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.

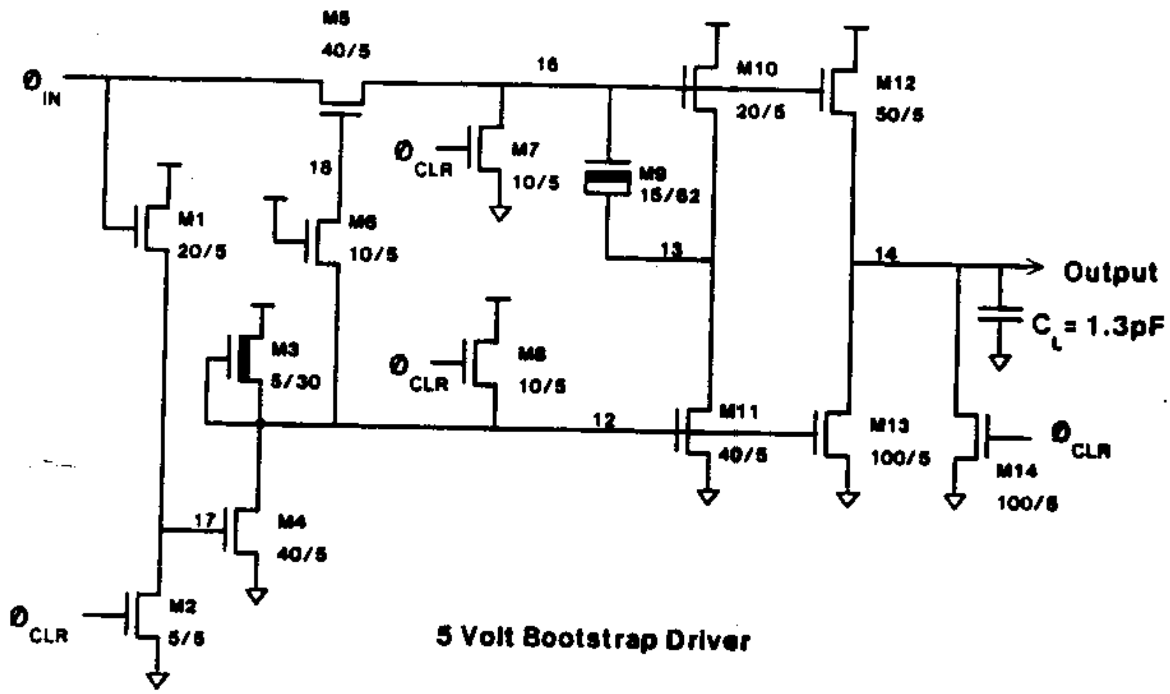
4. Offers core predictive framework for exploring a wide variety of qualitative representations.

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



5 Volt Bootstrap Driver

"When Φ_{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**)

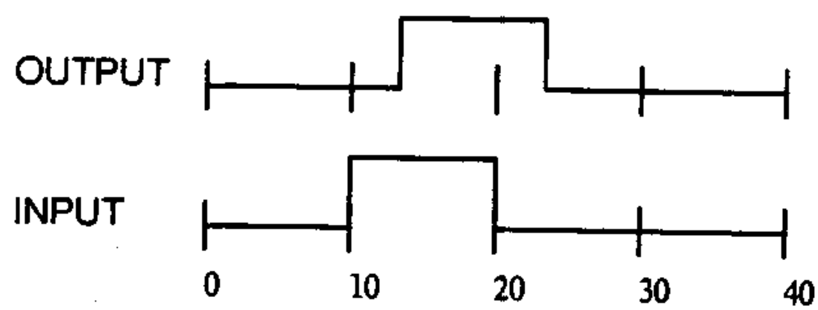
2. Physical principles (e.g., continuity)

3. **Modeling behavior over time**

Modeling Behavior Over Time

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

"describe" = What? + Why?



