https://refinery.tools

Refinery: Reasoning about modeling problems with partial models

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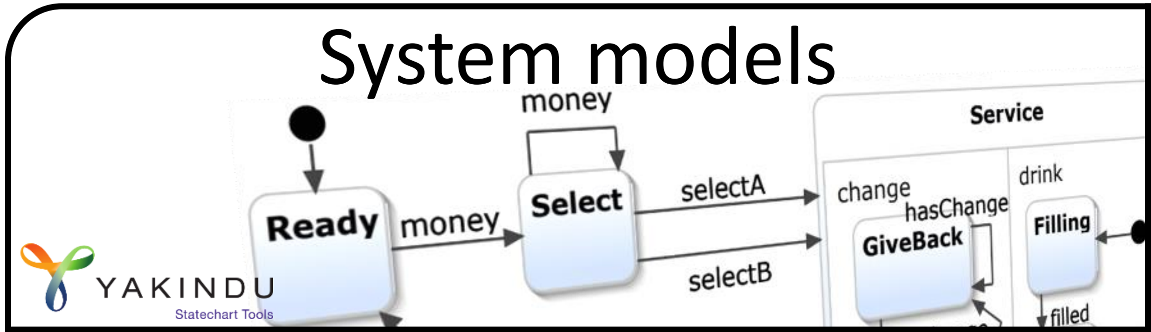
WASP WALLENBERG AI, AUTONOMOUS SYSTEMS AND SOFTWARE PROGRAM

amazon research awards

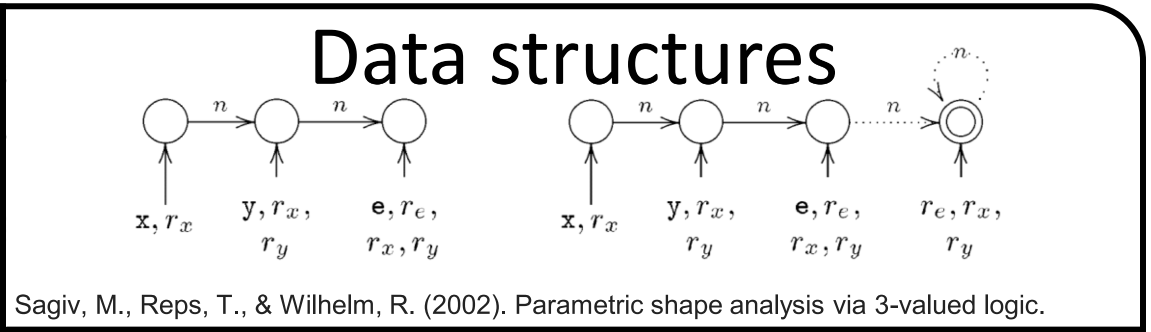
Office of Naval Research Science & Technology

Modeling with Graphs

- Graph based models are widely used in software engineering

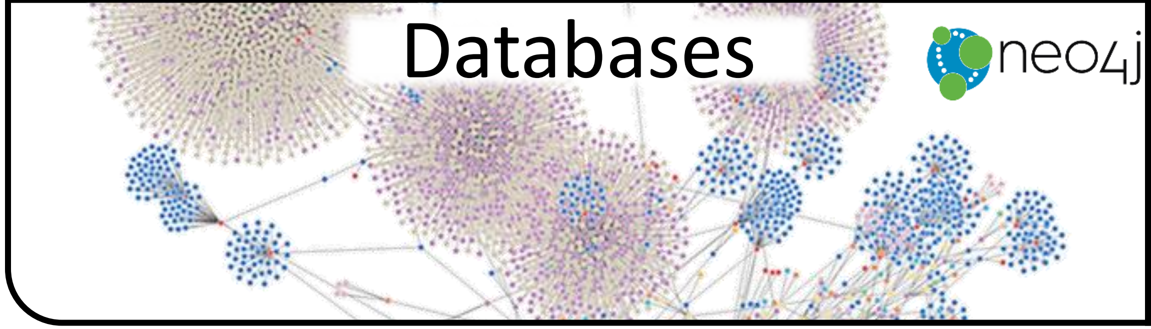


System models

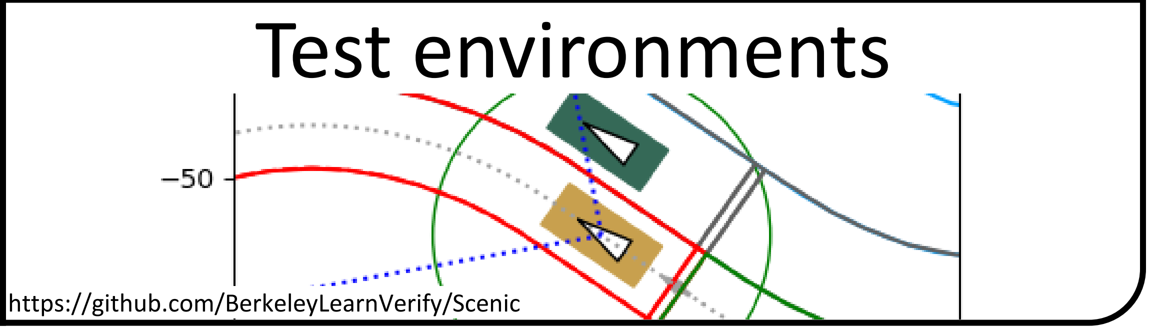


Data structures

Sagiv, M., Reps, T., & Wilhelm, R. (2002). Parametric shape analysis via 3-valued logic.



Databases



Test environments

https://github.com/BerkeleyLearnVerify/Scenic

- Testing, benchmarking or design space exploration scenarios

Generating **(consistent | realistic | diverse | scalable)** models

Hands-on demo

- Code examples available at https://refinery.tools/learn/tutorials/dlt/
- Watch out for numbered code examples!

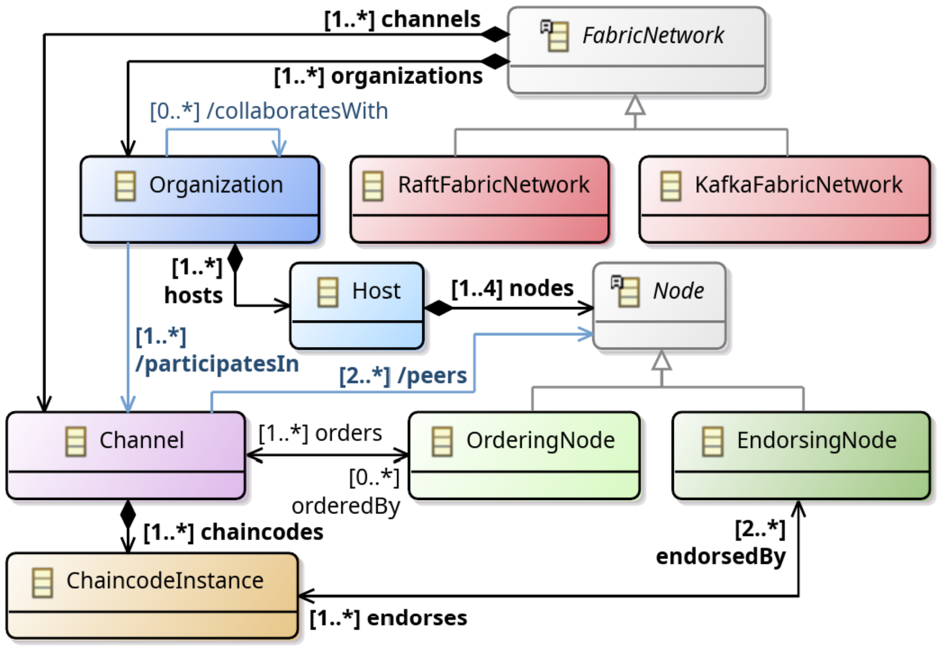
→ Example 1

Graph Structure: Hyperledger Architectures

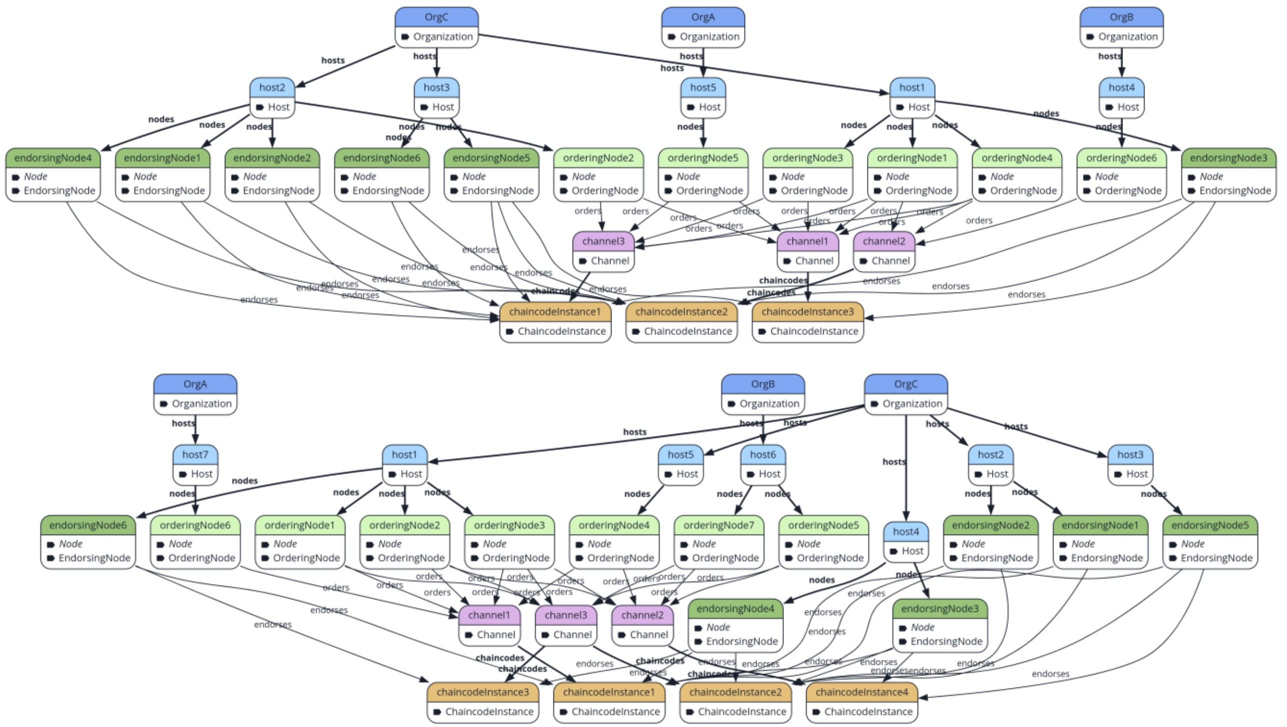
- Typical modeling workflow: **metamodel → instance model**
- **Example:** Organizations, nodes, and channels

