Lifecycle Management of Relational Records for External Auditing and Regulatory Compliance

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Policies and Constraints

- What is a business policy?
  - A specification of what should (or should not) happen in the operations of a business.
    - Typically written in natural language
- Policies manifest themselves in database systems as constraints or alerts
  - Check constraints
  - Transaction termination triggers
  - Access control restrictions

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Business Model

- Means of simplifying and summarizing a set of rules
  - Provides a high-level overview
  - Intermediate layer between natural language and implementation (code)
  - Logical or graphical
- Types of modeling:
  - Data modeling: ER, UML, …
  - Process modeling: Workflow, Flow-chart, PERT charts, …
  - Policy modeling: Hierarchical access control modeling, Object Constraint Language, …

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Database System Perspective

- Database reflects enterprise
  - Database instance ≡ overall ‘state of a business’
- Instance must comply with published policy
  - Database system must continuously monitor updates to ensure compliance.
  - Single compliance layer eliminates need to embed policy checking logic in every application
  - Significantly simplifies implementation of complex data constraints

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Difficulties

- Each department has its own constraints
  - Shared database ⇒ conflicts can be detected beforehand
  - Many are complex (temporal, conditional, path oriented)
    - "A student can take CS446 only if she has passed CS330 and CS245 with a score of 75% or more"
    - Typically correspond to complex transaction termination triggers
- Many constraints derived from business policies
  - Scale ⇒ manageability a major problem for DB administrators and programmers

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Why have existing models failed us?

- Complex (temporal, path) constraints difficult to model.
  - "A professor cannot teach CS448 and CS490 at the same time."
  - "A professor can teach CS348 only once in two years."
- No notion of policy-relevant object
- State of an "object" is static
  - Historical applications are "forgotten"
  - "Salary of an employee can only be increased three times in any one year period."
- Inter-rule dependencies cannot be expressed
  - For example: "Rule 1 should only be enforced if Rule 2 was never violated in the past by a transaction"

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Avoiding Hand-written Triggers

- Can we make the task of the programmer easier?
- Can we make the database level workflows more transparent to business level managers?
- Can we introduce policy-to-constraint transparency and manageability and offer compliance guarantees at the same time?

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Step 1
Basic Framework: Objects

- Start with the object definitions
  - An object definition is *any relational view* over a fixed database schema.
- Object = tuple (row) in such a view
  - View can represent a complete business artifact
    - *All* data needed for policy making
  - Assume each row in view is uniquely identifiable

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Step 2
Basic Framework: States

- State S: condition on objects in the view definition
  - Object x is in state S ⇔ its attributes satisfy S(x)
  - Example
    - EXPENSE_CLAIM_DETAILS is user-defined *view*
    - "Claim objects" are rows in the view
    - Object O (tuple t) is in state P, the "paid state", if the condition EXPENSE_CLAIM_DETAILS.PAID = TRUE for t
- An object can be in multiple states at once.

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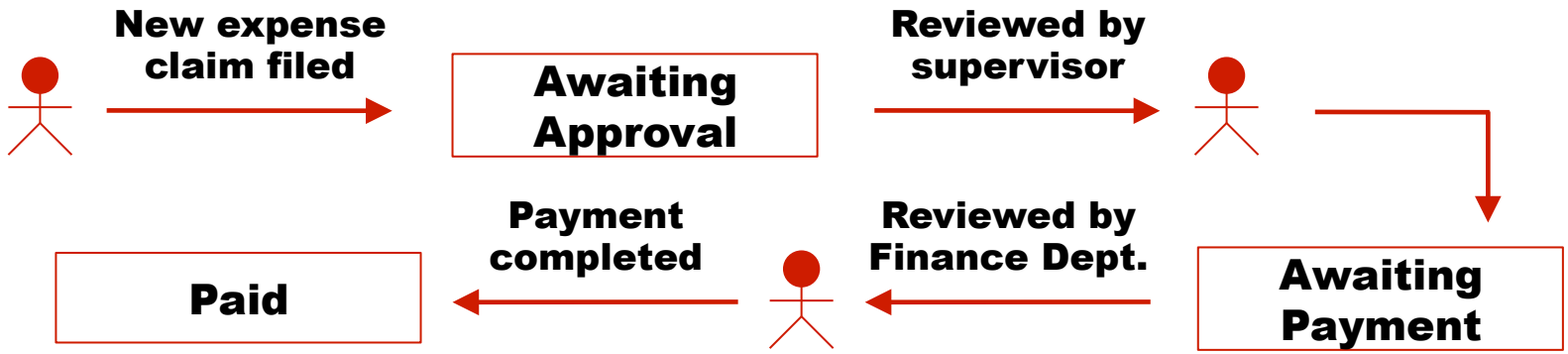
Step 3: Convert business model into enforcement model



