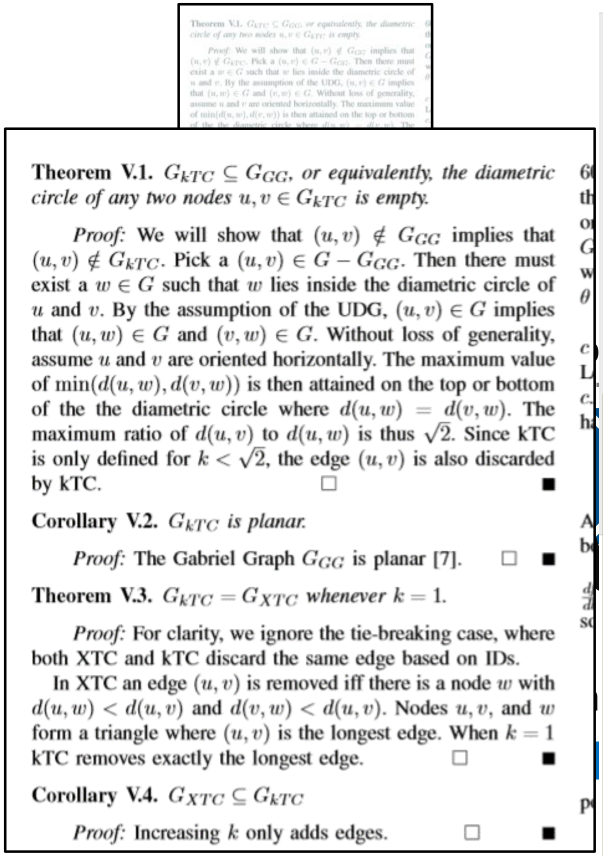
kTC rule:
"Inactivate a link **if (and only if)** it is
(i) the weight-maximal link in a triangle **and**
(ii) at least *k*-times longer than the weight-minimal link in the triangle."



The curse of low abstraction in traditional communication system development



Theorem V.1. $G_{kTC} \subseteq G_{GG}$*, or equivalently, the diametric circle of any two nodes* $u, v \in G_{kTC}$ *is empty.*

Proof: We will show that $(u,v) \notin G_{GG}$ implies that $(u,v) \notin G_{kTC}$. Pick a $(u,v) \in G - G_{GG}$. Then there must exist a $w \in G$ such that w lies inside the diametric circle of u and v. By the assumption of the UDG, $(u,v) \in G$ implies that $(u,w) \in G$ and $(v,w) \in G$. Without loss of generality, assume u and v are oriented horizontally. The maximum value of $\min(d(u,w), d(v,w))$ is then attained on the top or bottom of the the diametric circle where $d(u,w) = d(v,w)$. The maximum ratio of $d(u,v)$ to $d(u,w)$ is thus $\sqrt{2}$. Since kTC is only defined for $k < \sqrt{2}$, the edge (u,v) is also discarded by kTC. □ ■

Corollary V.2. G_{kTC} *is planar.*

Proof: The Gabriel Graph G_{GG} is planar [7]. □ ■

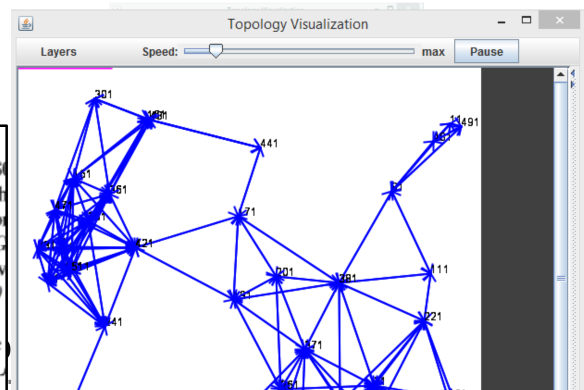
Theorem V.3. $G_{kTC} = G_{XTC}$ *whenever* $k = 1$.

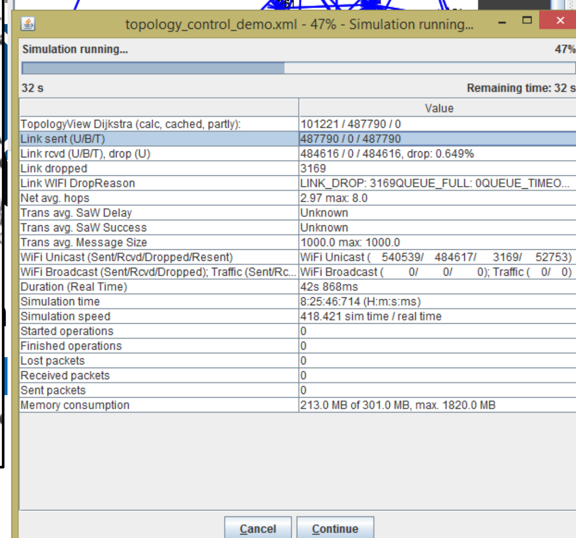
Proof: For clarity, we ignore the tie-breaking case, where both XTC and kTC discard the same edge based on IDs.

In XTC an edge (u,v) is removed iff there is a node w with $d(u,w) < d(u,v)$ and $d(v,w) < d(u,v)$. Nodes u, v, and w form a triangle where (u,v) is the longest edge. When $k = 1$ kTC removes exactly the longest edge. □ ■

Corollary V.4. $G_{XTC} \subseteq G_{kTC}$

Proof: Increasing k only adds edges. □ ■





topology_control_demo.xml - 47% - Simulation running...

Simulation running... 47%

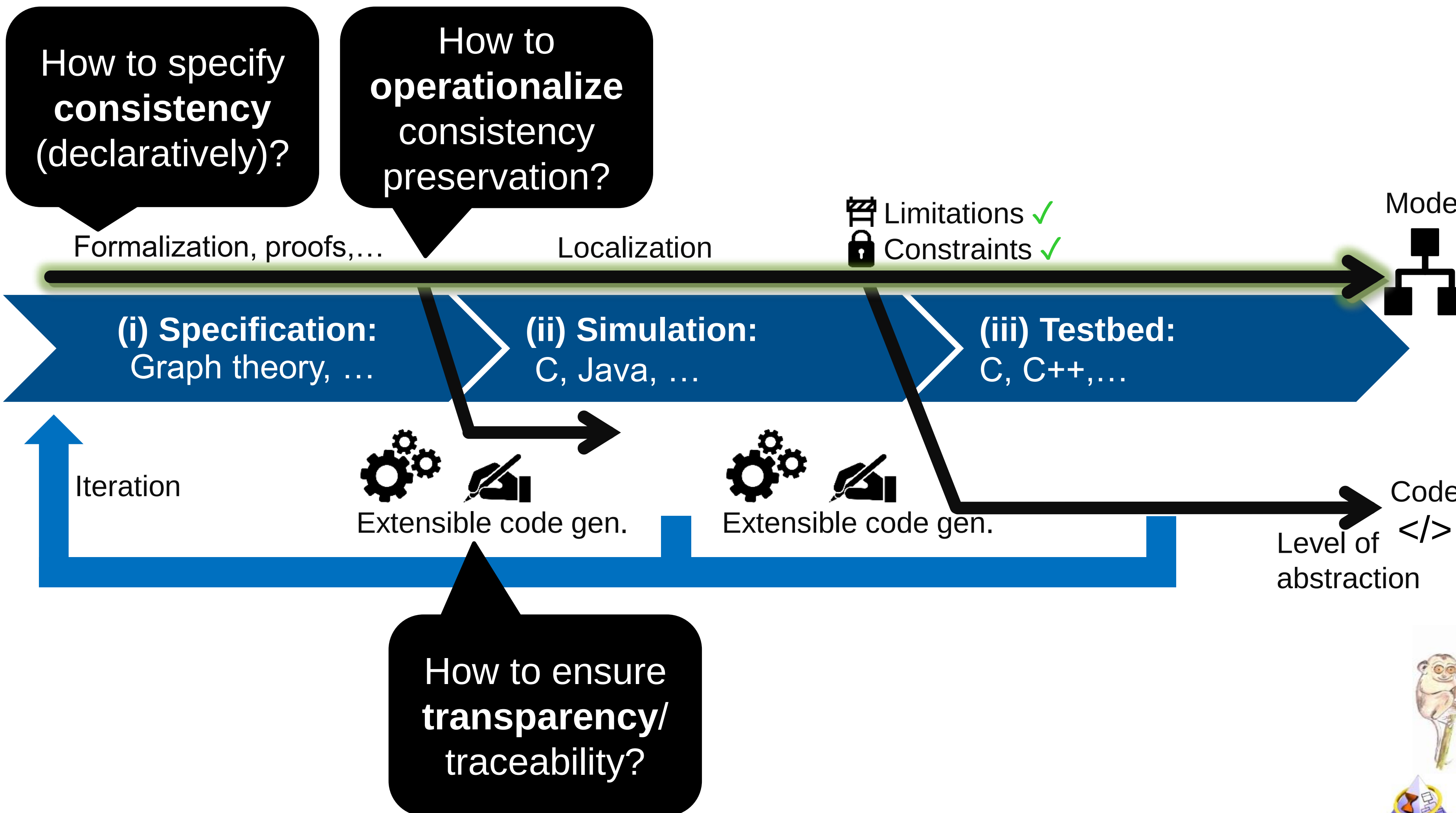
32 s — Remaining time: 32 s

	Value
TopologyView Dijkstra (calc, cached, partly):	101221 / 487790 / 0
Link sent (U/B/T)	487790 / 0 / 487790
Link rcvd (U/B/T), drop (U)	484616 / 0 / 484616, drop: 0.649%
Link dropped	3169
Link WIFI DropReason	LINK_DROP: 3169QUEUE_FULL: 0QUEUE_TIMEO...
Net avg. hops	2.97 max: 8.0
Trans avg. SaW Delay	Unknown
Trans avg. SaW Success	Unknown
Trans avg. Message Size	1000.0 max: 1000.0
WiFi Unicast (Sent/Rcvd/Dropped/Resent)	WiFi Unicast (540539/ 484617/ 3169/ 52753)
WiFi Broadcast (Sent/Rcvd/Dropped); Traffic (Sent/Rc...	WiFi Broadcast (0/ 0/ 0); Traffic (0/ 0)
Duration (Real Time)	42s 868ms
Simulation time	8:25:46:714 (H:m:s:ms)
Simulation speed	418.421 sim time / real time
Started operations	0
Finished operations	0
Lost packets	0
Received packets	0
Sent packets	0
Memory consumption	213.0 MB of 301.0 MB, max. 1820.0 MB

