Temporal Implications of Database Information Accountability

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TIME 2012

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Motivation

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Corporate collusion has given rise to regulations for trustworthy long-term data management.

- Code of Federal Regulations of FDA: Clinical trials

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Corporate collusion has given rise to regulations for trustworthy long-term data management.

- Code of Federal Regulations of FDA: Clinical trials
- Sarbanes-Oxley Act: Financial transactions
- HIPAA – Health Insurance Portability and Accountability Act; Canada's PIPEDA: Disclosure of medical information

Introduction

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- File systems & DB communities

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  - tamper detection / prevention mechanisms

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- Audit log security & compliant records
  - Creation
  - Storage
  - Access
  - Maintenance / Retention

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Governed by laws & regulations

Spectrum of Approaches to Achieve Trustworthiness

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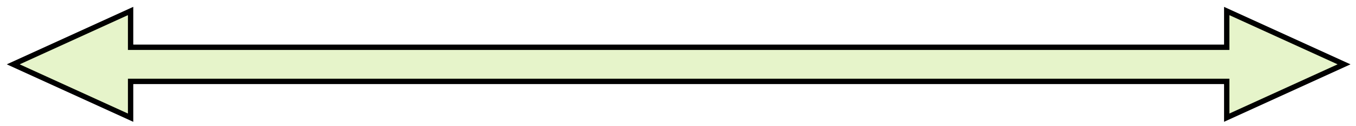

Information Restriction

immutable retained records

access control

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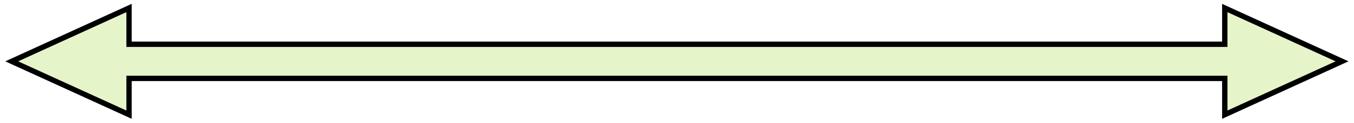

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Information Accountability

transparent information

set of rules

easily determine appropriate use

Spectrum of Approaches to Achieve Trustworthiness

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immutable retained records
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Information Accountability

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easily determine appropriate use

"[Information] accountability must become a primary means through which society addresses appropriate use." (Weitzner et al., CACM 2008)

Restriction vs Accountability

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- Home Security
  - Locked doors and windows (restriction)
  - Sweeping front yard, cameras (accountability)

Restriction vs Accountability

- Home Security
  - Locked doors and windows (restriction)
  - Sweeping front yard, cameras (accountability)
- Bank Security
  - The vault is unlocked during business hours.
  - Easy access
  - CCTV cameras everywhere

Information Accountability

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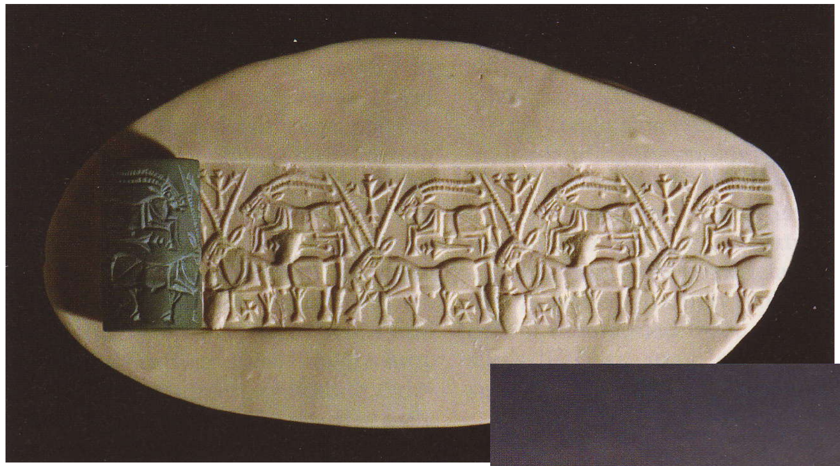

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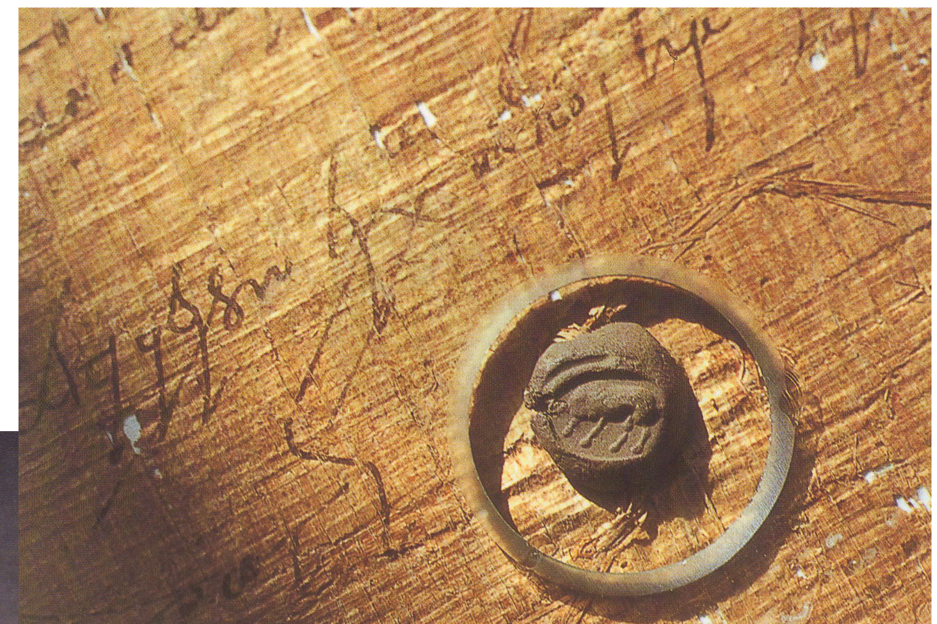

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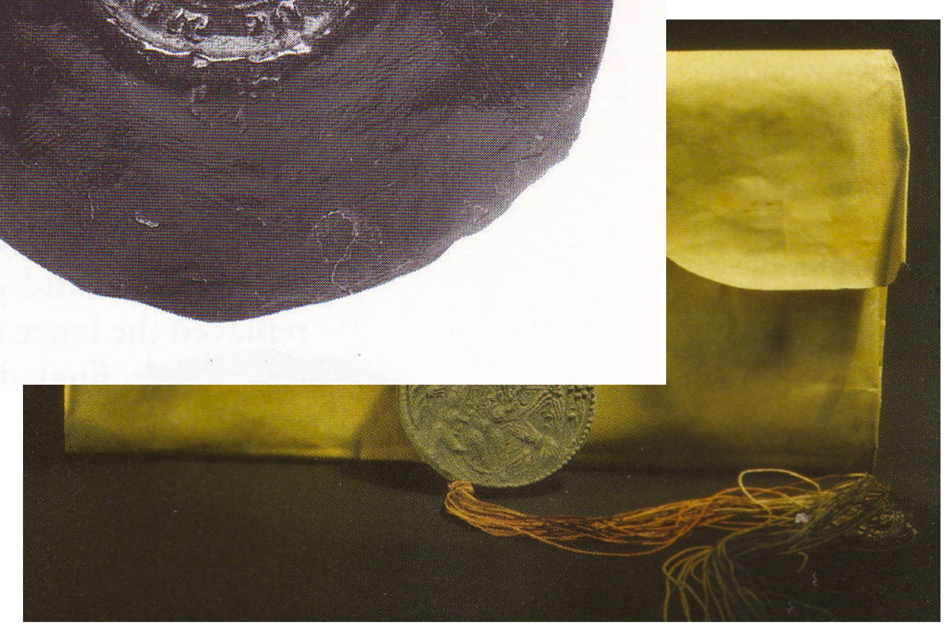

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Agencies using credit reports are accountable for their decisions.

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Do not attempt to prevent
the lawful use of works
they protect by using technology,
but rather set forth rules
regulating the use of the works.

Tamper-Indicating Seals for Nuclear Safeguarding

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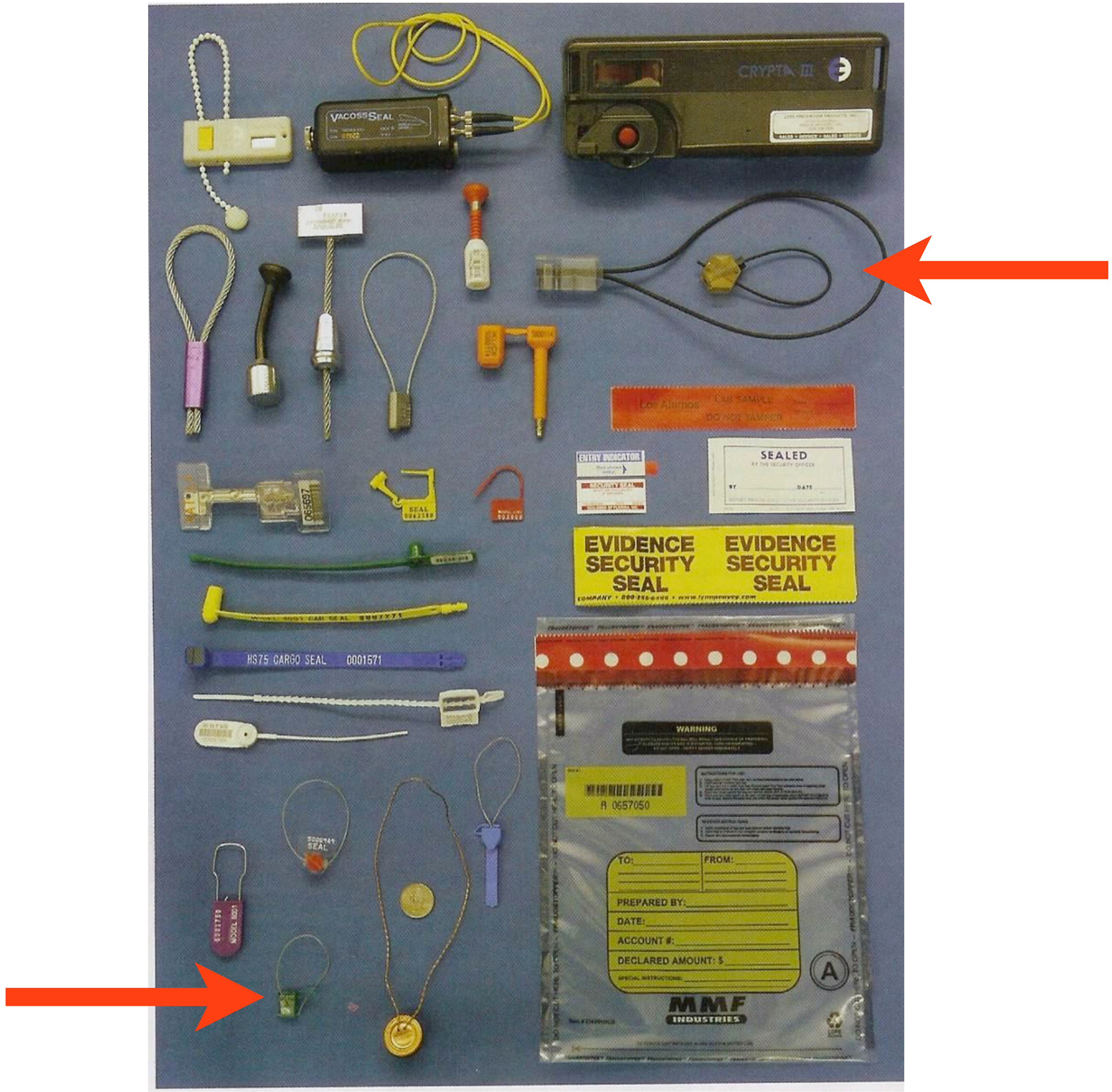
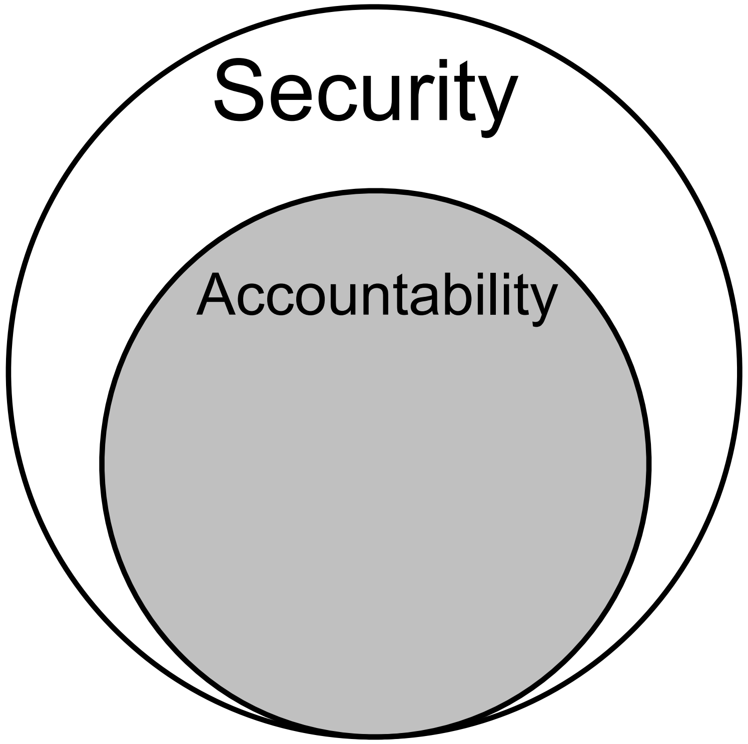


Accountability ∩ Databases



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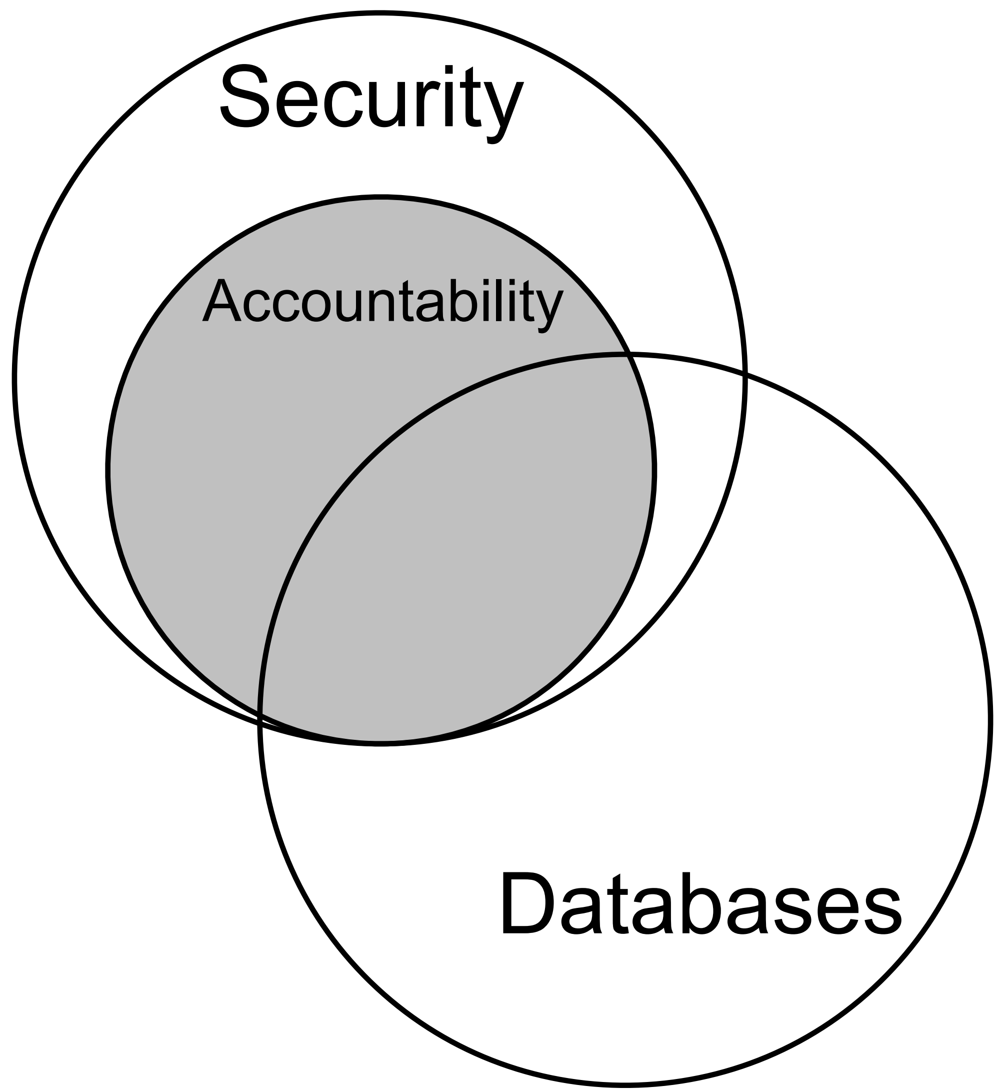
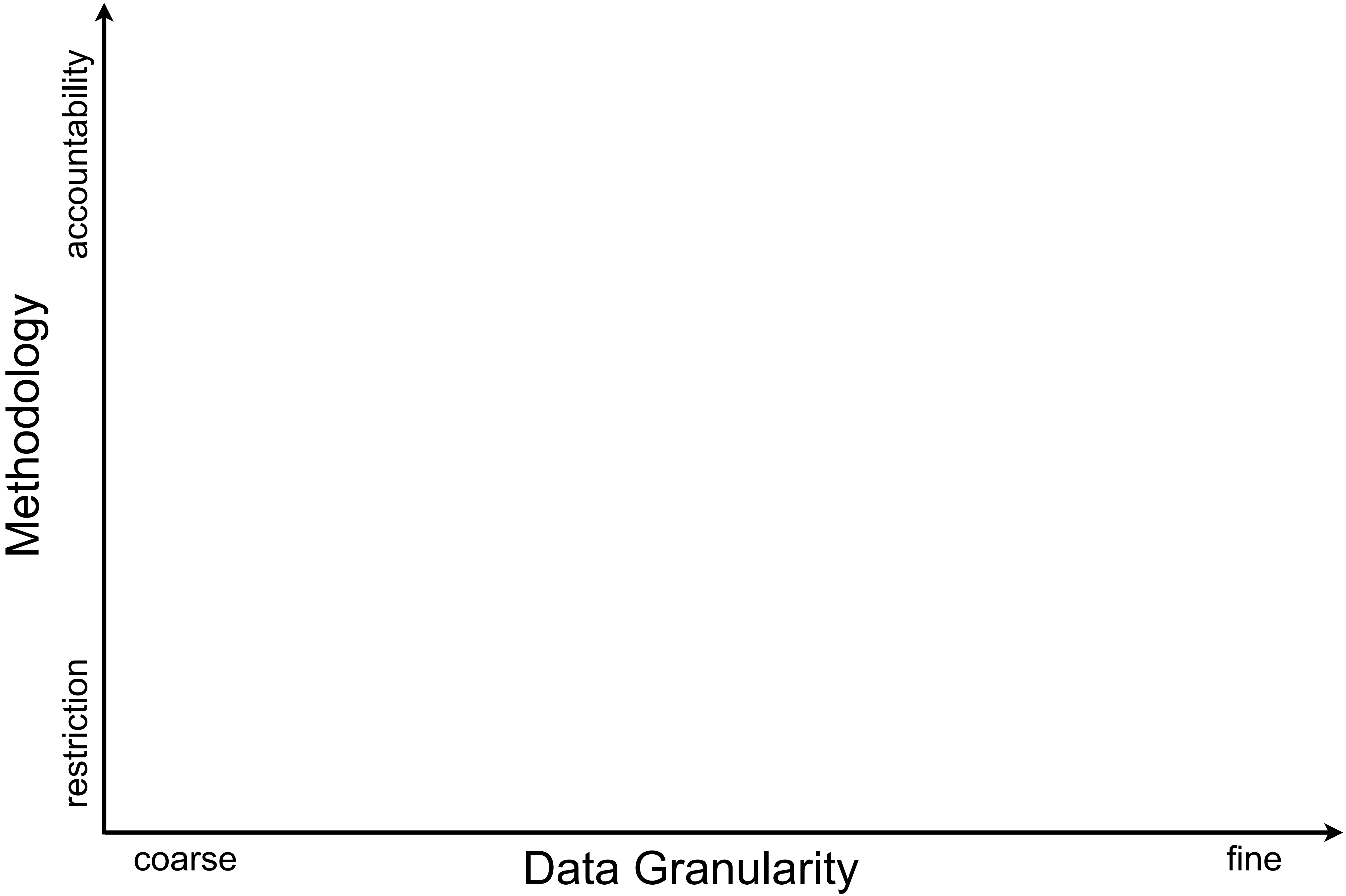


Related Work & Security Spectrum



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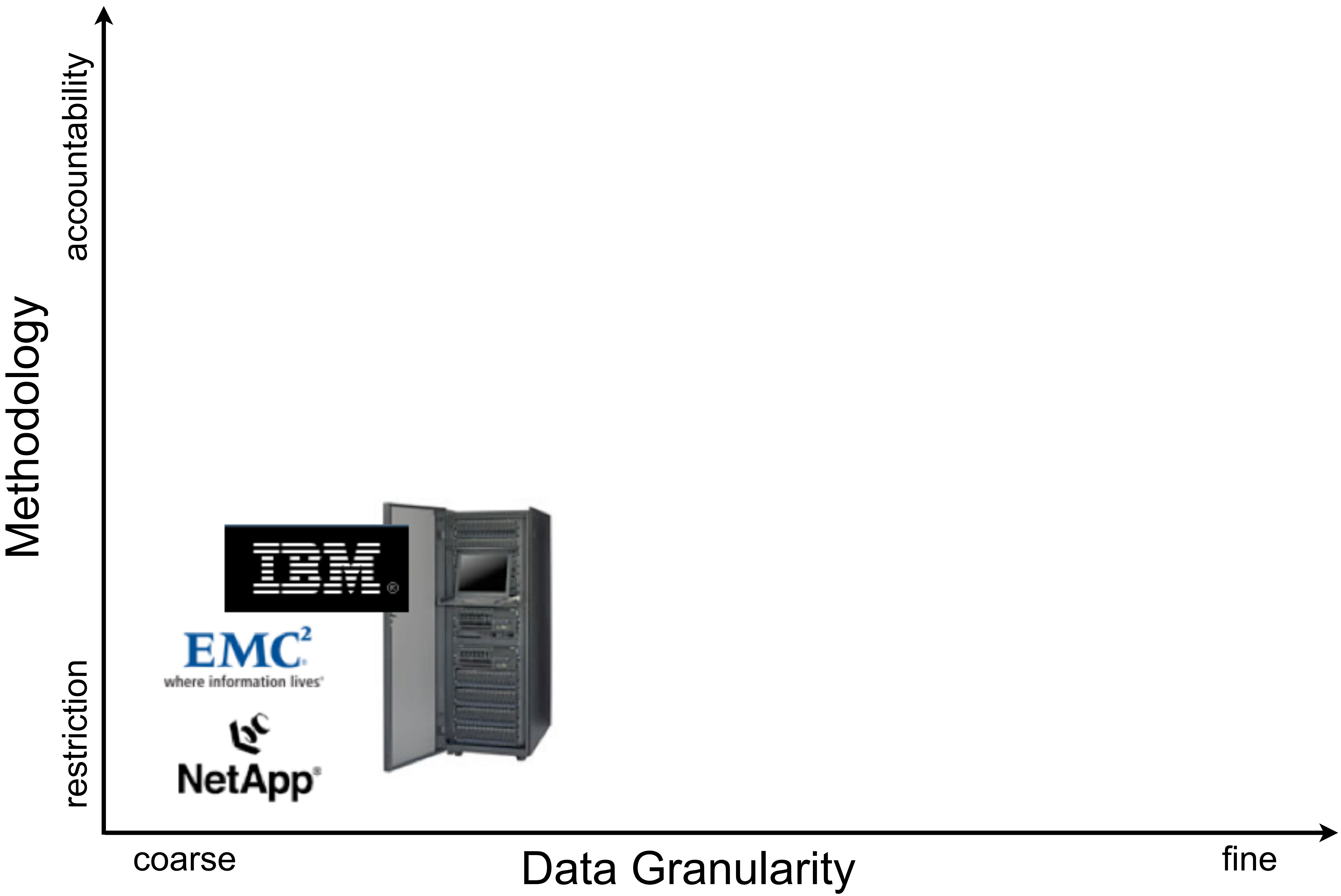

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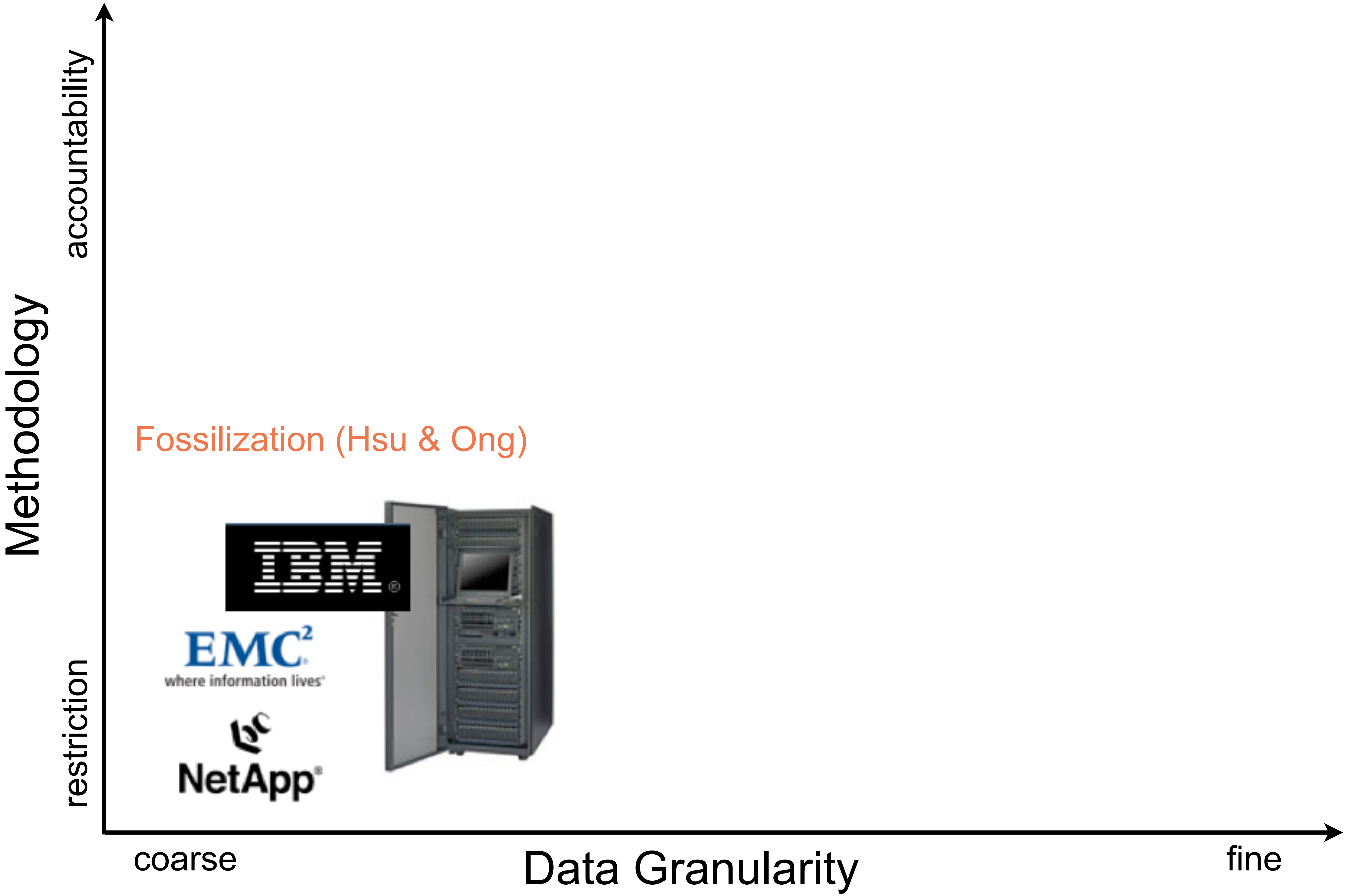

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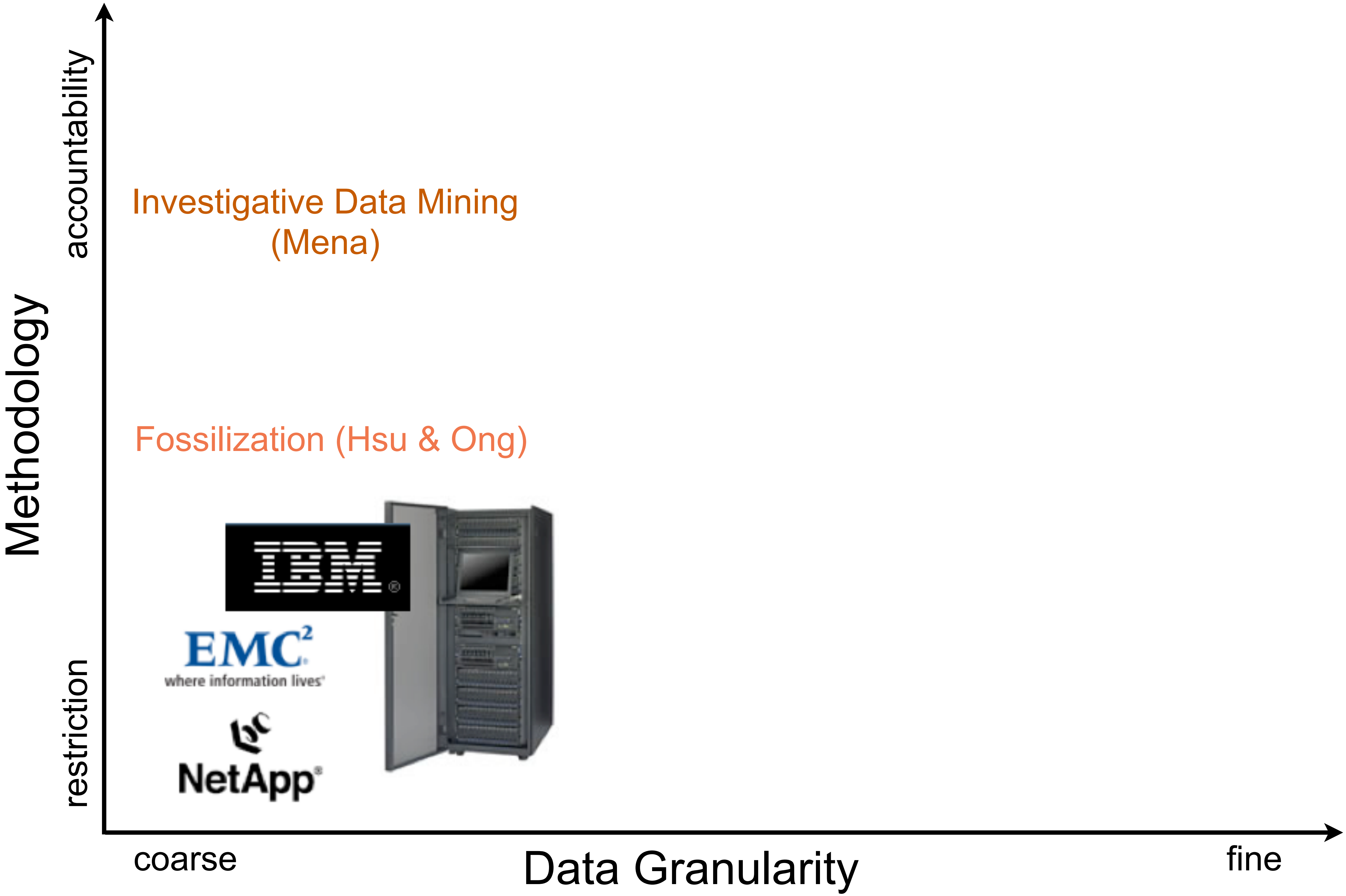


Related Work & Security Spectrum

accountability

Forensic Server Project
(Carvey & Kleiman)

Investigative Data Mining
(Mena)

Methodology

Fossilization (Hsu & Ong)

IBM

EMC²
where information lives

NetApp

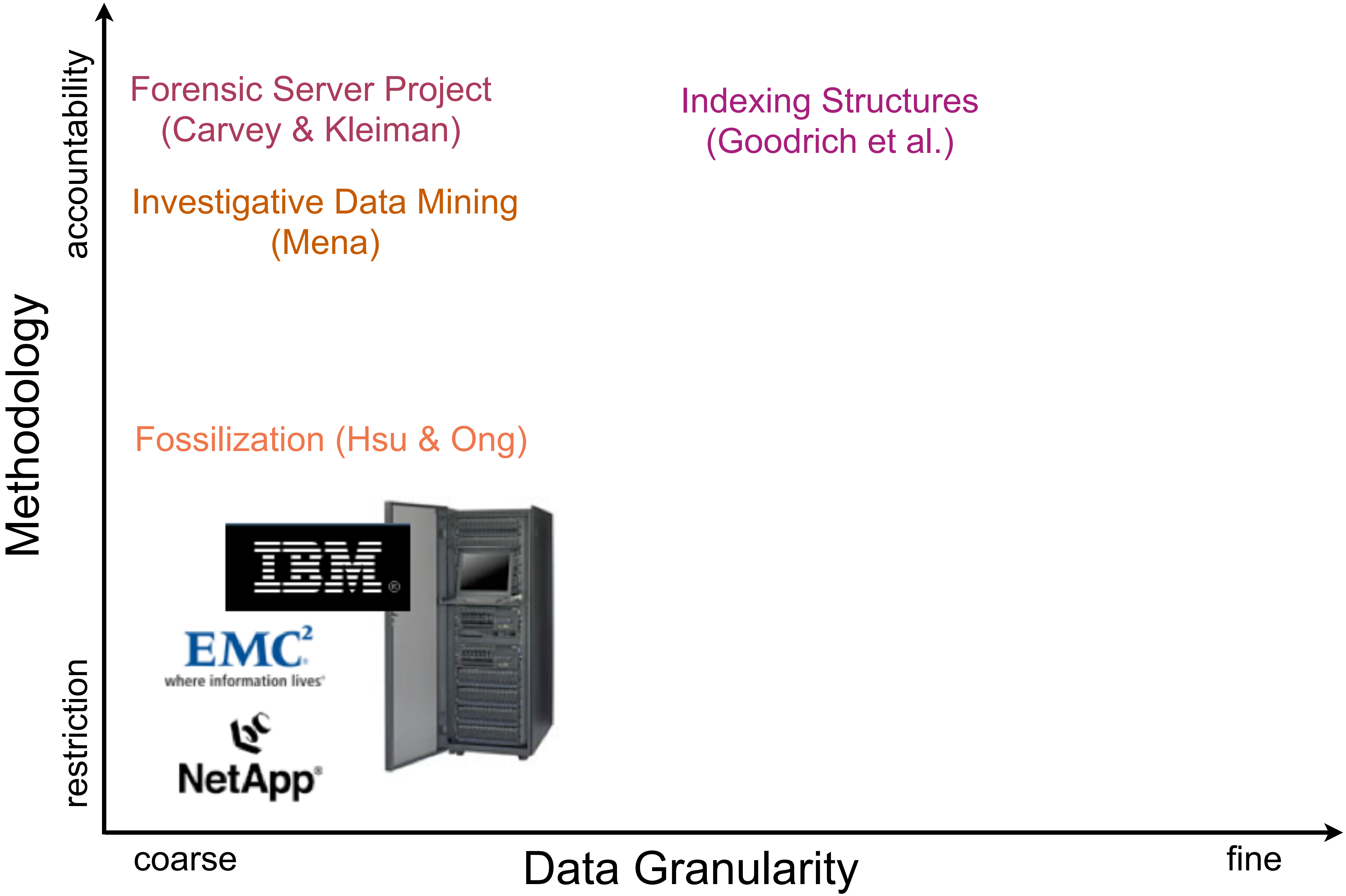
restriction

coarse

Data Granularity

fine

Related Work & Security Spectrum



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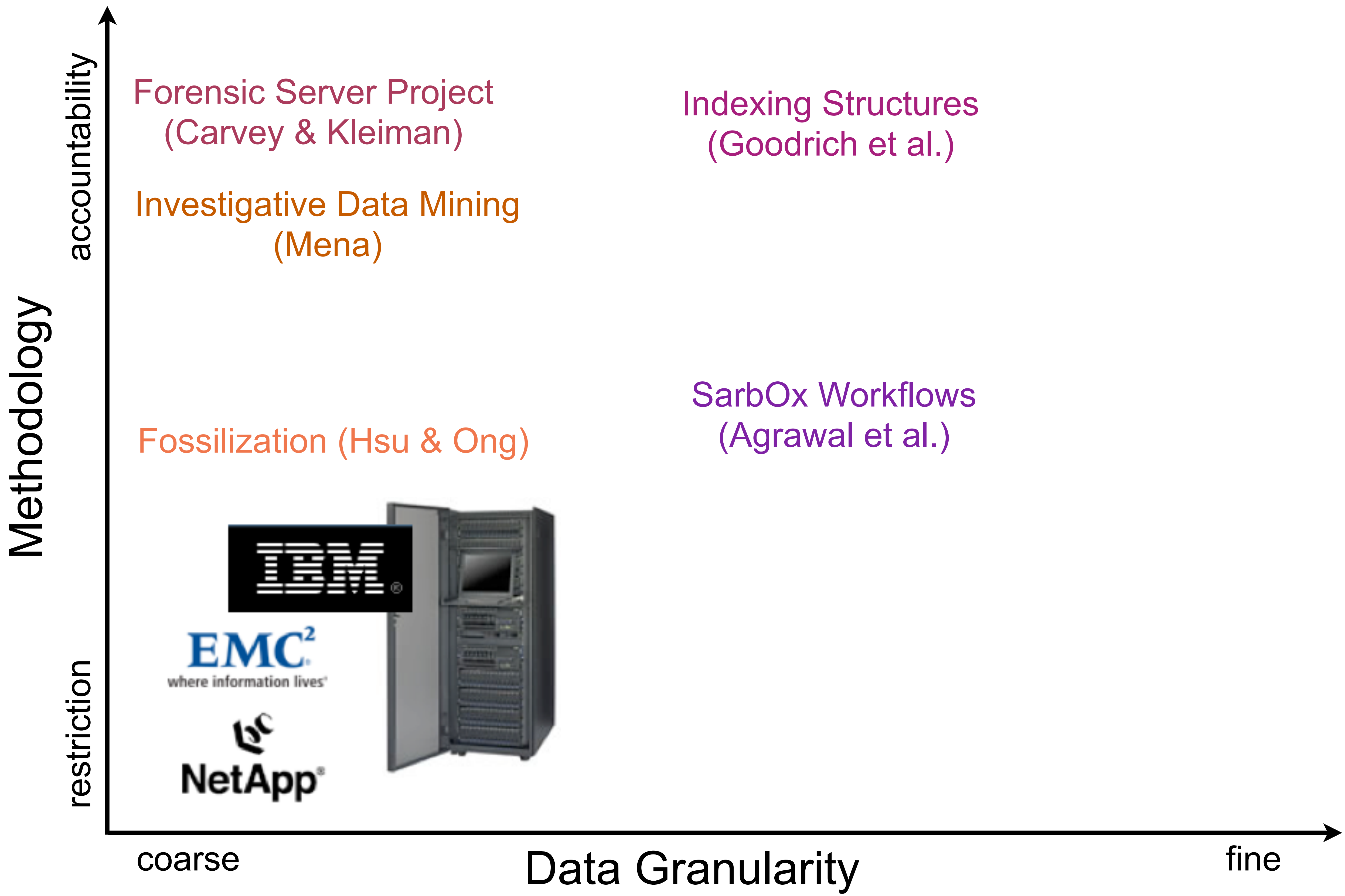