- Rectangles represent business states
- Transitions represent processes/actions
- Stick-figures represent agents
- Constraints implied by absence of transitions
  - E.g., Paid invoices are not deleted

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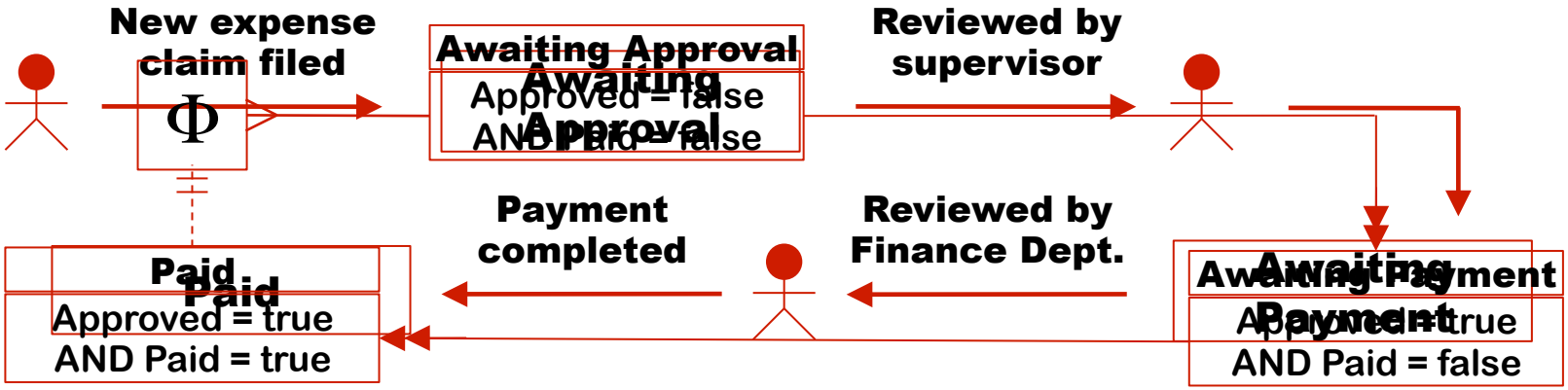
Business states and DB states



- States of an object are typically an interpretation of stages in business process.
  - Including object creation and destruction
- All constraints should be made explicit.

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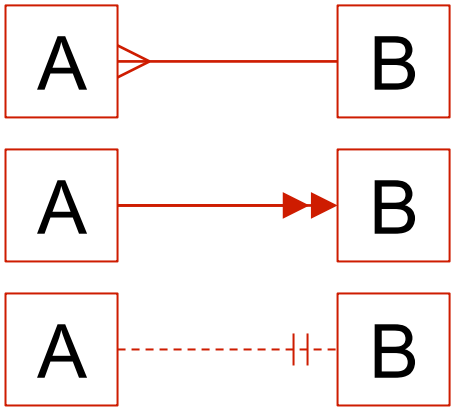
Constraints on State Transitions



$\bullet A(x) \wedge \neg A(x) \Rightarrow B(x)$

$\neg \bullet B(x) \wedge B(x) \Rightarrow \bullet A(x)$

$\blacklozenge A(x) \Rightarrow \neg B(x)$

- Define various types of constraint
  - Use past temporal logic
  - Create diagrammatic form
- Special interpretations for transitions to or from Φ