Cancel | Continue

Image Sources: FlockLab https://www.flocklab.ethz.ch/wiki/chrome/site/wiki_public/observer/outdoor_1.jpg

Goal: Support the correct-by-construction development of topology control algorithms

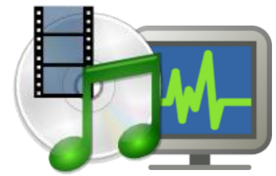


MAKI for a better Future Internet

Multi-Mechanismen-Adaption für das Künftige Internet

C: Communication systems (concrete self-adaptive systems)

P2P Streaming			C/S Streaming		
Mesh	Hybrid	Tree	DASH	HLS	...



B: Adaptation mechanisms (reusable components for adaptive systems)

Monitor → Analyze → Plan → Execute

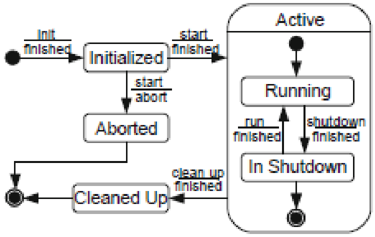
Knowledge

A: Construction methods (models, design patterns, languages)

Our area

- Network topologies and topology adaptation
- Specification languages
- Software engineering

M_i ⟷ **Transition** ⟷ M_j




```
filter(
  max(
    join(
      match(TP, T1, self <- e0 -> n1,
        n1 <- e1 -> n2),
      match(TP, T3, self <- e2 -> n3)),
    e0.weight),
  count(
    match(TP, T2, self - e3 -> n4)) = 0)
execute every match:
  at(self, TP, T2) add neighbor(n1)
```

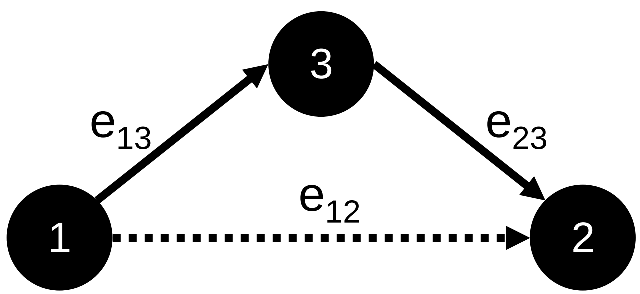
https://www.maki.tu-darmstadt.de/

Unstructured consistency specification

Unstructured formulation

kTC: "Inactivate a link if (and only if) it is
(i) the weight-maximal link in a triangle and
(ii) at least k-times longer than the weight-minimal link in the triangle."

Structured formulation



$$\varphi(e_{12}, e_{13}, e_{32}) = \bigwedge \begin{array}{l} w(e_{12}) > \max(w(e_{13}),w(e_{23})) \land \\ w(e_{12}) > k*\min(w(e_{13}),w(e_{23})) \end{array}$$

Structural constraint **Attribute constraints**

Problem 1: Implicit, unstructured, or informal specification of constraints.

Spec. Sim. Test.

Topology control algorithms form families

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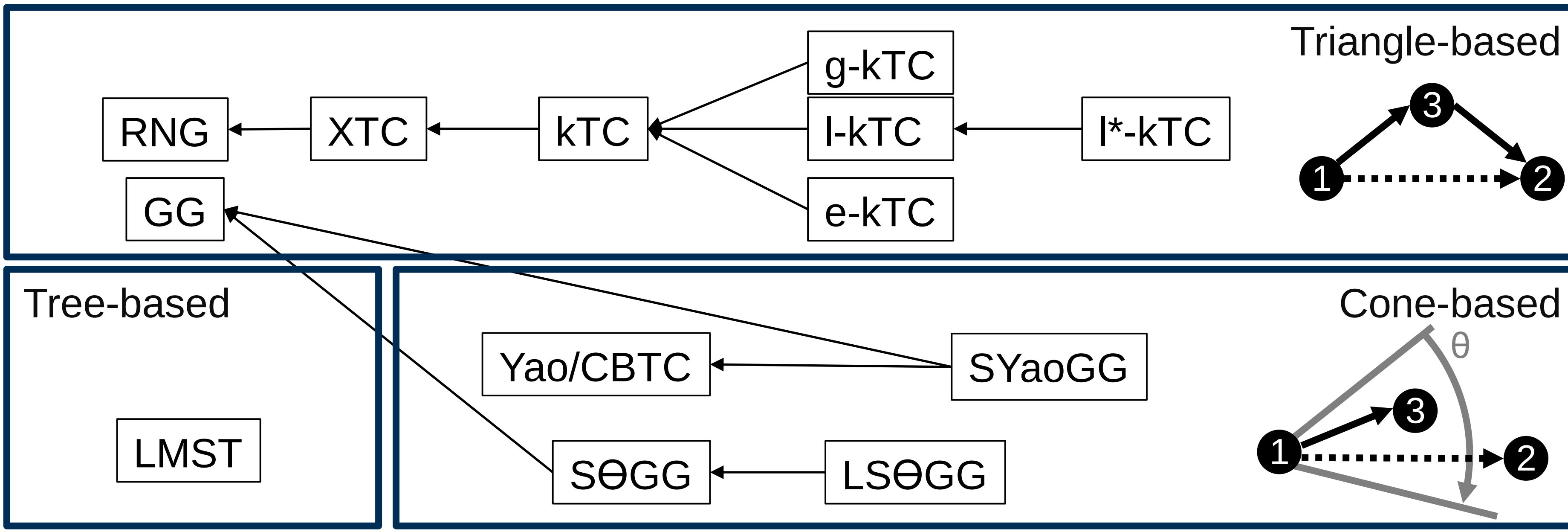
- Family: common structural pattern
- Algorithm: refinement based onattribute constraints

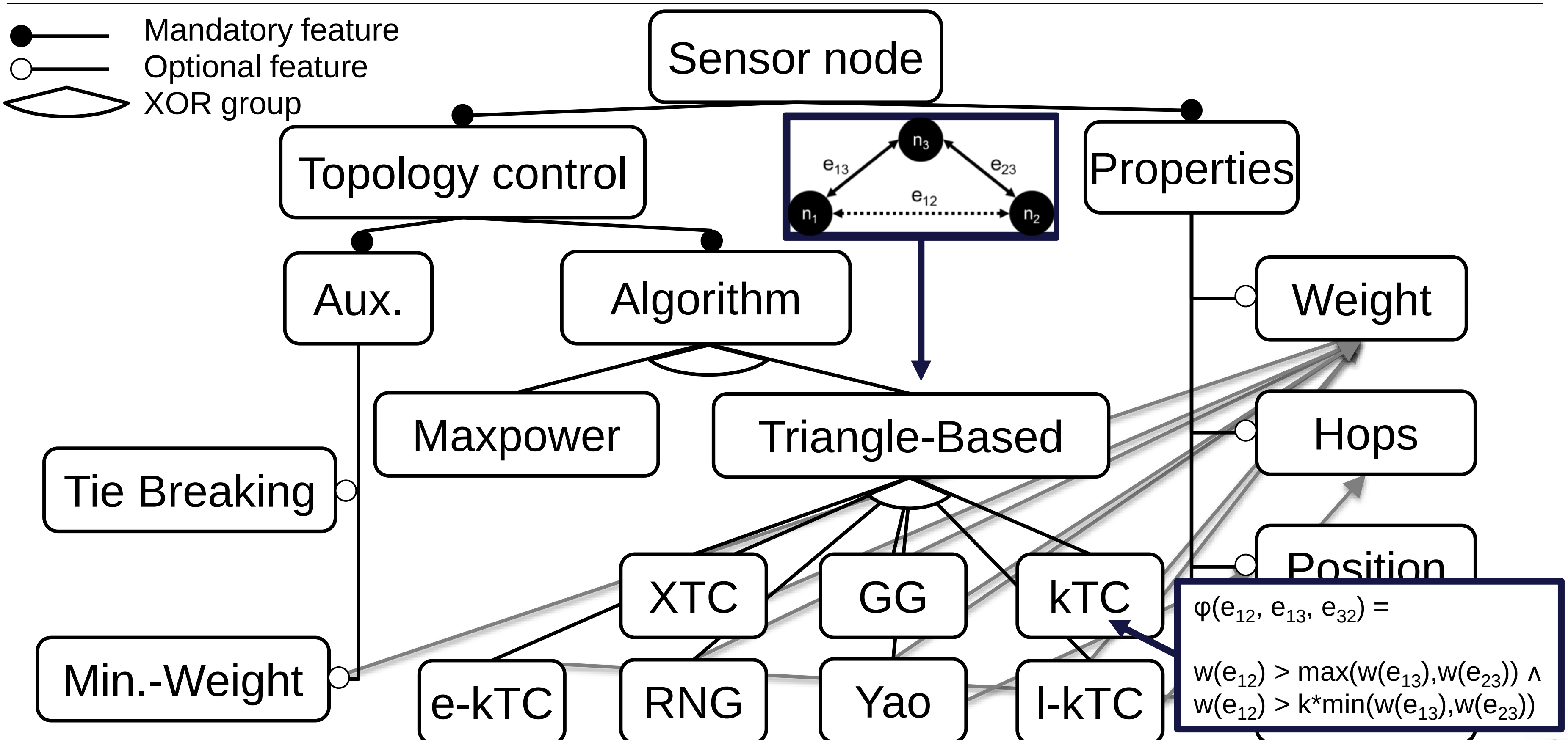


Problem 2: Insufficient usage of relationships among topology control algorithms

← builds on (uses/refines)

Spec. Sim. Test.