→ Example 2

Metamodel



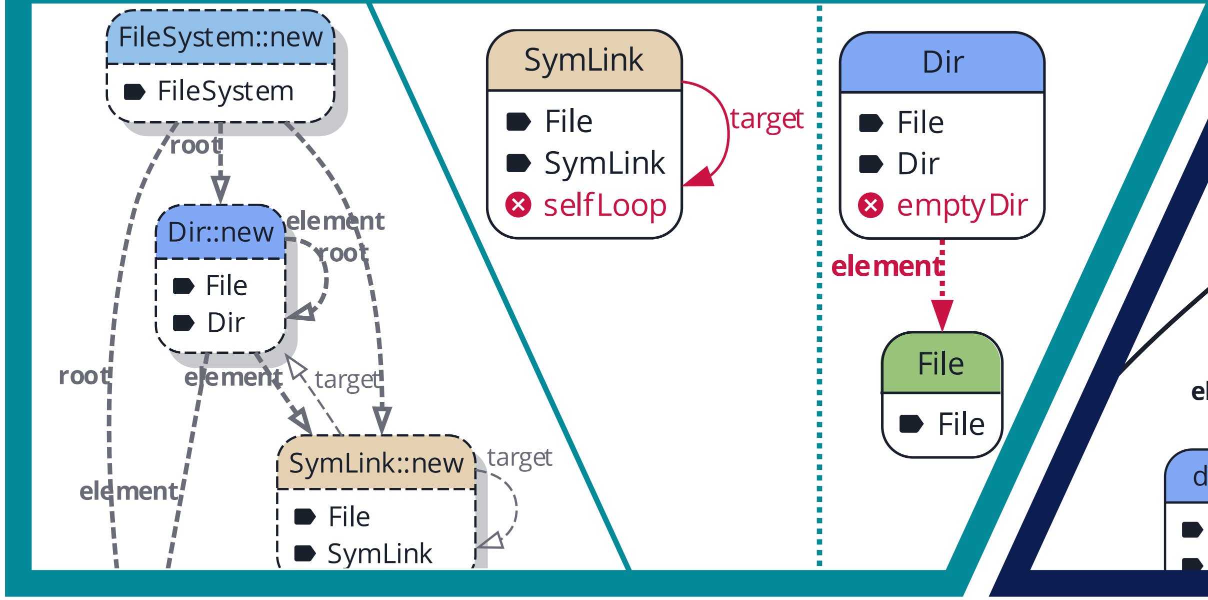
Instance Model



Models and Partial Models

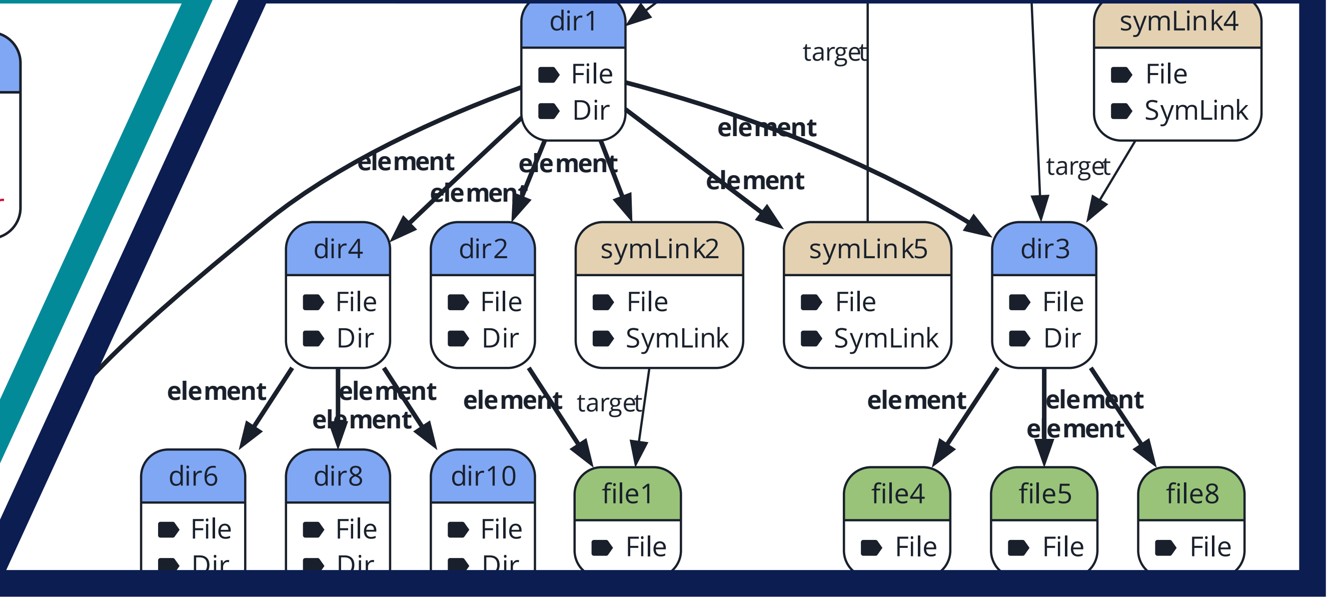
Input

Abstract models
(Metamodel + Constraints)



Output

Concrete models
(Labelled graphs)



Model generation: exploration process that gradually reduces uncertainty

Overview of the tutorial

Domain specification (metamodel)

- Define classes (nodes) and relations (edges)

4-valued partial model specification

- Seed partial model to extend (with reasoning)

Constraint specification

- Graph query language (inspired by Datalog / VIATRA Query)

Reasoning with propagation rules

- Derive new facts from the state of the knowledge base with custom rules

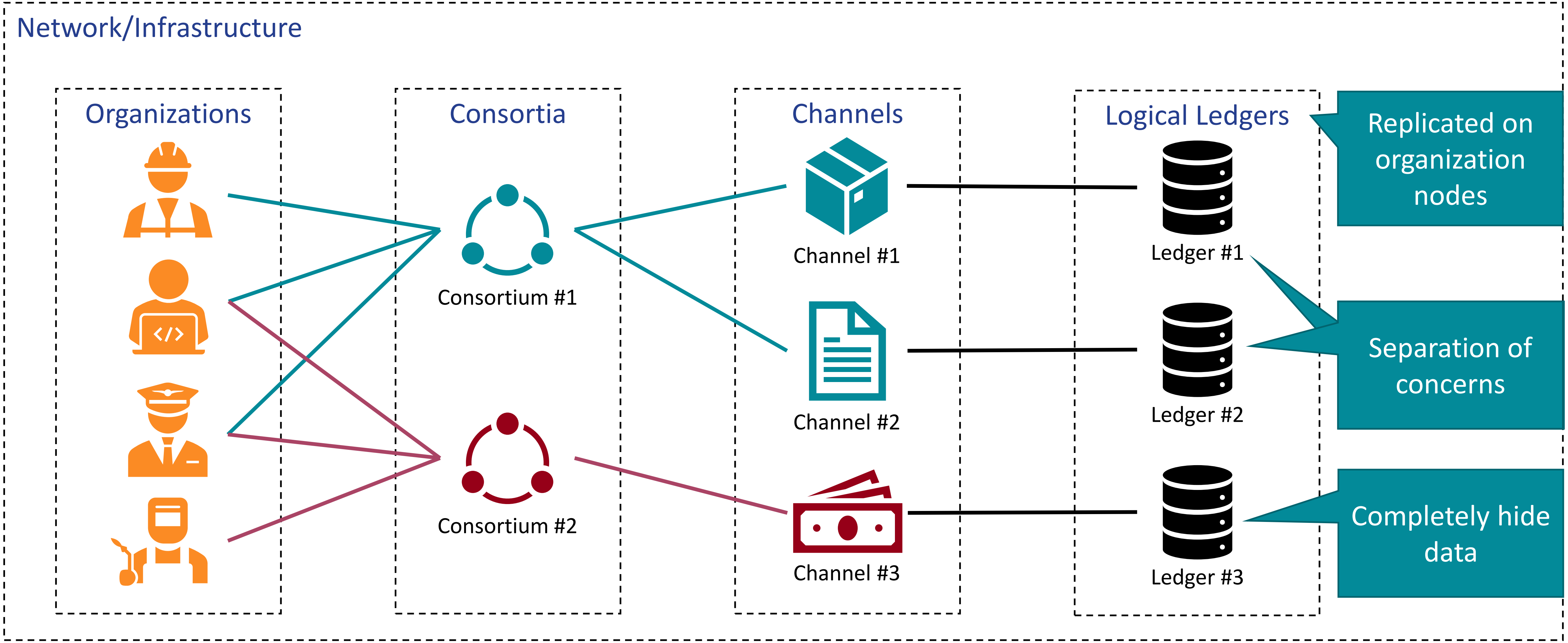
Case study

Architecture design for consortial Distributed Ledger Technology

One Network, Multiple Ledgers – Consortial DLT

HYPERLEDGER FABRIC

A Fabric network is a set of independently maintained ledgers.