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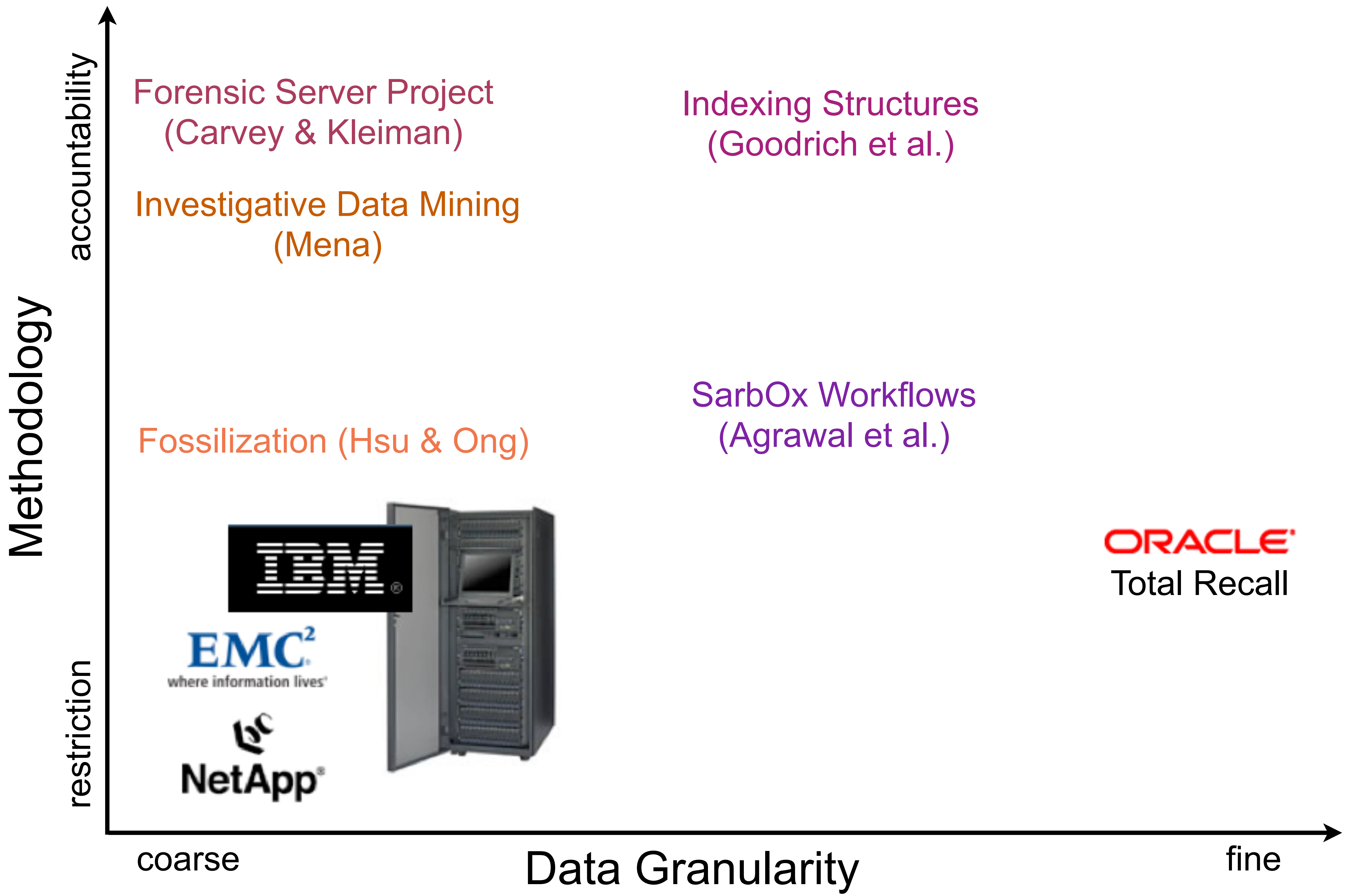

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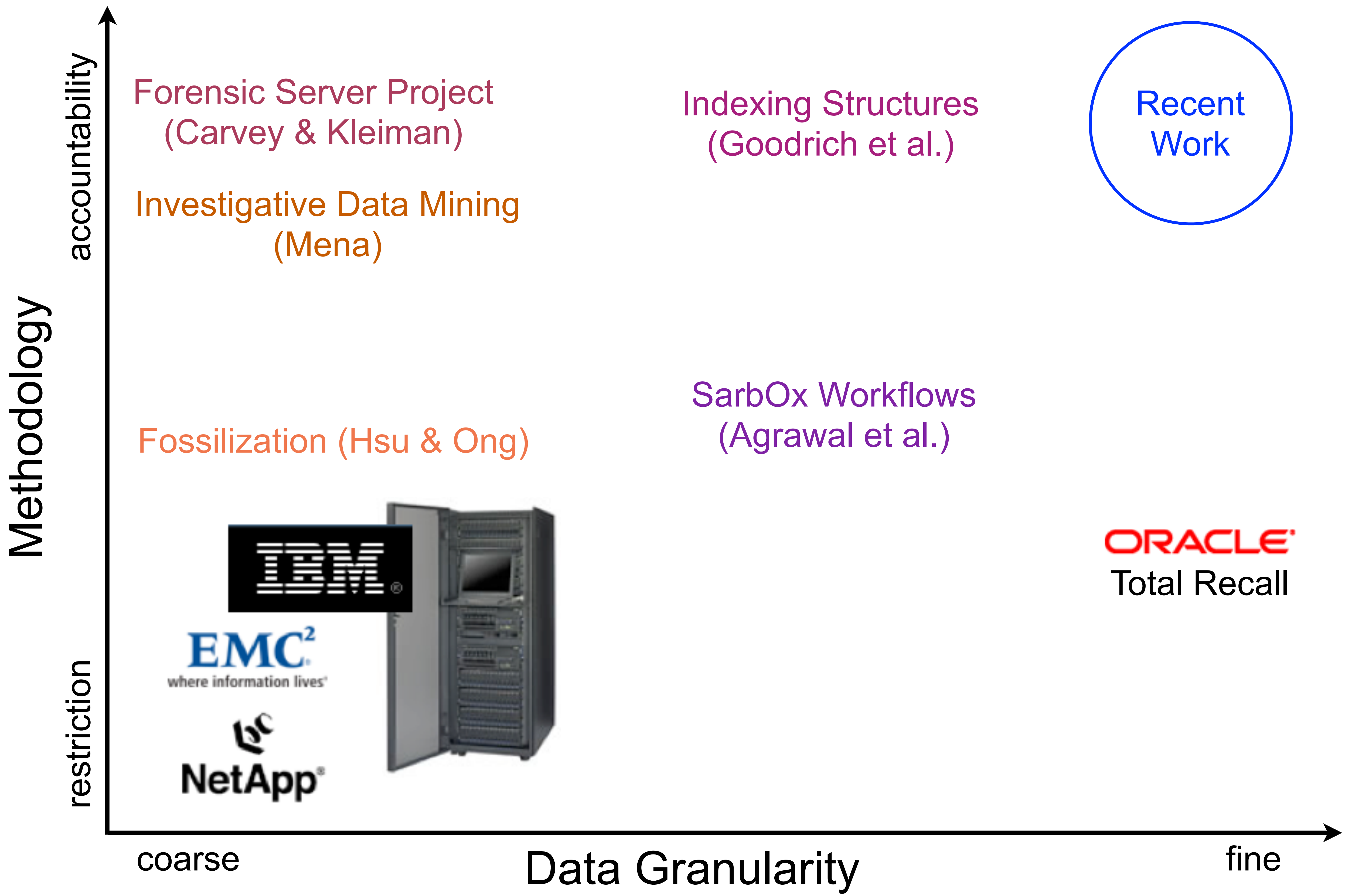
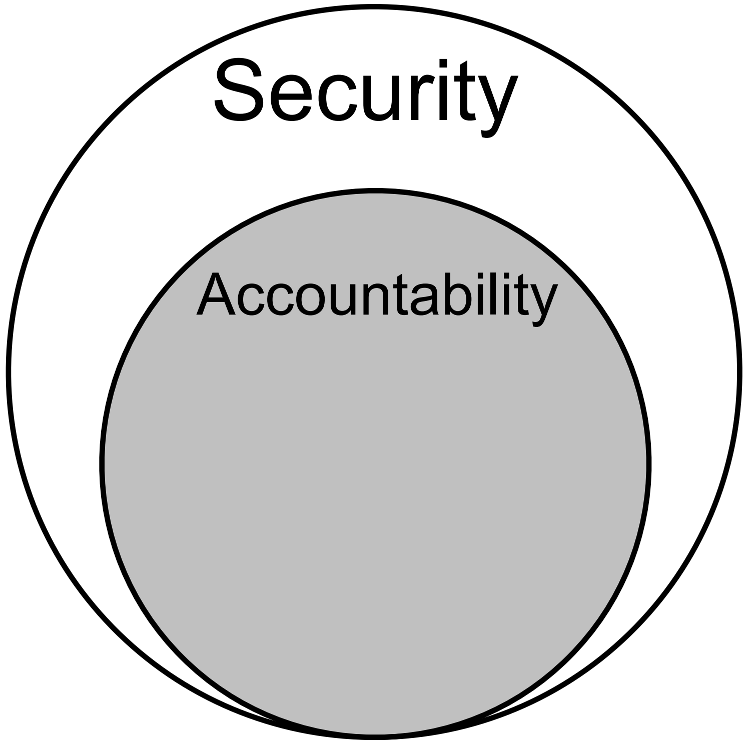


Info Accountability of Fine-Grained Data

- Fragile watermarking scheme for detecting malicious modifications of database relations [Guo, Li, Liu, and Jajodia 2006].
- Efficient audit-based compliance for relational data retention [Hasan, Winslett, and Mitra 2009].
- Tamper detection in audit logs [Snodgrass, Yao, and Collberg 2004].

Accountability ∩ Databases ∩ Time



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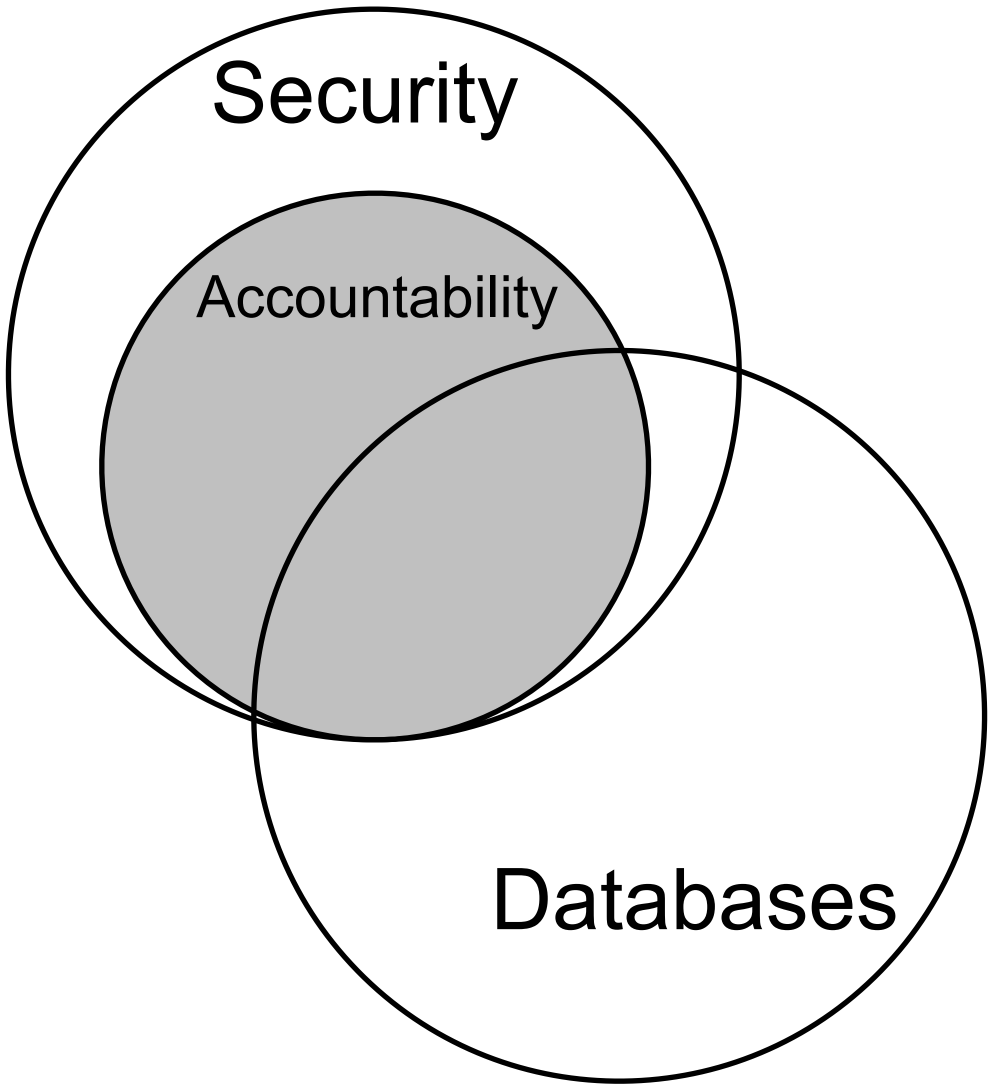

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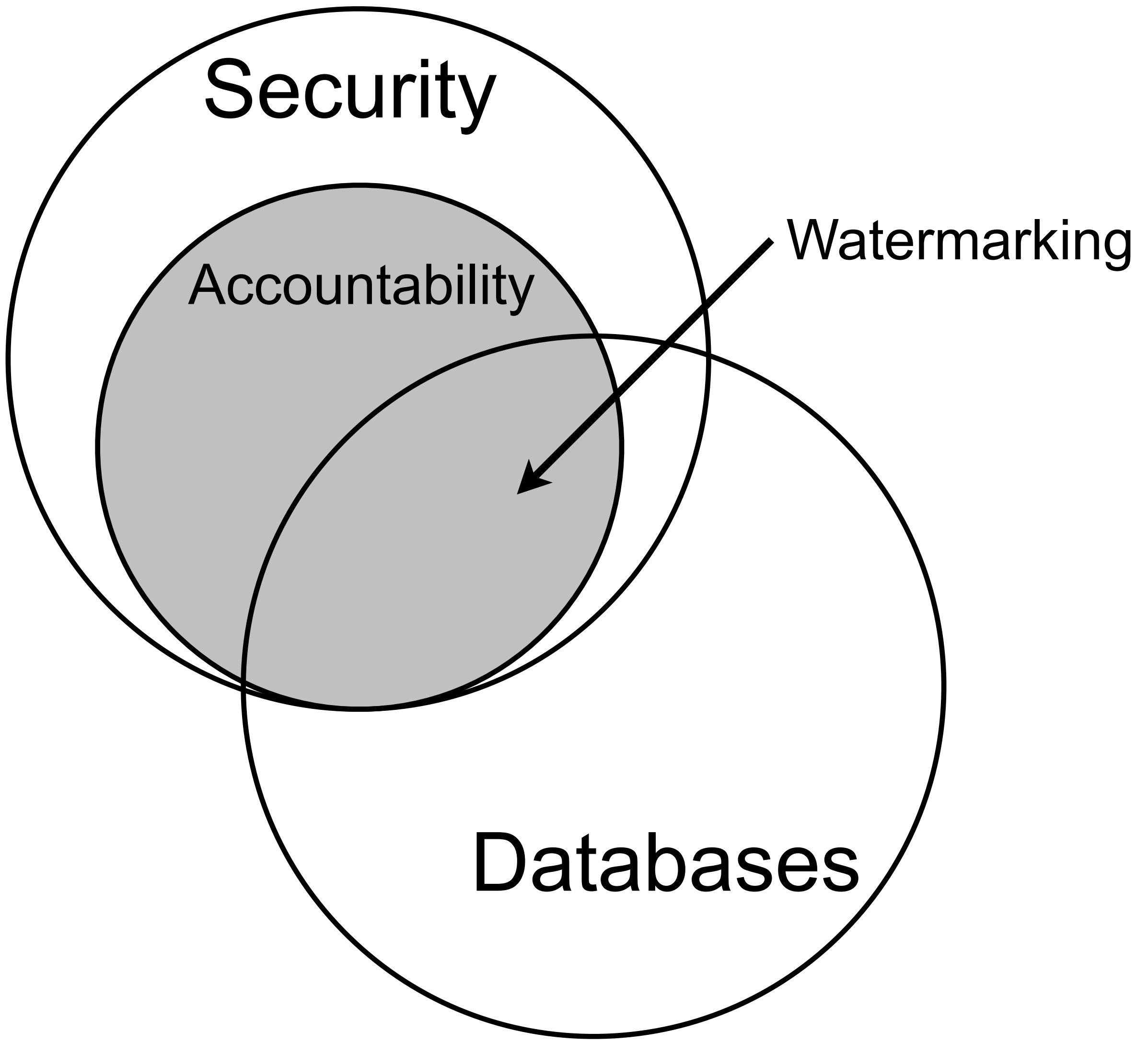

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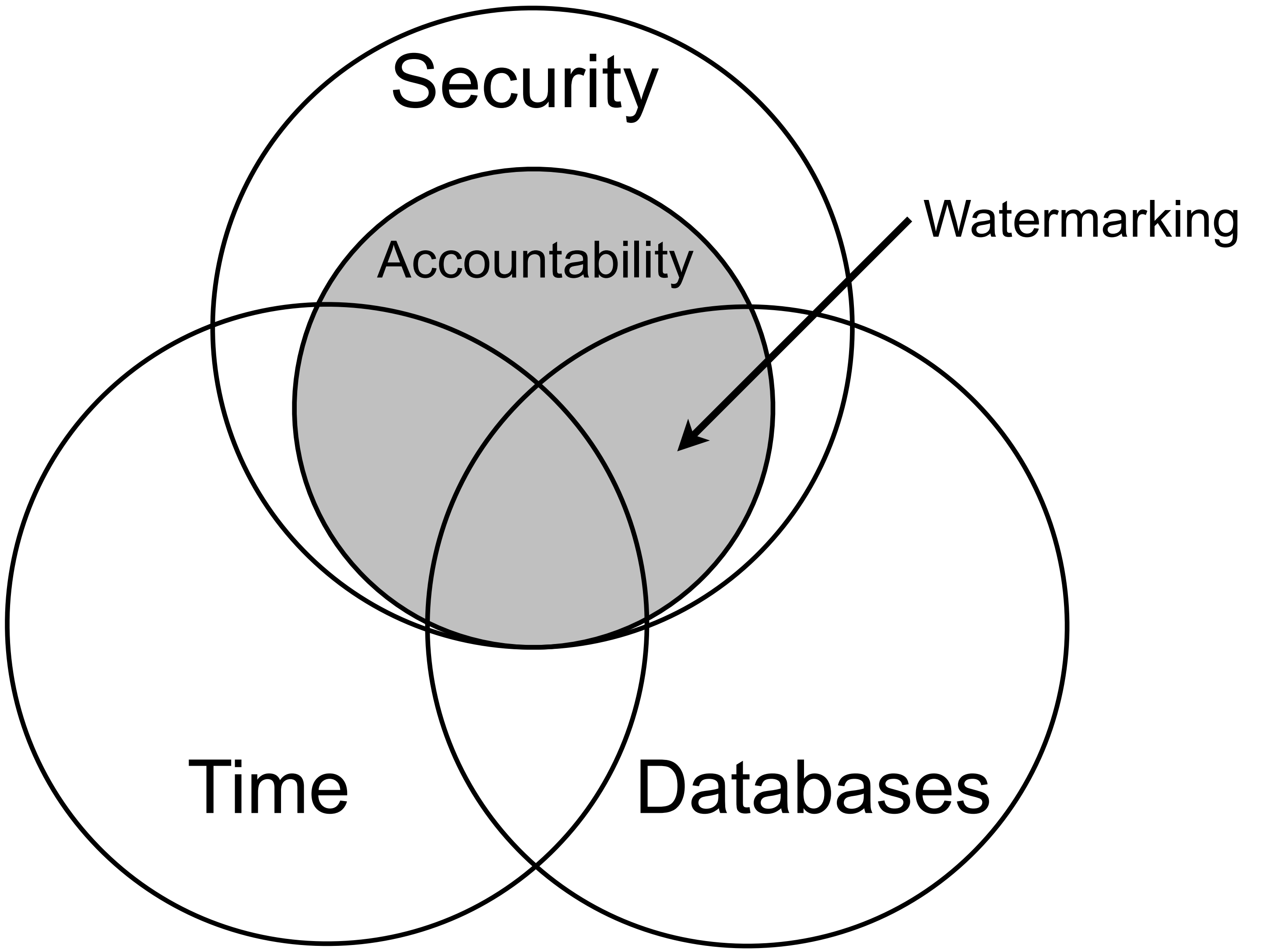

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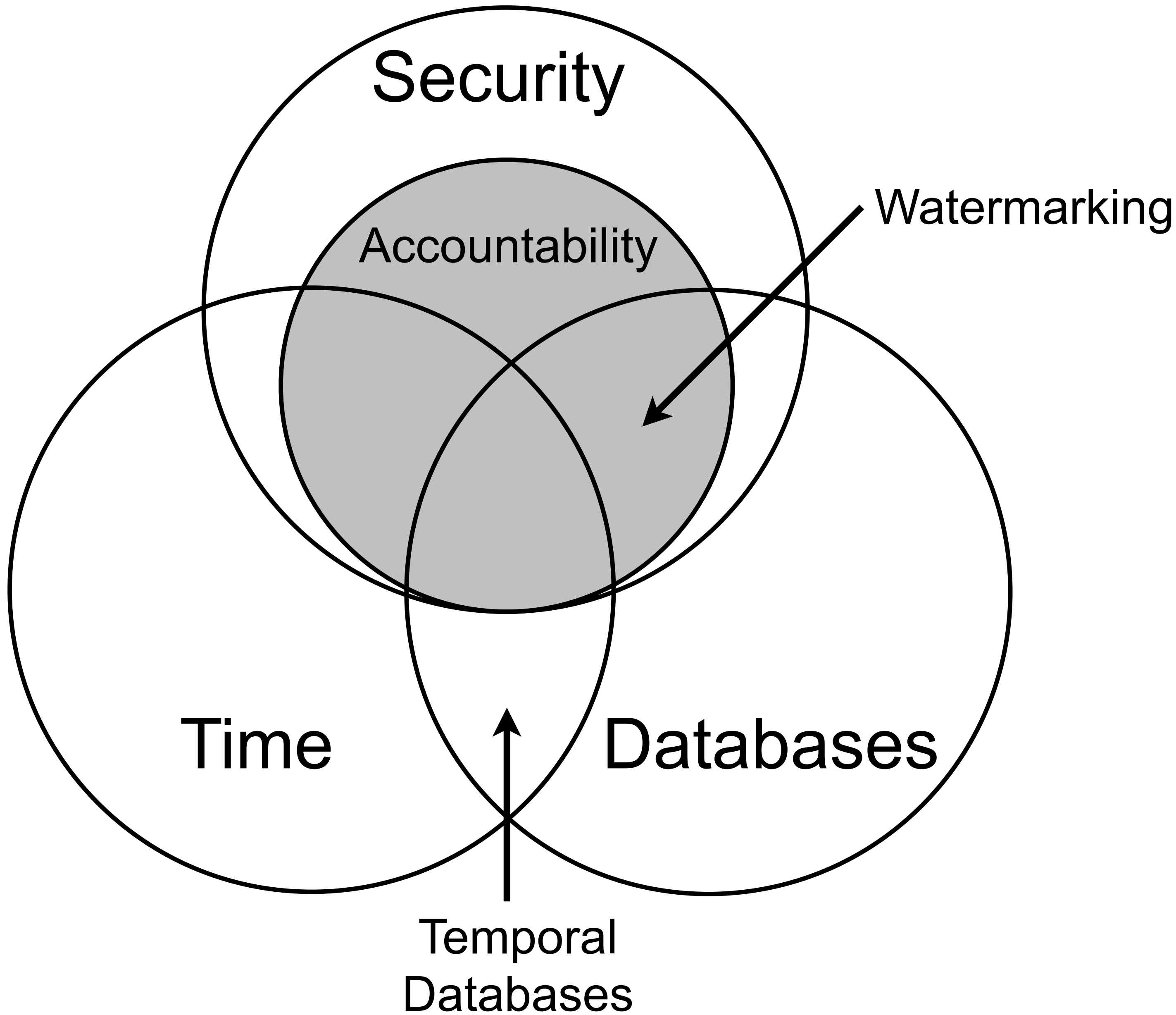

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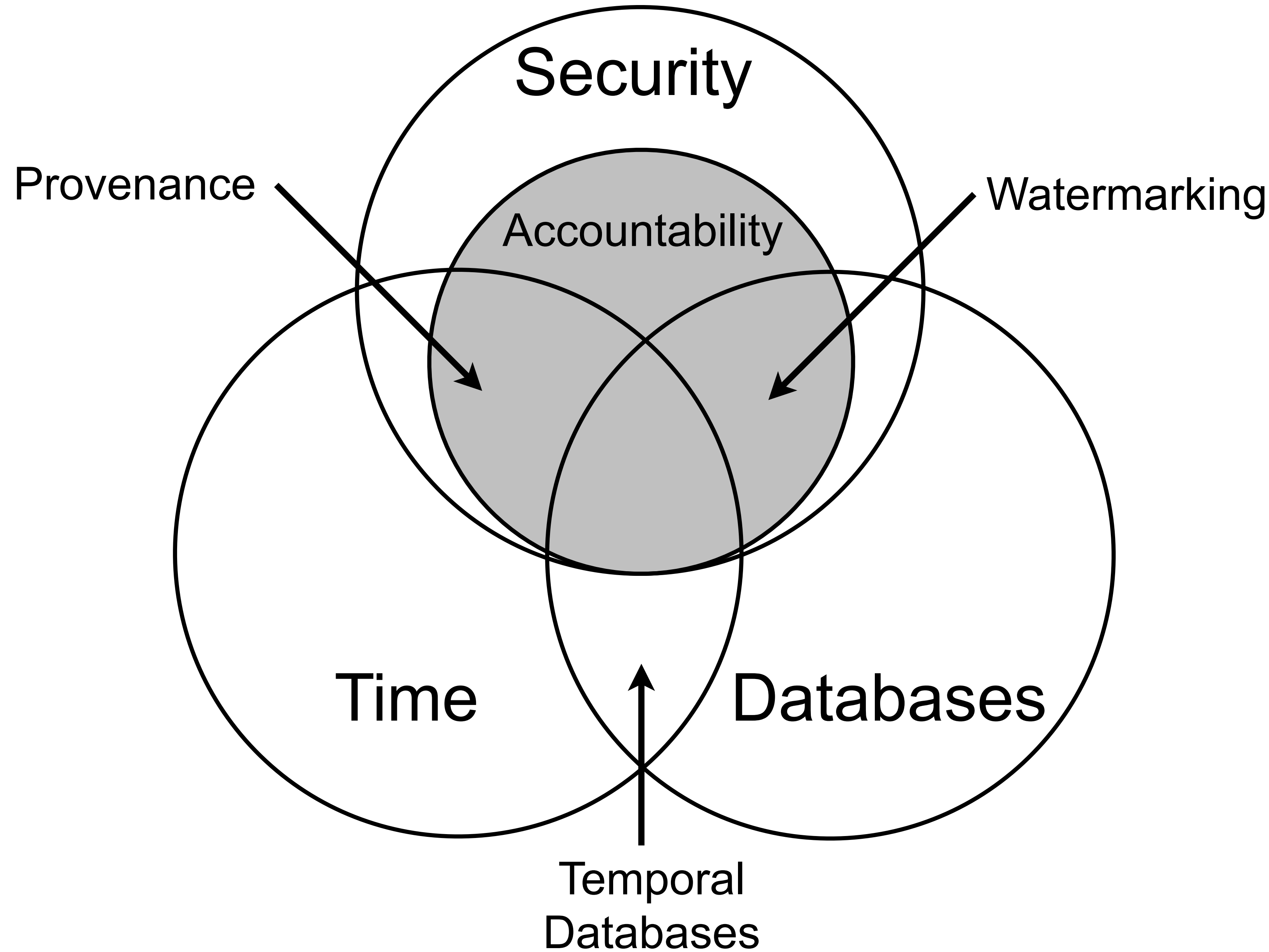

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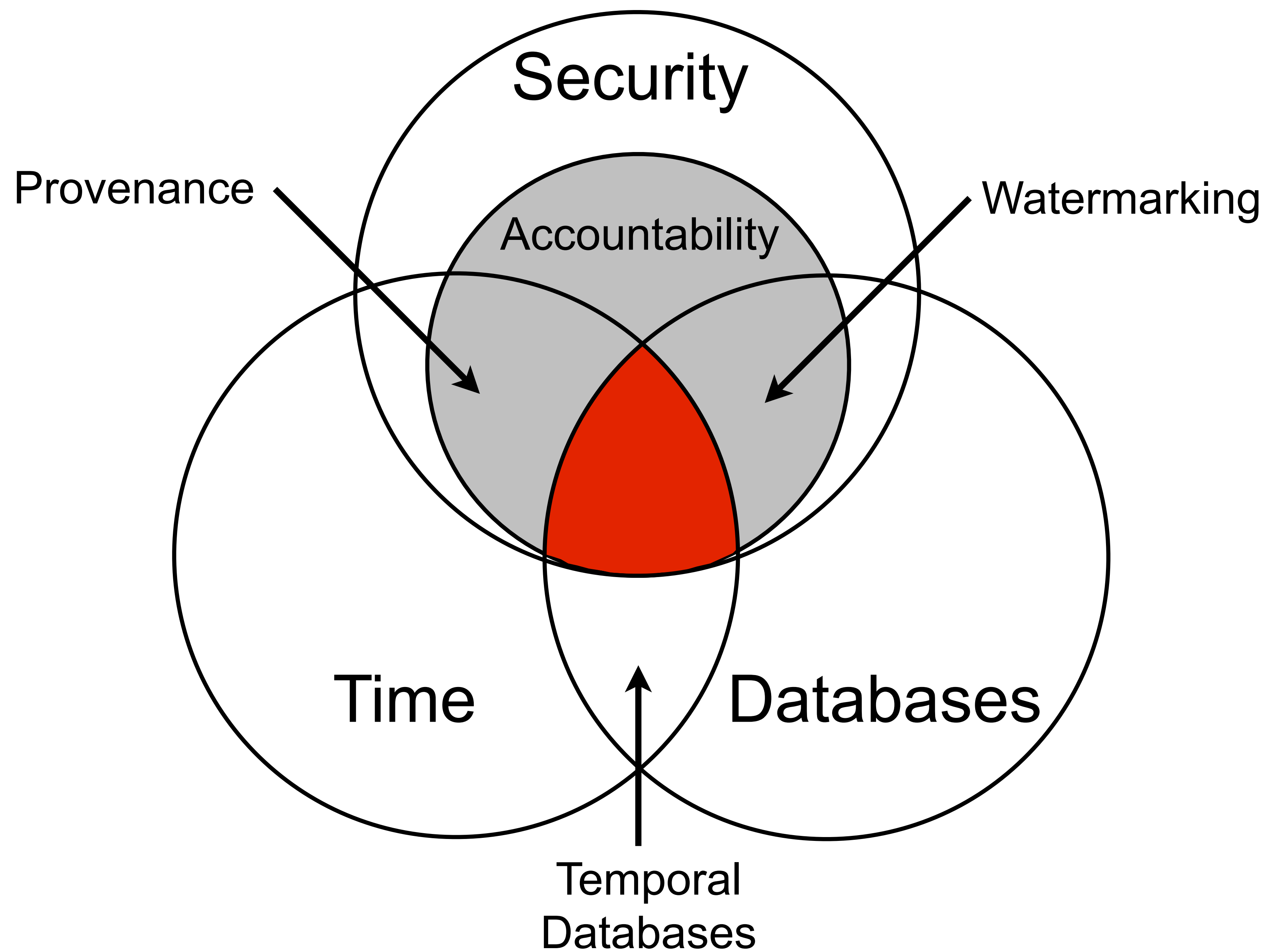

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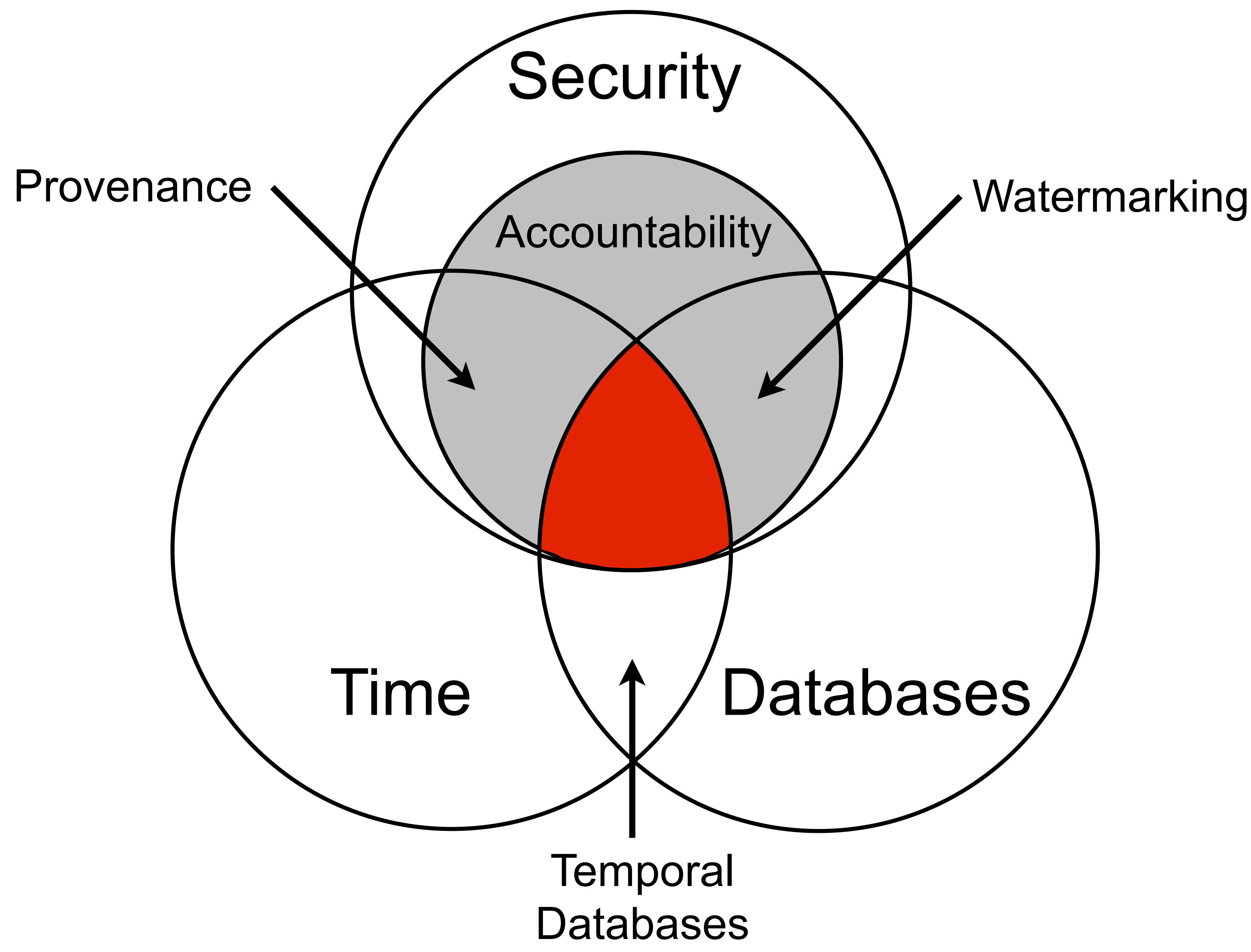

Temporal concepts are found throughout this area of interest.

Outline

- Information Accountability
- Reference Architecture & Execution Phases
- Forensic Analysis
- Refinements
- Enterprise Considerations

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    - provides technology-enabled auditing
    - produces audit results close to occurrence of relevant events
    - achieves meaningful operationalization of information accountability.

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  - provides technology-enabled auditing
  - produces audit results close to occurrence of relevant events
  - achieves meaningful operationalization of information accountability.
- Cryptographic hashing captures state of database as it evolves.