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

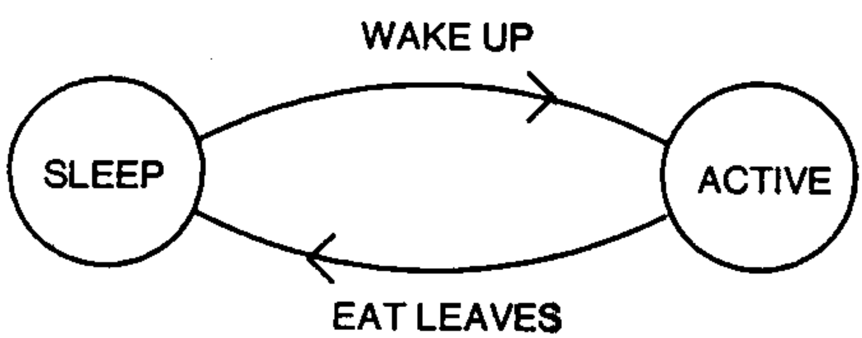
Limitation 2: Unnecessary Temporal Distinctions

Problem: Traditional use of state descriptions is **global**

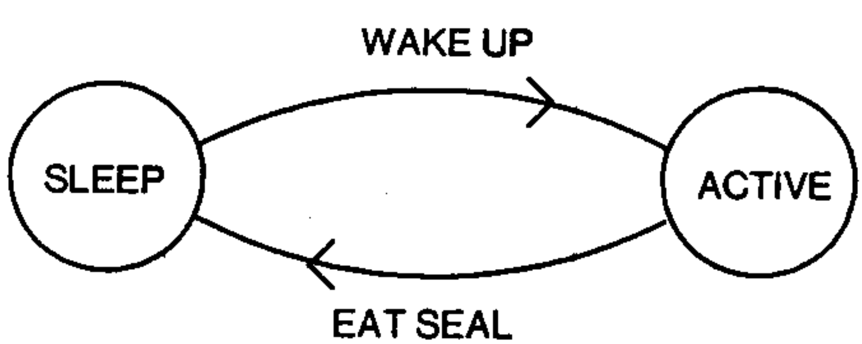
Consequence: Relationships specified between events which don't interact

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

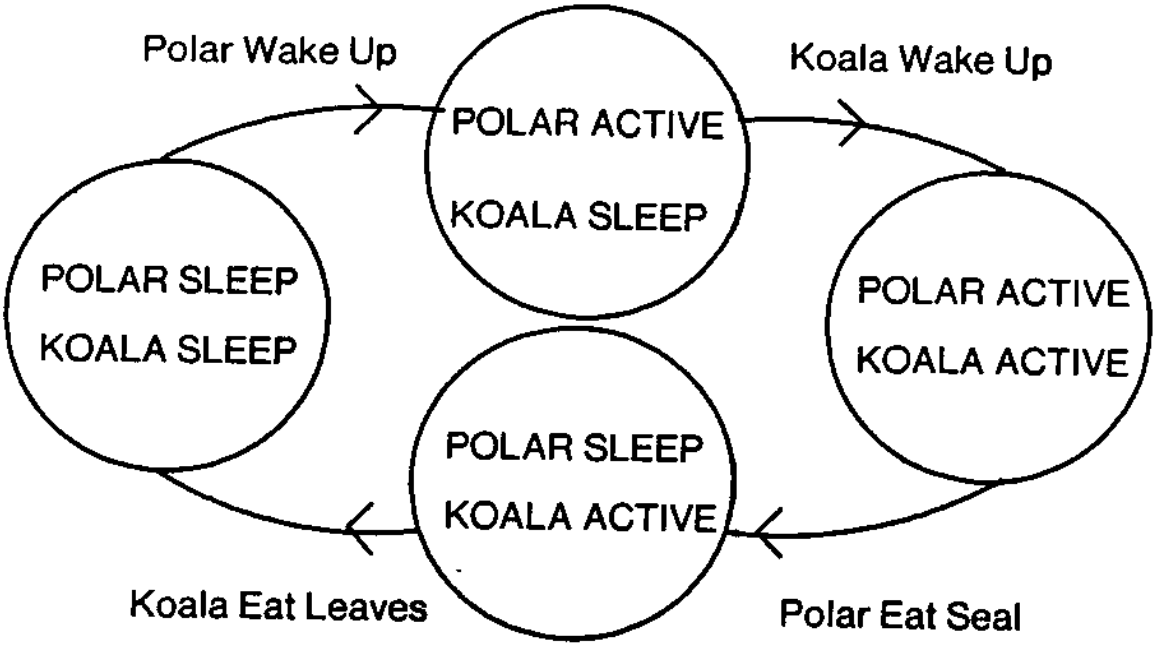
Koala



Polar



Bear Description Using Global States

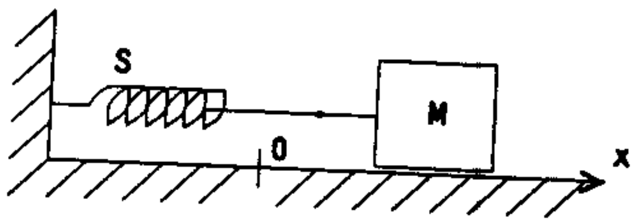


Problem: Traditional use of state descriptions is **global**

- irrelevant distinctions
- profusion of states
- wasted inference
- case splitting