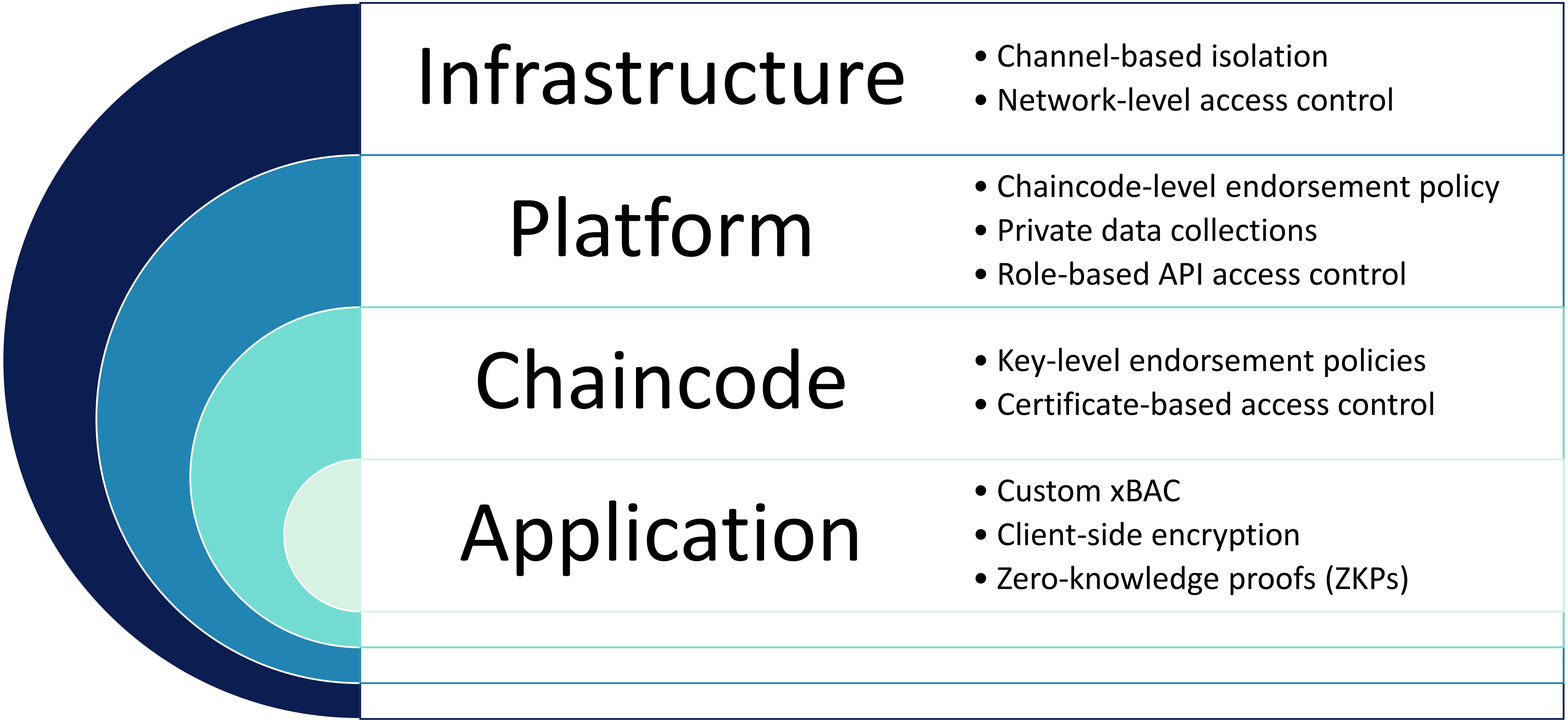


Replicated on organization nodes

Separation of concerns

Completely hide data

Engineered Privacy/Confidentiality in Fabric



Infrastructure

- Channel-based isolation
- Network-level access control

Platform

- Chaincode-level endorsement policy
- Private data collections
- Role-based API access control

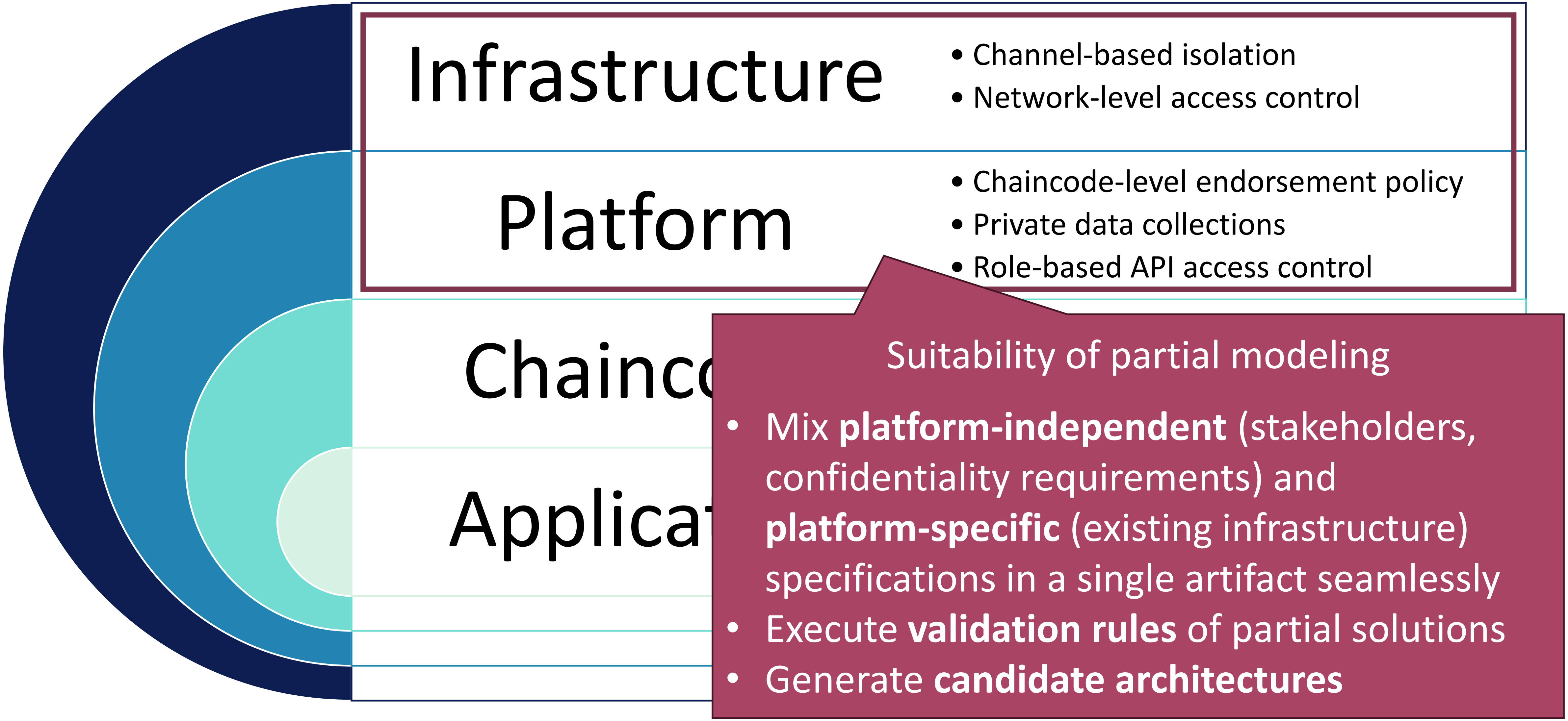
Chaincode

- Key-level endorsement policies
- Certificate-based access control

Application

- Custom xBAC
- Client-side encryption
- Zero-knowledge proofs (ZKPs)

Engineered Privacy/Confidentiality in Fabric



Infrastructure

- Channel-based isolation
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Platform

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- Private data collections
- Role-based API access control

Chainco

Applicat

Suitability of partial modeling

- Mix **platform-independent** (stakeholders, confidentiality requirements) and **platform-specific** (existing infrastructure) specifications in a single artifact seamlessly
- Execute **validation rules** of partial solutions
- Generate **candidate architectures**