Reference Architecture Threat Model

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- Trusted computing base (TCB)
  - Correctly booted and running hardware, OS and DBMS
  - TCB runs correctly until intrusion
- A trusted external digital notarization service (EDNS)
- The adversary could be
  - Inside/outside intruders who gain full control of the whole TCB and logs
  - Malware such as virus, bugs, power surge
- Regret Interval: minimum time before someone can reverse the change
  - Determined by the specific application

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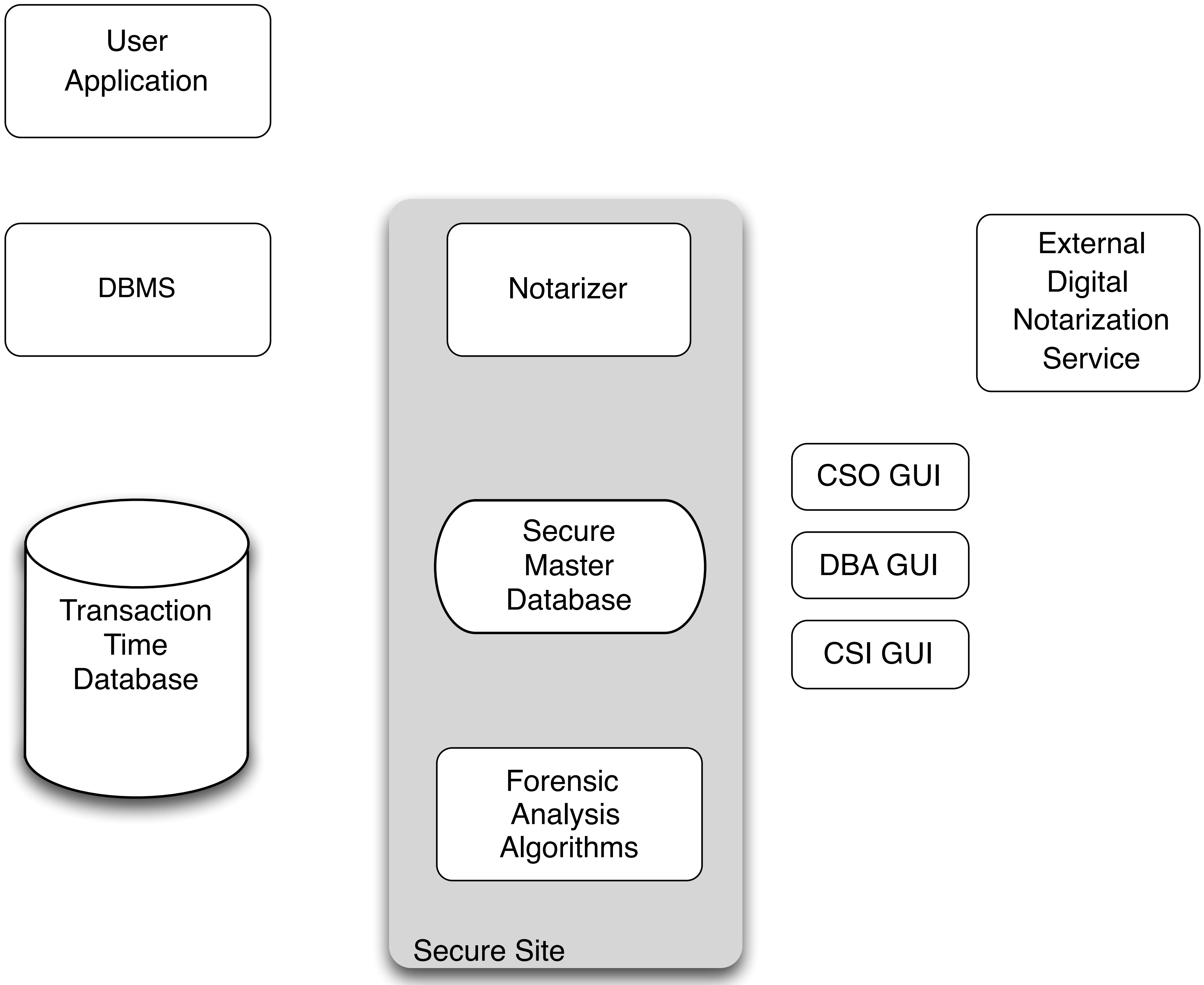

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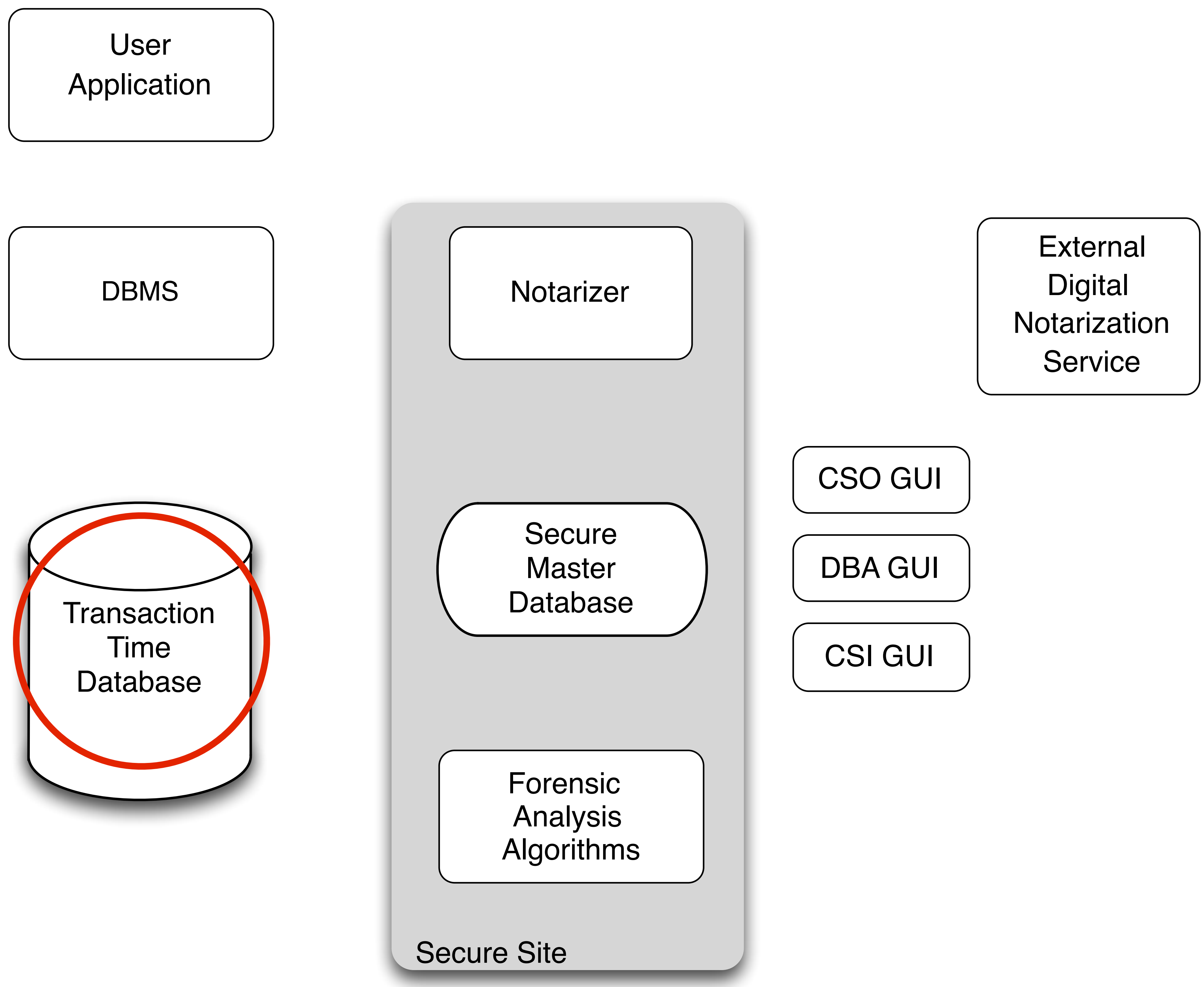

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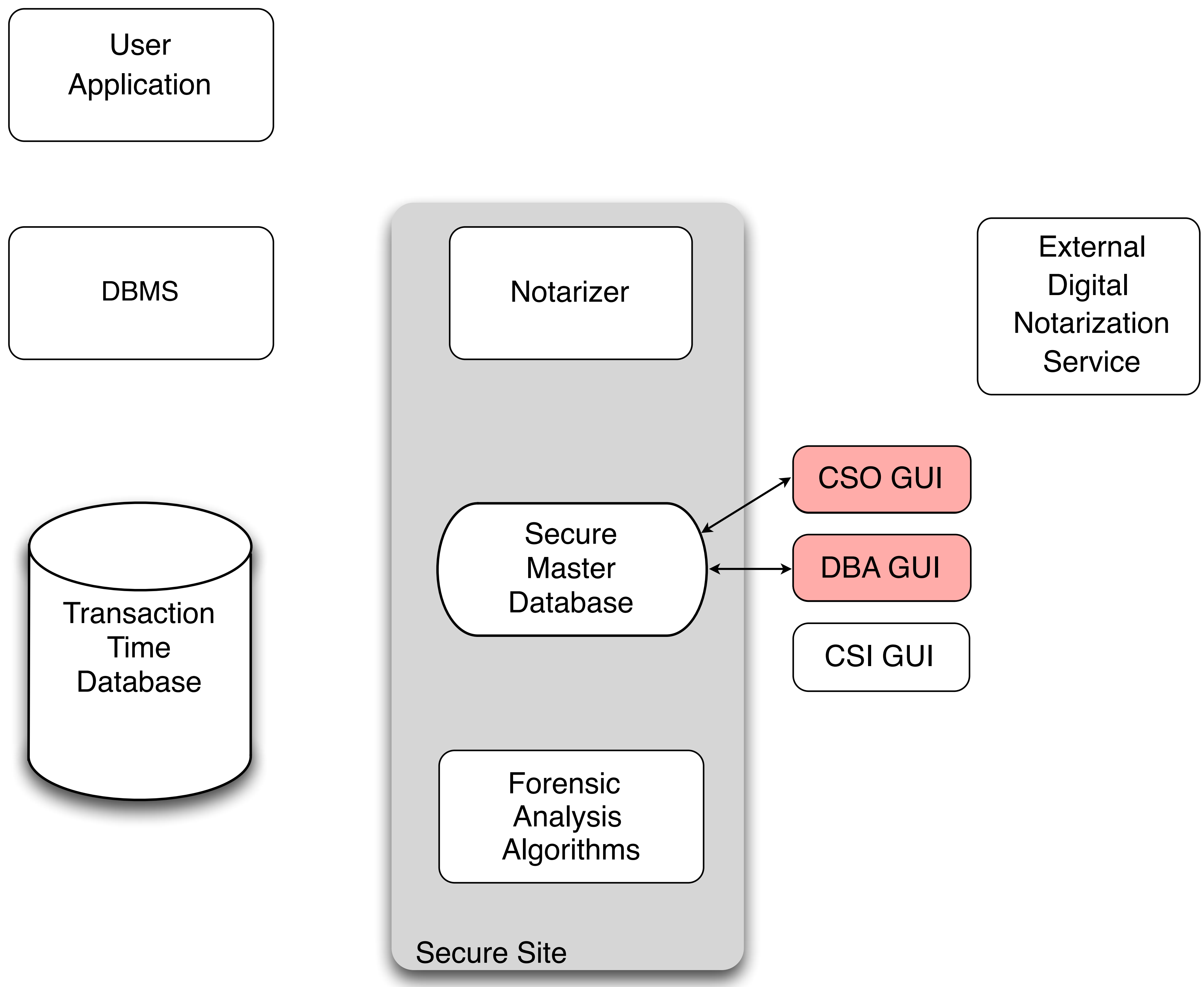

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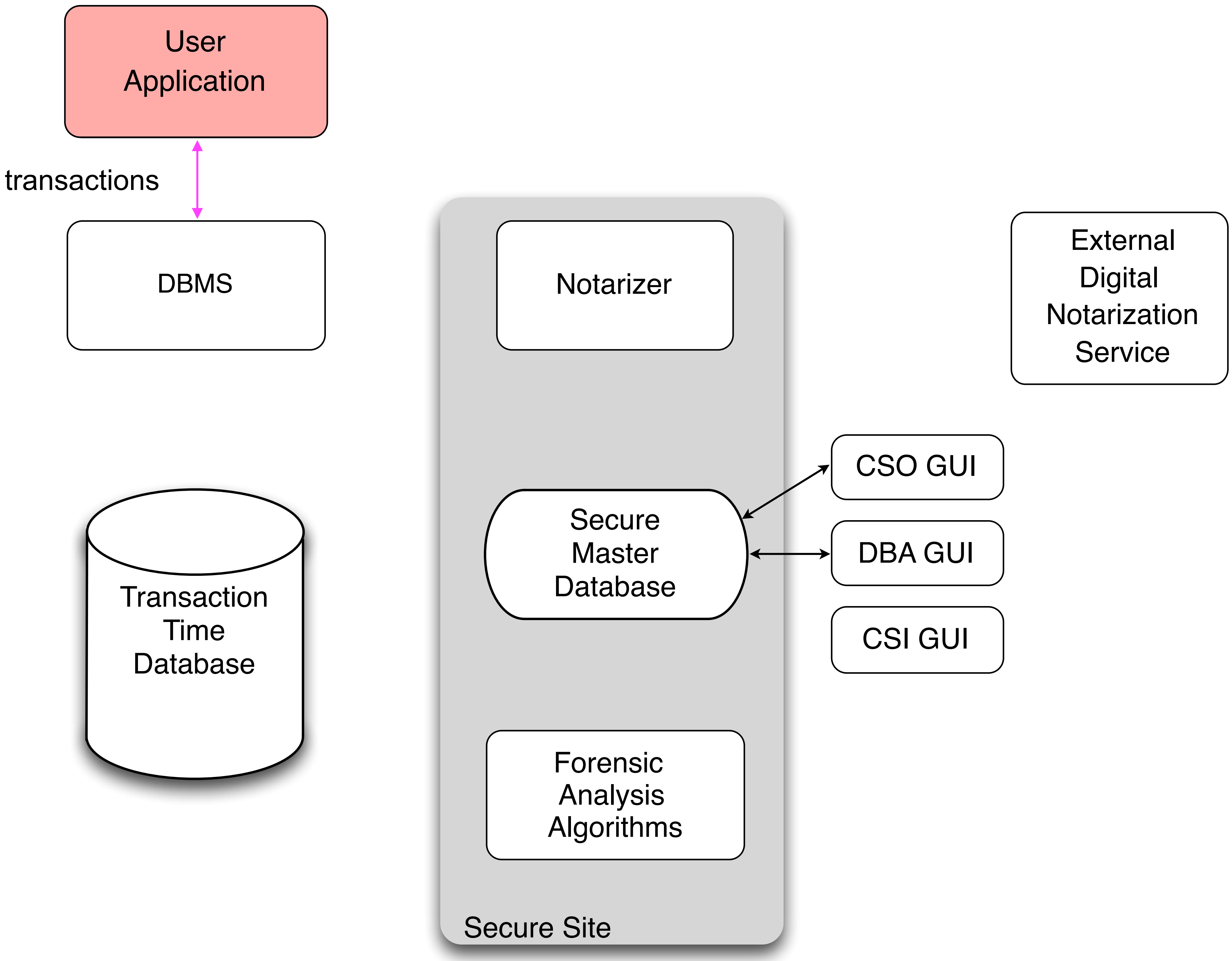

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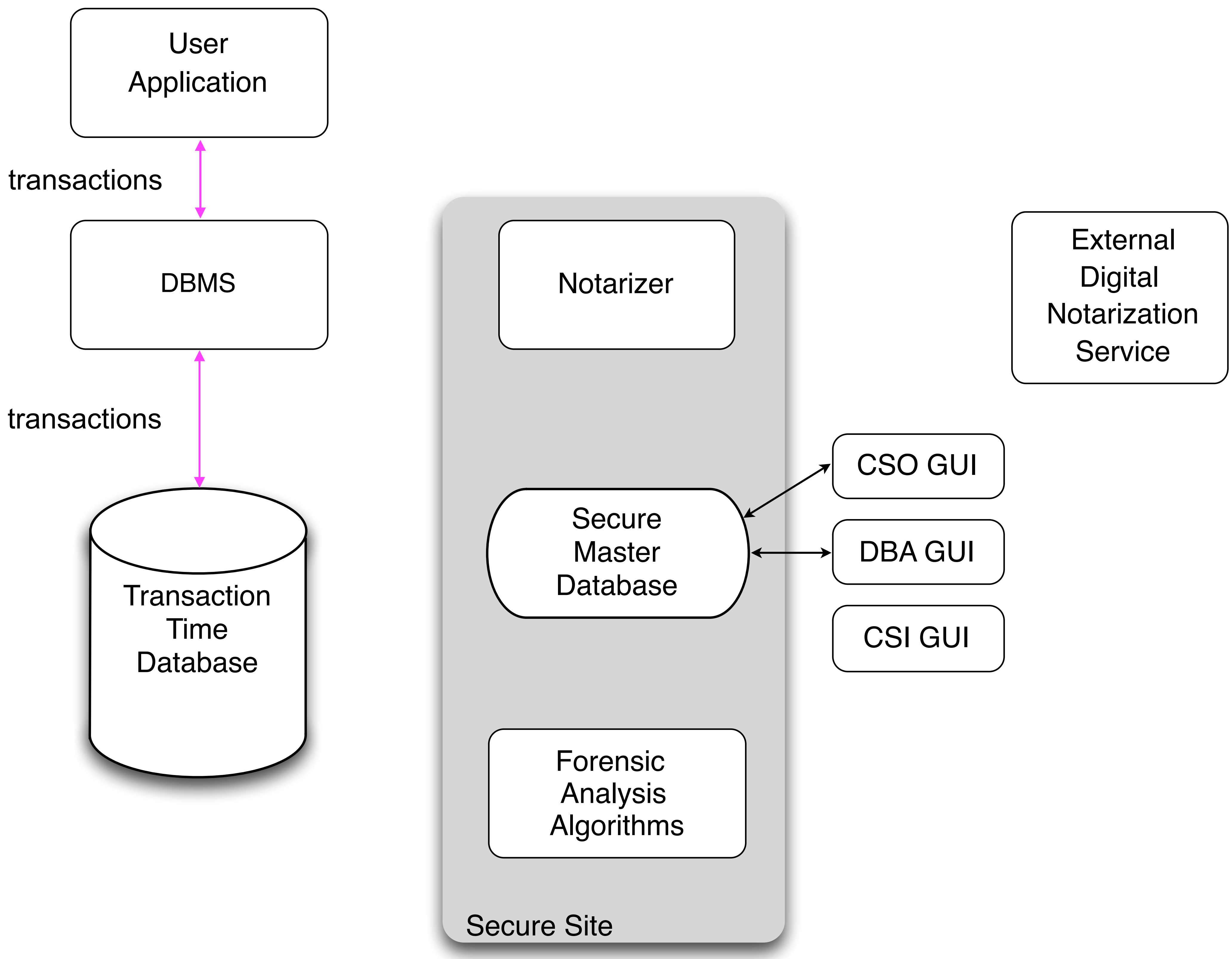

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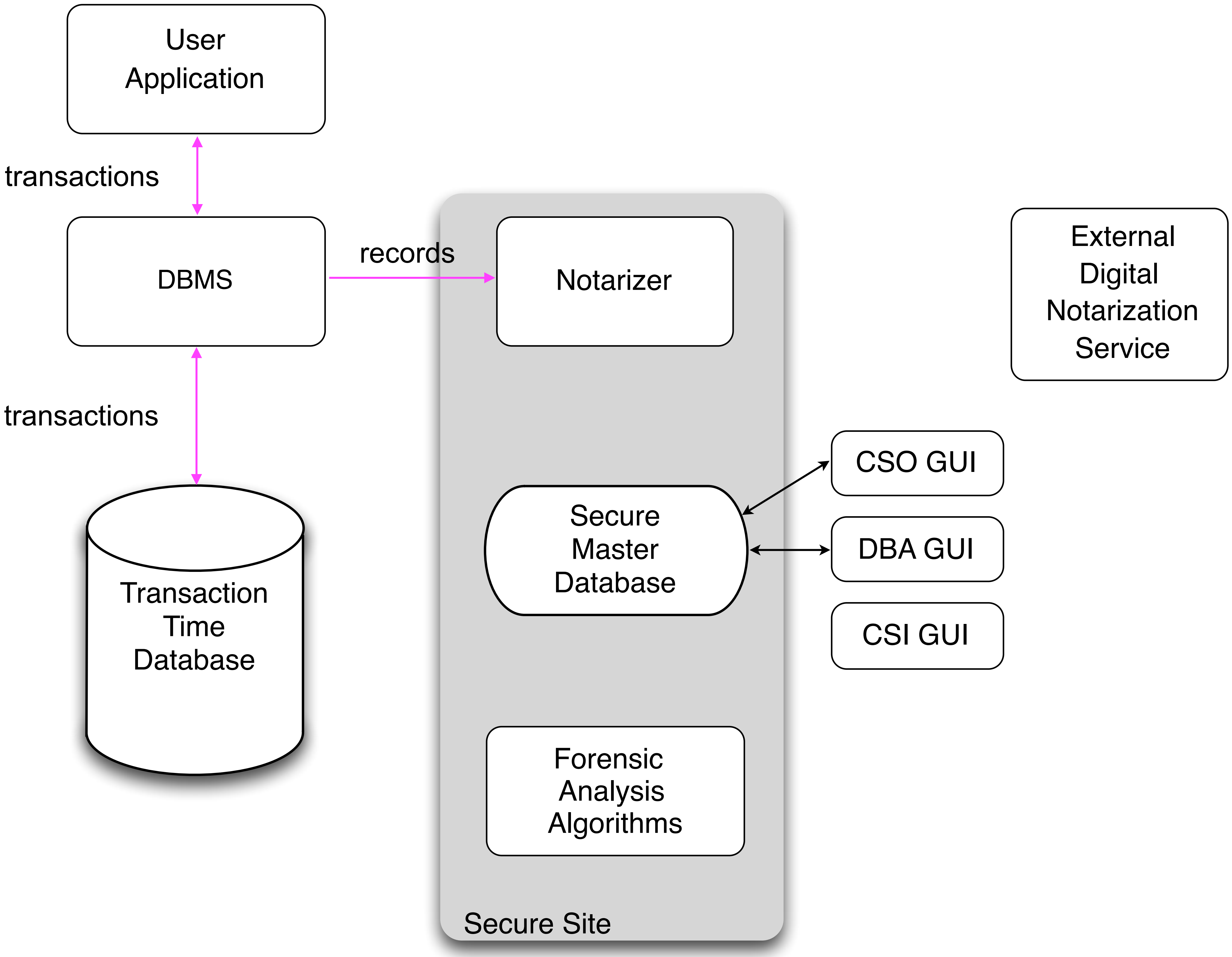

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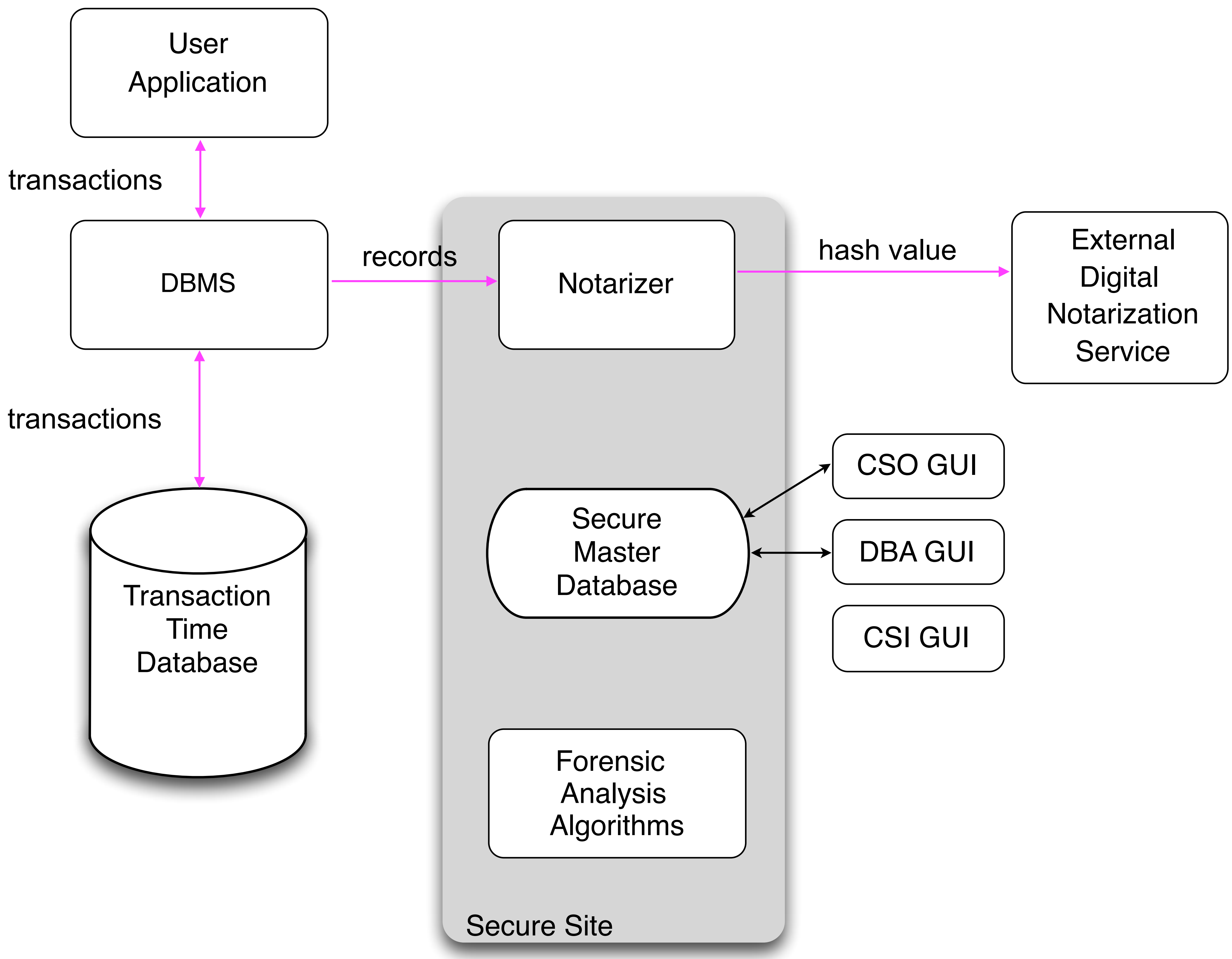

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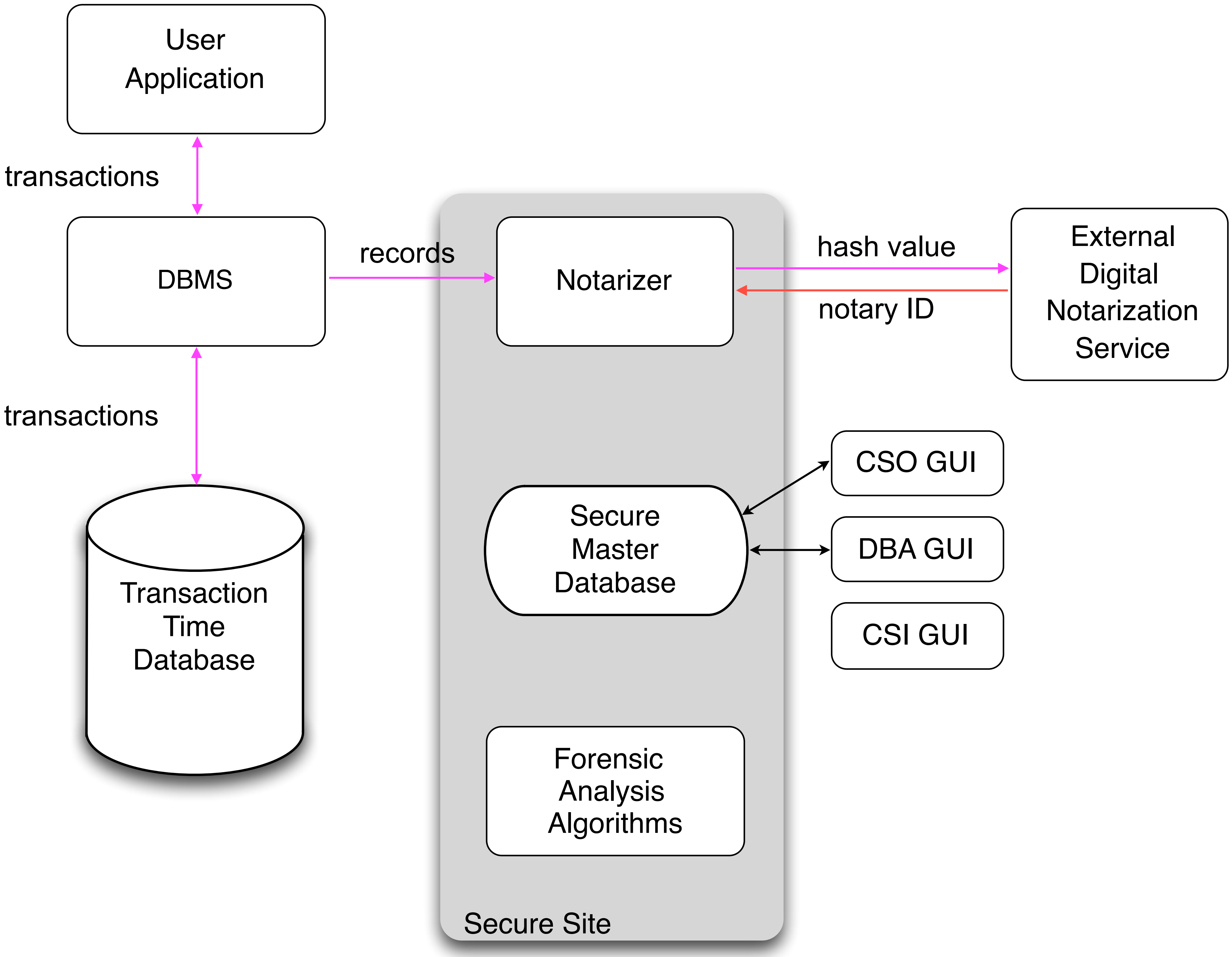

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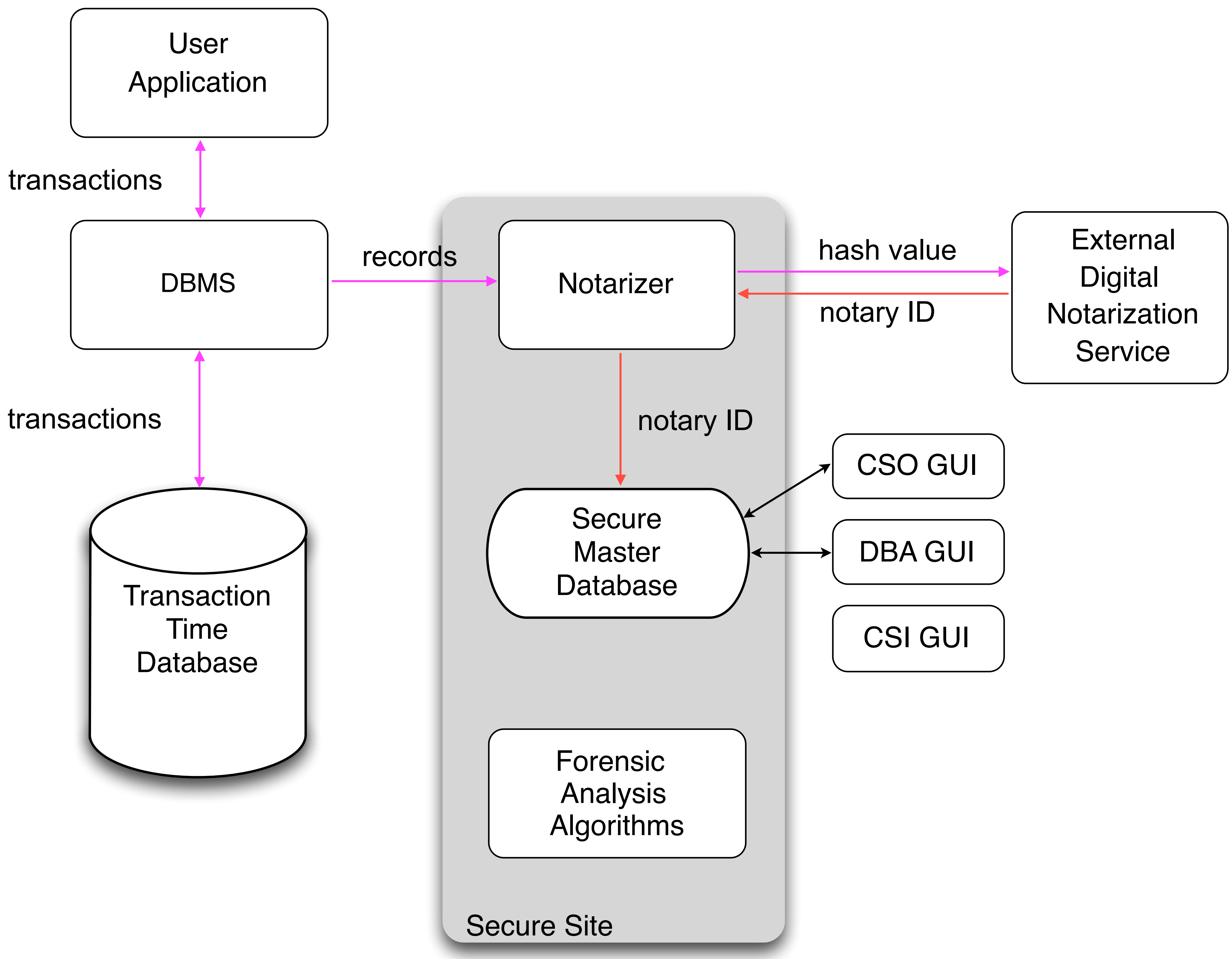
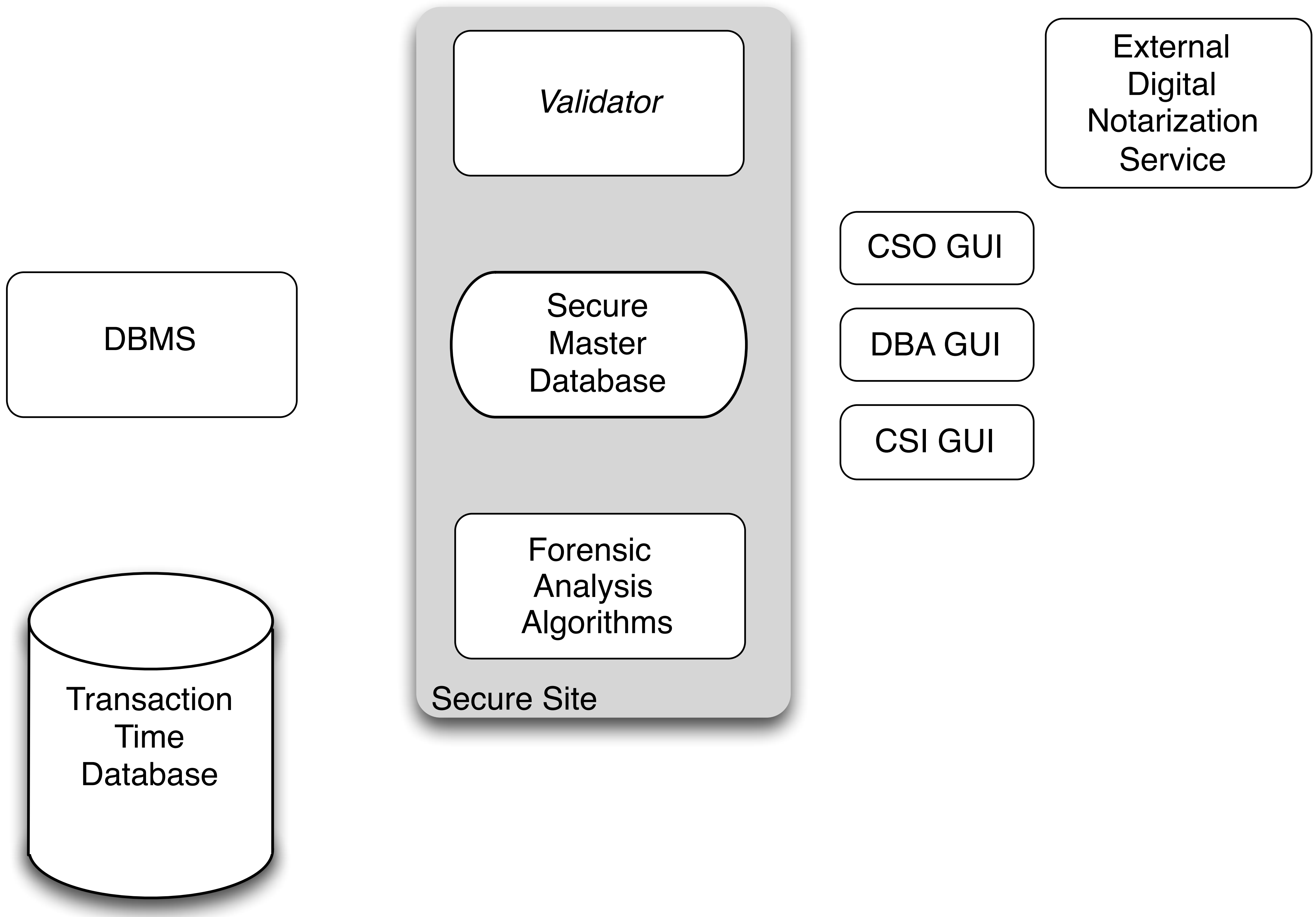


Tamper Detection and Forensic Analysis Phase



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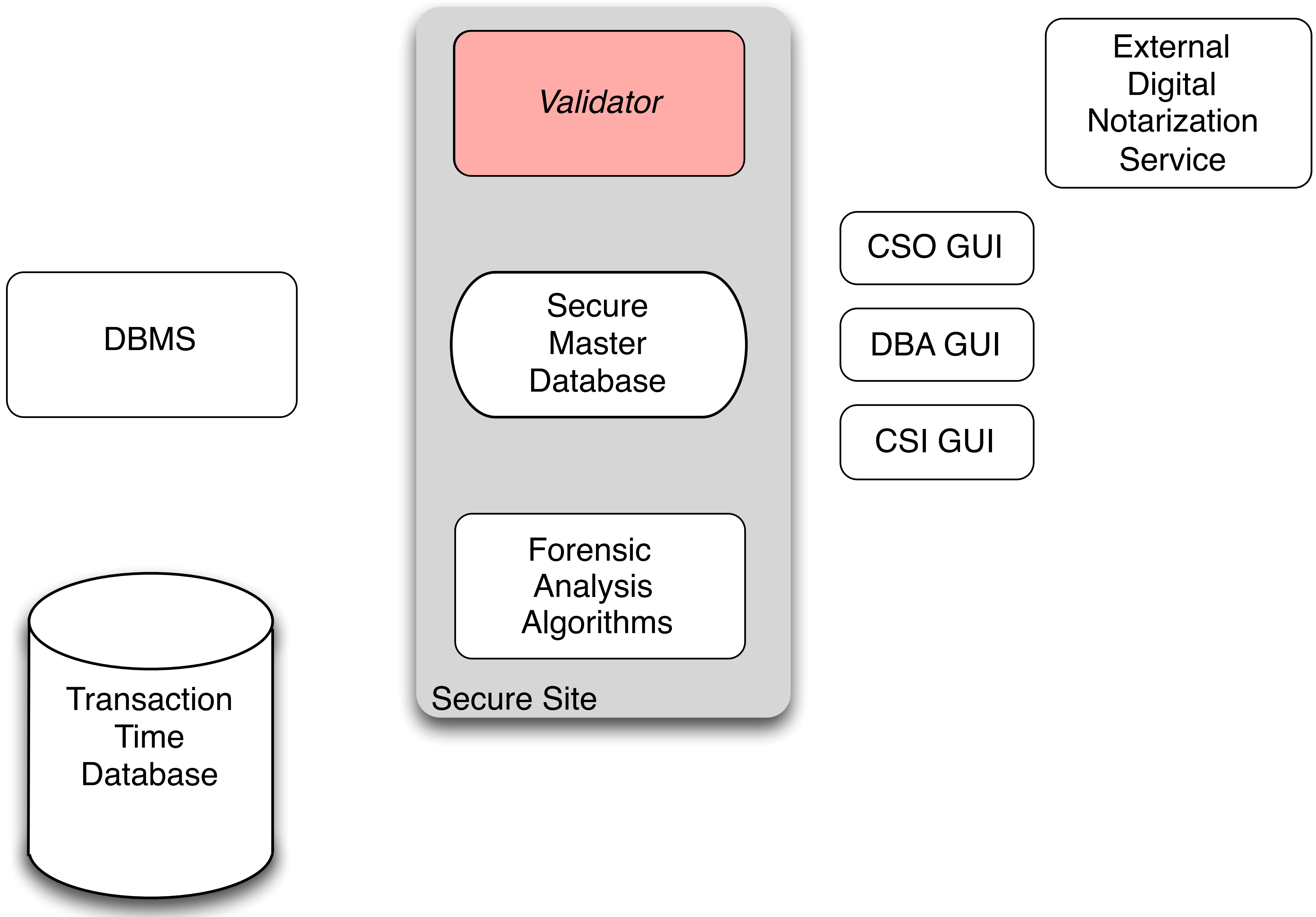