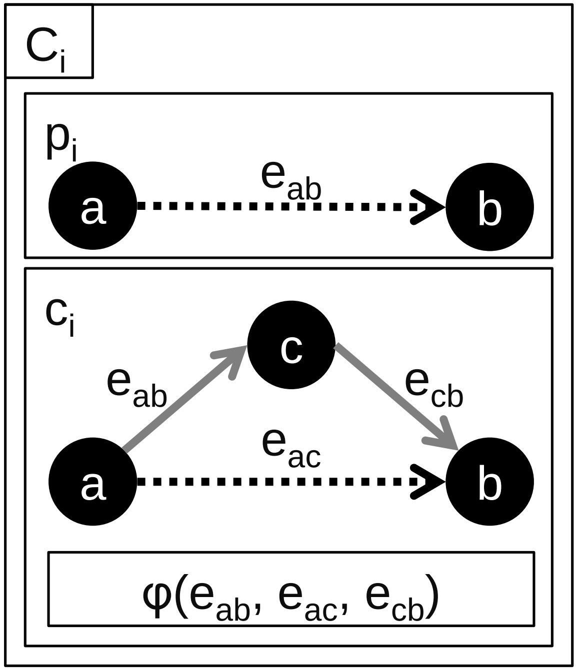
TC Algorithm families are Dynamic Software Product Lines

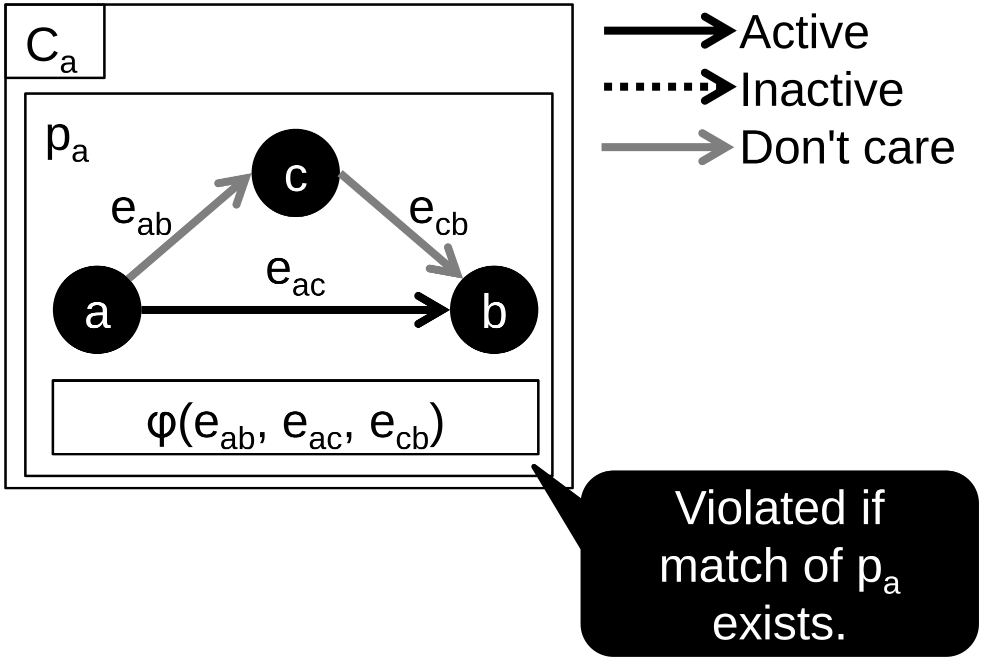


Advantages: Reuse in of predicates, spec. of topology control reconfiguration

Spec. Sim. Test.

Graph constraints for specifying local consistency properties





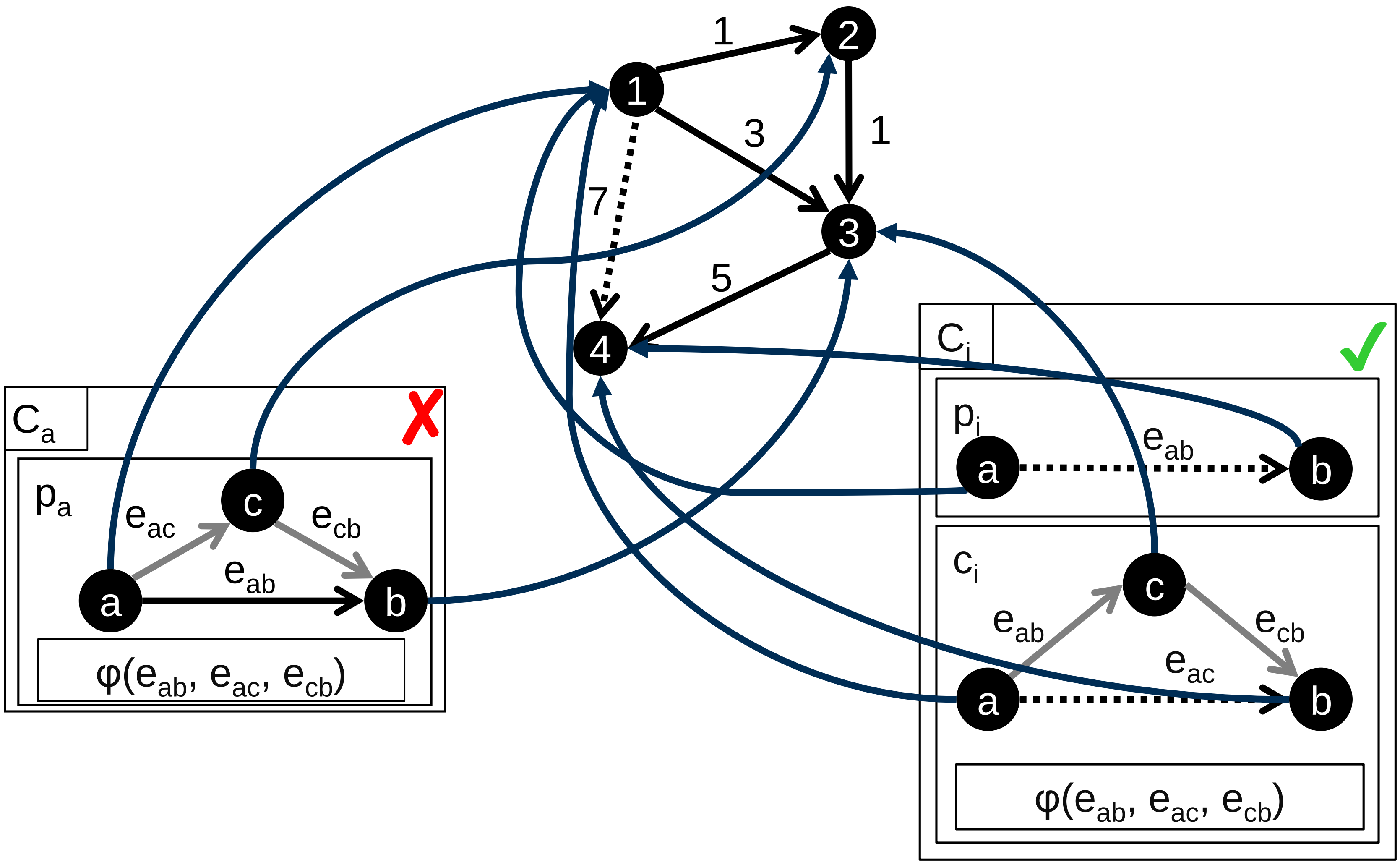
"**Each inactive link** should be part of a triangle for which φ holds"

"**No active link** should be part of a triangle for which φ holds"

Advantages: expressiveness, formal + domain-specific + operationalizeable

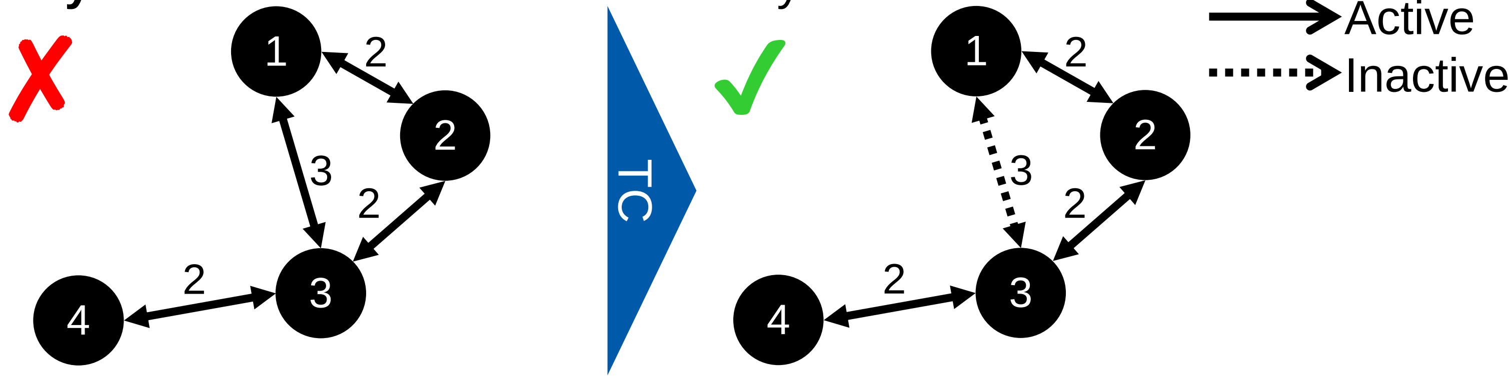
Spec. Sim. Test.

