A Framework for Supporting Updates to Database Components

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The Composition of this Talk

Part 1: The model of database components.

> **Based upon**: A Model of Database Components and their Interconnection Based upon Communicating Views (EJC 2007)

Part 2: Basic update support via cooperation.

> **Based upon**: Update Support for Database Views via Cooperation (ADBIS 2007, with Peggy Schmidt)

Part 3: Current work on update support.

> **Based upon**: Updates to Database Schemata Defined by Interconnected Components (TR 0805 with Peggy Schmidt, to appear).

The Model of Database Components

Managing the Complexity of Large-Scale Systems

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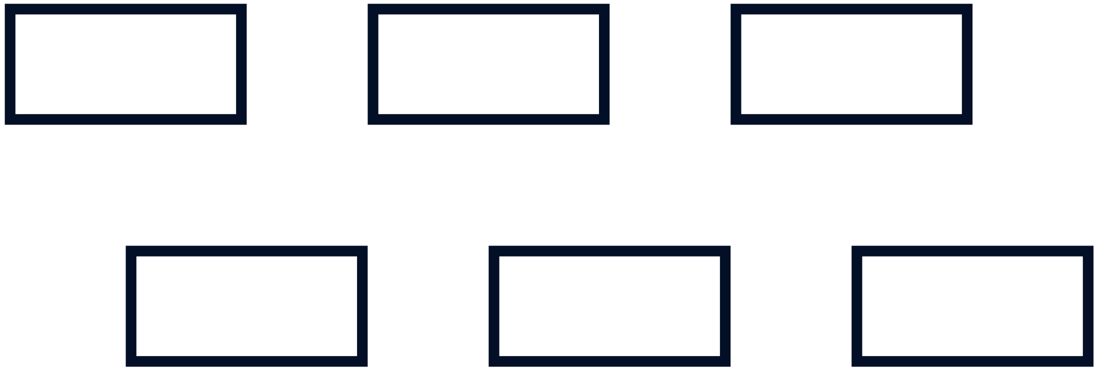

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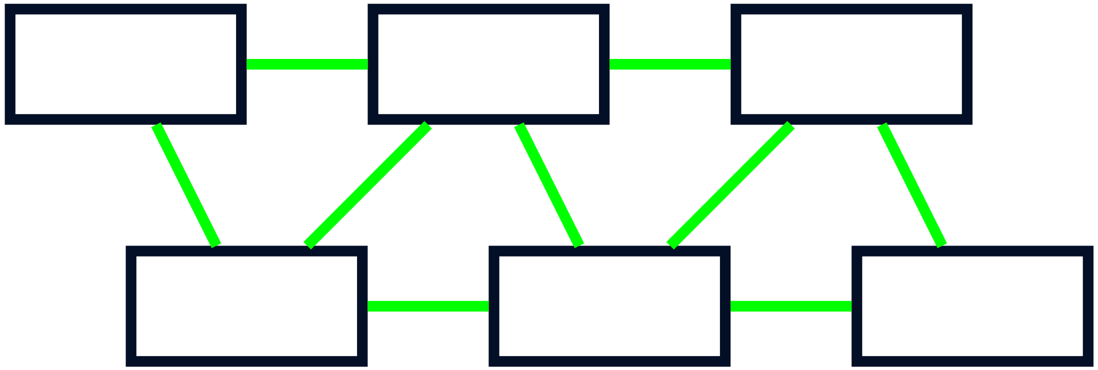

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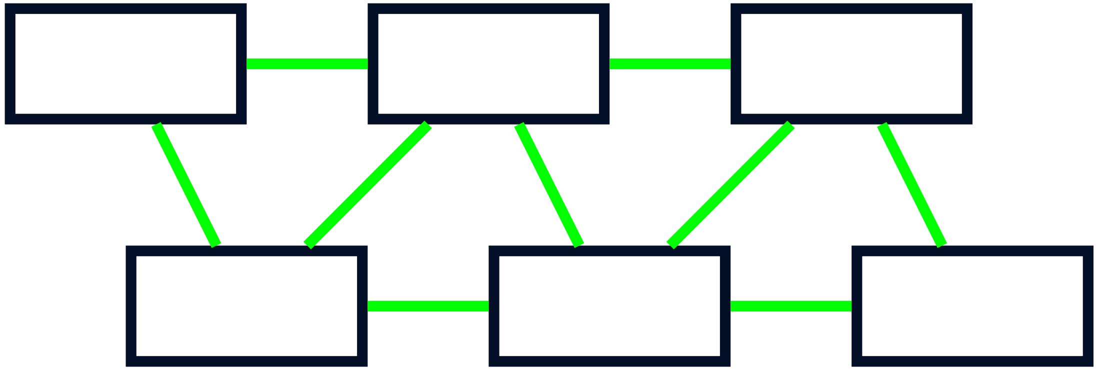

- This approach is standard for hardware systems.
- It is far less common for software systems.
- A reason is perhaps that software components are far less standard than hardware components.

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A Model of Software and Database Components

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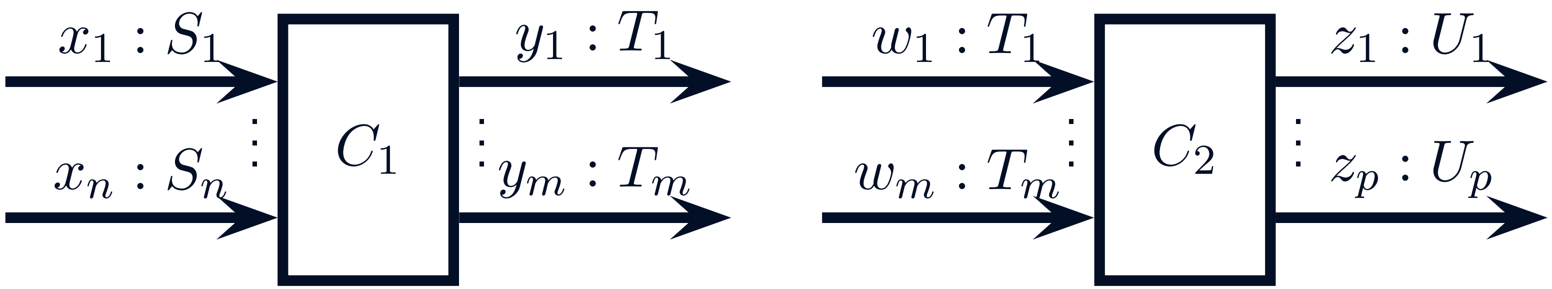
- Data on the channels takes the form of *streams*.



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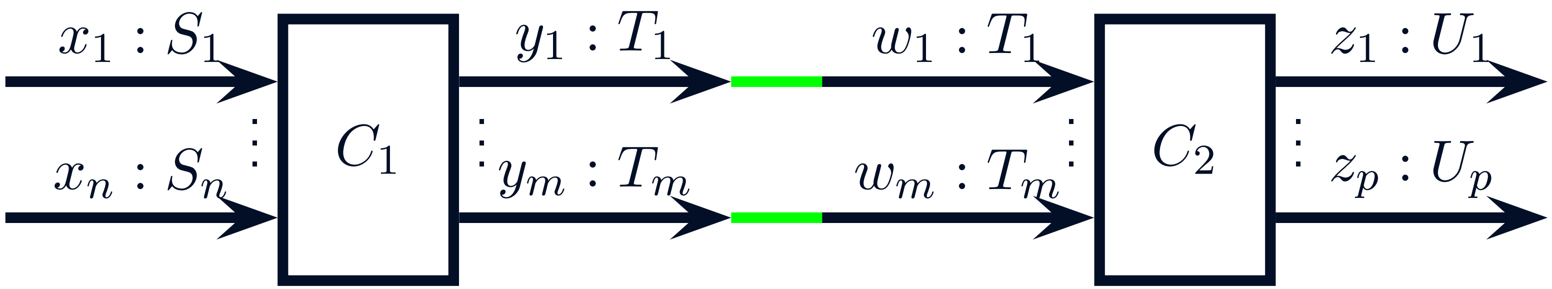
- The S_i's and T_i's are the *types* of the channels.
- Interconnection must respect the channel types.



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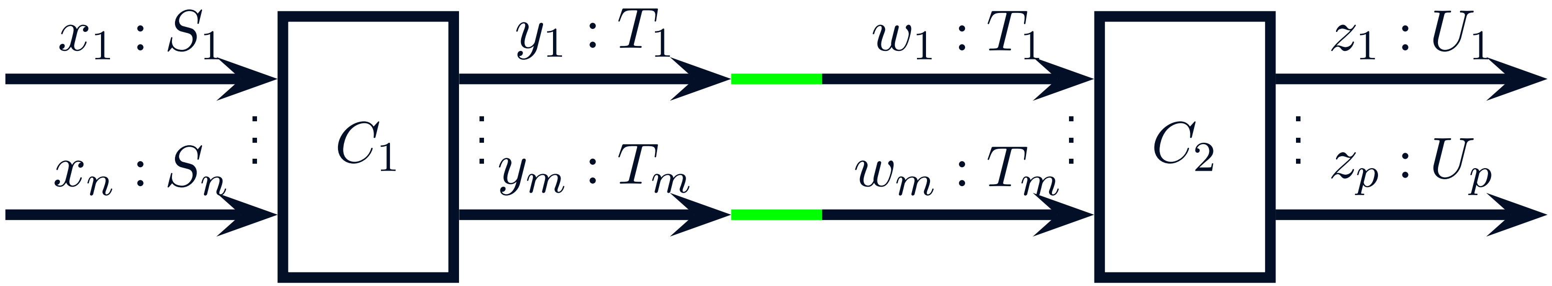
- The principle upon which this model is based in *co-design* – that applications are integrated into the components during the design process.
- This implies that communication via streams of view states as the fundamental notion of communication between database components.



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- The theory should be flexible and not limited to a particular data model.
- Nevertheless, it should be firmly motivated by constructions in the classical relational model.

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- The property of being *dependency preserving* (*commuting congruences*) is thus critical.
- Goal: Use these ideas to motivate the definition of a component.

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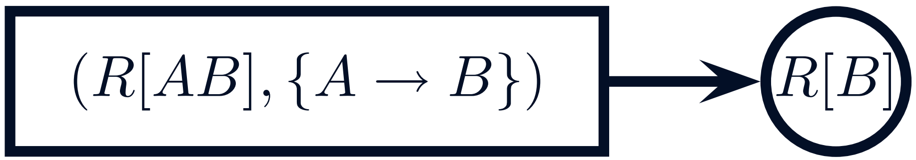

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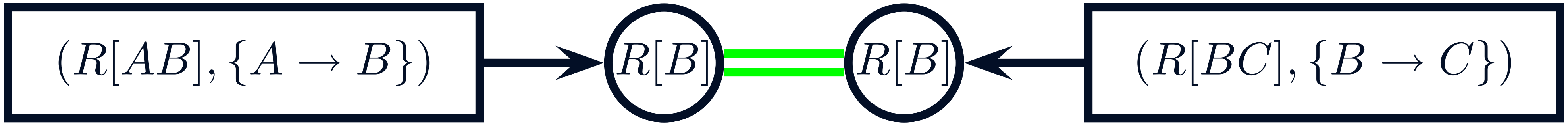

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- This recaptures lossless and dependency-preserving decomposition, but as a *composition* rather than as a decomposition.
- No reference to the main schema is necessary.

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General Notions of Database Components

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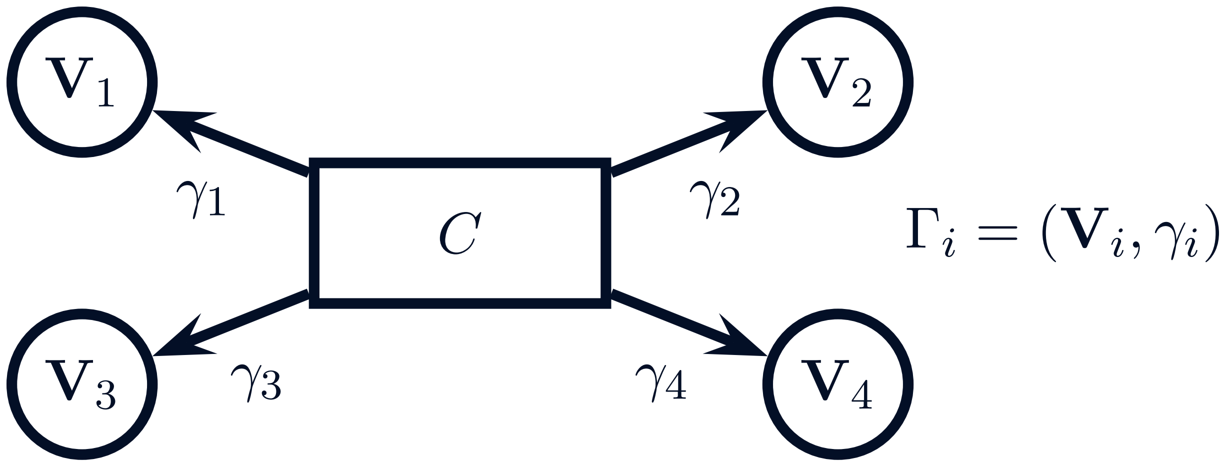

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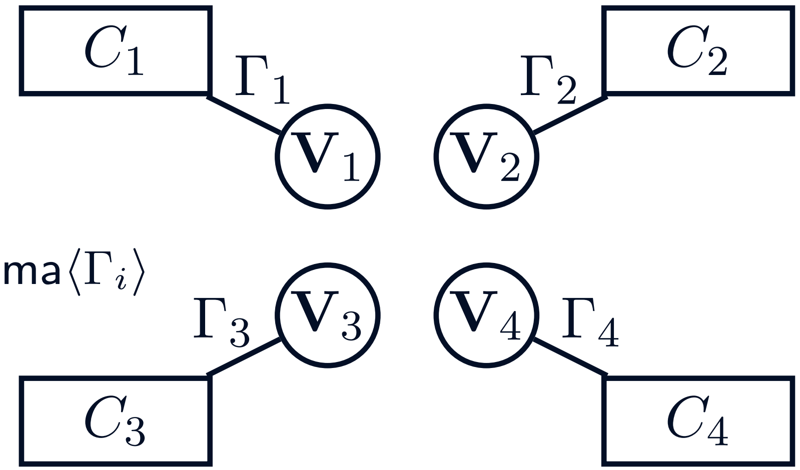

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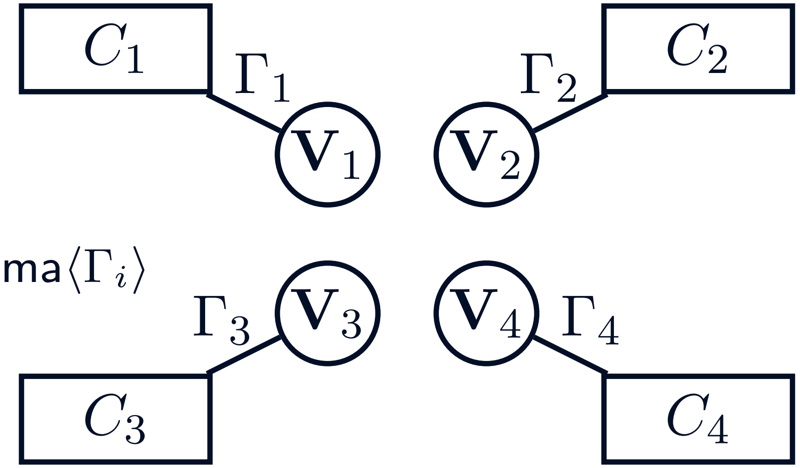

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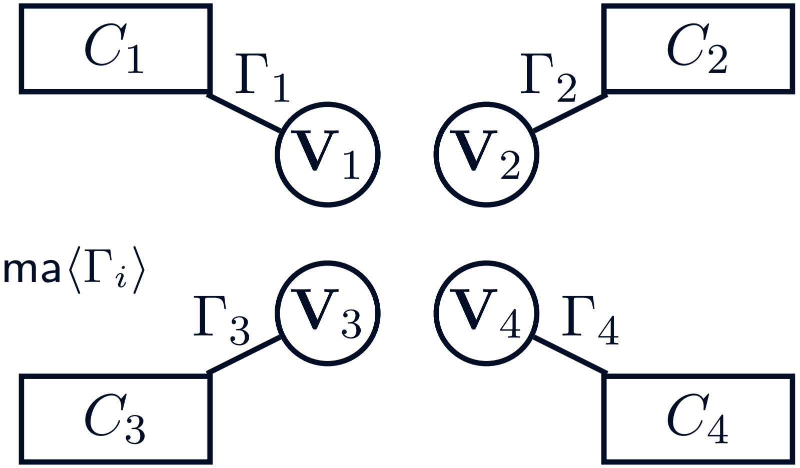

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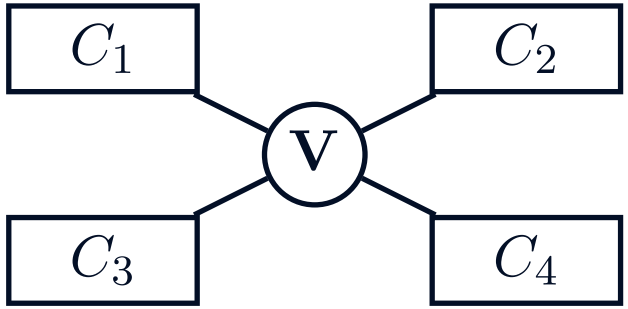

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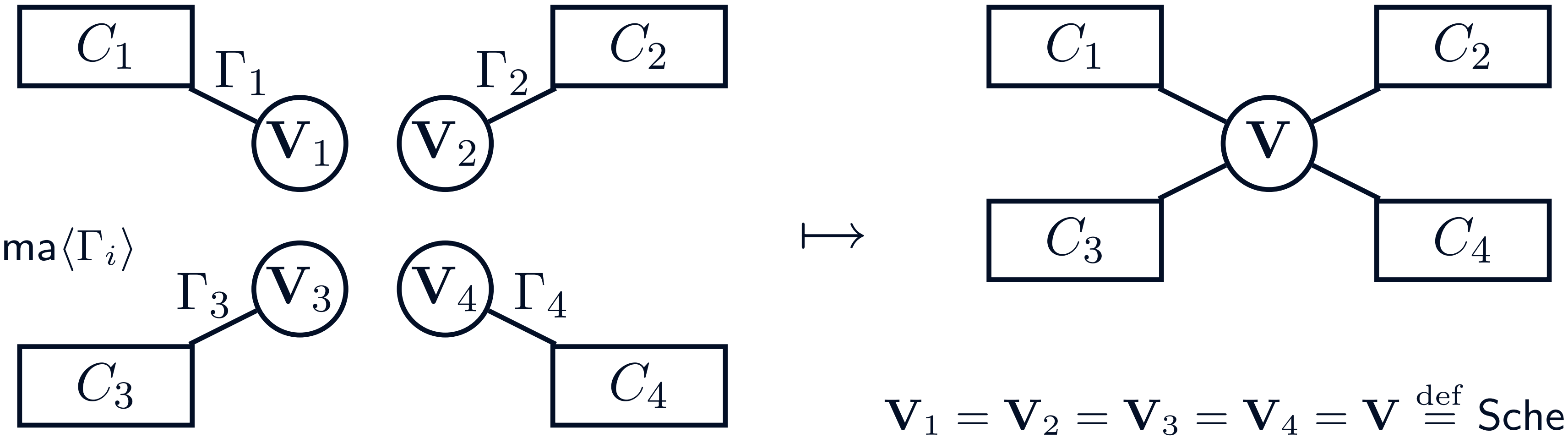

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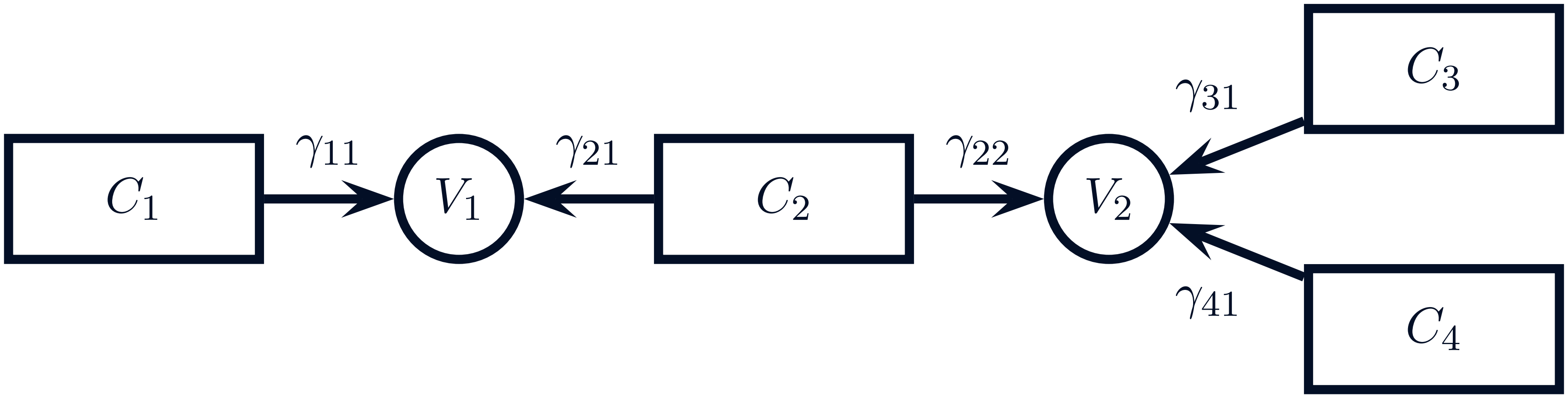
- An *interconnection family* is a set of star interconnections.

- In the case of an acyclic interconnection, the state is very easy to describe.



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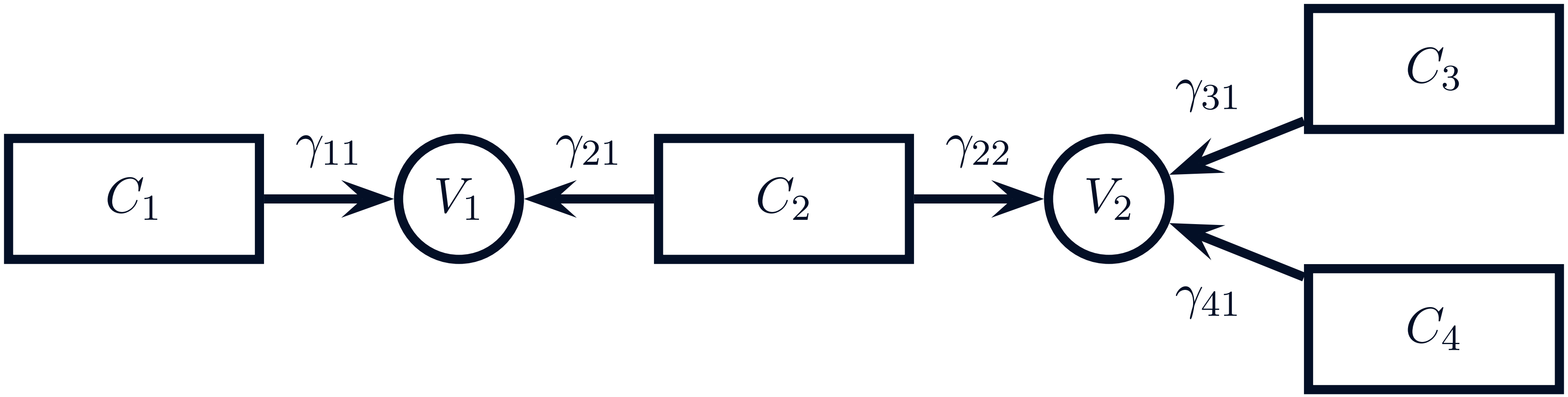

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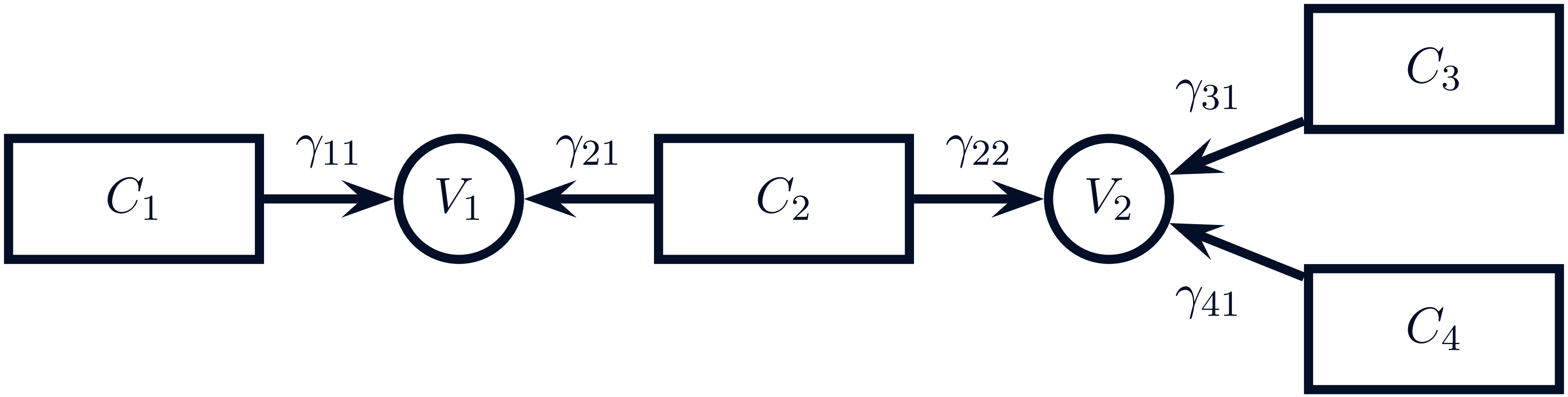
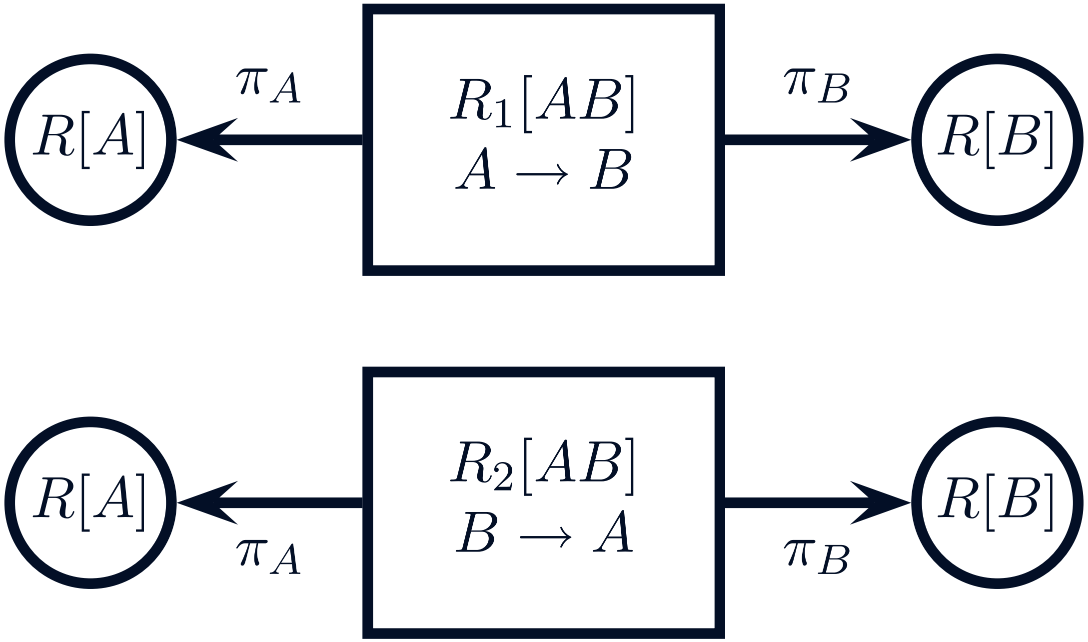
- Unfortunately, serious complications arise if the interconnection is allowed to be cyclic.



Cyclicity Issues



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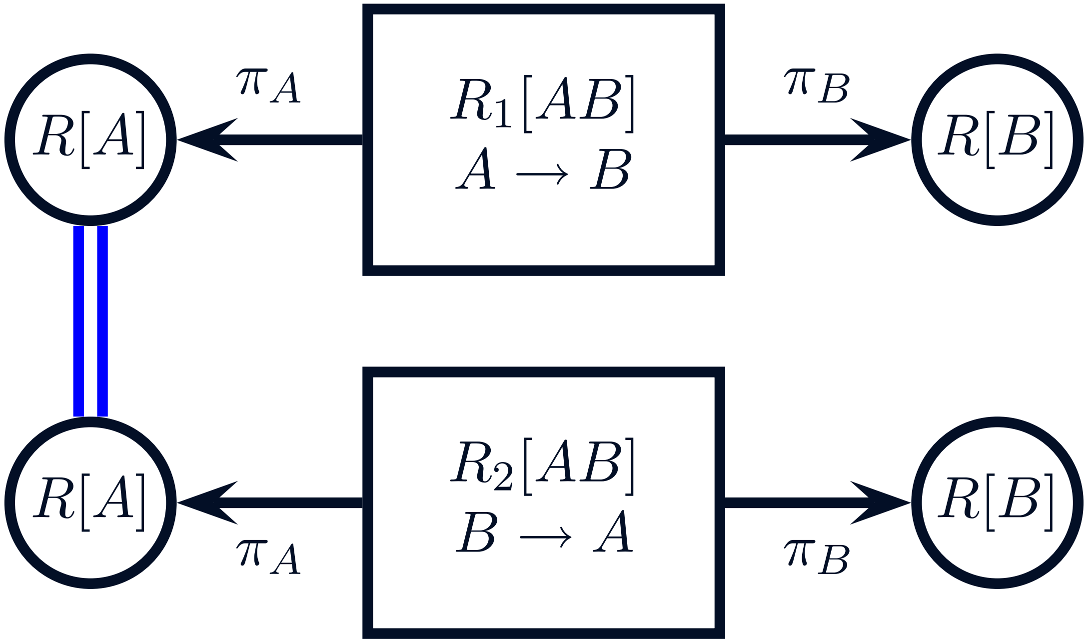

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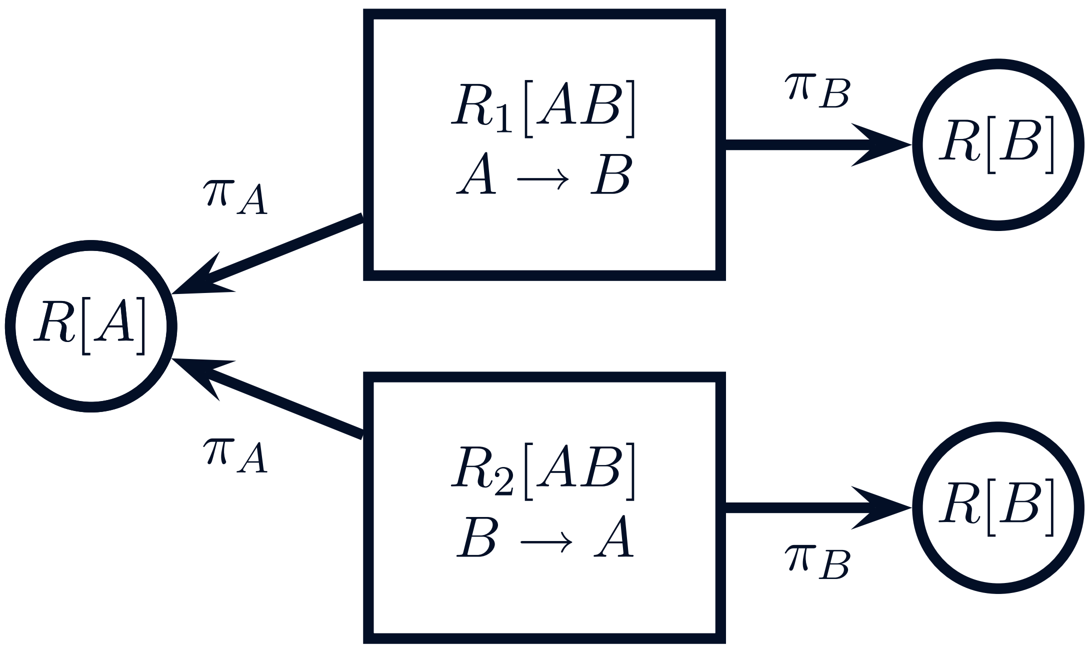

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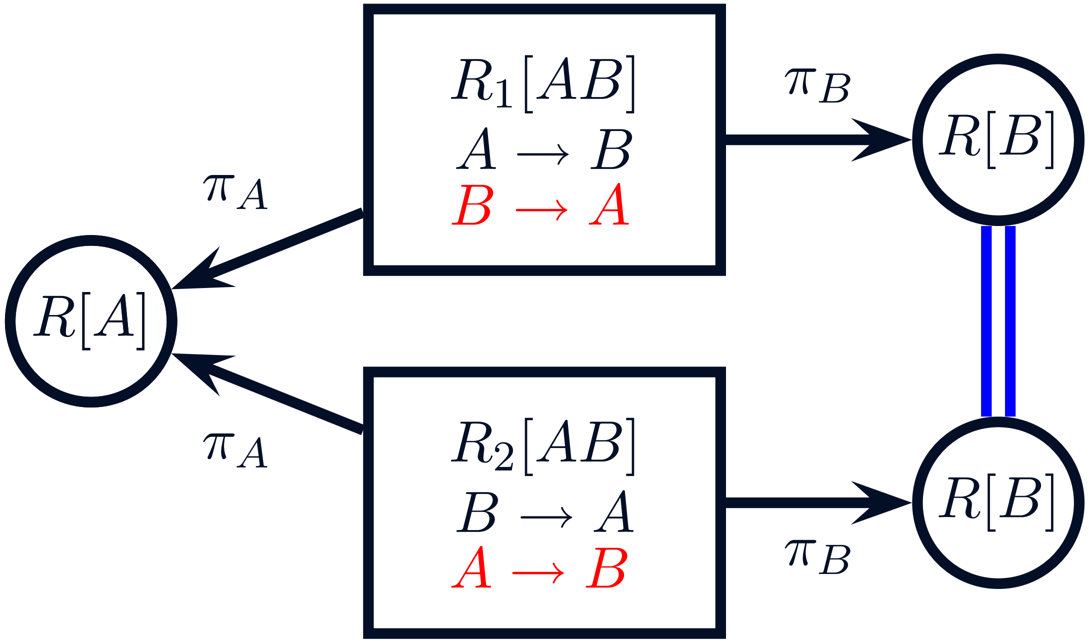

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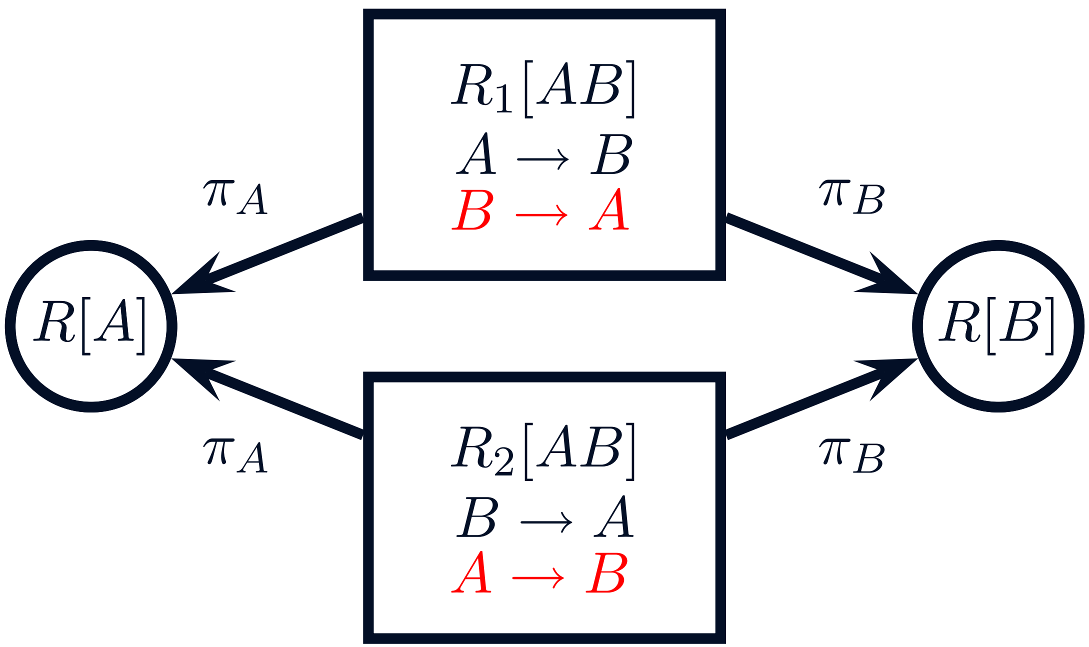

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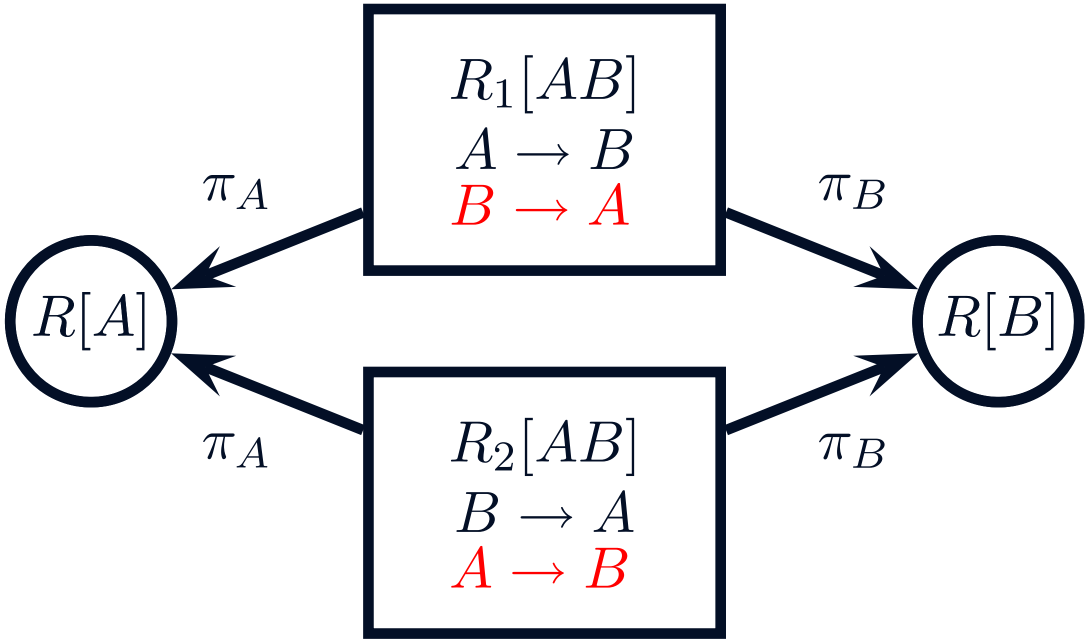

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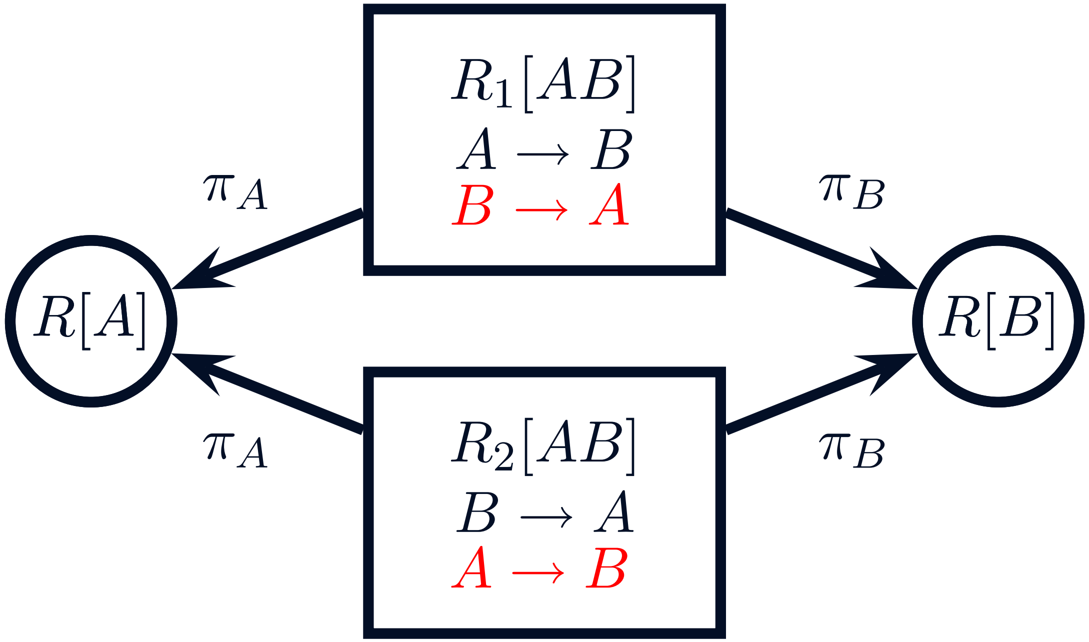

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- This type of cyclic interconnection is manageable.

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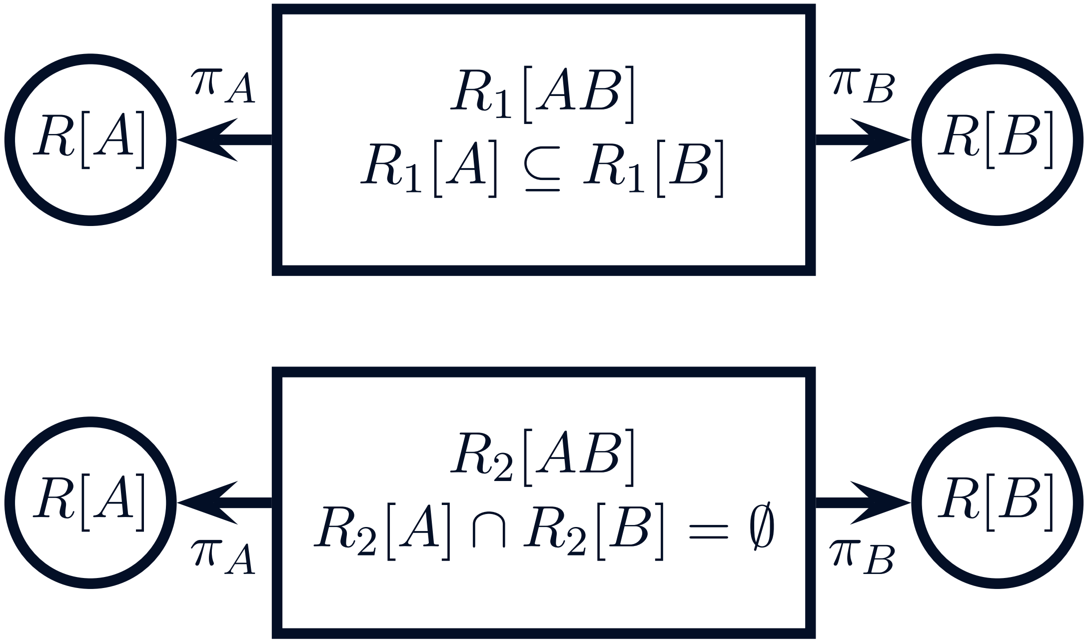

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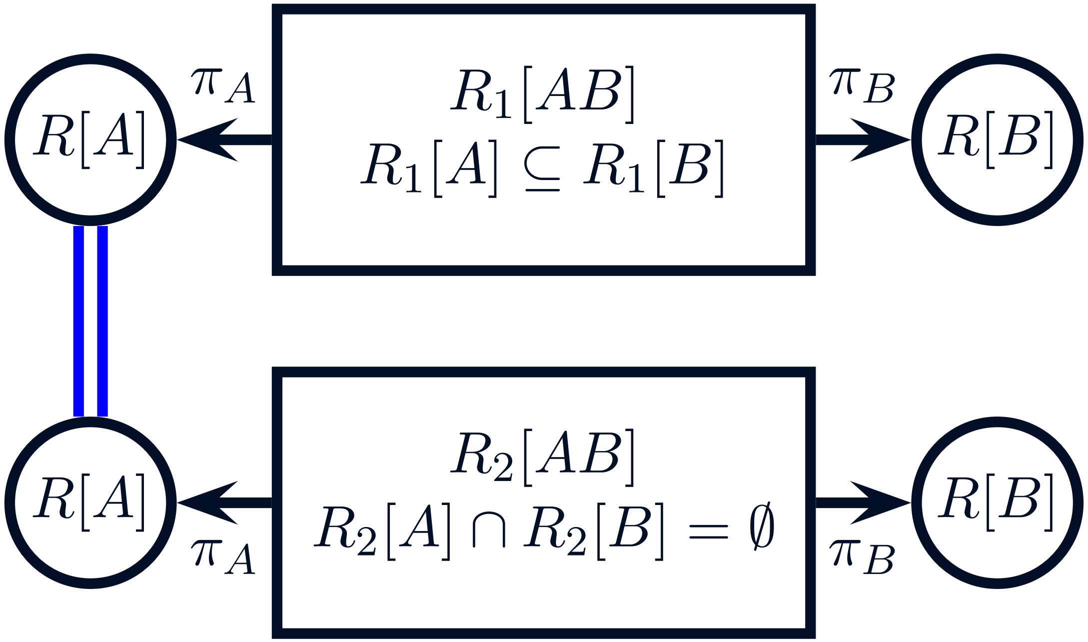

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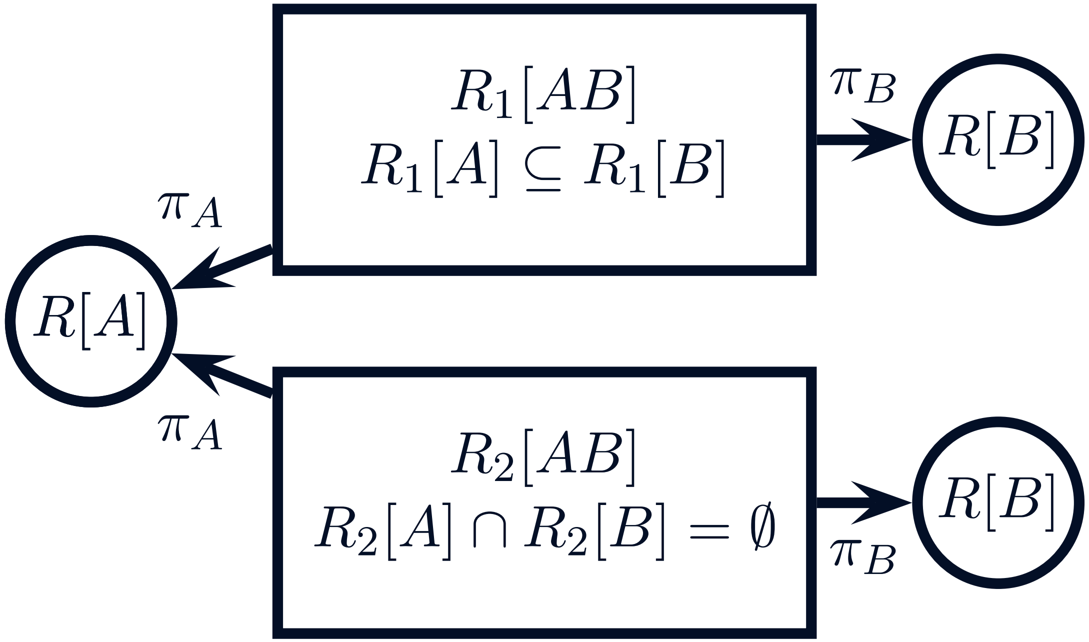

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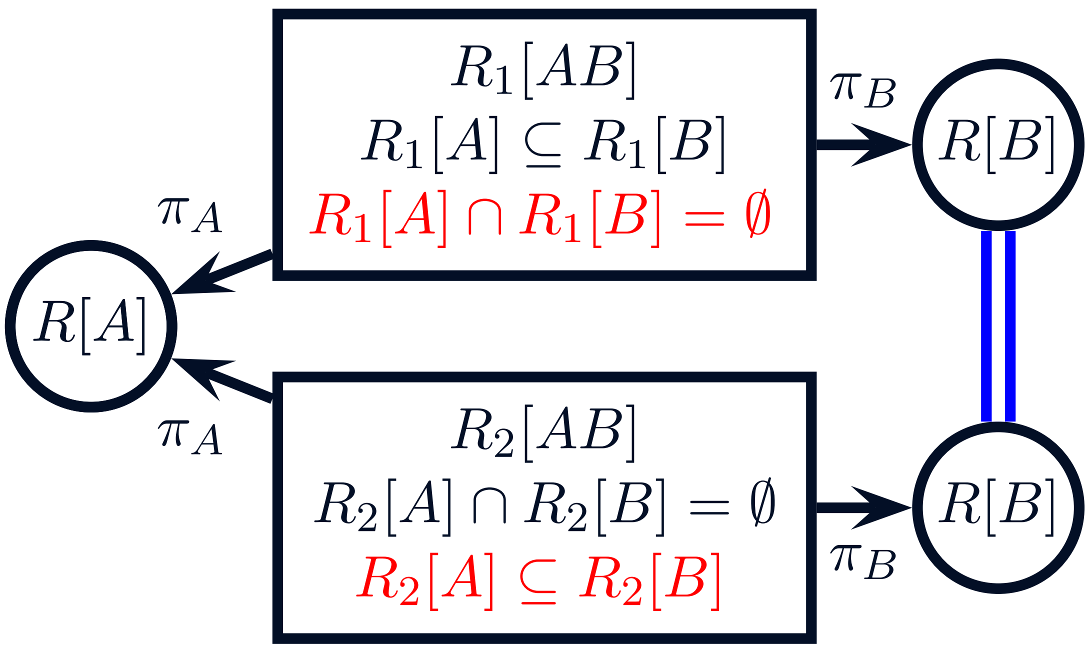

