# Reflecting on the past and the present with temporal graph-based models

A. García-Domínguez, N. Bencomo, Luis H. García Paucar

MRT'18, 14 October 2018

# Motivation

# Gaining trust on a self-adaptive system (SAS)

**Emergent behaviour in self-adaptive systems**

- Self-adaptive systems build a model of how their part of the world works, and how they can best meet their goals
- This results in emergent behaviour: it may be correct and meet the goals, but it could seem not immediately “obvious” to users or even developers

**Good self-explanation is needed**

- Developers can use it to debug the system and check if it meets certain safety criteria
- Users can ask questions and gain more confidence about why the SAS did something at a certain moment

# Reflection in self-adaptive systems

**Natural "compression" in most systems**

- Many SAS work by building a neural network / Bayesian network / other model from observations and decisions.
- In a way, this packs the history of the system into knowledge, but it may be "lossy", i.e. impossible to retrieve the original system state.
- It may be based on uncertain information: what if we kept track of how uncertain it was?
- What if we could look back at an explicit history of the system?

**Adding reflective capabilities to systems**

- What could we do if the system could ask explicit questions about its own past behaviour and its consequences?
- Could we make the system make better decisions?
- Could we make the system make more understandable decisions?

# Types of traces

**Traditional approach: textual output as we go along**

- Plain logging framework, just printing whatever we decide
- Easy to implement, easy for devs to read — hard to parse!

**Better: structured traces**

- Generate an XML/JSON snapshot of system state by timeslice
- Slightly more work, but computer-friendly
- What about history, though?

**We want trace models that are...**

- Based on a complete and reusable metamodel
- Stored in a way that allows "travelling in time"
- Answering questions about system history concisely
- Presenting answers in an accesible way

# Proposal

# Problem-independent trace models

**Many self-adaptive systems...**

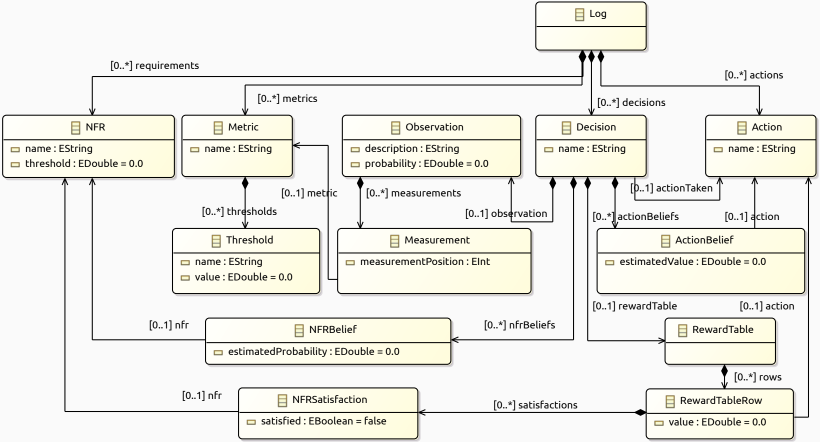
- Quantize time into *slices*
- Make observations and analyse them
- Plan future behaviour
- Execute plans

This is common in those based on the MAPE-K architecture.

**Can we define a domain-specific language for their state of mind?**

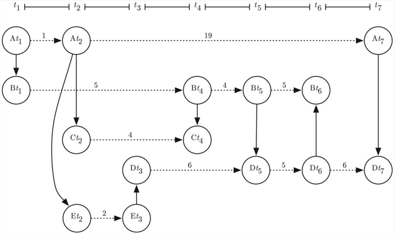
- We have a first version
- So far, tried it only on one SAS, though
- See next slide!

# Problem-independent trace metamodel

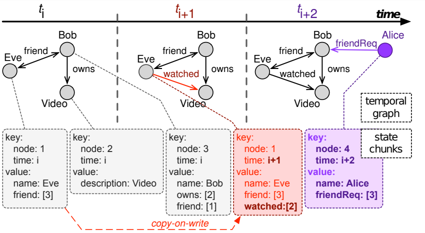


The SAS is trying to achieve NFRs by making a Decision among several Actions, guided by Observations of certain Metrics.