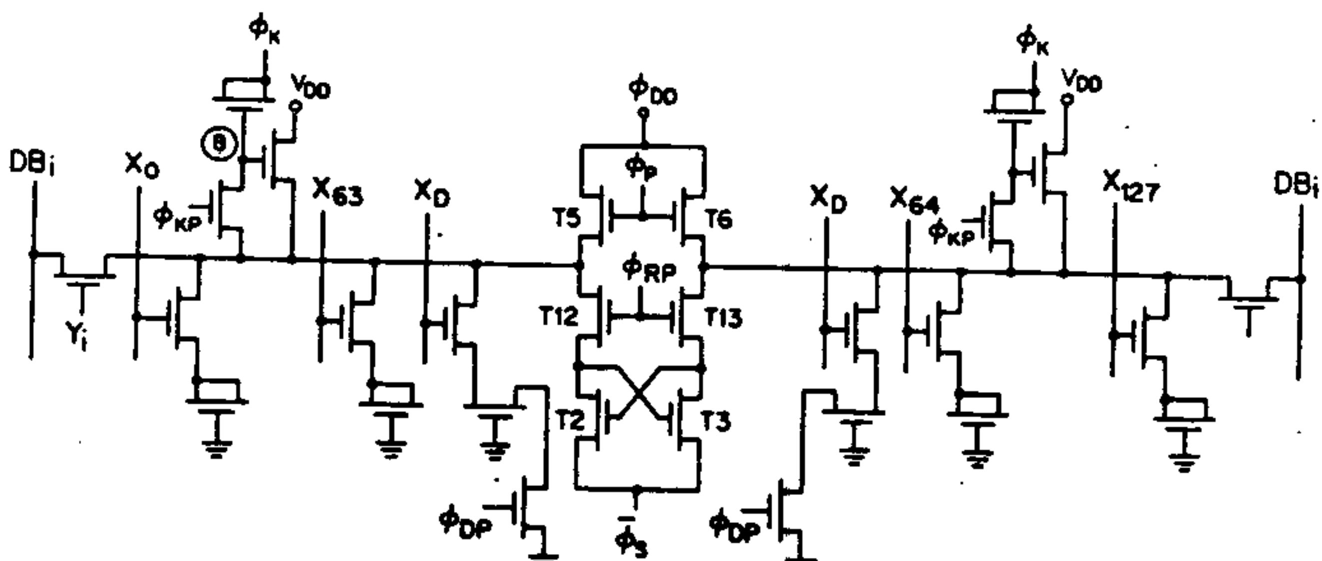
Are Irrelevant Distinctions Really a Problem?

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"

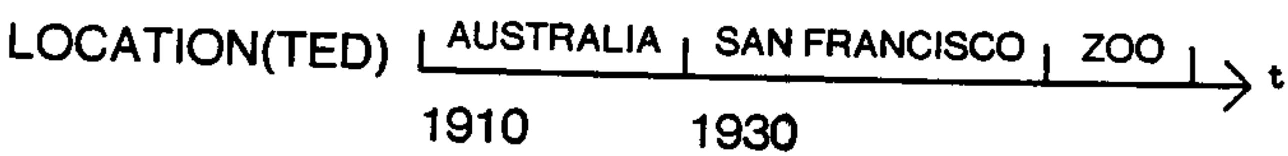
value = Australia

extent = [1910,1930]

Individual Variables (continued)

History - sequence of episodes

- contiguous
- non-overlapping



- 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

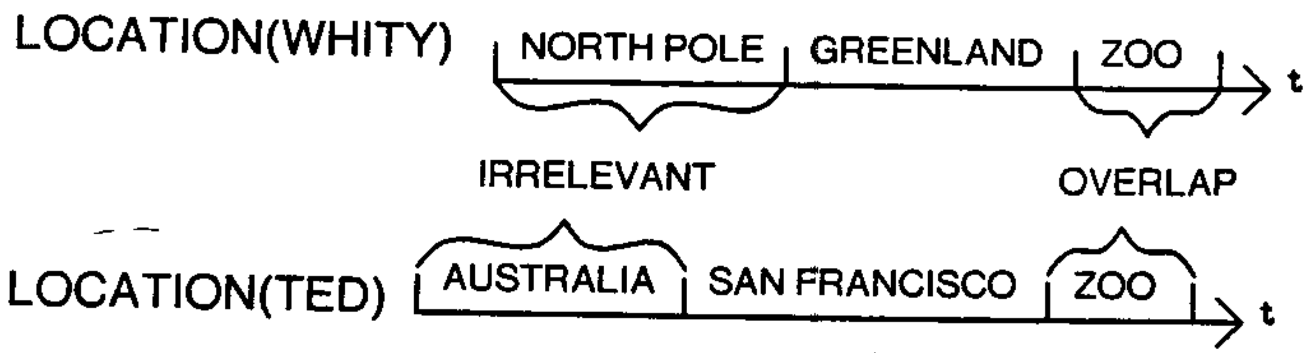
Description: Interactions Between Variables