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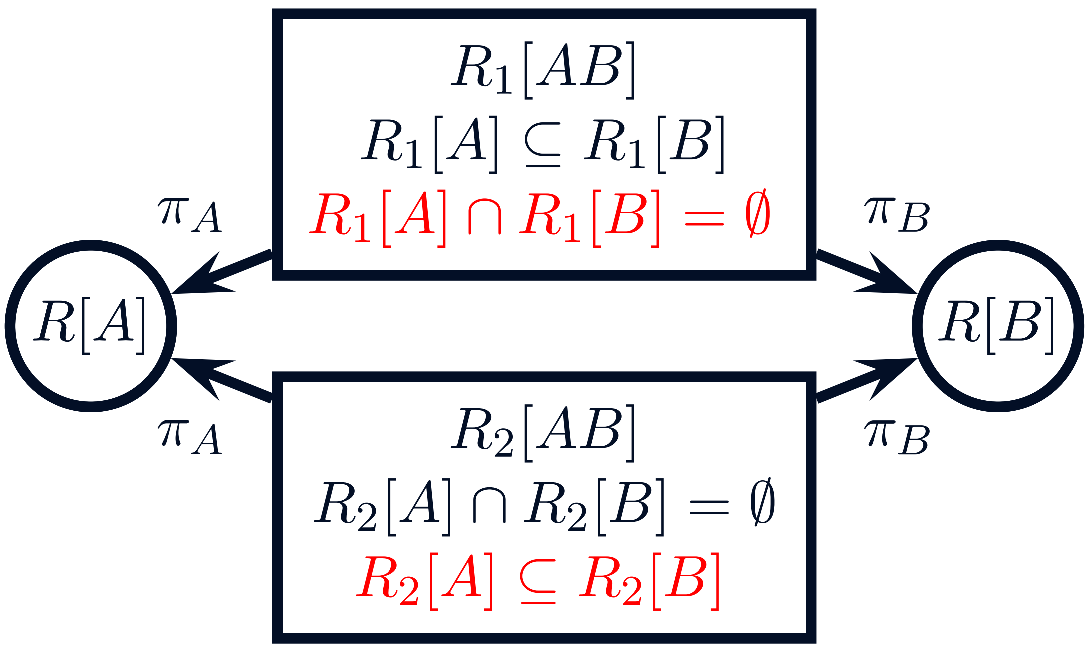

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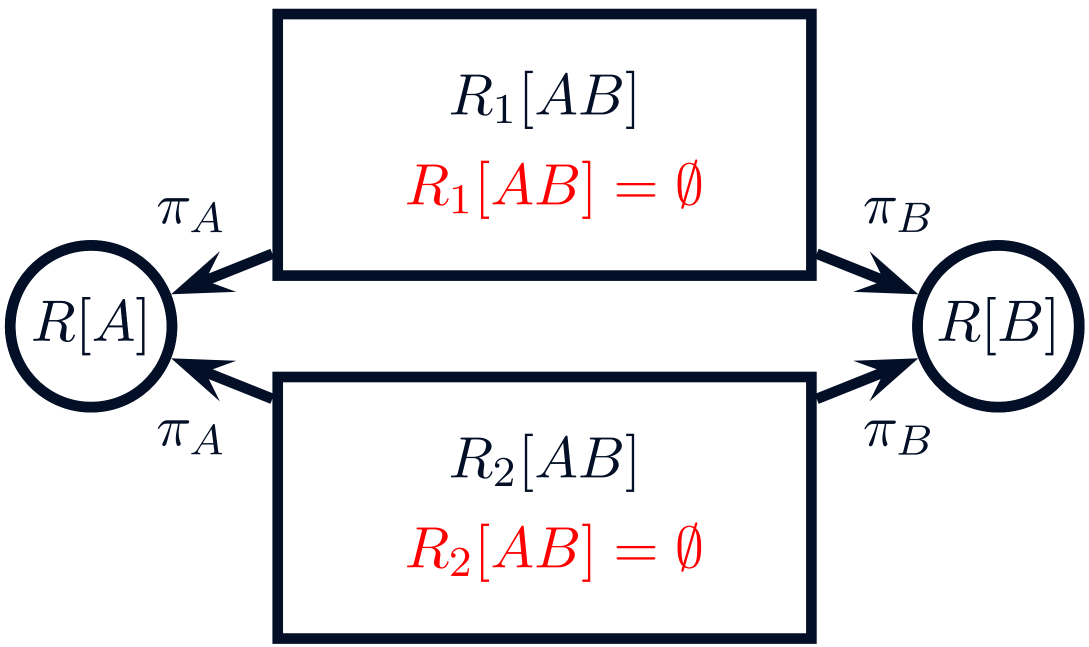

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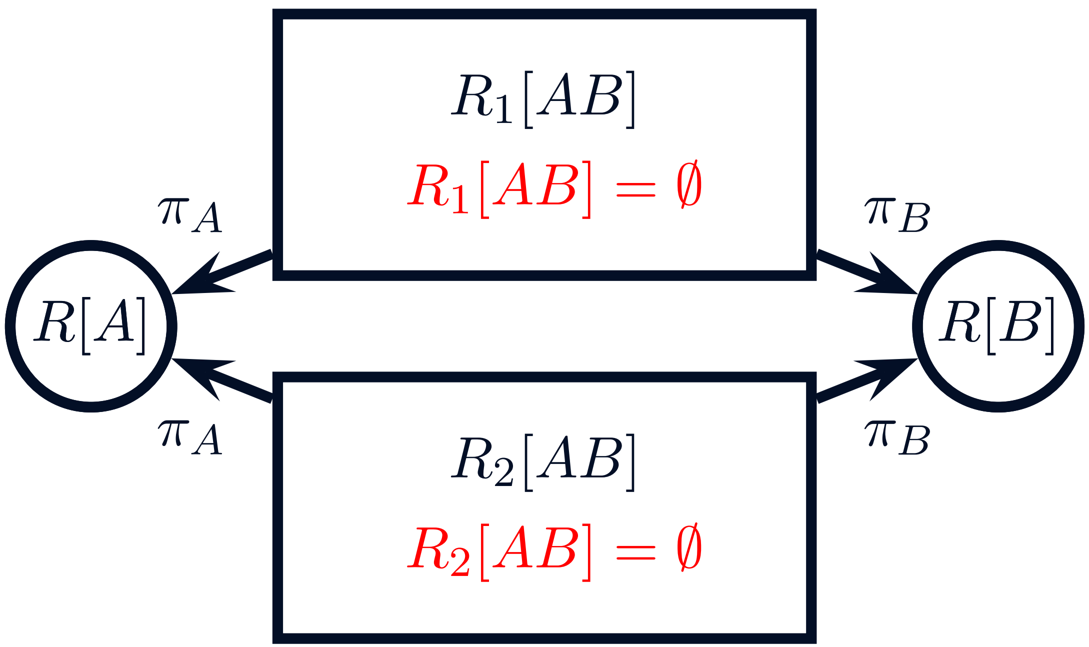

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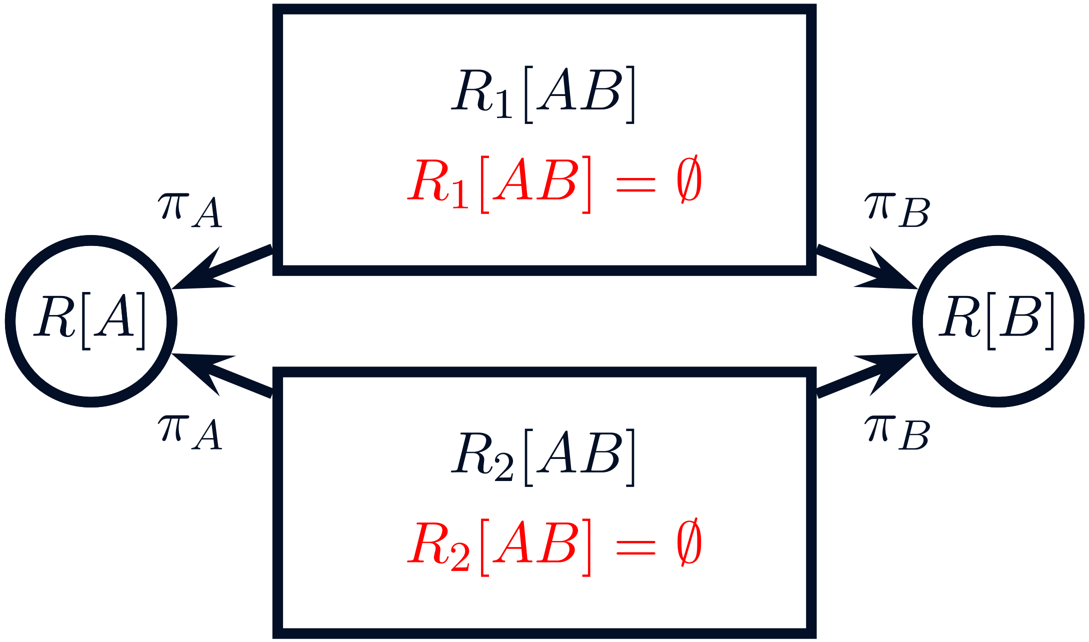

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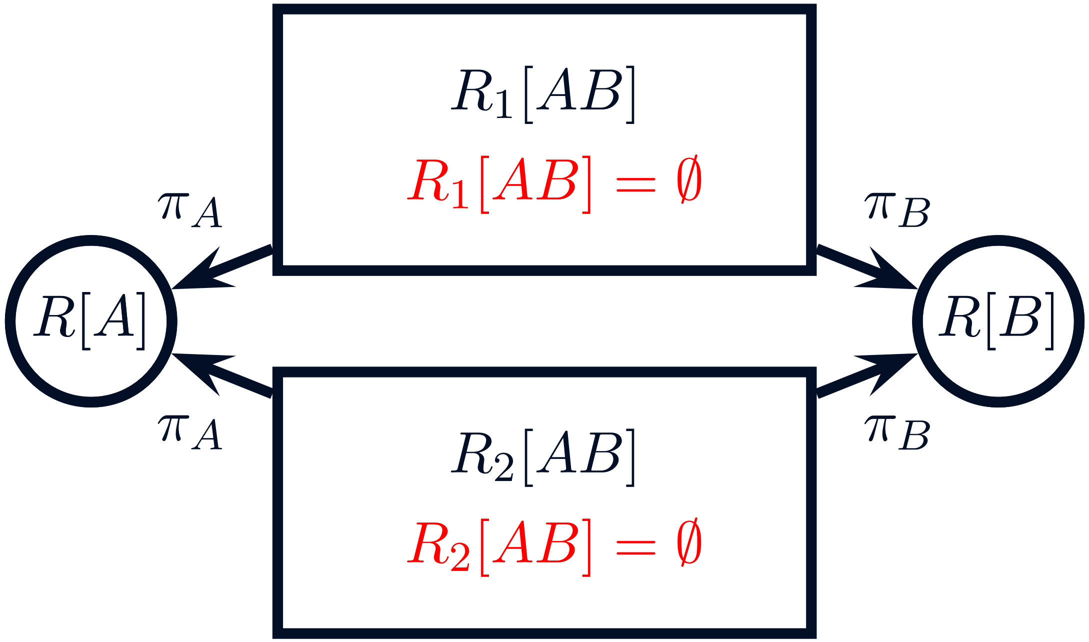

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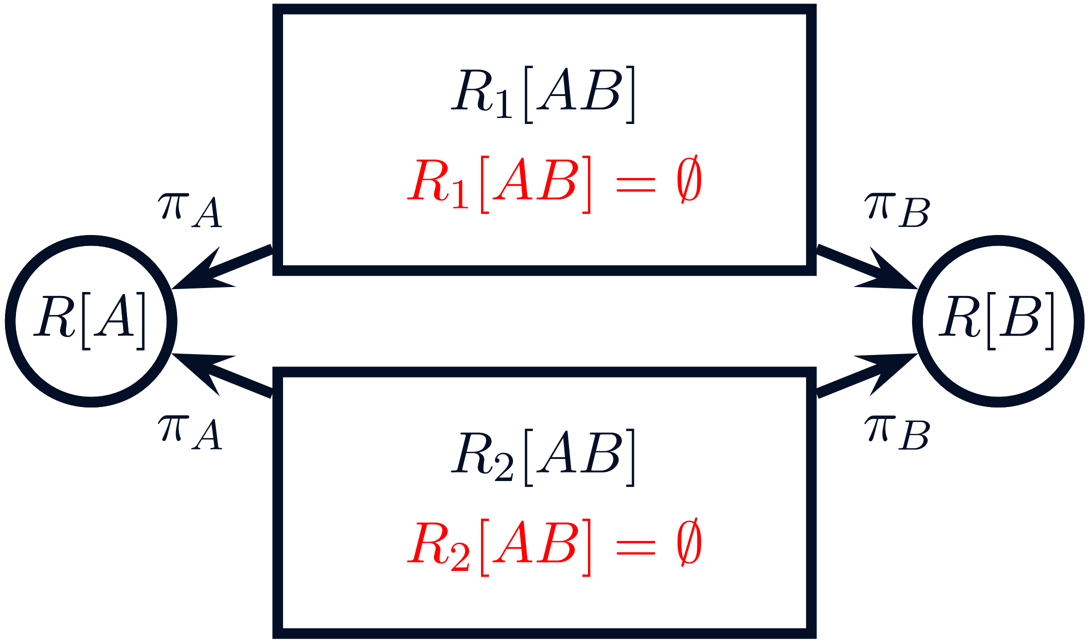

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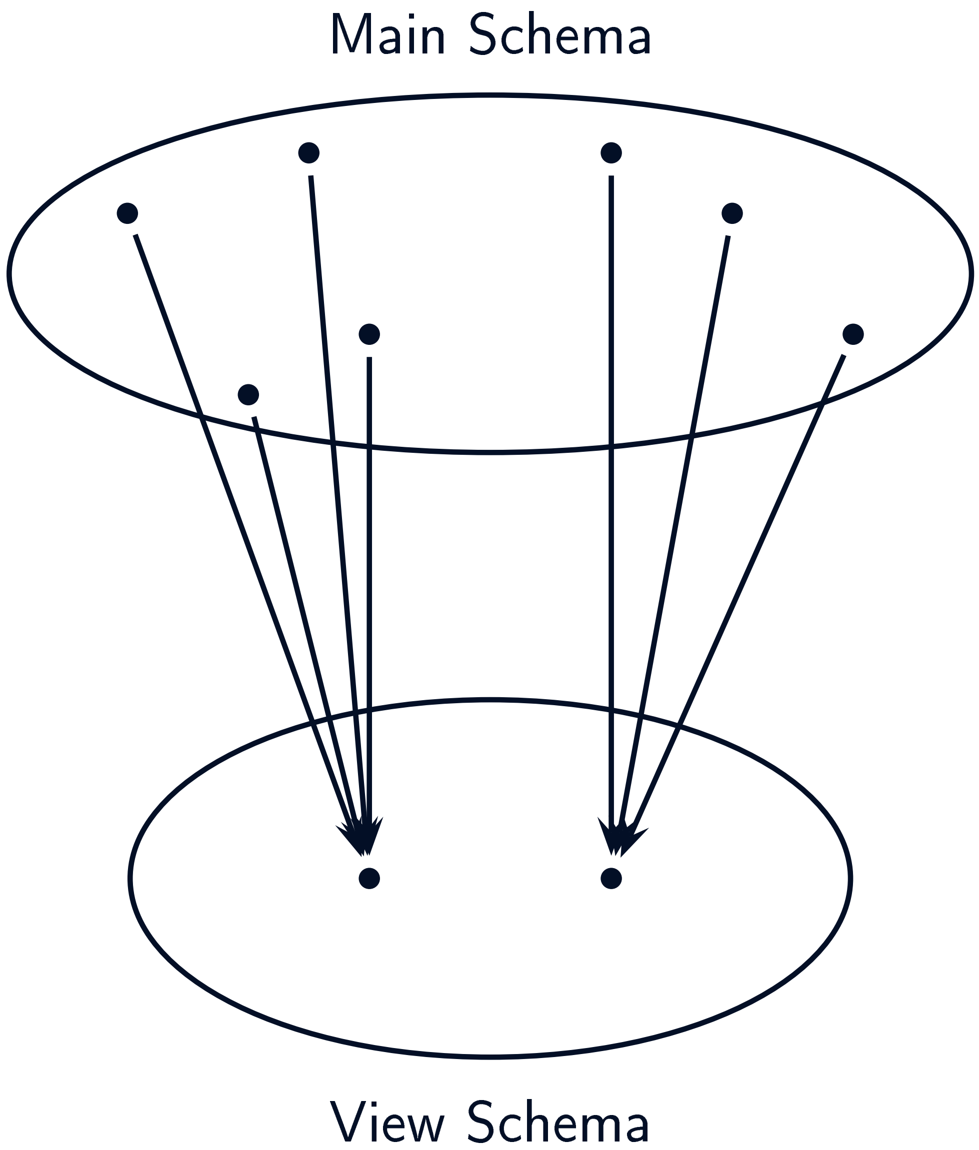
$\Rightarrow$ Cyclicity is a major issue to be addressed in the theory.

Basic Update Support via Cooperation

The Update Problem for Database Views

- On the underlying states, the view mapping is generally *surjective* (onto) but not *injective* (one-to-one).



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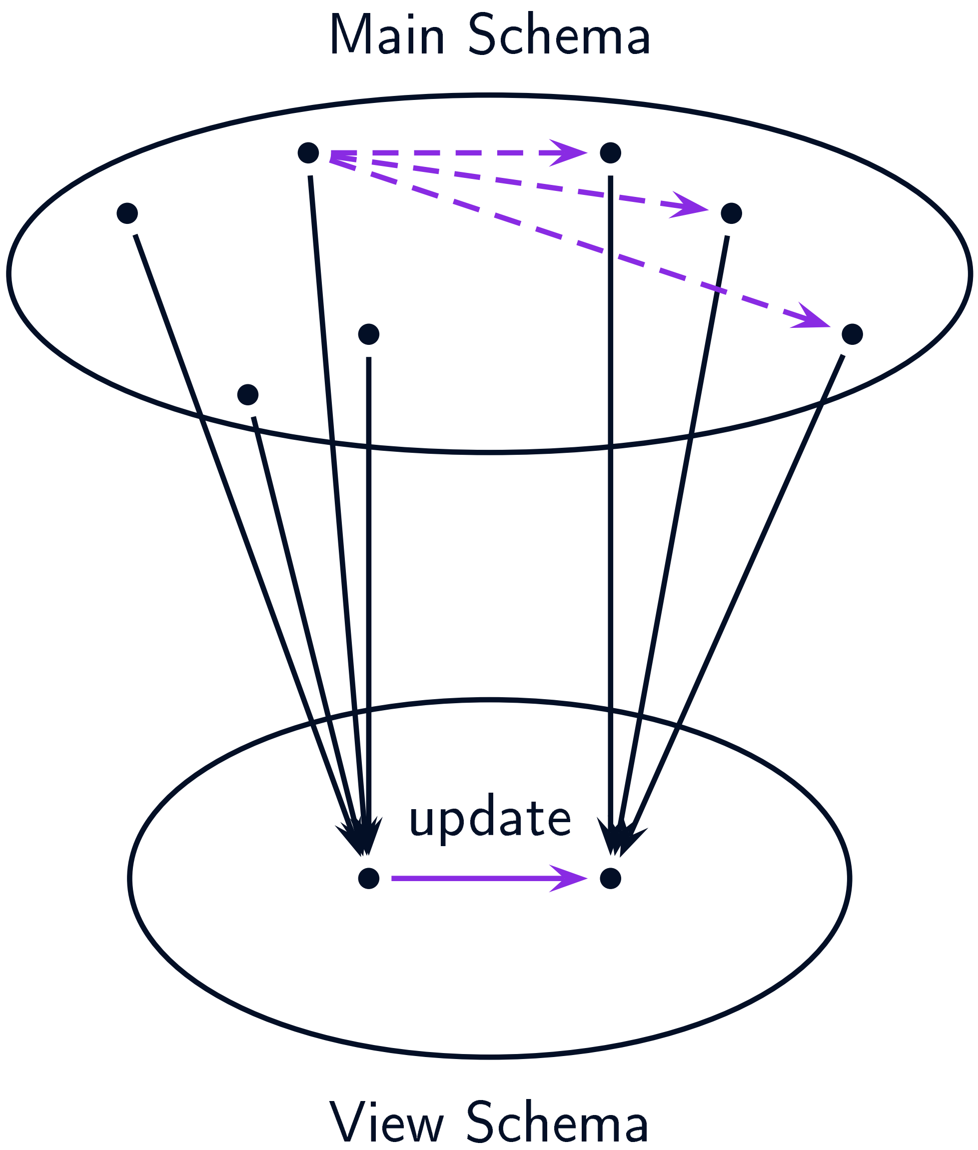

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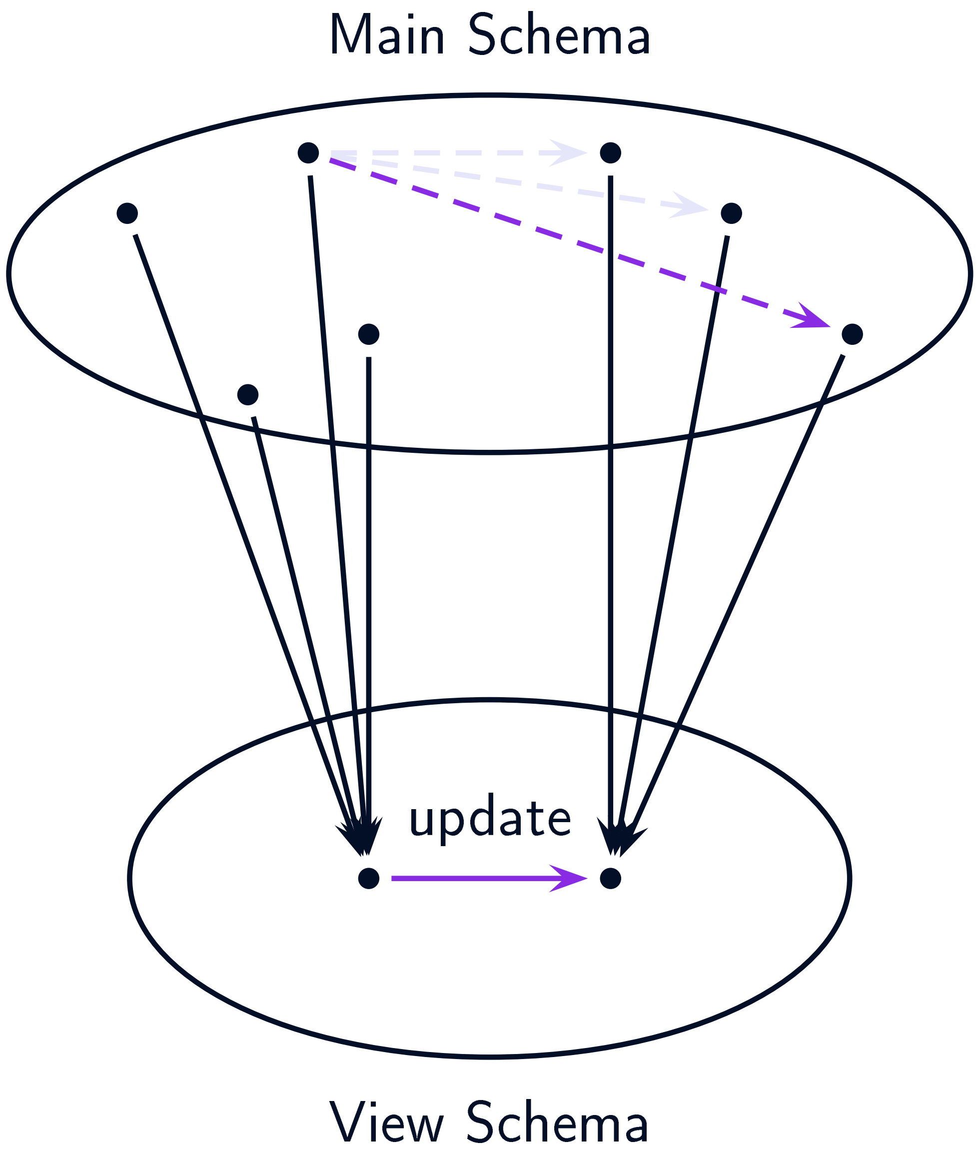

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- Thus, a view update has many possible *reflections* to the main schema.
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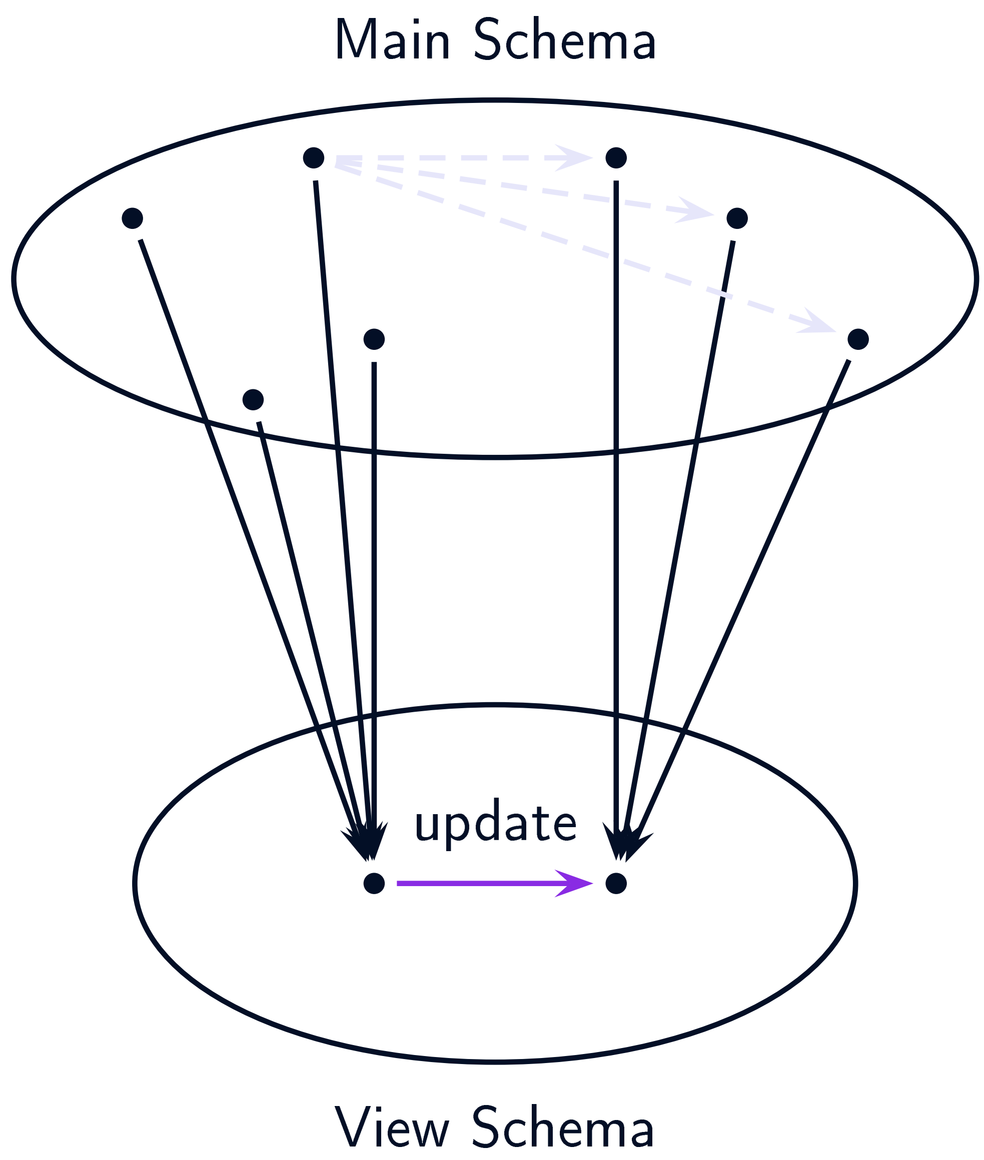
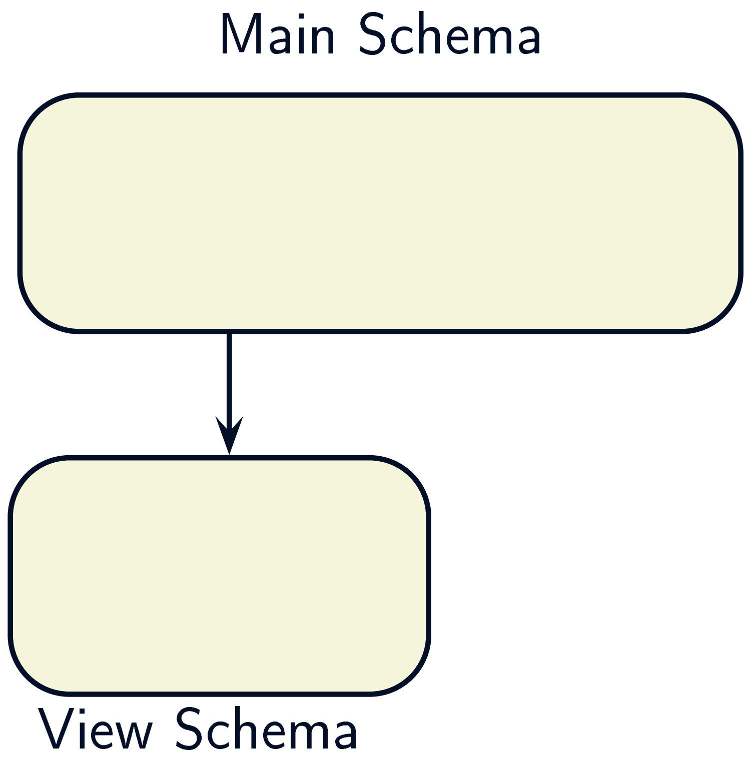
- With a reasonable definition of suitability, it may not be the case that every view update has a suitable translation.



The Constant-Complement Strategy



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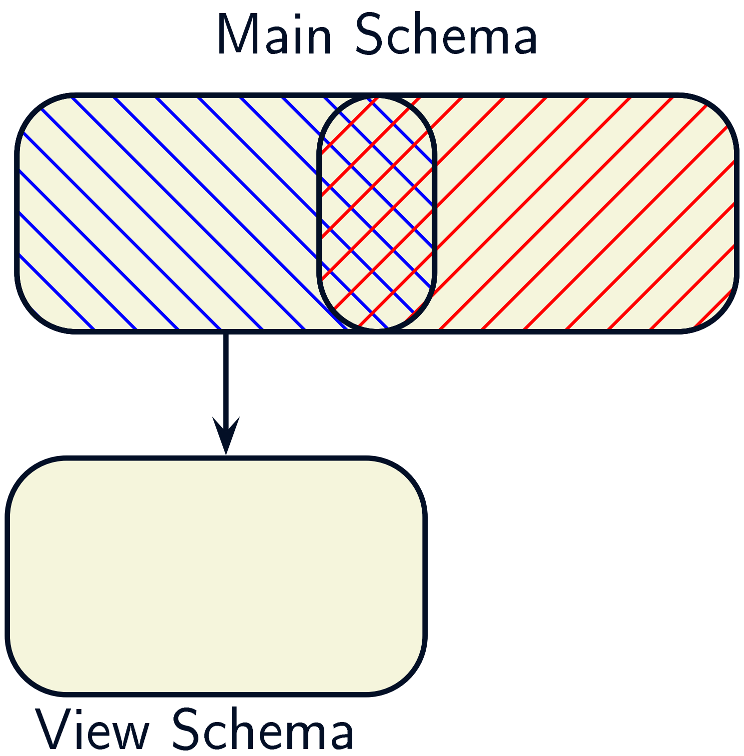

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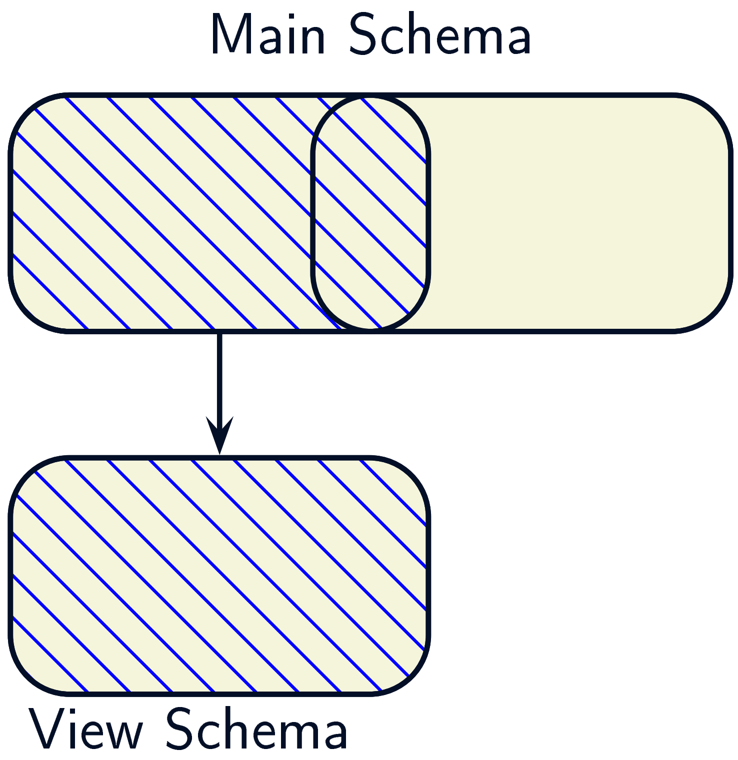

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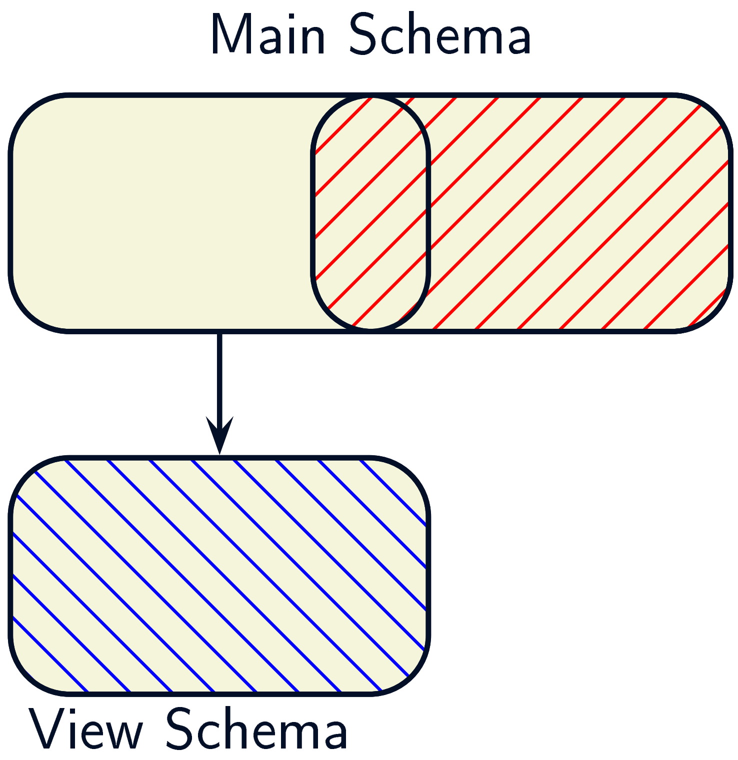

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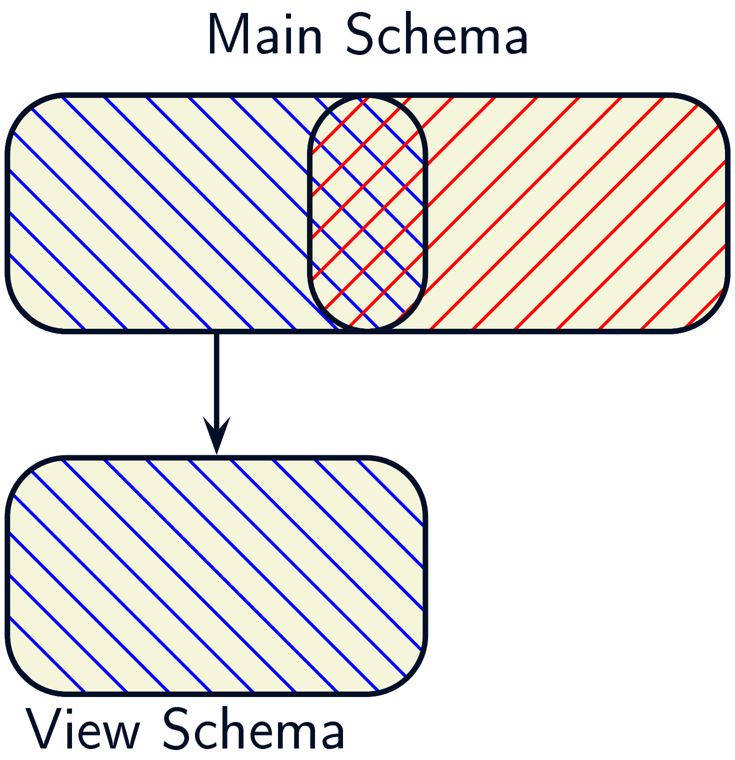

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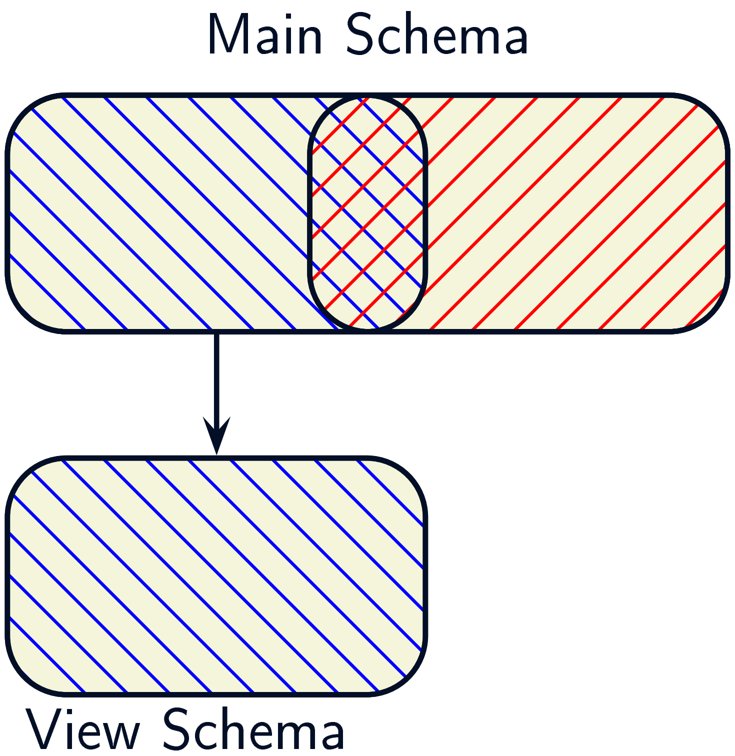

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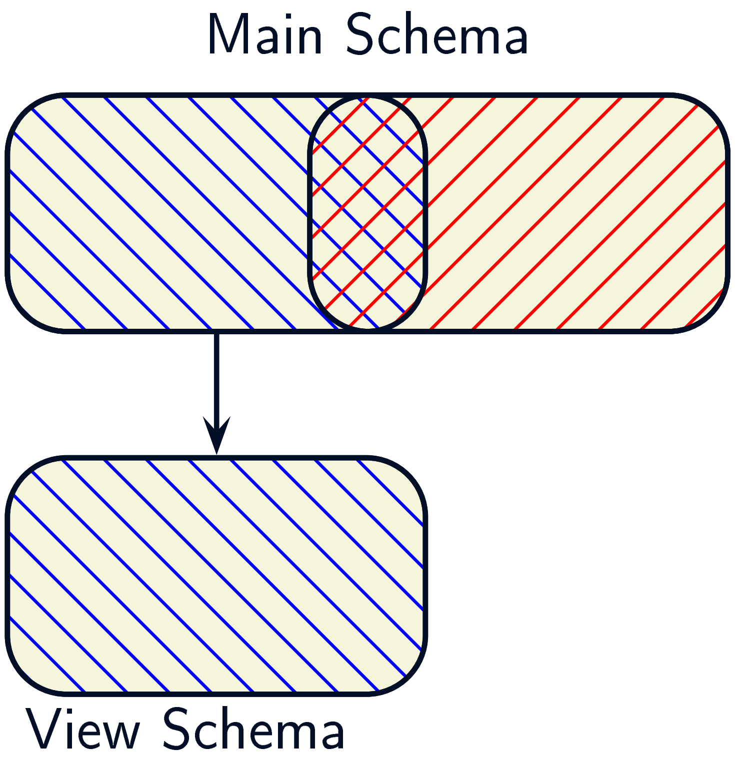

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Question: How can updates which are not supported by constant complement be realized?

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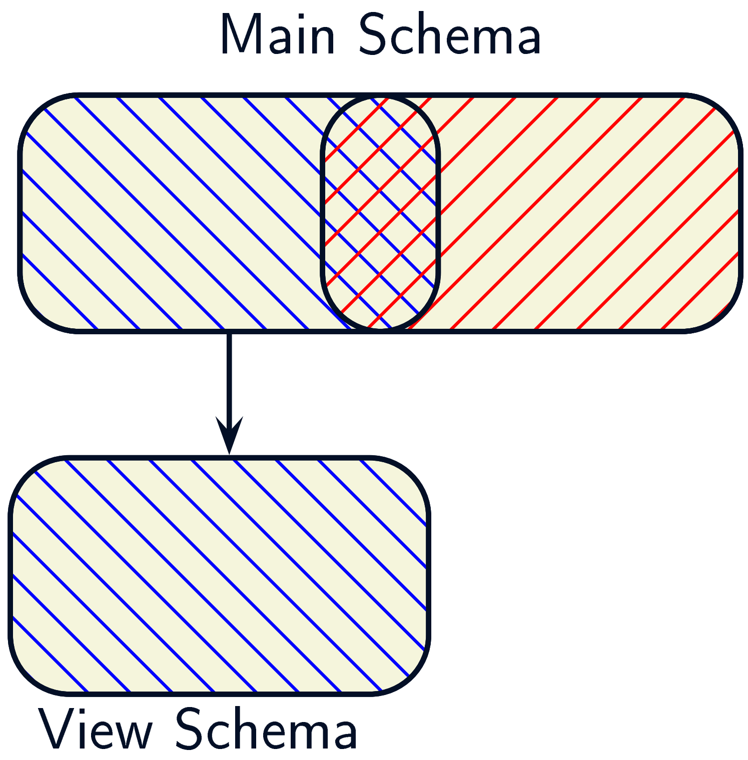

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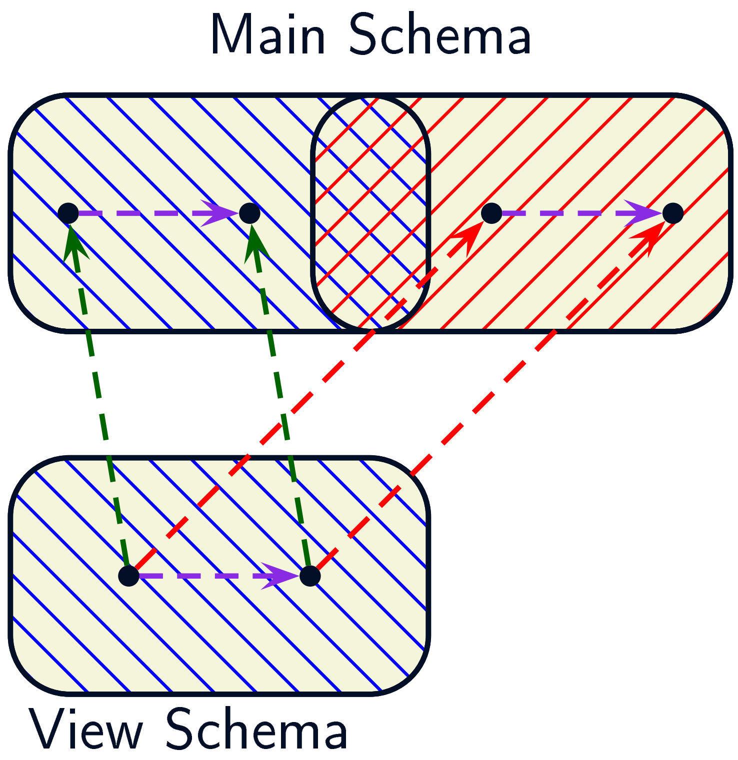

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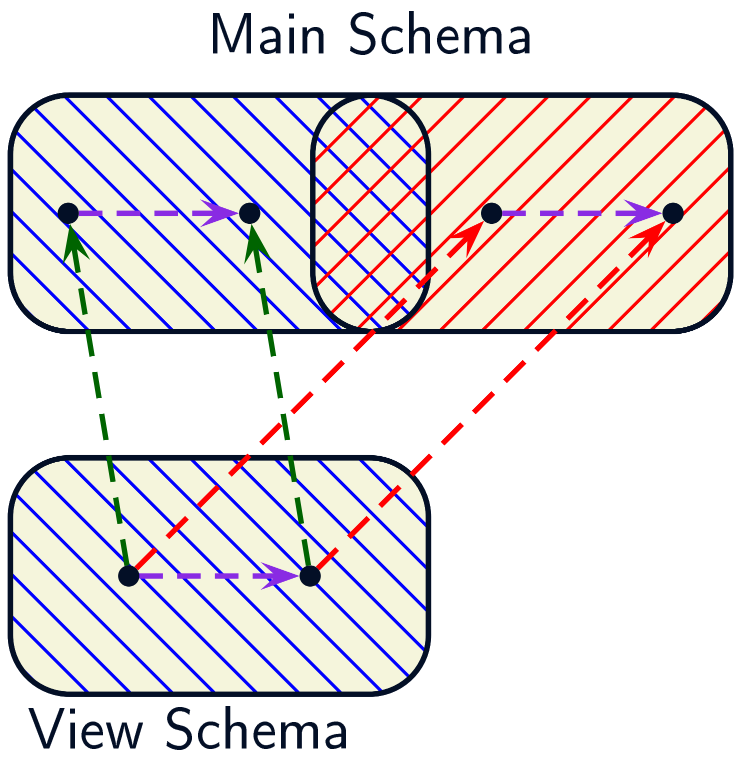

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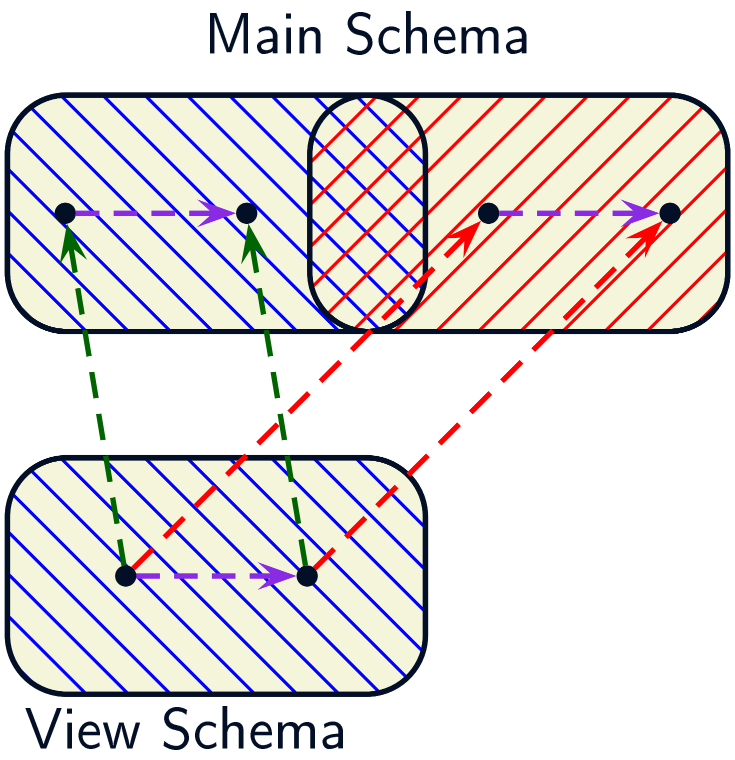

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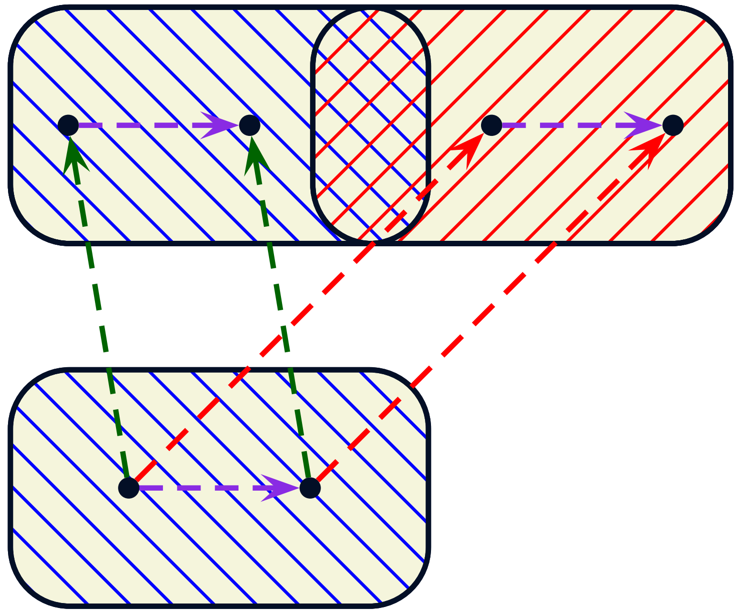

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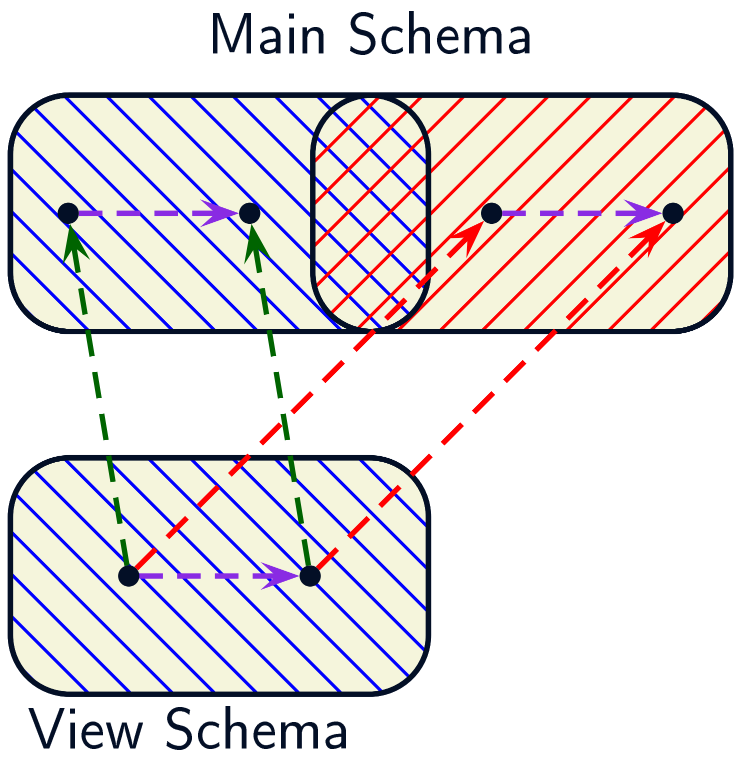

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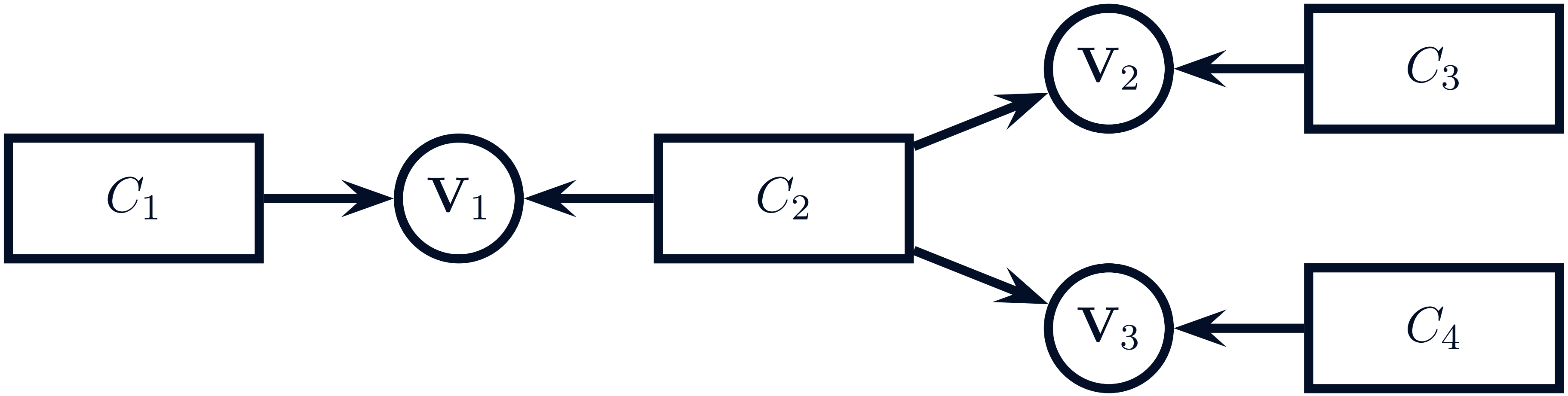
- The user of the view enlists the cooperation of other users to address both the visibility problem and the permission problem.
- All users operate within the limits of their vision of the main schema and their access rights.