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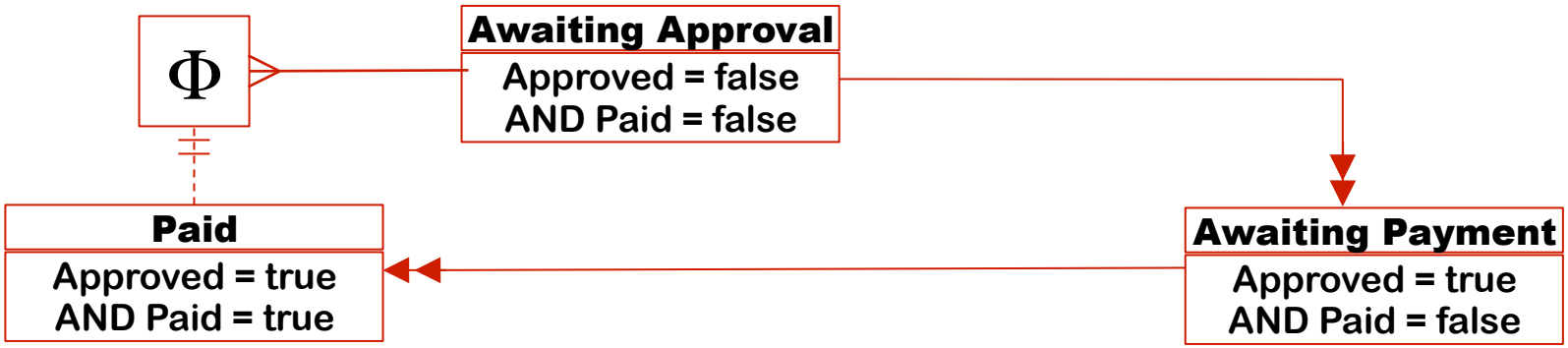
Back to the Example



- Convert to temporal logic

  New(x) ⇒ AwaitingApp(x)
  ¬ •AwaitingPay(x) ∧ AwaitingPay(x) ⇒ • AwaitingApp(x)
  ¬ •Paid(x) ∧ Paid(x) ⇒ • AwaitingPay(x)
  Paid(x) ⇒ *Retain*(x)

- Test these conditions in the database

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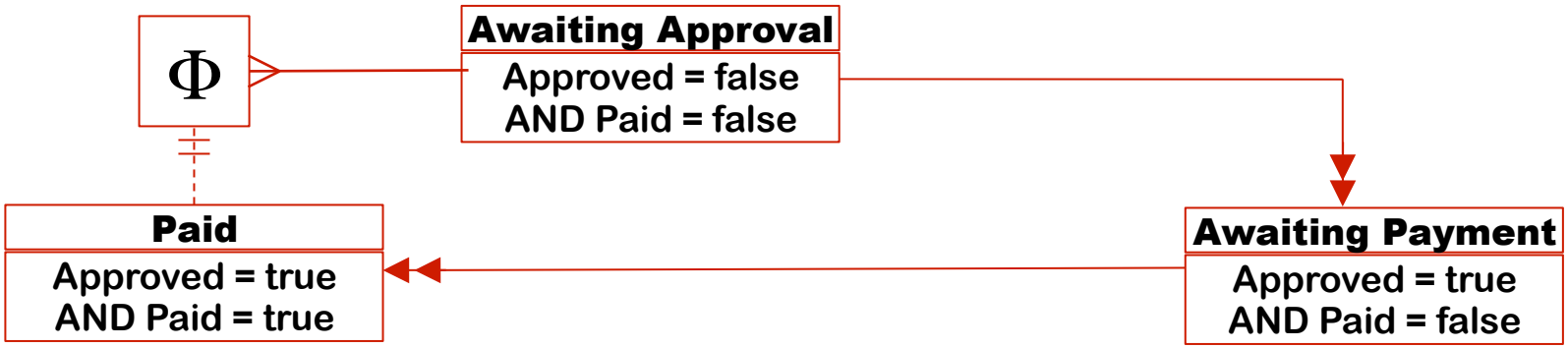
State Configuration of an Object



- States = { AwaitingApproval,
  AwaitingPayment,
  Paid}
- State space = {(0,0,0),(0,0,1),(0,1,0),…,(1,1,1)}
- Some configurations are not satisfiable

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Maintain State Configuration History

- A *complete, temporally ordered* list of state configurations for an object

Object O_1 history

Time	Awaiting Approval	Awaiting Payment	Paid
t1	0	0	0
t2	1	0	0
t3	0	1	0
t4	0	0	1

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Implementation: Tracking the State Configuration History

Time	Awaiting Approval	Awaiting Payment	Paid
t1	0	0	0
t2	1	0	0
t3	0	1	0
…	…	…	…
t_new	*0*	*0*	*1*

- Every time an object is modified, look back at the history and answer the query related to each constraint!