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



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

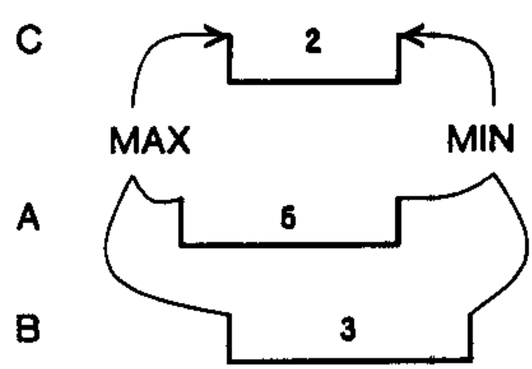
Rules Functions parameterized by time
e.g., $f(m, a(t)) = ma(t)$

Basic Inference:

1. Infer new episodes

   value apply rule to values of input episodes
   extent intersect extents of input episodes

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

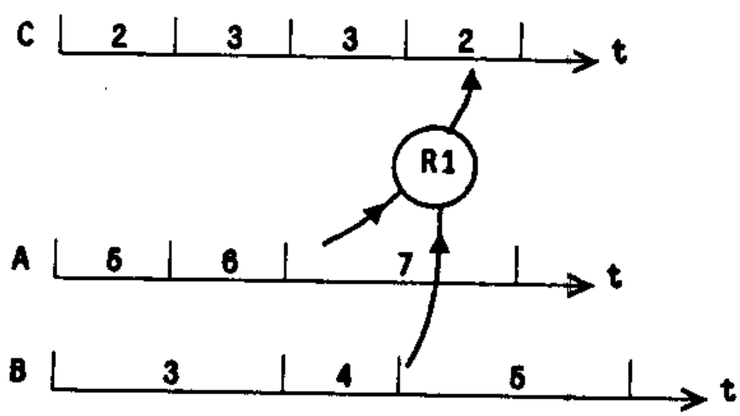


2. Check consistency

   - Overlapping episodes must have same value

Rules "walk" over histories, constructing new histories

Example: R1: $C = A - B$



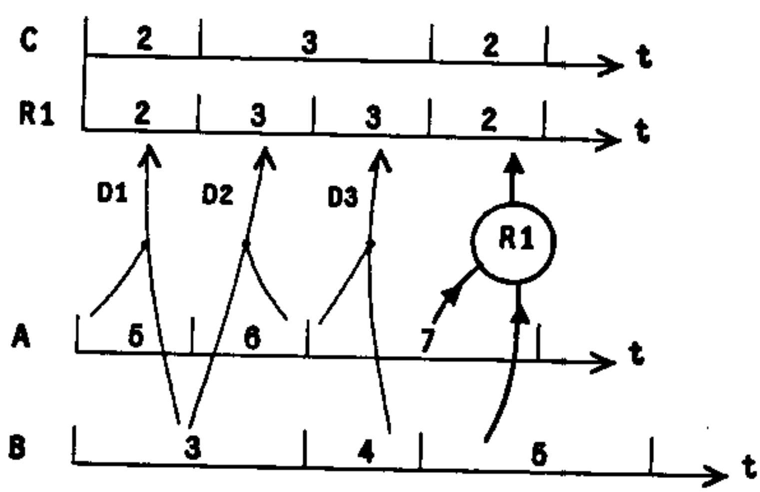
Observation: Deduced sequence isn't concise