The Propagation of Updates through Components



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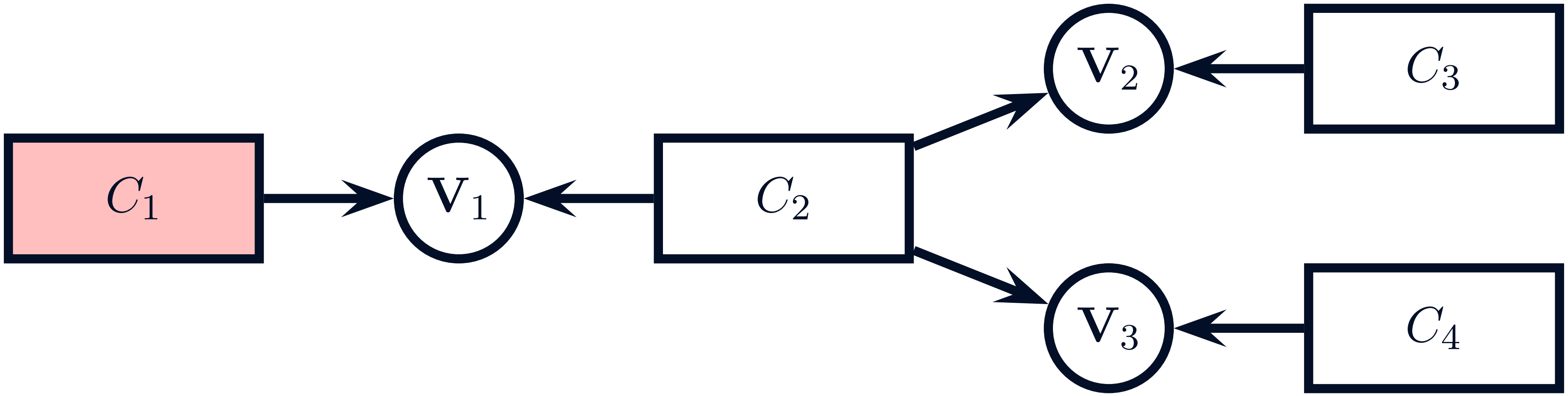

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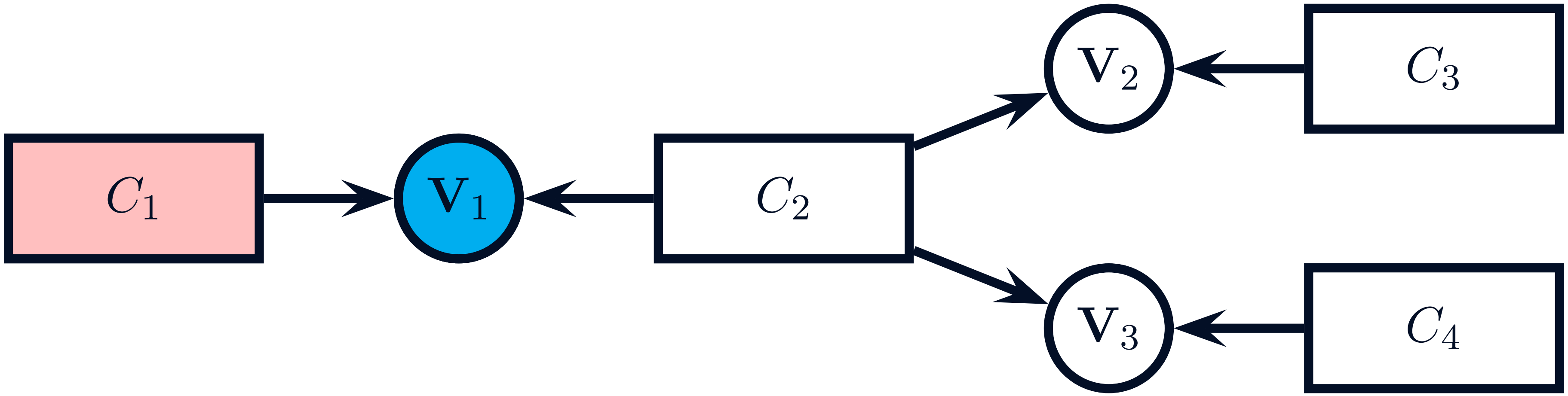

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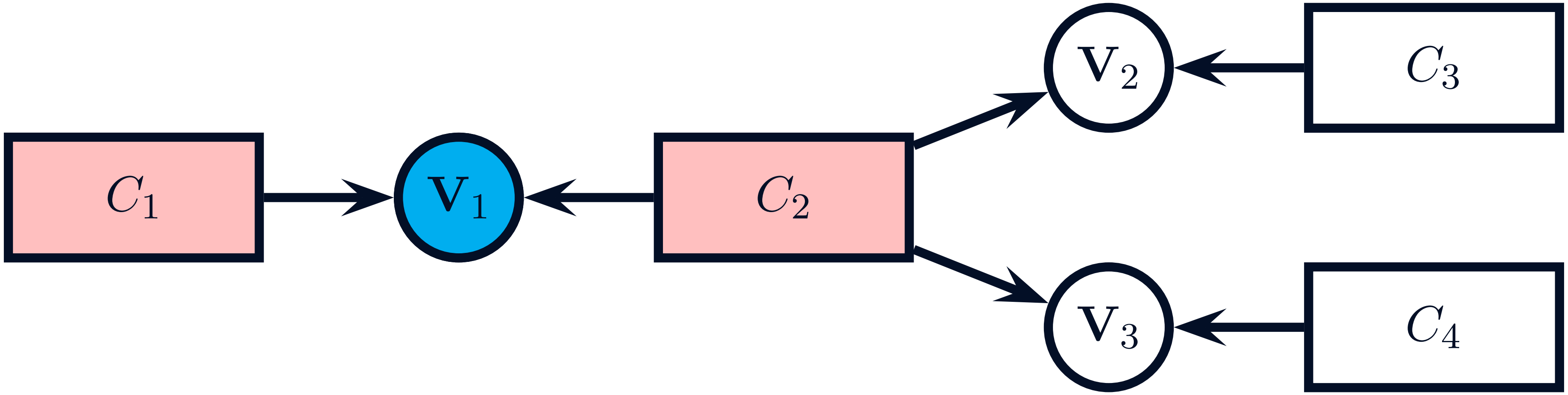

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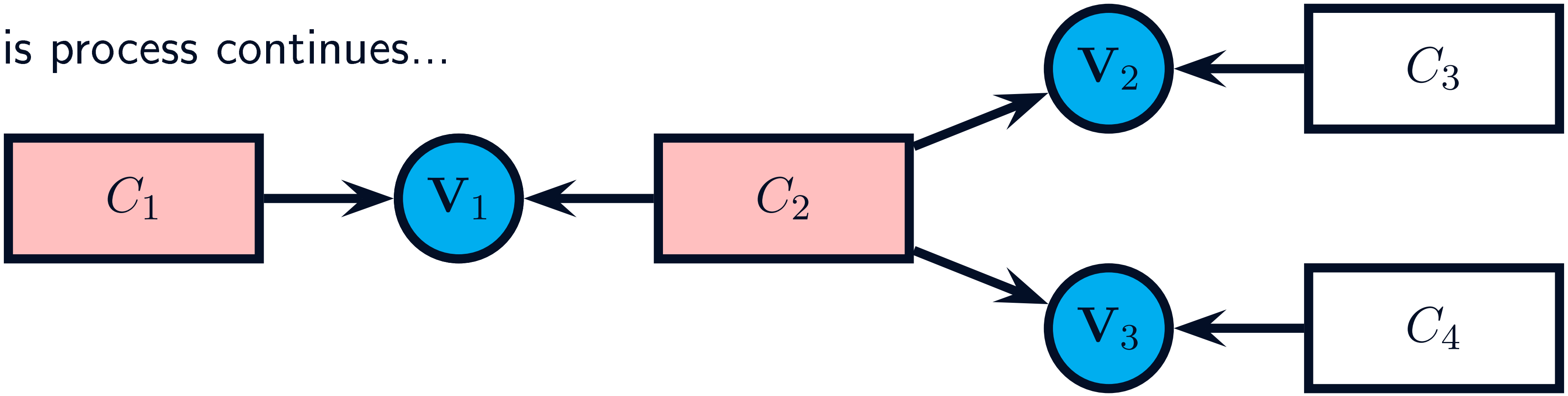

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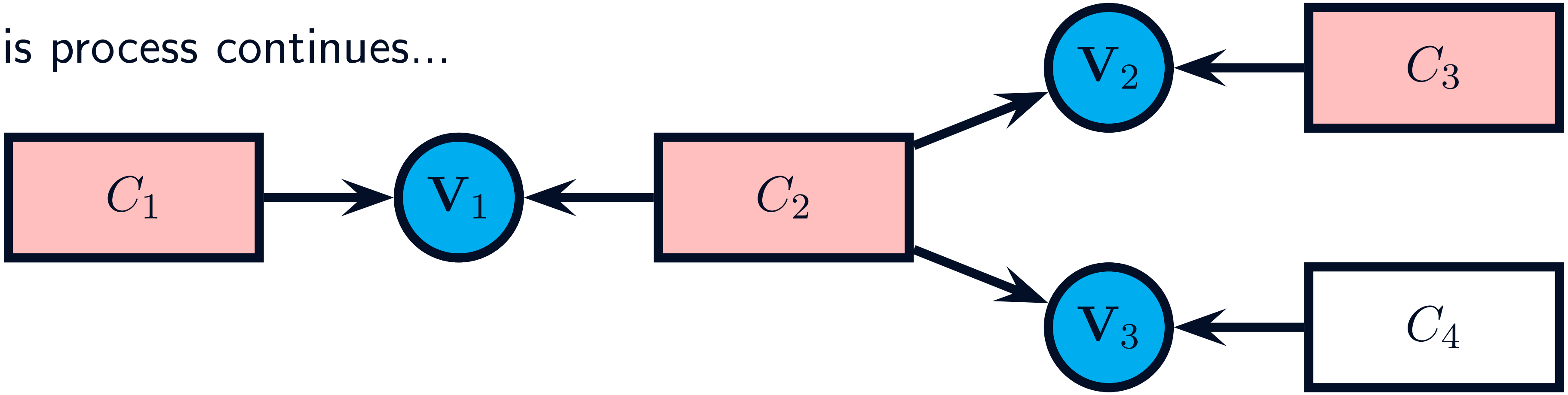

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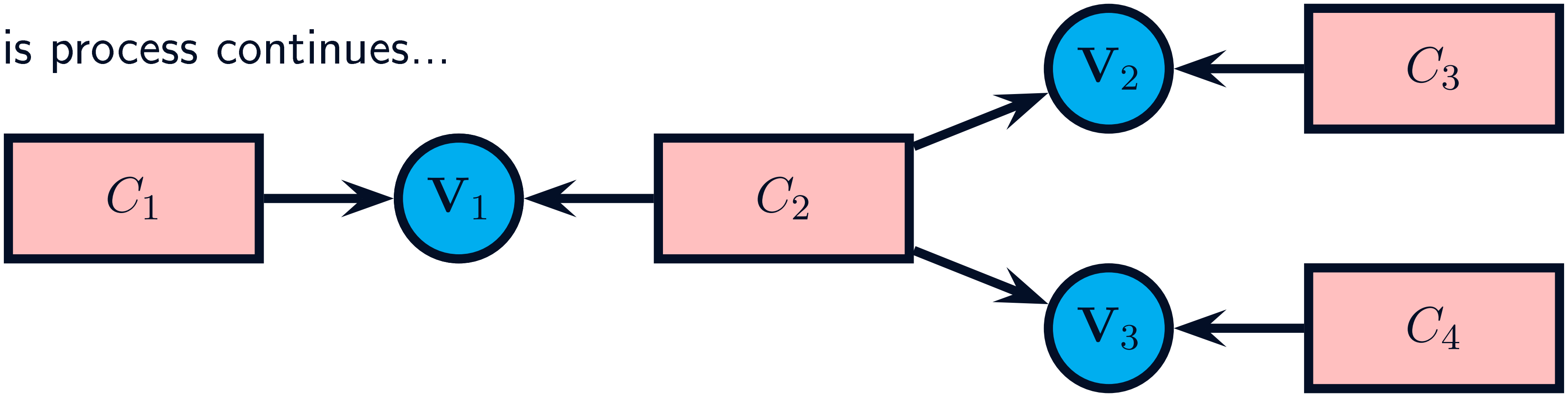

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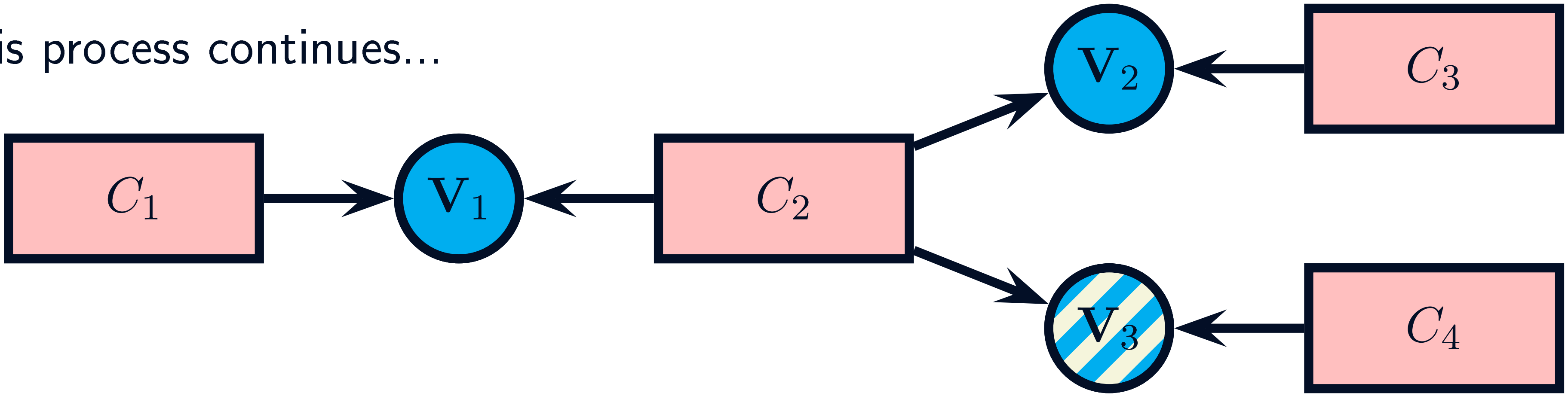

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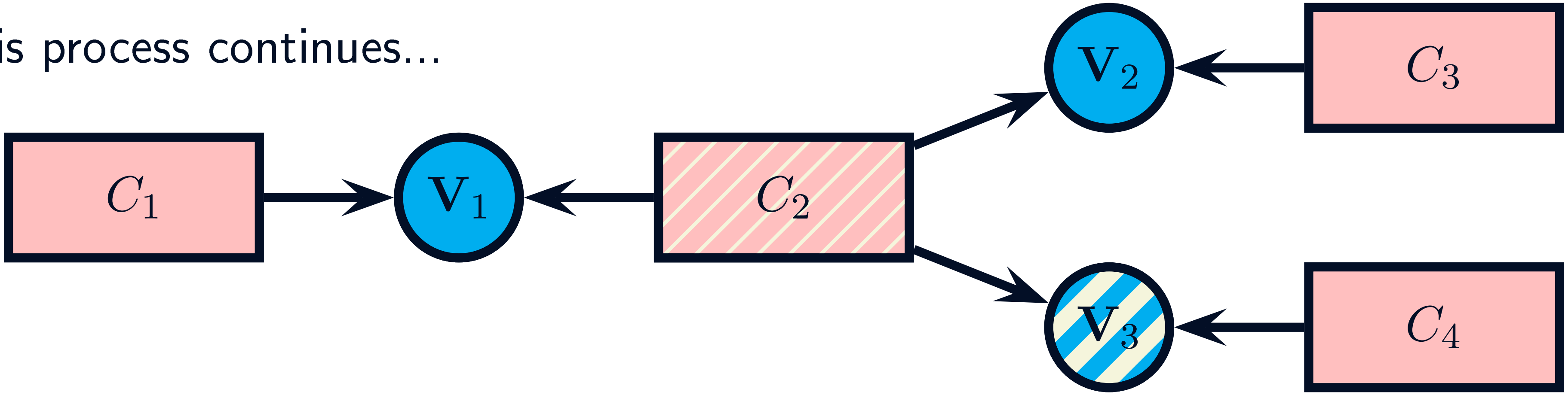

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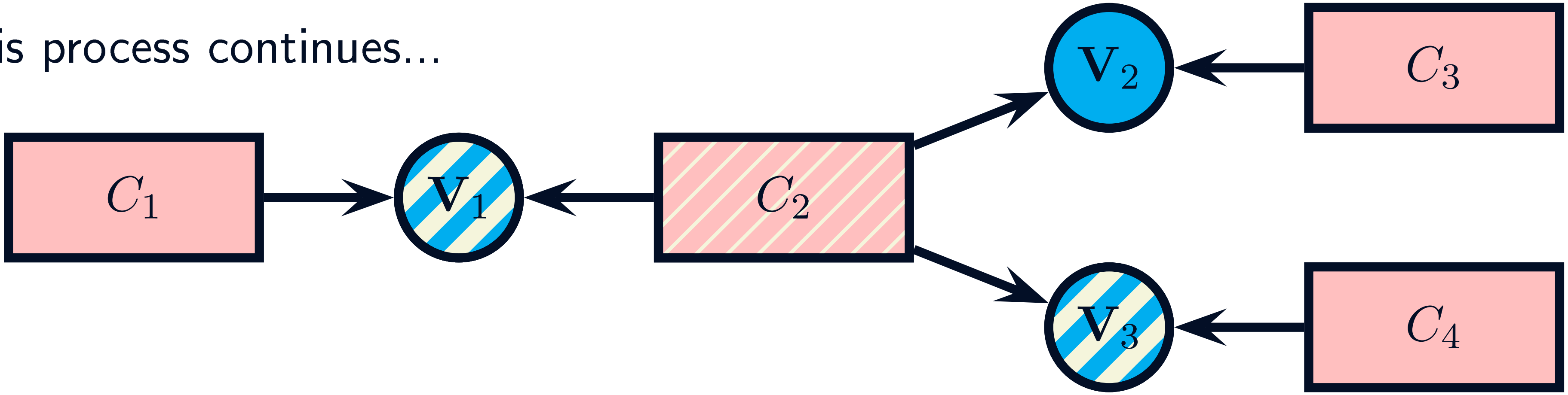

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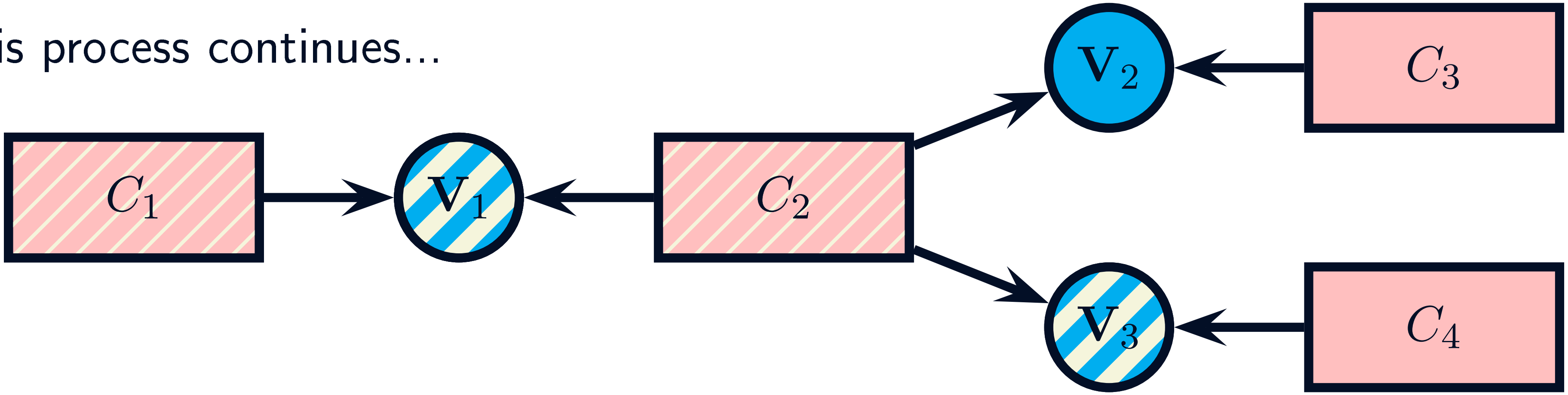

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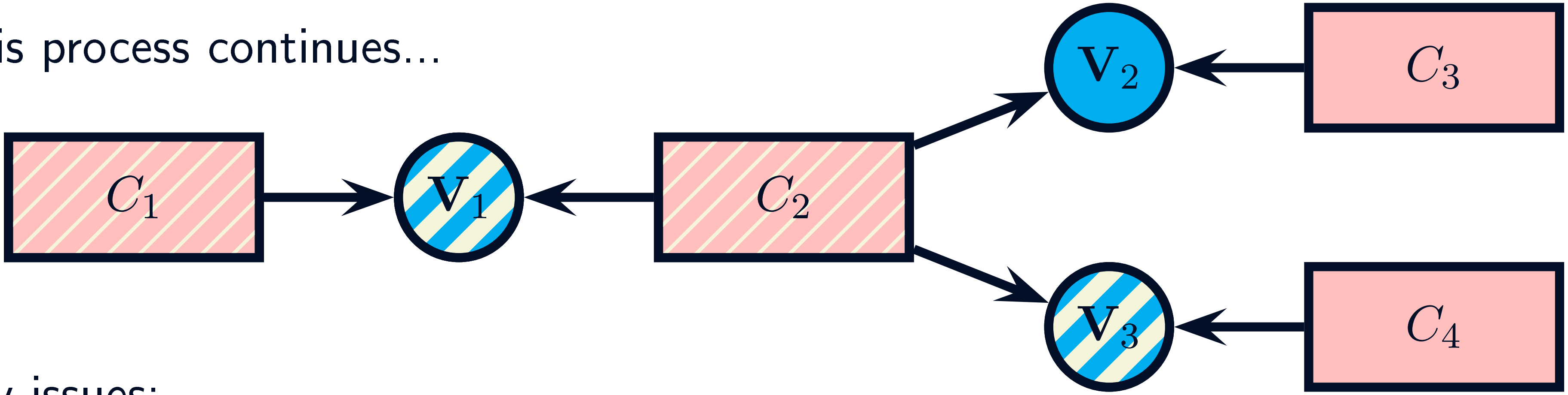

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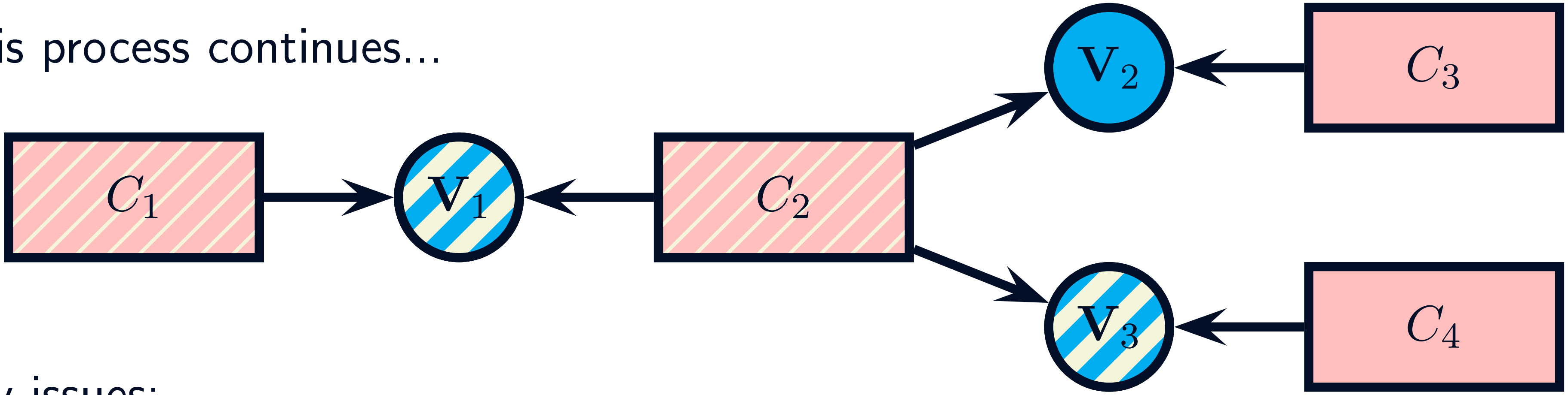

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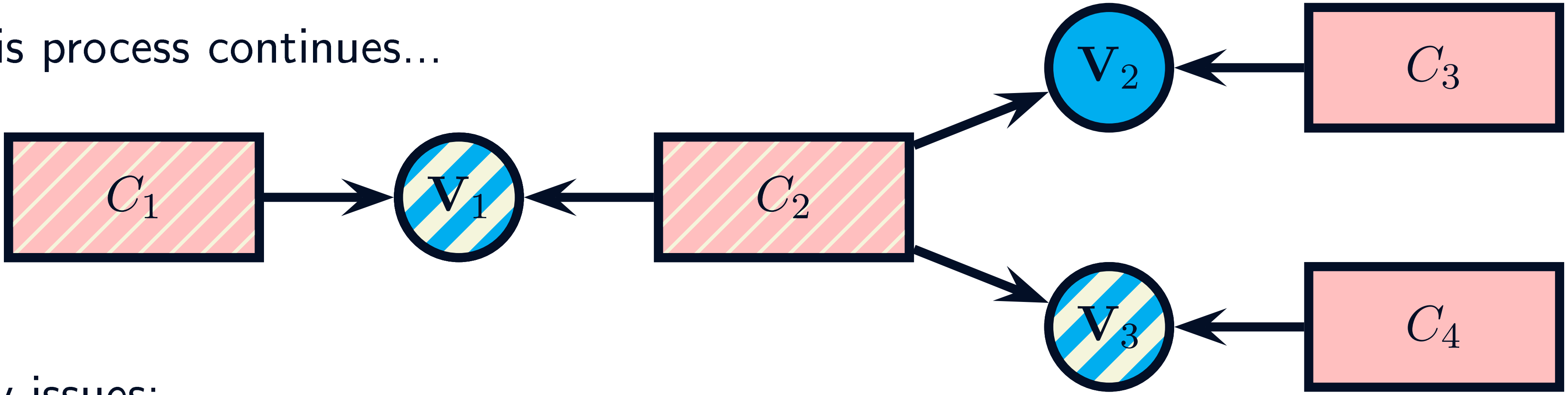

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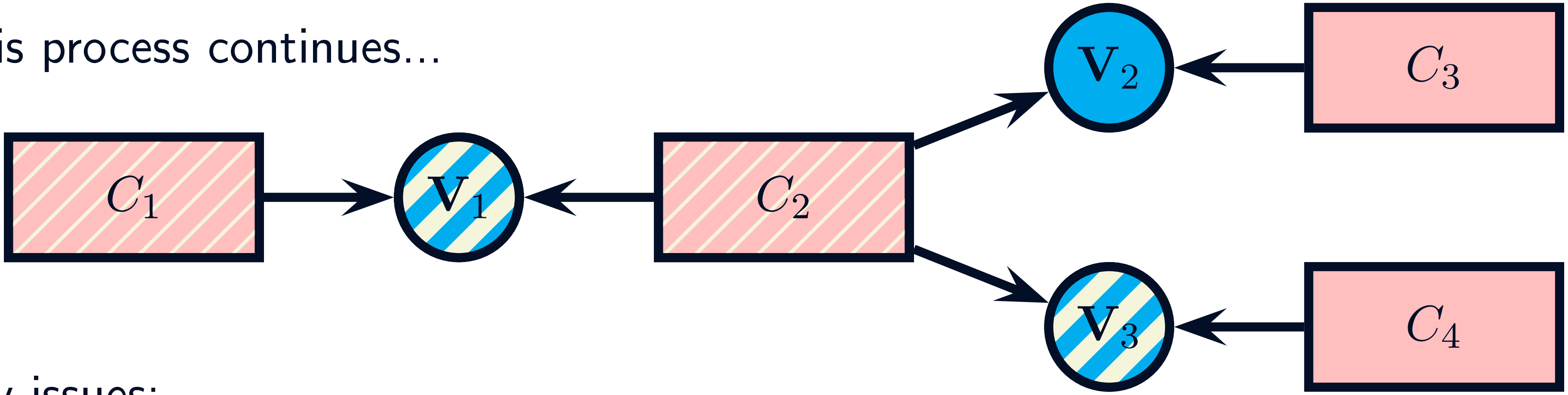
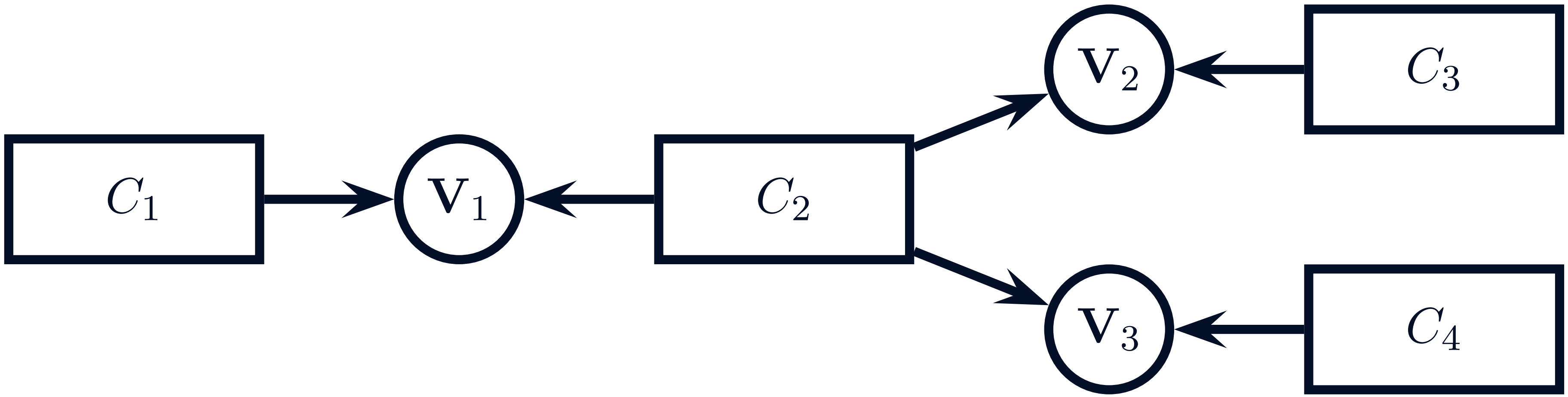


- Key issues:
  - *Database consistency*: Actual database update must be deferred until the negotiation process is complete.
  - *Termination*: The negotiation process must not go on endlessly.
- An architecture for the support of such *cooperative updates* is needed.

The Architecture of Cooperative Update Management



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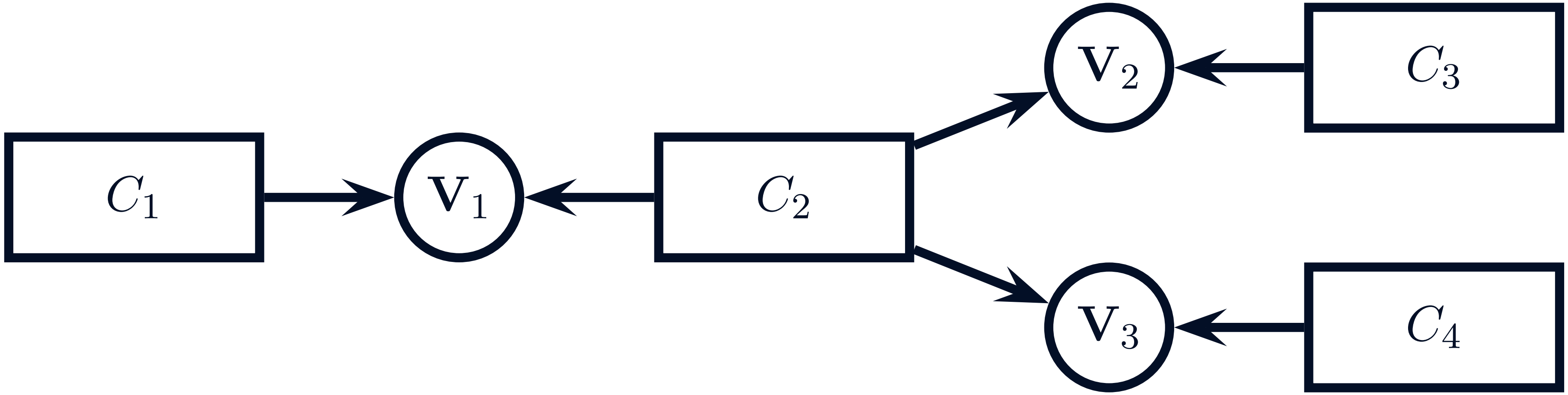

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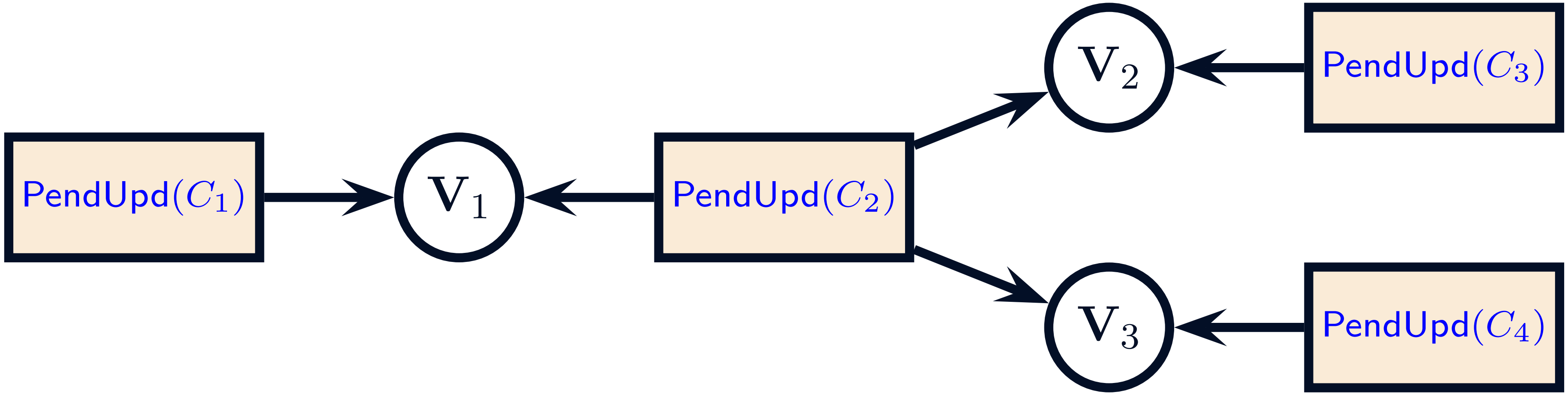

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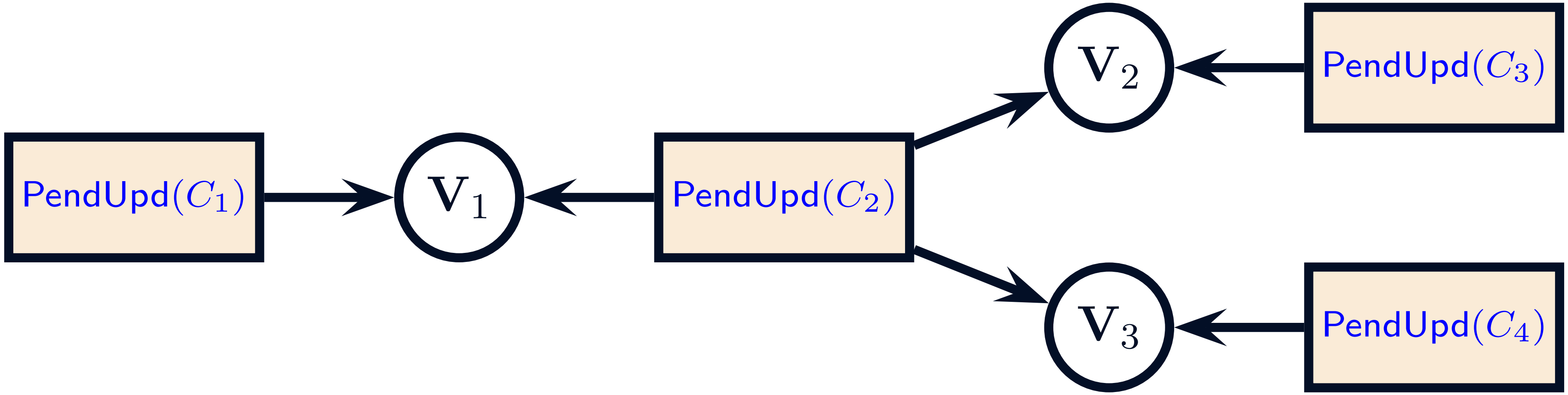

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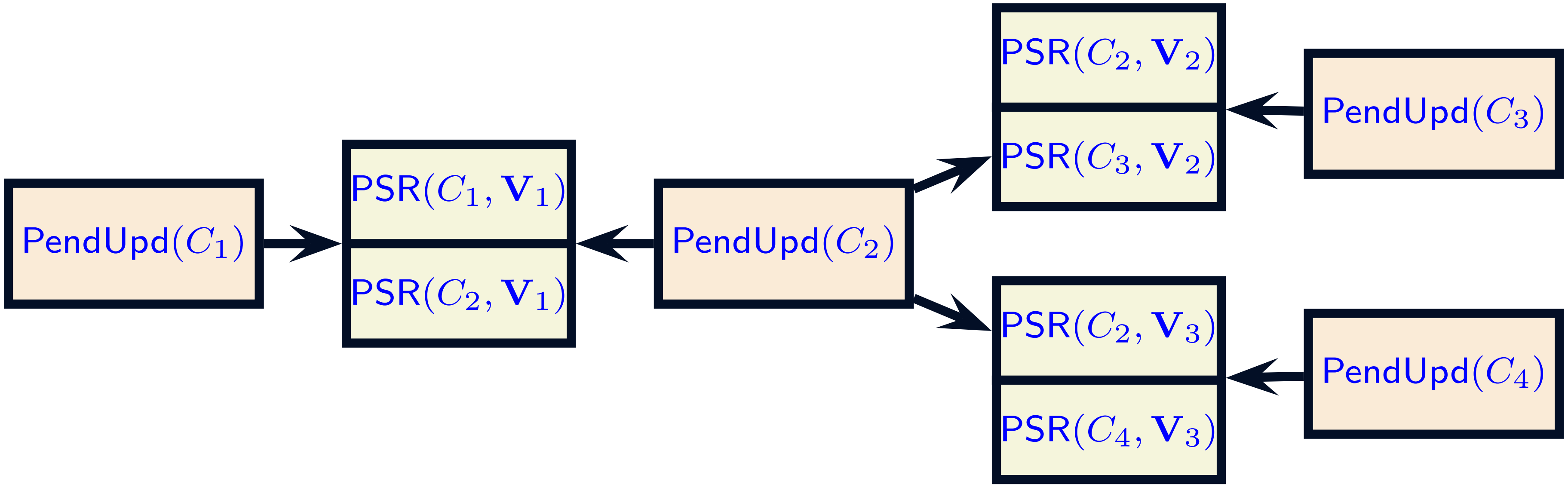

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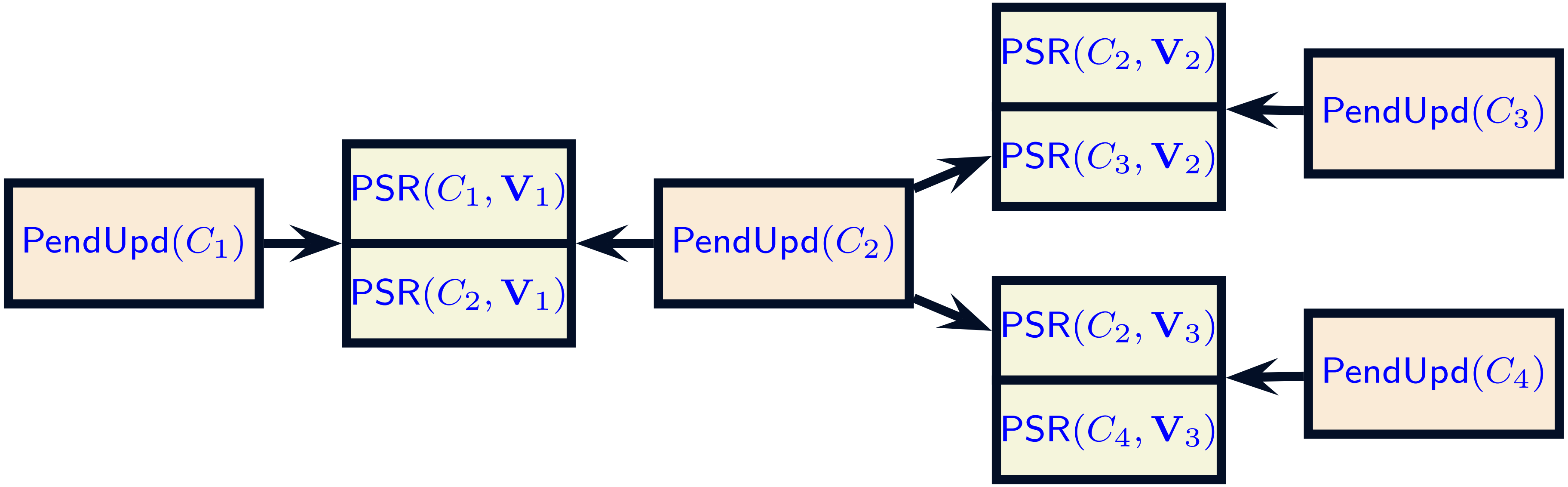

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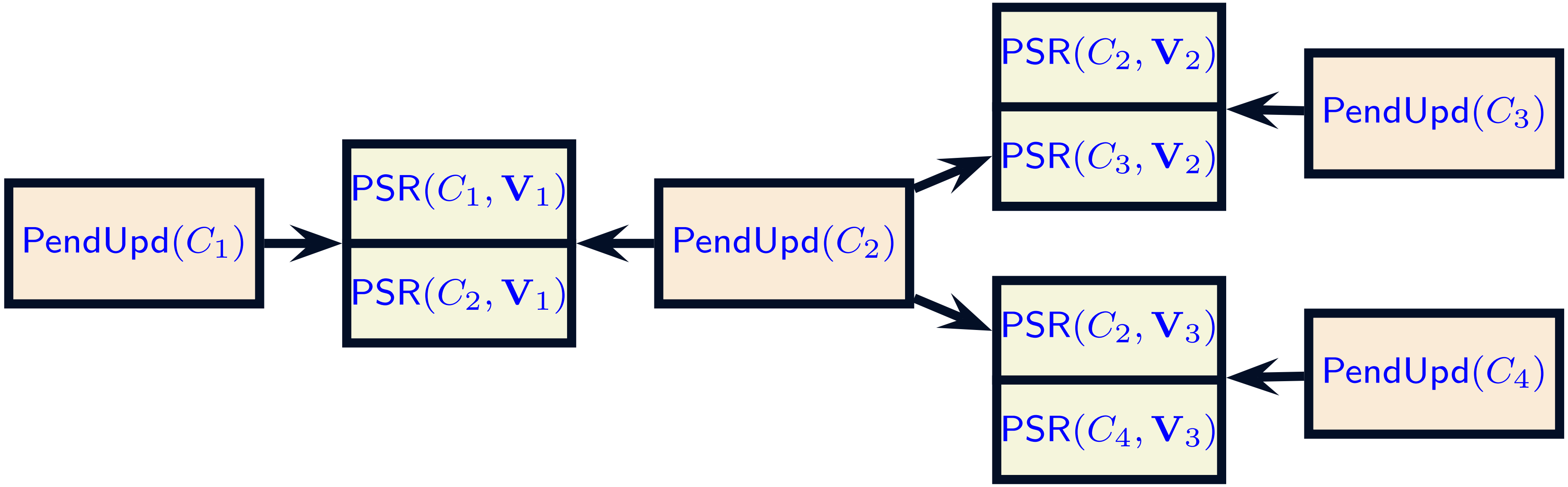
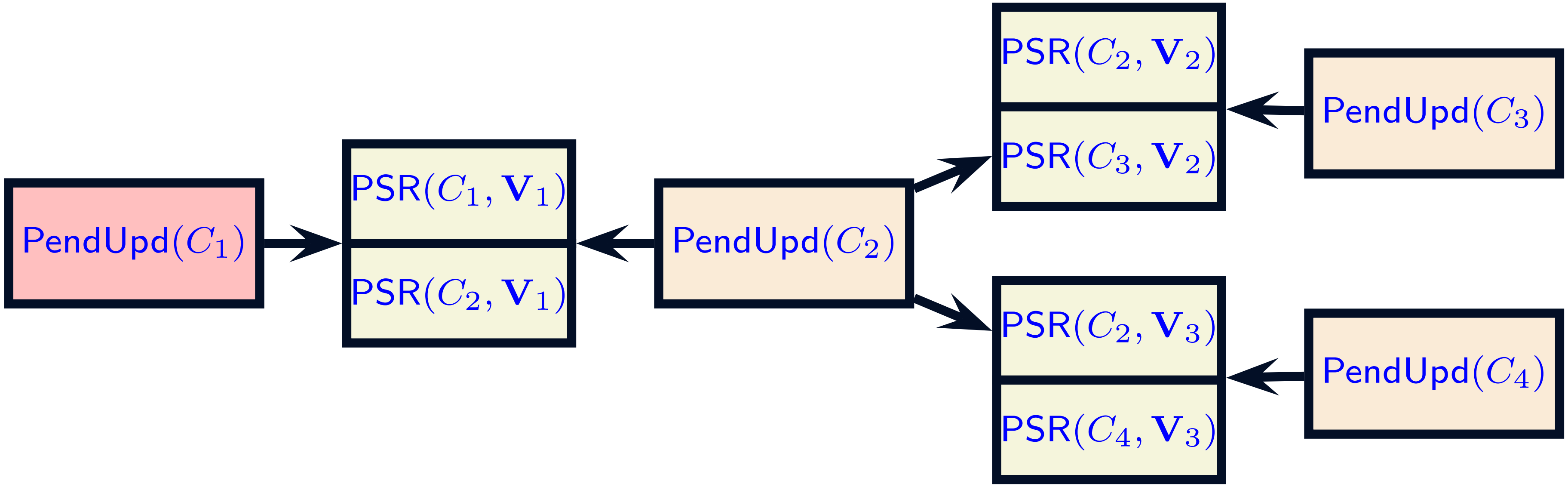
- These additional registers are part of the control structure, and are in addition to the database itself.