Domain-specific partial models

4-valued logic for reasoning about graph models

Graph Structure: Hyperledger Architectures

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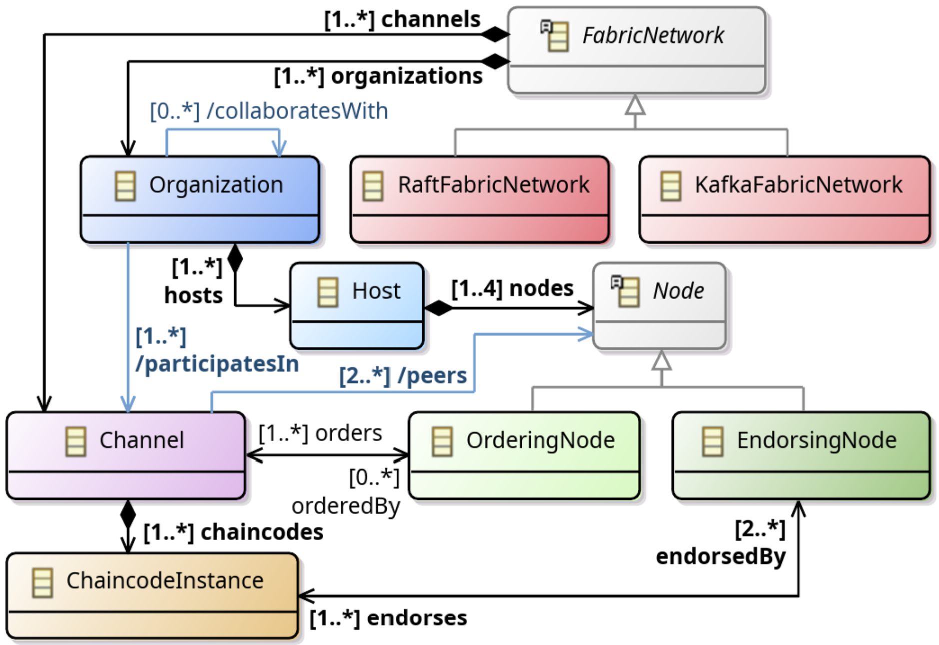
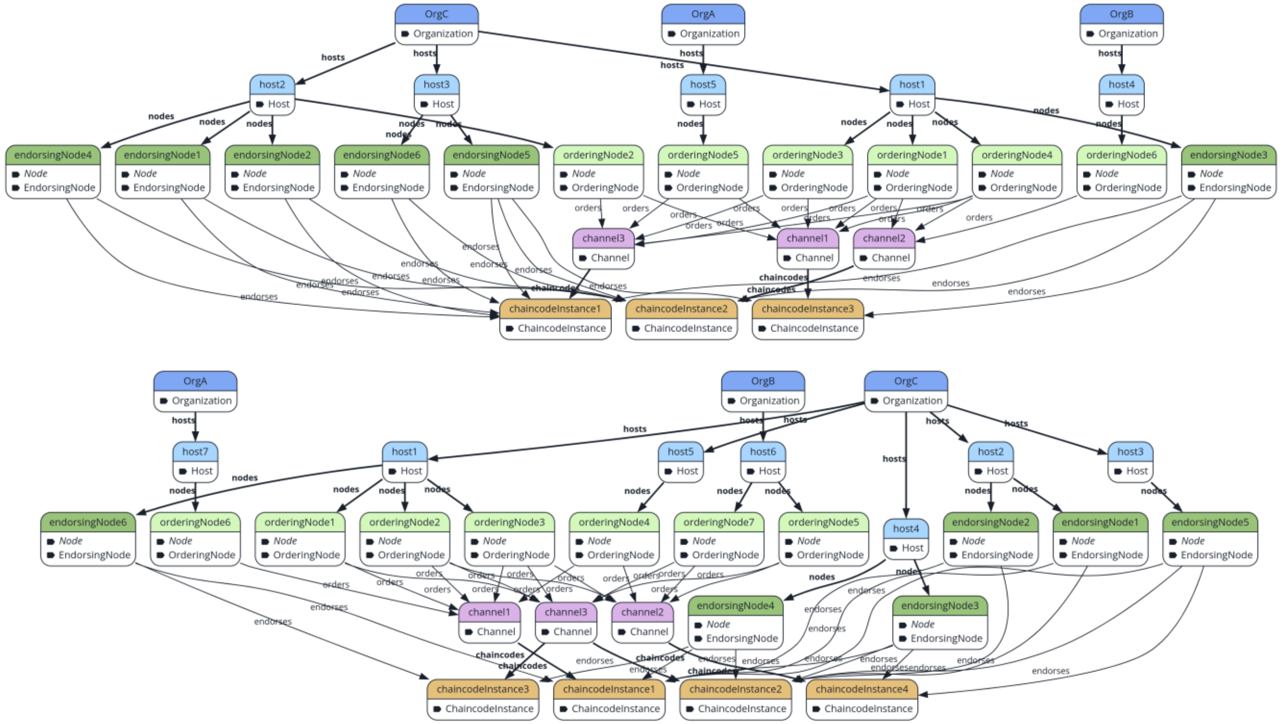
- **Example:** Organizations, nodes, and channels

→ Example 2

Metamodel



Instance Model



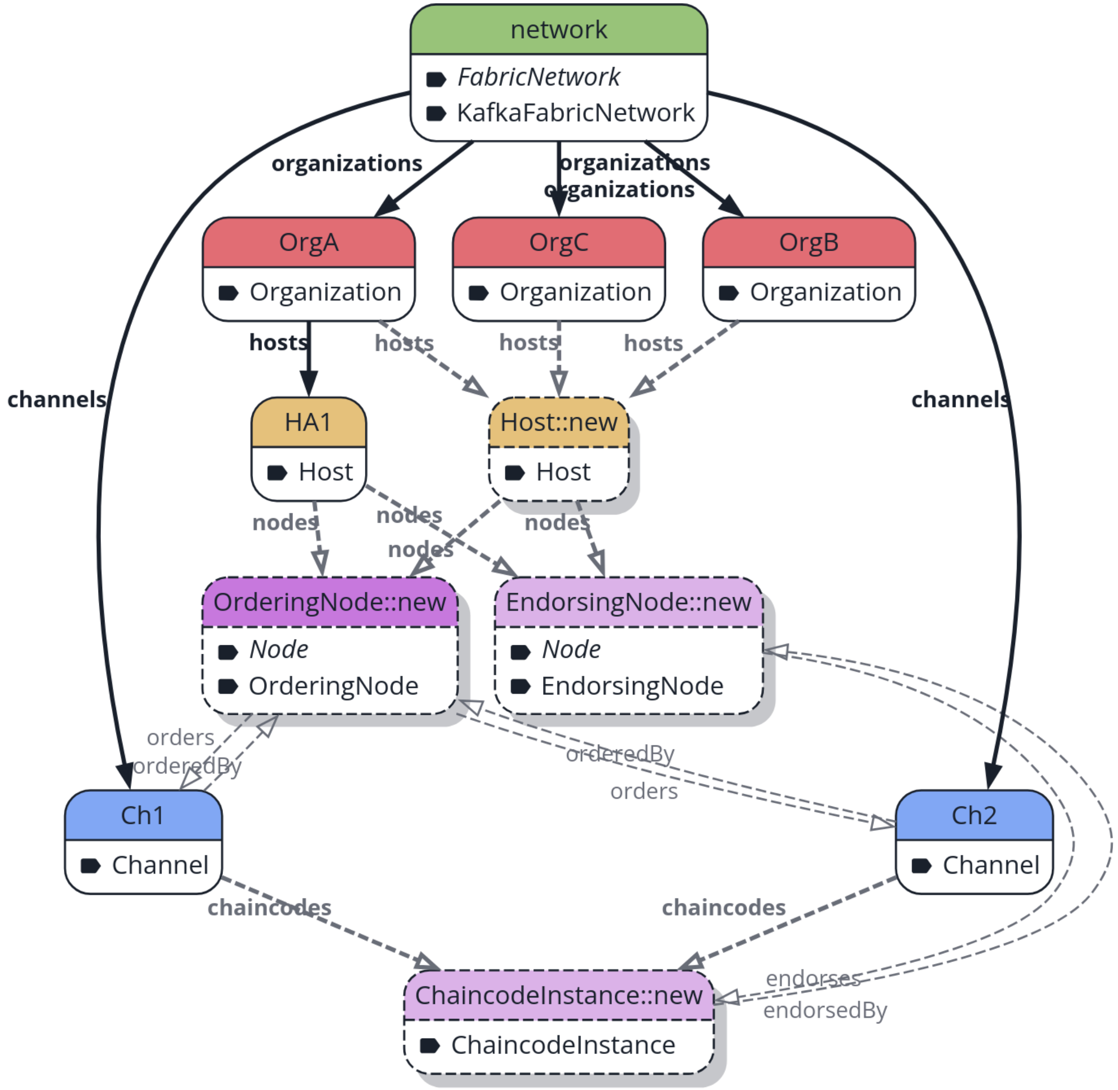
Partial Modeling with 4-valued Logic

- Represent all potential extensions with **uncertainty**
- Logic abstraction:

  ■TRUE | False |
  □Unknown | ⊗Error

  - 4-valued **exists**: added or removed
  - 4-valued **equals**: merging or splitting
- **Refinement:** reduces uncertainty → concrete models