# What is a temporal graph?



Contact sequence (Kostakos)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copy-on-write

Efficient storage (Hartmann)

## Conflicting definitions

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- Hartmann focuses on efficient storage of a versioned graph

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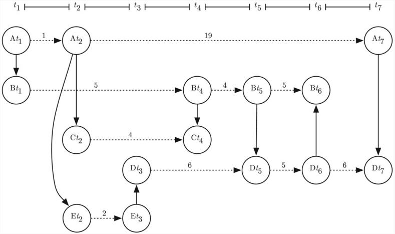

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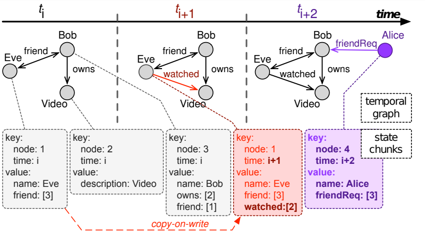

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## In this paper...

We use the vision of temporal graphs from Hartmann, in its Greycat TGDB implementation.

# Transparent temporal graph storage

### Object-oriented models are time-evolving graphs

- Objects = nodes (labelled by type)
- References = edges
- Nodes and edges have attributes (object/reference fields)
- Overall: model = *labelled attributed graph* that evolves over time

### Hawk + Greycat: our implementation

- Hawk is our open-source heterogeneous model indexing framework: `https://github.com/mondo-project/mondo-hawk`
- Watches over the models and mirrors all history into a Greycat temporal graph, applying changes incrementally
- SAS models can be used as-is if based on EMF

# Reusable time-aware query language

**So far...**

- We have a representation of our SAS' state of mind
- We keep track of the full history of this representation
- We want to start asking questions — how do we express them?

**Our approach**

- Extend an existing query language, with good tool support
- Hawk already supported the Epsilon Object Language ($\sim$ OCL + JS)
- More info: `http://eclipse.org/epsilon`
- Added temporal extensions based on Rose and Segev's work in the 90s with *history objects* for object-oriented databases

# Time-aware primitives for the Hawk EOL dialect

### Model element history

- Limited lifespan
- Instance-based identity
- New version when state changes

### Type history

- Unlimited lifespan
- Name-based identity
- New version when instances are created or deleted

| Operation | Syntax |
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| All versions (newest to oldest) | `x.versions` |
| Versions within a range | `x.getVersionsBetween(from, to)` |
| Versions from timepoint (incl.) | `x.getVersionsFrom(from)` |
| Versions up to timepoint (incl.) | `x.getVersionsUpTo(from)` |
| Earliest / latest version | `x.earliest`, `x.latest` |
| Next / previous version | `x.next`, `x.prev`/`x.previous` |
| Version timepoint | `x.time` |

# Reusable visualizations

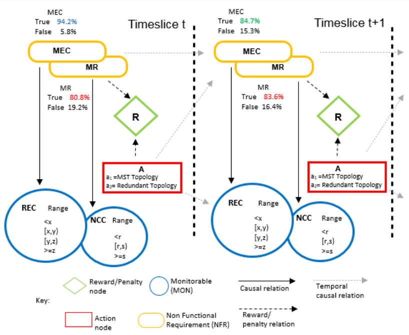
**Potential examples**

- Key instants in the SAS, with links to main changes in behaviour
- Predefined “why” questions for common queries:
  - Why was it doing this at this time?
  - Why did it stop doing the previous action?
  - Why was this change considered good?
  - What was the evaluation process like?
  - Why was the evaluation process configured that way?
- Visualizations would be bundled with the reusable representation and the appropriate time-aware queries

This is still work in progress!

# Case study

# Case study: Remote Data Mirroring



## Concept

SAS that protects against data loss by storing copies on servers.

## Configuration

- 2 topologies: min. spanning tree (MST), redundant (RT)
- 2 NFRs: max reliability (MR), min energy consumption (MEC)
- 2 monitoring variables: energy use, # of connections

## Goal

Switch between MST and RT to meet MR and MEC.