Operation of Cooperative Update Management



- All port-status registers are initially null.

Operation of Cooperative Update Management



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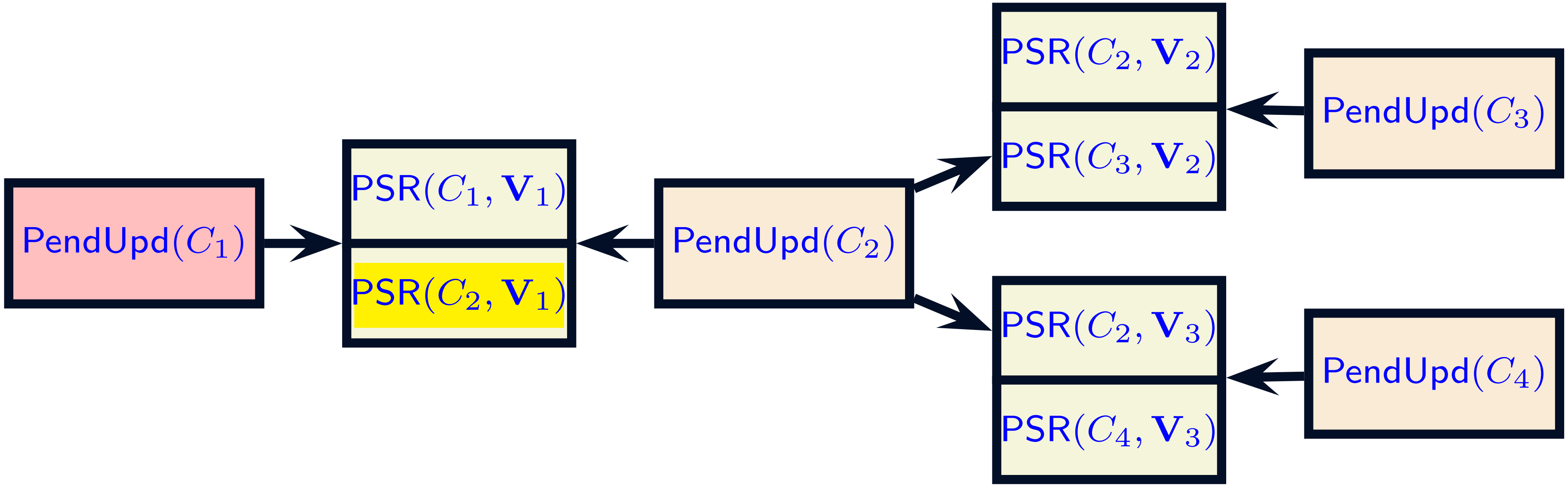

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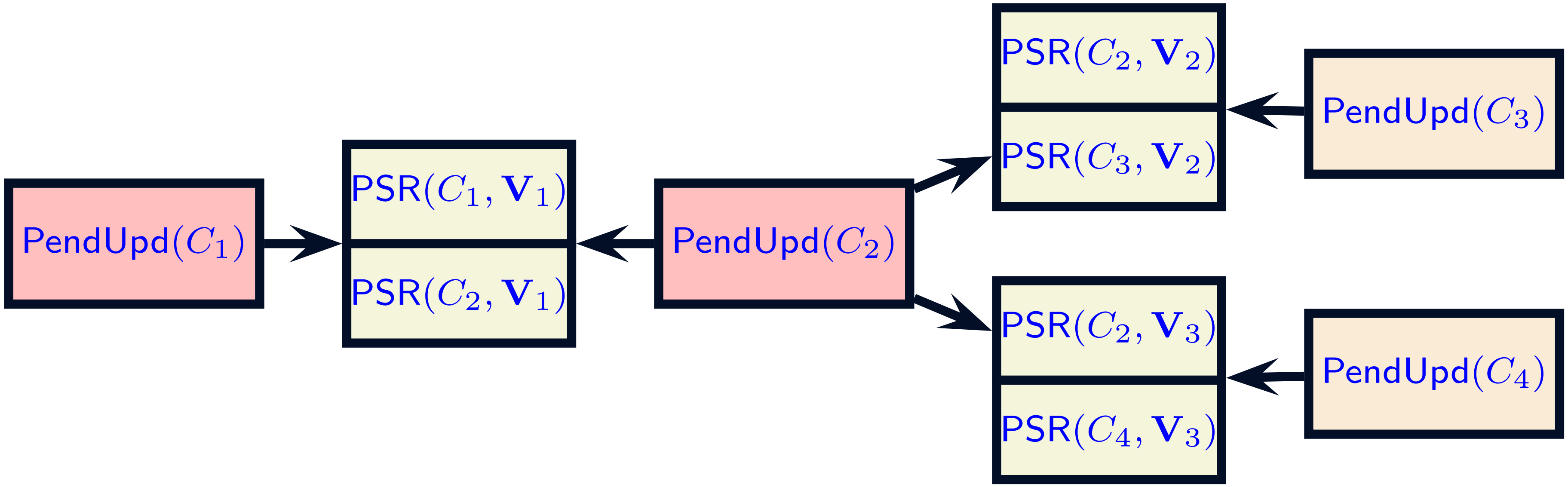

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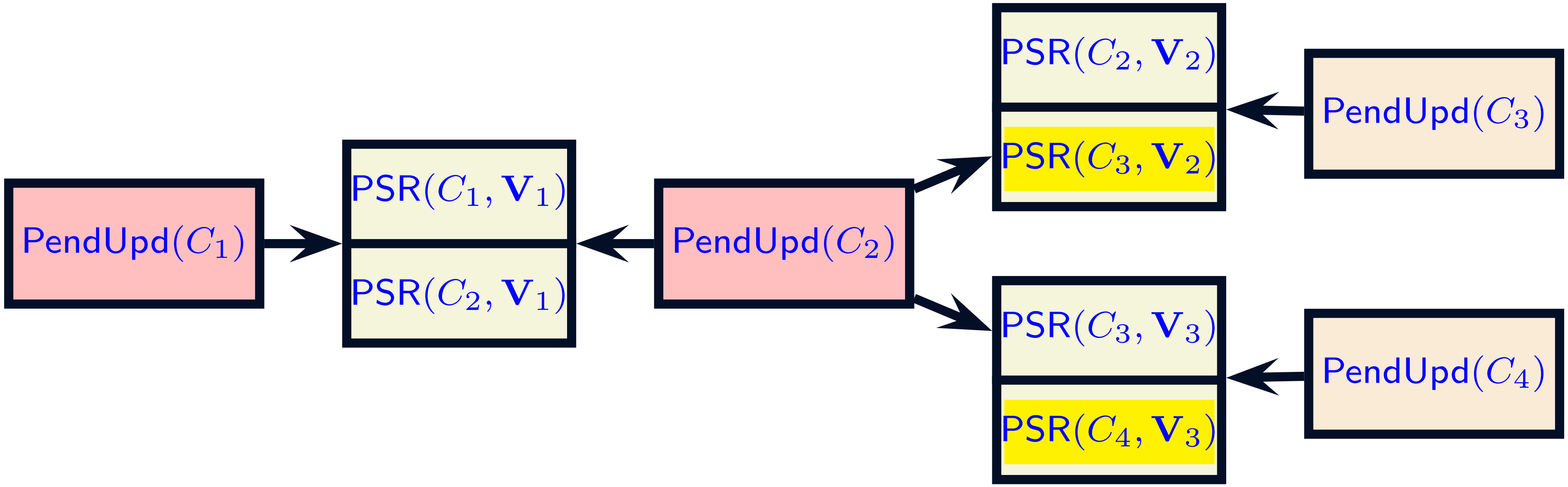

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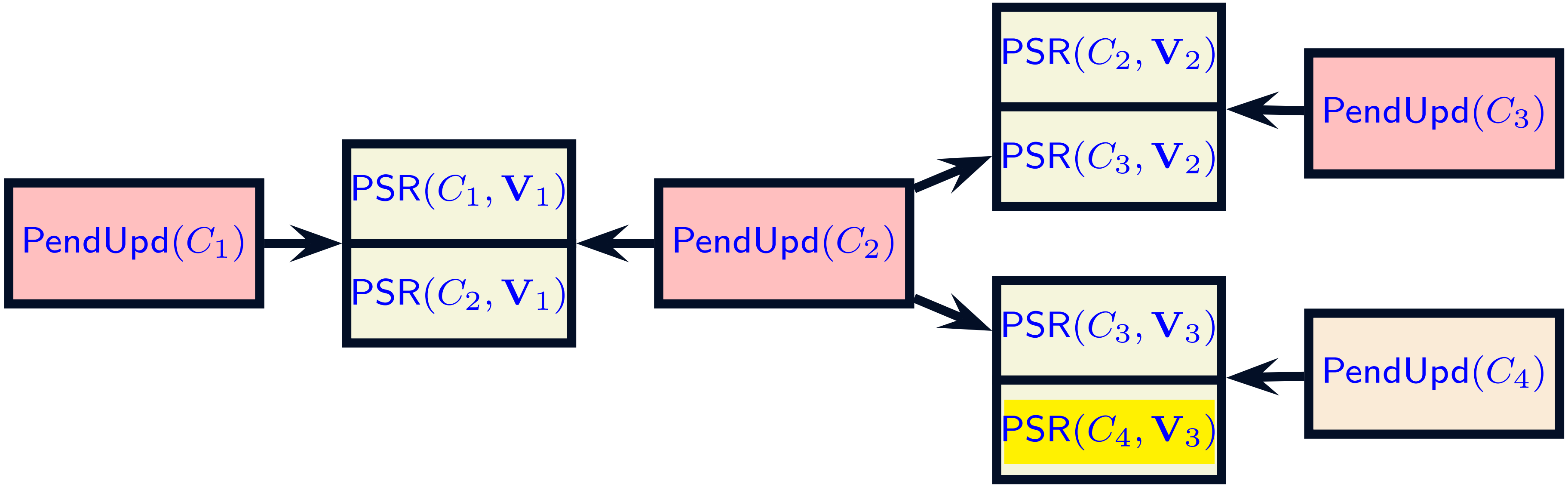

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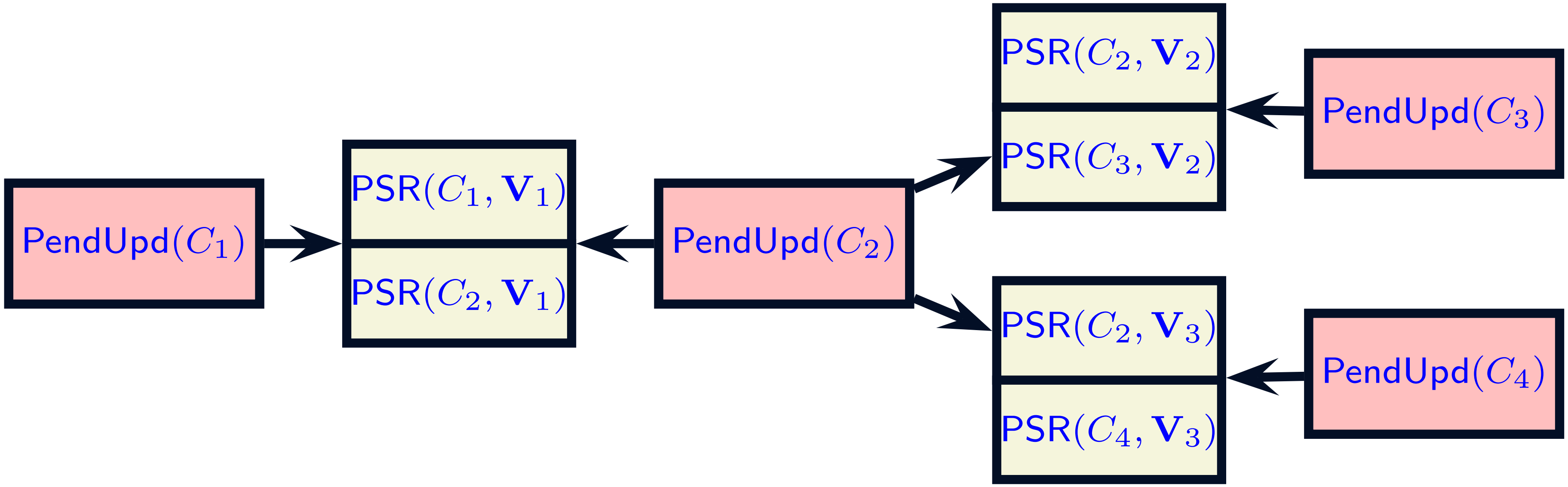

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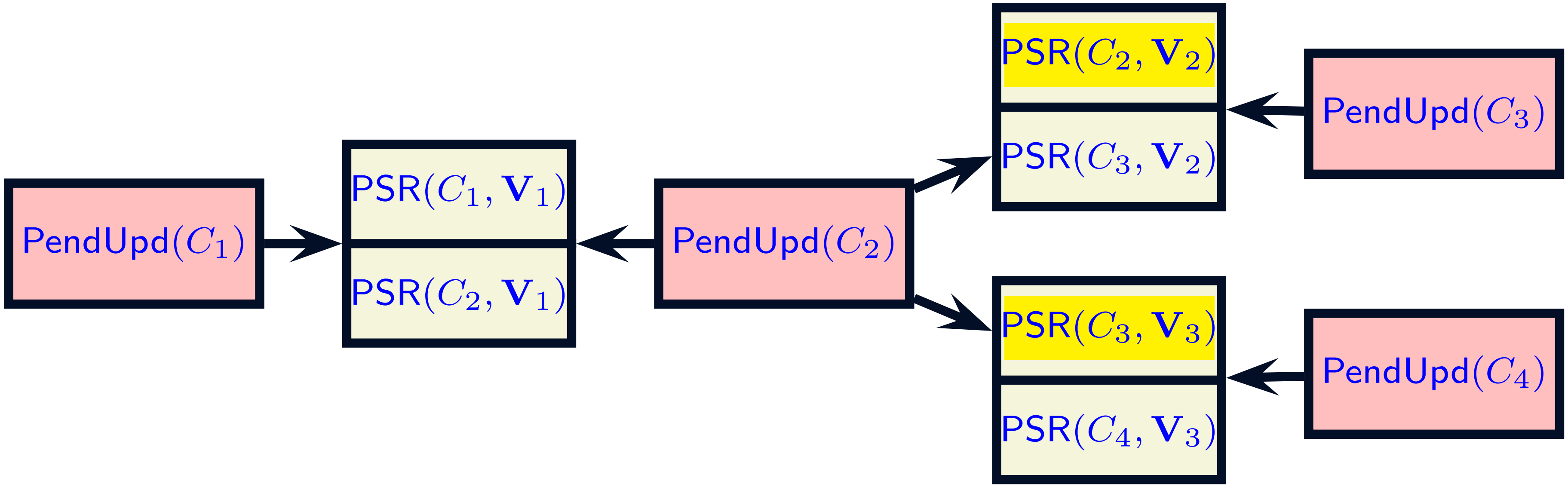

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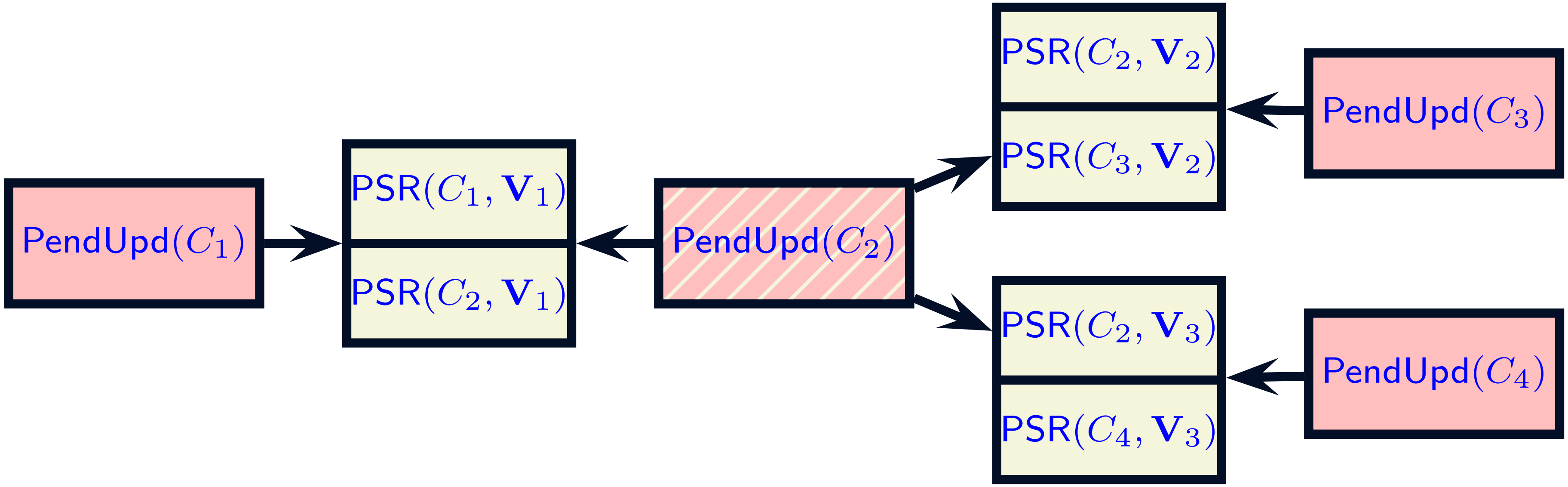

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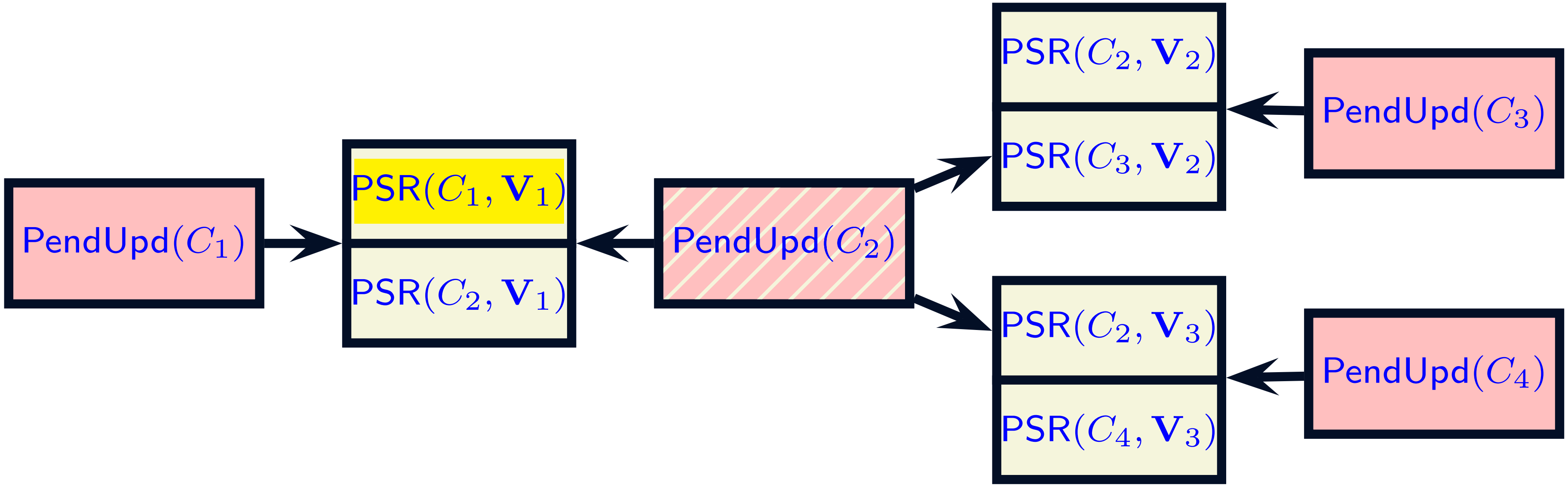

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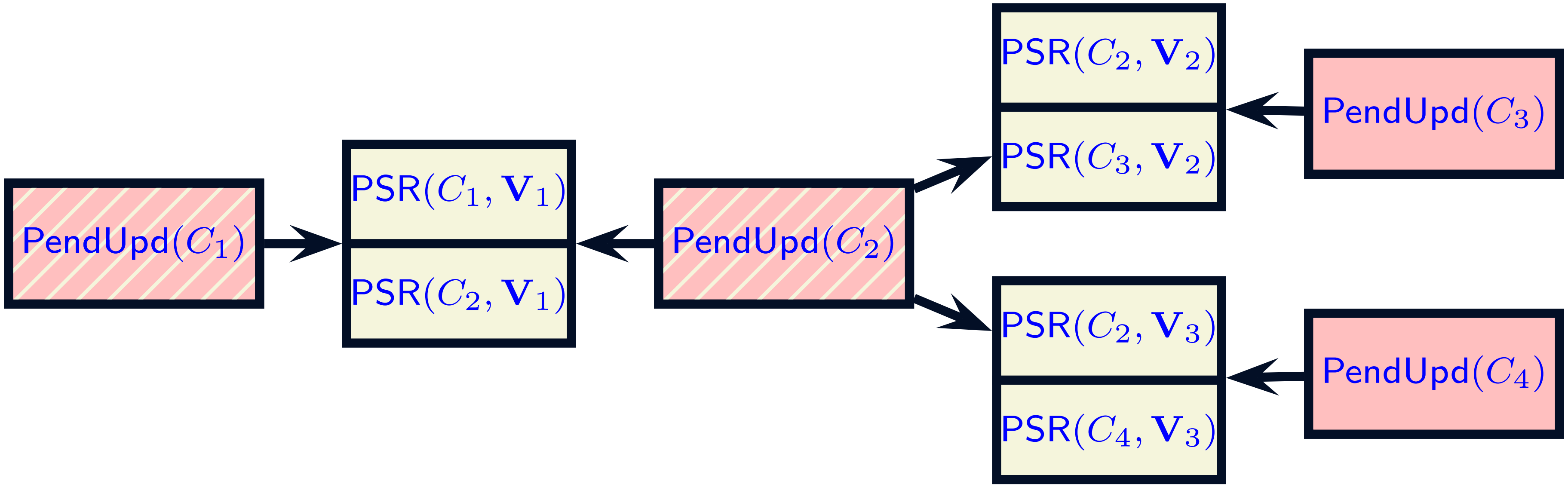

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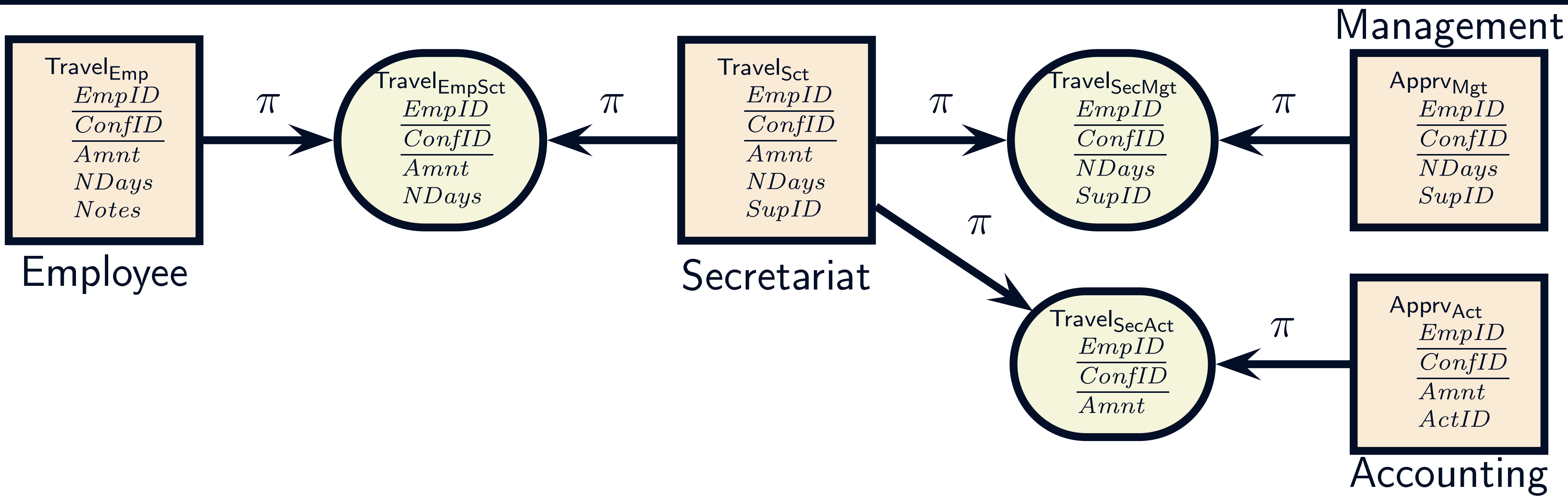
Example: Travel Request and Authorization



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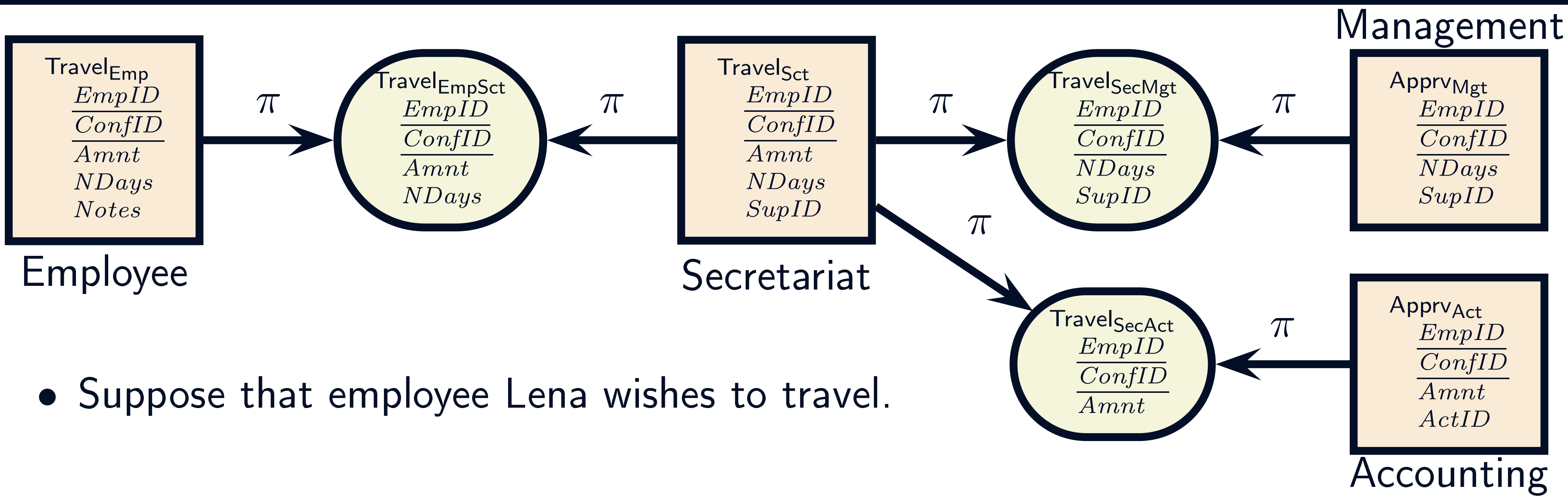

- Suppose that employee Lena wishes to travel.

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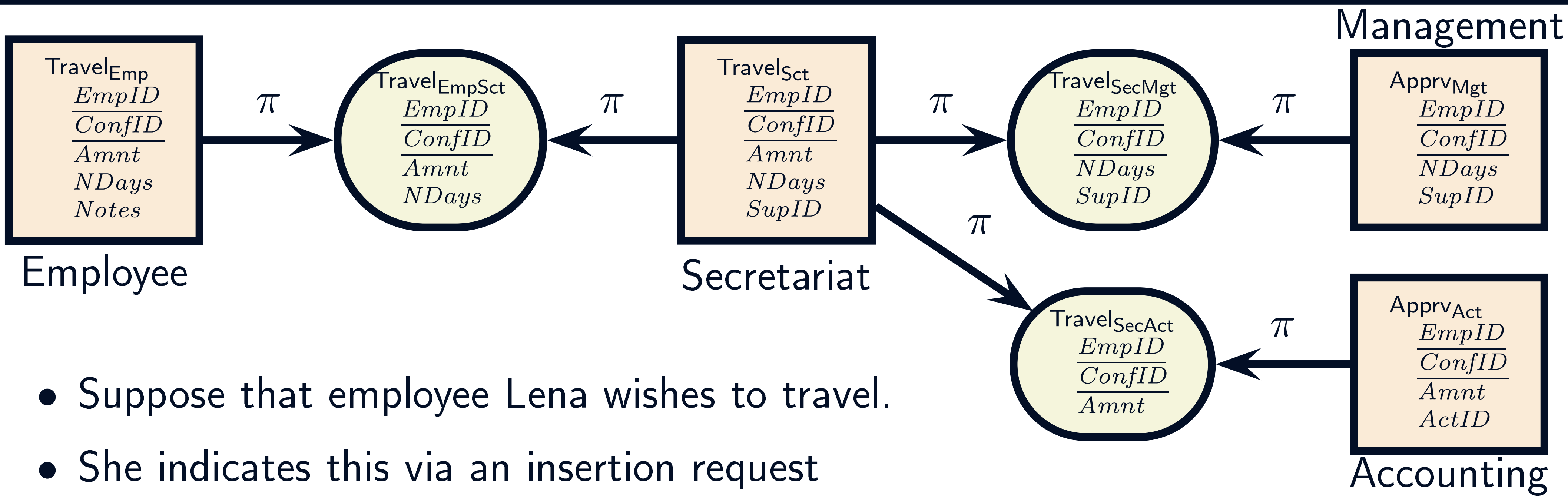

- Suppose that employee Lena wishes to travel.
- She indicates this via an insertion request into the schema of component Employee.

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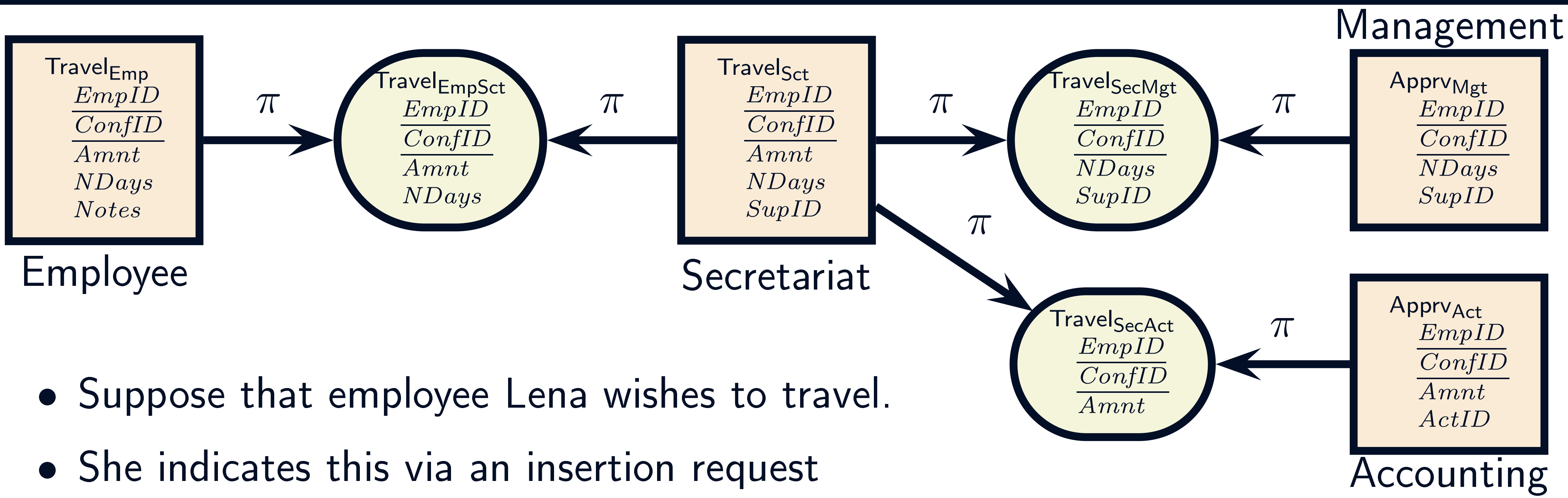

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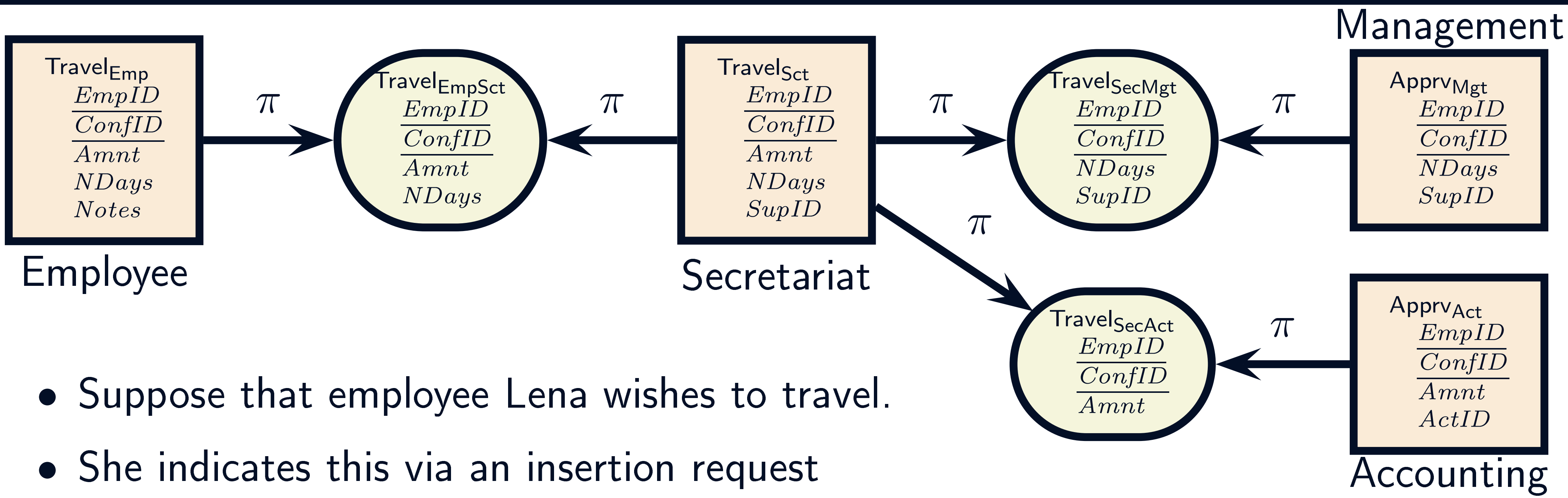

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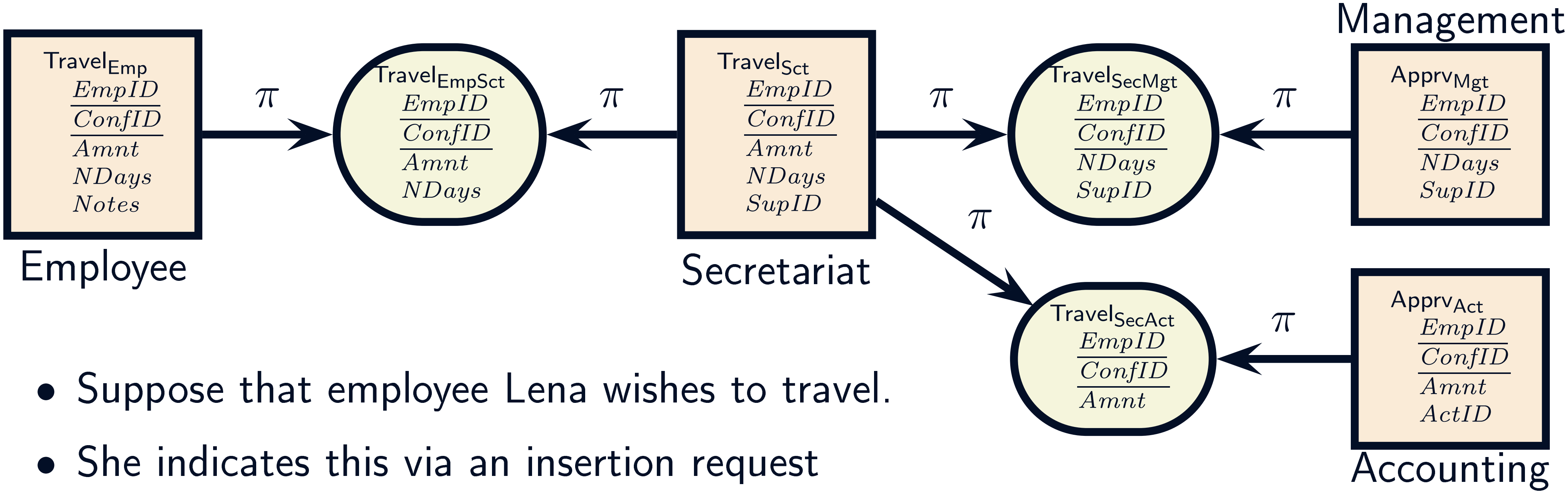

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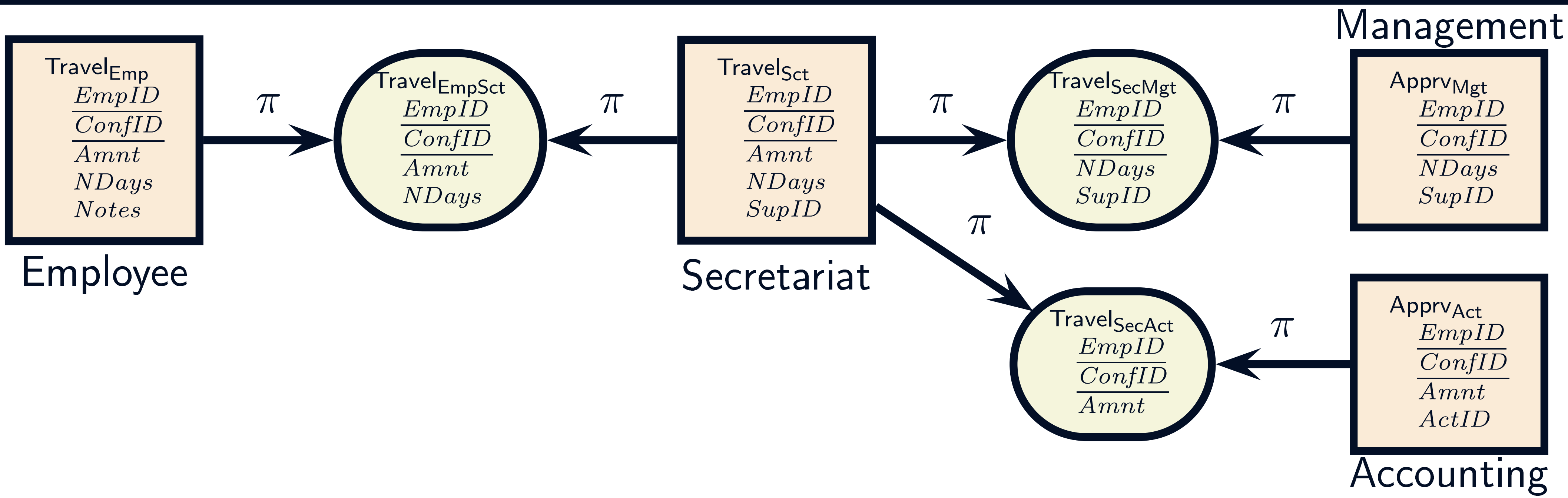
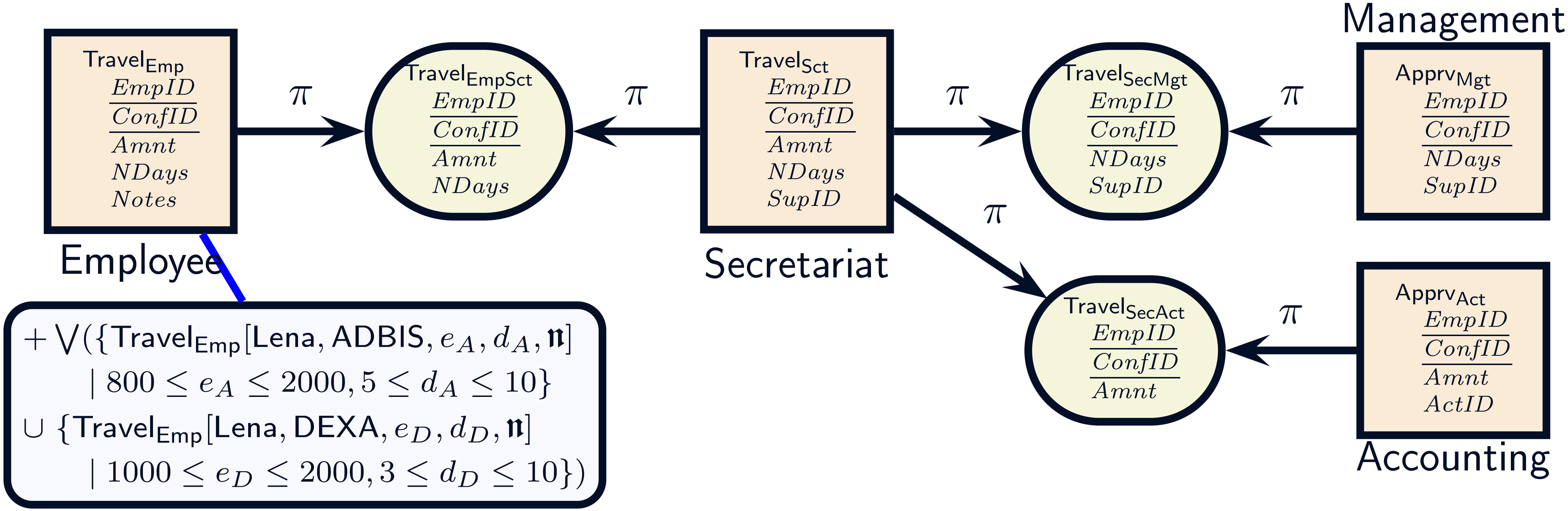
  - ADBIS is always preferred to DEXA.
  - For a given conference, more money and days are always preferred to fewer.

Example: Evolution of Travel Request and Authorization



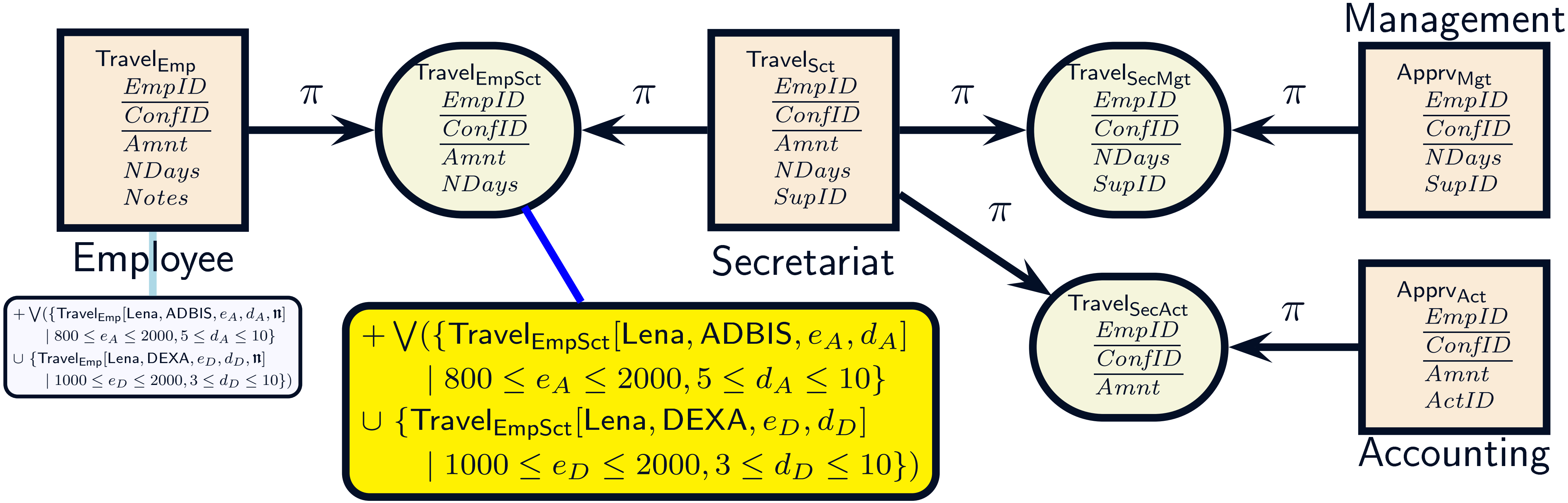
- The evolution of a specific update request will now be illustrated.



$$
\begin{aligned}
&+\bigvee(\{\mathsf{Travel}_{\mathsf{Emp}}[\mathsf{Lena}, \mathsf{ADBIS}, e_A, d_A, \mathfrak{n}] \\
&\qquad \mid 800 \leq e_A \leq 2000, 5 \leq d_A \leq 10\} \\
&\cup \{\mathsf{Travel}_{\mathsf{Emp}}[\mathsf{Lena}, \mathsf{DEXA}, e_D, d_D, \mathfrak{n}] \\
&\qquad \mid 1000 \leq e_D \leq 2000, 3 \leq d_D \leq 10\})
\end{aligned}
$$

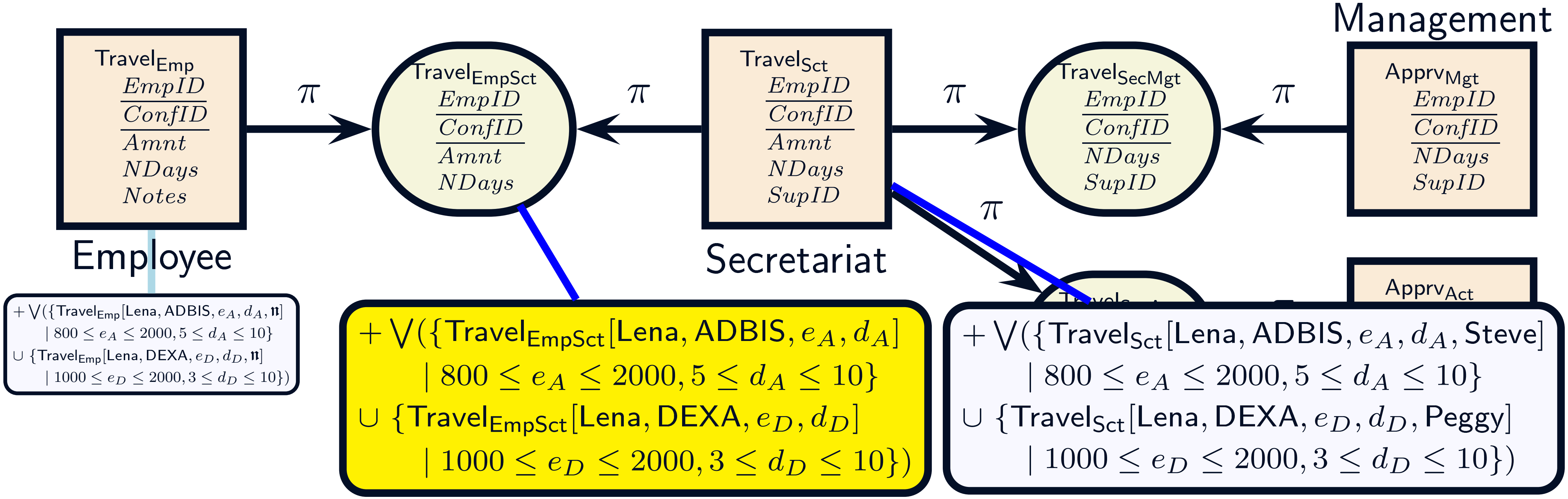
- First, the desired ranked update is entered into the pending-update register for Employee. Notation:
  - $+$ = Insert.
  - $\bigvee$ = Choose one of the alternatives.