Example: Fulfilled and violated constraints

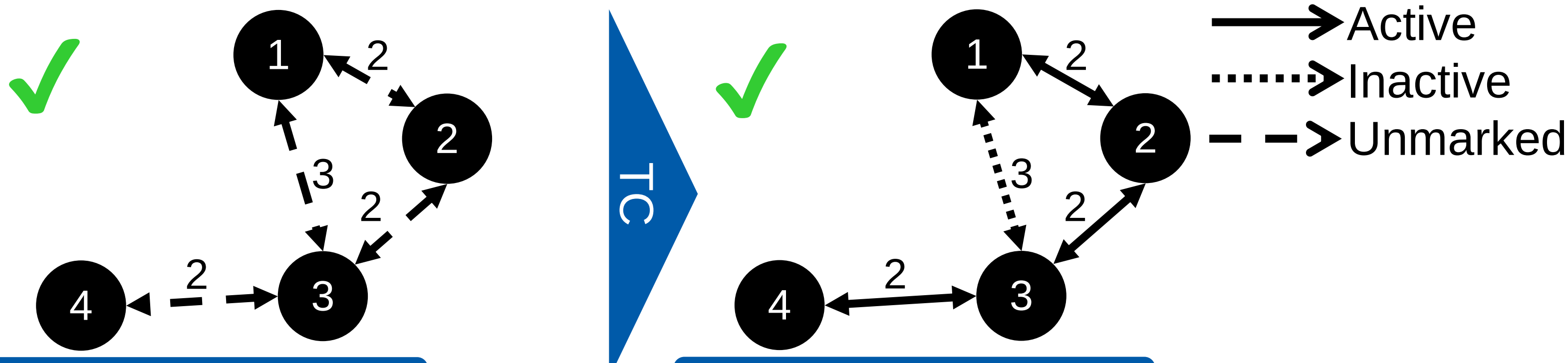


Enforcing and preserving consistency

Consistency enforcement: Recover from any inconsistent state



Consistency preservation: Weak and strong consistency



Weakly consistent

Strongly consistent

Chosen solution

Spec. Sim. Test.

Recap on consistency preservation

Global consistency properties

implies

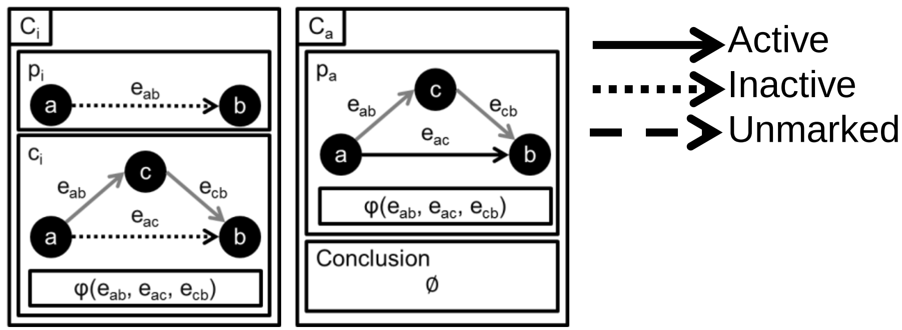
Local consistency properties (declarative)

preserves

Topology control algorithm specification (operationalized)

Generic → e.g., connectivity

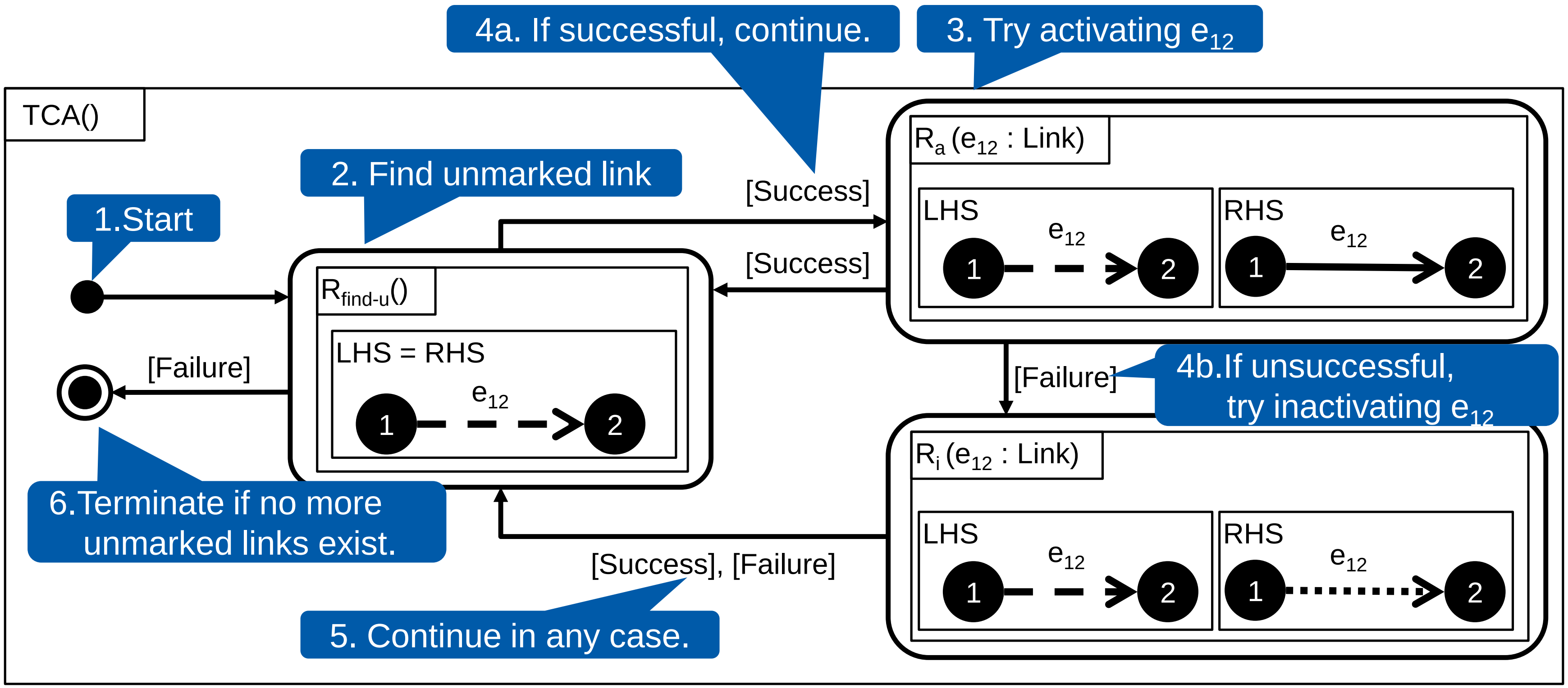
Algorithm-specific → e.g., "no φ-triangles"



?

Spec. Sim. Test.

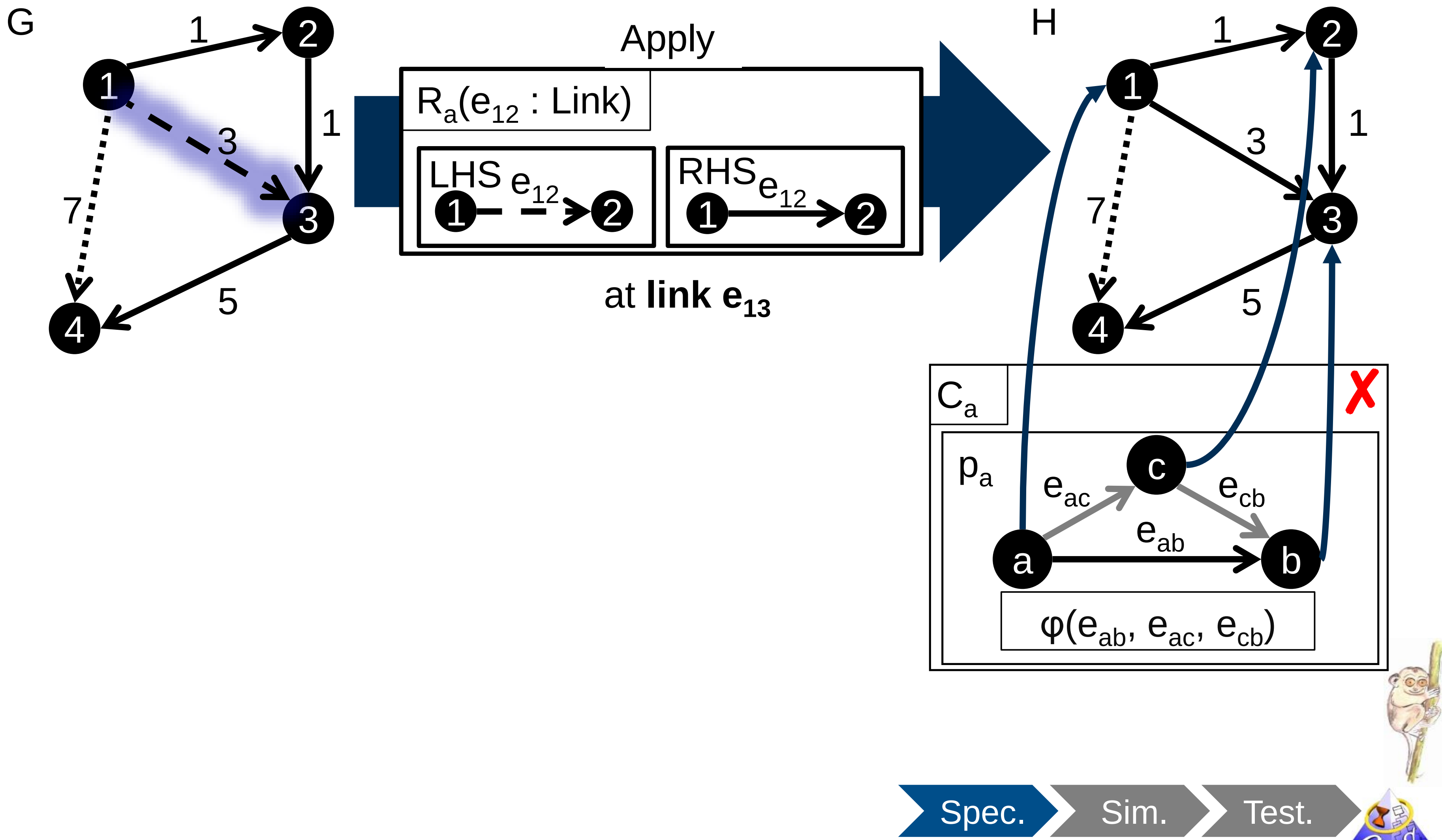
Specifying algorithmic implementation using Story-Driven Modeling [FNT+98]