→ Example 3



Partial Modeling with 4-valued Logic

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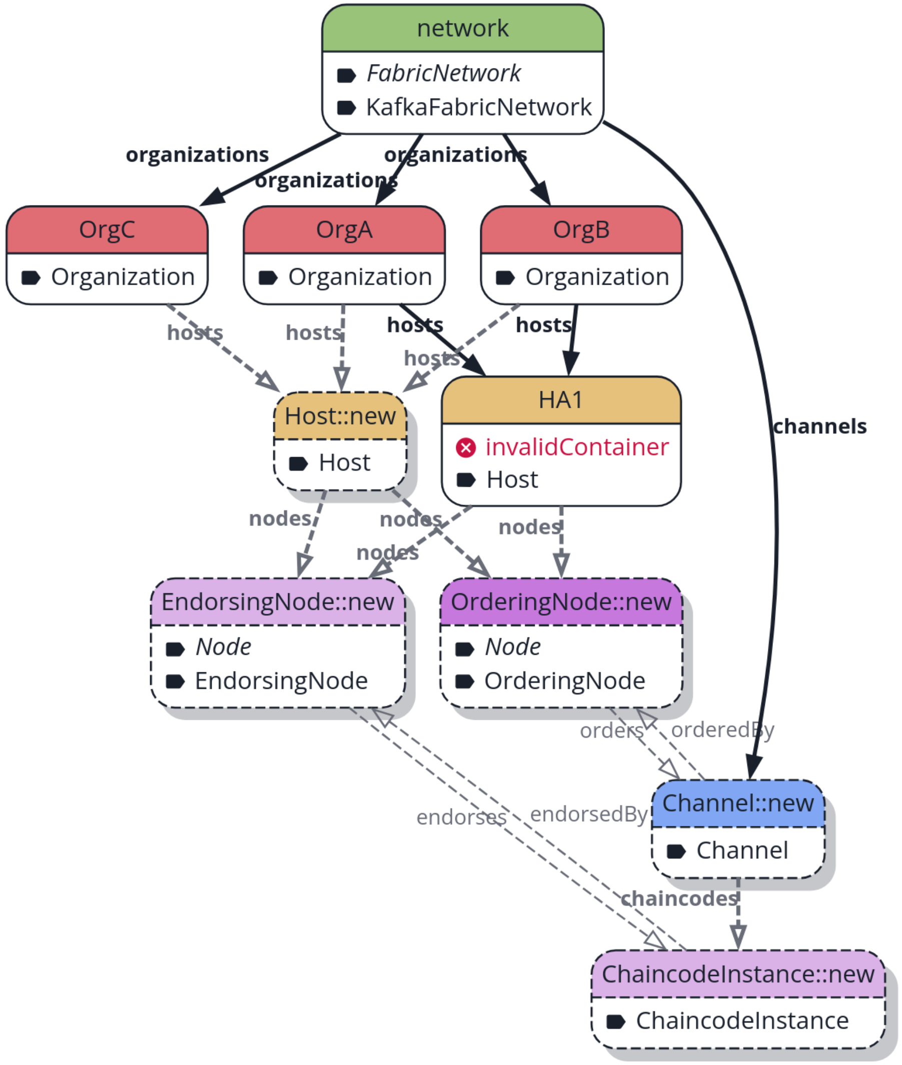
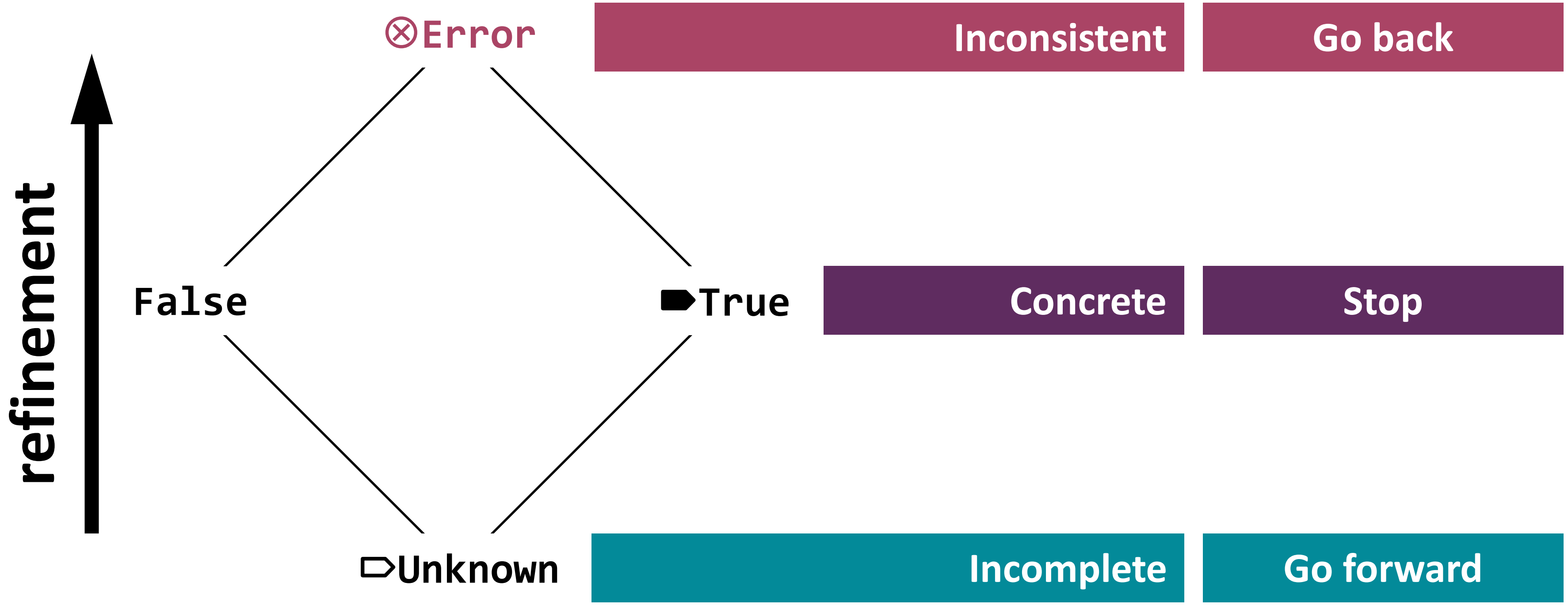
→ Example 4



Refinement: 4-valued Logic

- Model generation is executed with respect to model refinement



refinement

⊗Error

Inconsistent | Go back

False

■True

Concrete | Stop

□Unknown

Incomplete | Go forward

E.g.: $\texttt{person(\_,\_):}\mathbf{unknown} \xrightarrow{\texttt{+true}} \texttt{person(\_,\_):}\mathbf{true}$

$\texttt{person(\_,\_):}\mathbf{true} \xrightarrow{\texttt{+false}} \texttt{person(\_,\_):}\mathbf{error}$

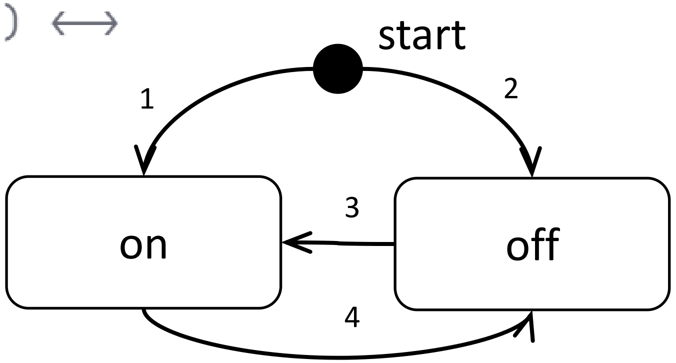
Constraint specification

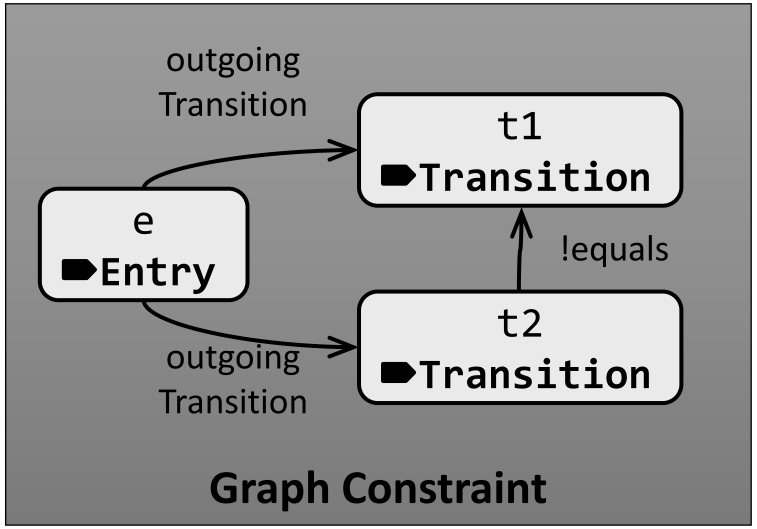
Using graph queries

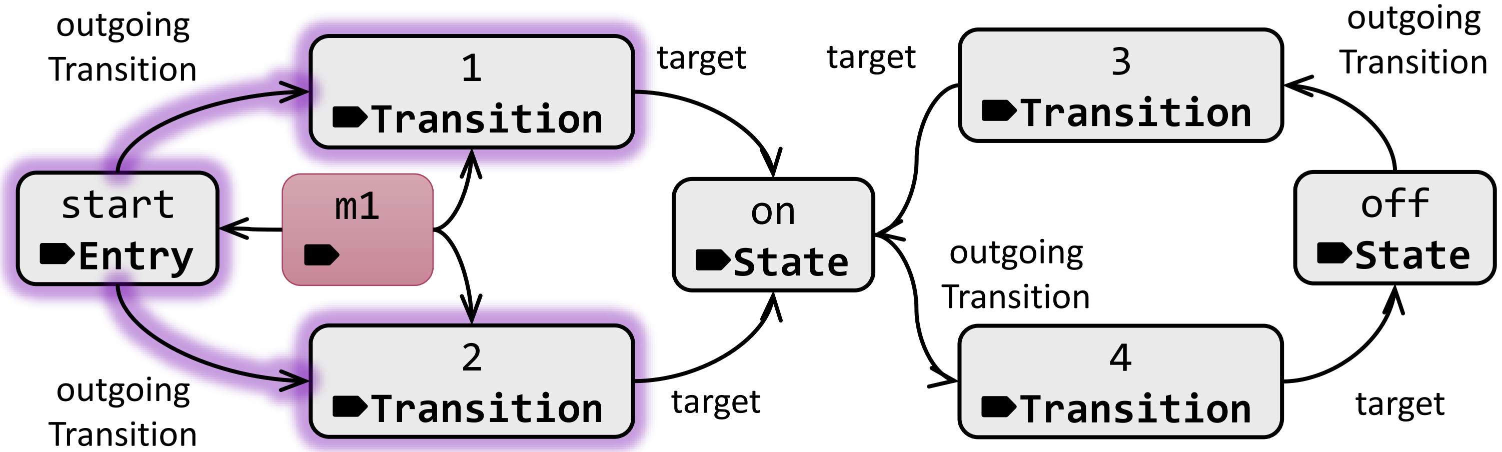
Graph Constraint Evaluation

→ Examples 5-7

```
error multipleTransitionFromEntry(Entry e, Transition t1, Transition t2) ⟷
    outgoingTransition(e, t1),
    outgoingTransition(e, t2),
    t1 ≠ t2.
```