Concise Histories and Explanations

Solution: Two Stage Representation

1. rules construct justification histories

2. justifications summarized into value histories



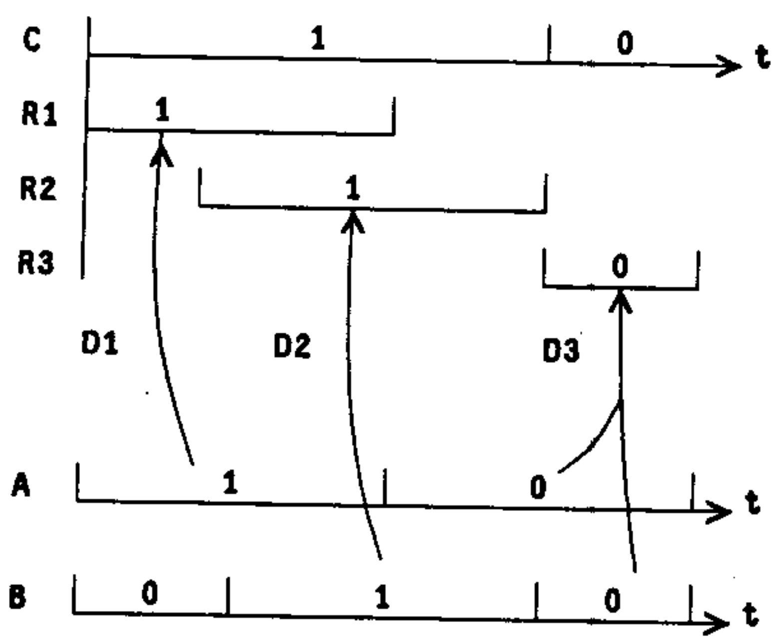
Additional Concerns

1. Rules are partial functions $\longrightarrow$ Gaps

2. Multiple rules deducing same values

Example: OR Gate

R1: $A = 1 \rightarrow C = 1$
R2: $B = 1 \rightarrow C = 1$
R3: $A = 0, B = 0 \rightarrow C = 0$



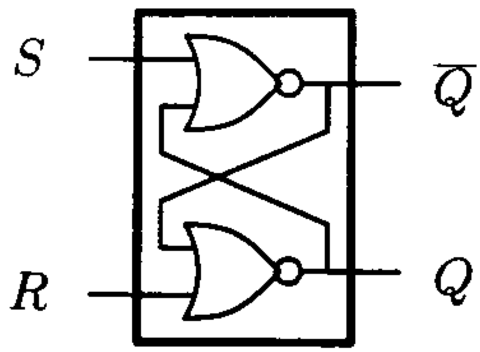
Modeling Systems with Feedback

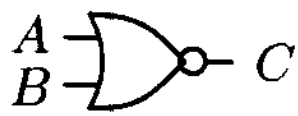
$$Q(t) = f(Q(t), ...)$$

- 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





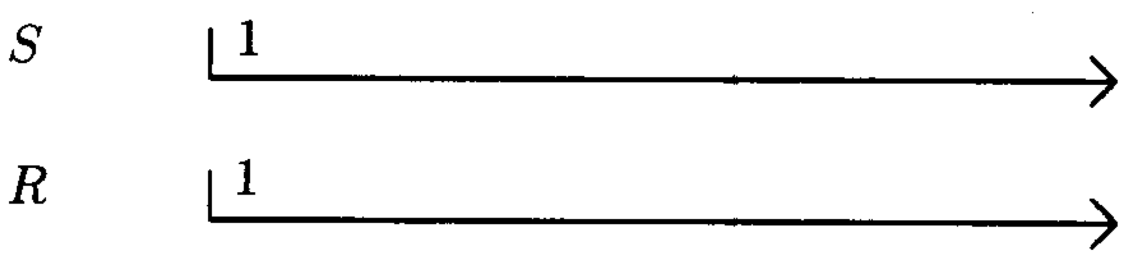
R1: If $A = 1$ then $C = 0$
R2: If $A = 1$ then $C = 0$
R3: If $A = 0, B = 0$ then $C = 1$