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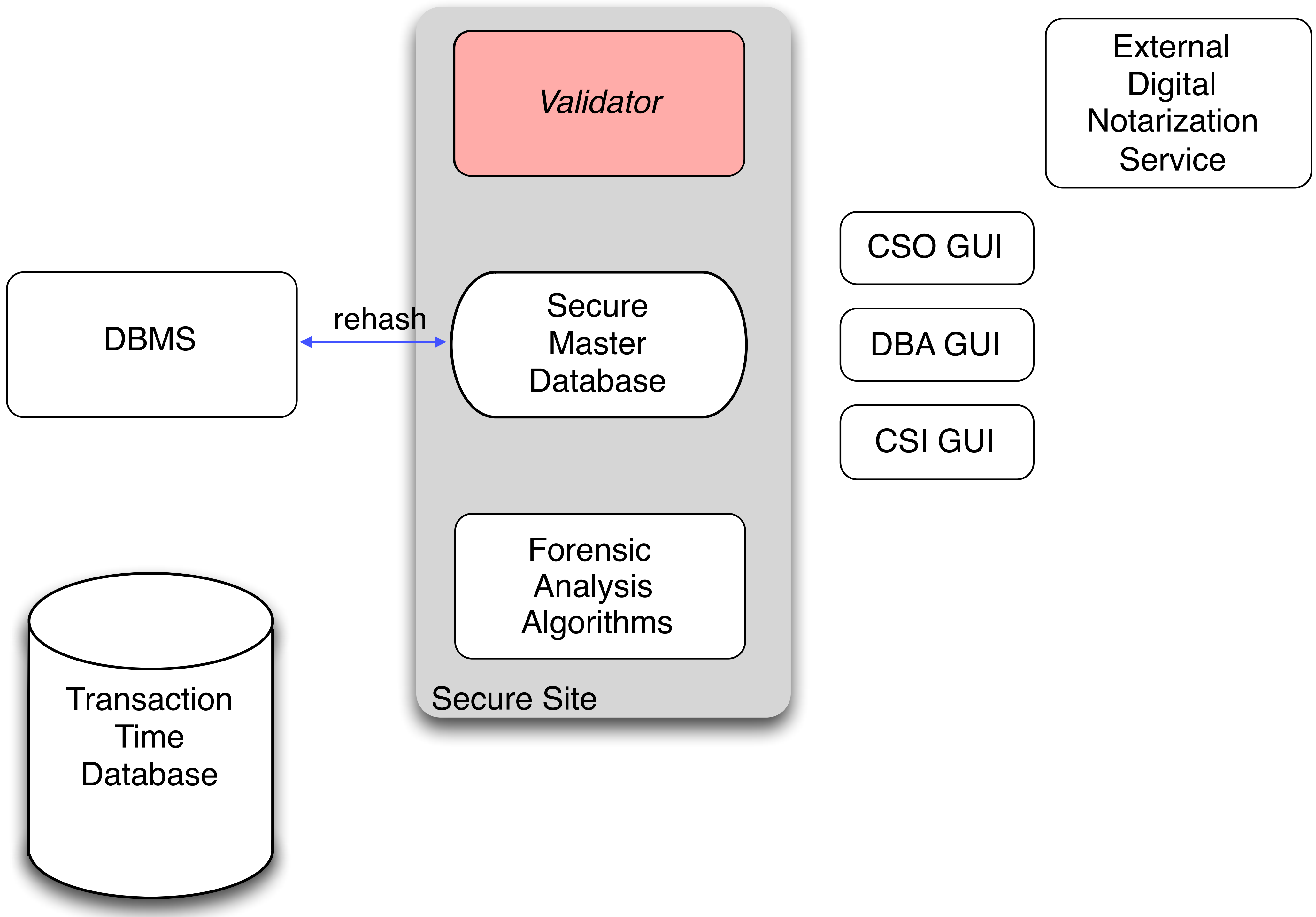

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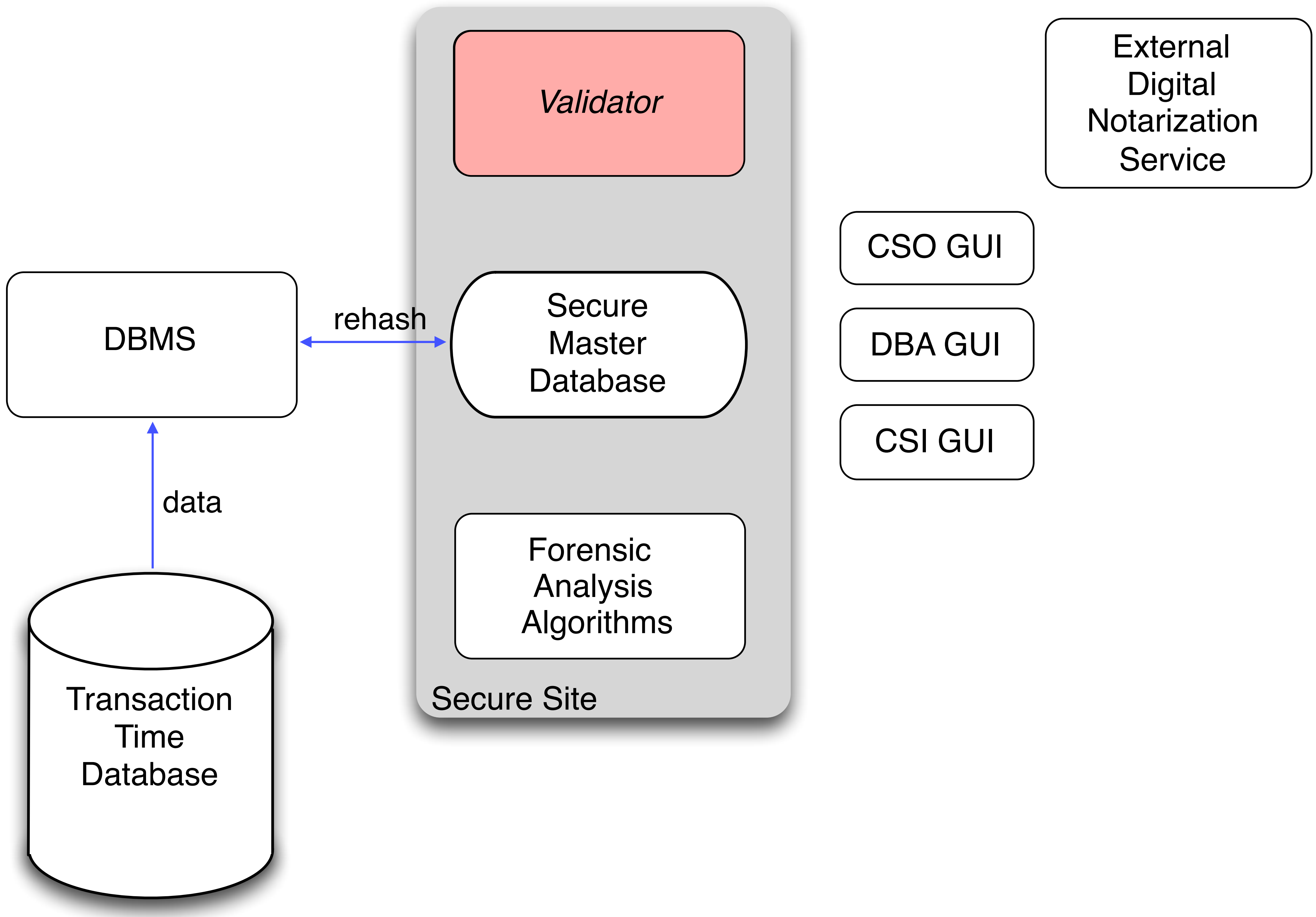

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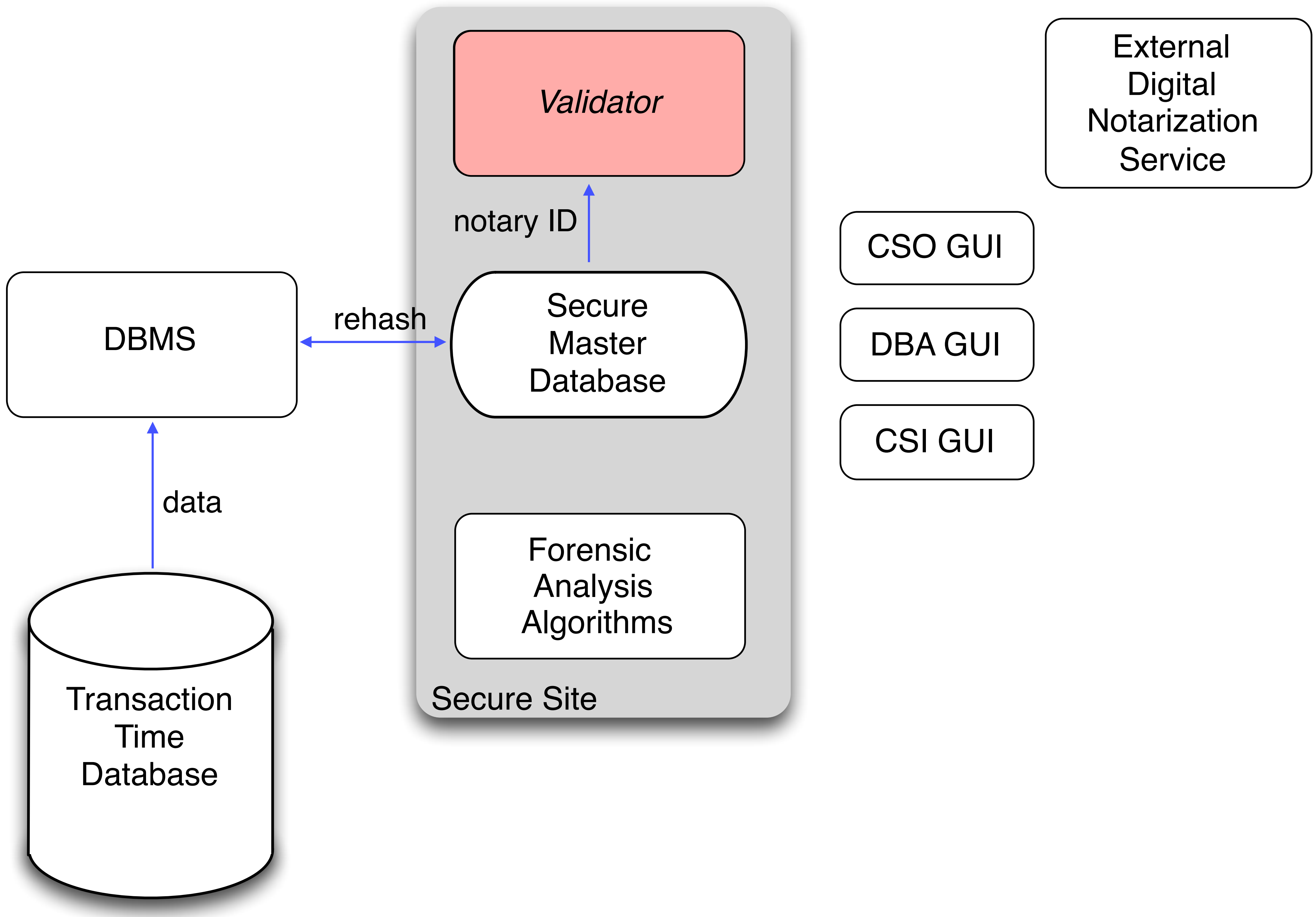

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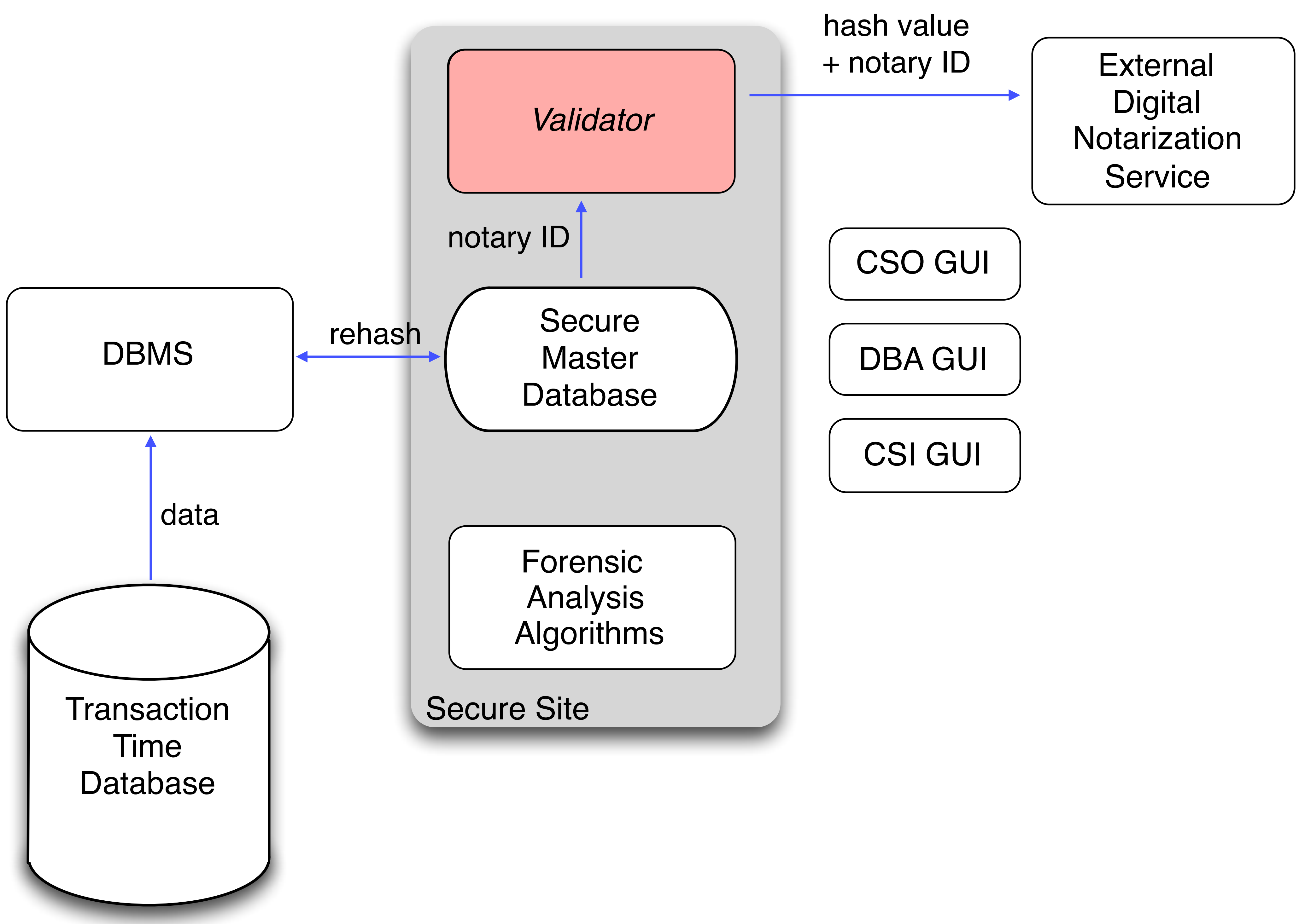

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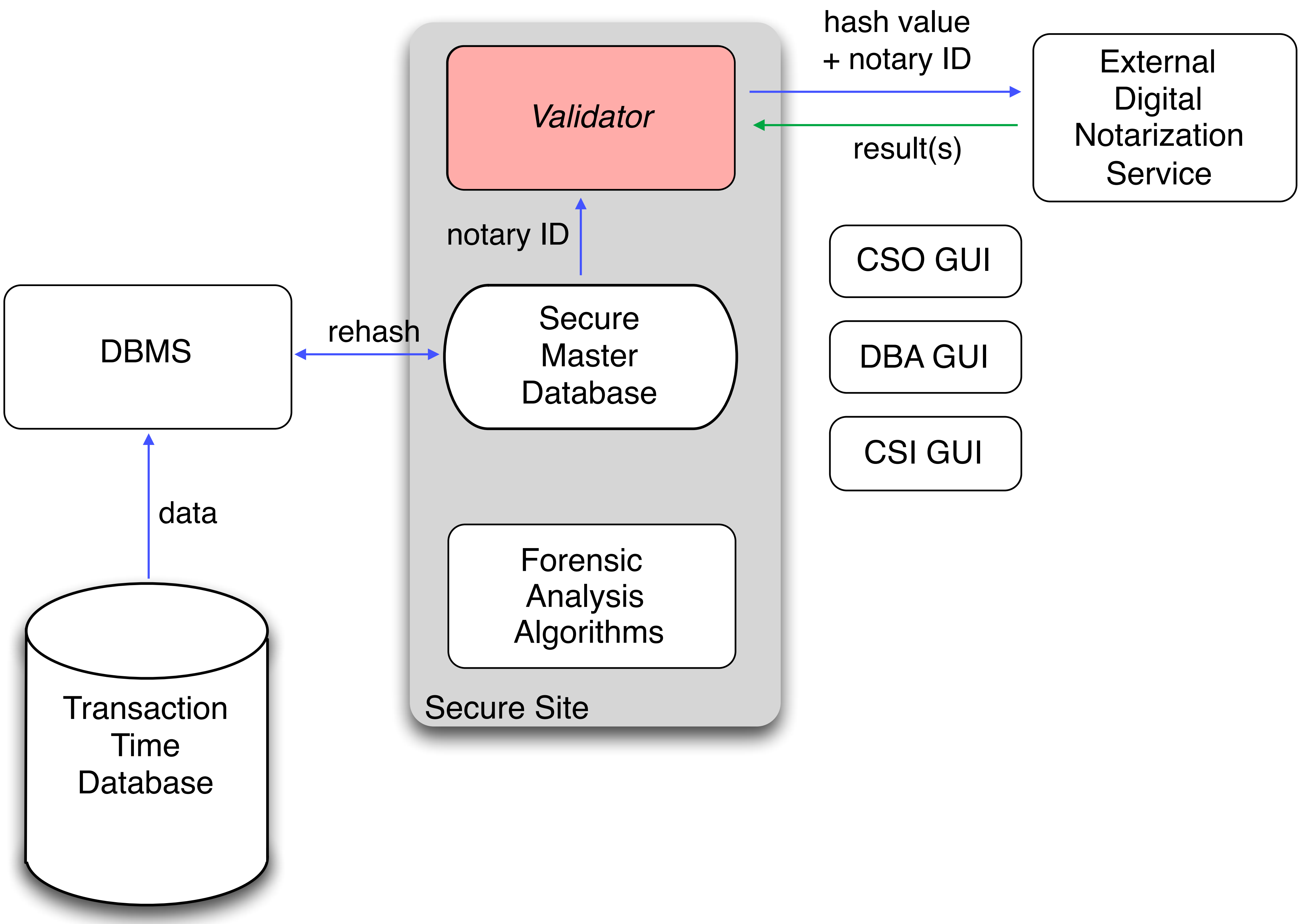

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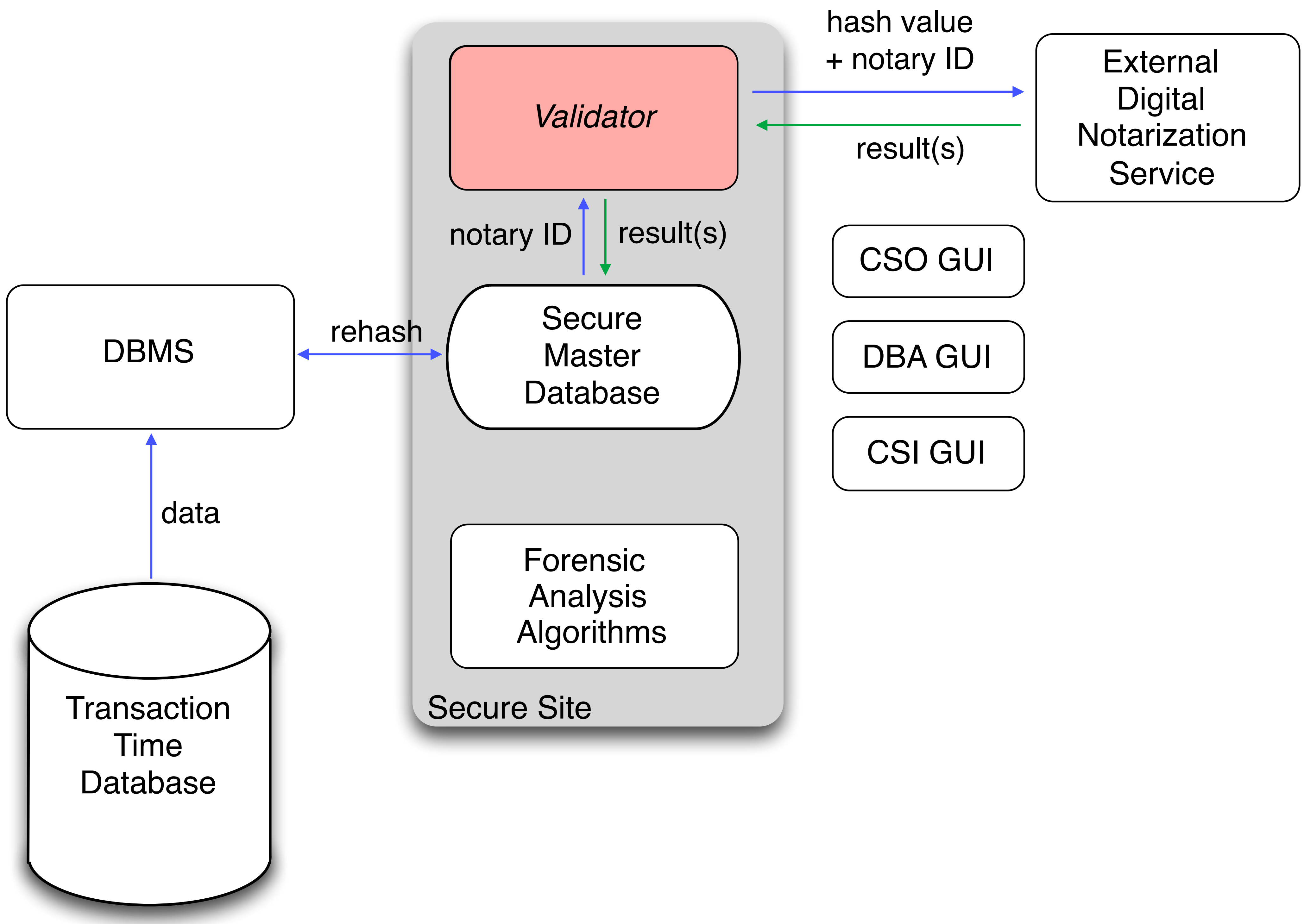

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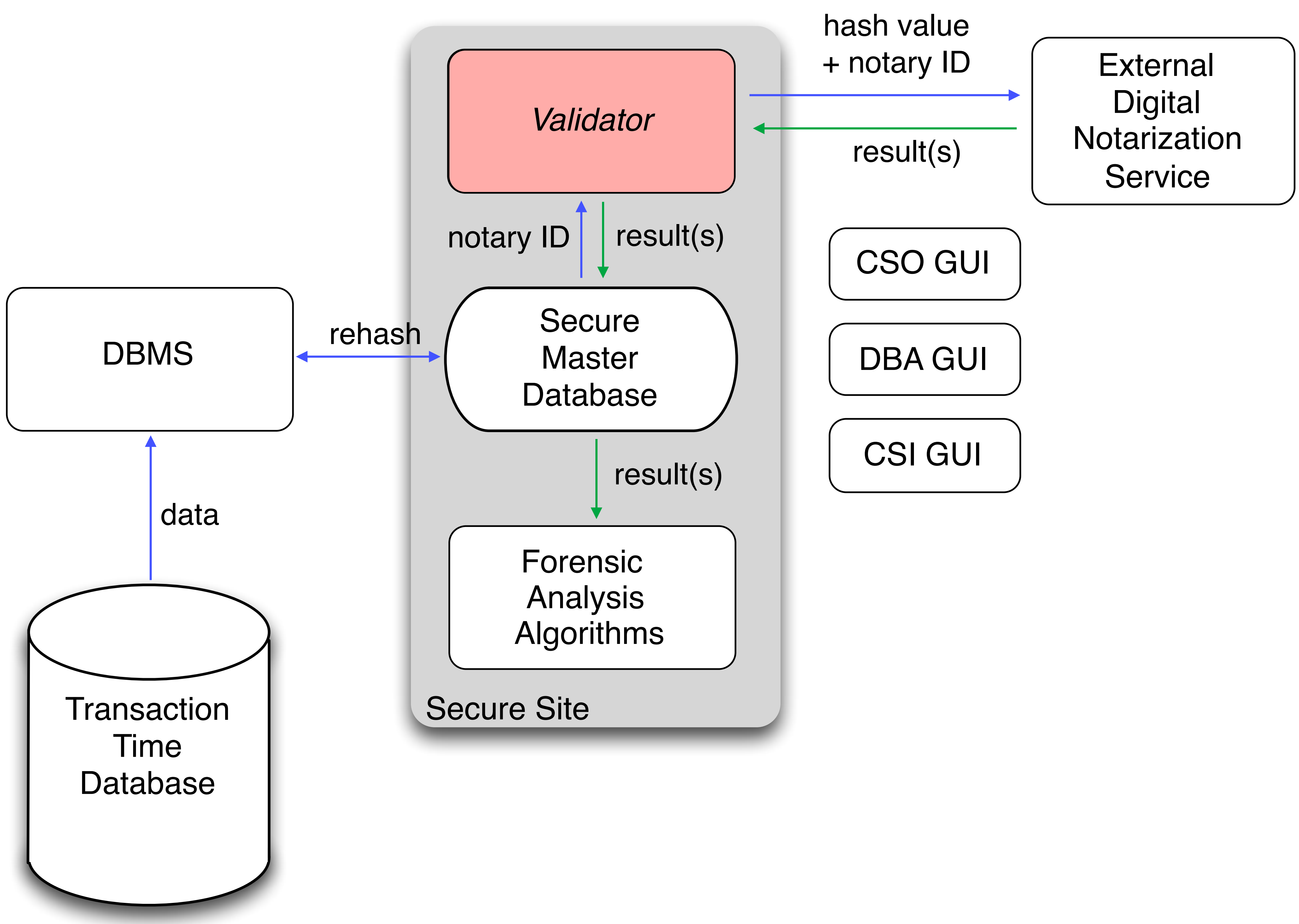

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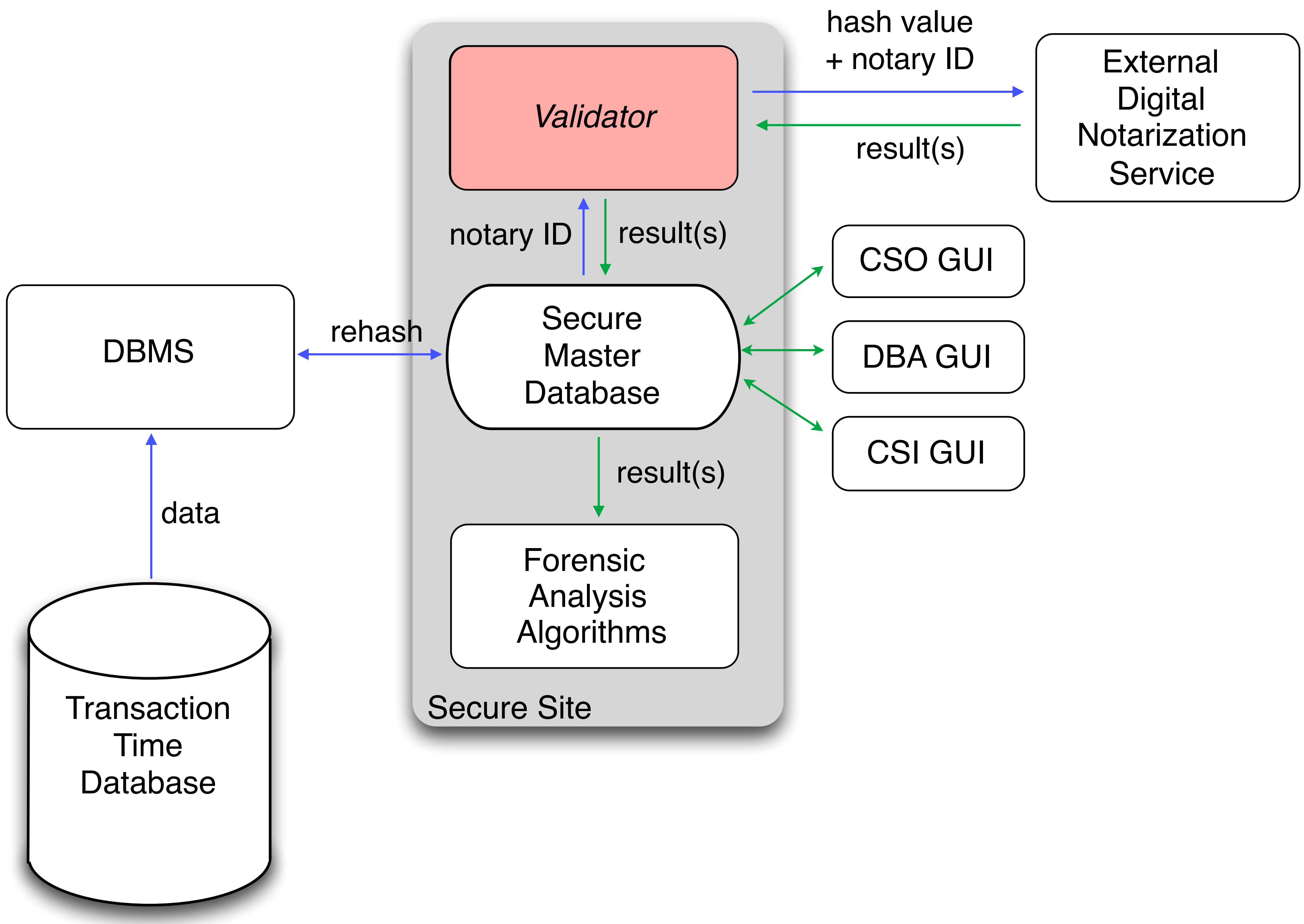

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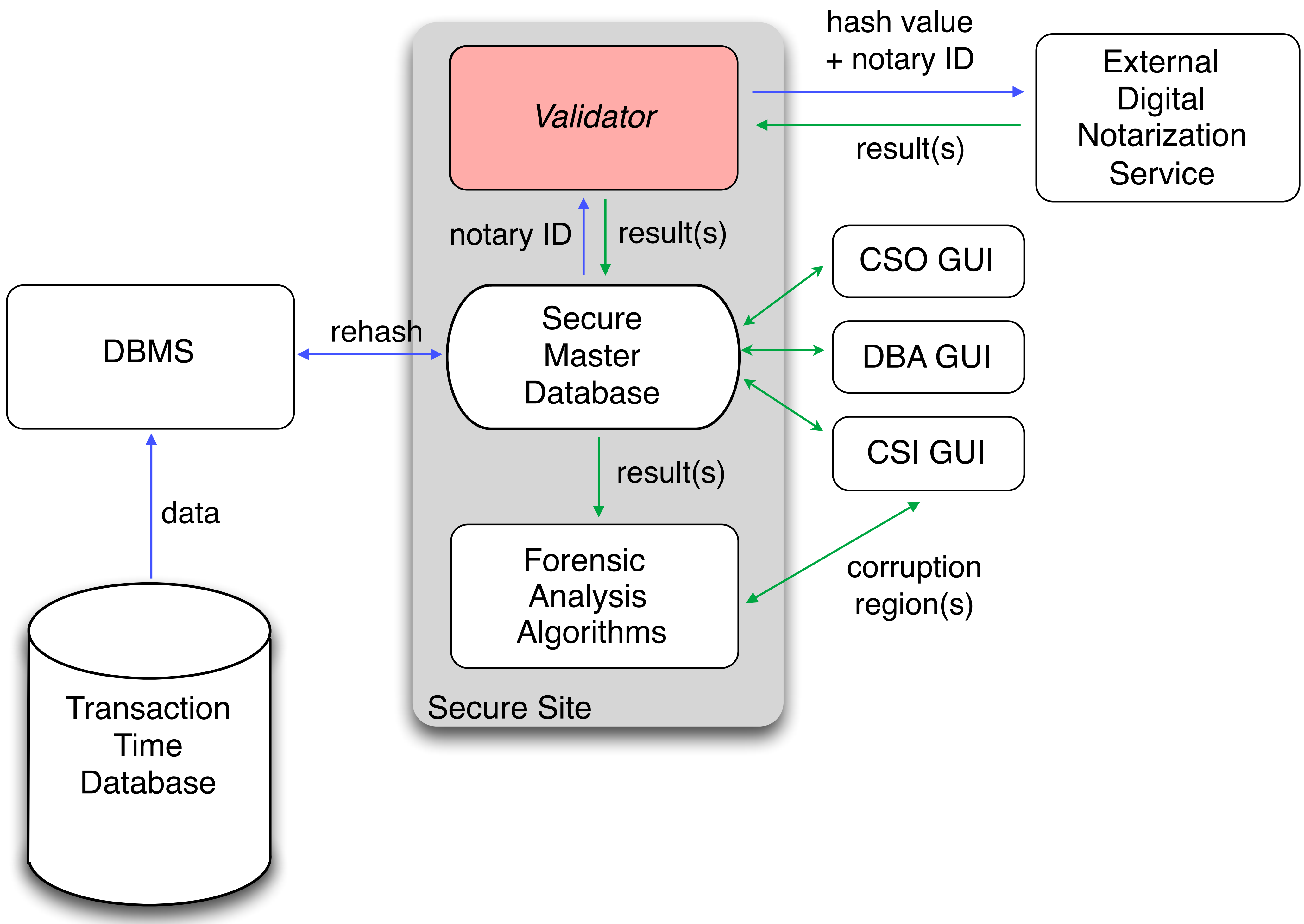

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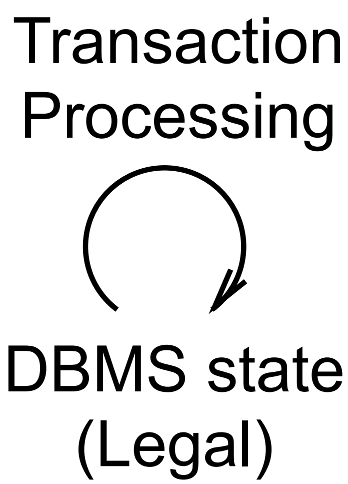
Tampering, Detection and Forensic Analysis



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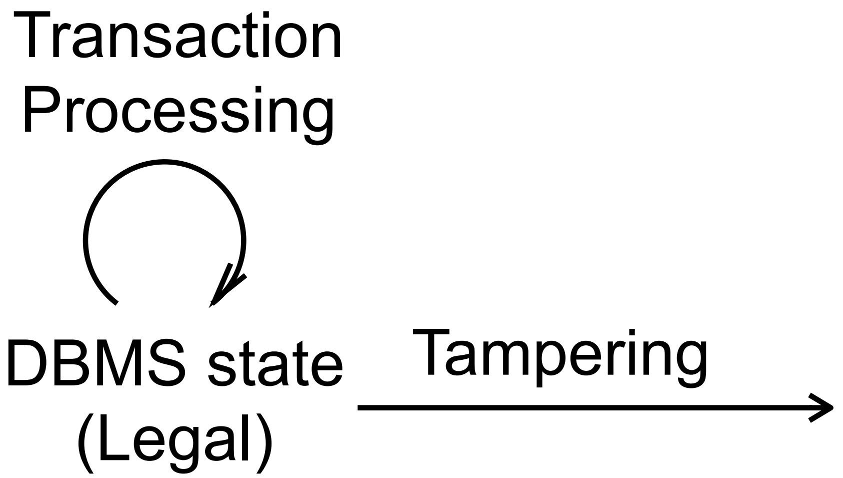

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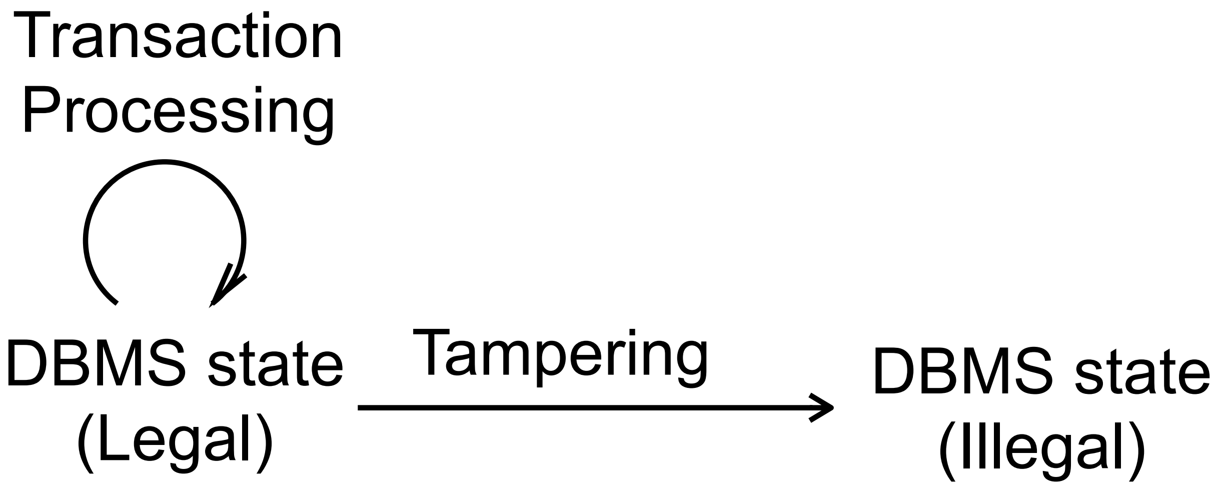

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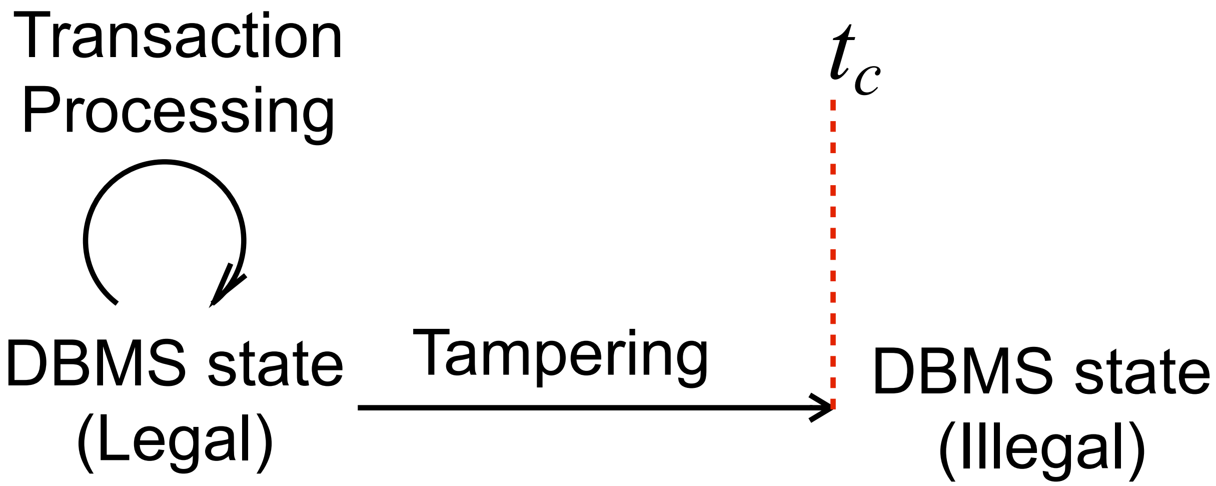