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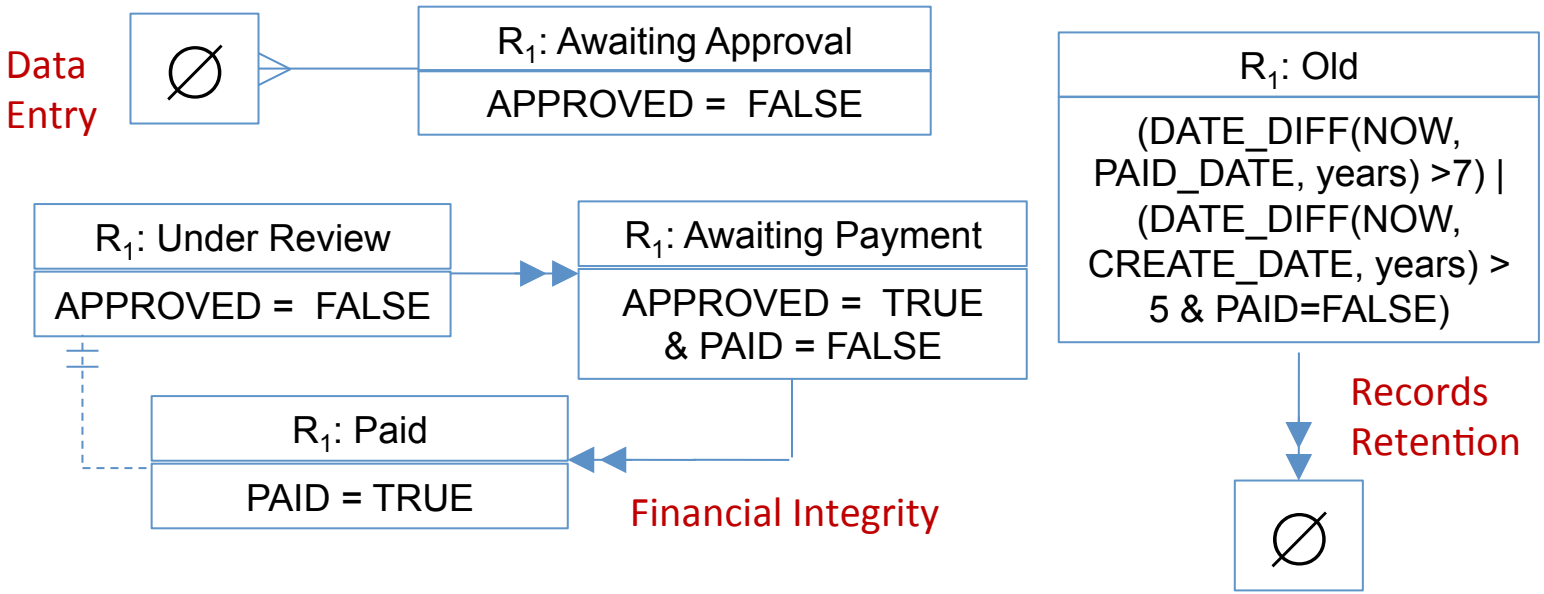
Allow Multiple Constraint Diagrams

- Model business processes as constraint diagrams



- Convert to temporal logic implemented as triggers
  - $\neg\ \exists x \in R_1 : \blacklozenge \text{Paid}(x) \wedge \text{UnderReview}(x)$
  - $\neg\ \exists x \in R_1 : \neg \bullet \text{AwaitingPayment}(x) \wedge \text{AwaitingPayment}(x) \wedge \neg \bullet\ \text{UnderReview}(x)$