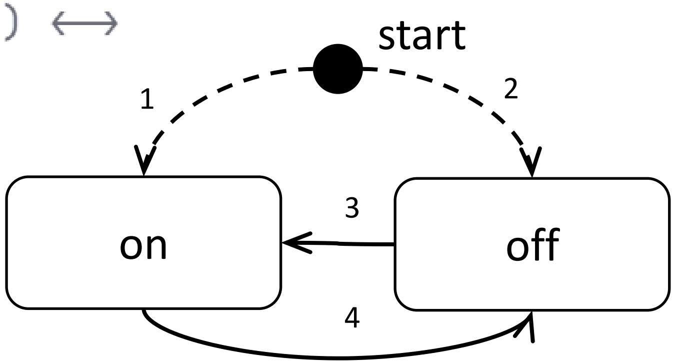


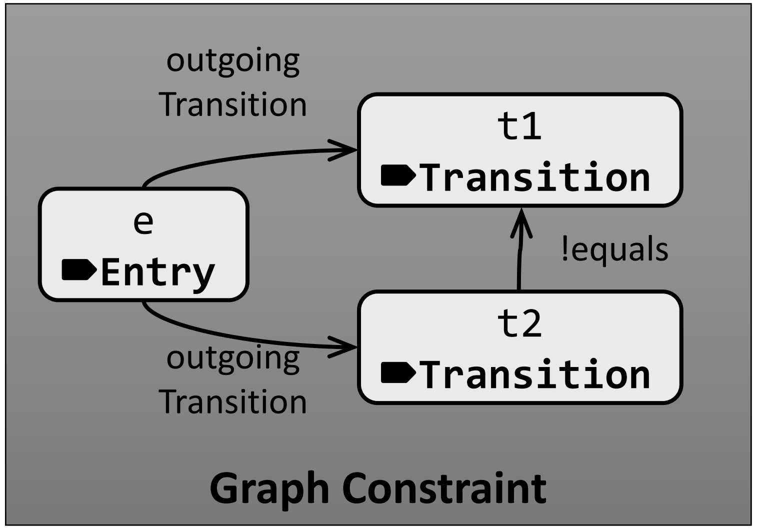


Each match of the query is a certain constraint violation (an error)

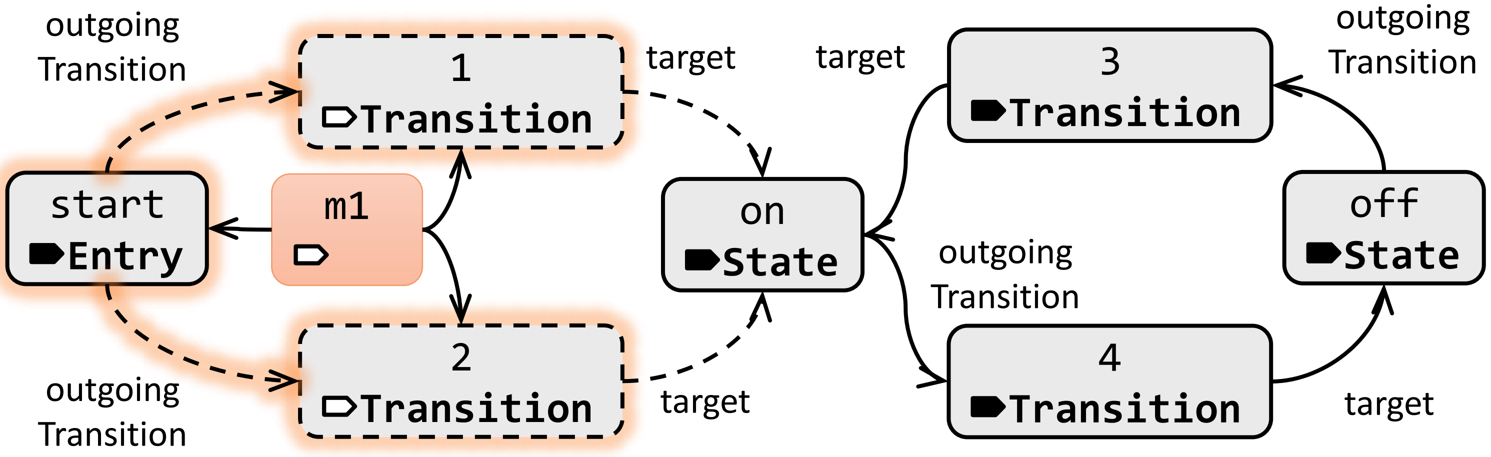
Partial Graph Constraint Evaluation

```
error multipleTransitionFromEntry(Entry e, Transition t1, Transition t2) ⟷
    outgoingTransition(e, t1),
    outgoingTransition(e, t2),
    t1 ≠ t2.
```





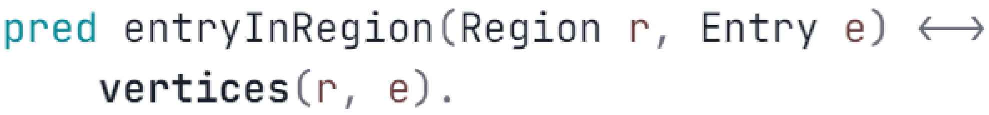
Graph Constraint



A may-match of a query is a *potential* error (which may disappear)

Predicates vs Constraints

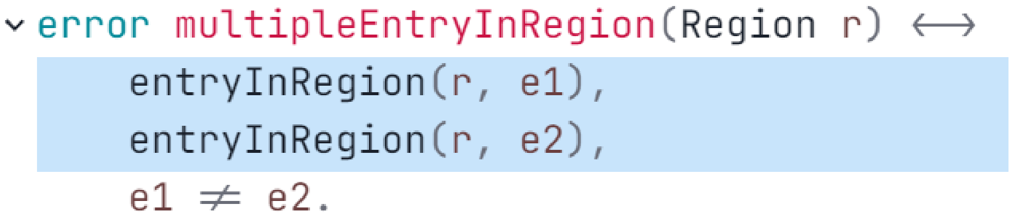
→ Example 8



```
pred entryInRegion(Region r, Entry e) ⟷
    vertices(r, e).
```

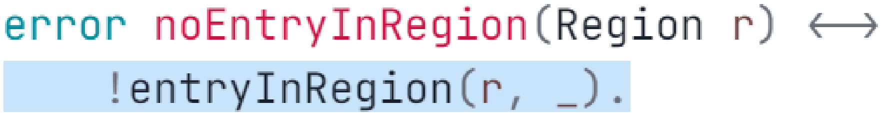
Predicates

- A graph query / predicate
- Composable: Reusable in other predicates or constraints
- Positive condition

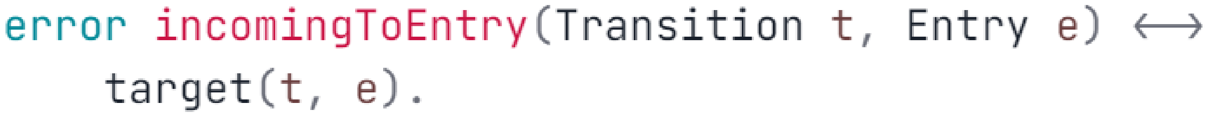


```
error multipleEntryInRegion(Region r) ⟷
    entryInRegion(r, e1),
    entryInRegion(r, e2),
    e1 ≠ e2.
```

- Negative condition



```
error noEntryInRegion(Region r) ⟷
    !entryInRegion(r, _).
```



```
error incomingToEntry(Transition t, Entry e) ⟷
    target(t, e).
```

Constraints (Error patterns)

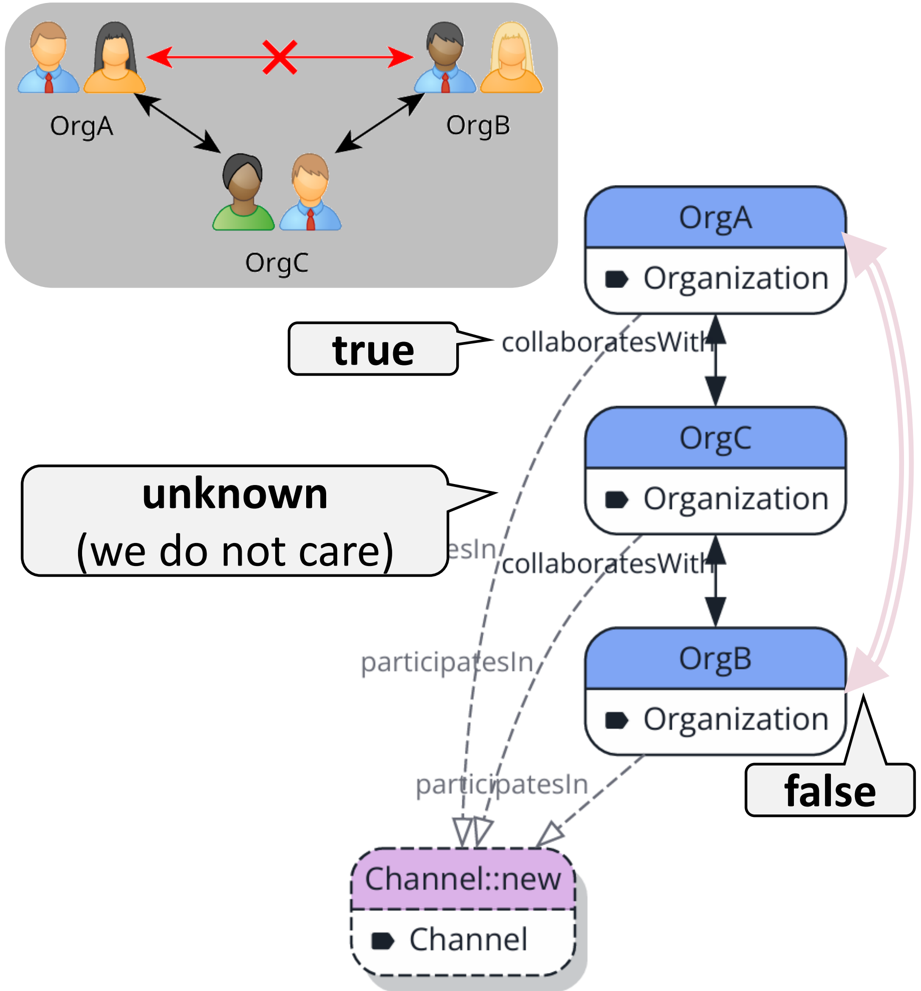
- Capture the violating cases of a domain constraint
- Each match is an error (inconsistency)
- Constraints vs. Types
  - 1-parameter constraint: special *node* type
  - 2-parameter constraint: special *edge* type