# Turning JSON traces into a temporal graph

```
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  "current_belief_mec_true": 0.5, "current_belief_mr_true": 0.25,
  "current_observation_code": −1,
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  "flagUpdatedRewards": 0,
  "observation_description": "None", "observation_probability": 0.0,
  "selected_action": "MST"
 },
 "1": {
  "current_belief_mec_true": 0.94, ...
 },... }
```

**Steps taken**

1. Collected JSON traces from existing RDM SAS for 1000 time slices
2. Transformed traces to execution trace models
3. Turned sequence of trace models into a Subversion repository
4. Told Hawk to index all model revisions into a Greycat TGDB

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### Current study limitations

- No changes were made to the SAS in this study
- The current case study focuses on *forensic analysis*

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**Ideally...**

- The SAS would simply work off from a model indexable by Hawk, and Hawk + SAS would operate concurrently
- The SAS could ask Hawk about the history of the model to make history-aware decisions

# Queries for developers

- Self-explanations must be tailored to the target audience:

  **Developer** Wants to know things about the system

  **User** Wants to know if the NFRs were met, and how

  **System** Wants to find similar patterns to current observations, what went well, and not so well

- Self-explanations must focus on the intended use.
- As an example, for forensic analysis:
  - Is a certain desired property holding over time?
  - If not, when did the system misbehave?
  - Why did it misbehave then?

# Queries for developers: did reward values change?

Let's start with a simple one:

```
return RewardTableRow.latest.all.collect(r_row | r_row.versions.size).max();
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4. .versions.size measures how many times the rewards changed,
5. .max() returns the number of times the most active reward table changed.

The most active reward table changed a total of 442 times in our traces.

# Queries for developers: distribution of shifts in reward values

```
var rs = RewardTableRow.latest.all.collect(row | row.getRewardShifts()).flatten();
return Sequence { rs.min(), rs.max(), rs.average() };

operation RewardTableRow getRewardShifts(): Sequence {
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  if (v.size <= 1) { return Sequence {}; }
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4. .prev compares adjacent values up to the second oldest version,
5. .min()/.max()/.average() compute descriptive statistics. 16 lines of EOL check that the SAS kept shifts bounded to ±0.034.

# Queries for developers: more examples

**Thrashing between two actions?**

- Is the SAS constantly changing actions?
- 33 lines of EOL later, we found a sequence of 8 timeslices in which the SAS was switching between RT and MST.
- Would this be acceptable behaviour for a SAS?

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- Would this be acceptable behaviour for a SAS?

**Unintuitive inferences?**

- Does the SAS think at some point that a NFR is not being met, even if the observation says it is within range?
- Wrote query in 22 lines of EOL — there are 18 time slices in which the SAS thought the MEC NFR was not being met, even though there is low energy usage.
- Is this obvious? We may need to look at neighbouring observations to find out.

# Queries for users: enabling exploration

**Differences from developer-oriented queries**

- These are problem-centric, rather than solution-centric
- Were my NFRs met? If not, what was done about it, and why?
- Queries may need to be organised in a way that promotes exploration

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**Initial dashboard-style query: overall system health**

- We defined a query in 10 lines that measures number of versions in which each NFR is met and unmet
- MEC: SAS had 670 belief levels as “met” out of 888
- MR: SAS had 665 belief levels as “met” out of 888