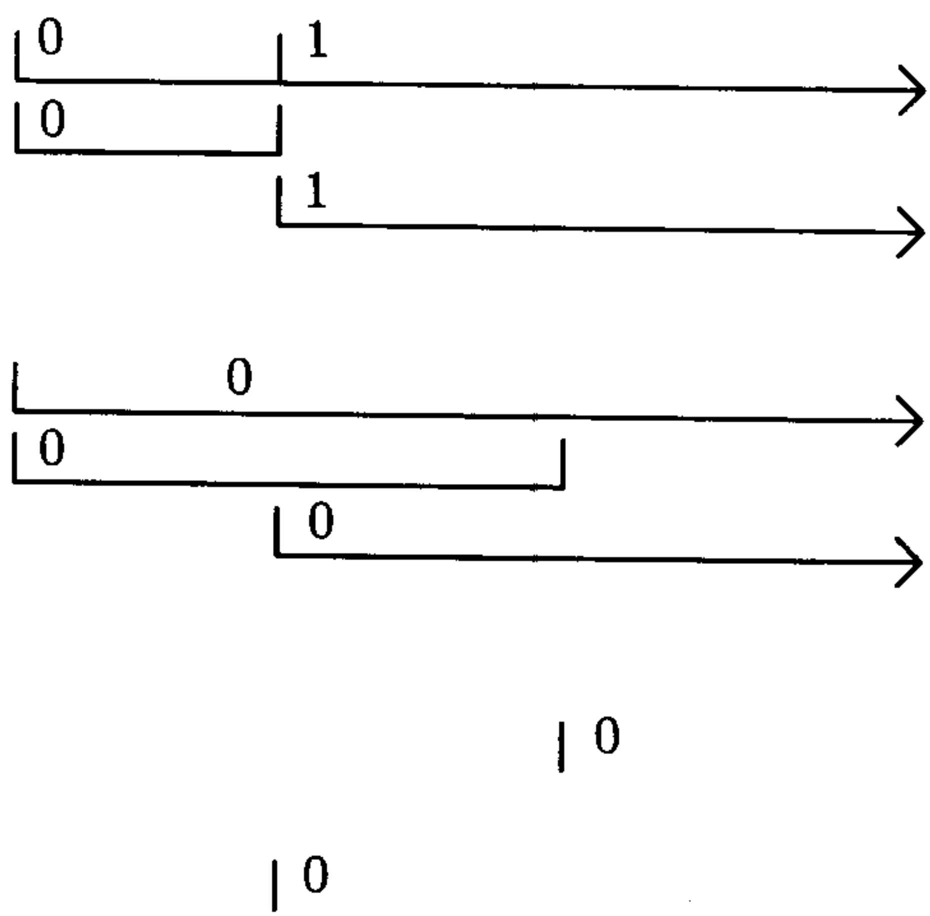
Q

$R2$
$R3$

$\overline{Q}$

$R1$
$R2$




0
1
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1
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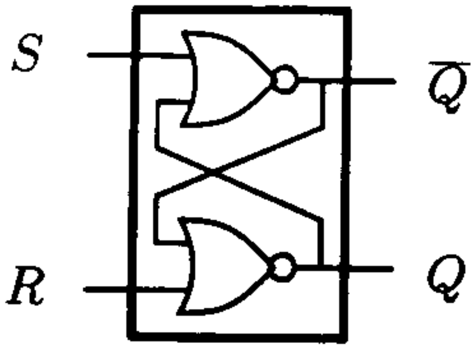
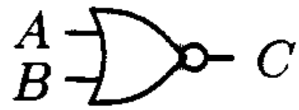
SR-Latch continued





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

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

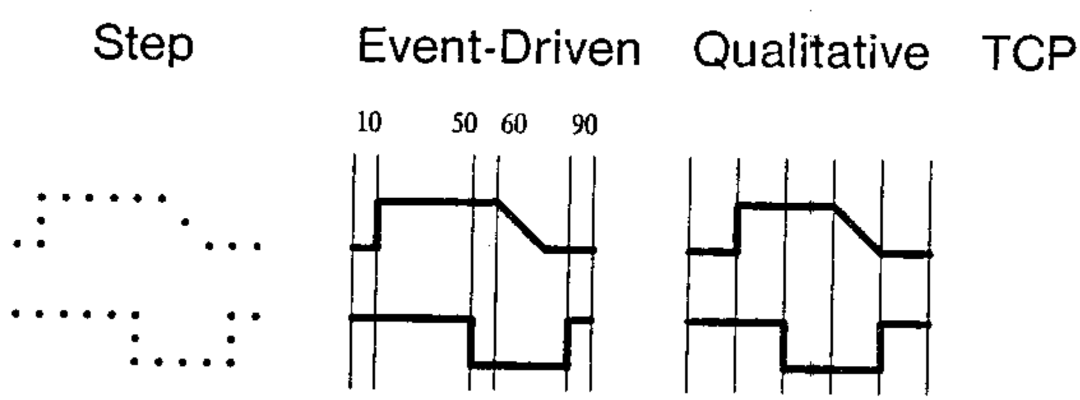
2. Recognized a common core for prediction

    - 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"


Step
Event-Driven
Qualitative
TCP
10
50
60
90