[FNT+98] Fischer et al.: "Story Diagrams: A New Graph Rewrite Language Based on the UML and Java," 1998

Spec. Sim. Test.

Rule applications may violate consistency!



Ensuring inductive consistency preservation

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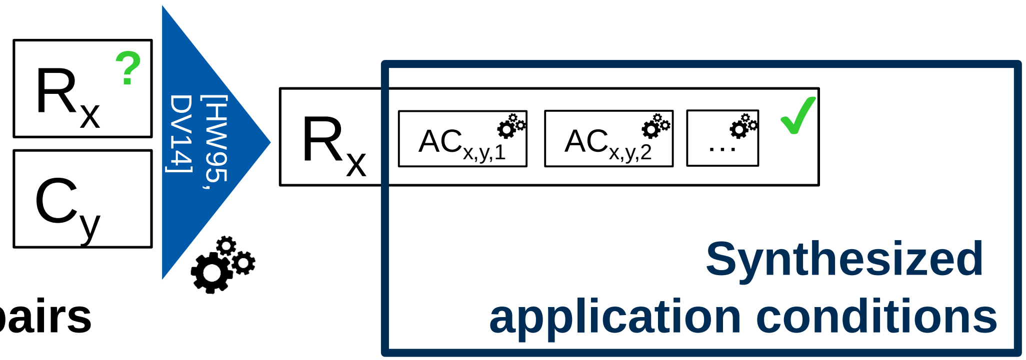
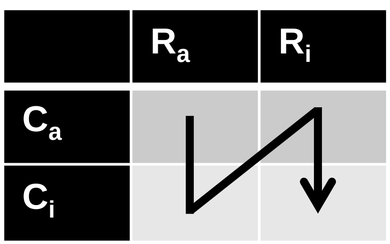
Pairwise refinement

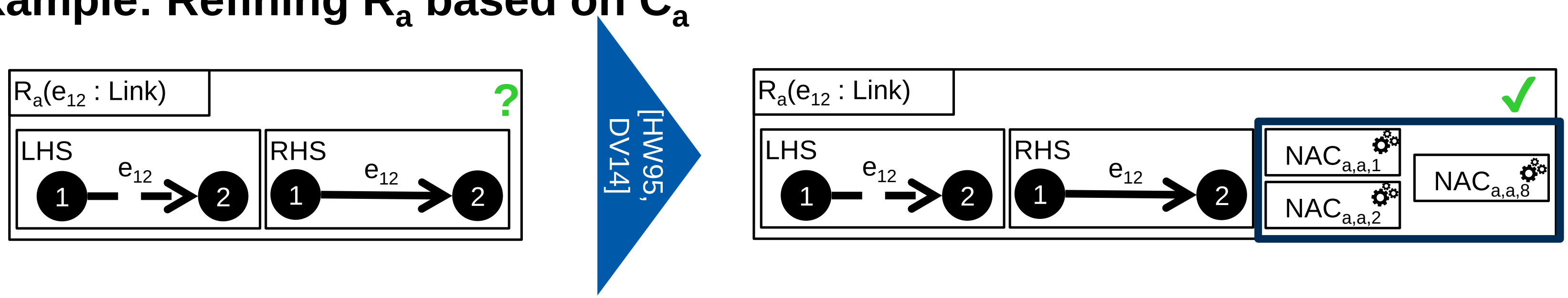


Repeat for all (R_x, C_y) pairs



Advantages:
mechanical algorithm,
existing tool support

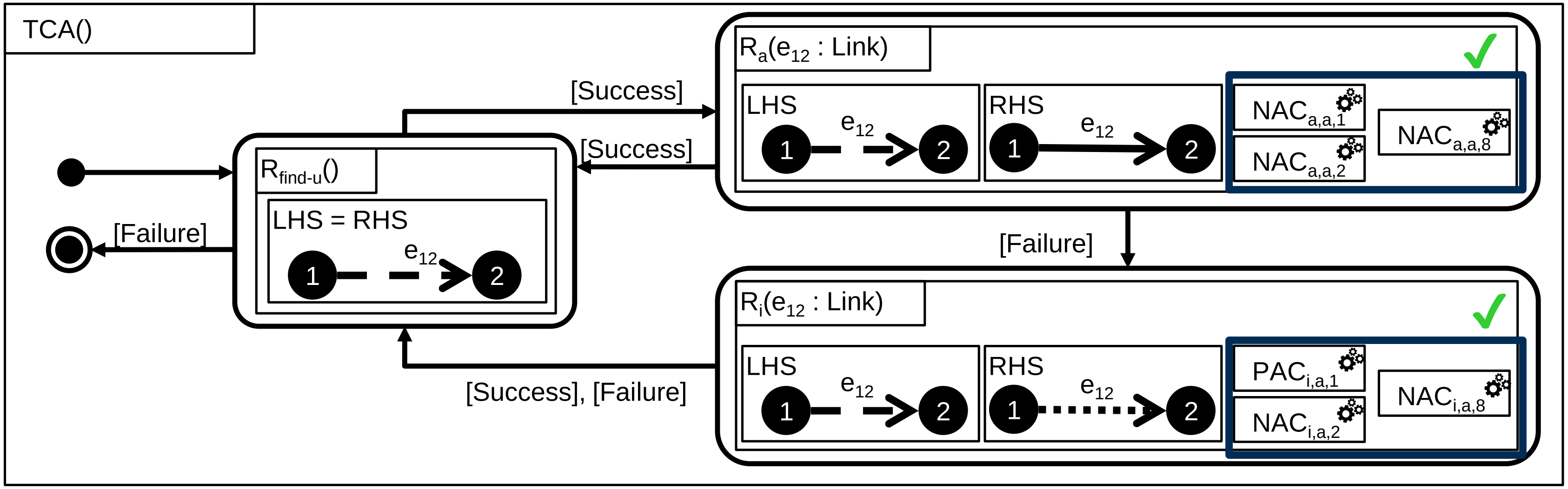
Example: Refining R_a based on C_a



[HW95] Heckel, Wagner: "Ensuring consistency of conditional graph grammars-a constructive approach," ENTCA, 1995
[DV14] Varró, Deckwerth: "Attribute Handling for Generating Preconditions from Graph Constraints," ICGT, 2014.

Spec. | Sim. | Test.

Refined algorithm specification



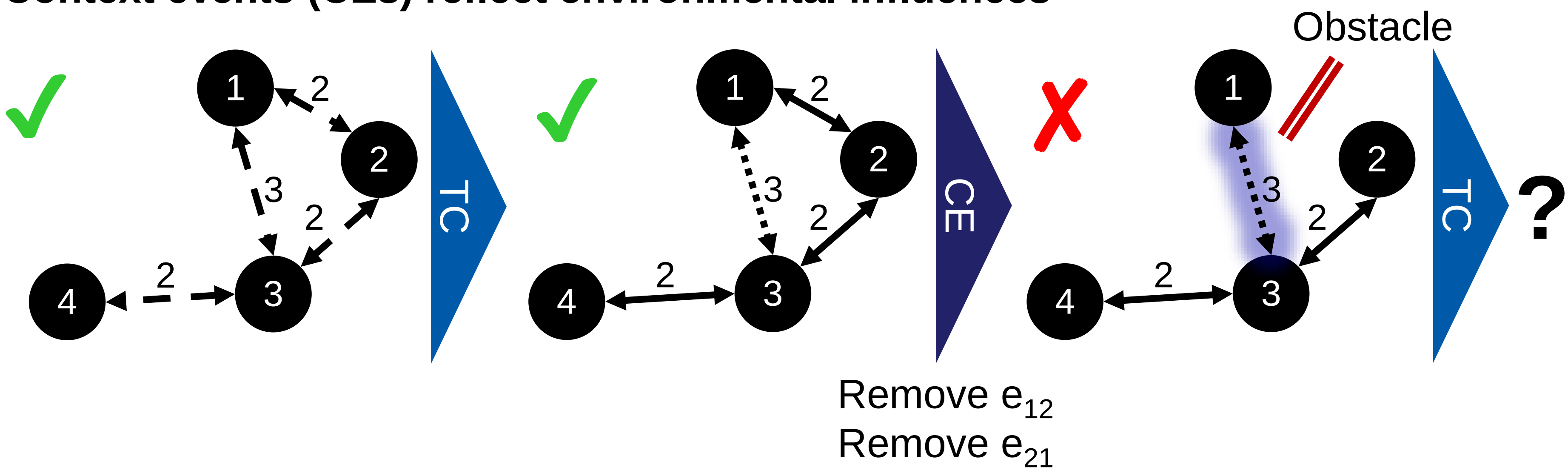
Advantages: inductive invariant, strong consistency on termination