Example: Evolution of Travel Request and Authorization



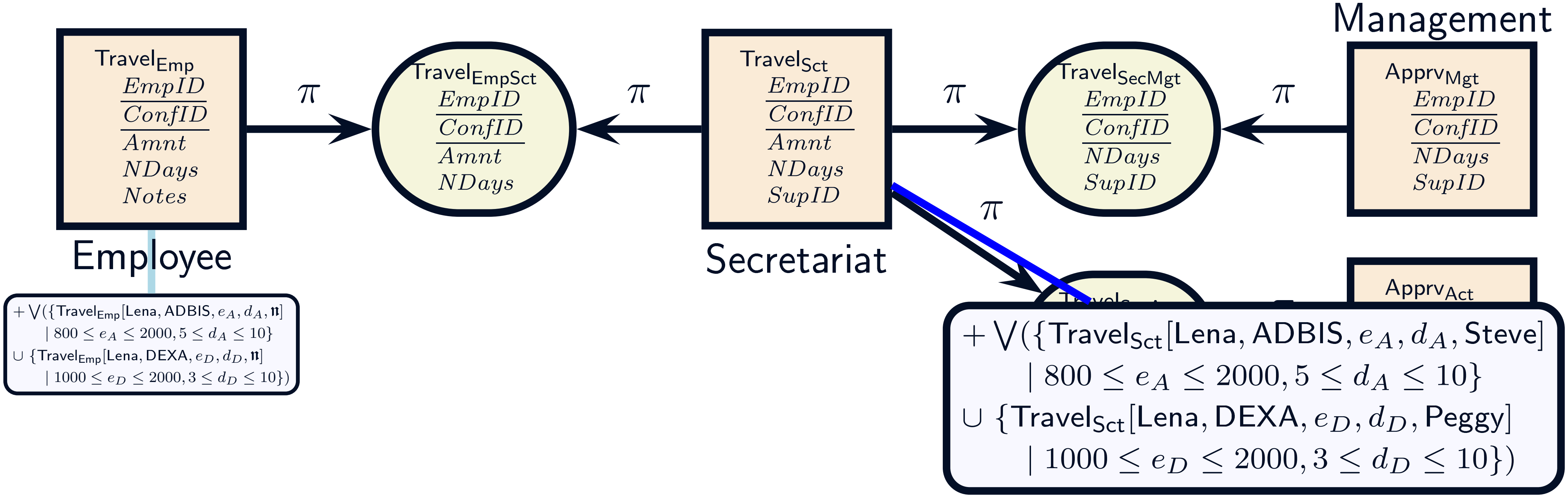
- This update is then projected to the port-status register which connects Employee to Secretariat.

Example: Evolution of Travel Request and Authorization



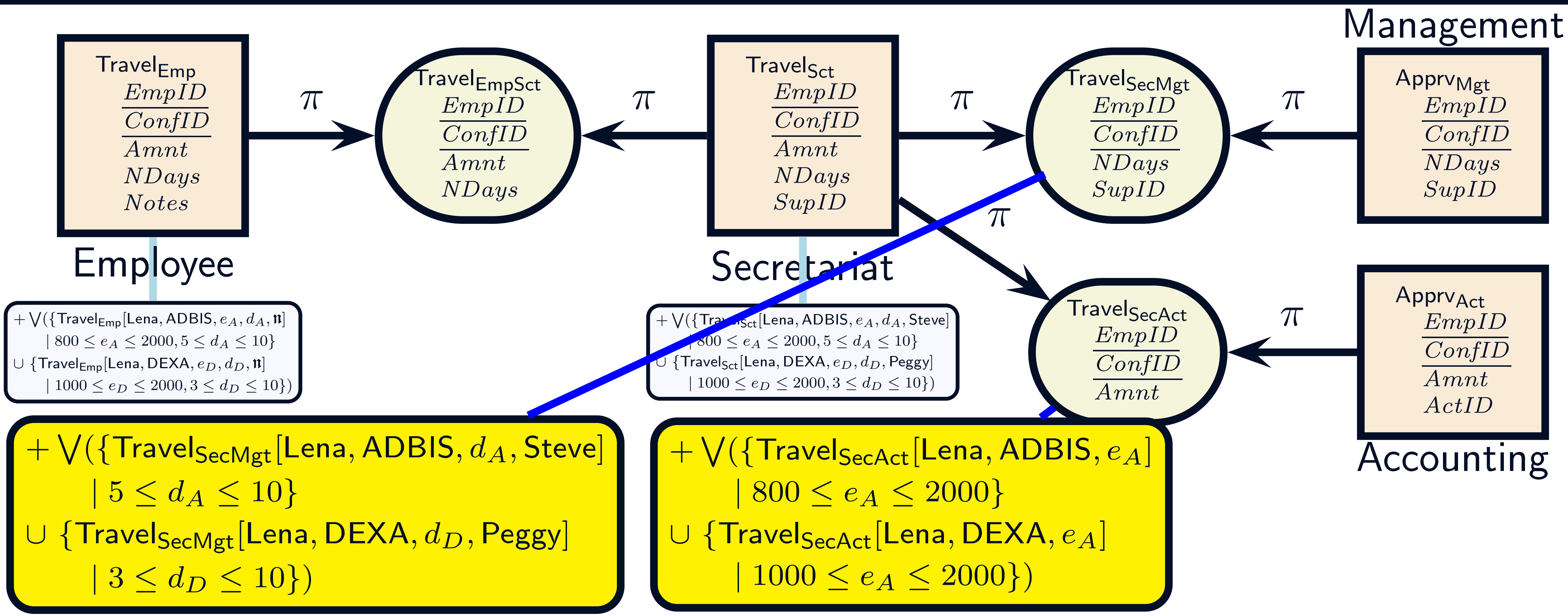
- The user of the Secretariat component then lifts this update to one on that component. It is placed in the pending-update register for that component.
  - Note that decisions must be made.
  - One of many possible liftings must be selected.

Example: Evolution of Travel Request and Authorization



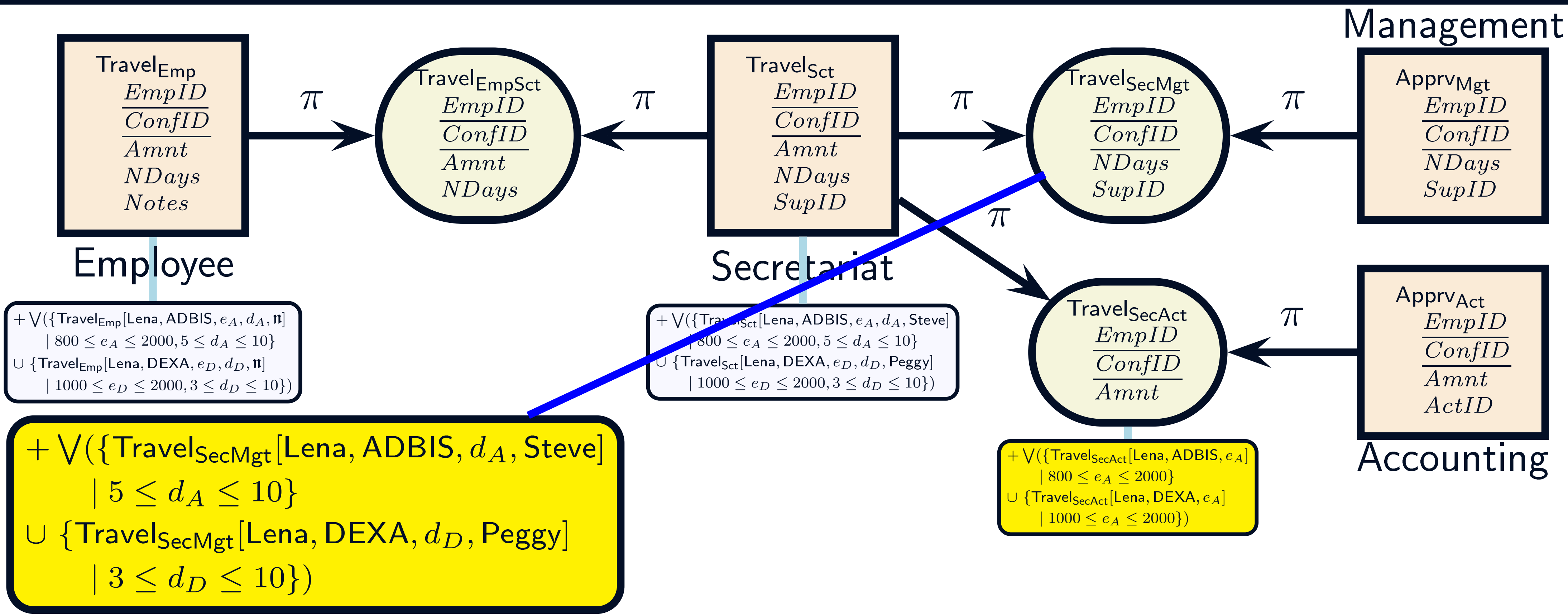
- The port-status register is then cleared, since this update has been processed.

Example: Evolution of Travel Request and Authorization



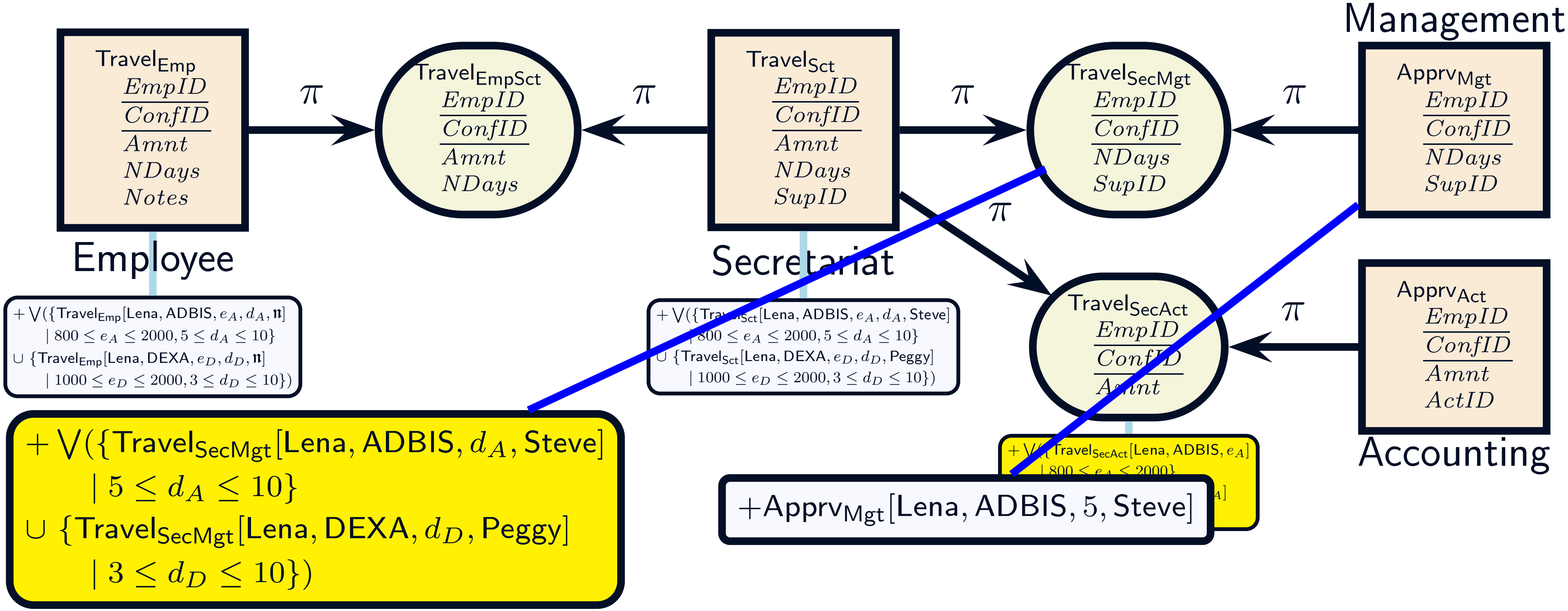
- This lifted update is then projected into the appropriate port-status registers which connect Secretariat to Management and Accounting.
- It is not projected back onto the port-status register which is connected to Employee, because the new value would be the same as the old one.

Example: Evolution of Travel Request and Authorization



- First consider lifting the projected update to the Management component.
    - Again, there are decisions to be made.

Example: Evolution of Travel Request and Authorization



- Manager Steve processes the request, and decides to allow Lena to attend ADBIS for five days.

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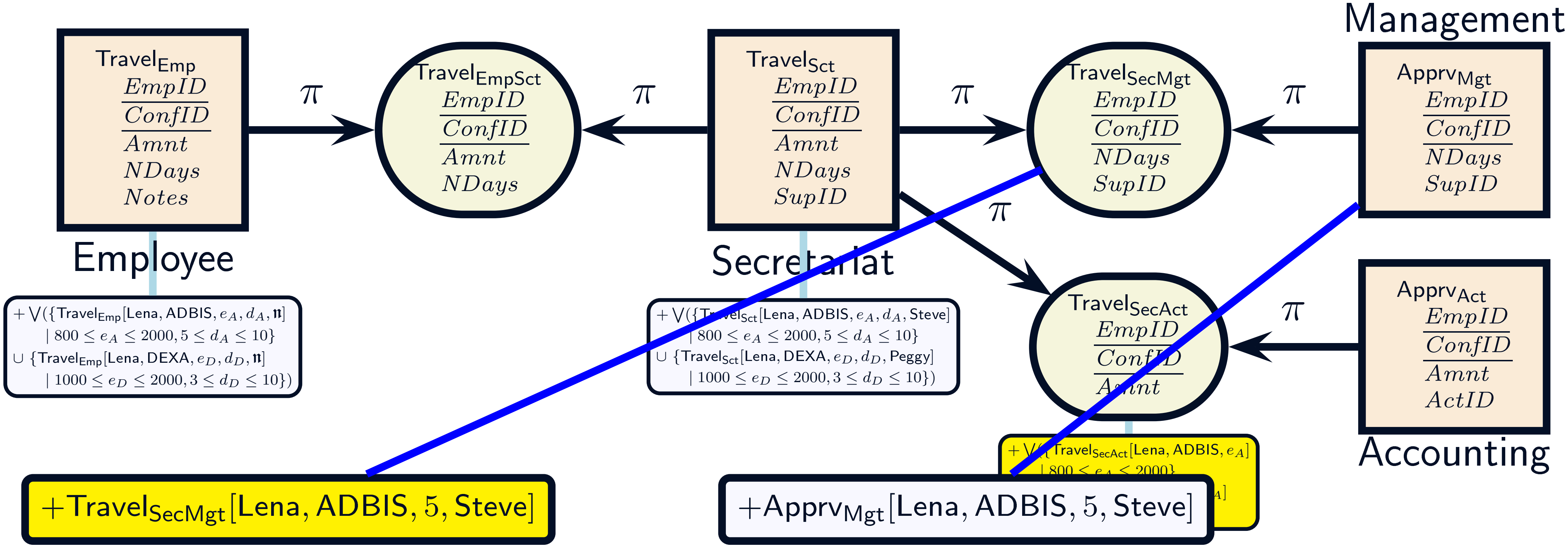
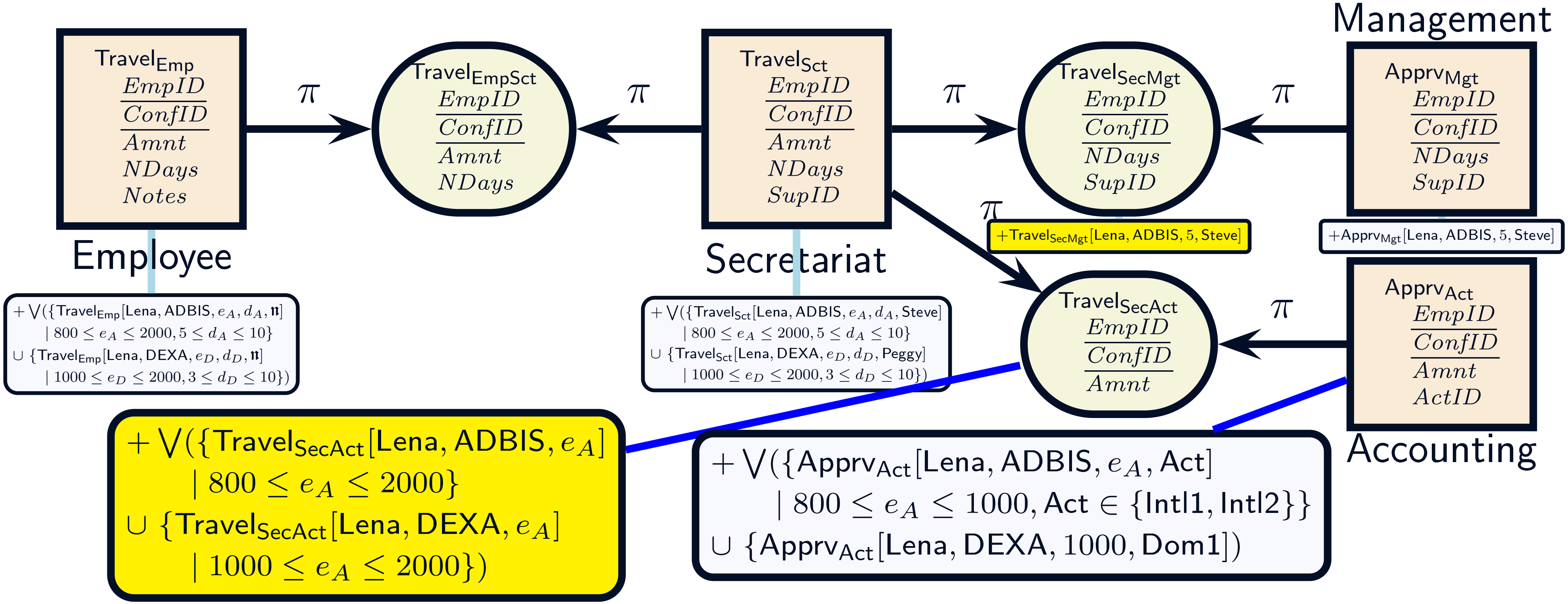
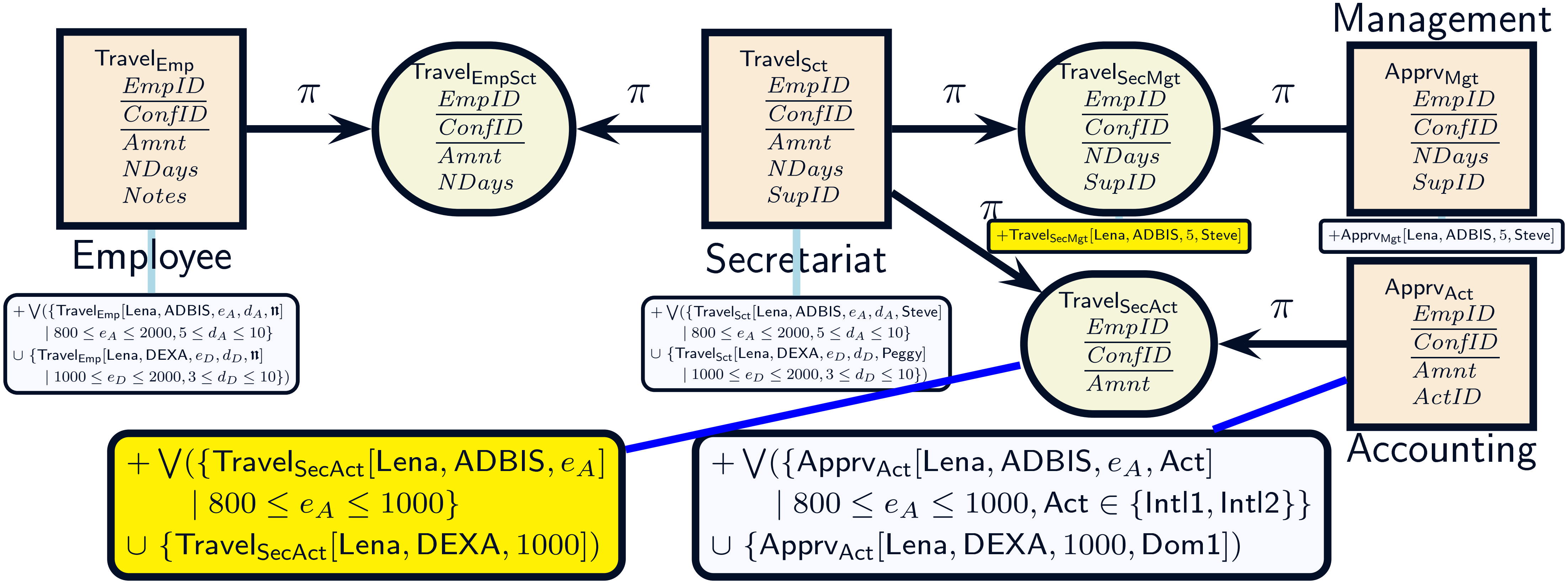


- The value in the port-status register for the Management component is removed, but a new value for the port-status register for Secretariat is inserted.



- Now consider lifting the projected update to the Management component.
  - The accounting manager decides to award €1000 for the requested travel.
  - The appropriate accounts are also identified.

Example: Evolution of Travel Request and Authorization



- The value in the port-status register for the Accounting component is cleared, but a new value for the port-status register for Secretariat is inserted.

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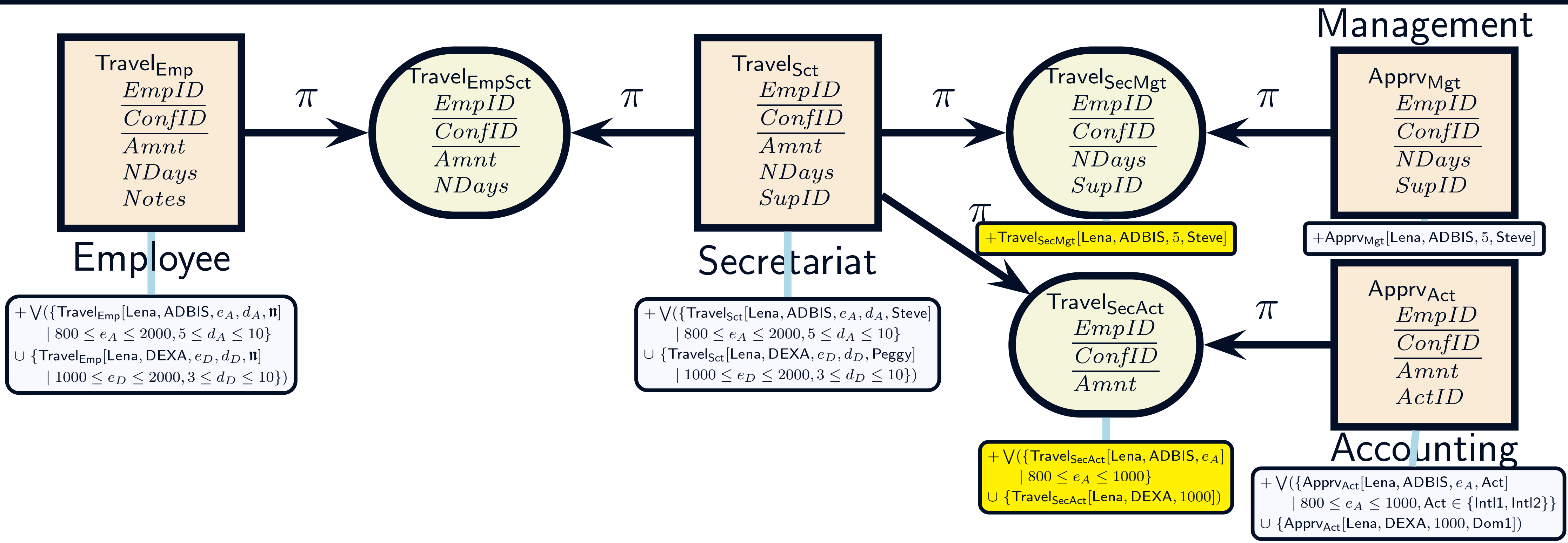
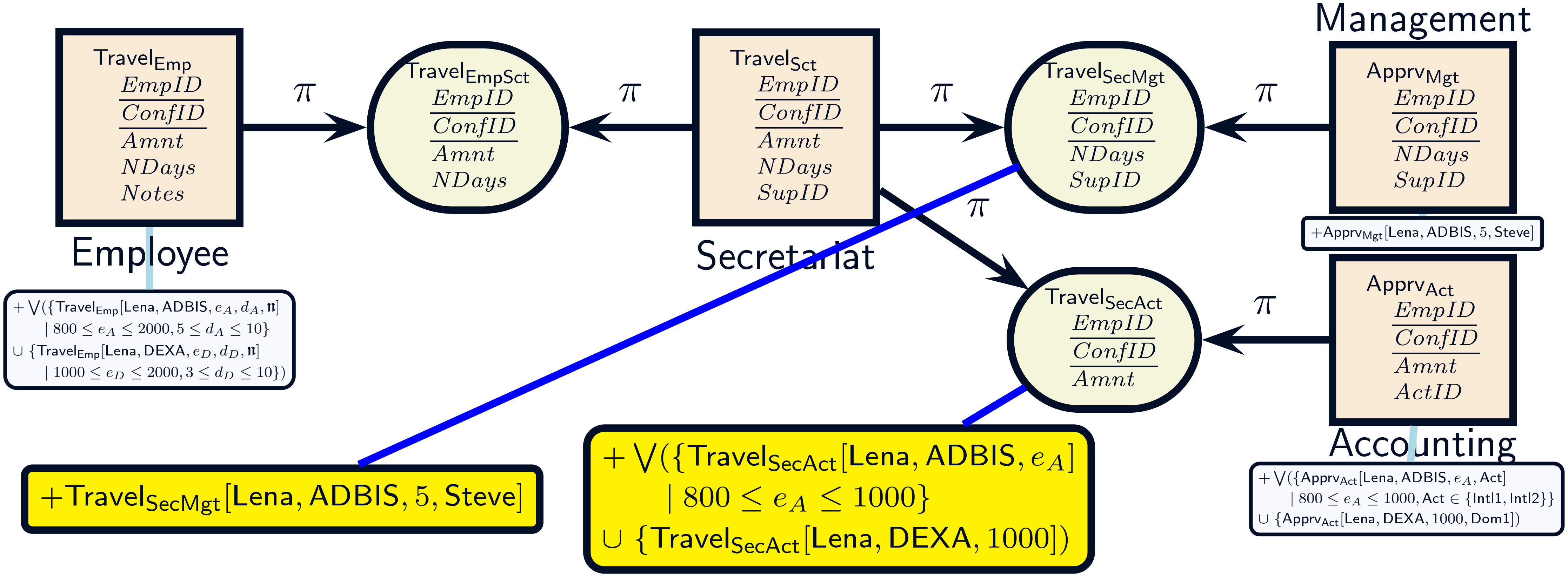


- Now the update negotiation propagates back right to left.

Example: Evolution of Travel Request and Authorization



- The two values in the port-status registers must be lifted to the Secretariat component simultaneously.

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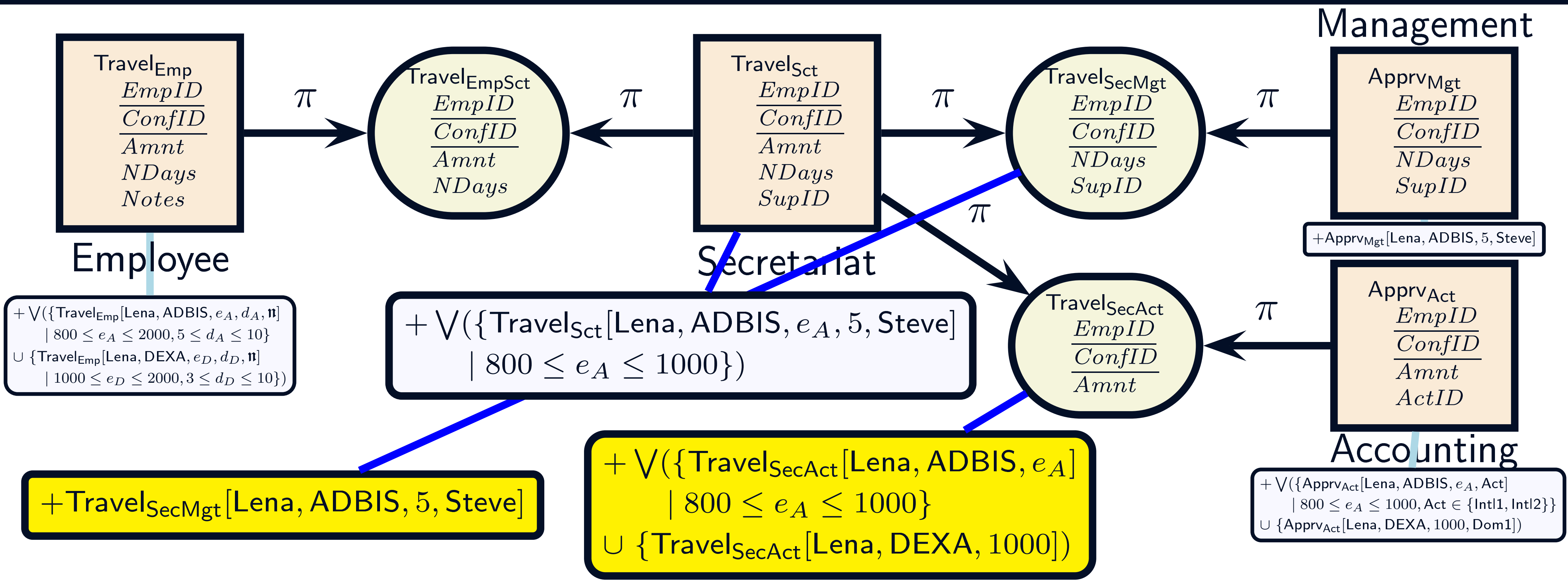
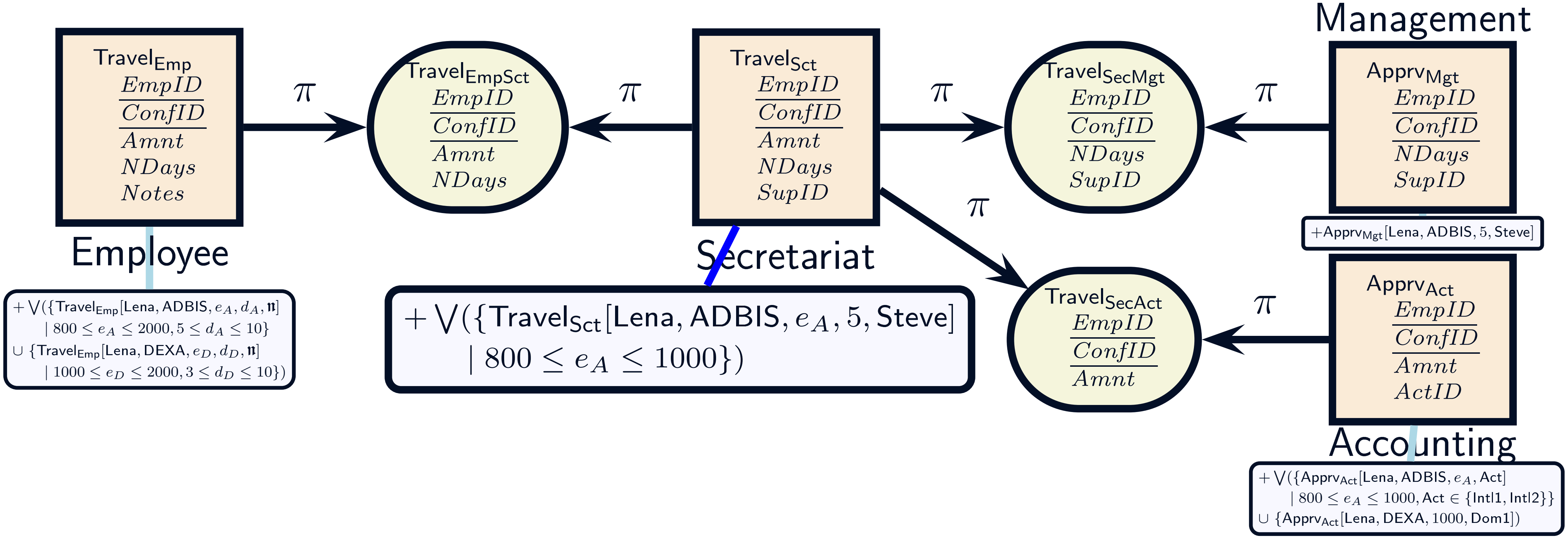
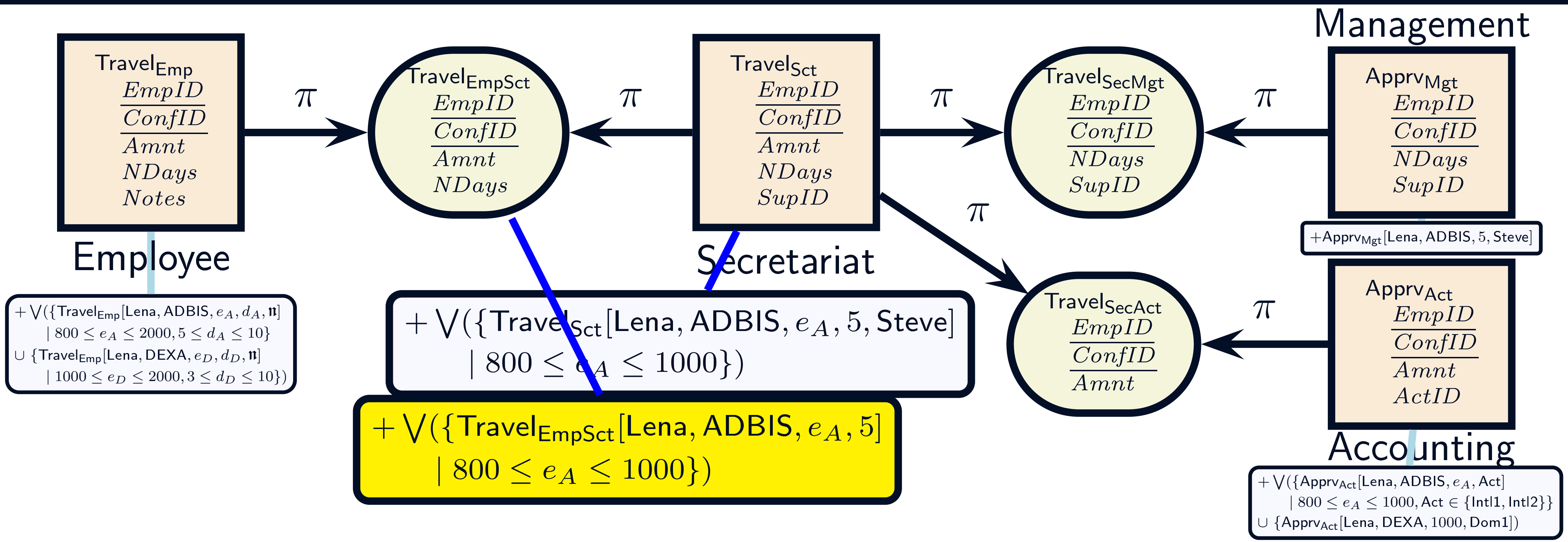


- The maximal lifting is selected.
  - The Secretariat imposes no additional limitations.

Example: Evolution of Travel Request and Authorization



- The two port-status registers are now cleared.



- The update request is then projected to the appropriate port-status register connecting Secretariat to Employee.

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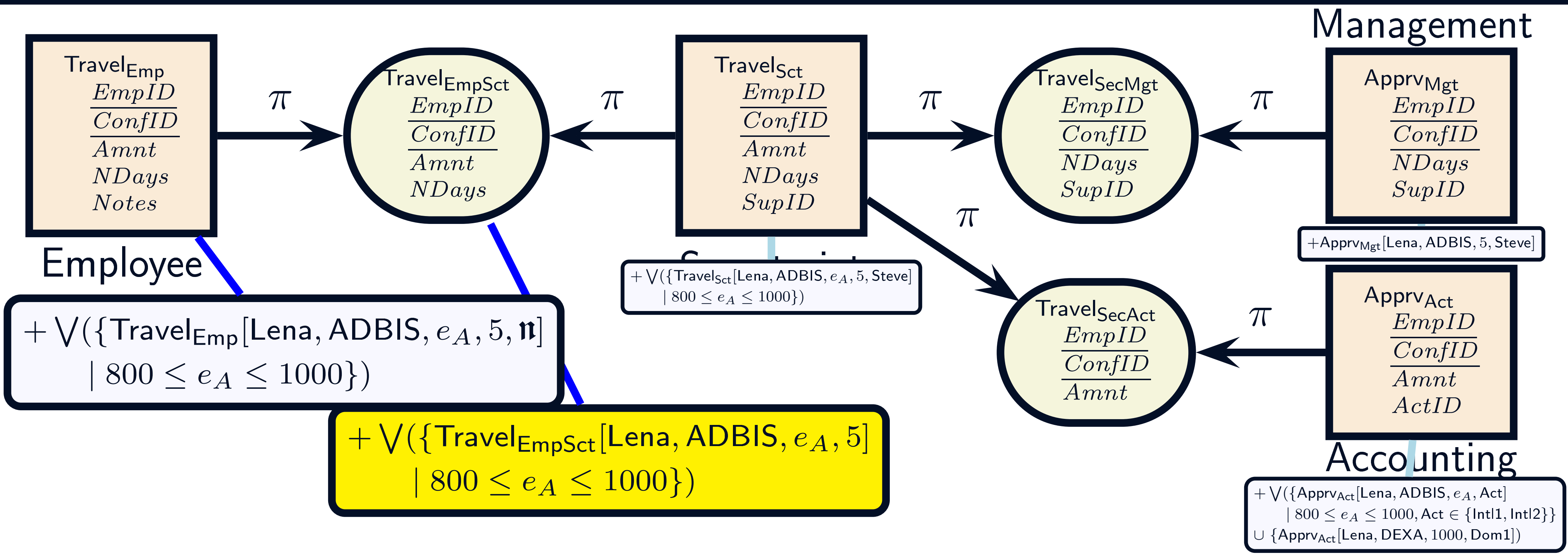

- This update request is then lifted to the Employee component.
    - Again, the maximal lifting is selected.

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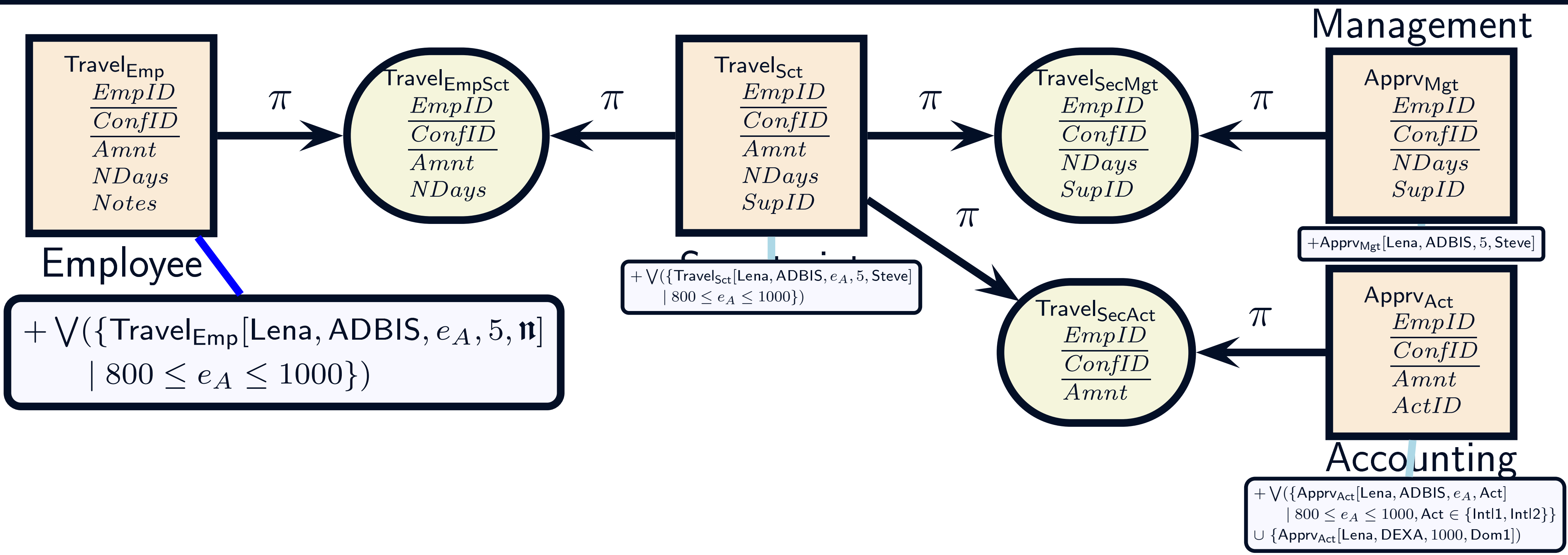

- The port-status register is cleared.
- Note that all port-status registers are now clear.

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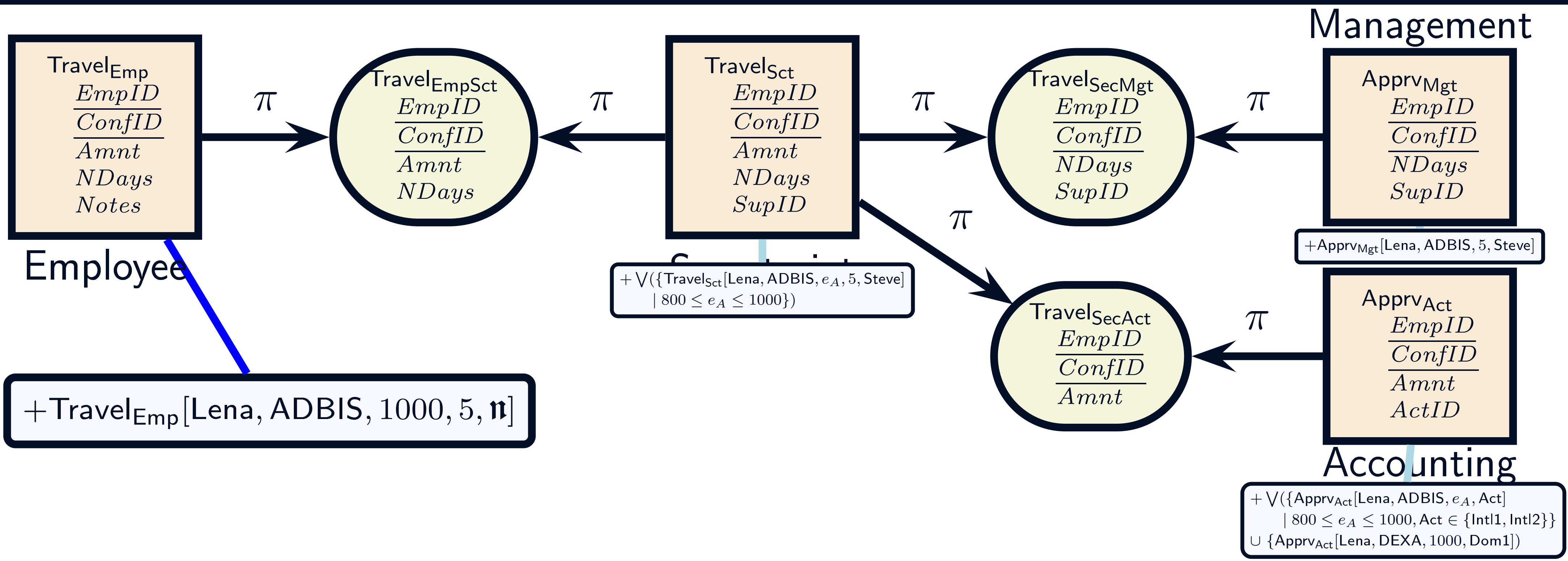

- Finally, Lena selects an update from amongst the possibilities.

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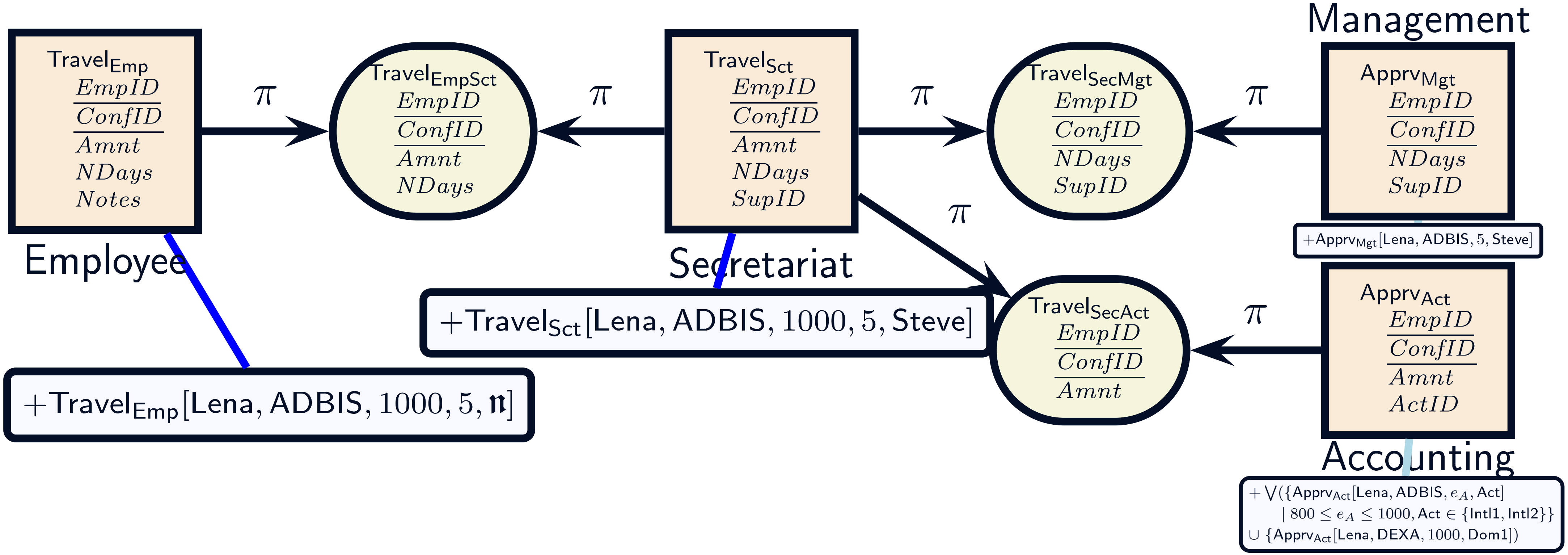

- This update is propagated to the other components for agreement.
- The messages passed through the port-status registers are not shown.

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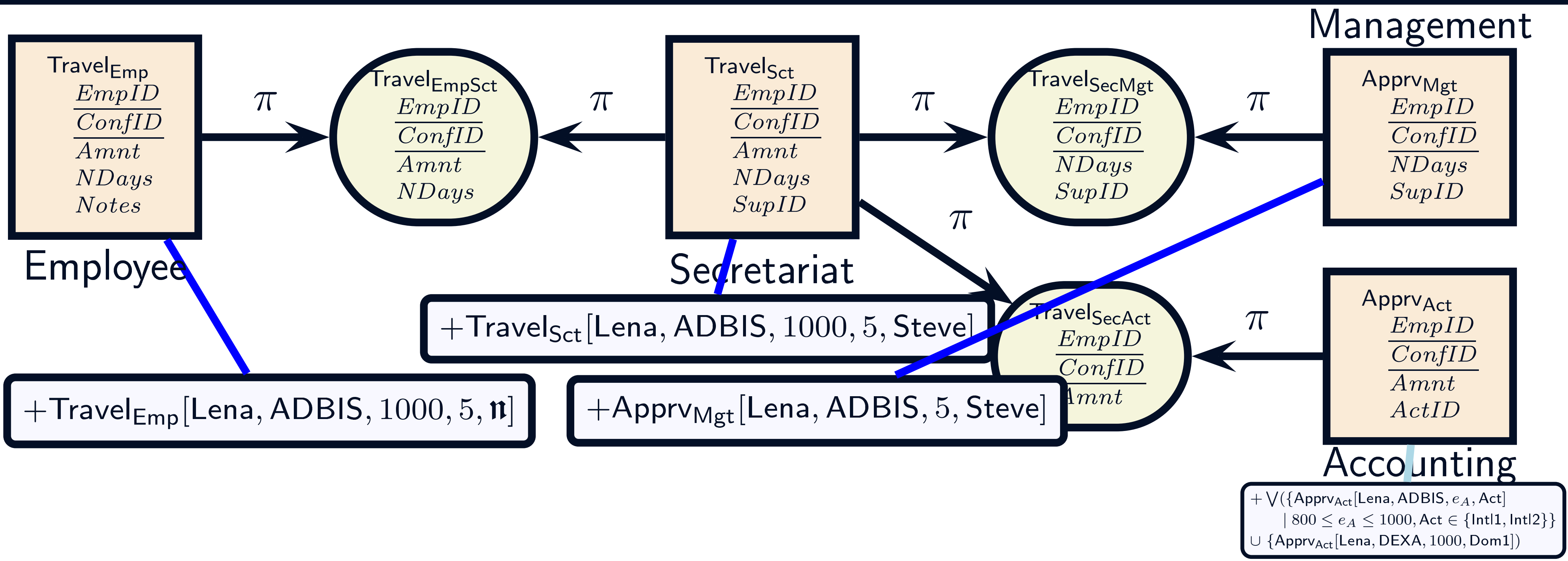

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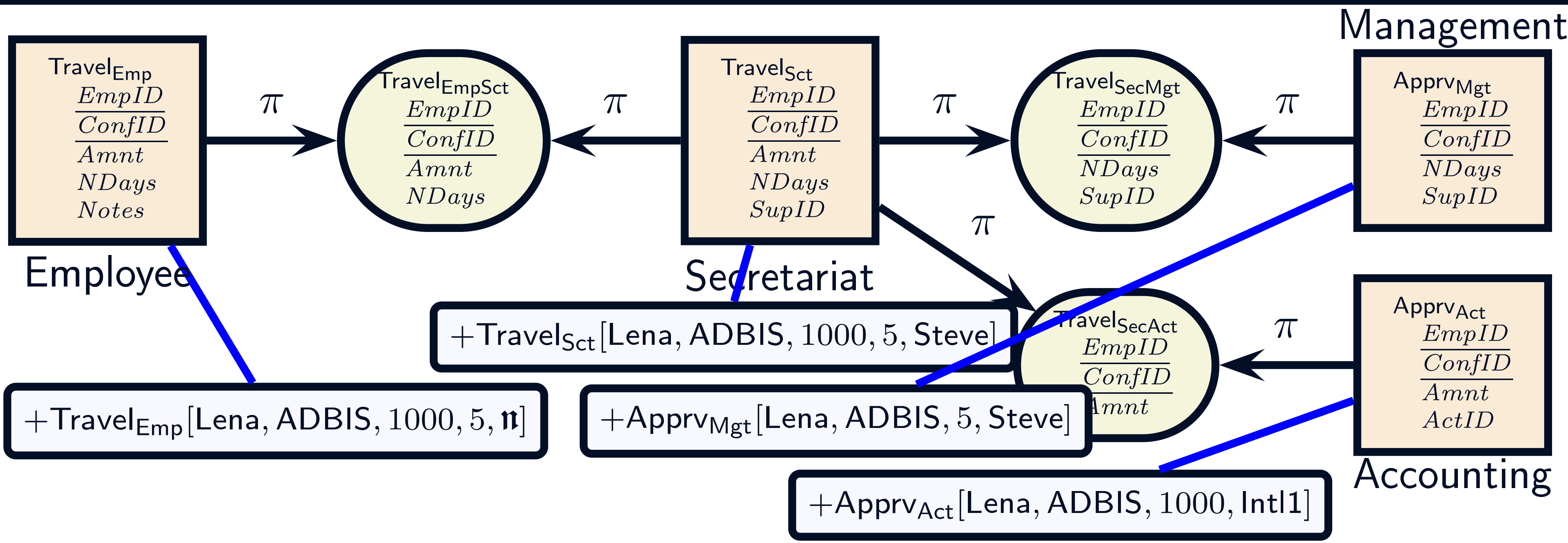

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- Note that a decision of which account to use is made by Accounting, but is not propagated since it is local to that component.