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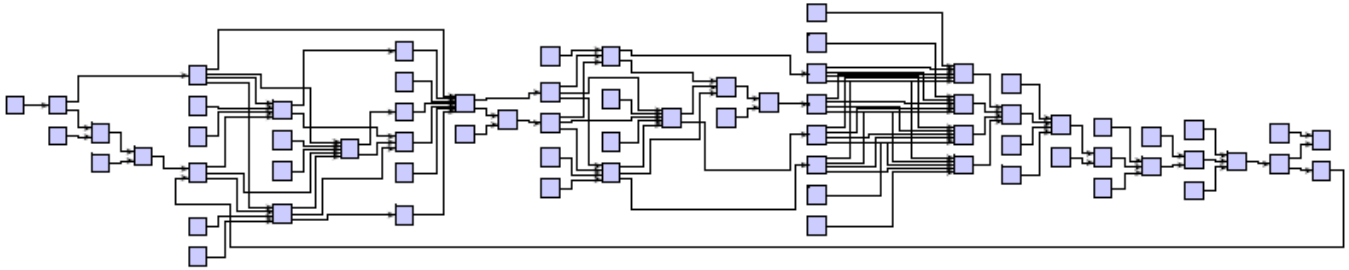
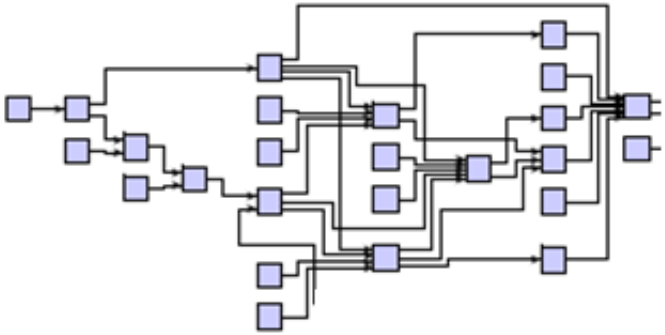
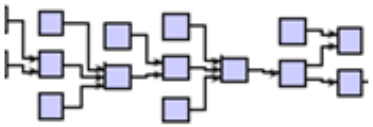
Benefits: Separation of Duties

- Instead of a single large complex workflow



- Each department, person, or stakeholder can independently establish state oriented path restrictions





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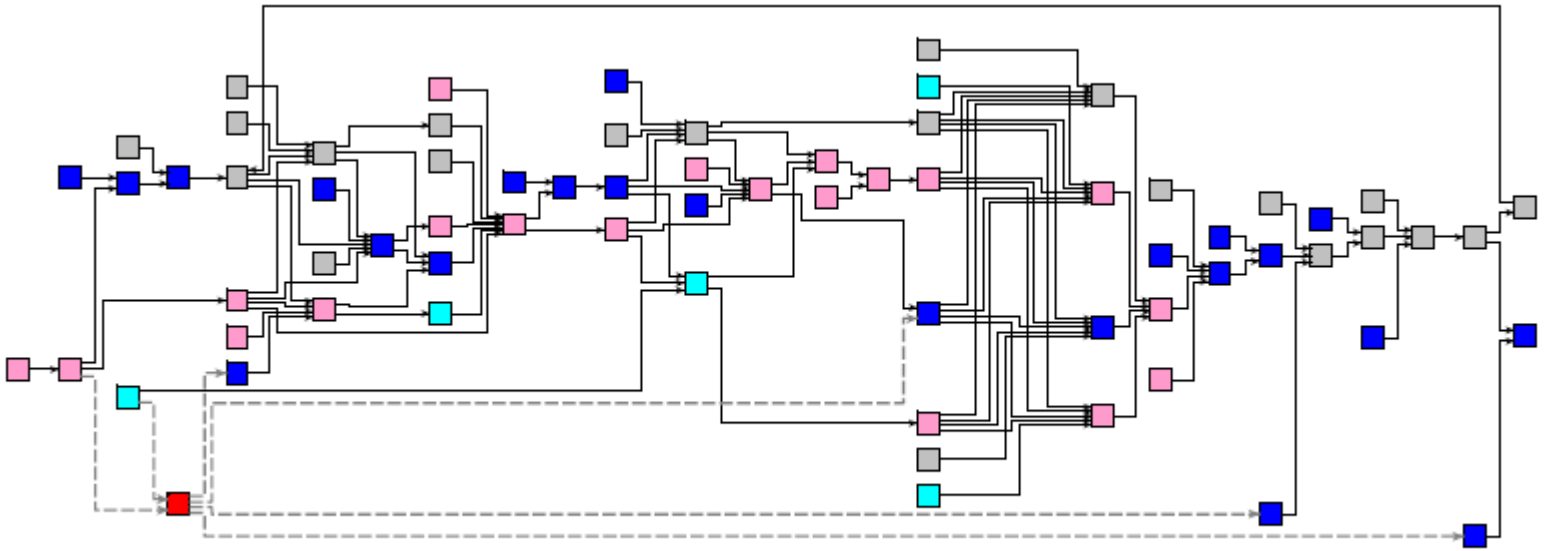
Multi-user lifecycles



