Doing Time:
Putting Qualitative Reasoning
on Firmer Ground

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Objective

1. avoids limitations of earlier approaches

2. more broadly applicable
Punchlines

Features of system to be described:

1. Allows us to efficiently generate clear, concise descriptions of behavior.

2. Avoids producing irrelevant distinctions by identifying only the relevant interactions.

3. Models the dynamic behavior of a wider class of feedback systems than previously possible.

4. Offers core predictive framework for exploring a wide variety of qualitative representations.
Outline

1. Motivation

2. The current approach

3. Limitations

4. The Ideal Description

5. Temporal Constraint Propagation

6. What has been accomplished
Why Qualitative Reasoning?

Circuits are difficult to analyze quantitatively

"When $\Phi_{IN}$ starts to rise, it charges capacitor $M9$ and starts to turn $M10$ and $M12$ on. $M6$ isolates node 18, allowing that node to bootstrap and keep $M5$ turned on hard... ."

**Insight:** Most circuit analysis by humans involves very few equations.
Qualitative Analysis

*Idea:* Analyze behavior directly in terms of properties of interest

*Concerned with:*

1. Qualitative representations
   (e.g., *increasing*, *decreasing*)

2. Physical principles
   (e.g., *continuity*)

3. *Modeling behavior over time*
Modeling Behavior Over Time

**Problem:** Describing system's behavior in terms of relevant events

"describe" = What? + Why?

![Diagram of output and input over time]

**What?**

**Why?** "A rising edge on the input causes the output to drop"

"relevant" details = changes in values of interest
Limitations of Qualitative Simulation

1. Domain restrictions

2. Unnecessary temporal distinctions

3. Inadequate representation for temporal relationships
Limitation 2: Unnecessary Temporal Distinctions

Problem: Traditional use of state descriptions is global

Consequence: Relationships specified between events which don’t interact

Example: effect of bear’s eating habits on sleep cycle

Koala

Polar

Polar
Bear Description Using Global States

Problem: Traditional use of state descriptions is global

- irrelevant distinctions
- profusion of states
- wasted inference
- case splitting
Are Irrelevant Distinctions Really a Problem?

Literature:

Reality:

HIGH PERFORMANCE SENSE AMPLIFIER
Limitations of Qualitative Simulation

1. Domain restrictions

2. Unnecessary temporal distinctions

3. Inadequate representation for temporal relationships
The Desired Description

1. Behavior of variables individually
   
   - intervals of "uniform behavior"
   - points where behavior changes

2. relations between events where variables interact
Behavior of Individual Variables

Episode - interval of uniform behavior

- value
- extent

Example:

"Ted lived in Australia from 1910 to 1930"

value = Australia

extent = [1910,1930]
Individual Variables (continued)

History - sequence of episodes

- contiguous

- non-overlapping

LOCATION(TED) | AUSTRALIA | SAN FRANCISCO | ZOO | t
1910 1930

- concise - only need to express changes (i.e., events)
Making Histories Concise

Maximal Episodes encompass largest contiguous interval of uniform behavior

Concise Histories composed of maximal episodes
Description: Interactions Between Variables

Need relevant relations between episodes where state variables interact

1. relations specified between events

2. Language of relations
   - partial orders, min and max
   - numerical values, algebraic constraints, etc.

3. relations should be "relevant"
   - i.e., directly affect the behavior of some quantity
Relations Should Be “Relevant”

Example: Fight at the Washington Zoo

\[
\text{LOCATION(Whity)} \quad \text{NORTH POLE} \quad \text{GREENLAND} \quad \text{ZOO} \quad t
\]

\[
\text{LOCATION(Ted)} \quad \text{AUSTRALIA} \quad \text{SAN FRANCISCO} \quad \text{ZOO} \quad t
\]

Relevant overlap in Washington zoo

Irrelevant overlap in homelands
Constraint Propagation

1. Constraints
   
   • model behavior
     
     (e.g., \( f = kx \))
   
   • composed of a set of rules
     
     (e.g., \( k = f/x, \ x = f/k \) and \( f = kx \))

2. Cells
   
   • hold values deduced

3. Inference
   
   • deduce new values from known values
   
   • records dependencies
   
   • forward driven
Temporal Constraint Propagation (TCP)

**Values** Concise histories

**Rules** Functions parameterized by time
   e.g., $f(m, a(t)) = ma(t)$

**Basic Inference:**

1. Infer new episodes
   
   - **value** apply rule to values of input episodes
   - **extent** intersect extents of input episodes

**Example:** Rule 1: $C = A - B$

2. Check consistency
   
   - Overlapping episodes must have same value
Rules "walk" over histories, constructing new histories

Example: R1: $C = A - B$

Observation: Deduced sequence isn't concise
Concise Histories and Explanations

Solution: Two Stage Representation

1. rules construct justification histories

2. justifications summarized into value histories
Additional Concerns

1. Rules are partial functions $\rightarrow$ Gaps

2. Multiple rules deducing same values

Example: OR Gate

R1: $A = 1 \rightarrow C = 1$
R2: $B = 1 \rightarrow C = 1$
R3: $A = 0, B = 0 \rightarrow C = 0$
Modeling Systems with Feedback

\[ Q(t) = f(Q(t), ...) \]

- Most systems exhibit feedback
- Feedback has been particularly a problem for CP modelling static behavior

  - **Problem:** feedback produces impasse
  - **Solution:** "Plunking"

- TCP facilitates a similar approach for dynamic behavior

**Key Idea:** propagate episode before completely specified
Example: SR-Latch

R1: If $A = 1$ then $C = 0$
R2: If $A = 1$ then $C = 0$
R3: If $A = 0, B = 0$ then $C = 1$

Q
R2
R3

$\overline{Q}$
R1
R2

S
1

R
1
SR-Latch continued

When can $Q$ change its value from 1?

Not until $R$ changes value.

Why?

$Q$ will be 1 as long as $R$ and $\overline{Q}$ are both 0. However, $\overline{Q}$'s value is constrained by $Q$. Hence $Q$ can't change its value until after $Q$ does. Therefore, $Q$ will be 1 as long as $R$ is zero.

Key ideas:

1. Episodes are maximal

2. Partially constrained episodes are propagated symbolically

3. Constraints specified between symbolic time points
What Has Been Accomplished

1. Replacing global state description with concise histories
   
   • no irrelevant orderings
   • computationally more efficient
   • produces clearer, more concise description

2. Recognized a common core for prediction
   
   • more generally applicable

3. Propagating episodes symbolically before they are completely constrained allows us to concisely model dynamic behavior of feedback systems

4. Framework for exploring mixed qualitative models
   
   • broaden scope of "qualitative reasoning"