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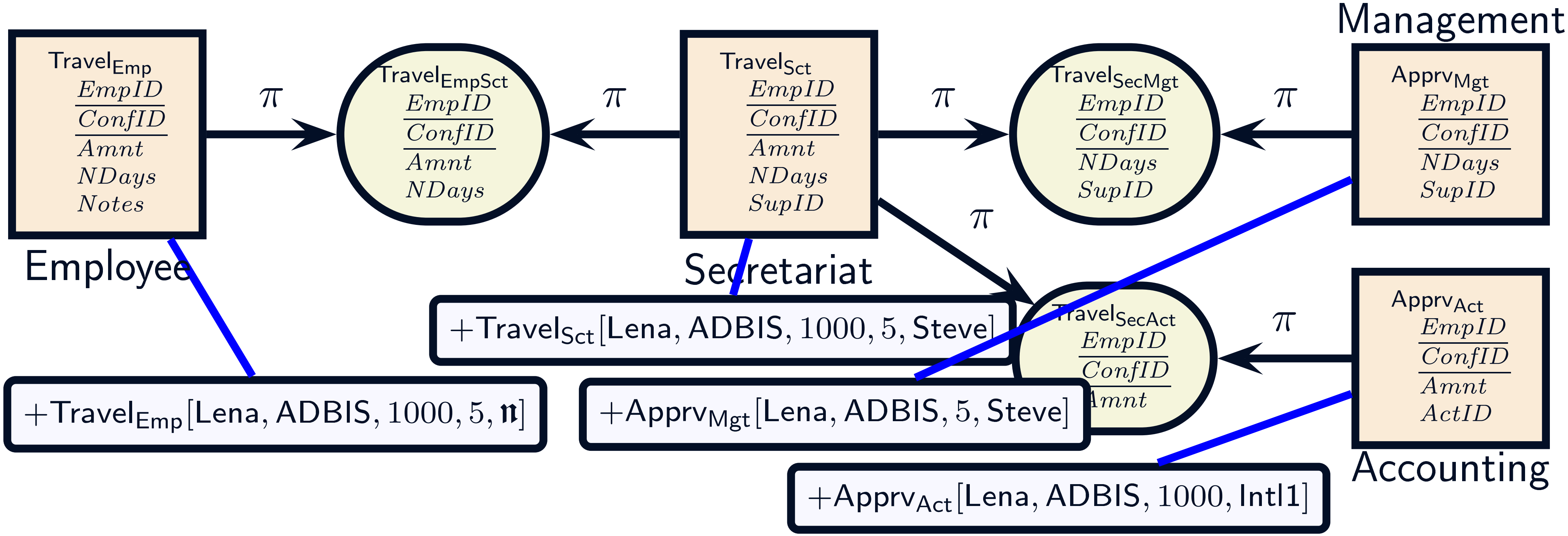

Commit!

- Finally, these proposed updates may be committed to the database.

Current Work on Update Support

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✔ Hierarchy of authority and coercion

- In the proof-of-concept model, all components have equal authority to limit a nondeterministic update proposal.
- In reality, some components/users would have more authority than others.

Example: The secretariat might have less authority than an employee applying for travel.

- This hierarchy of authority should be respected in the update negotiation process via *coercion*.

Extension of the Current Work

✔ A model of user-defined flow of control

- In the proof-of-concept model, a lifted update is immediately communicated to all neighboring components.
- Certain efficiencies can be achieved by allowing components to route update proposals to one component before the other.

Example: The secretariat might route an update request to management before sending it to accounting for a funding request.

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✔ A model which supports simultaneous update proposals

- This is conditioned upon a suitable locking mechanism, of course.

Extension of the Current Work

✔ A bounded model of update negotiation

- In the proof-of-concept model, the update process is guaranteed to converge, but the maximum number of steps is bounded only by the number of update alternatives in all inititial liftings.
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✔ An executable simulation model written in CoreASM.

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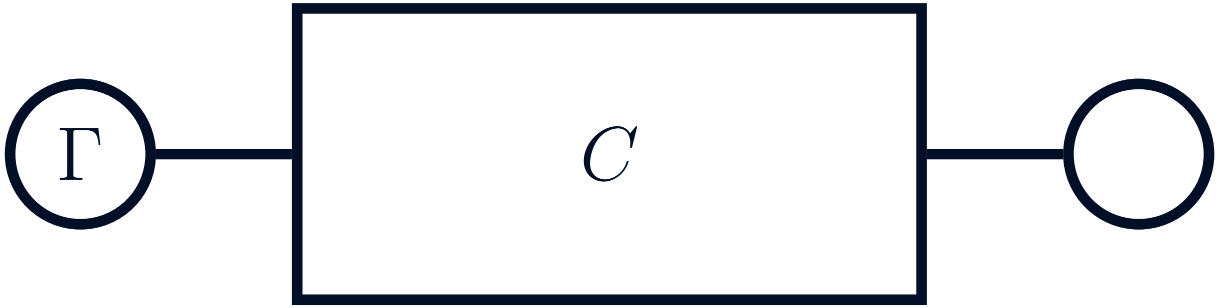
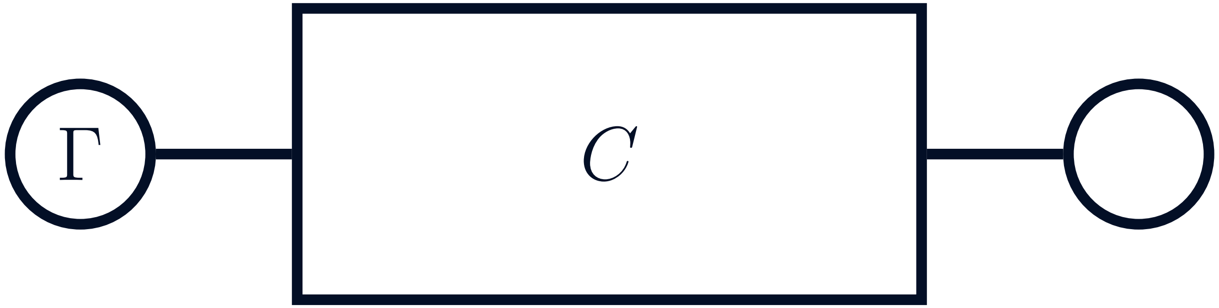
Lifting Strategies



- A key process in update support for interconnected components is the *lifting* of updates from the schema of a port Γ to the main schema of a component C.



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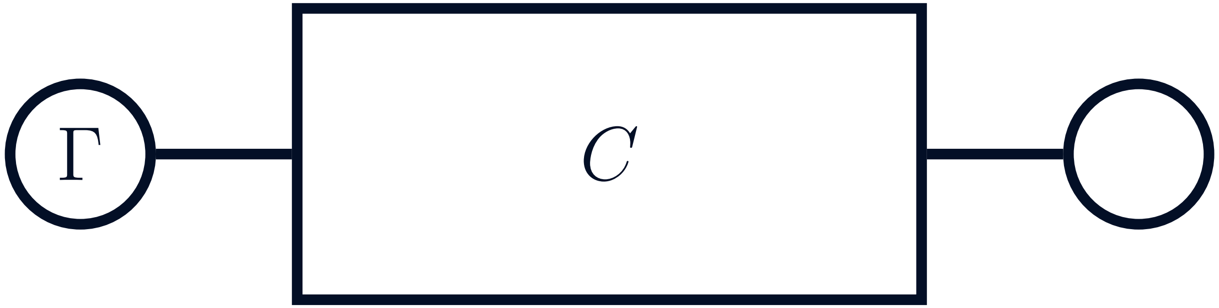

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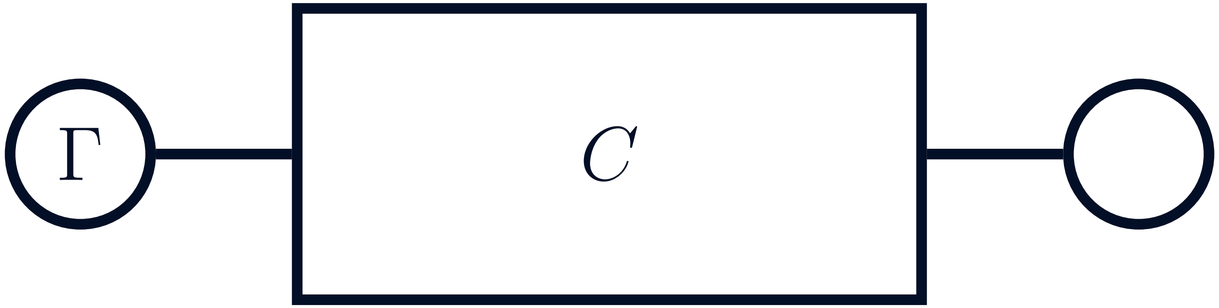

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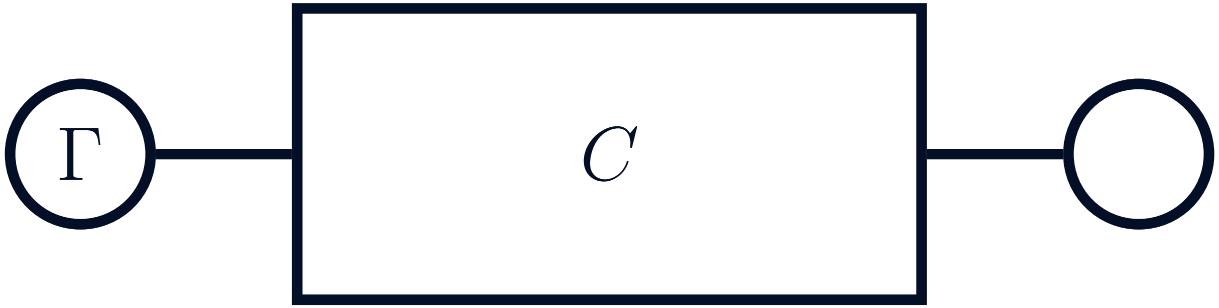

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- It is important to have some formalisms to manage this process.

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- The lifting strategy λ for Γ is *context free* if for every $M_1 \in$ LDB($\mathbf{D}$) and every update family $\mathbf{u}'$ for $\gamma(M_1)$,

$$\lambda\langle M_1, \mathbf{u}\rangle = \bigcup\{\lambda\langle M_1, \{u\}\rangle \mid u \in \mathbf{u}\}$$

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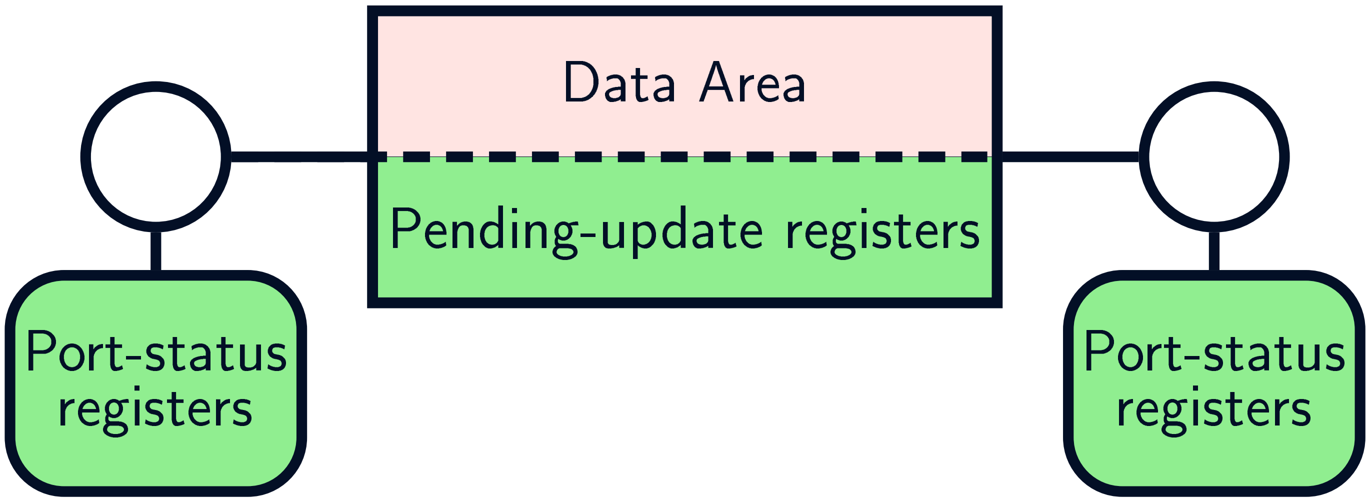
- Minimality will not be discussed further in this talk, but will be assumed.
- Another important concept is the *minmax lifting*, which consists of the set of all minimal liftings for an update family on the view.

The Architecture of a Component



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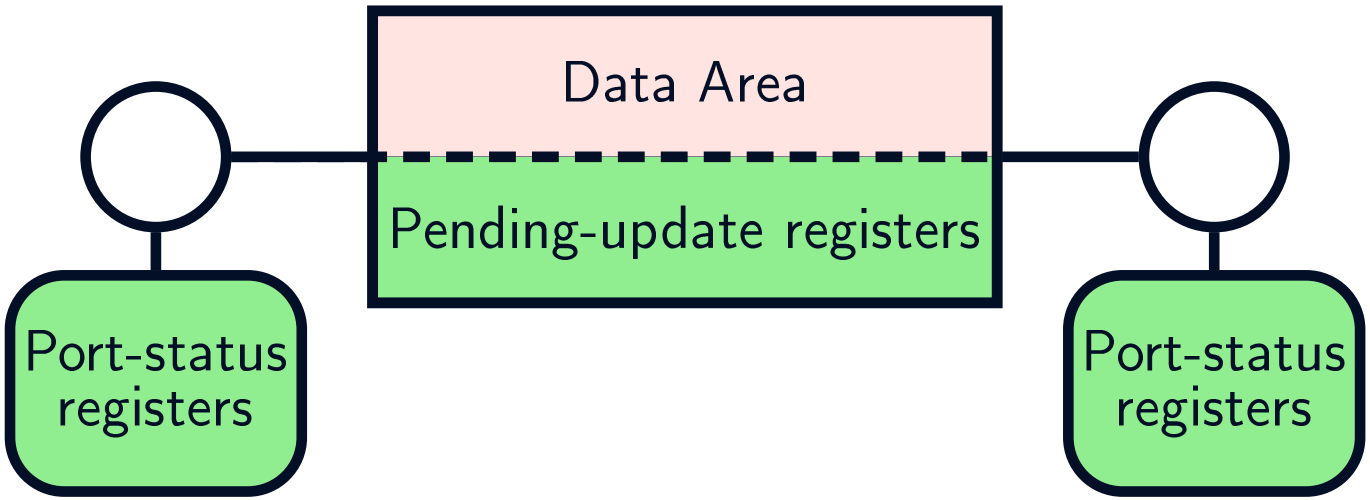

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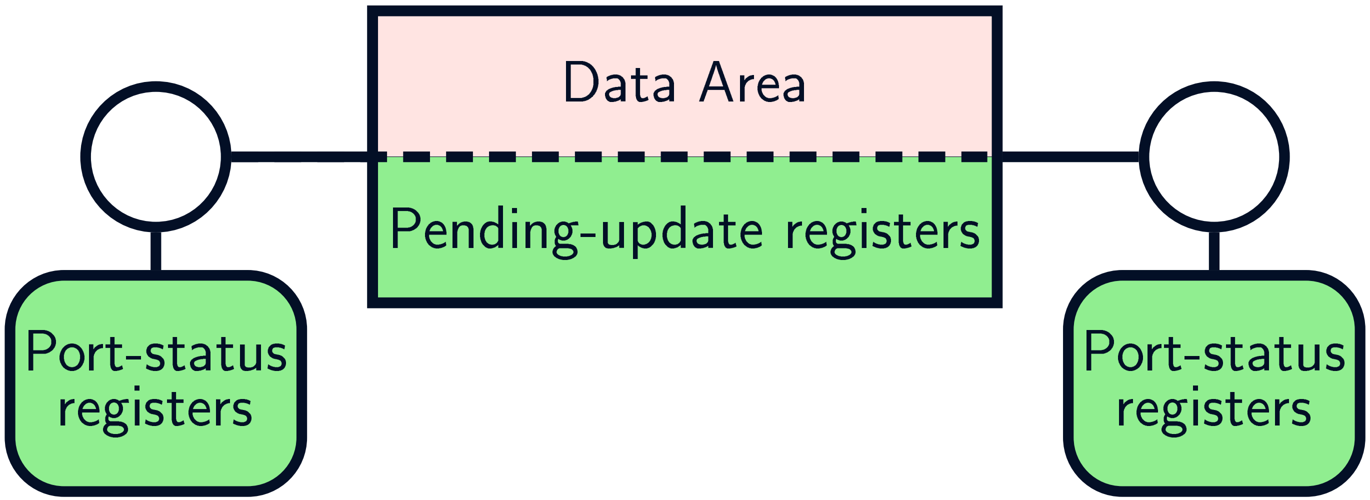

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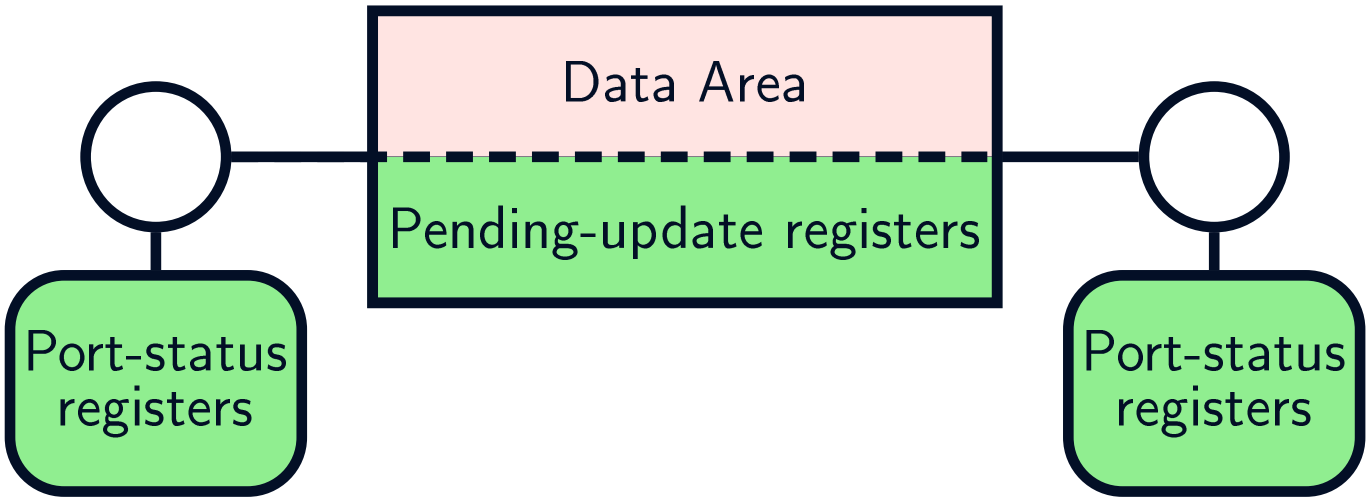

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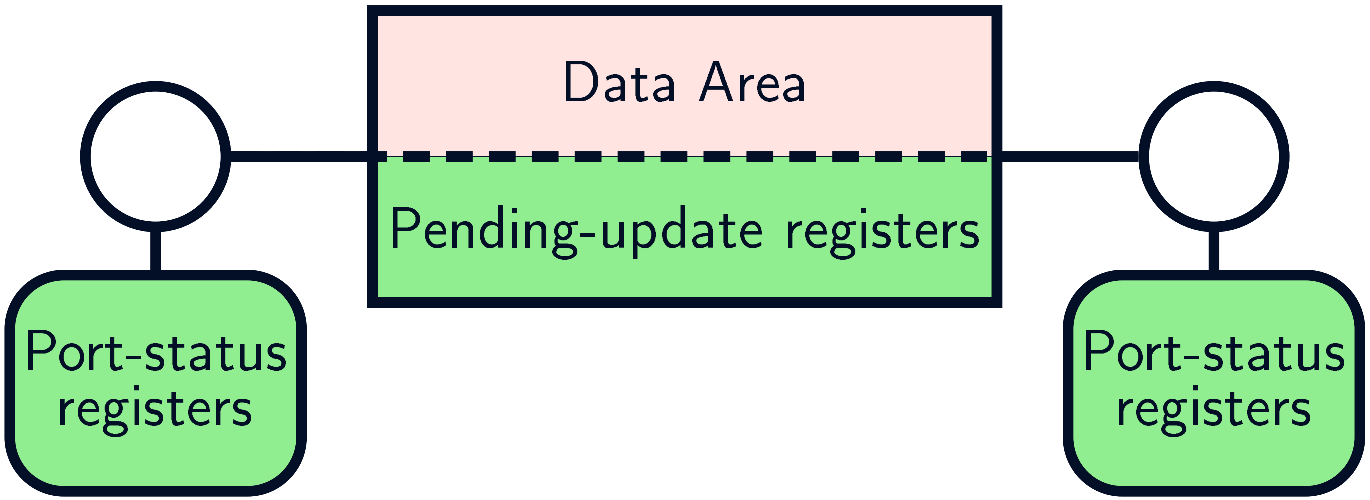
- The *pending-update register* for a given transaction records the current (possibly nondeterministic) update which is proposed on the given component.
- The *port-status registers* contain:
  - The current (possibly nondeterministic) update to be applied at that port.
  - State and control information necessary for support of the update process.



- Overview of the fields of a pending-update register:

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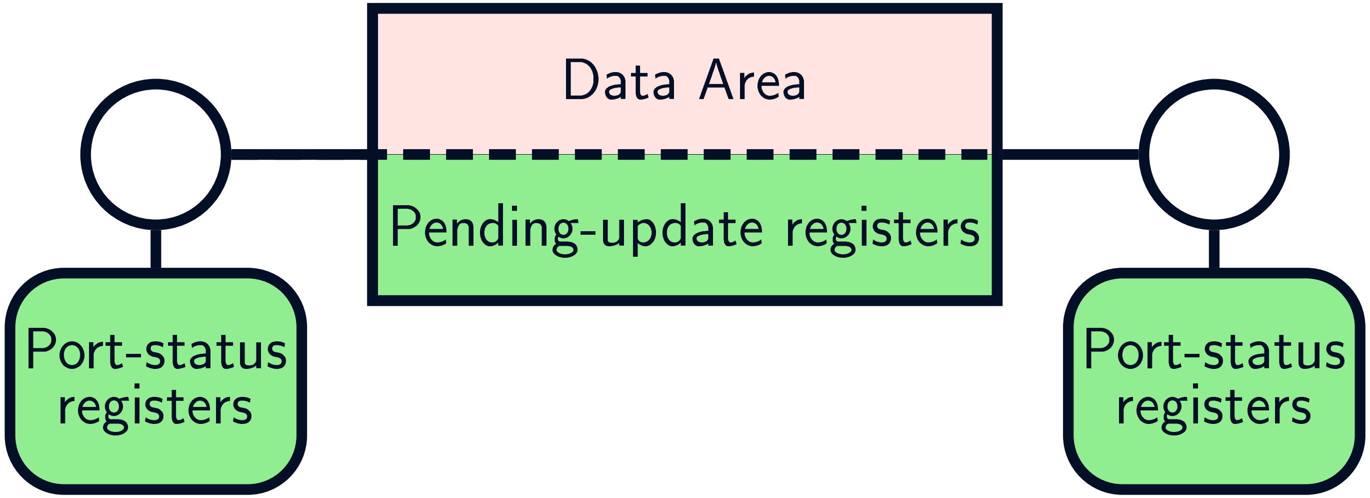

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`Transaction_ID:`	ID_type
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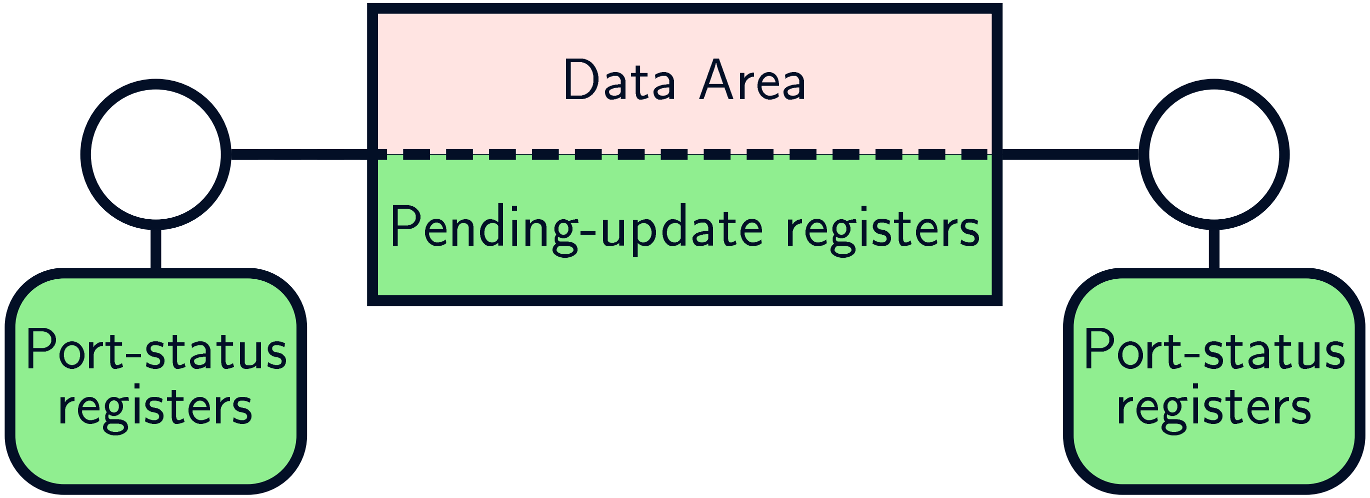

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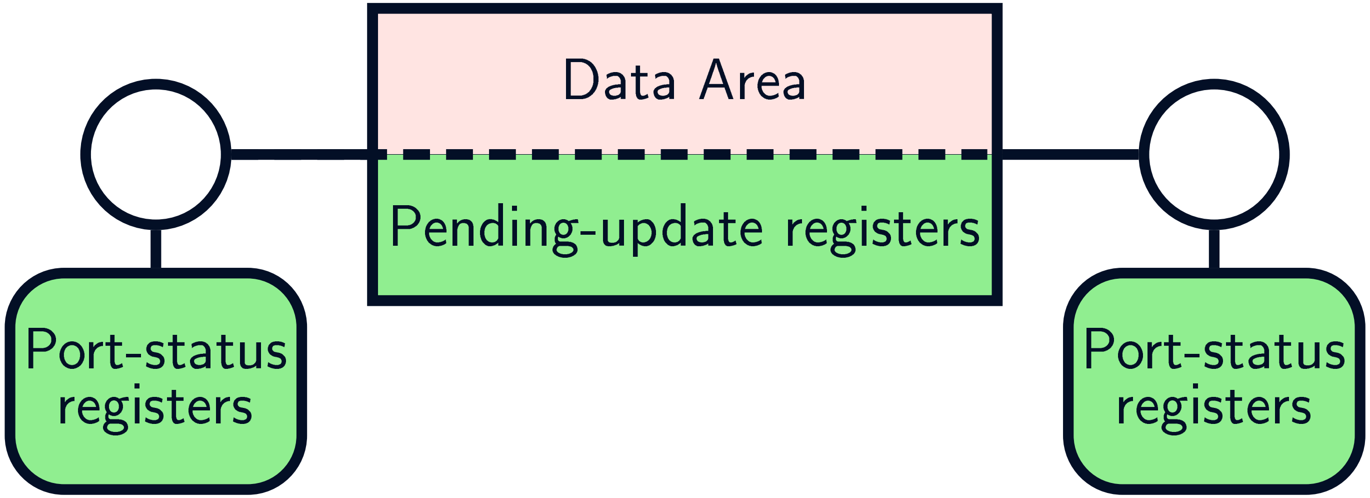

- Overview of the fields of a port-status register:

`Transaction_ID:`	ID_type
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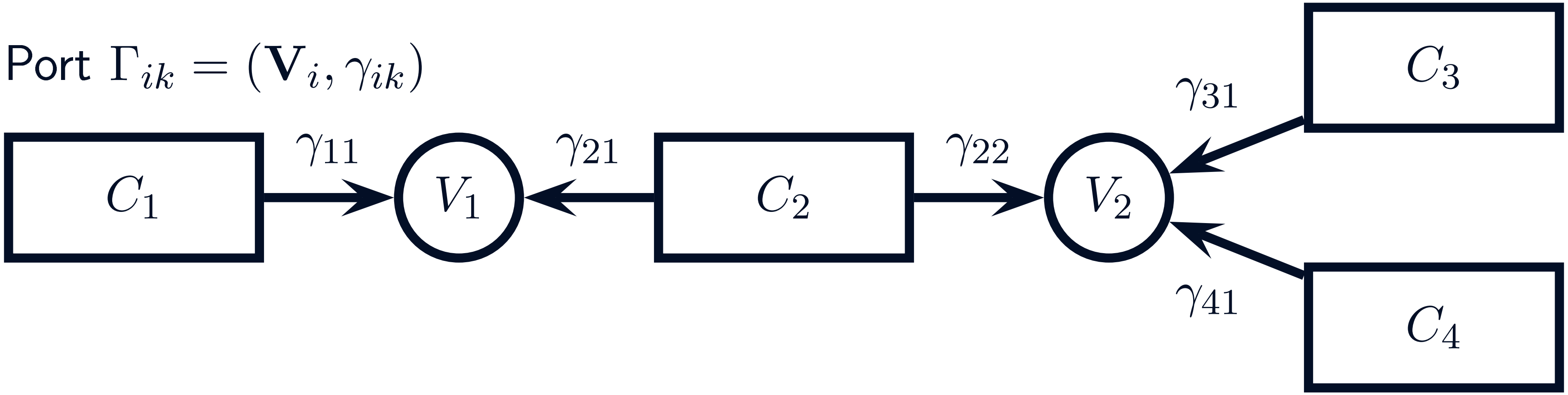
`Pending port state:`	update family
`Type:`	{Inner, Outer}
`Status:`	{NULL, Initial, Revised} (Inner)
	{NULL, Preliminary, Final} (Outer)
Writers:	C_1: Boolean
	$\vdots$ (Neighboring components)
	C_k: Boolean

Inner Ports, Outer Ports, and Extreme Components

Port $\Gamma_{ik} = (\mathbf{V}_i, \gamma_{ik})$



Context: Acyclic interconnection family J, C_i and C_j components.

Think: C_i is the component which initiates the update request.
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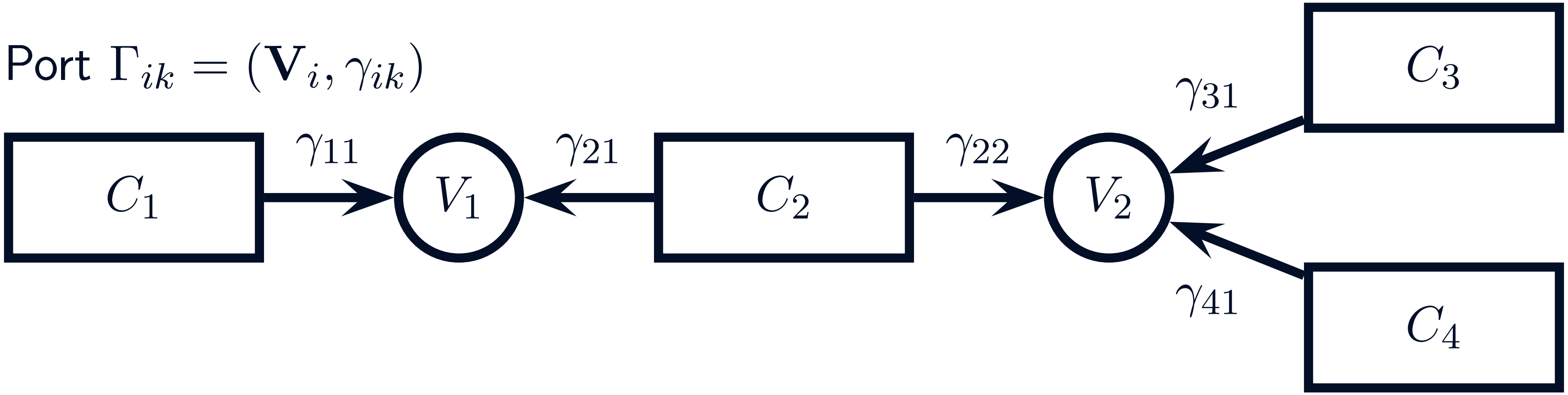

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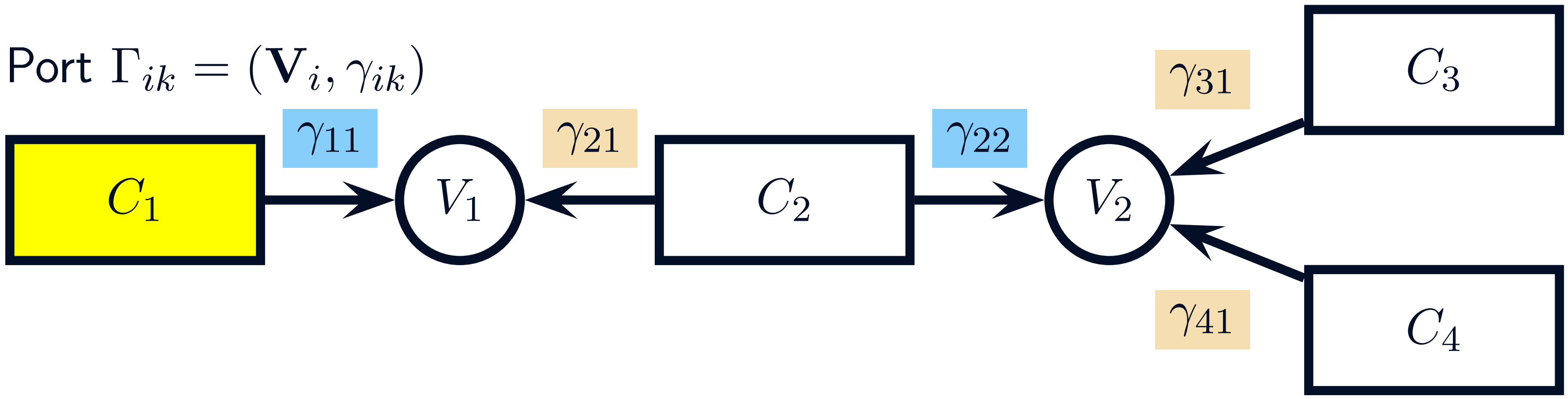

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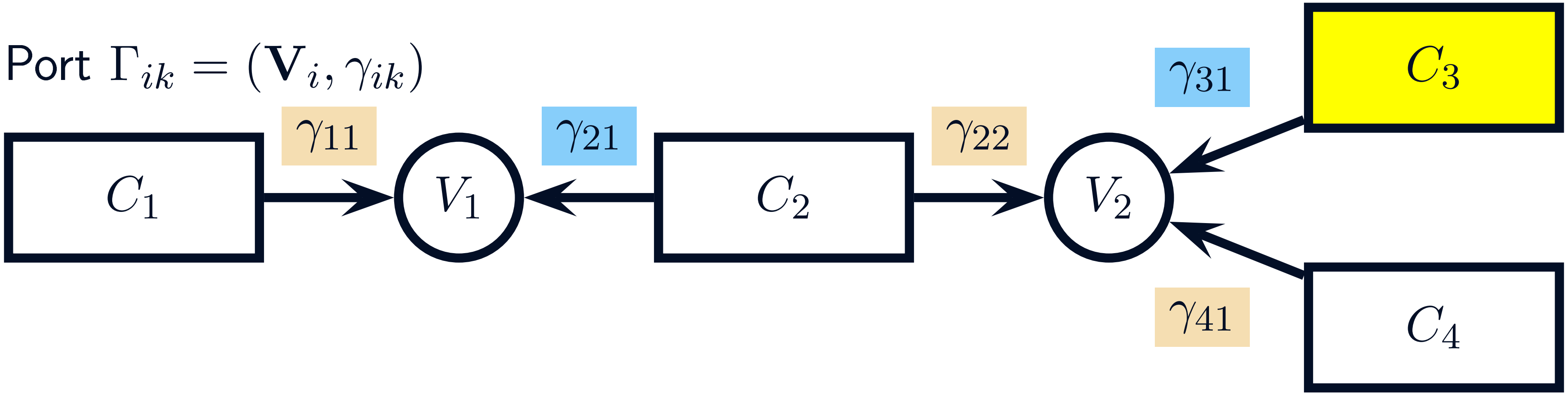

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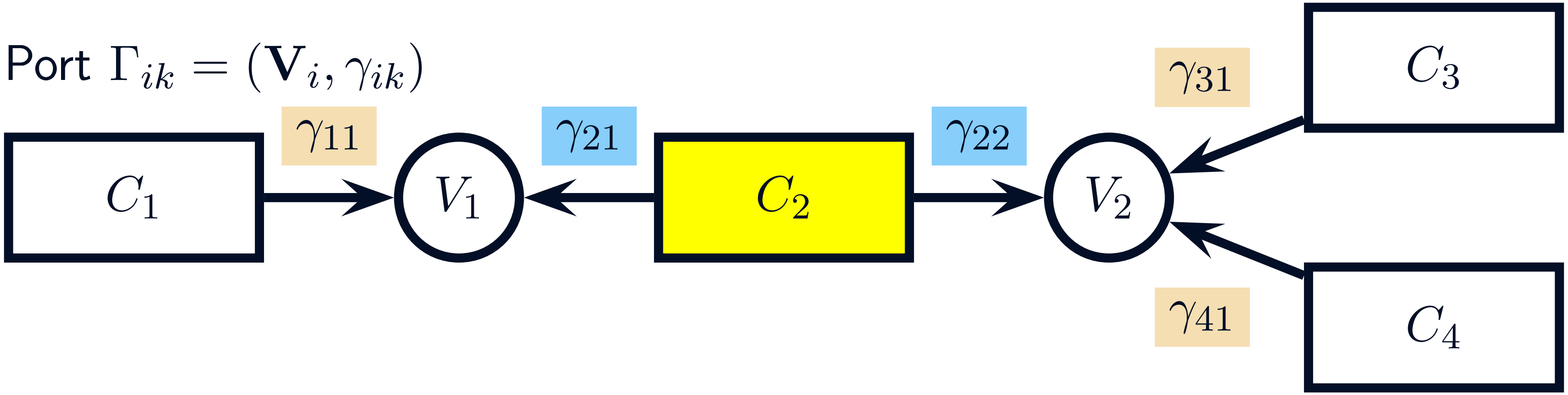

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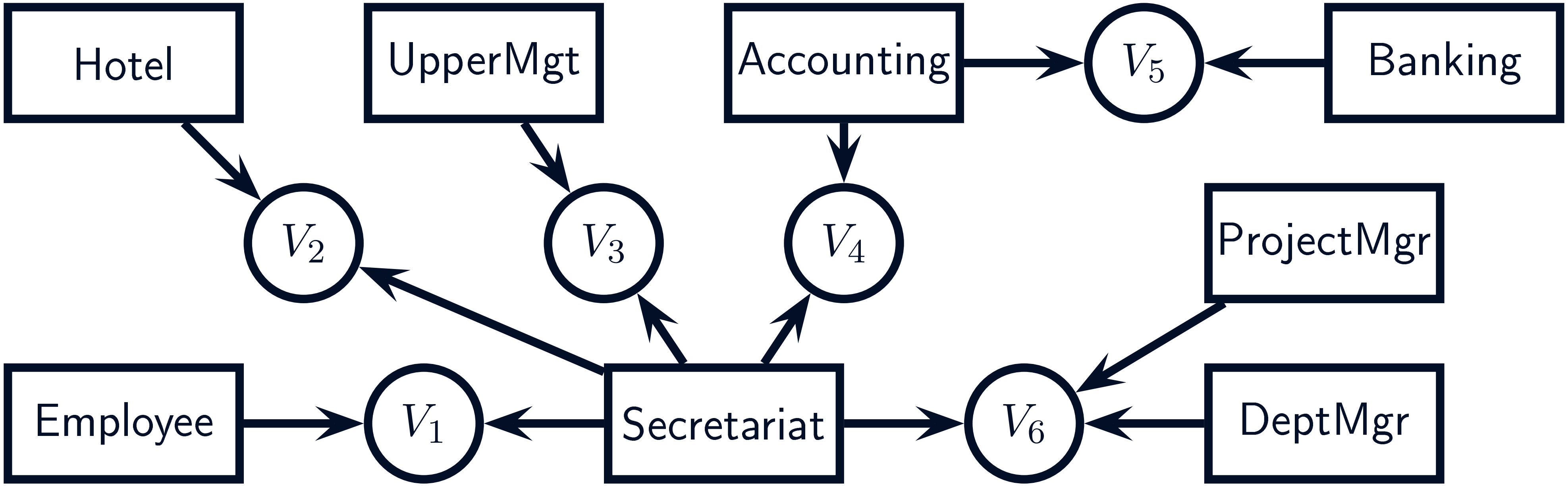
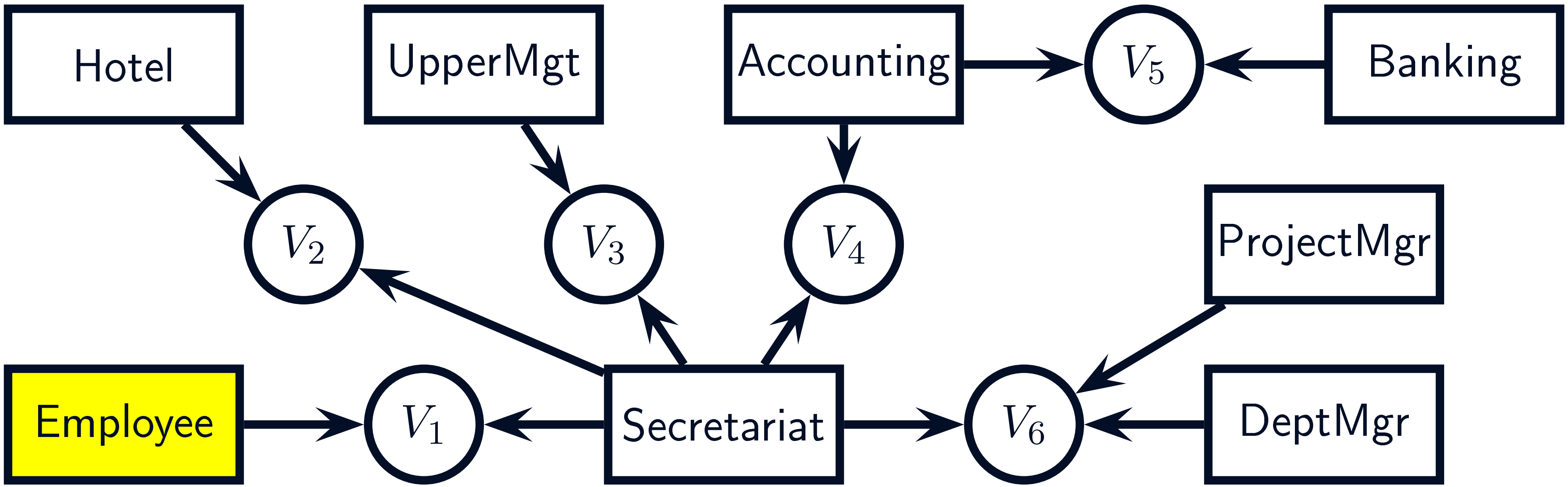
A More Complex Example to Illustrate All Aspects

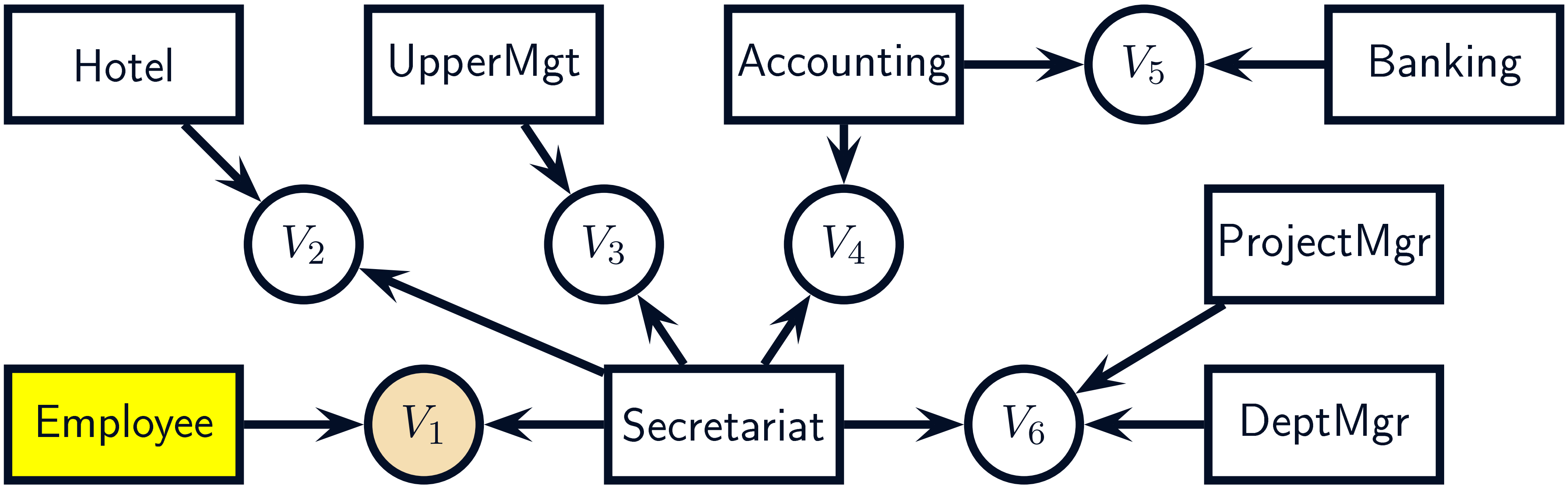


- The *Hotel* and *Banking* *components* are autonomous.
- They are automated suppliers of information; there are no human decisions involved.

The Three-Stage Update-Negotiation Process



Stage 1: The initial update is passed, step-by-step, to the inner ports of neighboring components, following a project-lift cycle.