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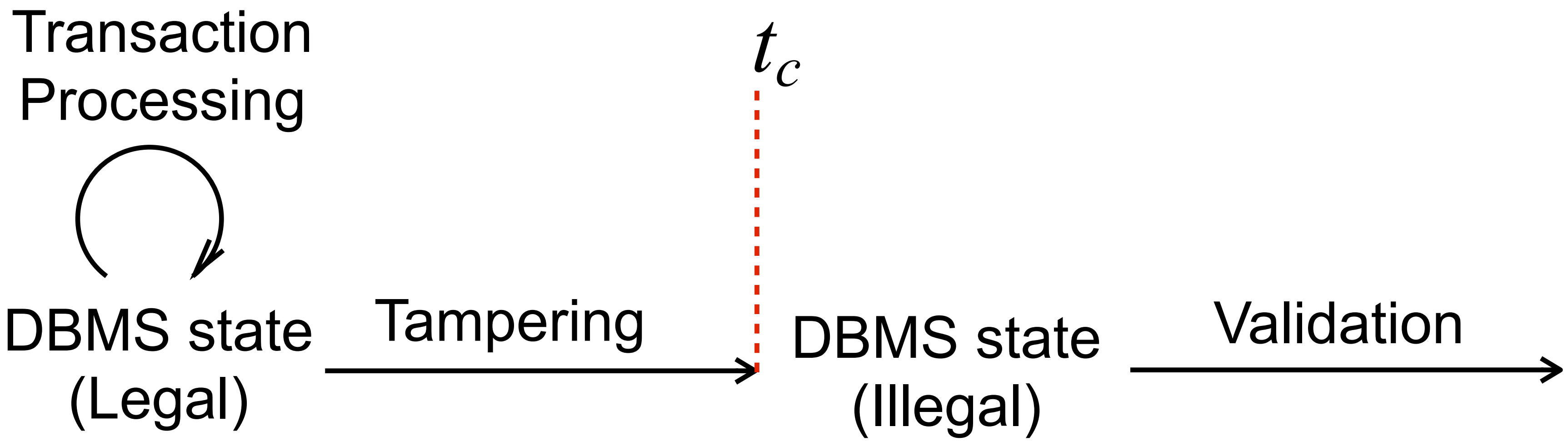

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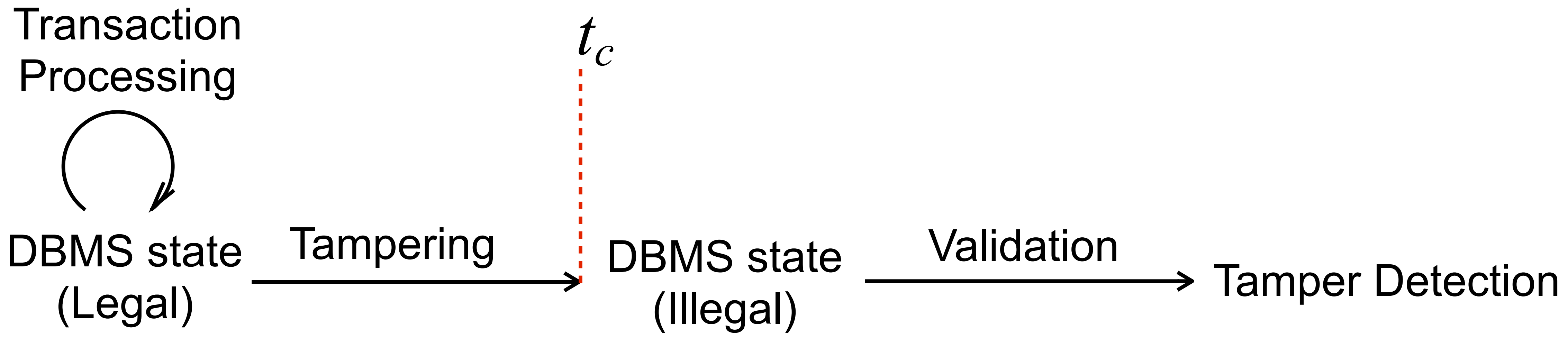

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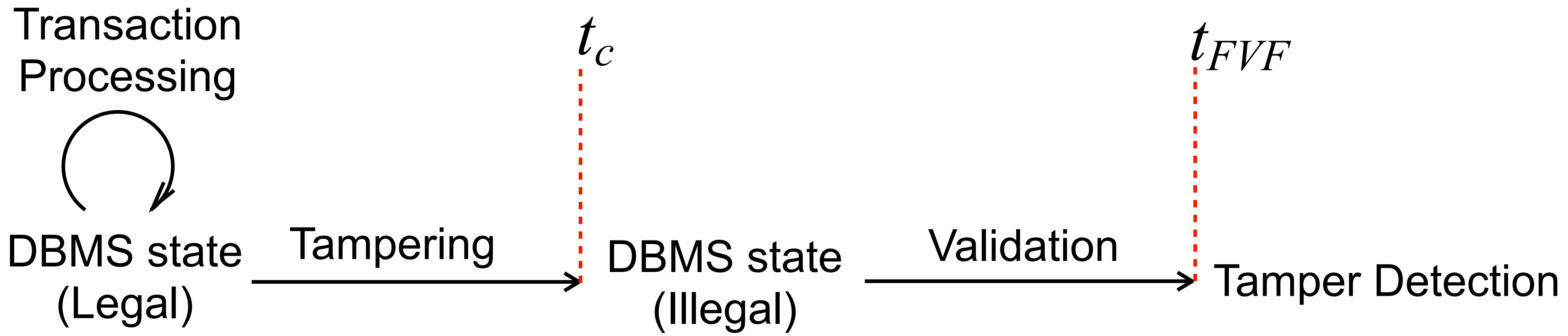

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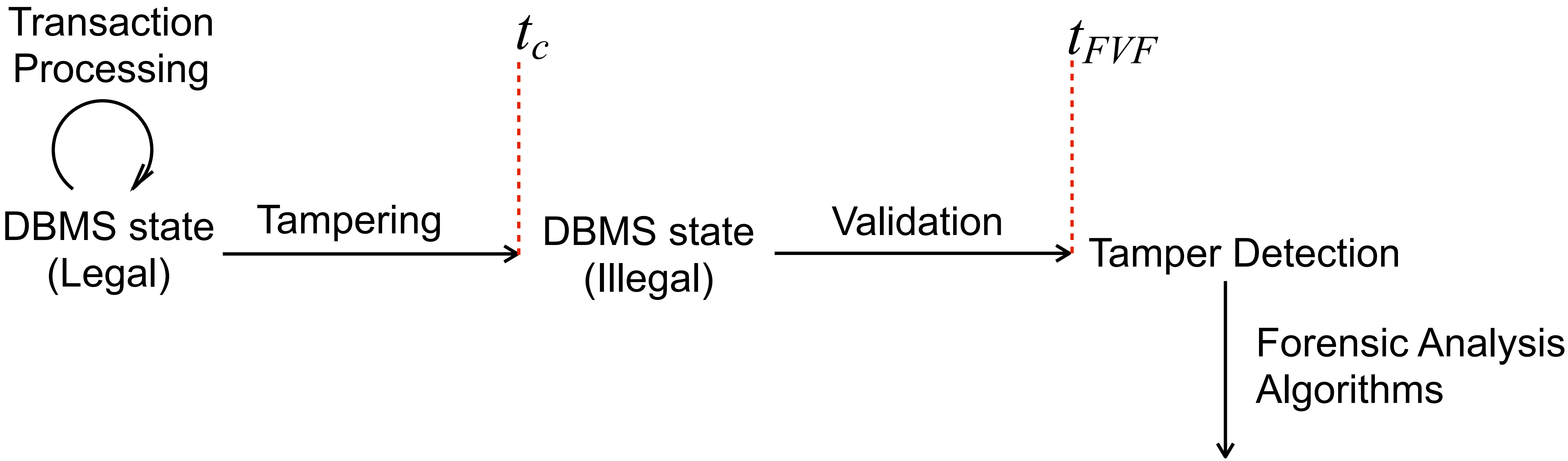

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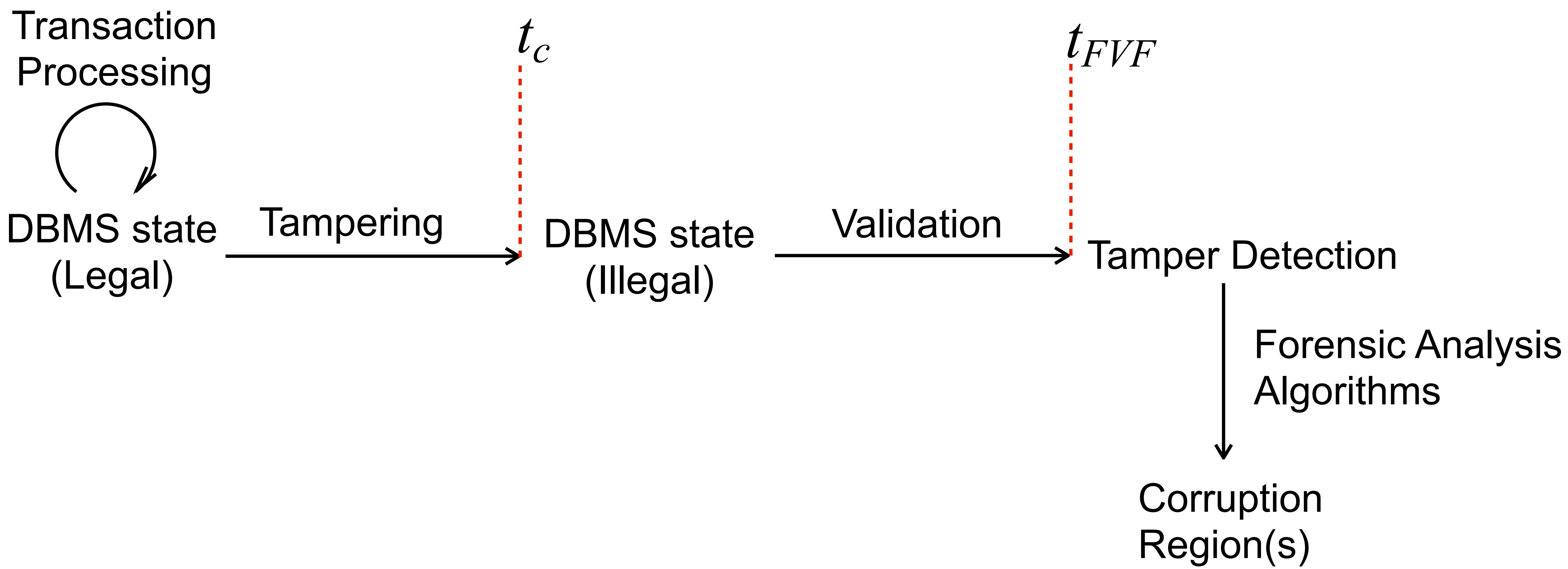
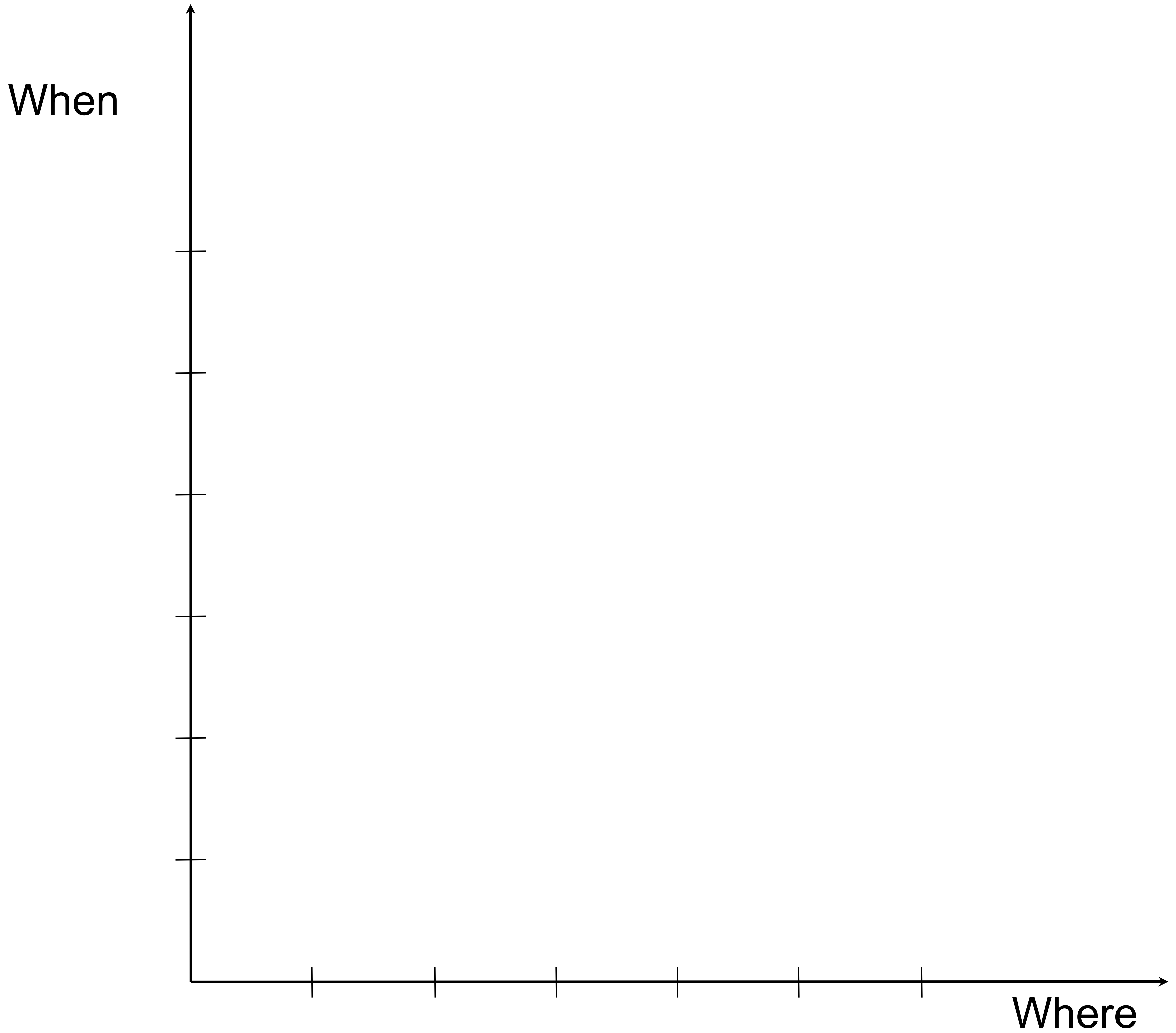
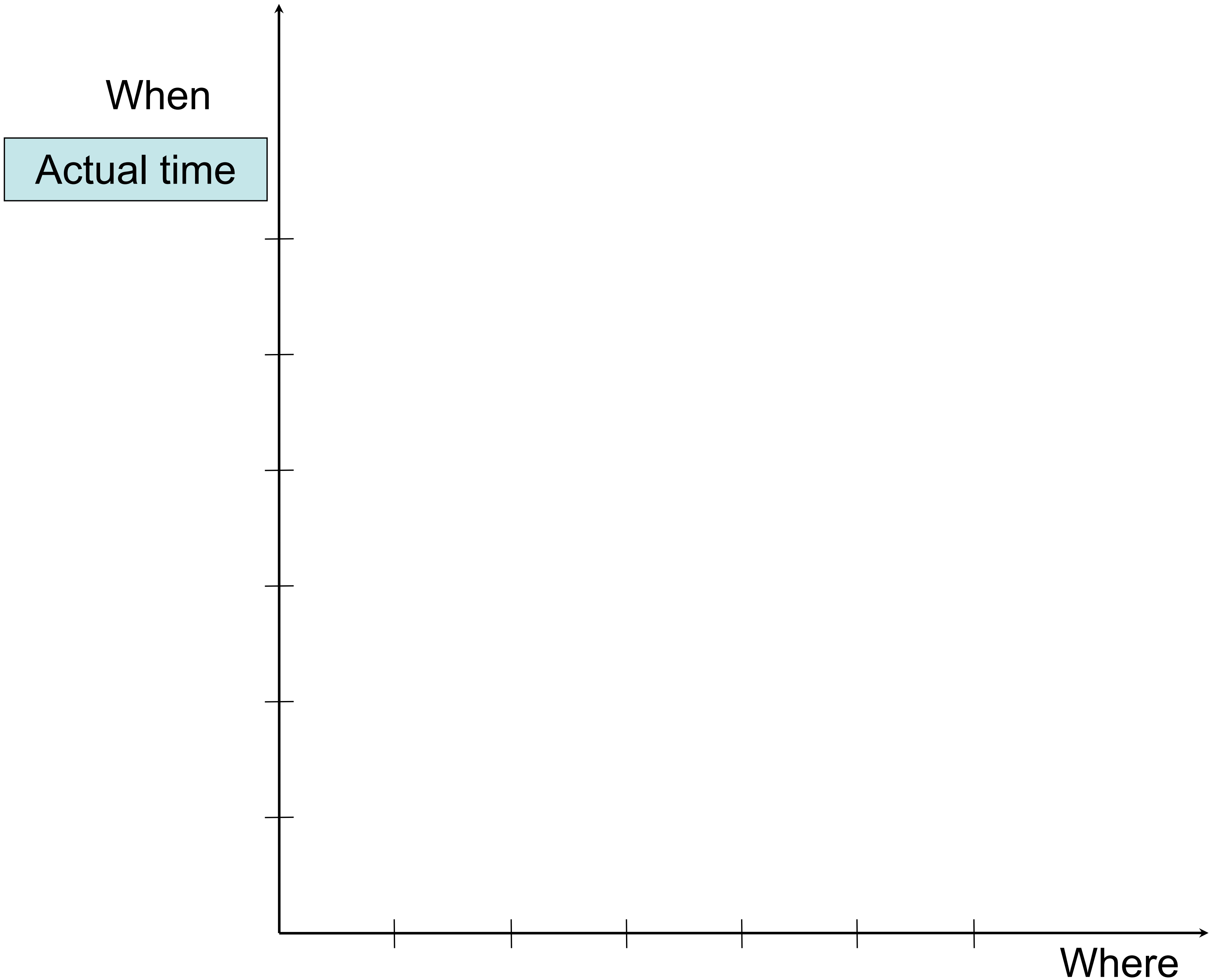


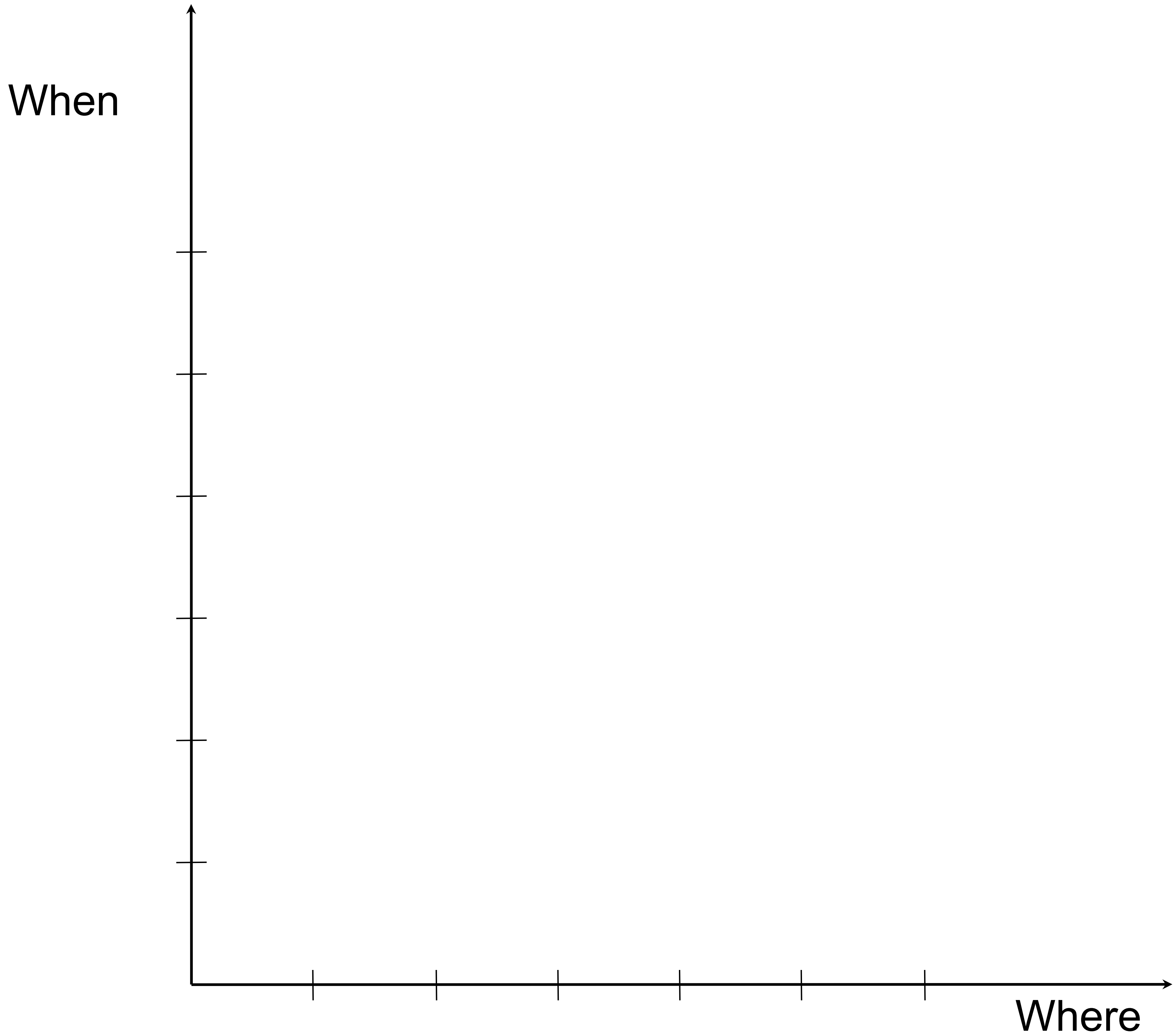
The Corruption Diagram



The Corruption Diagram



The Corruption Diagram



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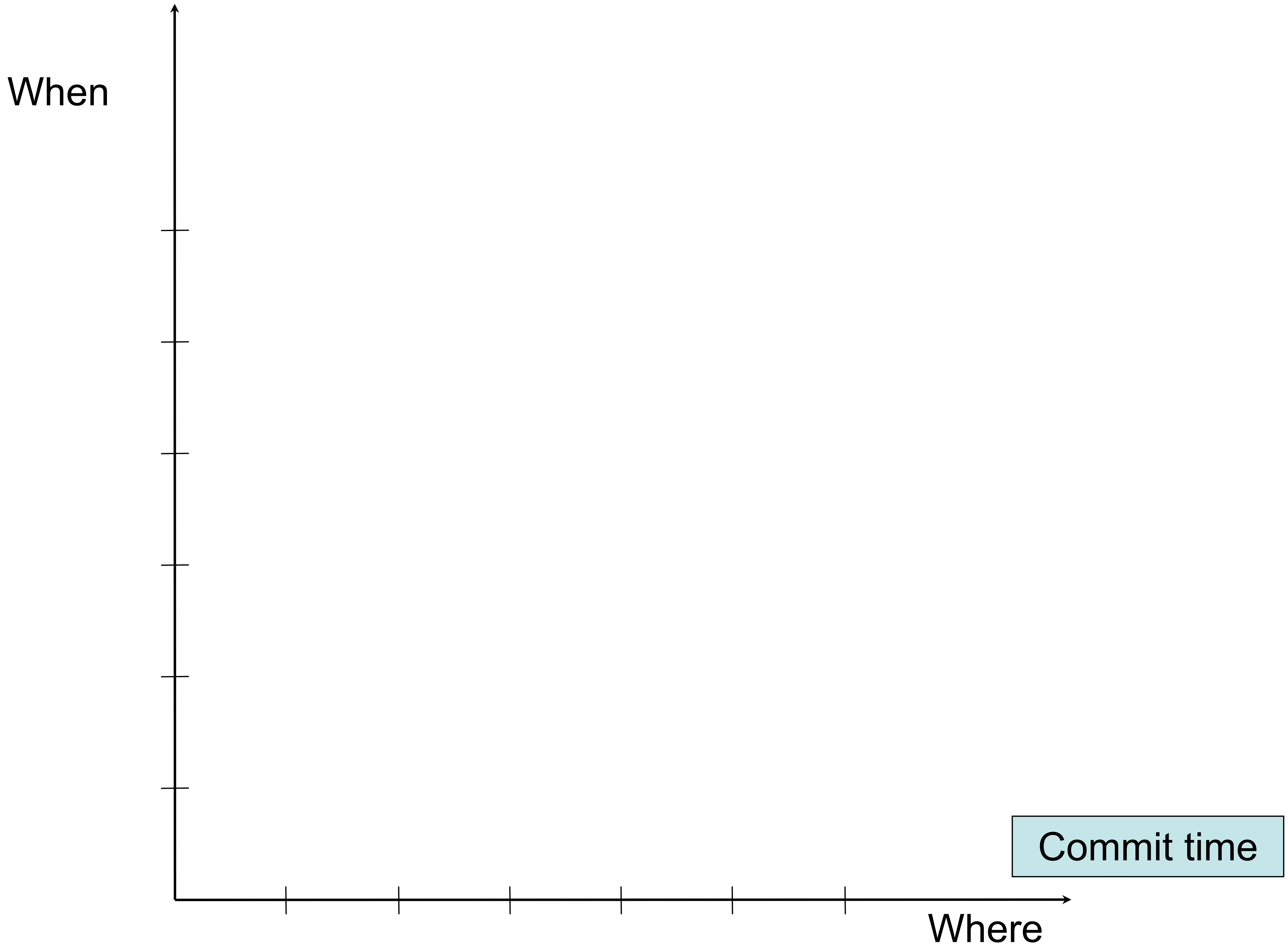

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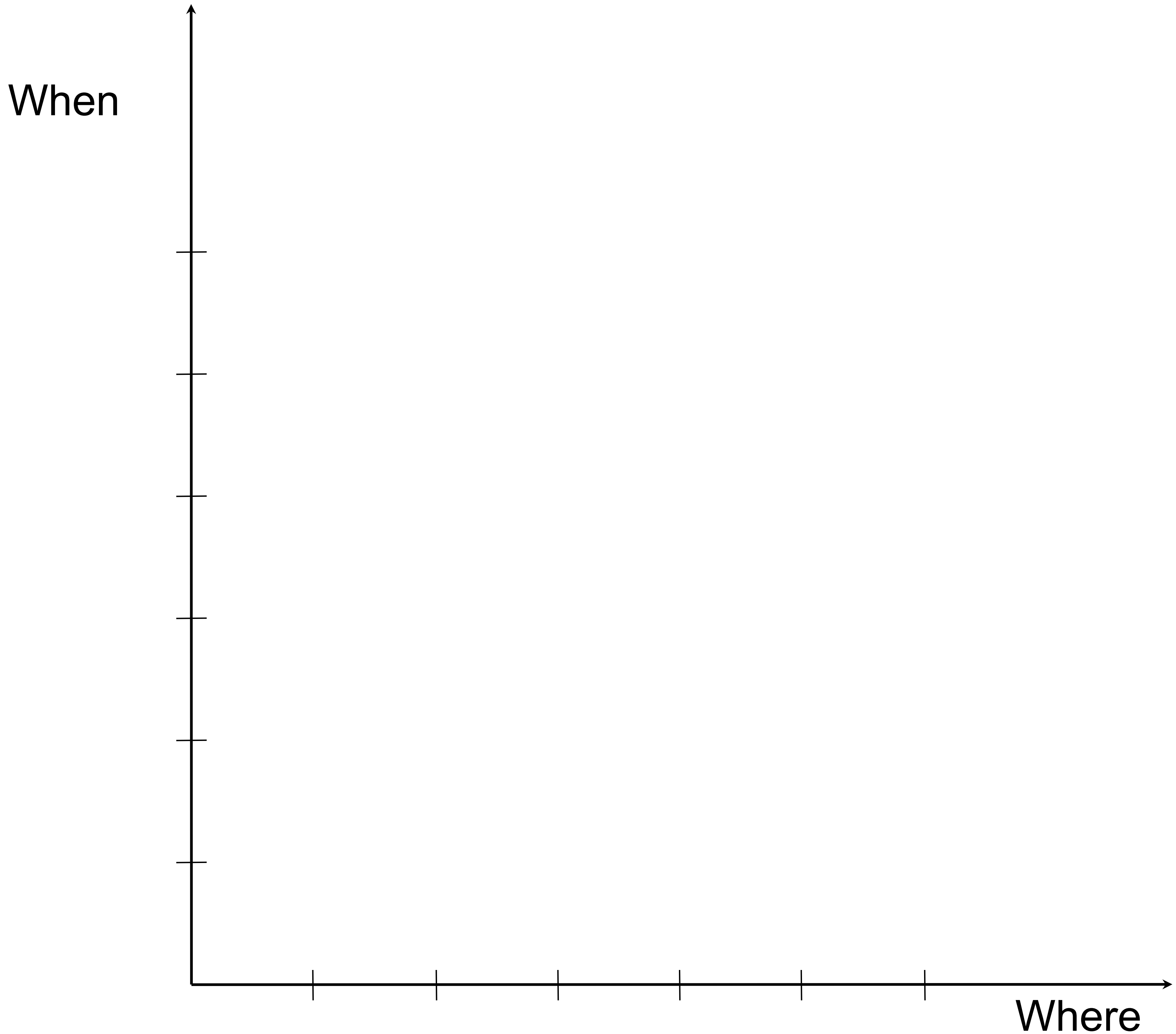

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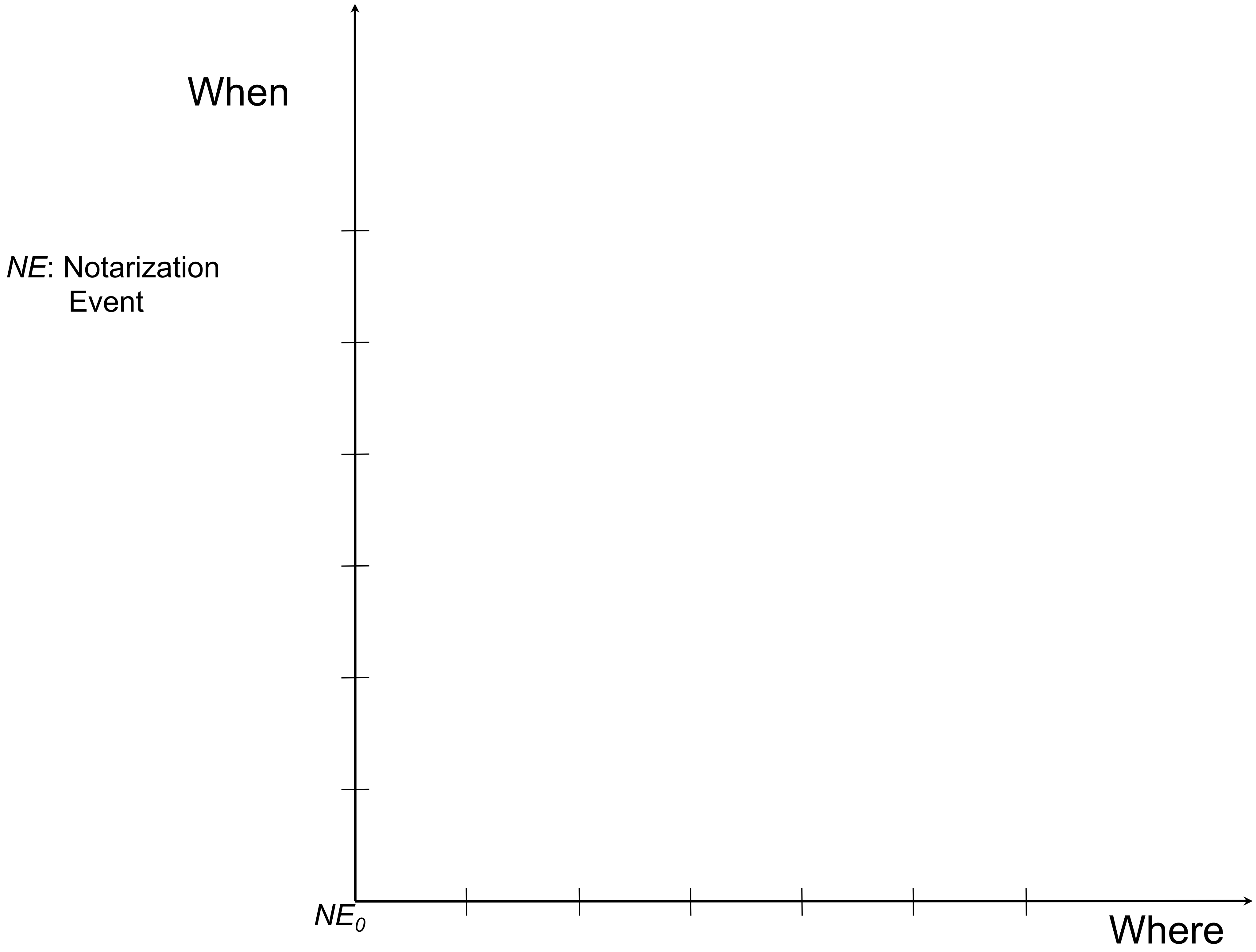

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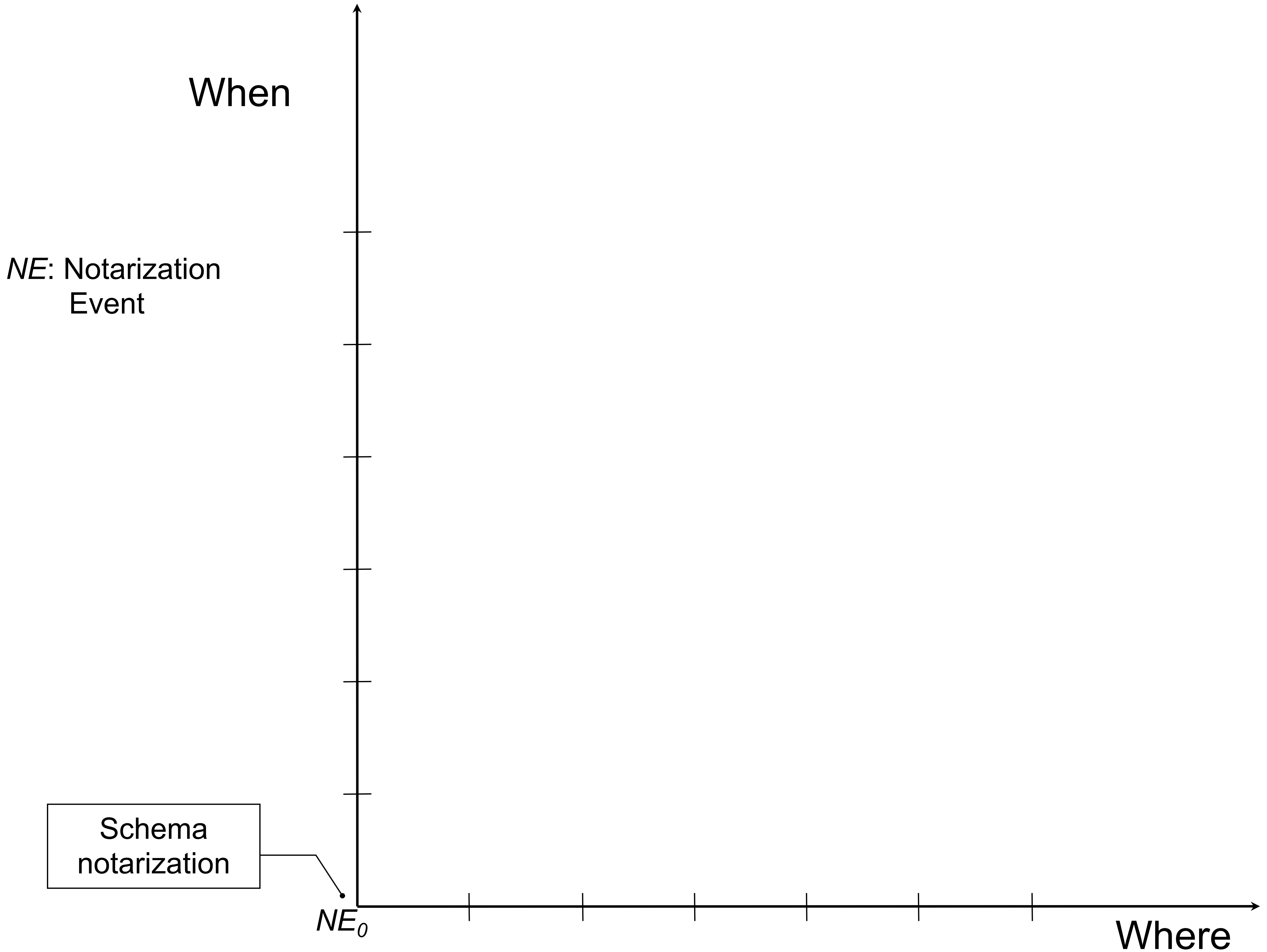

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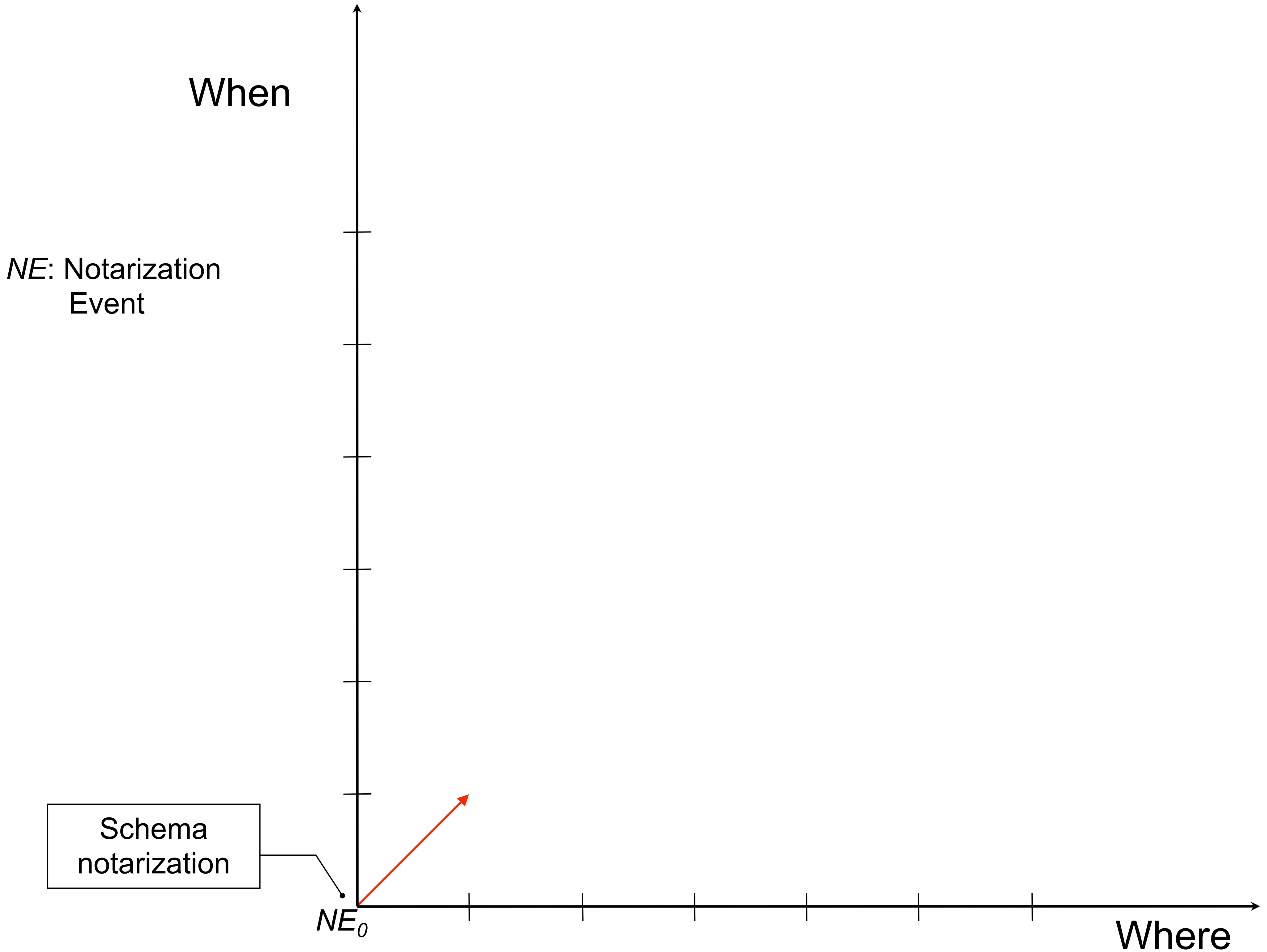