Capturing functional requirements as Partial Models

- Requirements = assertions about the architecture

> *"**C** must communicate with **A** and **B**,*
> *but **A** and **B** cannot communicate"*

- Encode **families** of requirements by graph predicates
  - Requirements that should hold everywhere *(characteristics of the DLT platform):* **error** patterns
  - Requirements for specific model elements *(functional requirements raised by stakeholders):* logical **assertions** about predicates

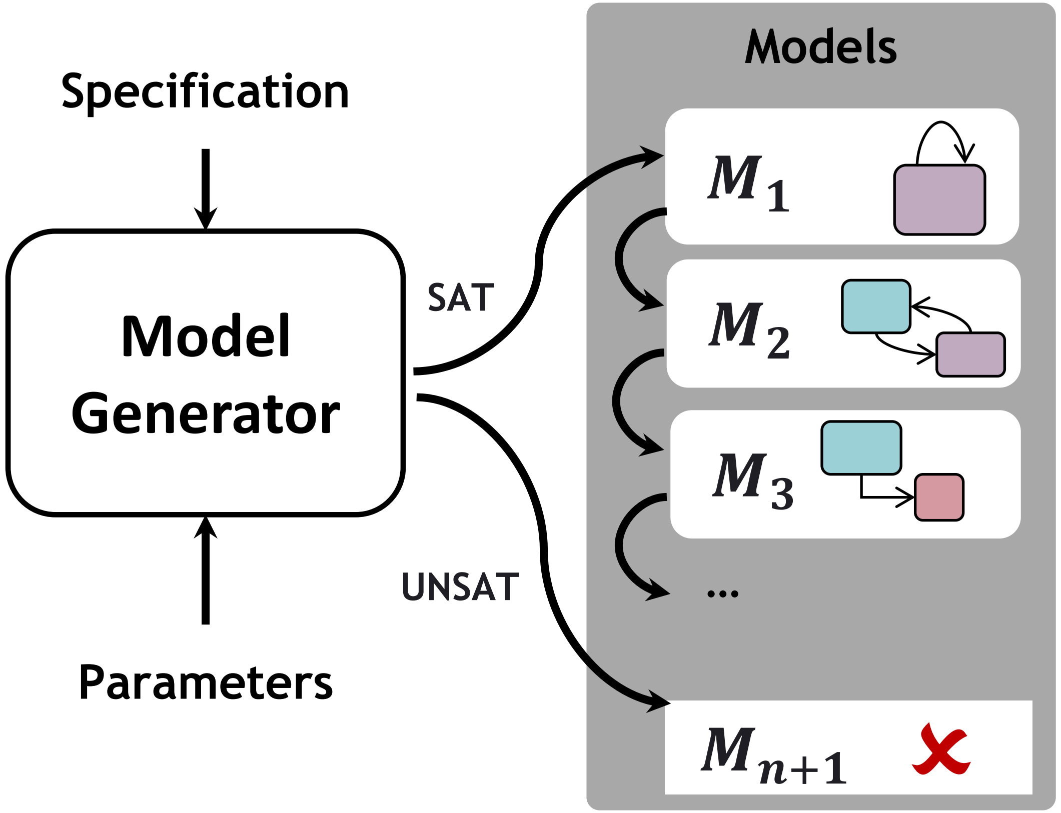


Consistent Graph Generation

→ Example 9

Architecture of a generator:

- **Input:** Problem Specification
  Defines the structure of the models
  Defines the consistency constraints
  Defines an initial model fragment
- **Input:** Search Parameters
  Configures the generation process
- **Output:** Models
  Sequence of consistent models
- **Output:** Inconsistency
  Proving that there are no such consistent model



Search Parameters for Model Generation

- Constraints are continuously reevaluated
- Automatically searching for valid models by applying refinements
- Search is parametrized
  - Number of different solutions
  - Difference between the solutions (non-isomorphic)
  - Random seed
- Scope: *”size of the models”*

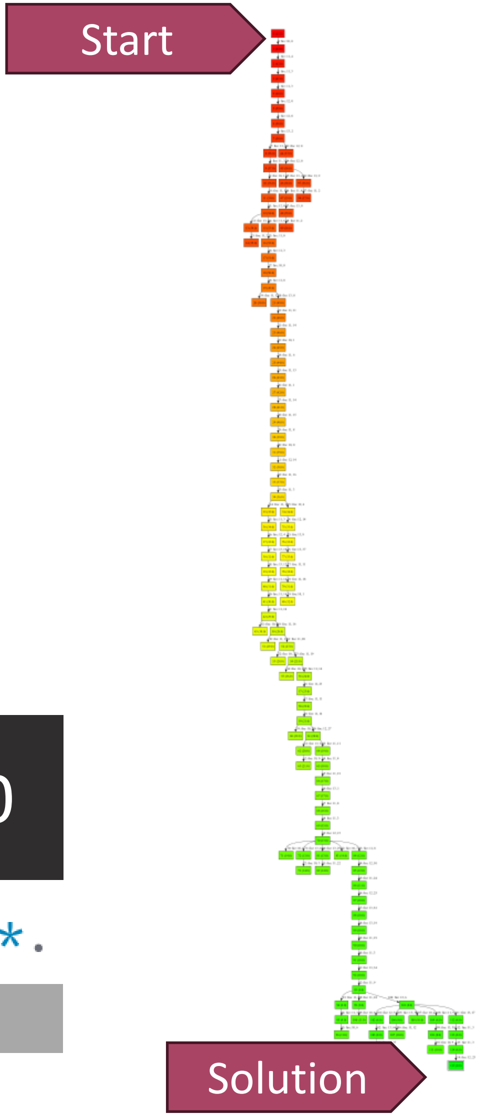
→ Example 10

```
scope node = 15..60, Node = 8..30, FabricNetwork = 1, Channel += 3..*.
```

# of nodes

nodes by type

# of new objects



Propagation rules

Reasoning with partial models

Propagation rules

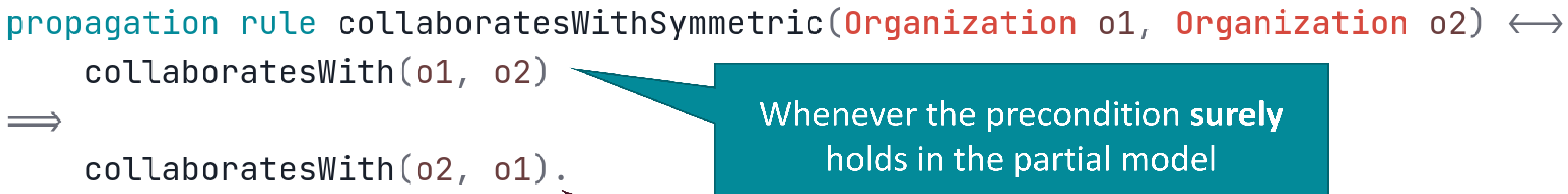
- Deduce **new facts** from the existing knowledge base
- **Preserves** all possible **consistent refinements**
- Fired until **fixed point**
- Firing a single activation **disables** it

Decision rules

- **Branching points** in the search for consistent refinements
- **Reduces uncertainty** by excluding some refinements
- Single decision activation is fired before executing propagation
- Not always self-disabling

Propagation rules

→ Examples 11-13



```
propagation rule collaboratesWithSymmetric(Organization o1, Organization o2) ⟷
    collaboratesWith(o1, o2)
⟹
    collaboratesWith(o2, o1).
```

Whenever the precondition **surely** holds in the partial model

And the postcondition is **not yet** part of the partial model

Add the postcondition to the partial model

- Only valid if the precondition is **logically implied** by the postcondition
- Add implications not automatically discovered by Refinery as propagation rules to improve **reasoning power**

Advanced propagation

→ Examples 14-15

- **Shadow predicates:** lightweight graph patterns with “forward-only” reasoning

```
shadow pred endorsesChaincode(EndorsingNode n, Channel c, ChaincodeInstance i) ⟷
    chaincodes(c, i), endorses(n, i).

shadow pred endorsesMultipleChaincodes(EndorsingNode n, Channel c) ⟷
    endorsesChaincode(n, c, i1), endorsesChaincode(n, c, i2), i1 ≠ i2.
```

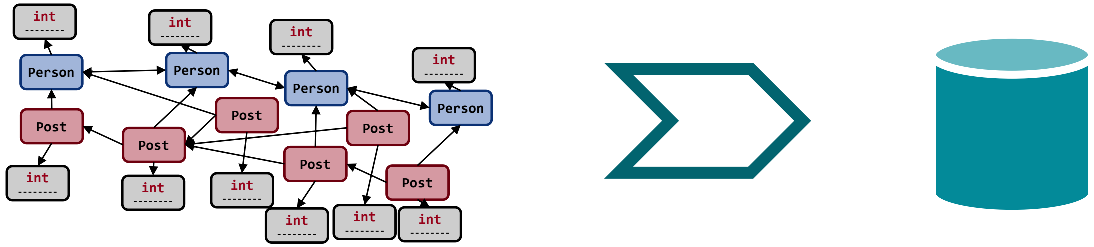
- **Modal operators** in preconditions and shadow predicates

```
propagation rule mustEndorse(EndorsingNode n, ChaincodeInstance i) ⟷
    peer(n, c), !endorsesMultipleChaincodes(n, c), chaincodes(c, i),
    may endorses(n, i)
⟹
    endorses(n, i).
```