# Queries for users: timeline views

Listing 1: Excerpt of output from query

```
[[{Maximization of Reliability=false, Minimization of Energy Consumption
    =false}, 1, 1532385574820, REC LOWER X AND NCC GREATER S, Redundant
     Topology],
[{Maximization of Reliability=true, Minimization of Energy Consumption=
    true}, 1, 1532385575022, REC IN Y_Z AND NCC GREATER S, Minimum
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```

- Queries bring together beliefs and observations at decision points:
    - Beliefs can be simplified to yes/no if deemed useful.
    - Observations can be translated from the solution domain (e.g. “code 3”) back to the problem domain (“high use of energy”).
- We can simplify the timeline to points where the decision changed.
- The paper shows a 35-line query that does this.

# Conclusion and future work

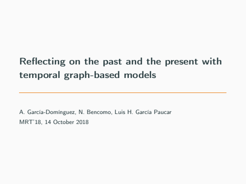
### Key points

- Text logs, structured traces not enough for good self-explanation
- For reusable self-explanation and reflection in SASs, we need:
  - A reusable trace metamodel
  - A transparent way to store versioned models as temporal graphs
  - A reusable time-aware querying language
  - A set of reusable visualizations based on the trace metamodel
- We showed the approach on a small case study (RDM)

### Future lines of work

- Build visualizations!
- Create a taxonomy of typical questions to ask from a SAS
- Try out the trace metamodel on more SAS, and allow "profiling"
- Extend the time-aware primitives to cover linear temporal logic
- Leverage time-awareness for better simulations and decision-making

# Thank you!



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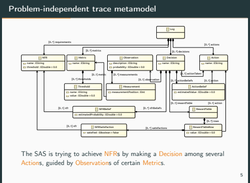

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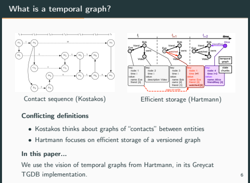

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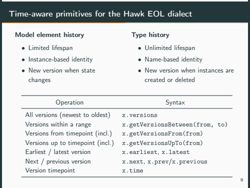

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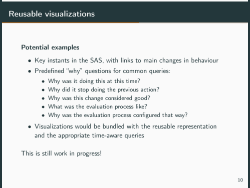

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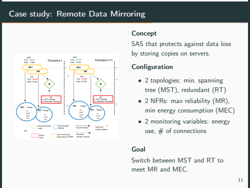

### Case study: Remote Data Mirroring

**Concept**

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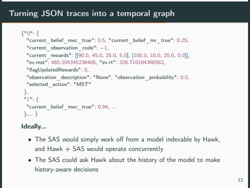

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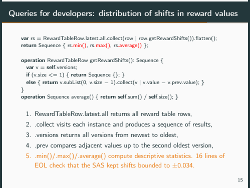

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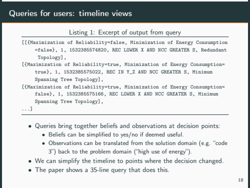
operation RewardTableRow getRewardShifts(): Sequence {
  var v = self.versions;
  if (v.size <= 1) { return Sequence {}; }
  else { return v.subList(0, v.size − 1).collect(v | v.value − v.prev.value); }
}
operation Sequence average() { return self.sum() / self.size(); }
```

1. RewardTableRow.latest.all returns all reward table rows,
2. .collect visits each instance and produces a sequence of results,
3. .versions returns all versions from newest to oldest,
4. .prev compares adjacent values up to the second oldest version,
5. .min()/.max()/.average() compute descriptive statistics. 16 lines of EOL check that the SAS kept shifts bounded to ±0.034.



### Queries for users: timeline views

Listing 1: Excerpt of output from query

```
[[{Maximization of Reliability=false, Minimization of Energy Consumption
    =false}, 1, 1532385574820, REC LOWER X AND NCC GREATER S, Redundant
     Topology],
[{Maximization of Reliability=true, Minimization of Energy Consumption=
    true}, 1, 1532385575022, REC IN Y_Z AND NCC GREATER S, Minimum
    Spanning Tree Topology],
[{Maximization of Reliability=true, Minimization of Energy Consumption=
    false}, 1, 1532385575166, REC LOWER X AND NCC GREATER S, Minimum
    Spanning Tree Topology],
...]
```

- Queries bring together beliefs and observations at decision points:
  - Beliefs can be simplified to yes/no if deemed useful.
  - Observations can be translated from the solution domain (e.g. "code 3") back to the problem domain ("high use of energy").
- We can simplify the timeline to points where the decision changed.
- The paper shows a 35-line query that does this.