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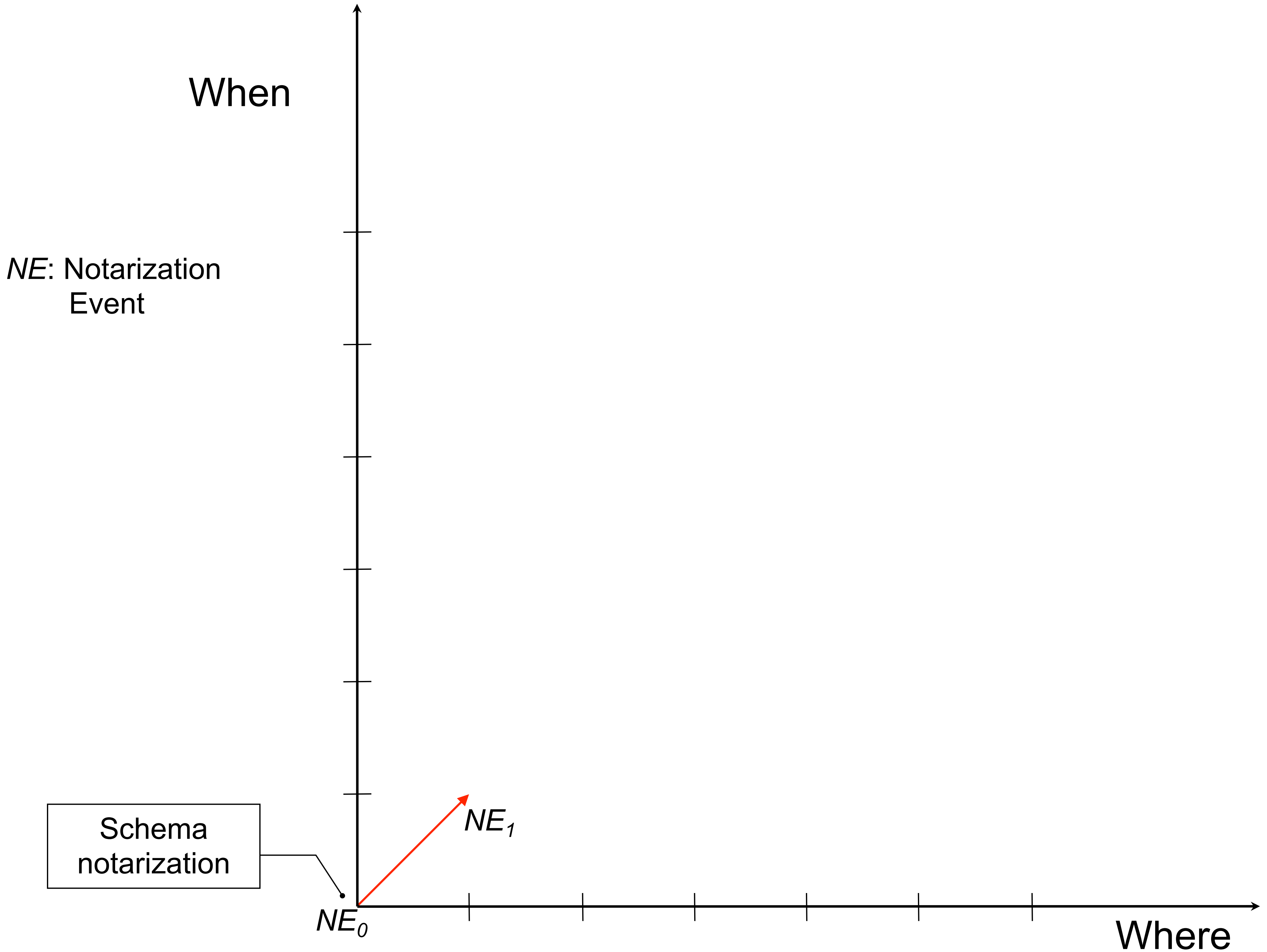

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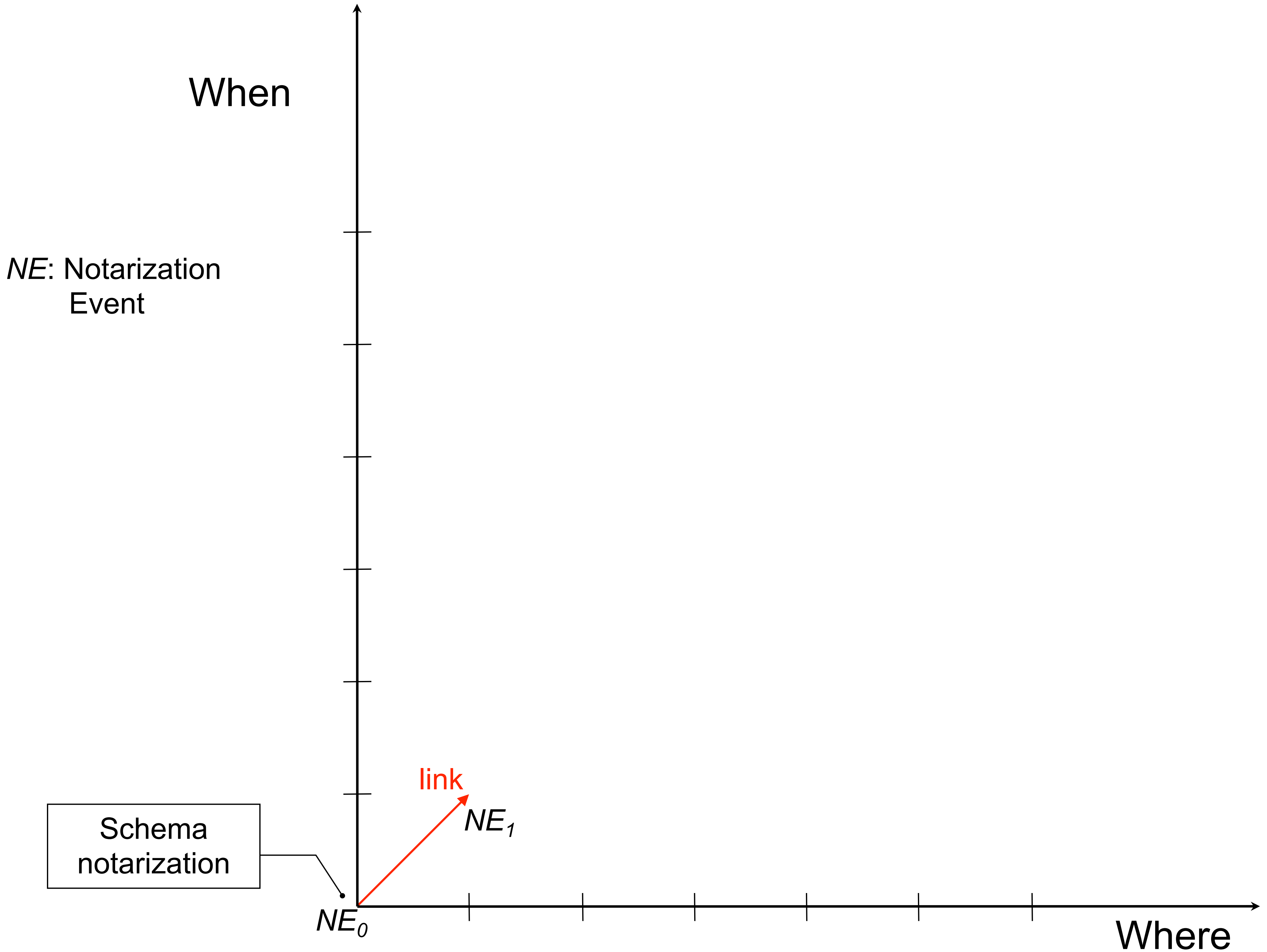

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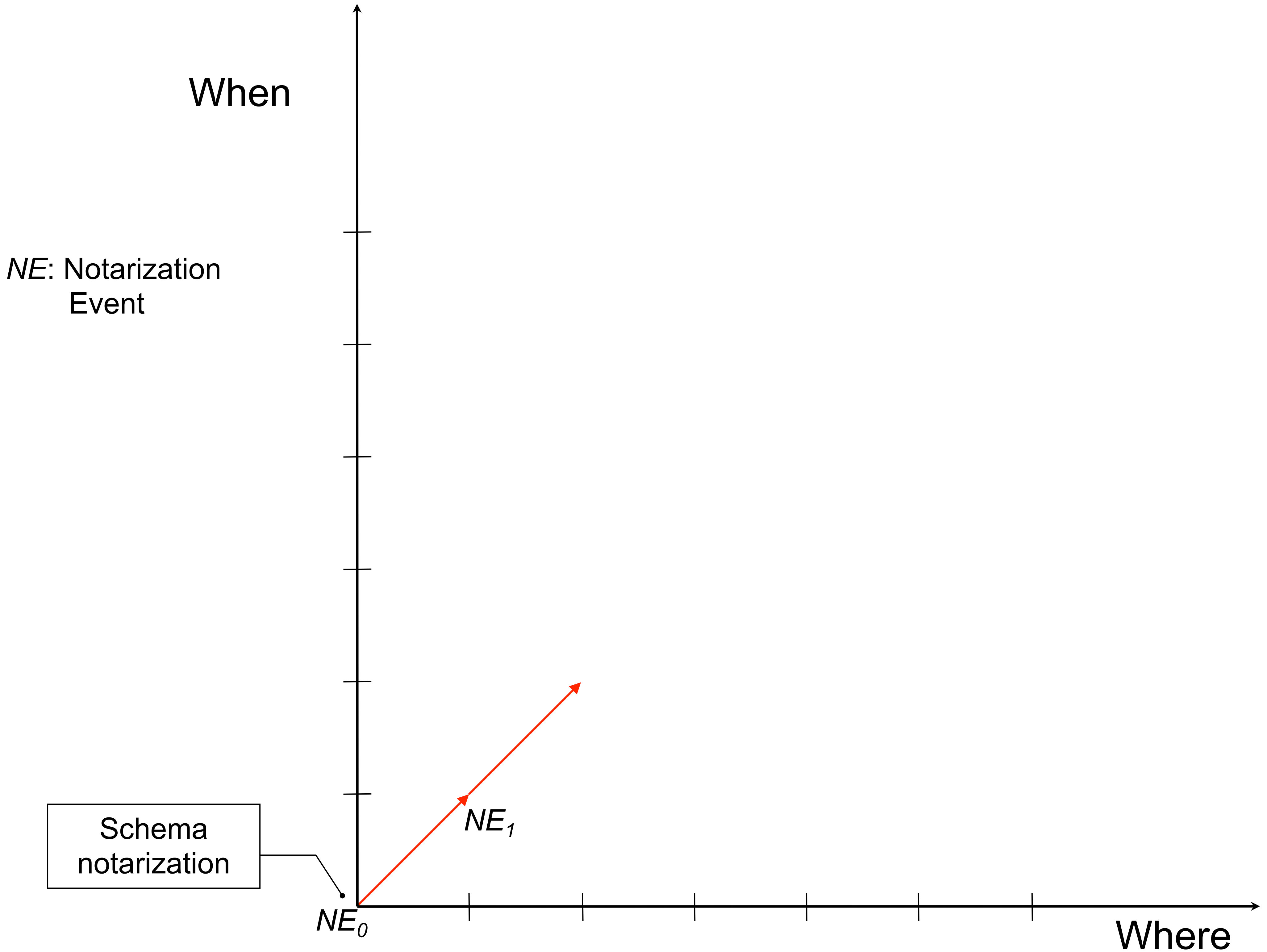

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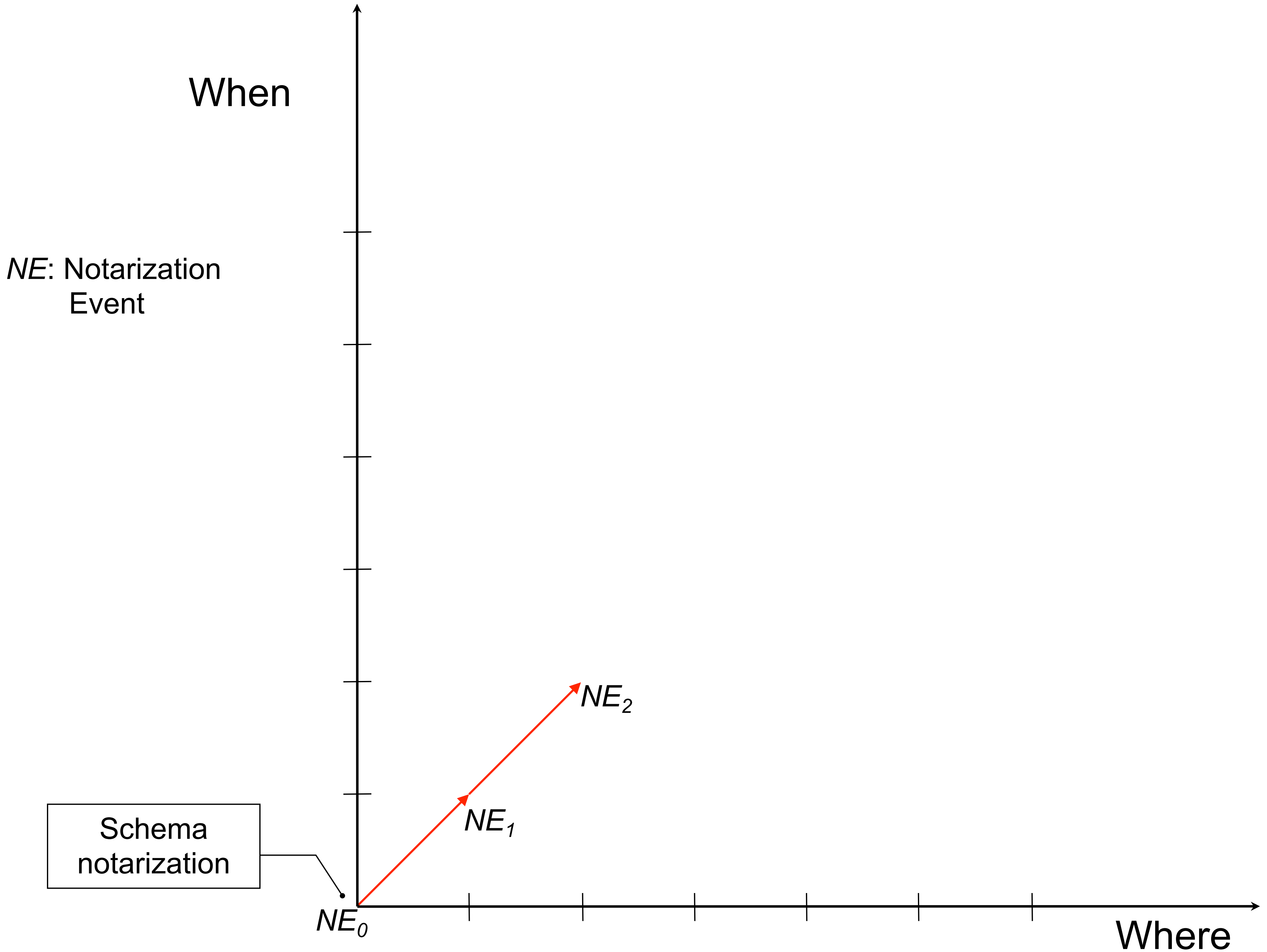

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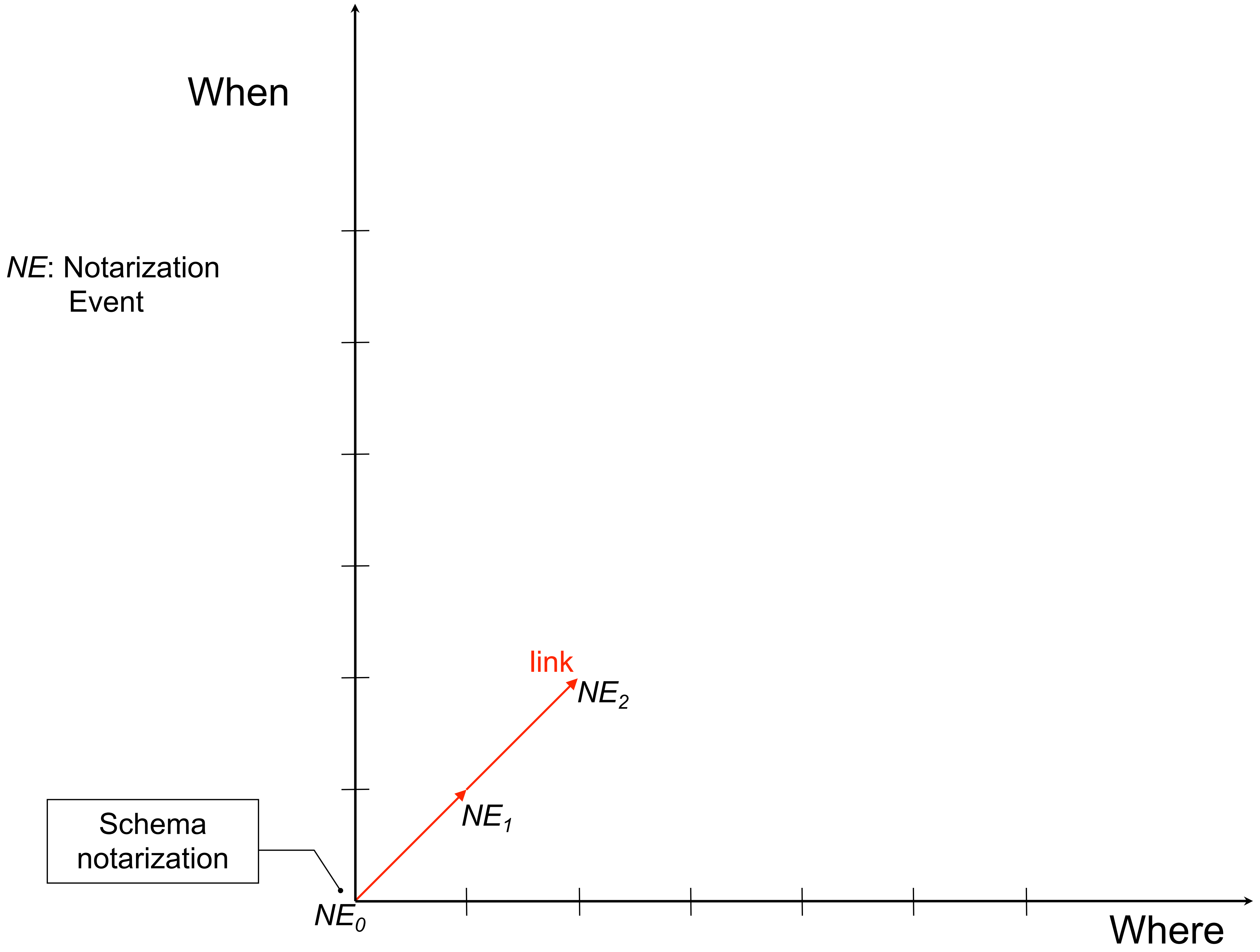

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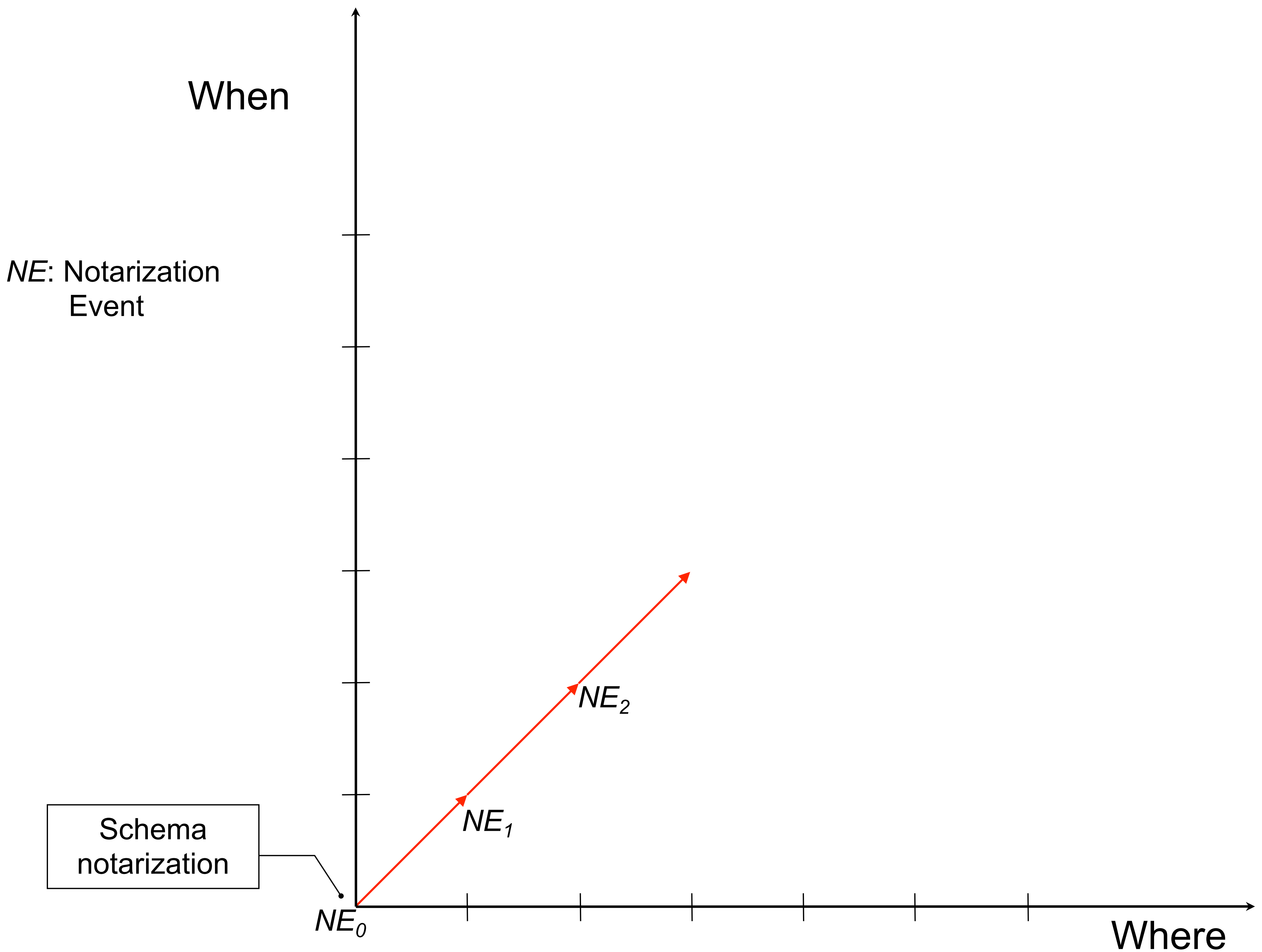

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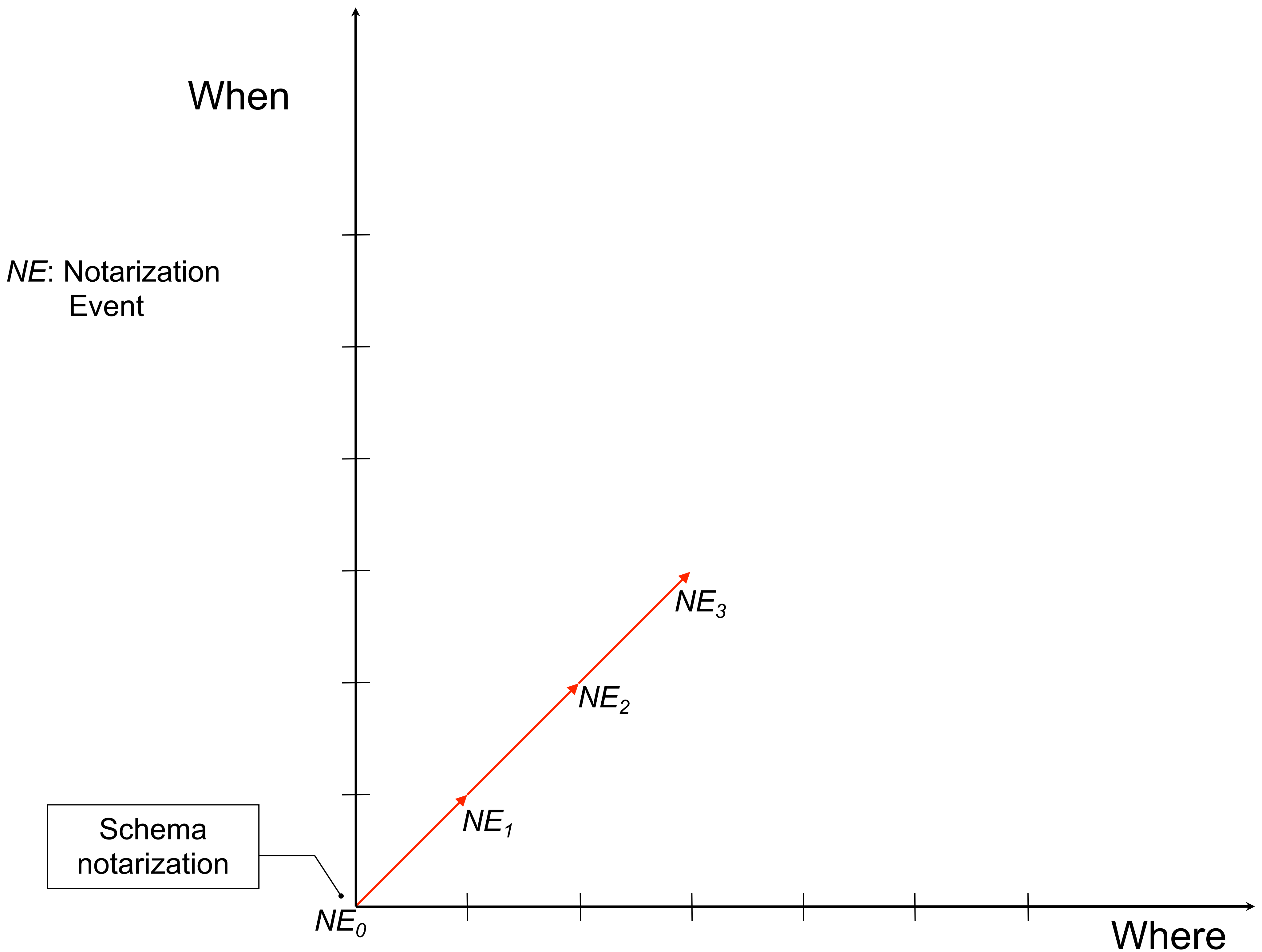

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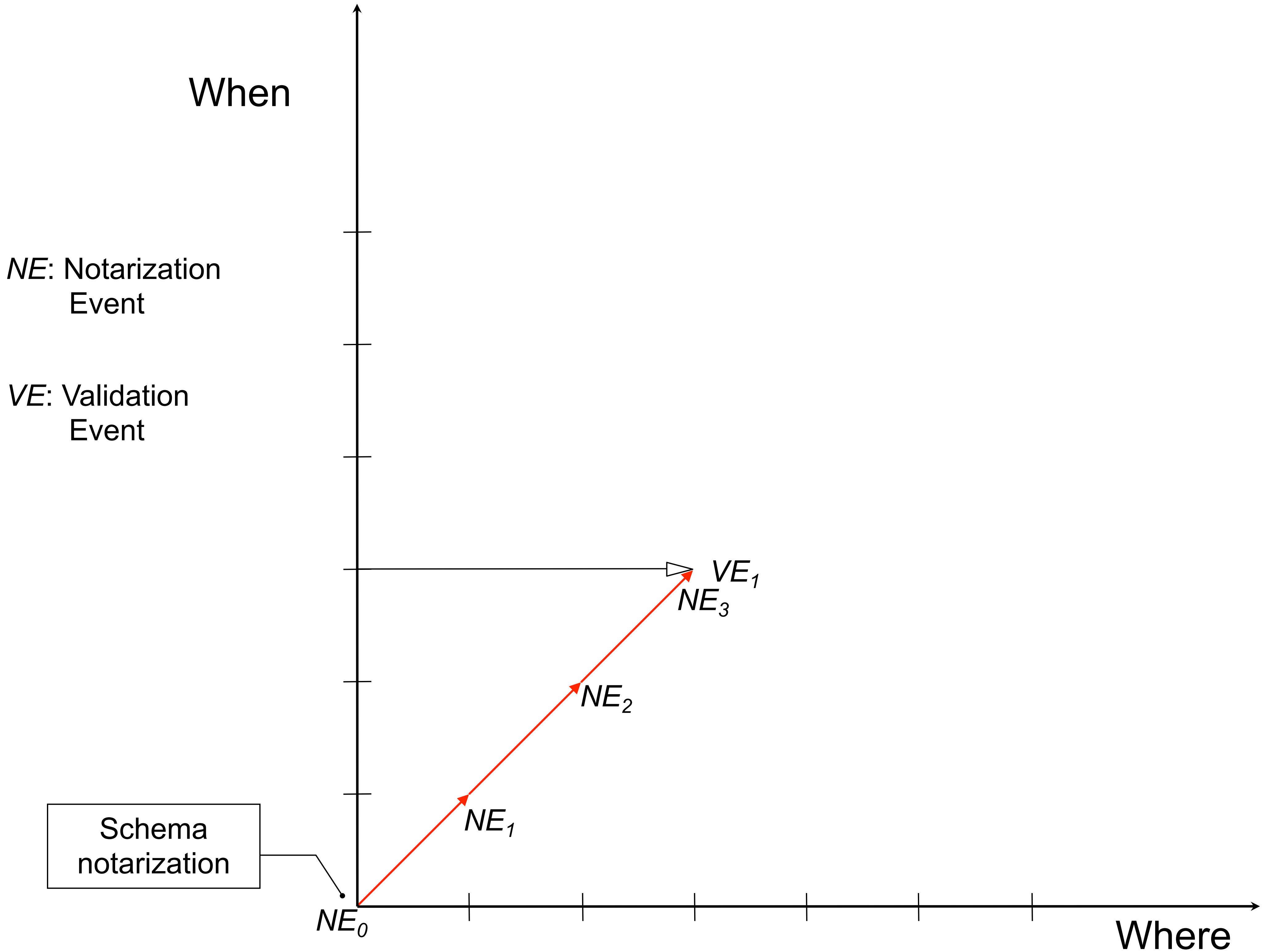

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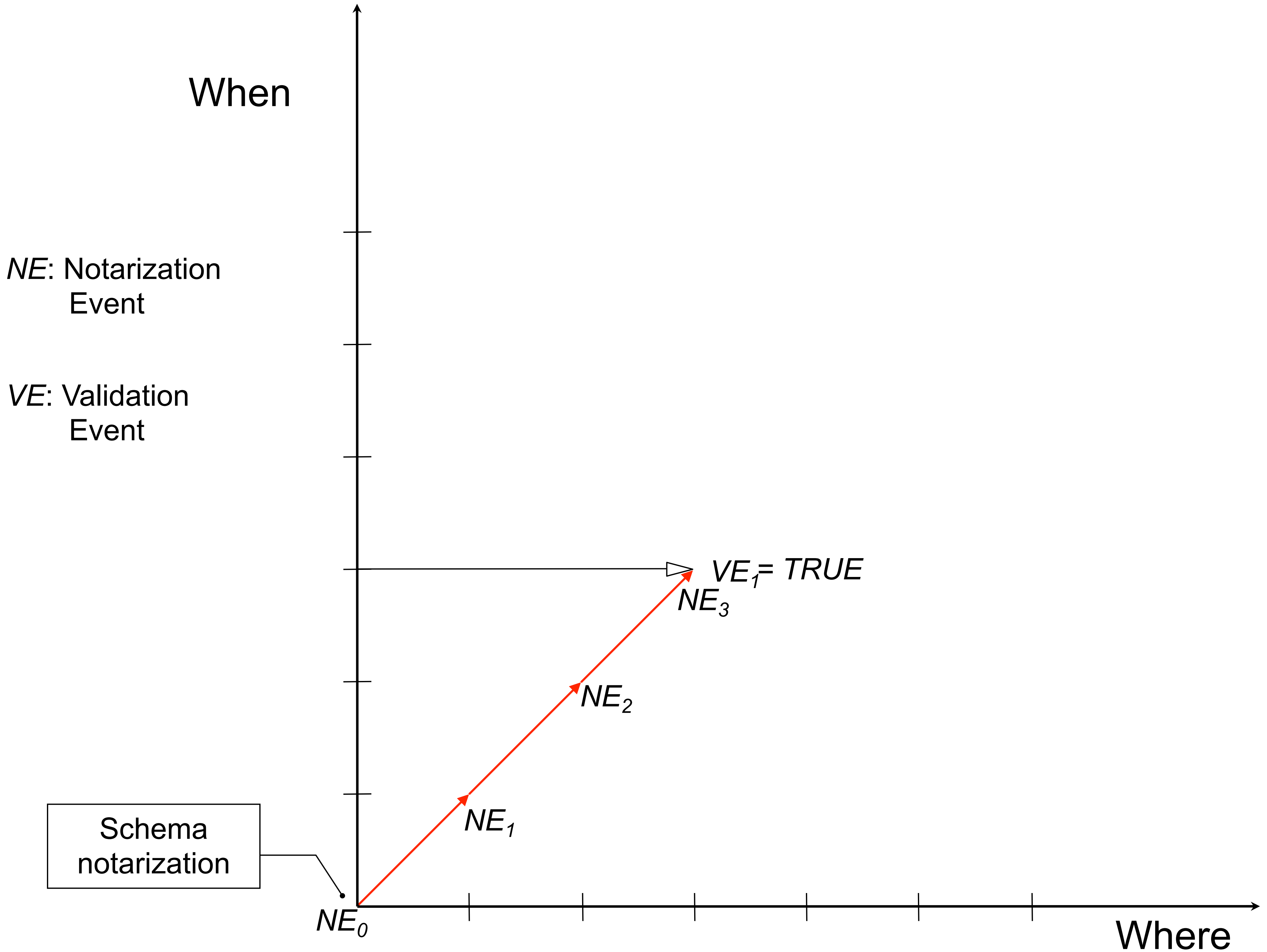

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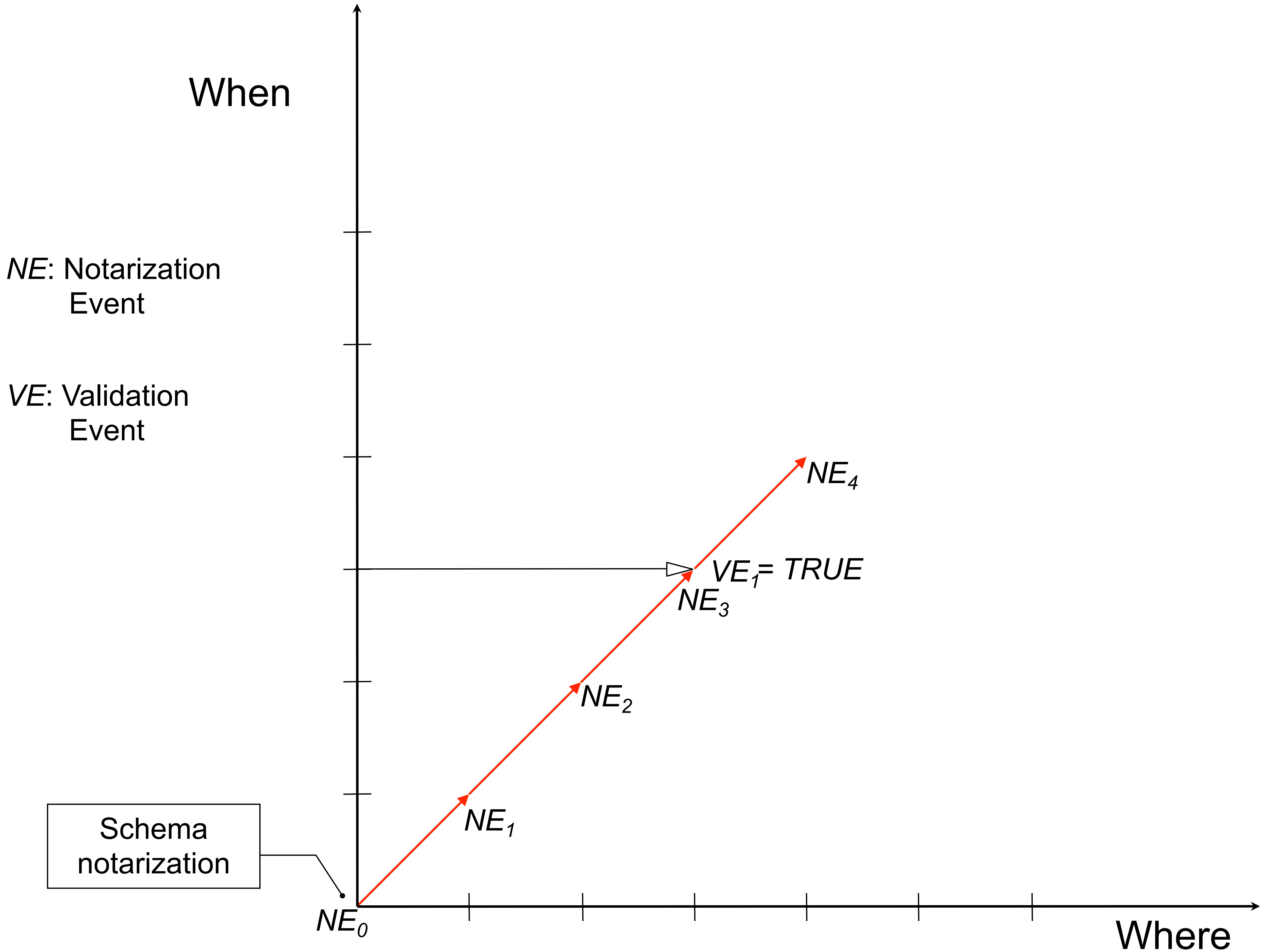