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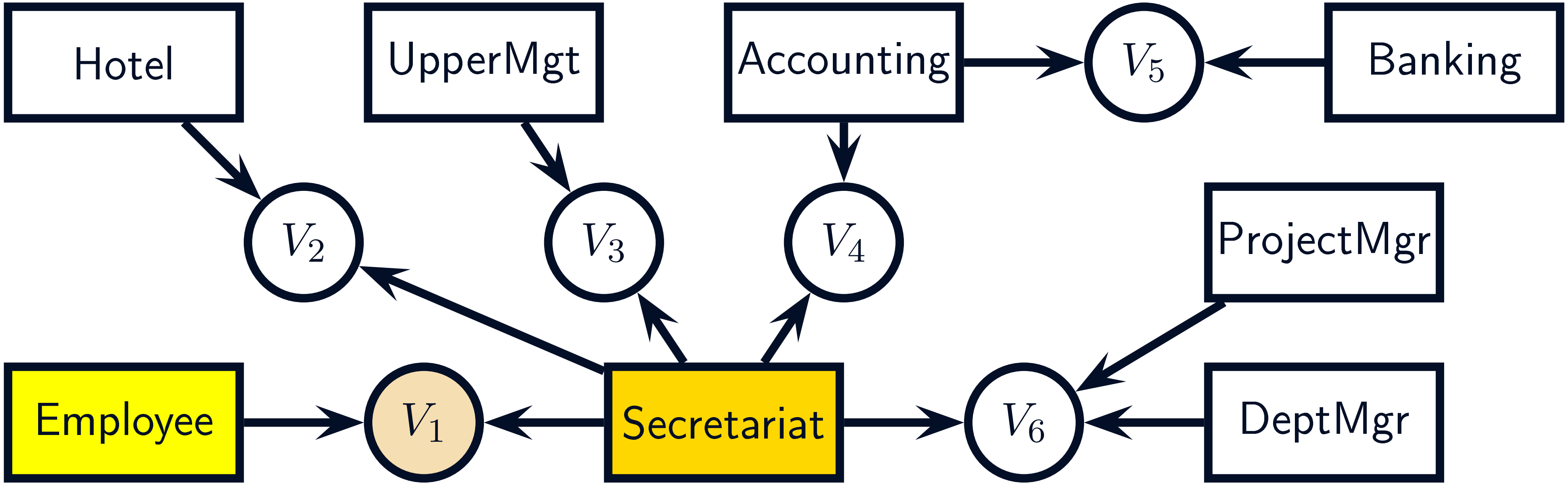

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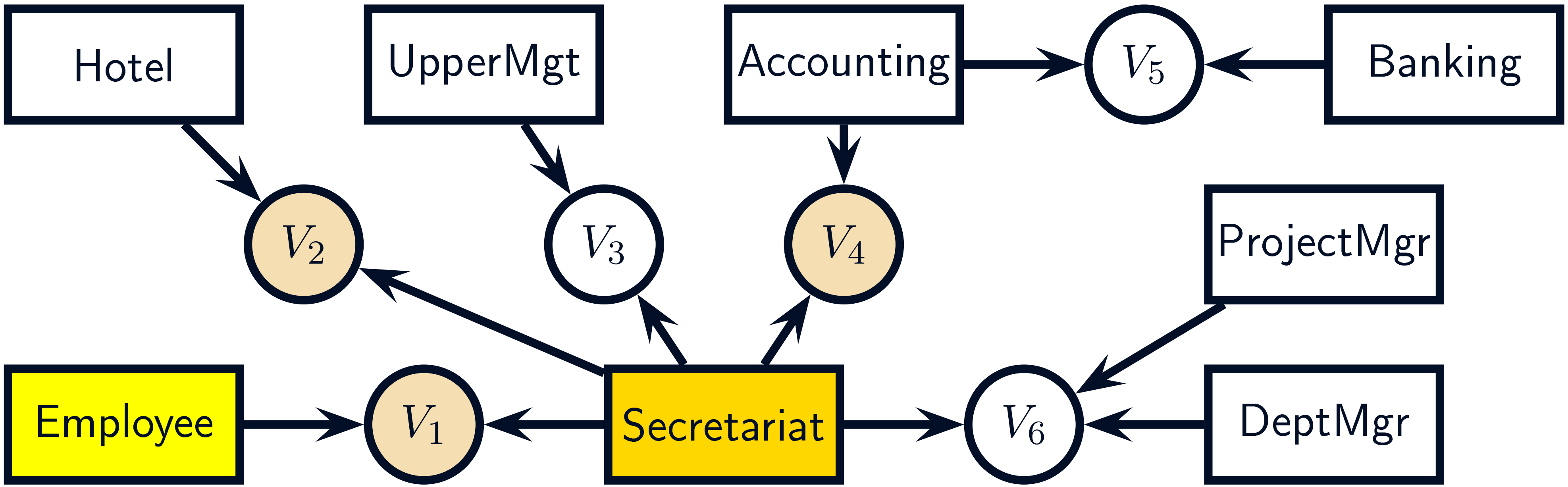

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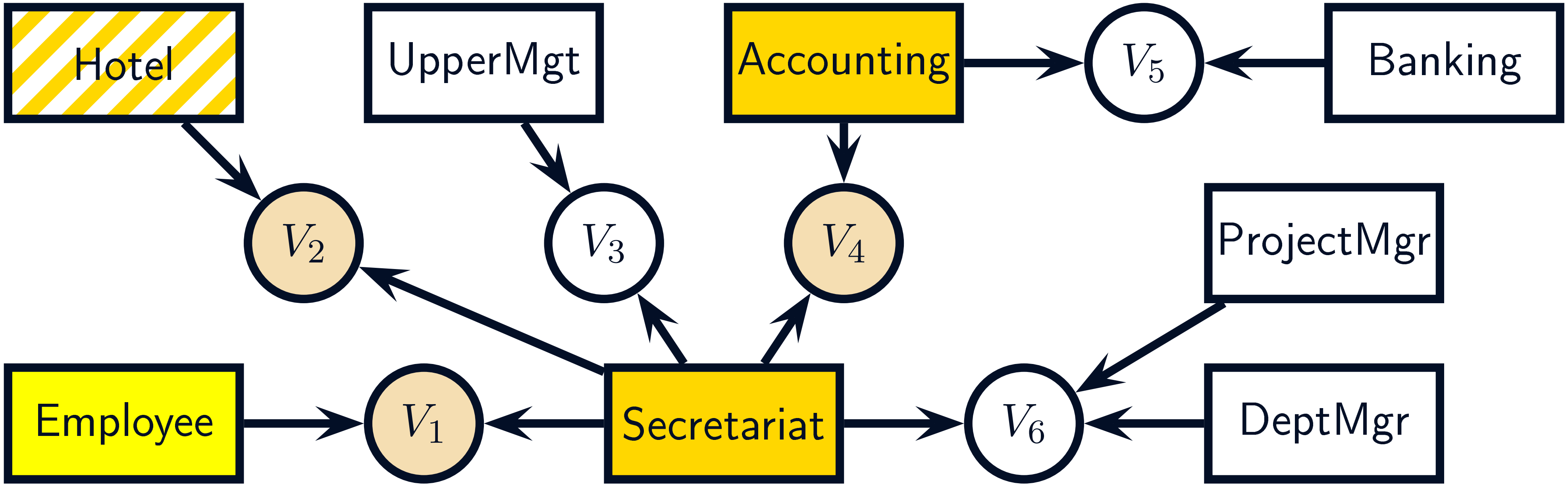

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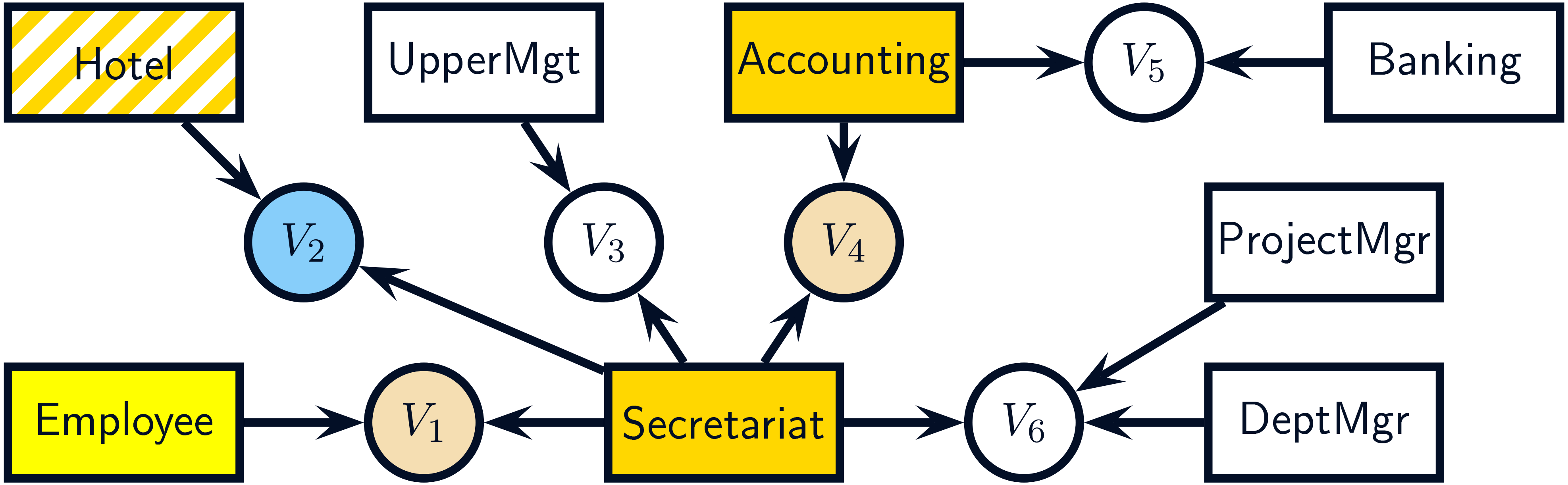

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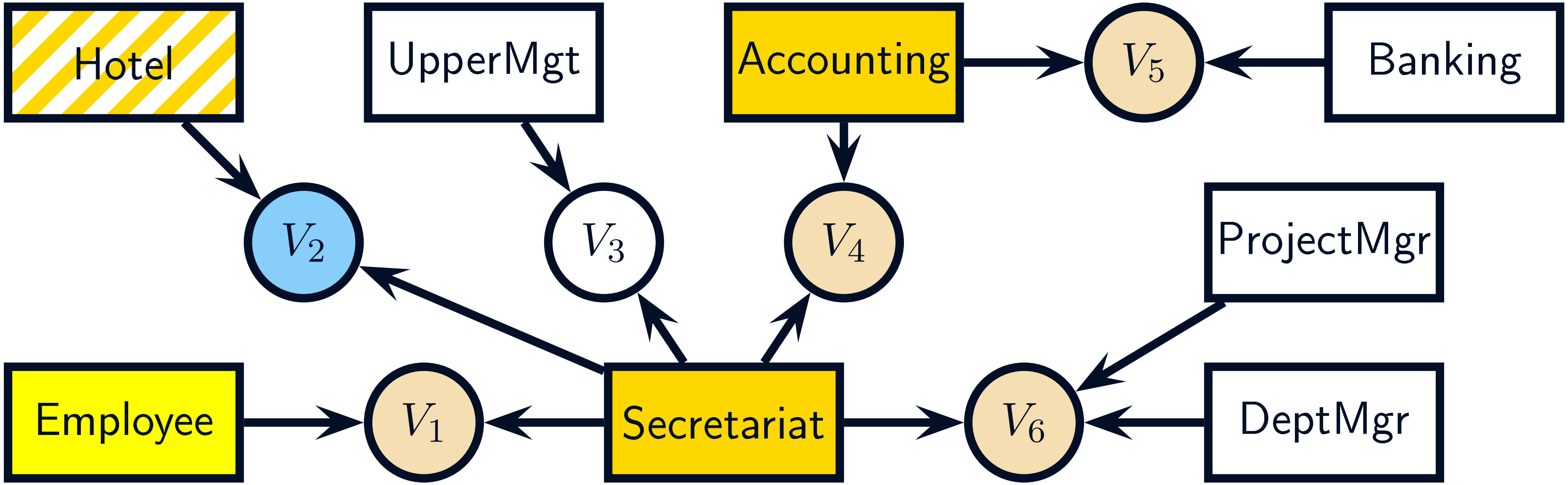

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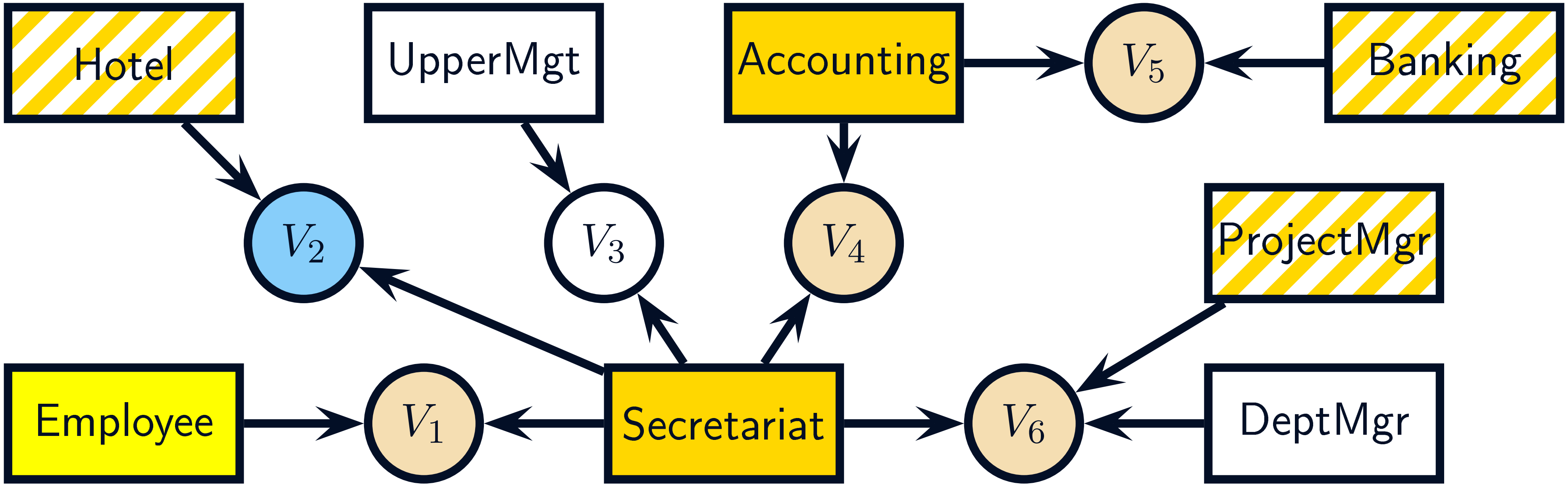

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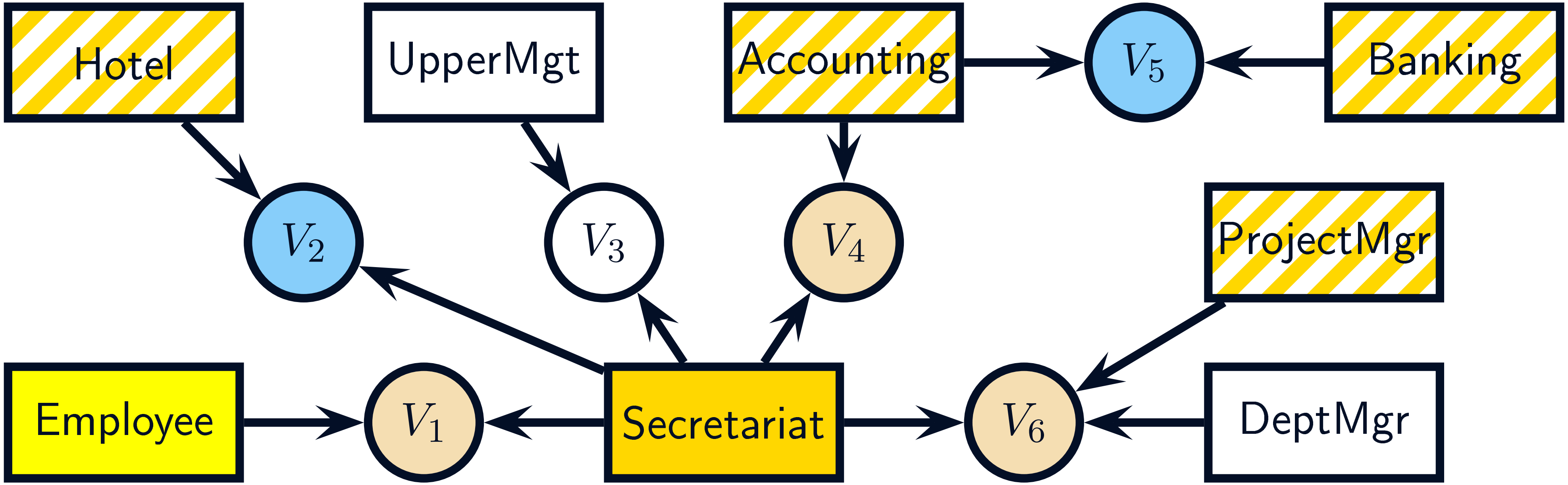

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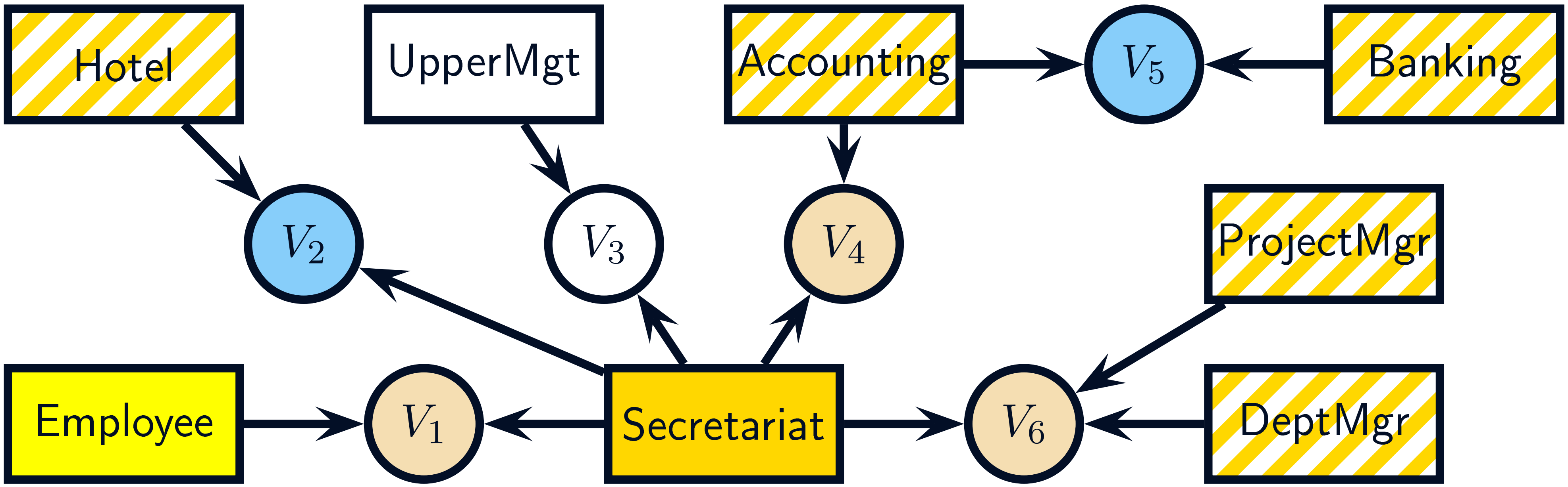

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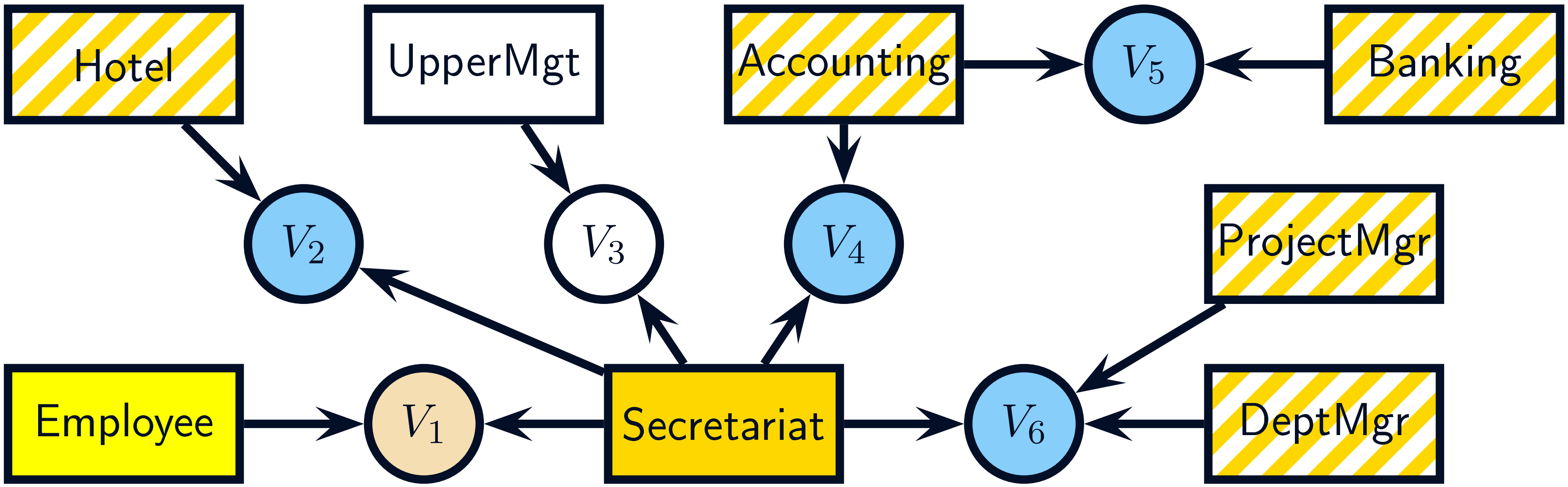

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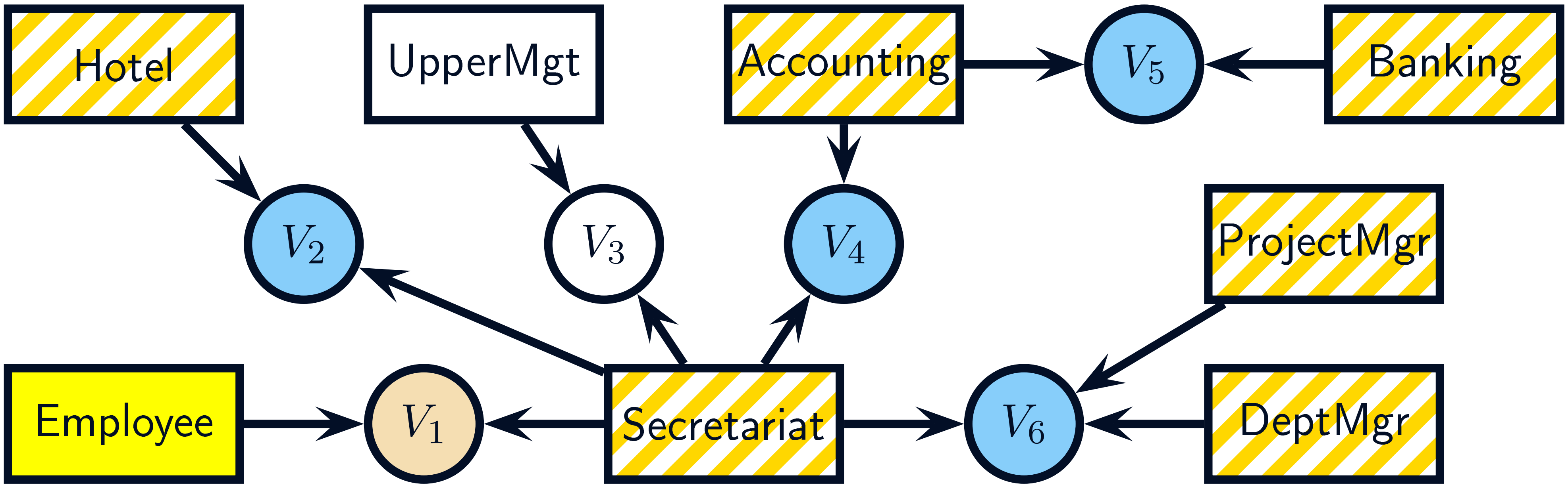

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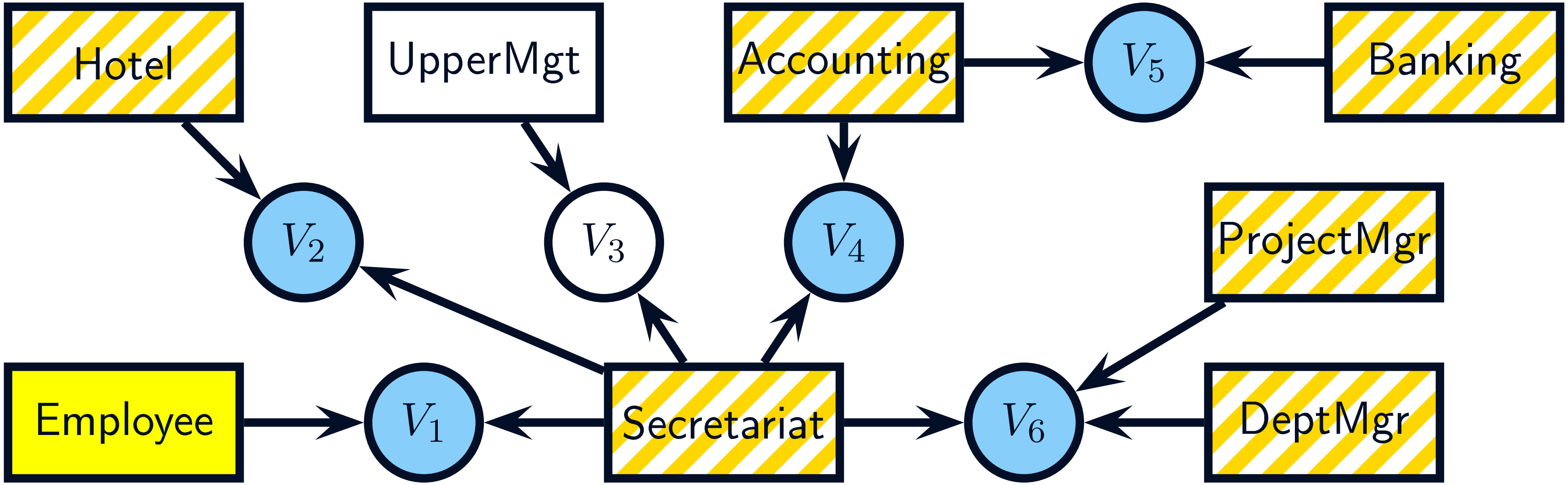

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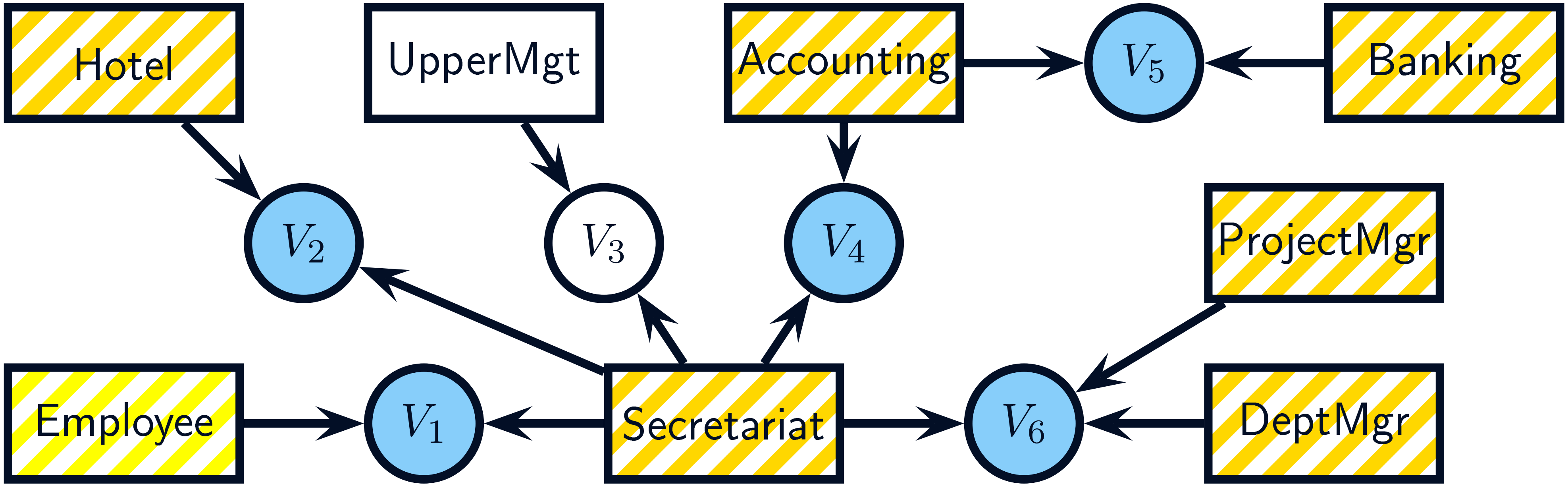

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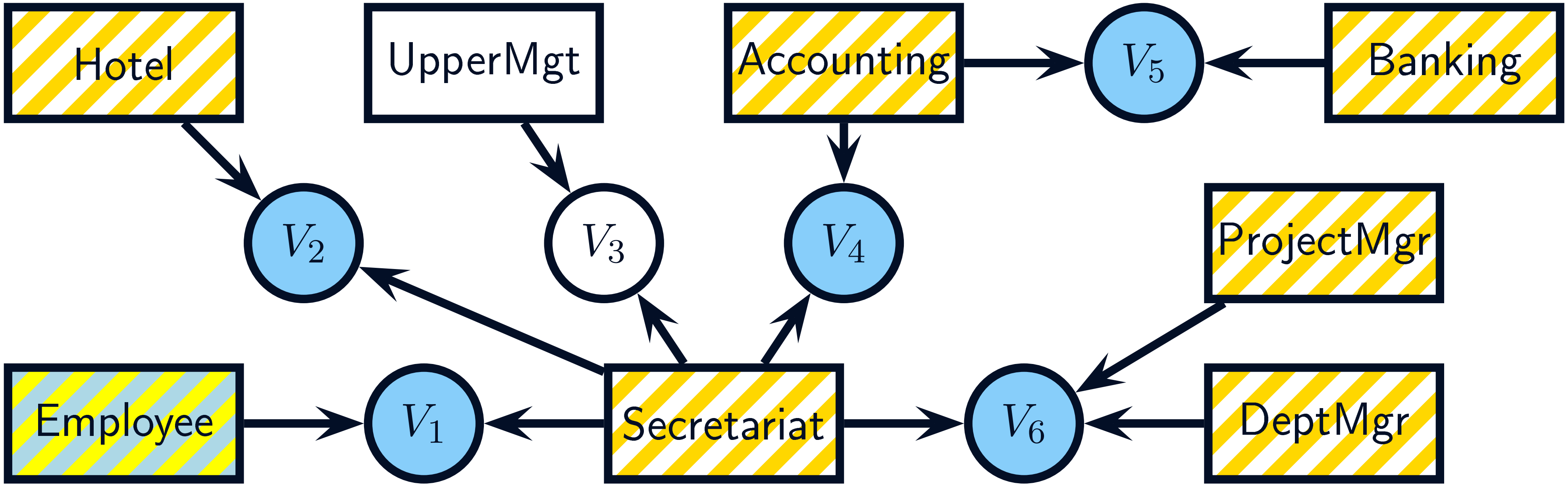

Stage 3: The initiator selects a specific update from amongst the alternatives.

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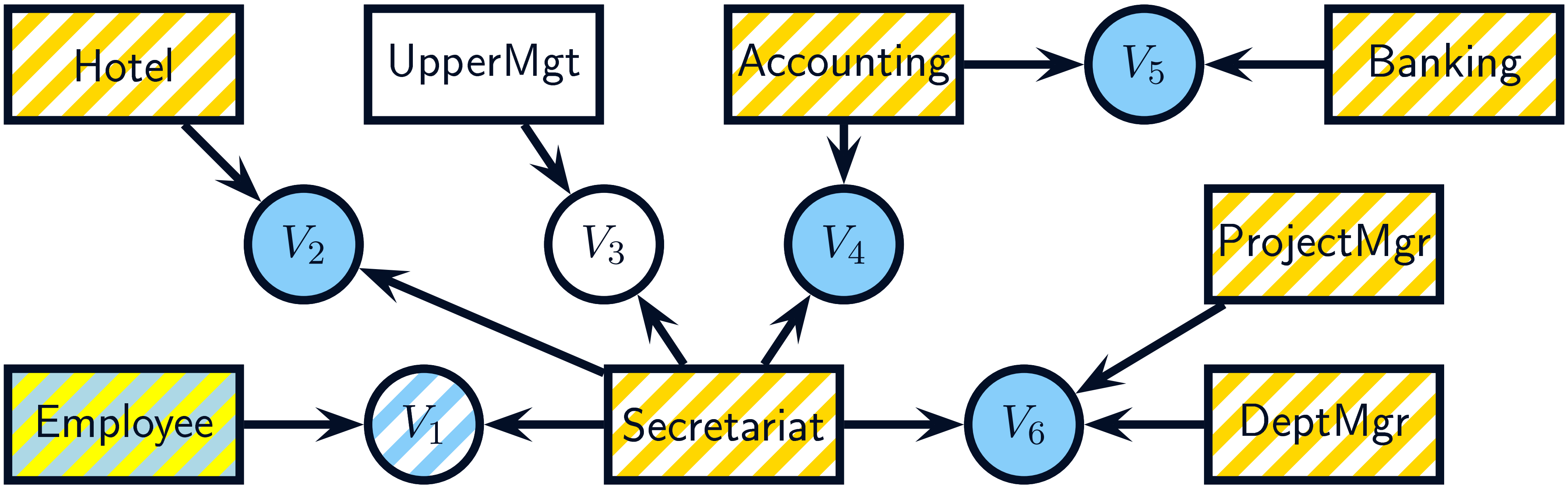

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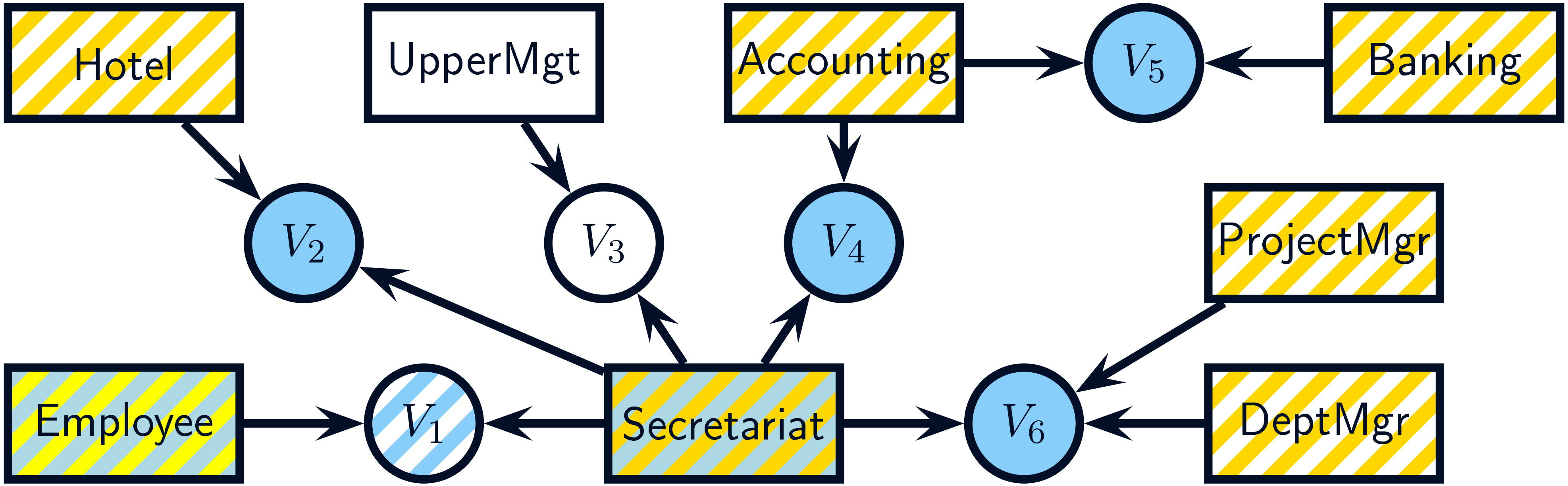

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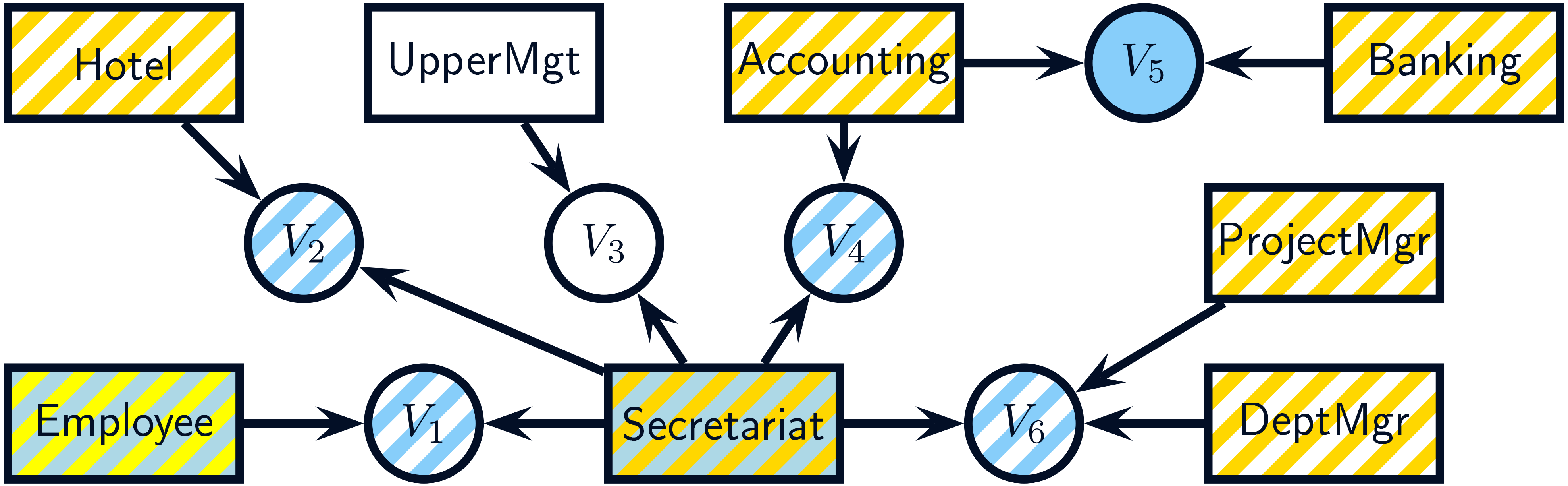

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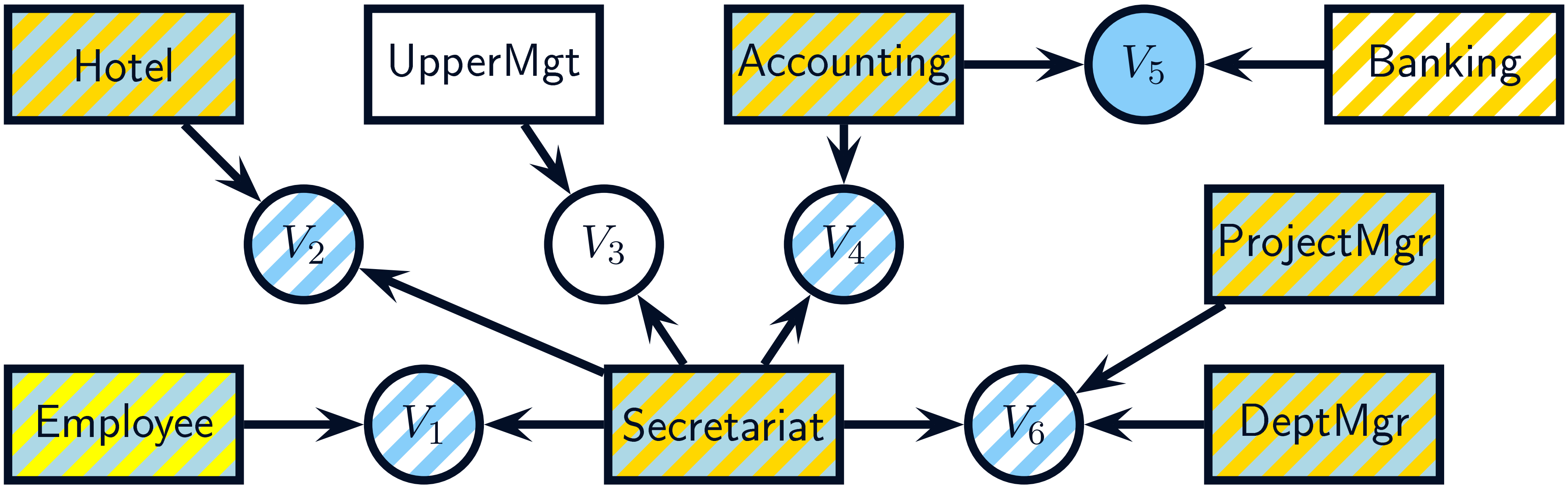

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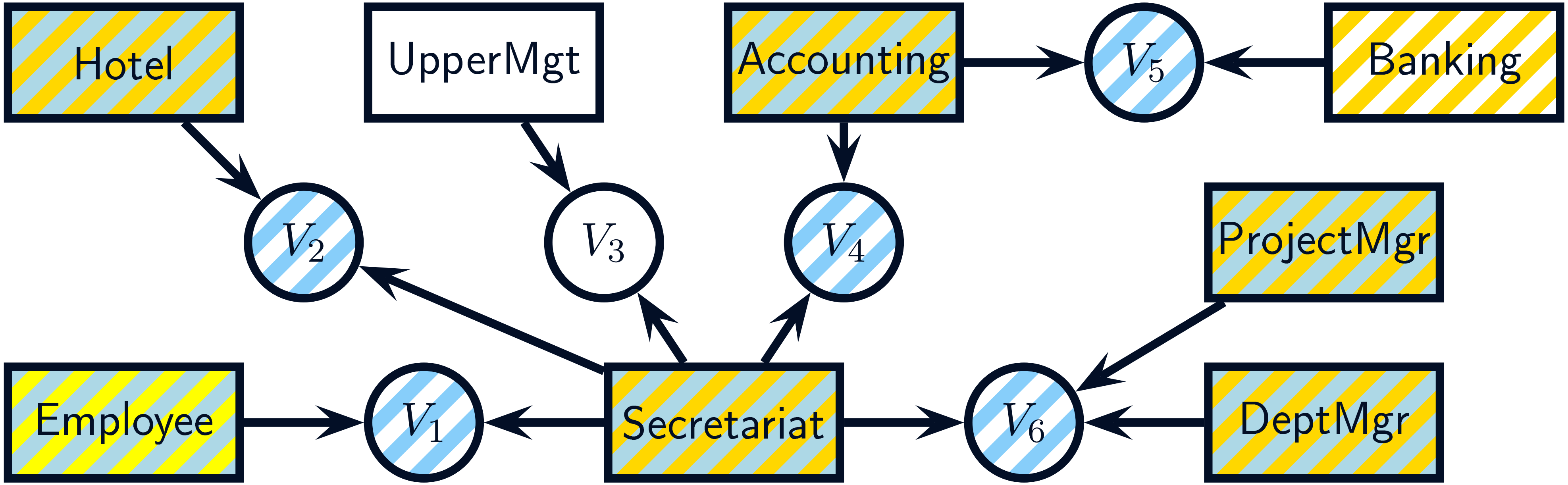

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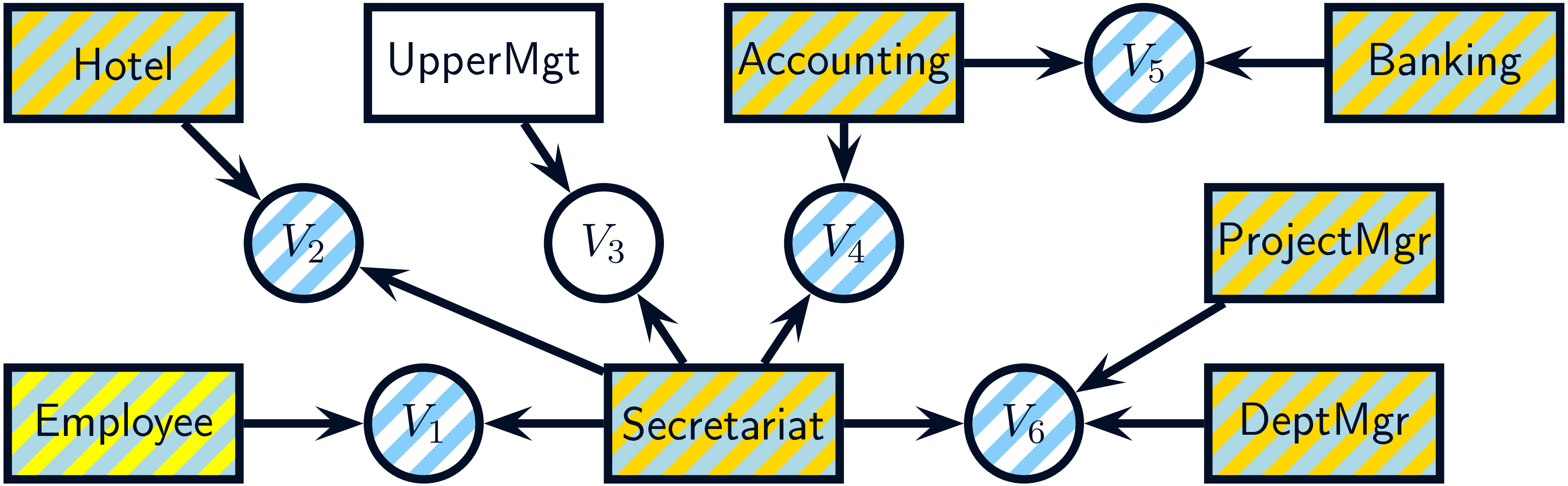

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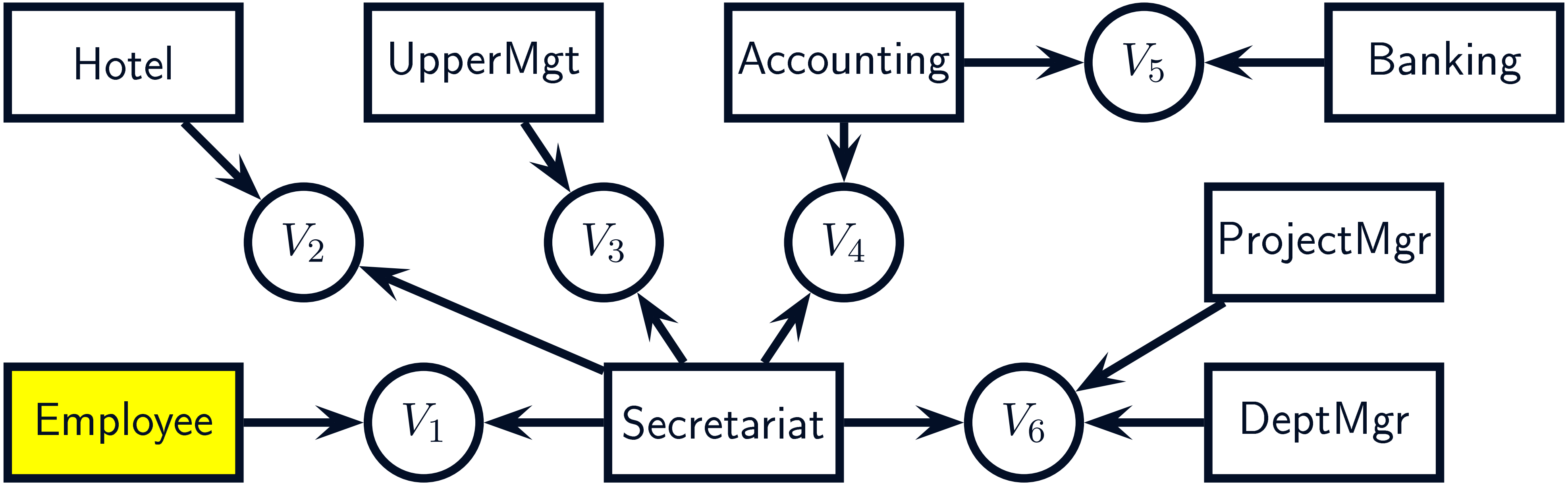

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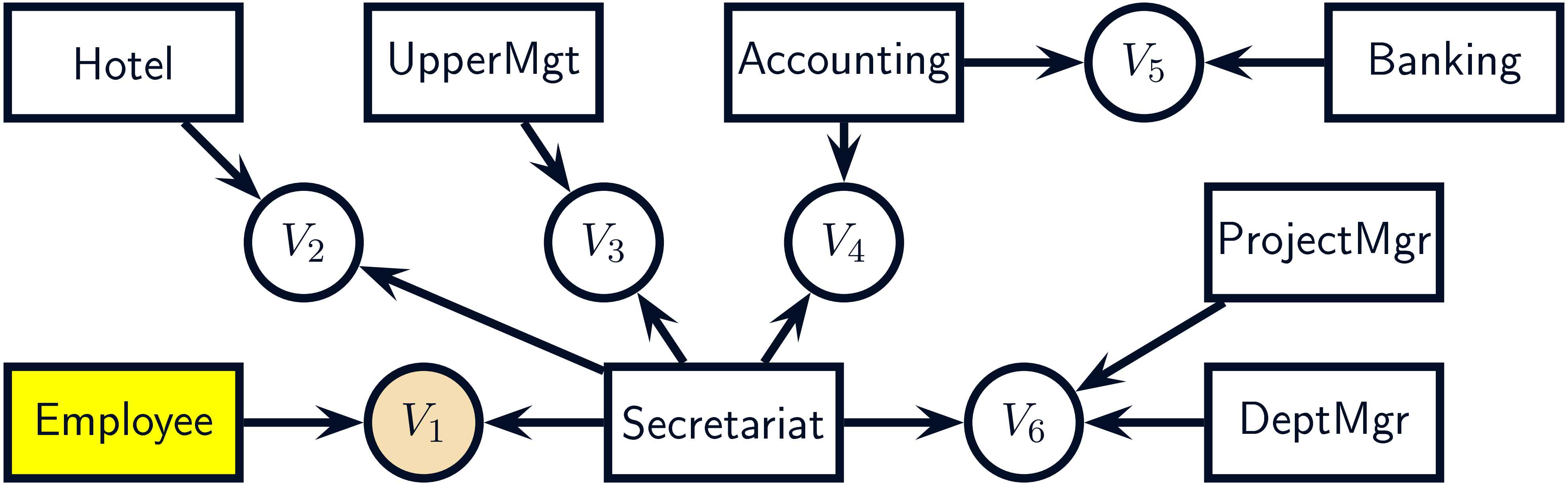