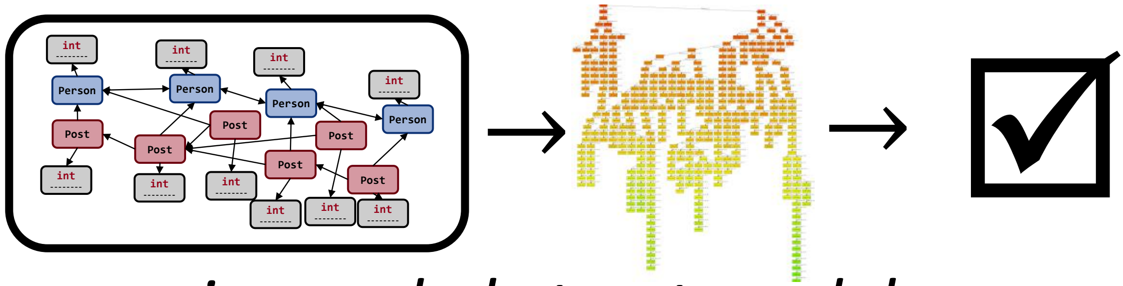
Matches if `endorses(n, i)` is either **true** or **unknown**

The Refinery framework

- **Management:** *store/compare multiple versions of (abstract) models*



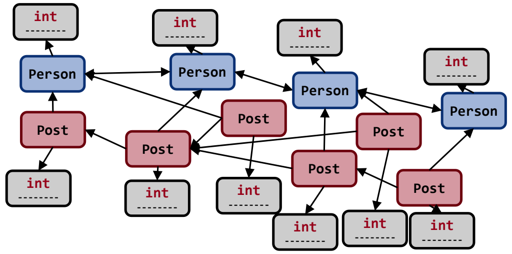
- **Exploration:** *transformation and optimization of models*



- **Reasoning:** *logic reasoning and abstract model concretization*

invalidTime(*p1*,*p2*)↔
 target(*p2*,*p1*)∧target(*p1*,*t1*)
 ∧ created(*p2*,*t2*)∧ (*t2*≤*t1*)

→

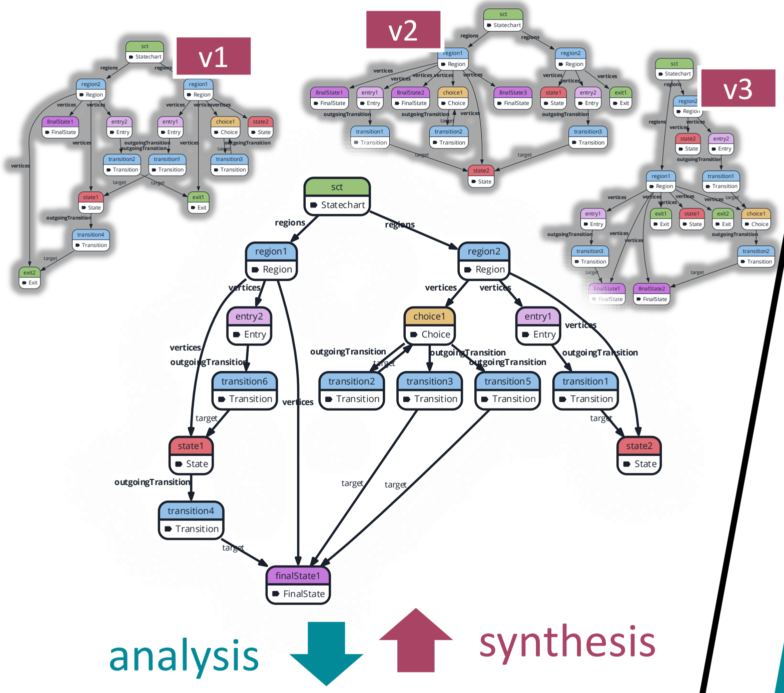


Refinery elsewhere

Applications & appearances

Graph analysis and synthesis

- Powerful mathematical **analysis techniques** for models
- Novel graph-based logic solver for the **automated synthesis** of design alternatives
- **Precision + Scalability**
- **Goal:** solve problems with complex structure



☒ ☑ validation

$$$ cost

◢◢ performance

%% coverage

Recent Results

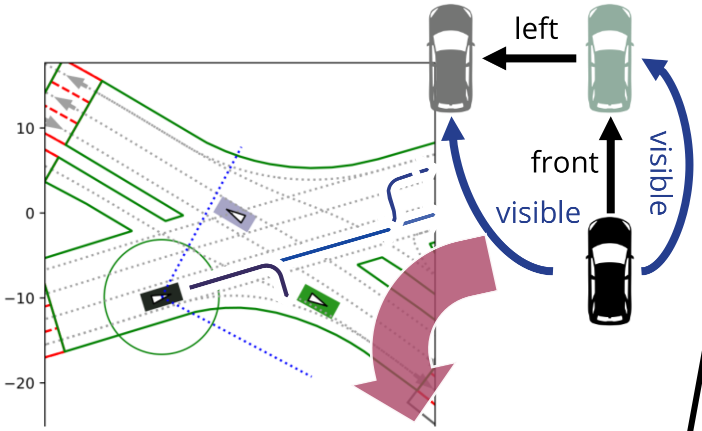
- Research project

VERIFIABLE AI/ML TECHNIQUES FOR PNT APPLICATIONS

esa

Verification/Testing of AI/ML Applications

- AI applications are **data-oriented** systems
- **Complex, dynamic** environment
- Novel **generation** + Advanced **simulators**
  → Diverse **tests**
- Systematic testing of **AI applications**



Recent Results

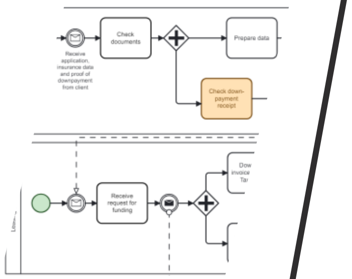
- R&D project with Knorr-Bremse
- Research project with USA Navy

Office of Naval Research Global

Advancing DLT applications

- **Hungarian Blockchain Coalition**
  - Prof. Pataricza – member of the board
  - I. Kocsis: Education WG lead, L. Gönczy: FinTech WG
- **Supporting the EMAP project (PM/NAV)**
  - "Even-based Data-sharing Platform" pilot
  - Employer data provisions: event-based, single-channel
  - Blockchain-based implementation in preparation
- **CBDC research cooperation with MNB**
  - Mapping out: blockchain ↔ Central Bank Digital Currency
  - Payment, car leasing, energy support, industrial cooperation
  - Currently: "ecosystem" research
- **EDGE-Skills: data veracity in EU data spaces**
  - Blockchain-backed Verifiable Credentials

BLOCKCHAIN Koalíció


Receive application, insurance data and proof of downpayment from client
Check documents
Prepare data
Check down-payment receipt
Receive request for funding
Dow invoice Ta

Recent results

Energy price support CBDC prototype: BIS Rosalind finalist

Fabric ↔ Ethereum CBDC bridge in Hyperledger Cacti

Smart gas meters and readings – in production

Refinery@MODELS2024

- Friday 14:30 (FAME) – *Refinery hands-on session*
- Sunday 16:00 (Super Mario Bros)
  T9: Refinery: Logic-based partial modeling
- Wednesday 15:24 (HS7 – Applications 1)
  Ulf Kargén, Dániel Varró. Towards Automated Test Scenario Generation for Assuring COLREGs Compliance of Autonomous Surface Vehicles
  - Find inconsistencies in maritime traffic rules with partial modeling
- Thursday 15:45 (HS1 – MDE&AI)
  José Antonio Hernández López, Máté Földiák, Dániel Varró. Text2VQL: Teaching a Model Query Language to Open-Source Language Models with ChatGPT
  - Generate graph models to verify graph queries generated by Large Language Models
- Thursday 15:45 (HS7 – Applications 2)
  Noor Al-Gburi, András Földvári, Kristóf Marussy, Oszkár Semeráth, Imre Kocsis. Requirement-Driven Generation of Distributed Ledger Architectures
  - Generate architectures for consortial blockchain systems

Further Information

Specification language

- K. Marussy, O. Semeráth, A. Babikian, D. Varró: A Specification Language for Consistent Model Generation based on Partial Models. J. Object Technol. 19(3): 3:1-22 (2020)

Consistent graph generation techniques

- O. Semeráth, A. Nagy, D. Varró: A graph solver for the automated generation of consistent domain-specific models. ICSE 2018: 969-980
- K. Marussy, O. Semeráth, D. Varró: Automated Generation of Consistent Graph Models With Multiplicity Reasoning. IEEE Trans. Software Eng. 48(5): 1610-1629 (2022)
- A.. Babikian, O. Semeráth, A. Li, K. Marussy, D. Varró: Automated generation of consistent models using qualitative abstractions and exploration strategies. Softw. Syst. Model. 21(5): 1763-1787 (2022)

Diverse and realistic graph generation

- O. Semeráth, R. Farkas, G. Bergmann, D. Varró: Diversity of graph models and graph generators in mutation testing. Int. J. Softw. Tools Technol. Transf. 22(1): 57-78 (2020)
- O. Semeráth, A. Babikian, B. Chen, C. Li, K. Marussy, G. Szárnyas, D. Varró: Automated generation of consistent, diverse and structurally realistic graph models. Softw. Syst. Model. 20(5): 1713-1734 (2021)

Correctness proofs

- D. Varró, O. Semeráth, G. Szárnyas, Á. Horváth: Towards the Automated Generation of Consistent, Diverse, Scalable and Realistic Graph Models. Graph Transformation, Specifications, and Nets 2018: 285-312

Summary

- **Logic reasoning** and **model generation** over graphs
- **Web-based editor:**
  - **Live editing** and **feedback**
  - Support for partial models and graph constraints
- **Containerized execution:**
  - Continuously deployed at https://refinery.services
  - Available as **Docker image**: https://refinery.tools/learn/docker/
- **Open-source project:** https://refinery.tools

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