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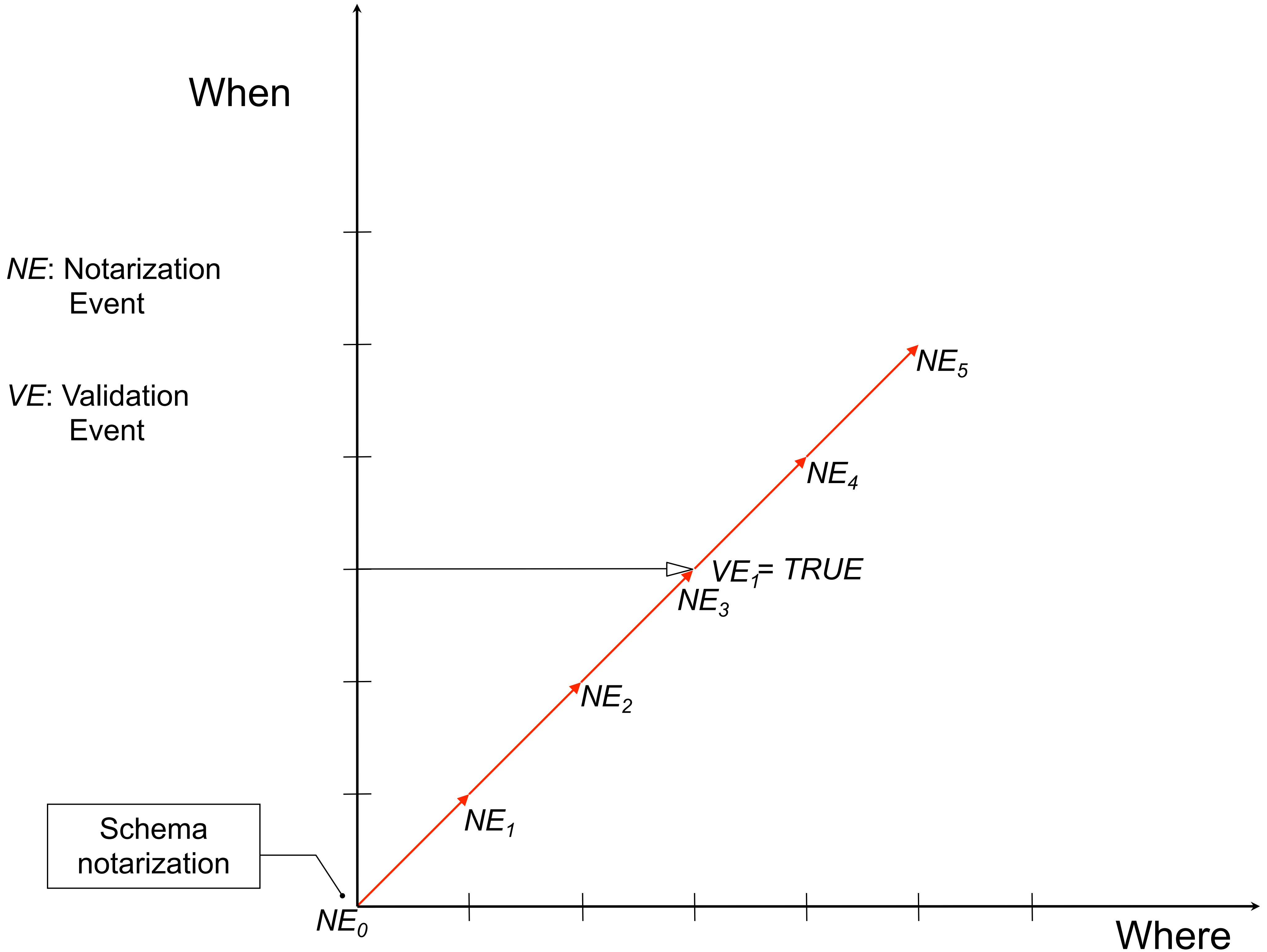

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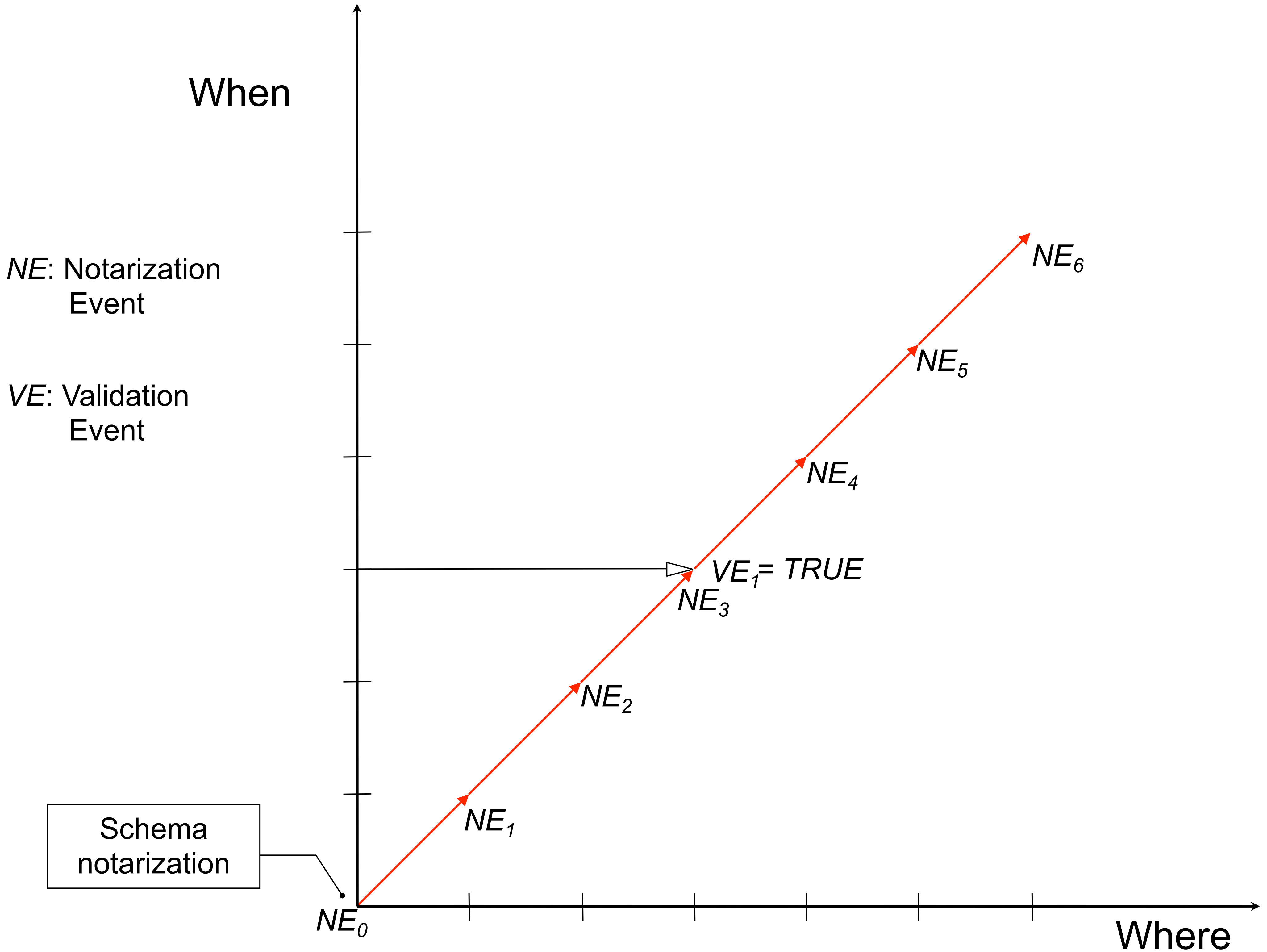

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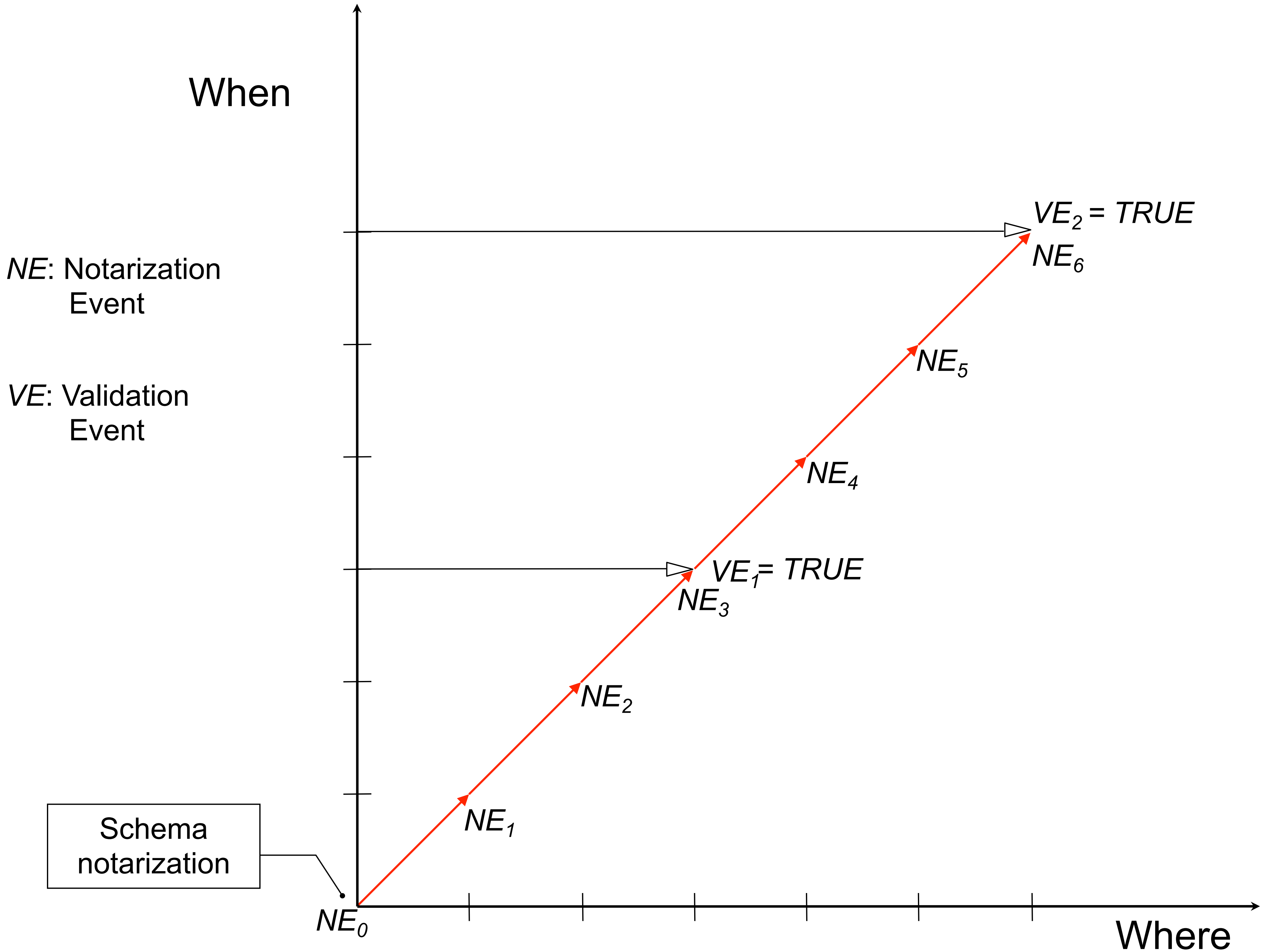

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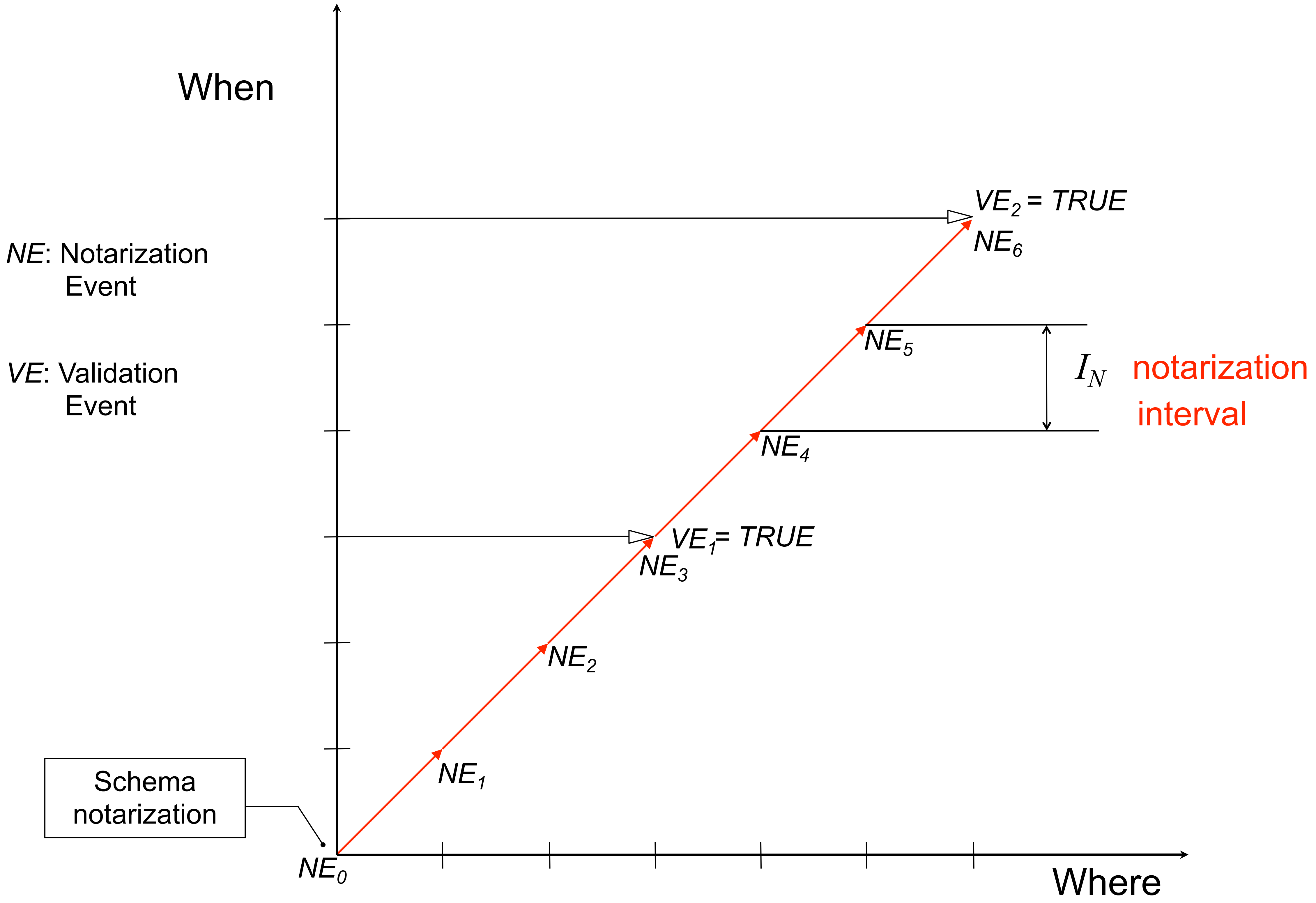

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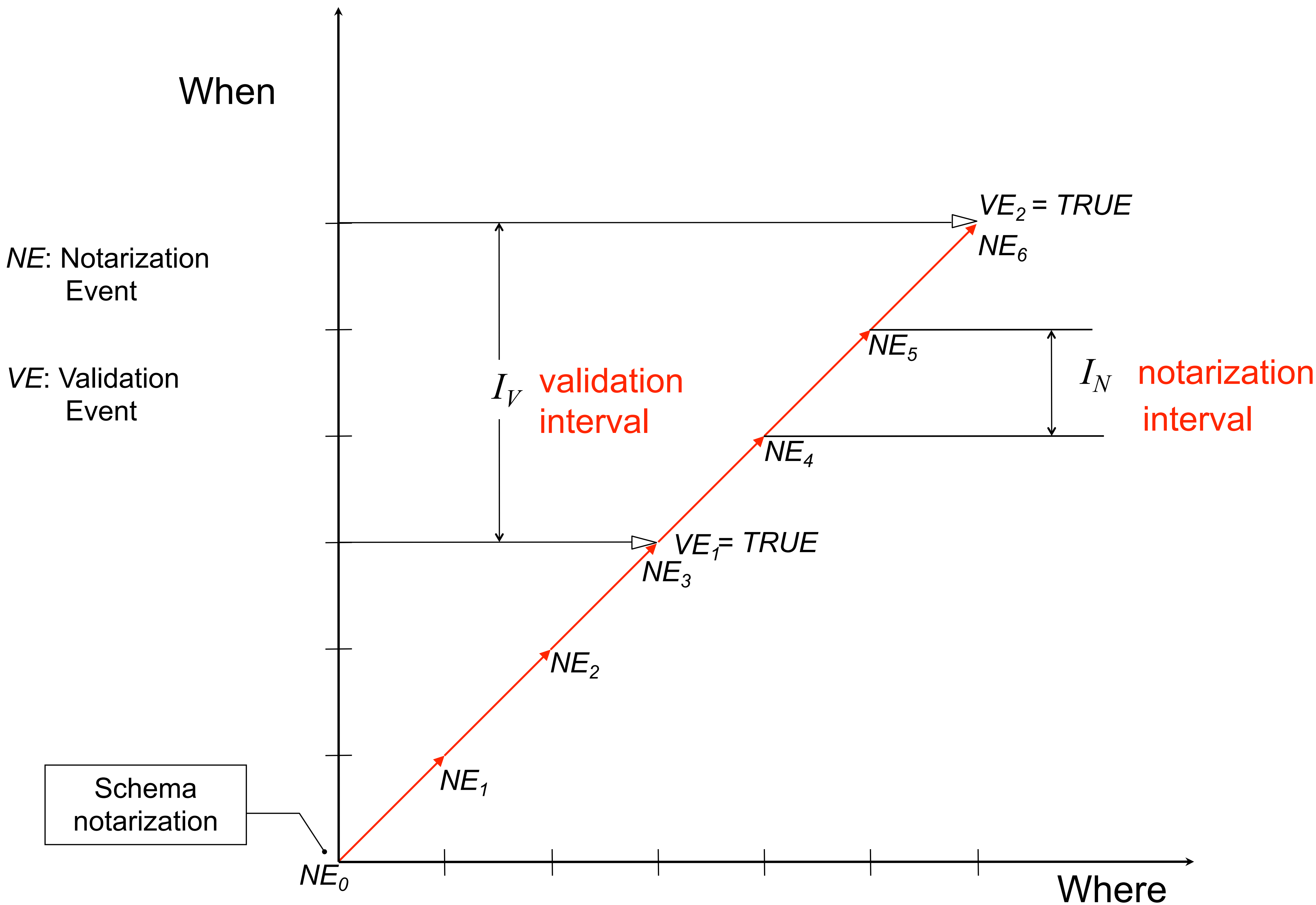

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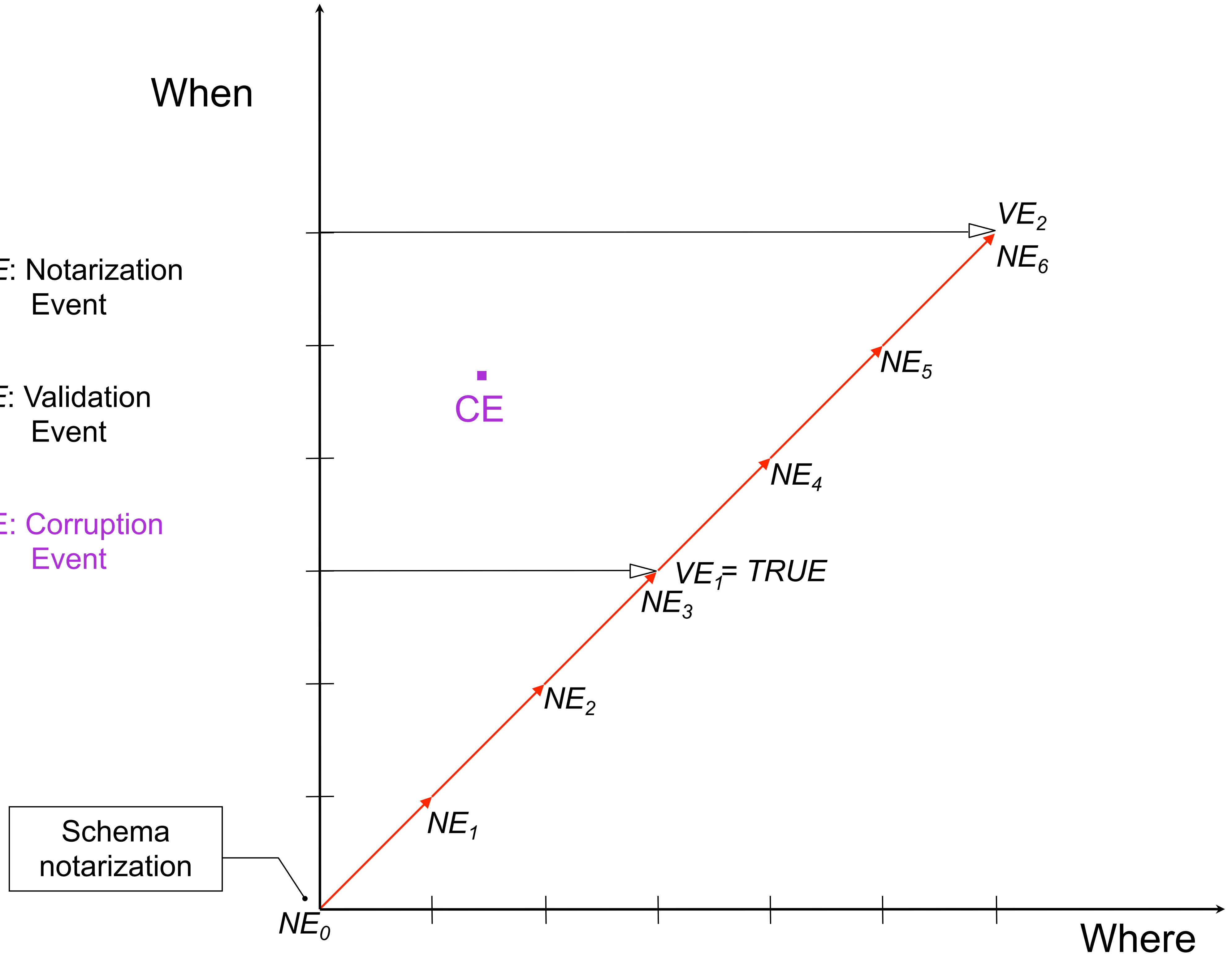
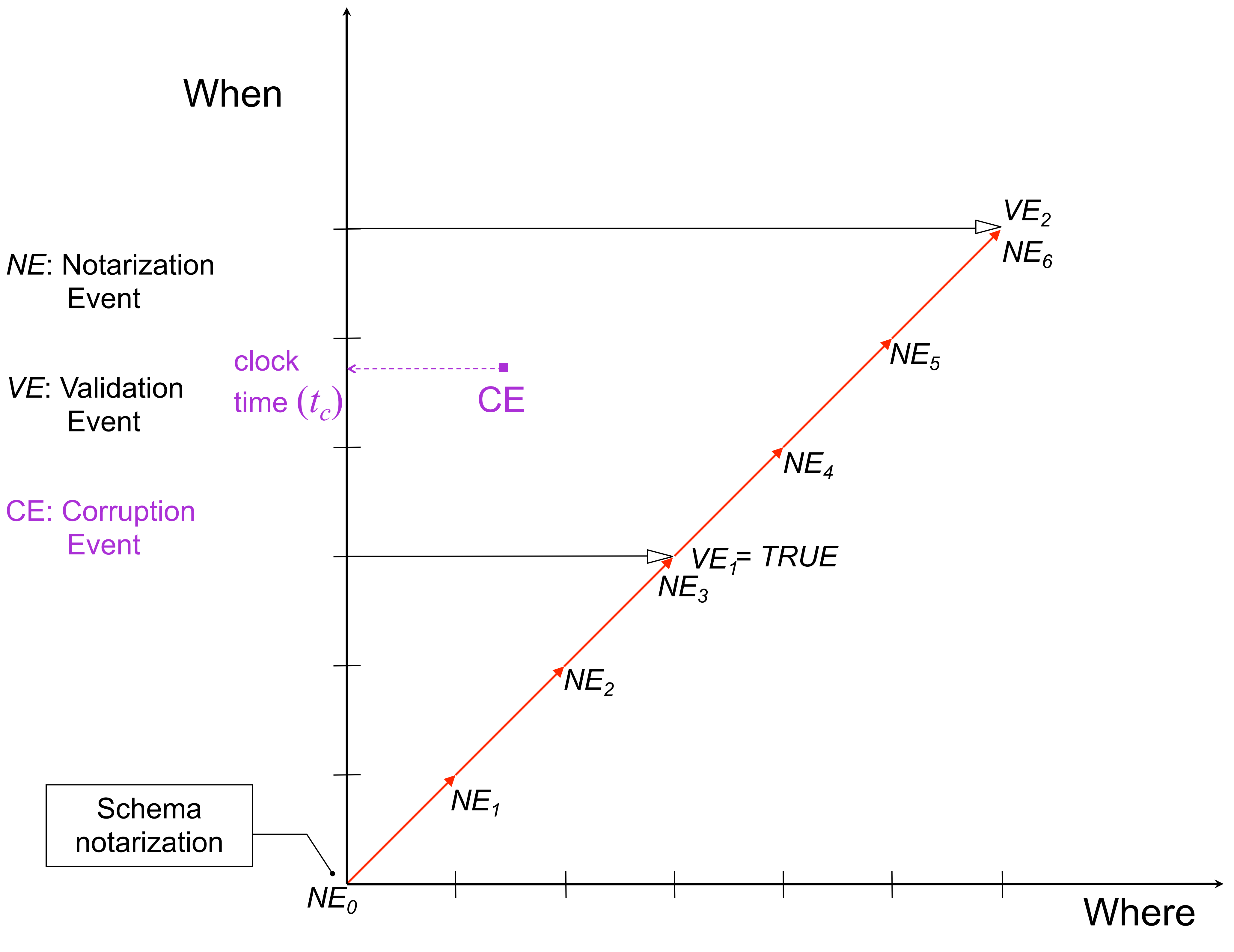


NE: Notarization Event

VE: Validation Event

CE: Corruption Event

The Corruption Diagram



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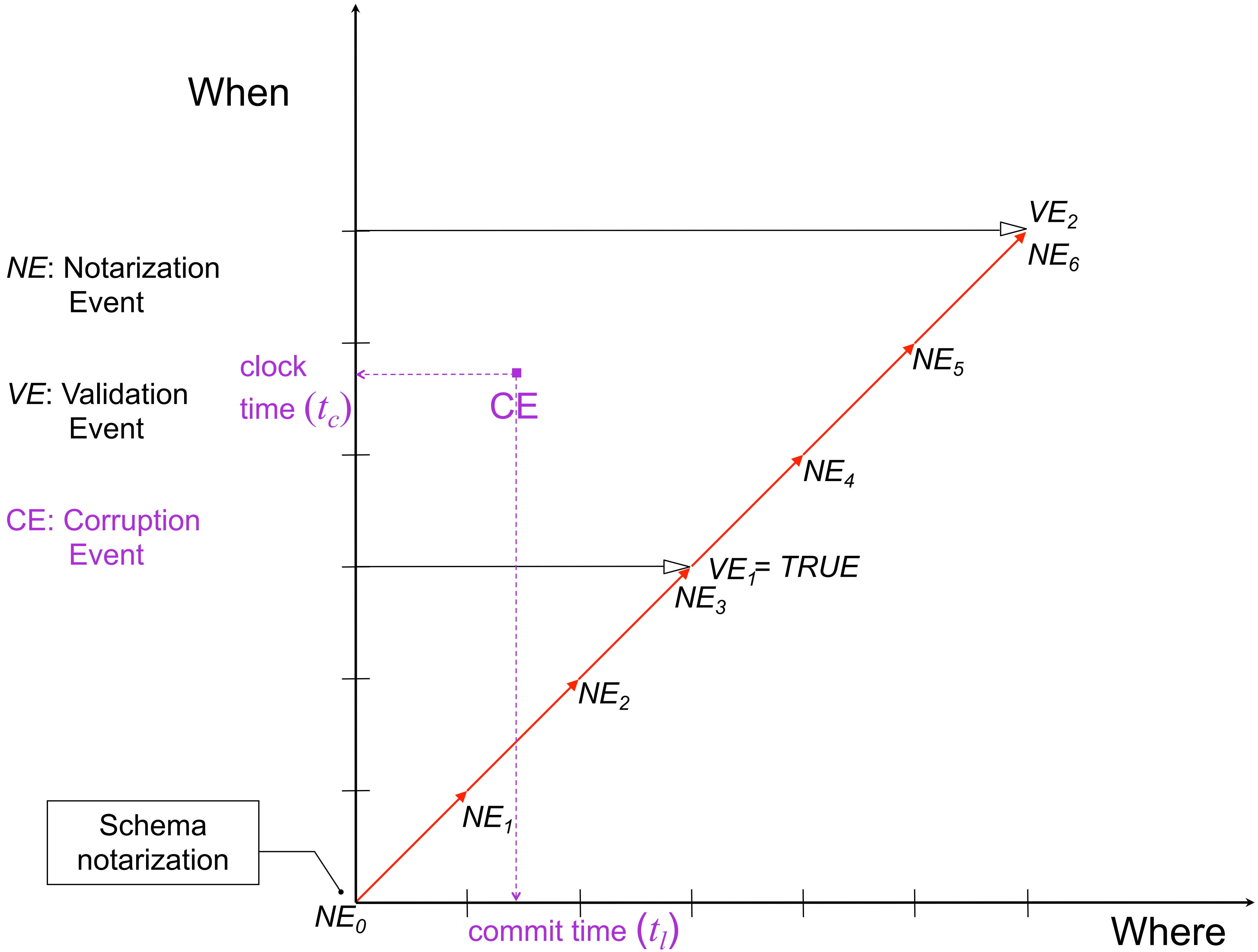
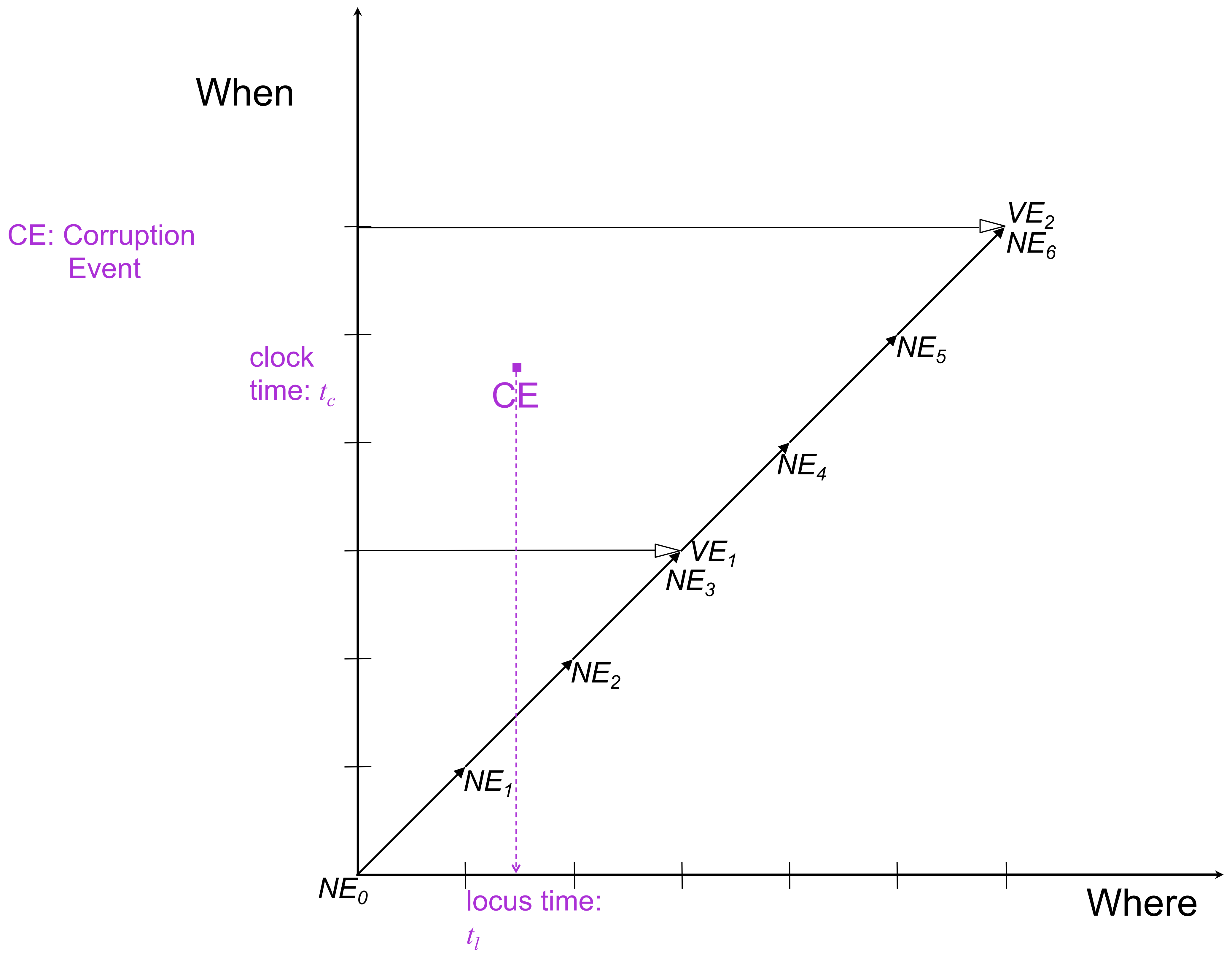


Types of Corruption Events



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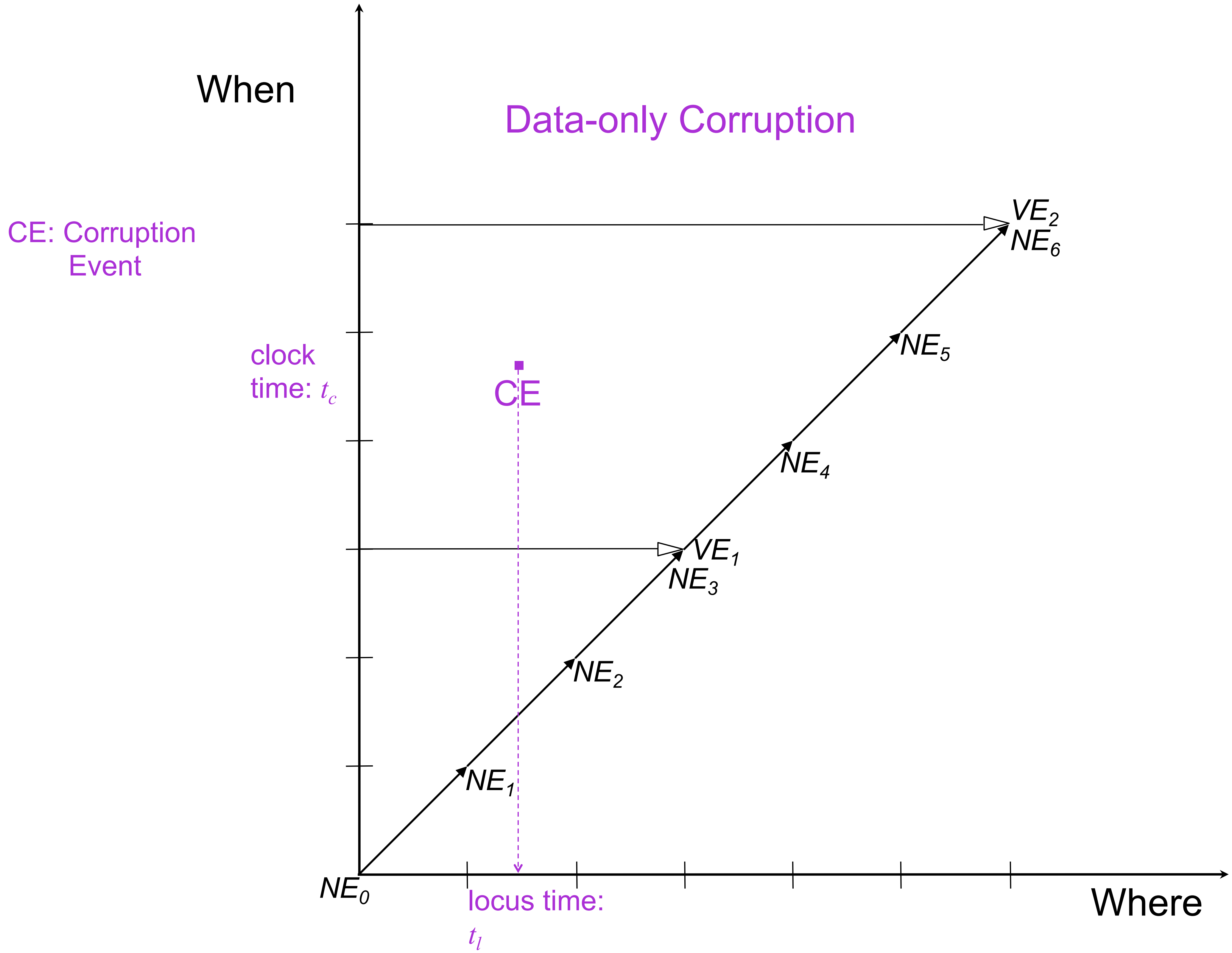

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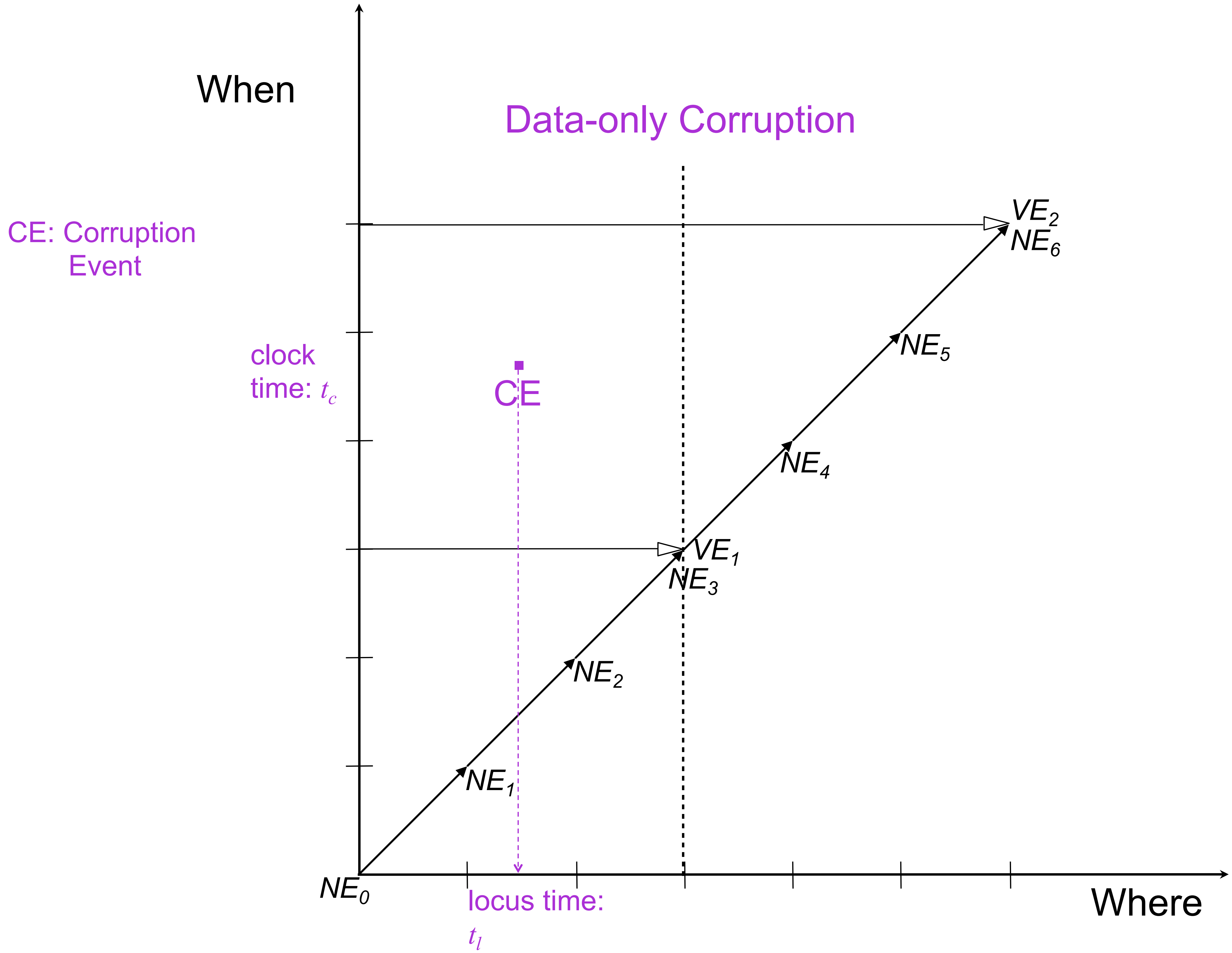