Required: proof of termination

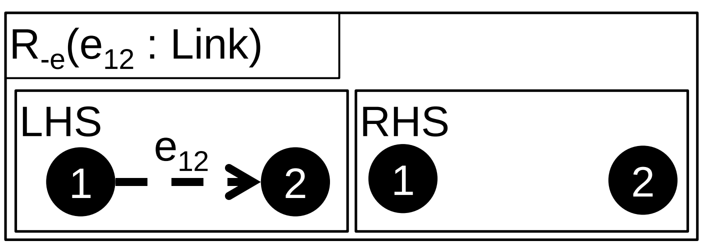
Spec. Sim. Test.

Topologies are never stable: Context events and dynamic topology control

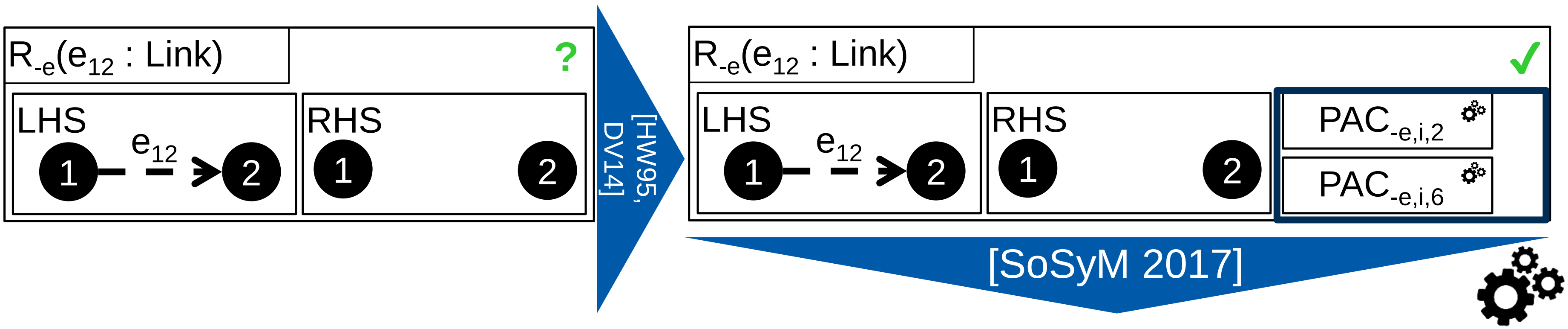
Context events (CEs) reflect environmental influences

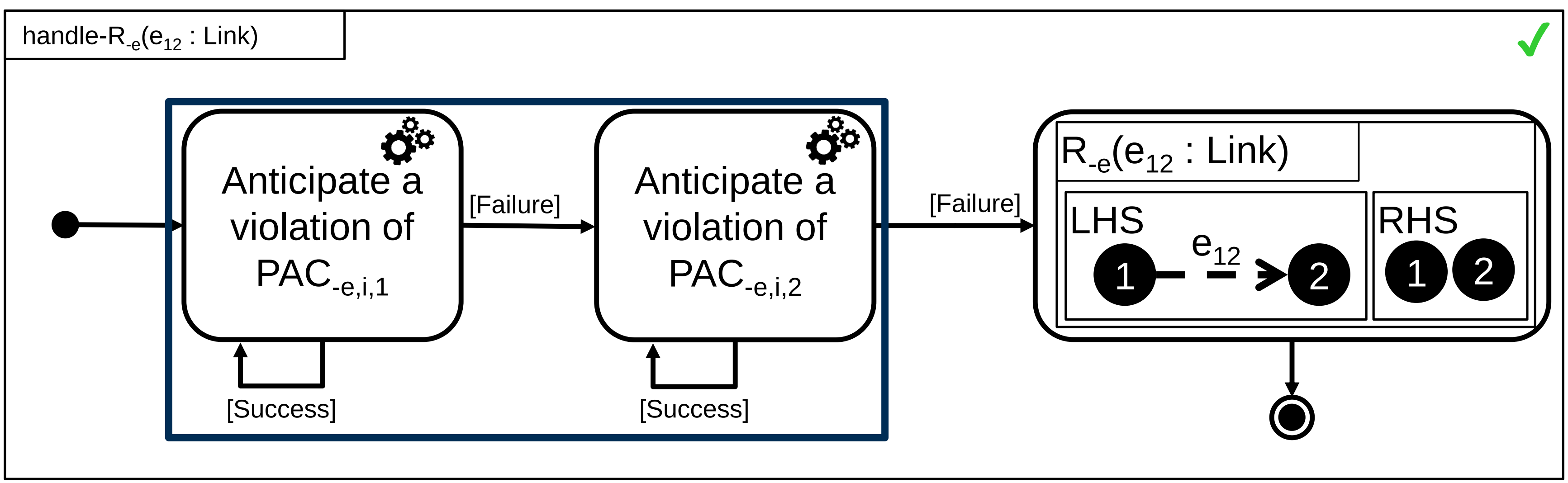


Example: Link removal rule



Context event handlers: Anticipating consistency violation

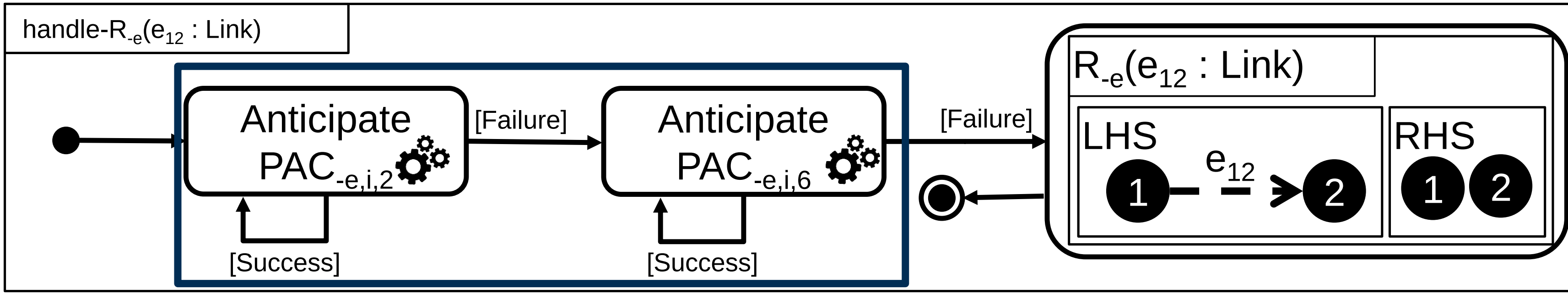




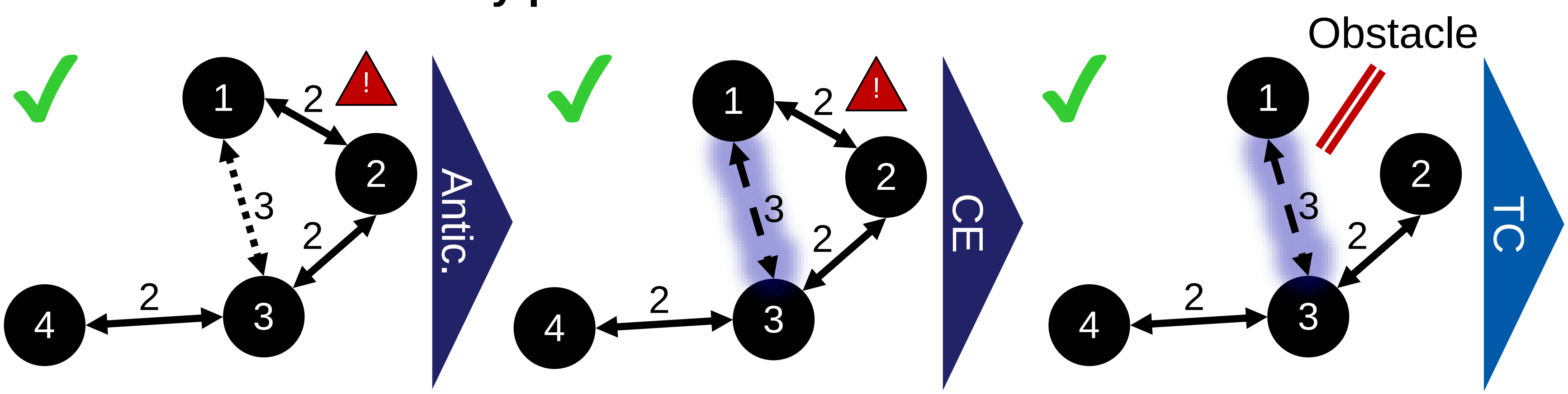
Spec. Sim. Test.