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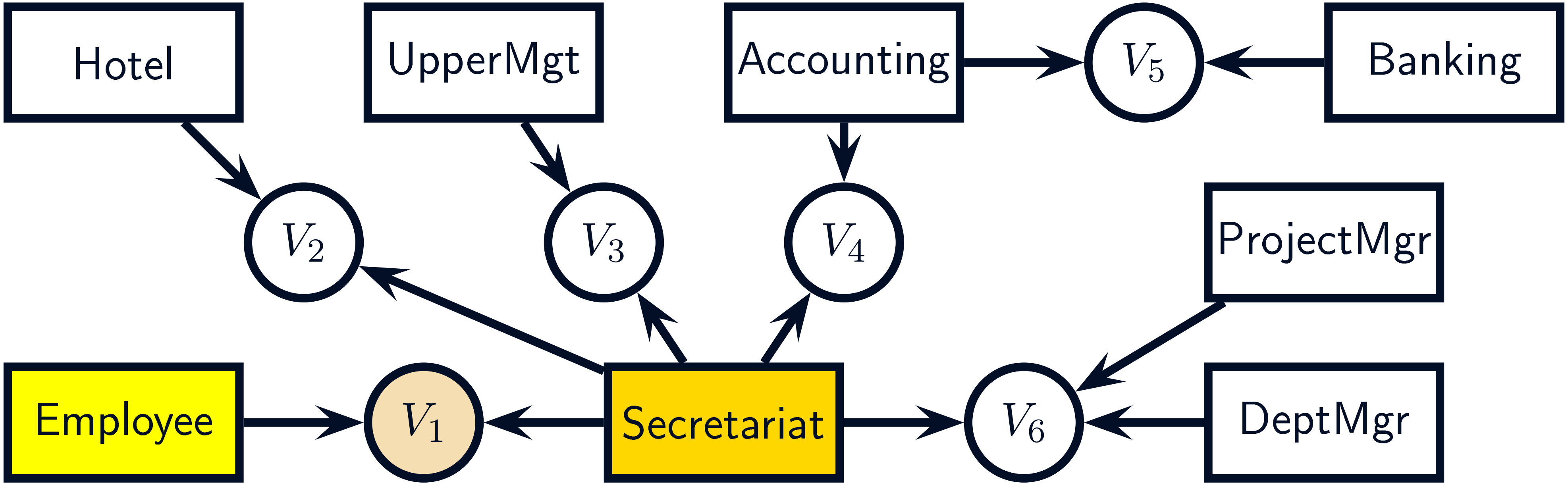

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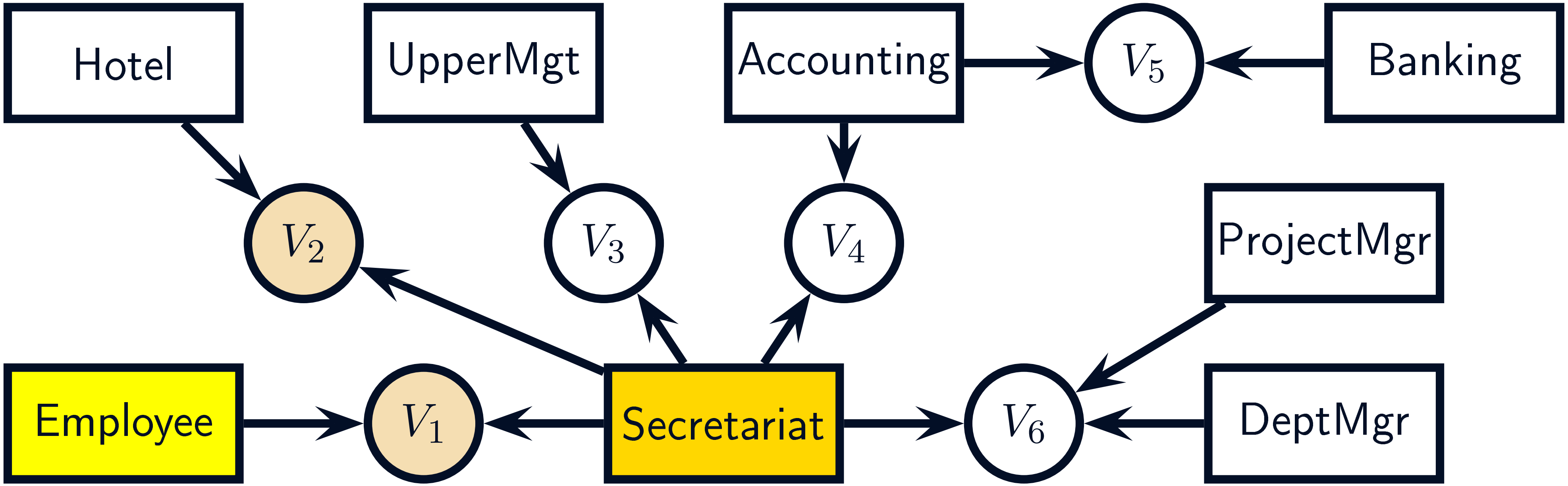

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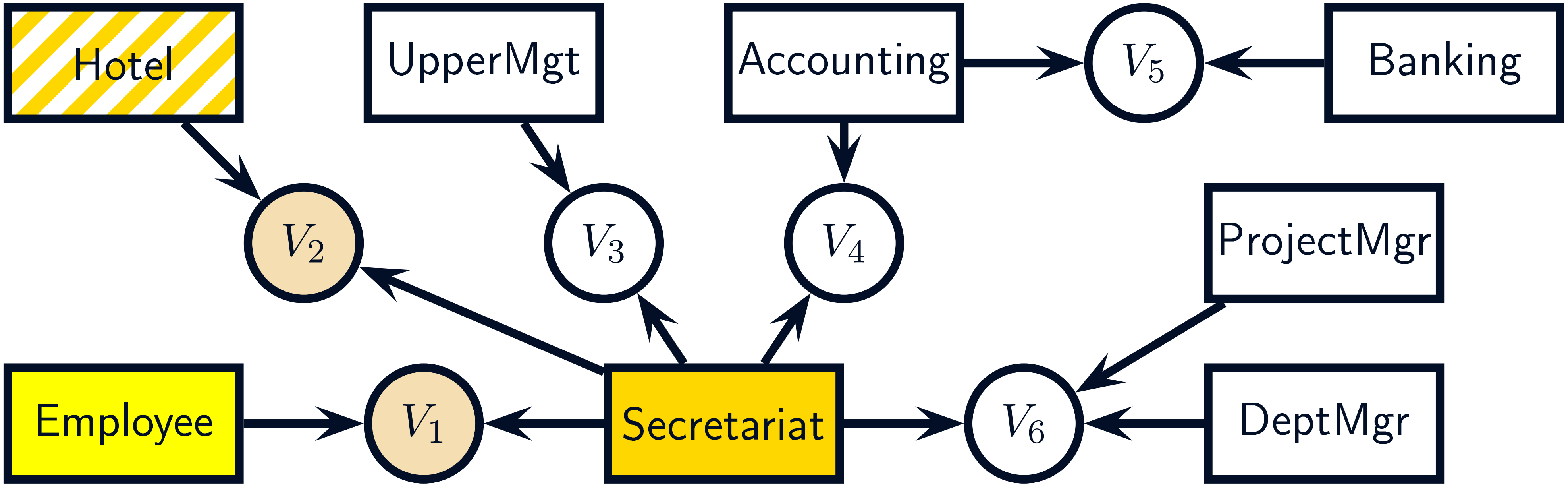

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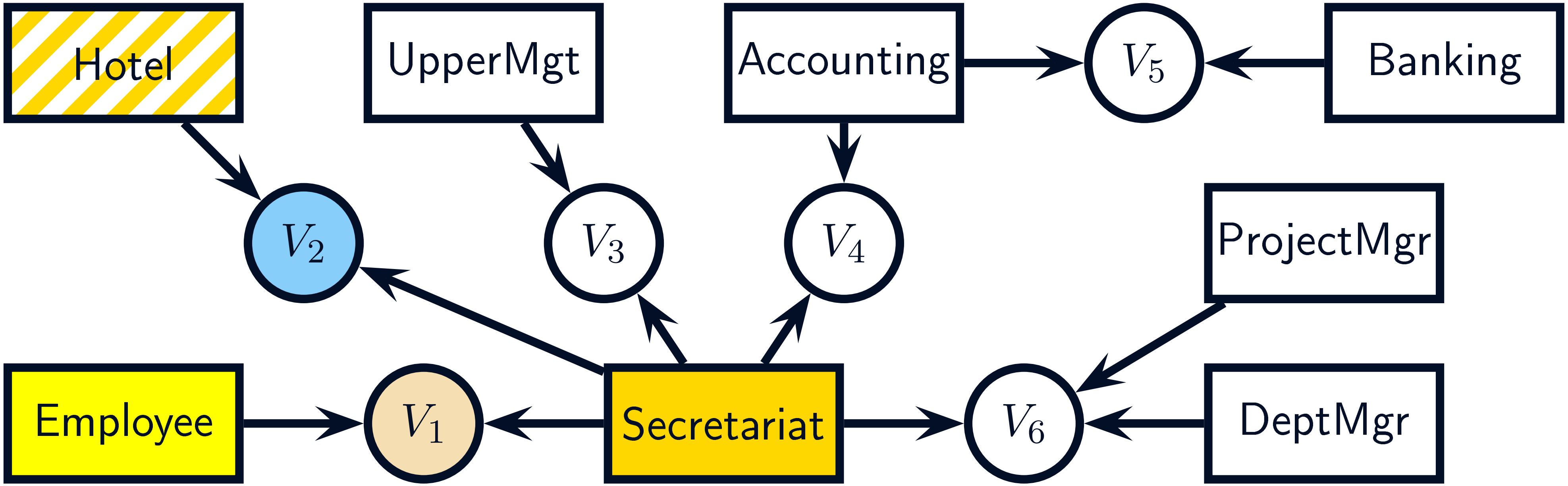

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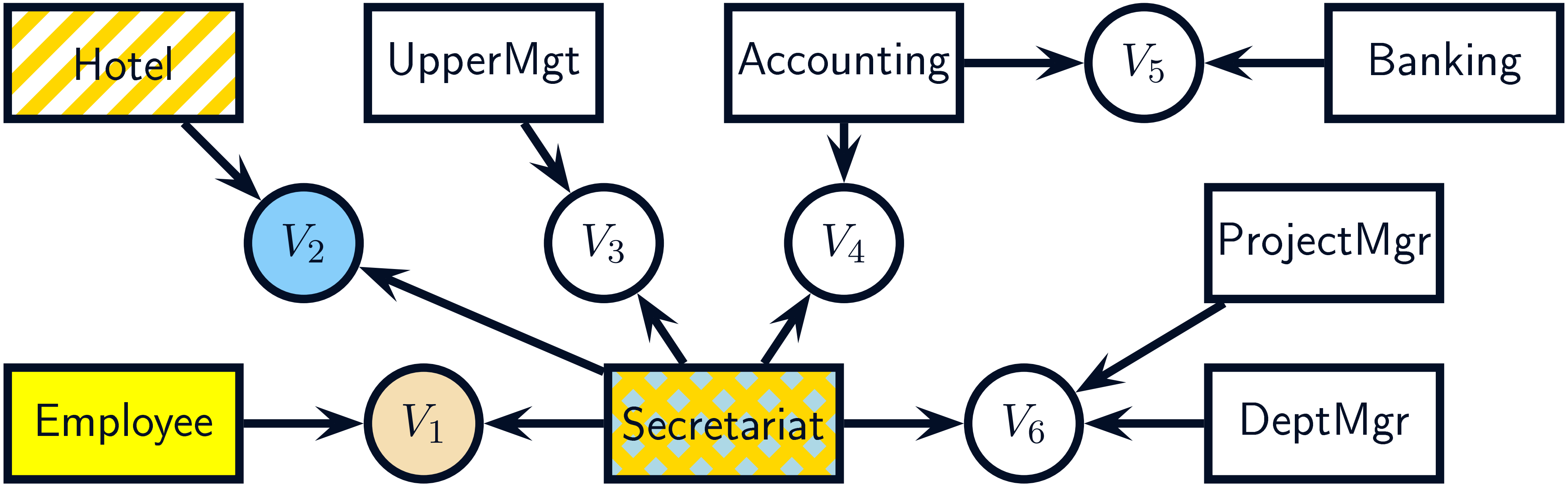

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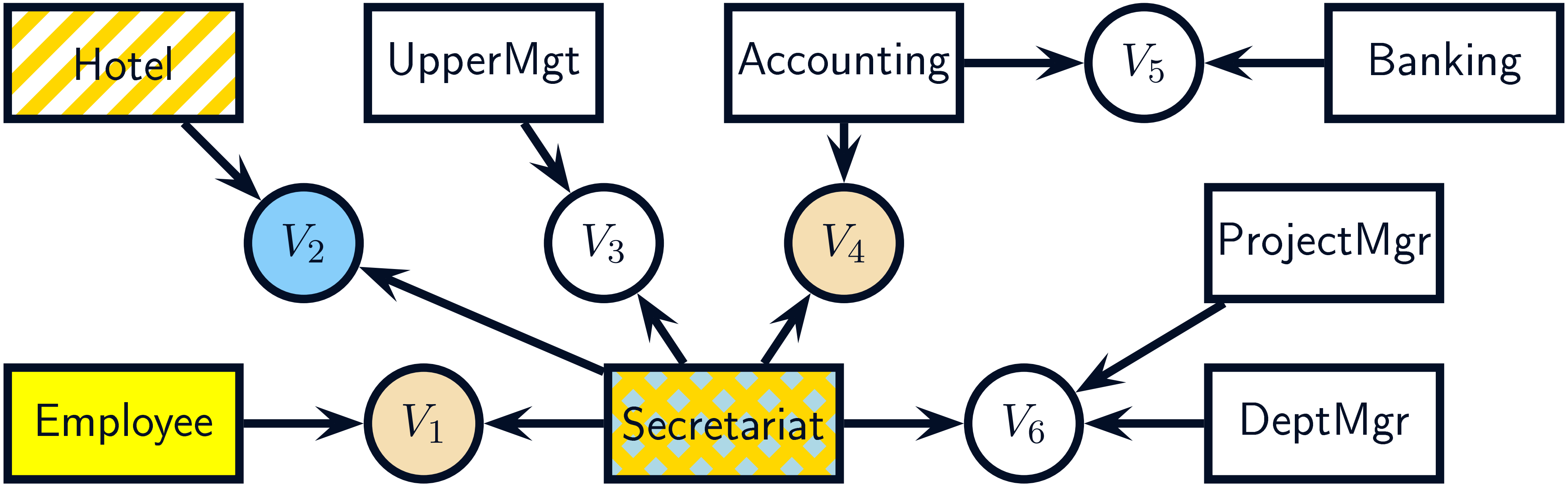

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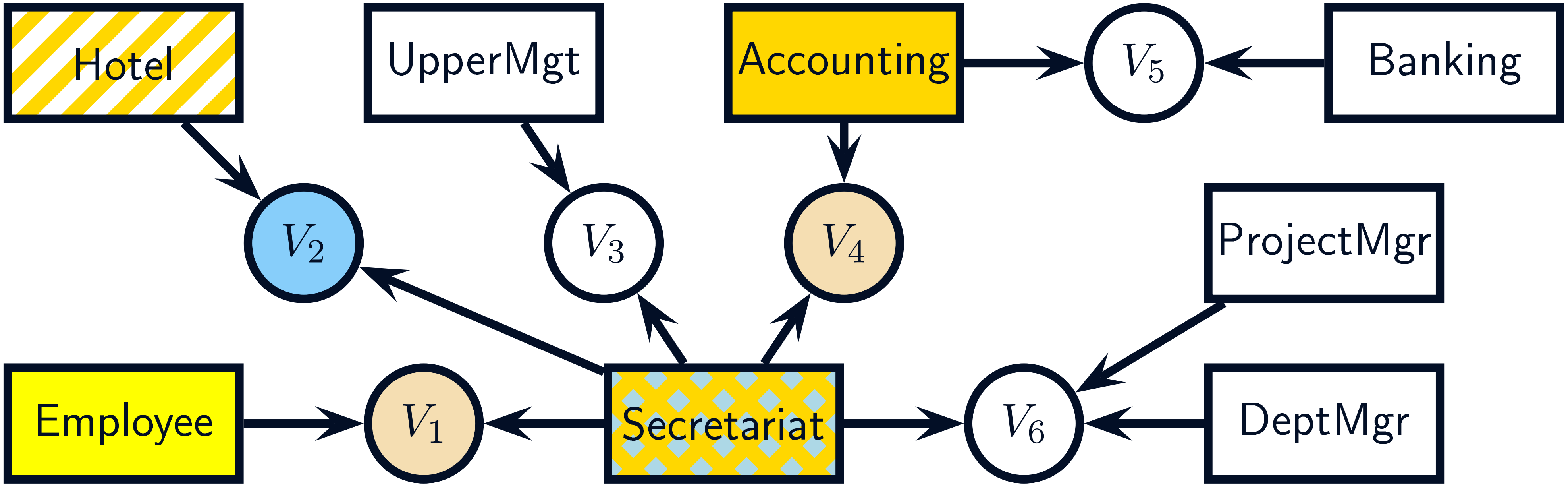

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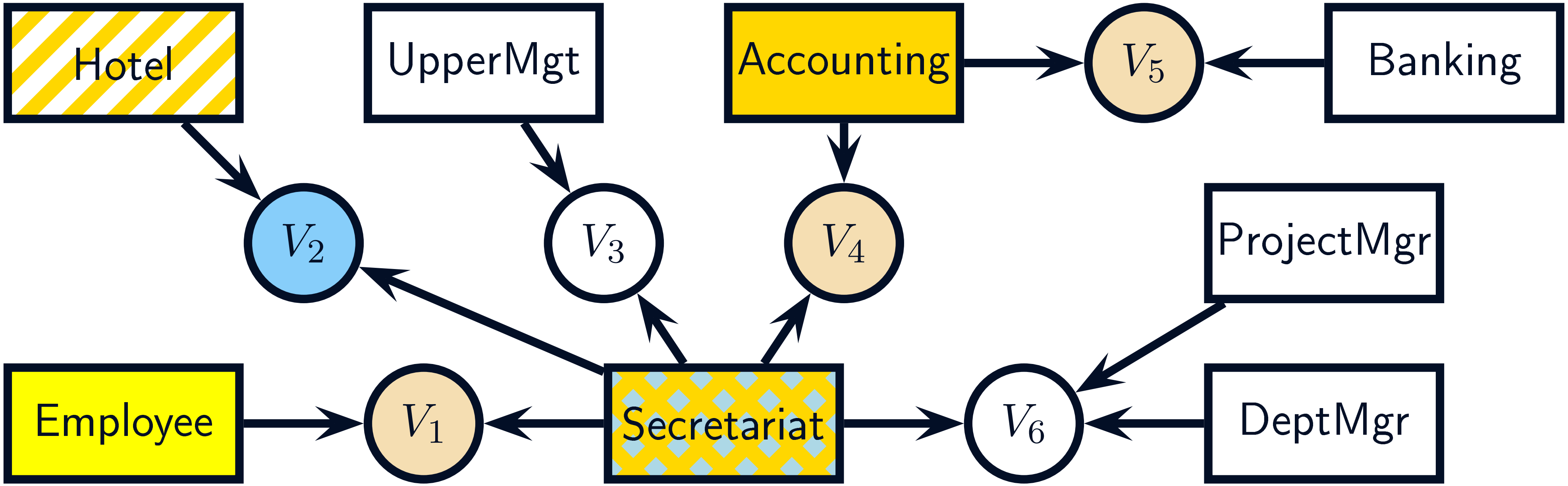

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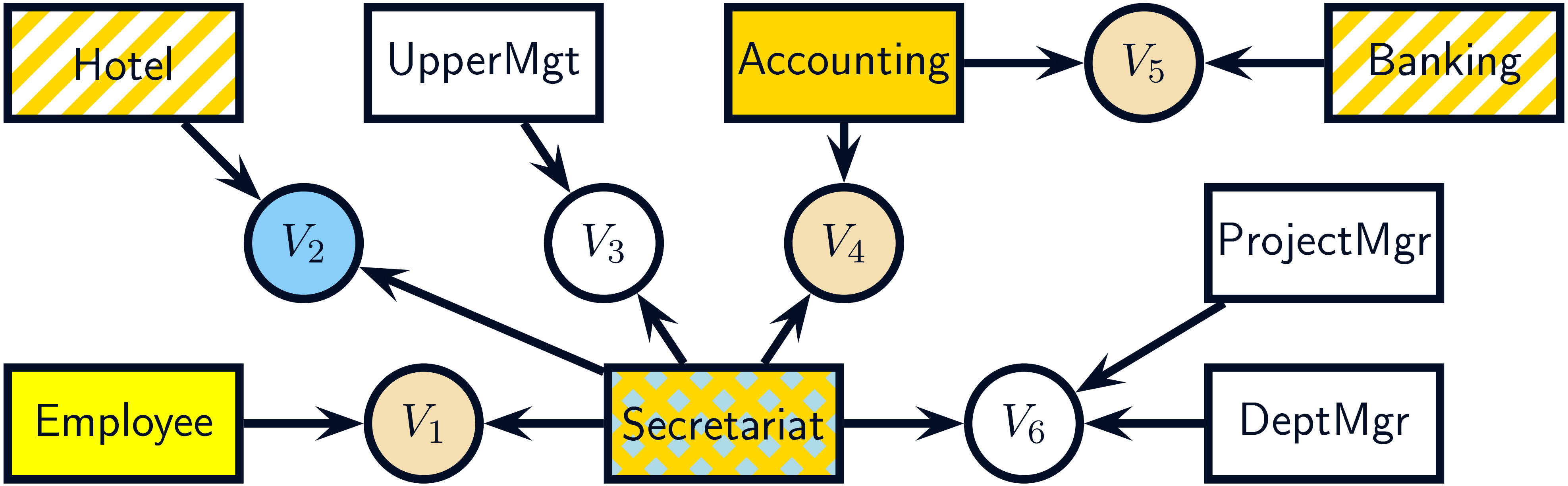

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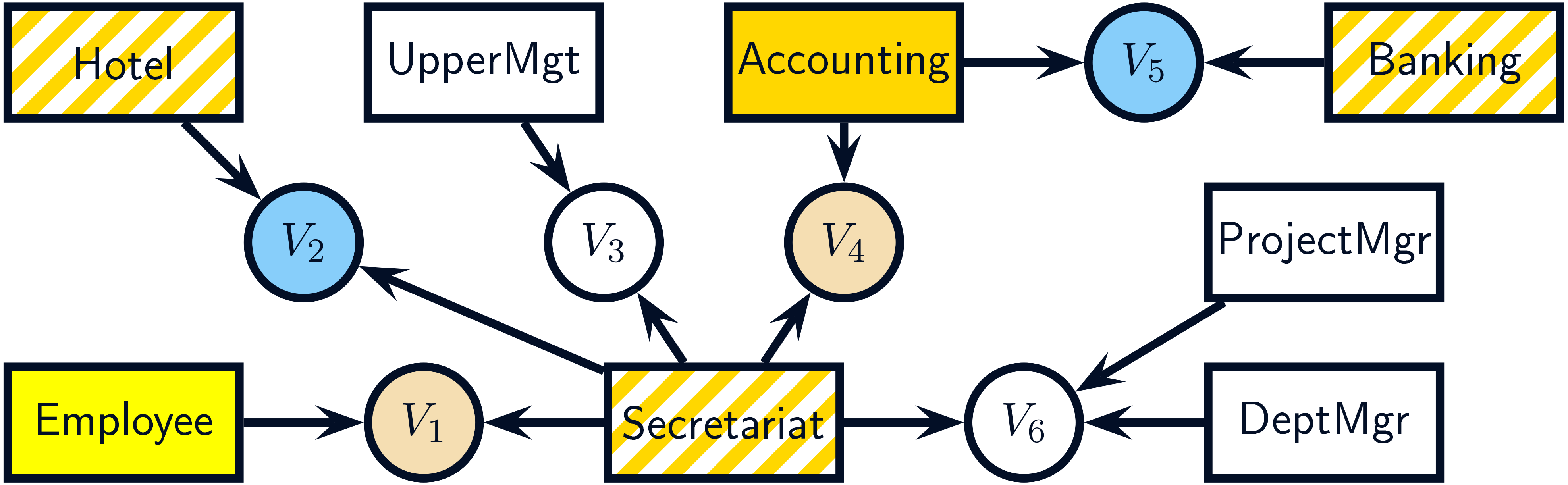

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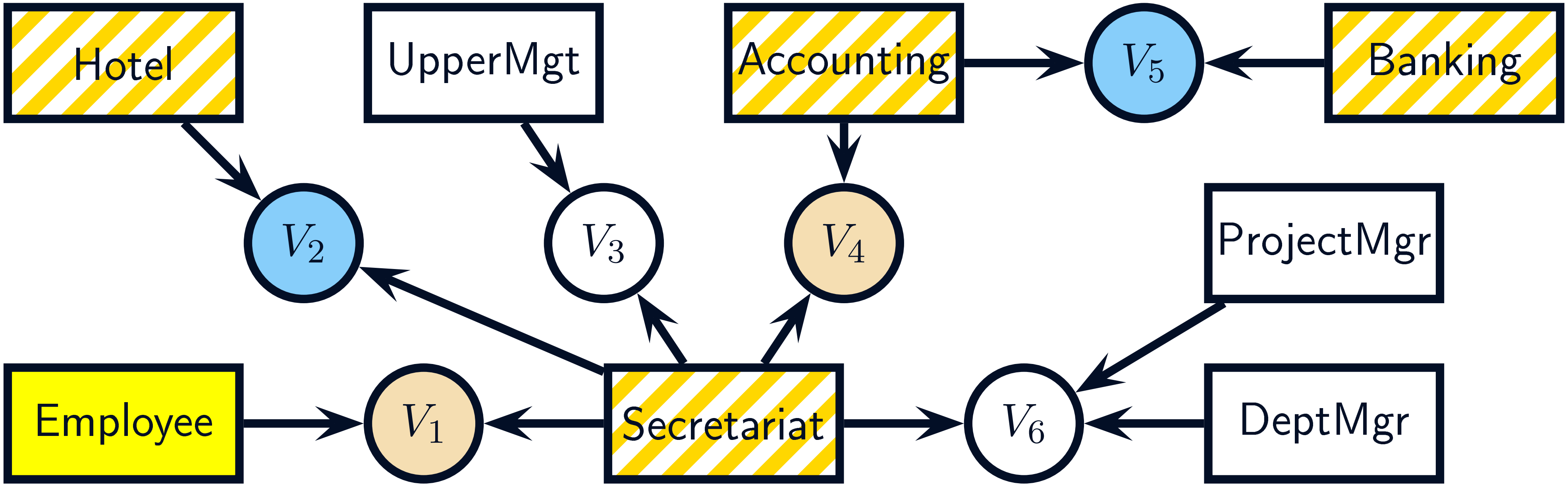

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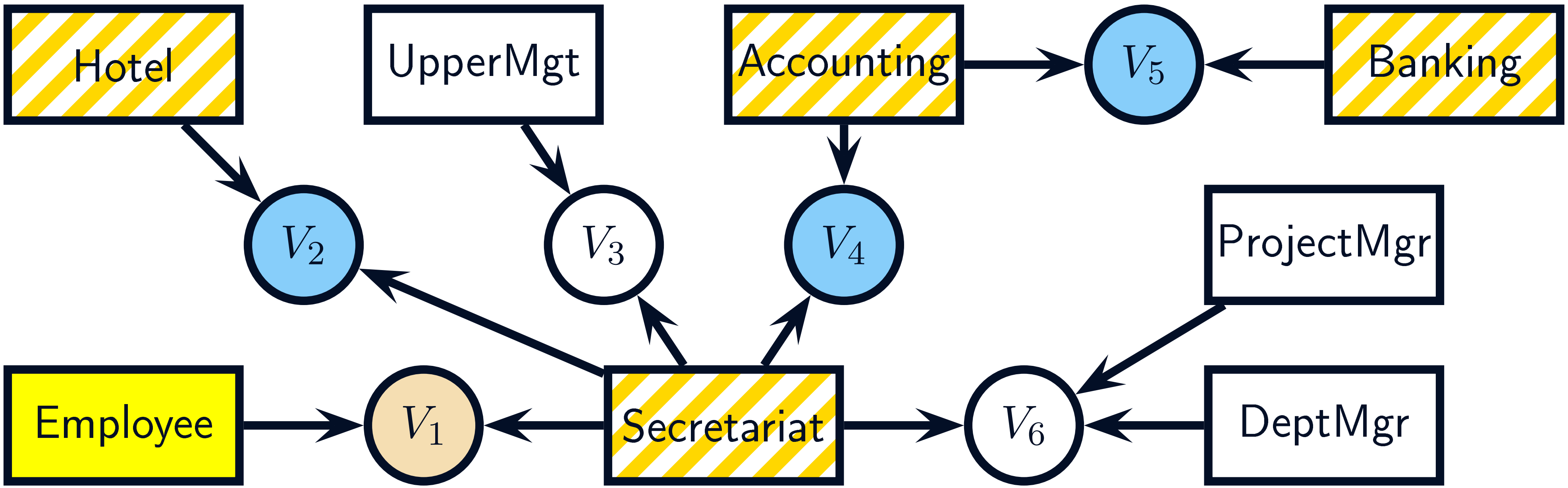

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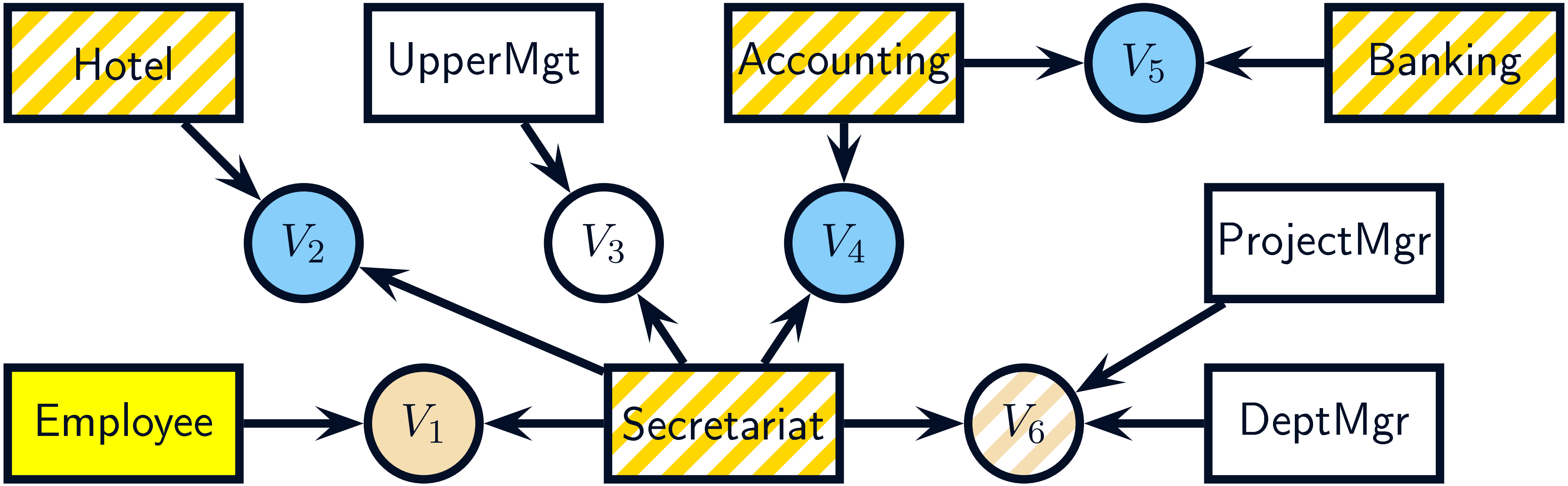

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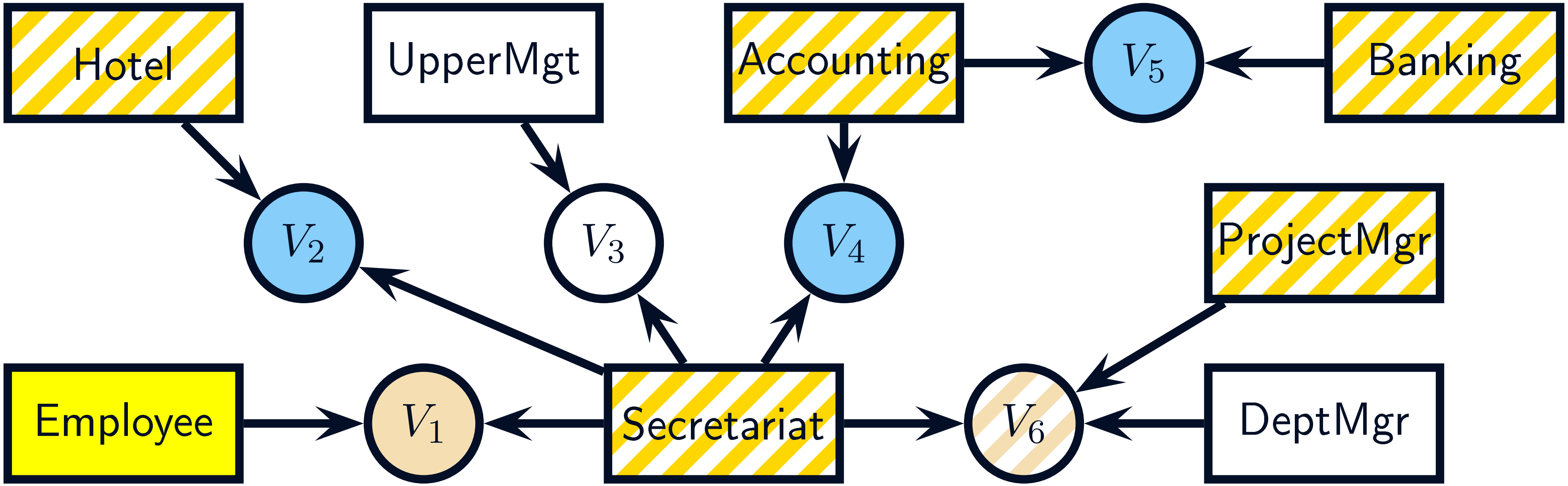

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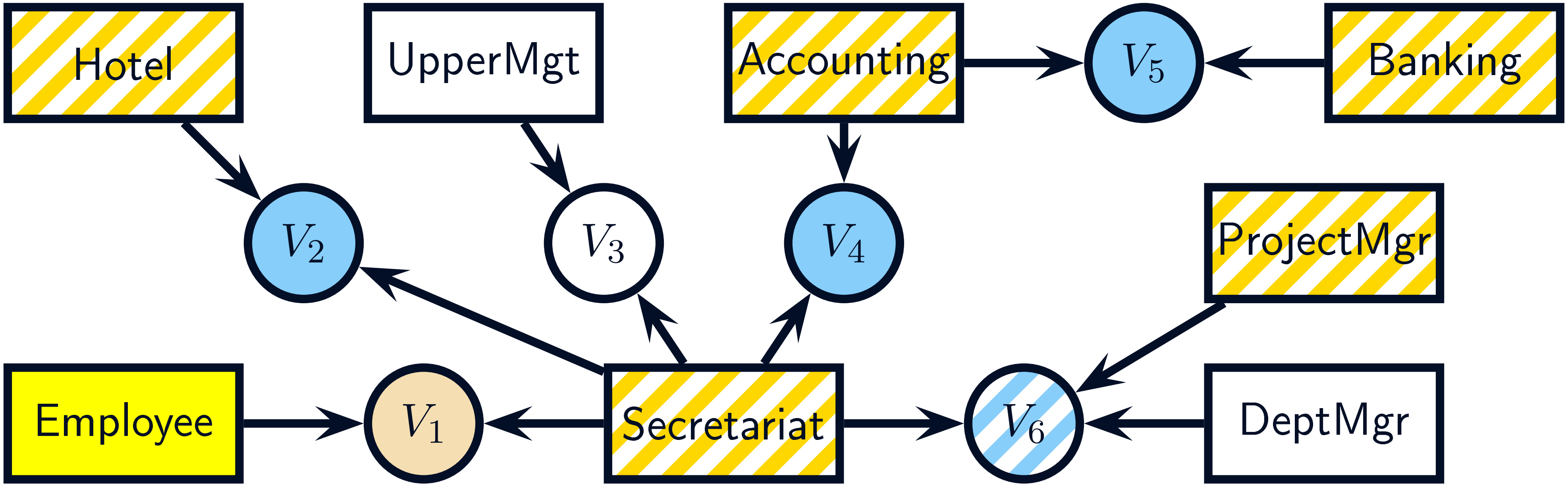

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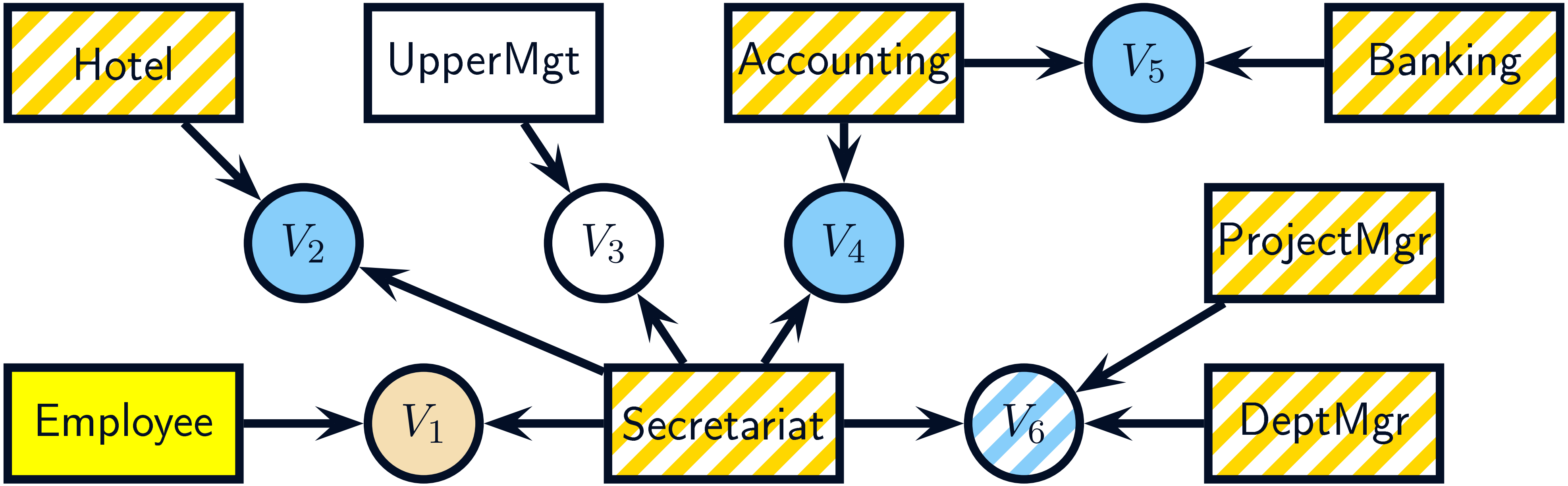

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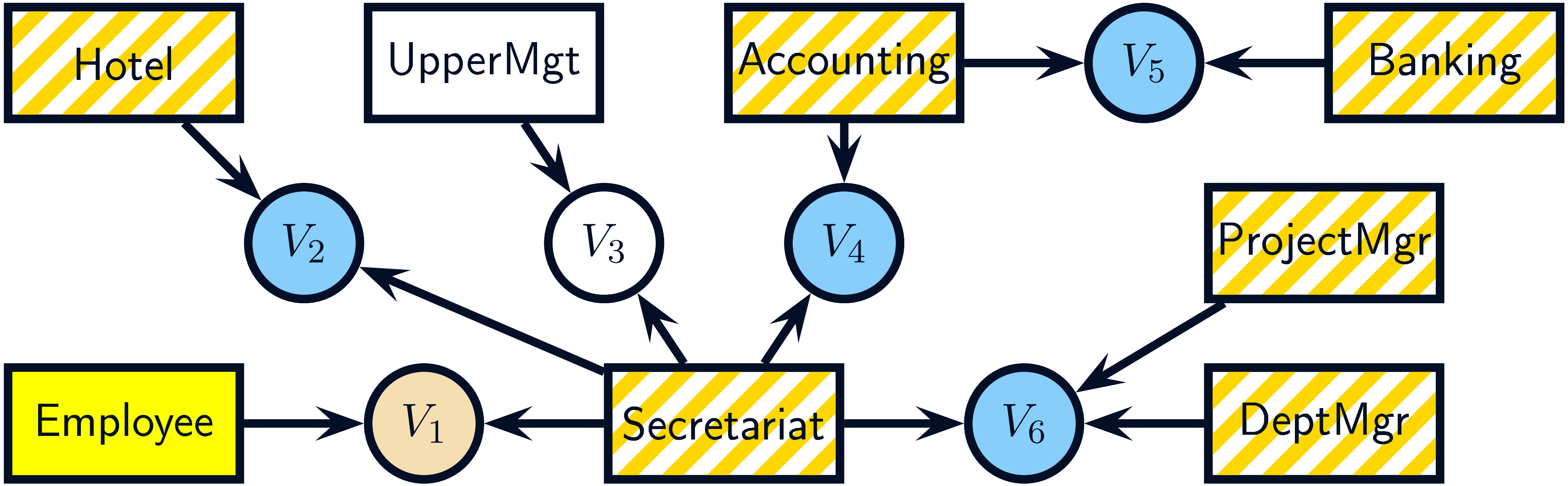

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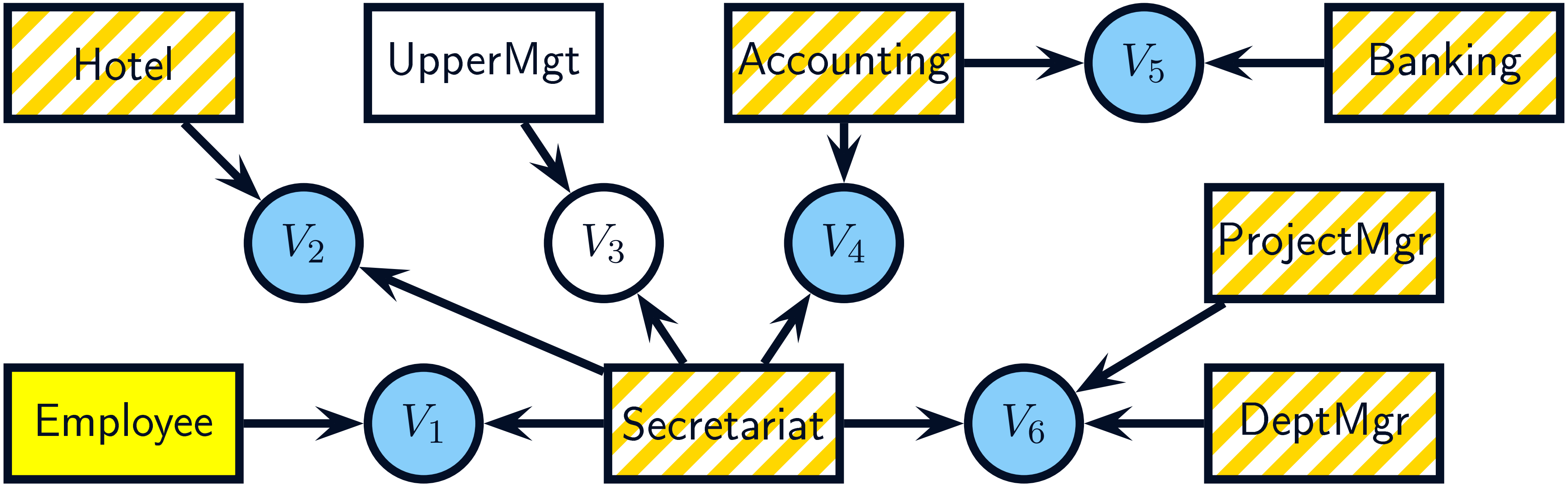

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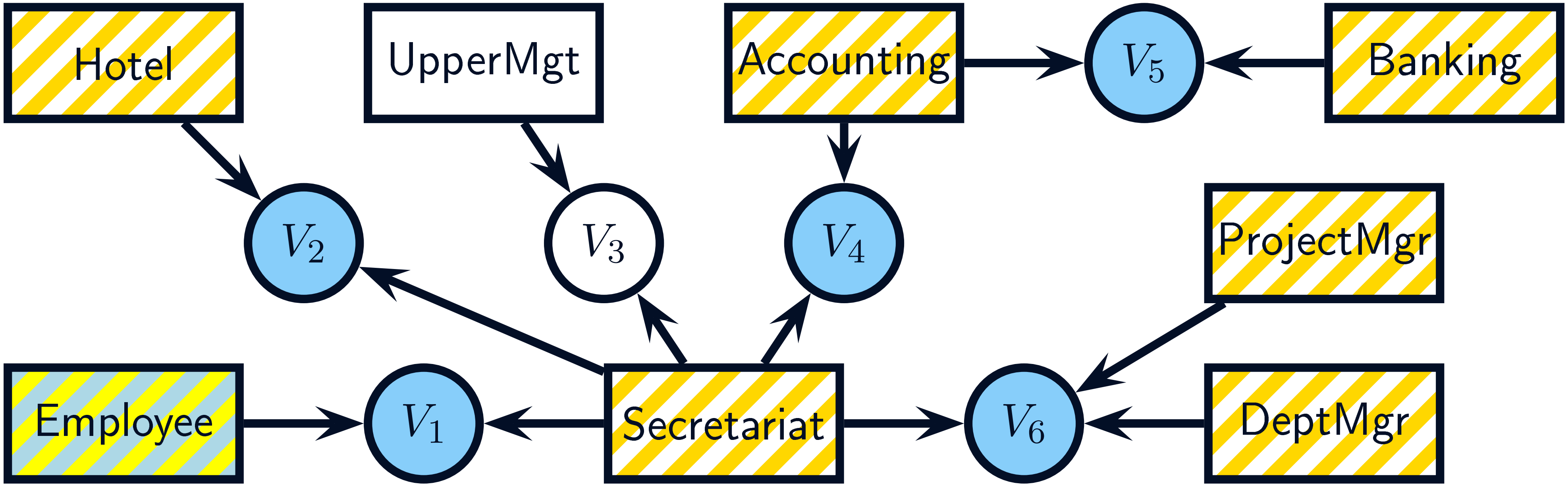

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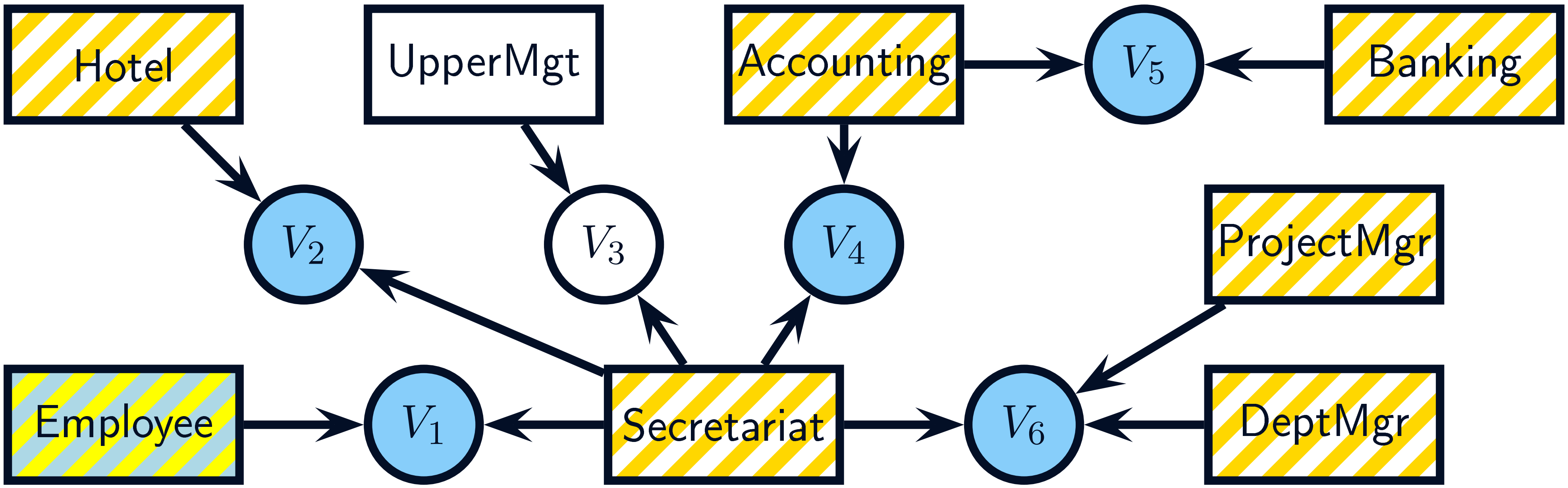

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Fact: If all lifting policies are context free, then the result is independent of the timing order. □

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$$\begin{tikzcd} & & \text{Managers} \\ \text{Secretaries} \arrow[r, dash, "<"] & \text{Scientists} \arrow[ur, dash, "<"] \arrow[dr, dash, "<"'] & \\ & & \text{Accountants} \end{tikzcd}$$

- However, more complex rôles are easily envisaged; for example, *Travel_Managing_Secretary* who would be given rights to manage travel requests, but nothing else.

Access Rights for Database Components

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- There are four classes of access rights.
  - The right to initiate an update.
  - The right to limit an update family during lifting.
  - The right to order in time the forwarding of update requests to distinct ports.
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The Right to Initiate an Update Proposal

Form: Initiate(Component : C, View : Γ, Authority_class : A).

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- The formalization of "entirely visible" is based upon semantically bijective mappings [Hegner SDKB 08].

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- Timing control is allowed if the authority class of the incoming update family is below A in the authority hierarchy.

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- All ports Γ' to which the lifting is not transmitted immediately must satisfy $\Gamma' \leq \Gamma$.
- Variations which distinguish controlling the timing to separate ports vs. controlling the timing to distinct components in the same interconnection are also possible.