- Each colour represents states of interest for a different party

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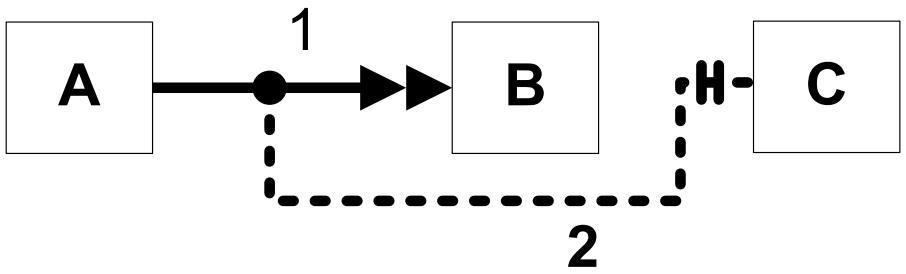
Allow Complex Path Constraints

- E.g., an object should never reach state C if it has previously transitioned from A to B



- Constraint 1 : $B(r) \wedge \neg \bullet B(r) \Rightarrow \bullet A(r)$
- Constraint 2 : $\blacklozenge 1(x) \Rightarrow \neg C(x)$

$$\blacklozenge(B(r) \wedge \neg \bullet B(r) \Rightarrow \bullet A(r)) \Rightarrow \neg C(x)$$

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Summary

- Policy designer only needs to list the "states of interest"
  - By specifying the conditions that the object must satisfy to be in those states
  - Each policy designer in the organization can list his/her own states of interest
- Policy restricts paths that an objects can (or should) traverse
  - Constraint diagram (the model)
    - Some paths must always be taken, some must never be traversed, and others can be conditionally traversed
  - Need flexibility in specifying constraints

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Keep DB State History (audit)

- Define business records as database views

  Invoice = (INV_ID, CREATE_DATE, PAID, AMOUNT, PAID_DATE, APPROVED)

  - PAST-TL constraint is a restriction on current state of a view given its history

- Augment DB audit trail with state vector

  x_t= (timestamp,a_1,a_2, …, a_n, user, user_group, purpose, application_context, transaction_type, txn_starttime, …, s_1, s_2, s_3, …, s_k)

  - Check all constraints on newly entered states

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Extending the model

- Define additional transition constraint types
- Include temporal access control
  - Use transactional meta data
  - E.g., claim can only be approved by someone in the "management" user group and can only be paid by someone in the "finance" user group

Time	A	B	C	User_Group = Management	User_Group = Finance
t1	0	0	0	0	0
t2	1	0	0	0	0
t3	0	1	0	1	0
…	…	…	…	0	1
t_new	*0*	*0*	*1*	…	…

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Performance Analysis: Storage Overhead

- Additional storage space required to store the current (extended) state configuration
- 1 bit for each state
  - 256 states = 32bytes or characters
- For business scenarios where large text fields are logged, the additional overhead will be minimal

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Performance Analysis: Computational Costs

- CPU time spent computing the (extended) state configuration history
  - One check per state to establish membership
  - Proper nesting of these checks can minimize computation costs
- Cost is insignificant compared to writing audit entry onto disk

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Conclusions and Future Work

- Bridge between business policy manager and database
  - Constraint diagram makes policy statements explicit
  - Emphasizes data but models processes and user interactions
  - Allows multiple diagrams and multiple concurrent states
  - Equivalent to past temporal logic
  - Implementable as database triggers on meaningful views
  - Experiments show that extra space and time to check constraints is insignificant overhead on auditing.
- Future work
  - Translating NLP policies into constraint diagrams
  - Extracting workflows from database transaction logs