Consistency preservation by context event handling

– Context event handler for R_{-e}



– Achieved consistency preservation



Remove e_{12}
Remove e_{21}

Inactivate e_{13}
Inactivate e_{31}

! Pending context event

Recap on specification phase

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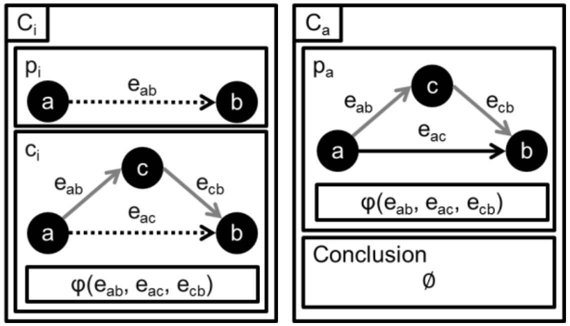
Global consistency properties

- Generic → e.g., connectivity
- Algorithm-specific → e.g., "no φ-triangles"

implies

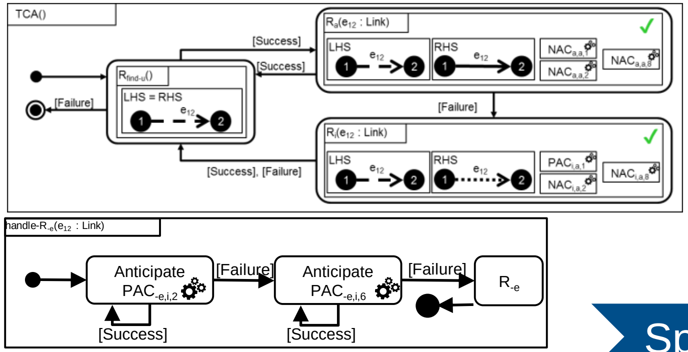
Local consistency properties (declarative)



[HW95, DV14]

preserves

Topology control algorithm specification (operationalized)



Spec. | Sim. | Test.

Tool support for simulation and testbed

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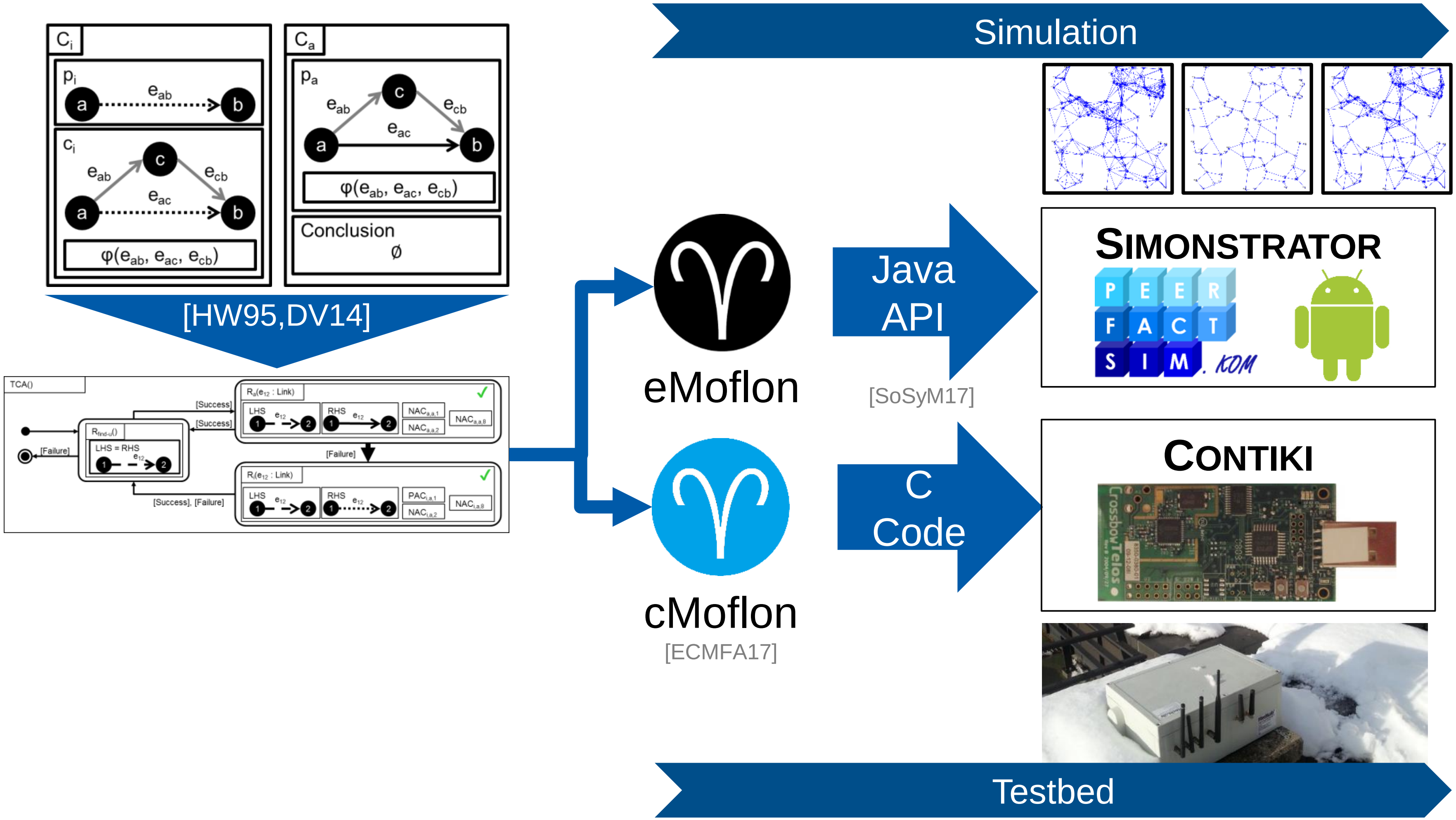
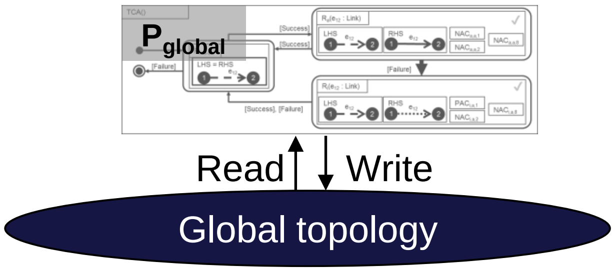


[ECMFA17] Kluge et al: cMoflon: Model-Driven Generation of Embedded C Code for Wireless Sensor Networks. In: ECMFA 2017. LNCS 10376.

Spec. Sim. Test.

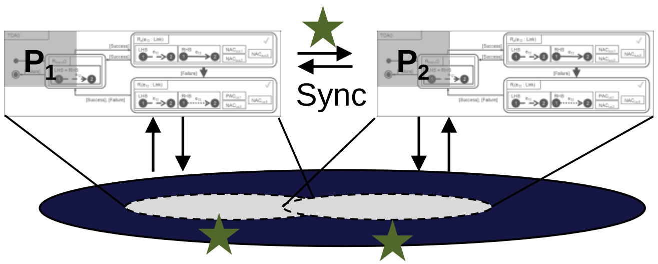
Ongoing Work: From centralized to distributed topology control algorithm specifications



Centralized-global perspective of TC:

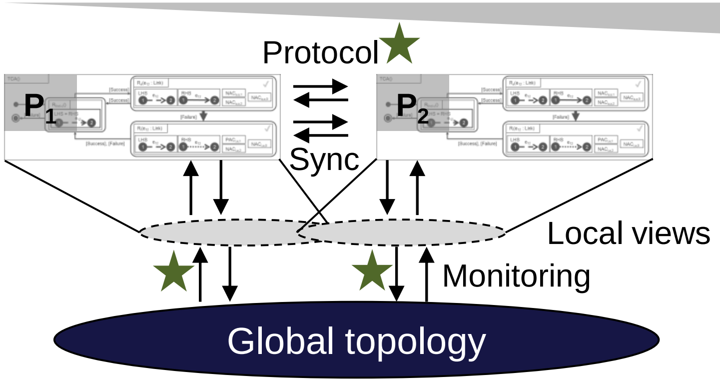
TC: sequential

Topology: global, consistent view



TC: **distributed**

Topology: local consistent view



Distributed-local perspective of TC:

TC: distributed

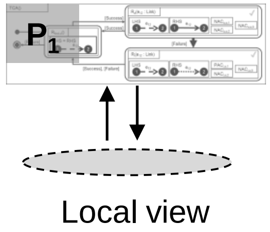
Topology: local, **inconsistent + monitoring**

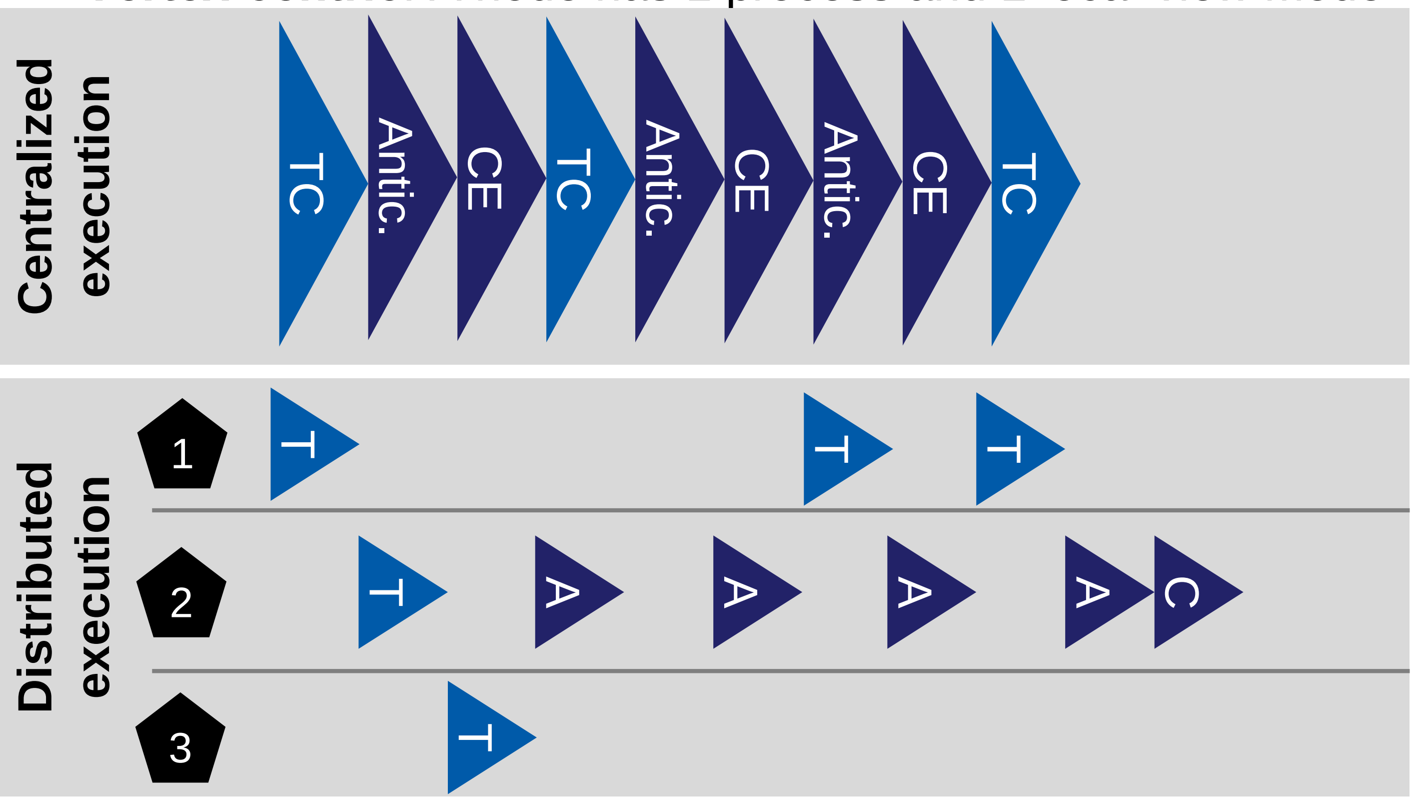
Spec. | Sim. | Test.

Computation model

Goal: Characterize concurrent execution + identify potential problems

- **Atomic actions**: rule applications and synchronized view of topology
- **Interleaved execution**: no two events at same point in time
- **Vertex-centric**: A node has 1 process and 1 local-view model

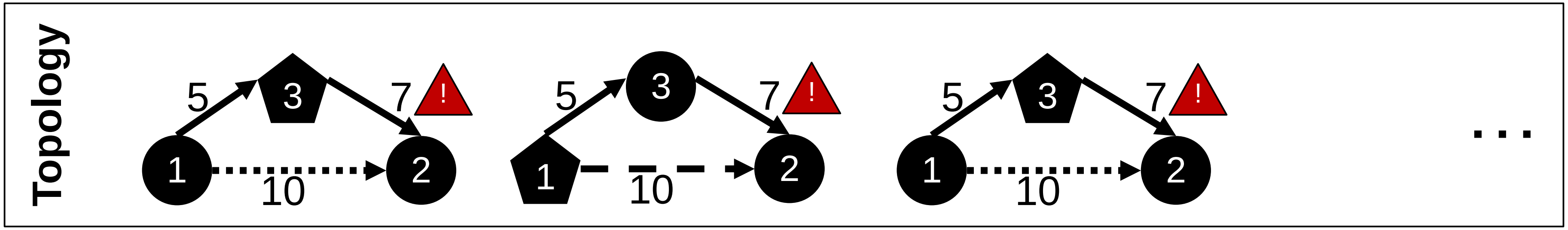


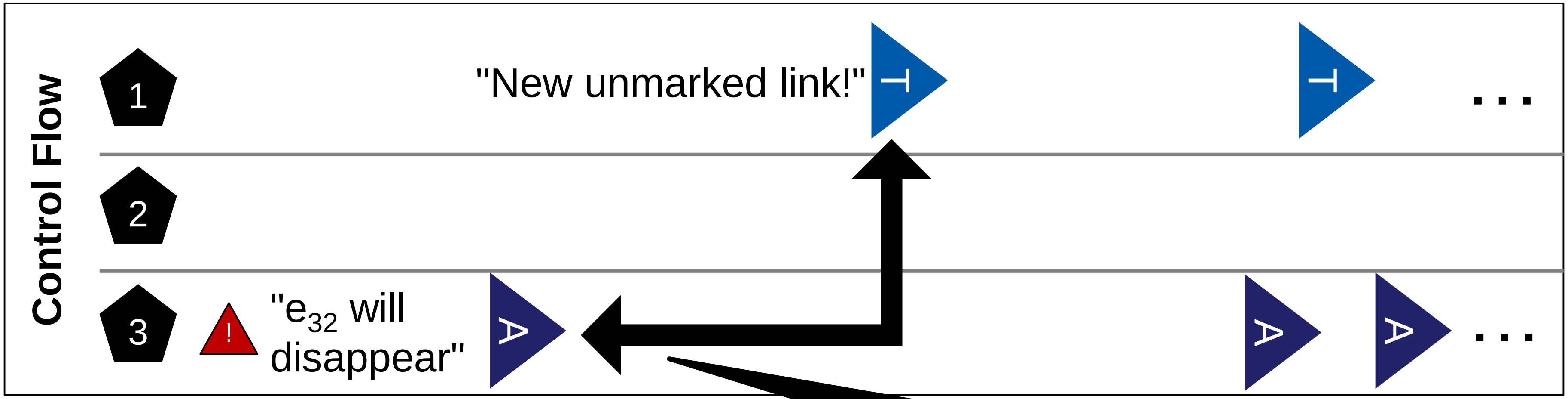


Global control flow

Per-node control flow ("happened-before")

Example: Non-termination of context handling





Liveness problem due to
Mutual dependency (**necessary**)
Return to same state (**sufficient**)

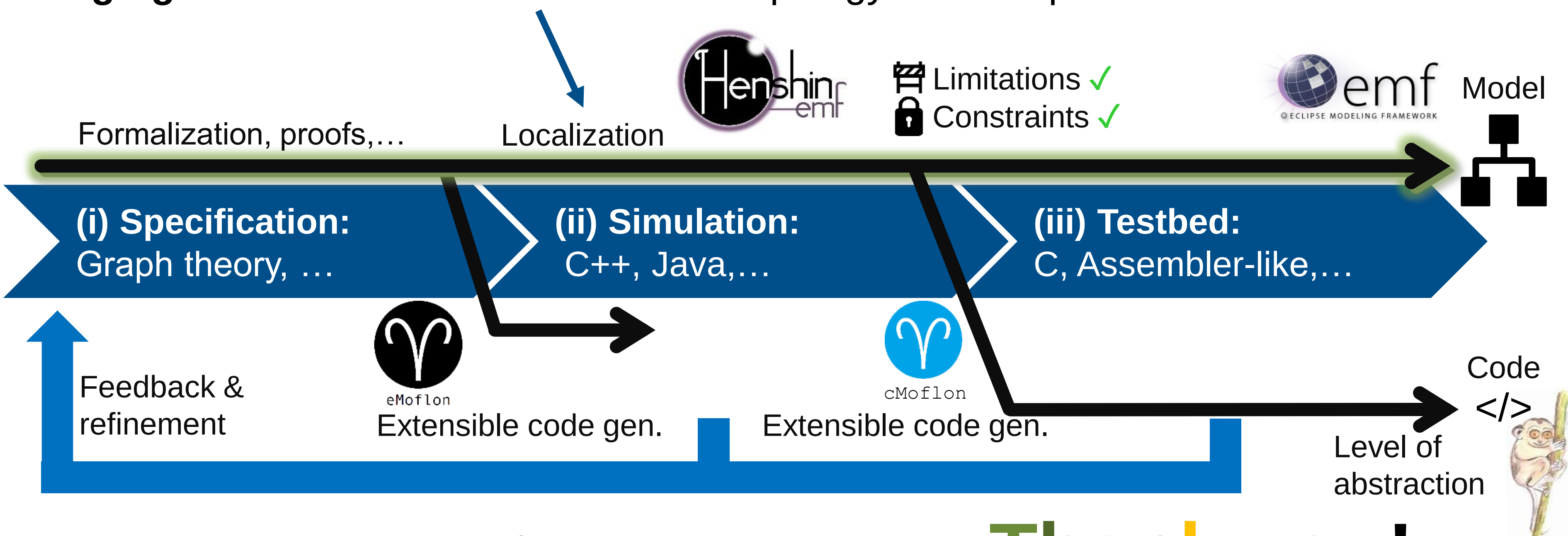
! Pending context event

Take-Home Messages

Goal: Overcome curse of low abstraction in dev. of topology adaptations

Result: Correct-by-construction development methodology TC algorithm families

Onging work: Toward distributed-local topology control specifications



Supplementary material on GitHub

Thank you!

References

- **eMoflon/cMoflon logos:** Work of the eMoflon developer team. Subject to Fair Use conditions.
- **Peerfact logo:** Multimedia Communications Lab (KOM), TU Darmstadt, https://www.kom.tu-darmstadt.de
- **Henshin logo:** https://www.eclipse.org/henshin/
- **EMF logo:** https://www.eclipse.org/modeling/emf/
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