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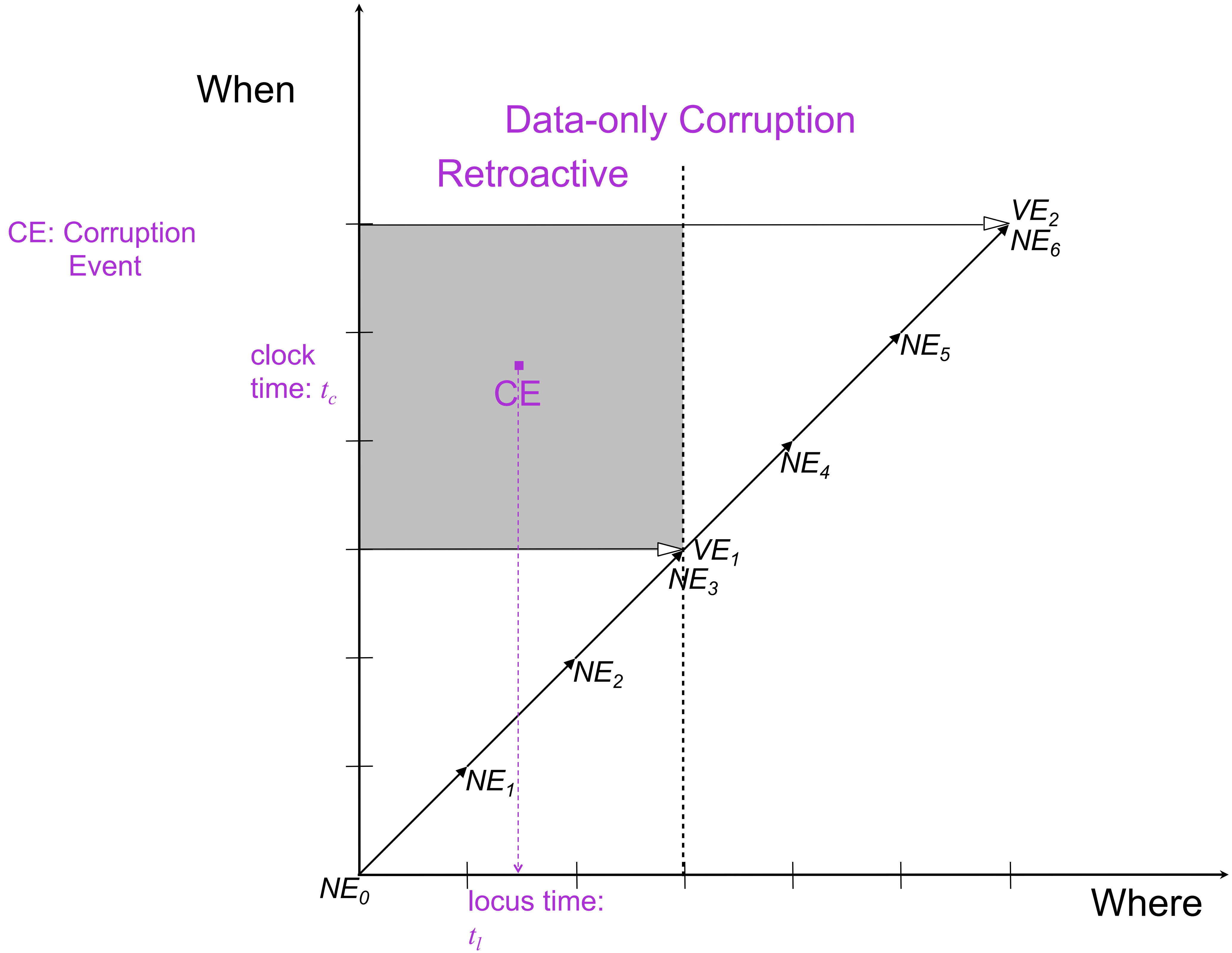

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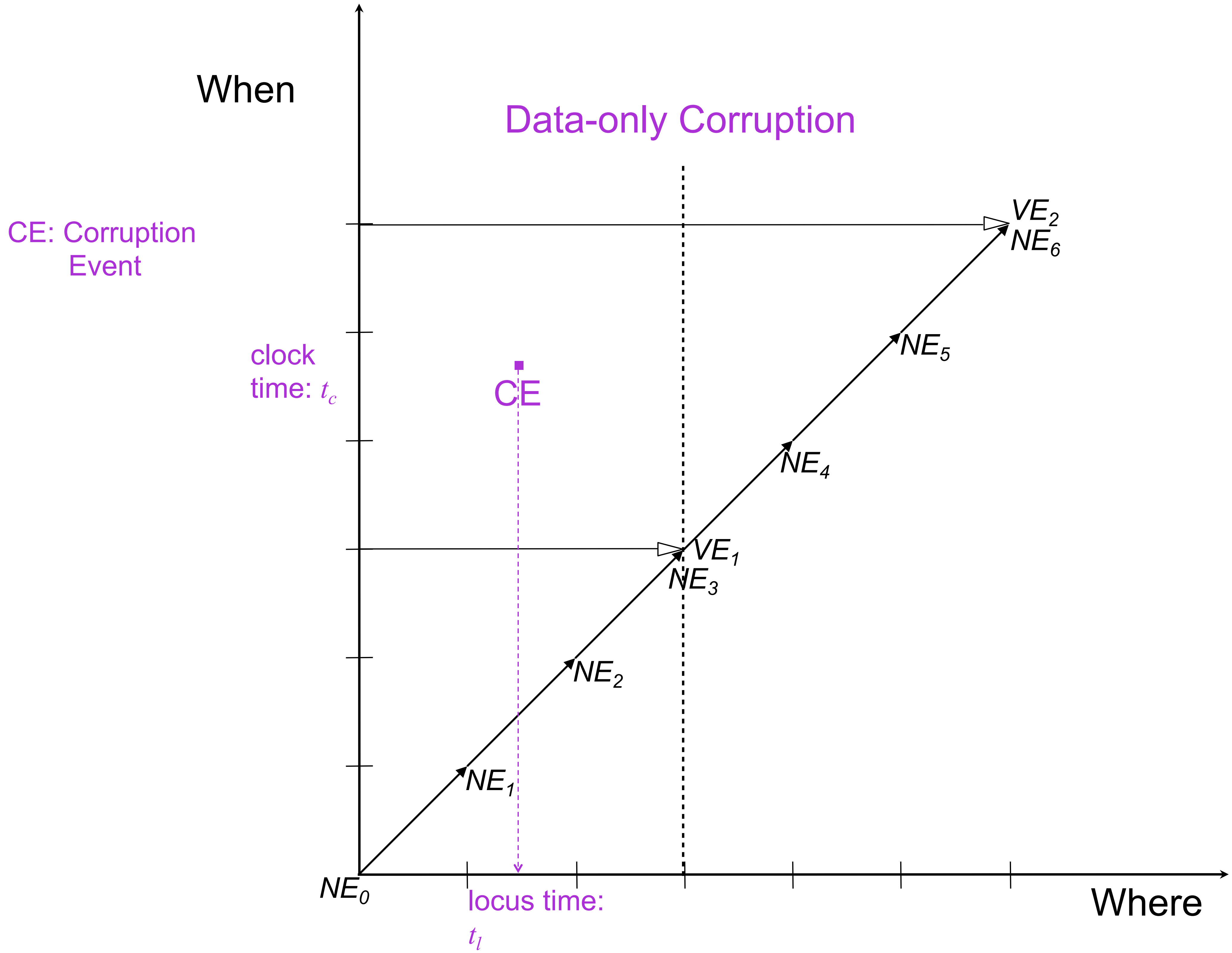

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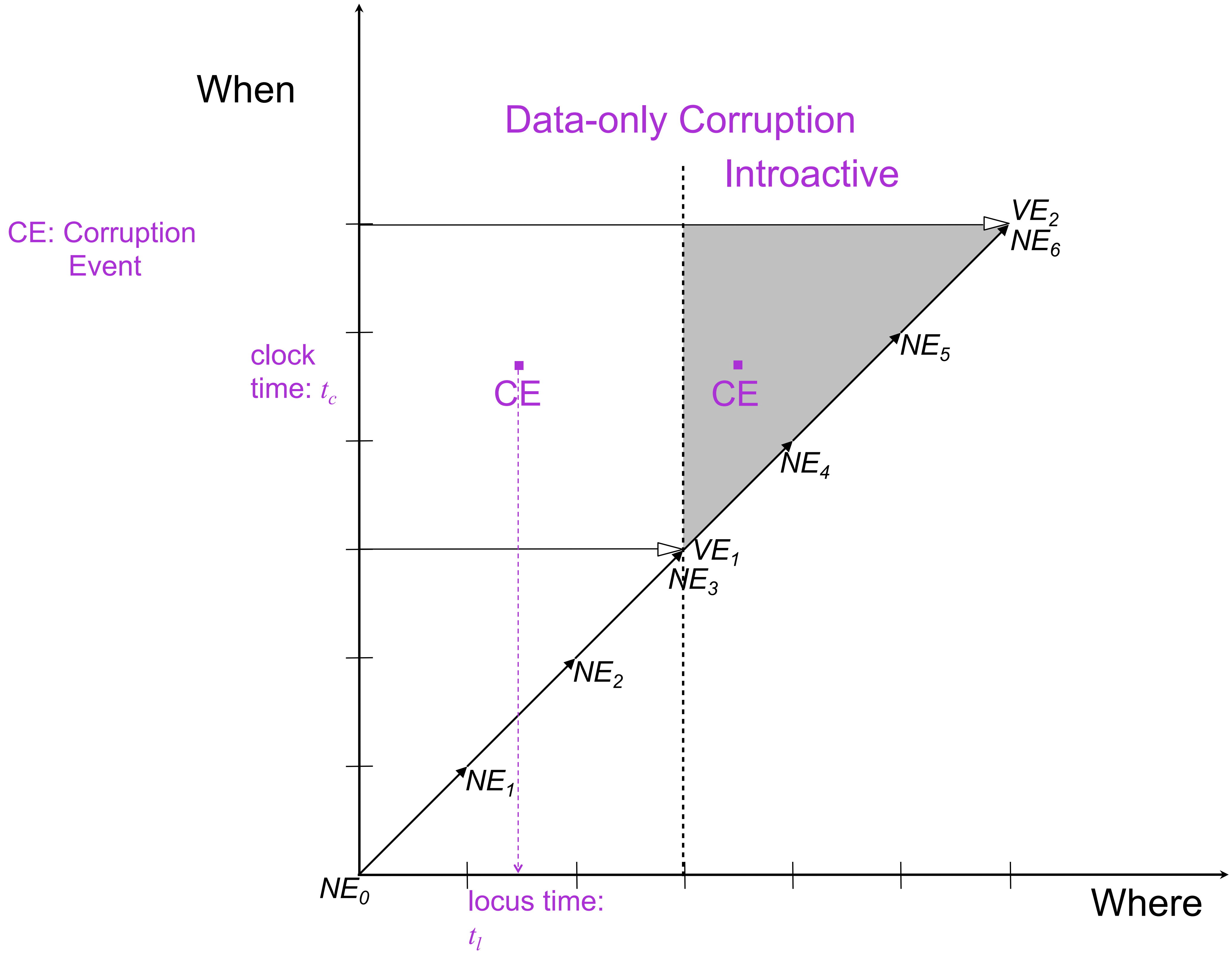
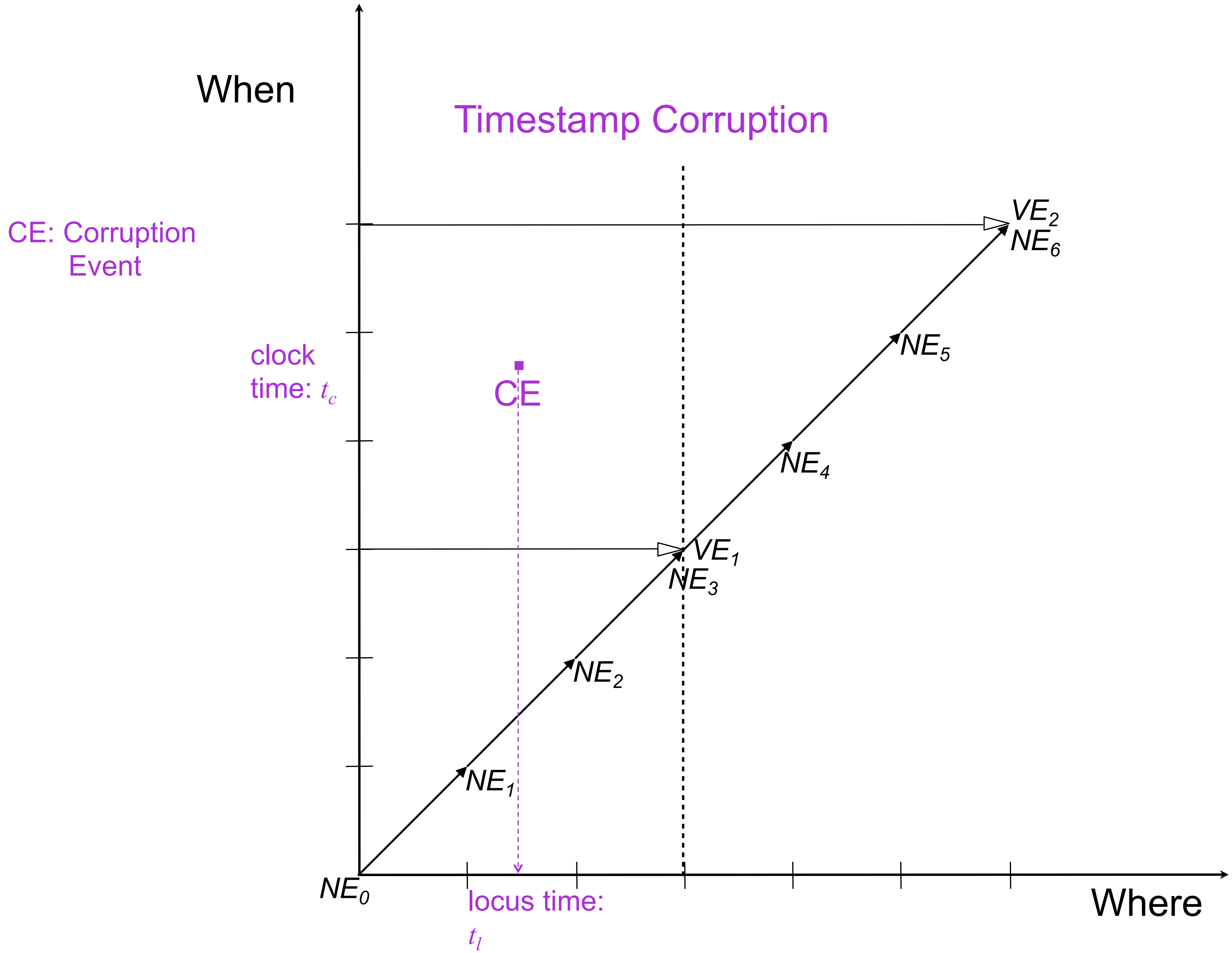
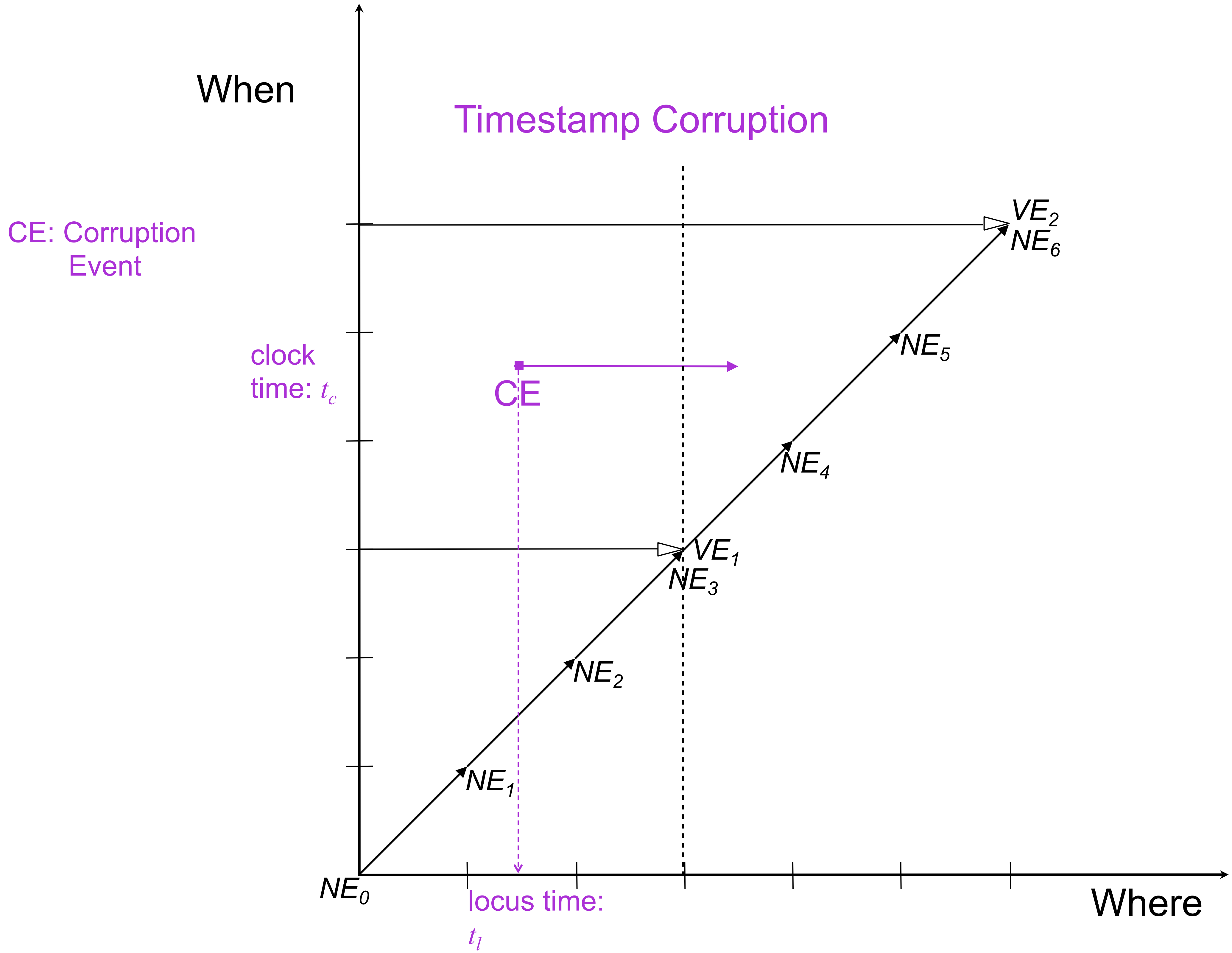


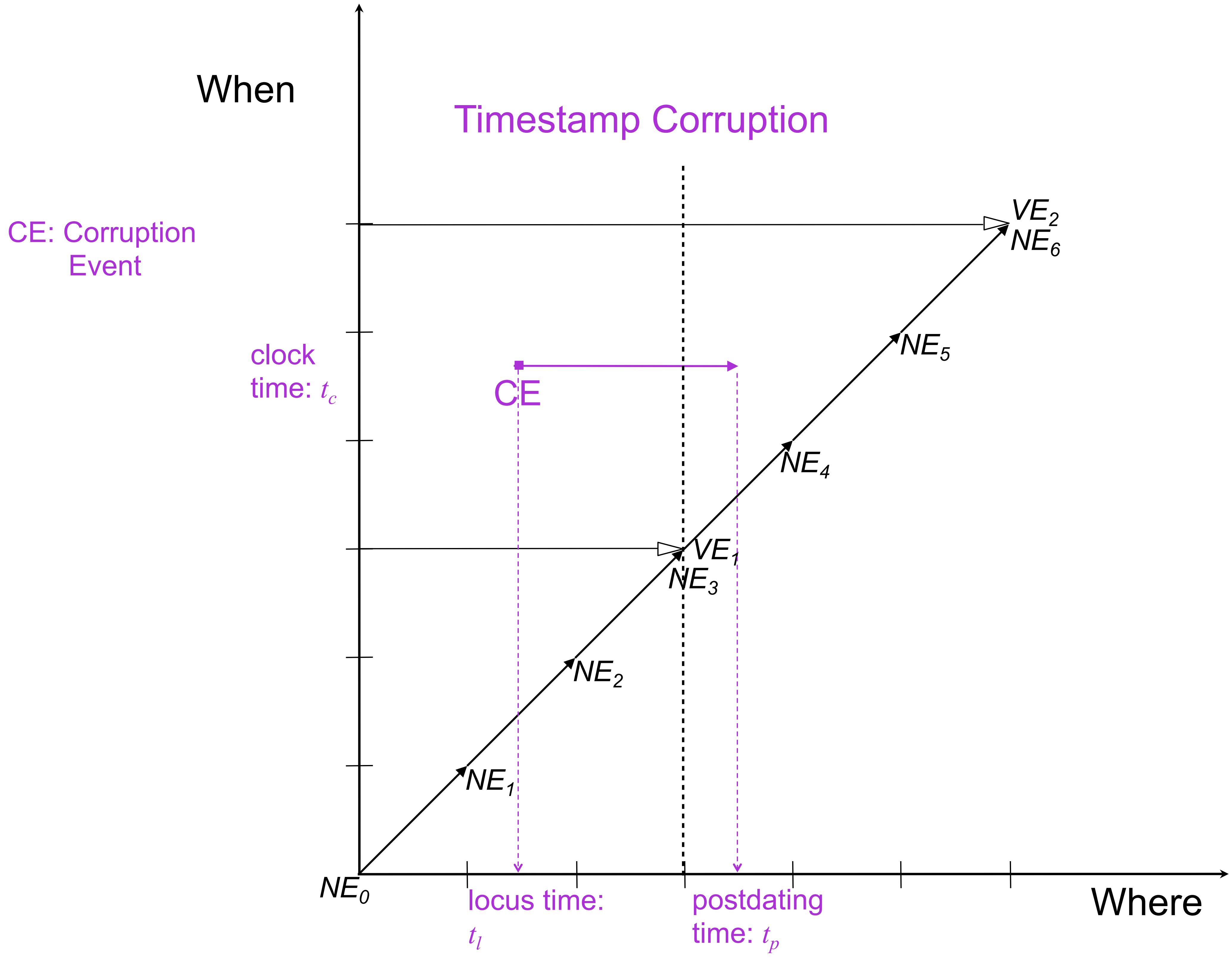
Types of Corruption Events



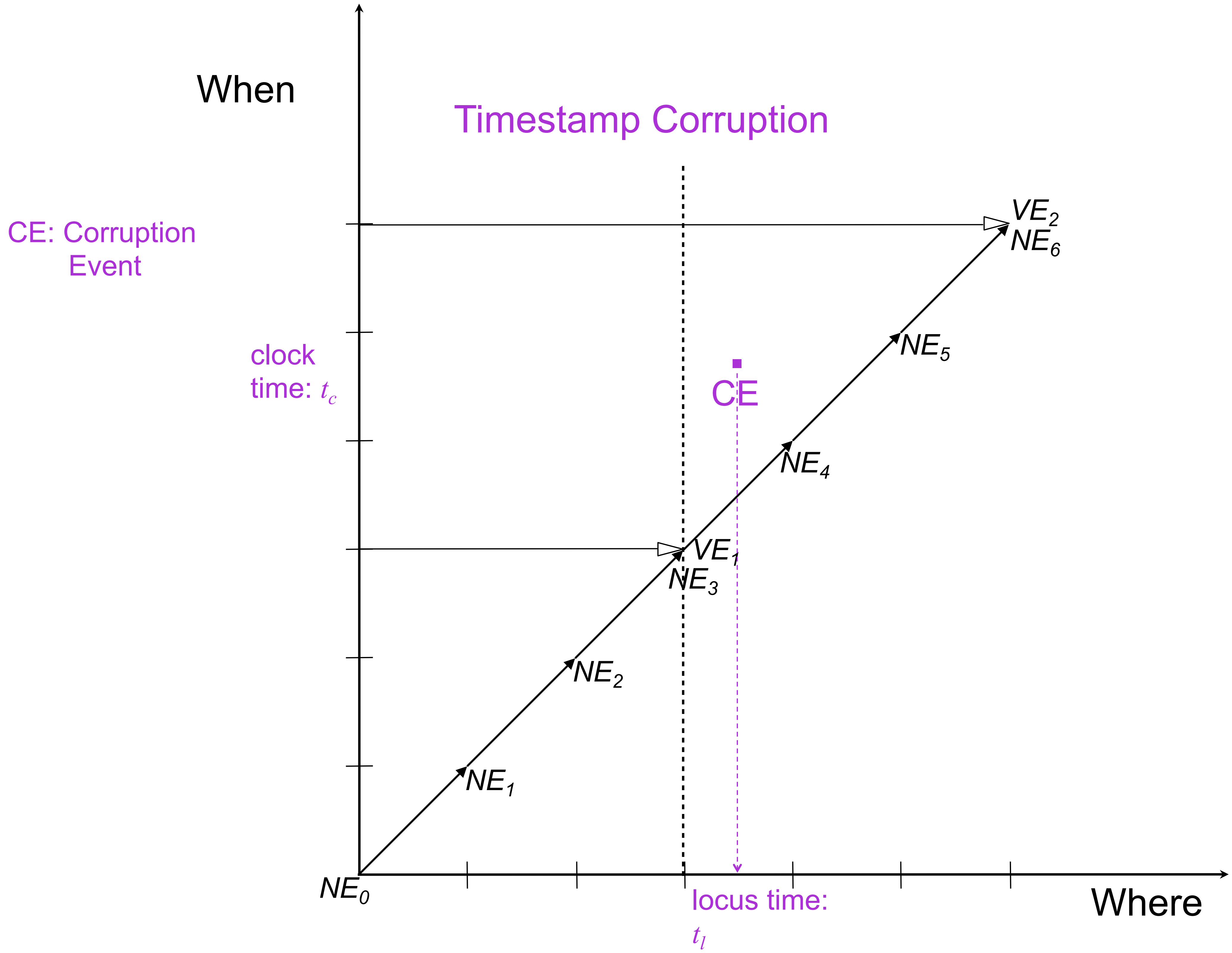
Types of Corruption Events



Types of Corruption Events



Types of Corruption Events



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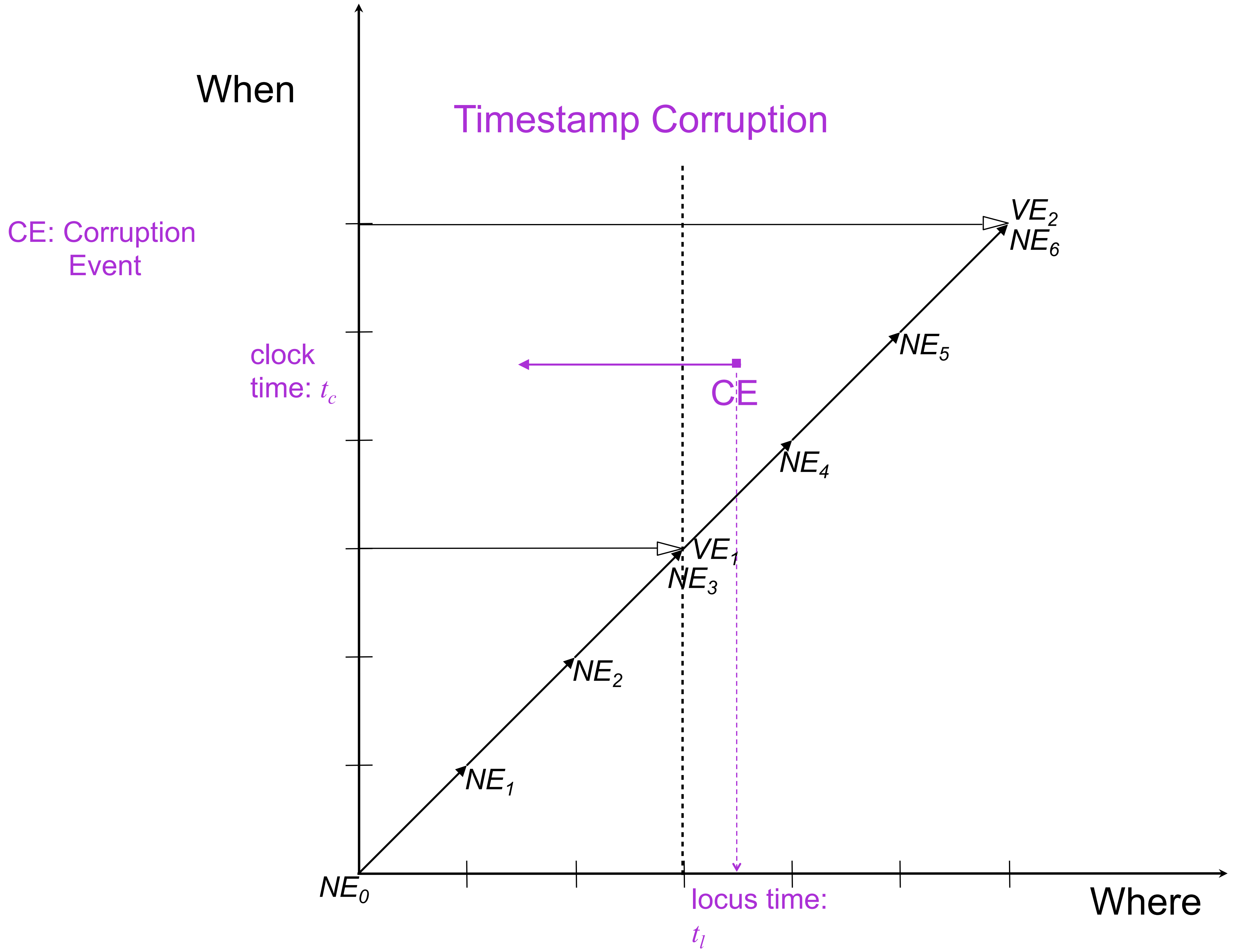

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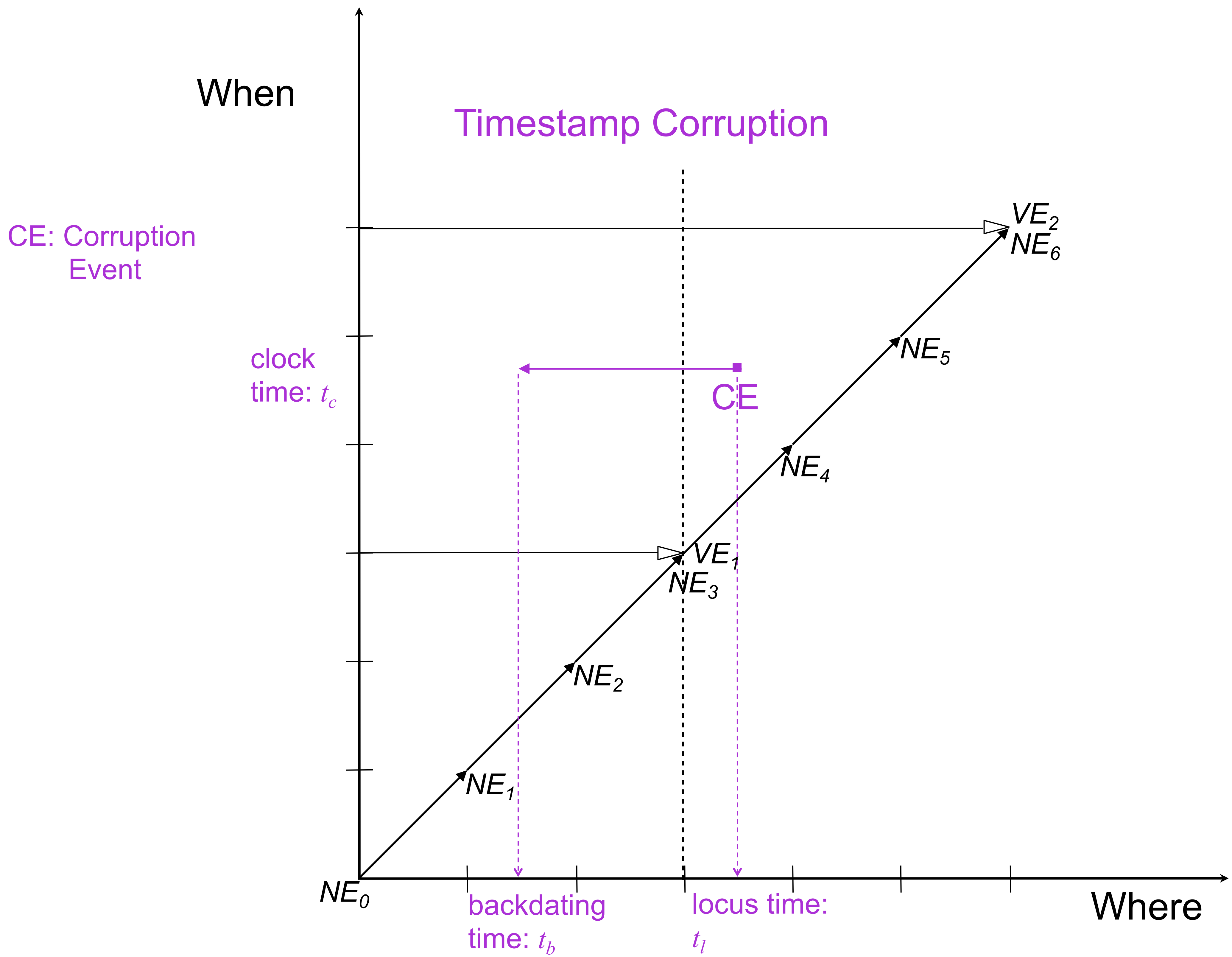

Forensic Analysis

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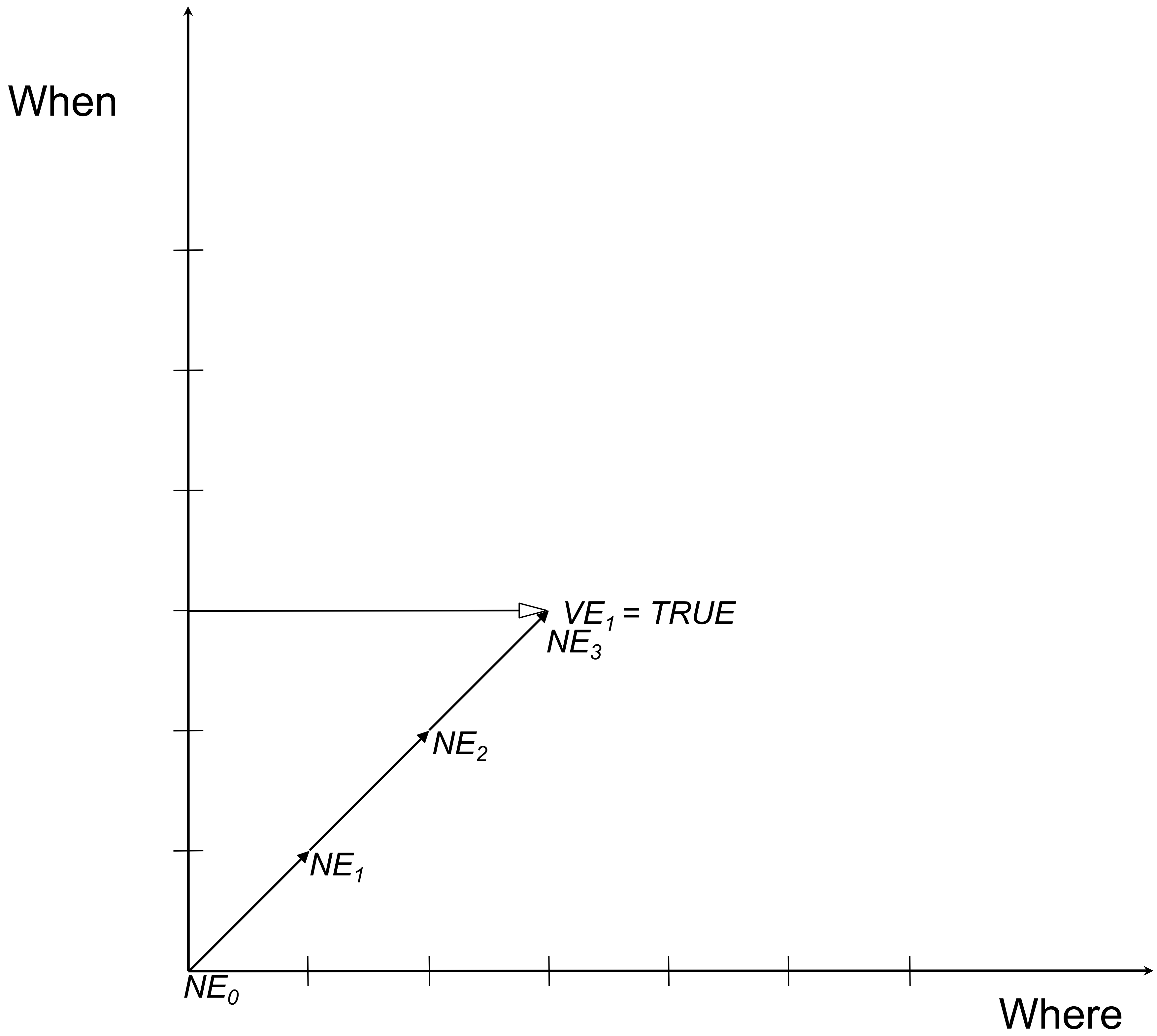
- Attempt to ascertain a *corruption region*: the bounds on the uncertainty of the “where” and “when” of the corruption.

Detection Resolution

- Temporal Detection Resolution (R_t): the finest granularity of temporal bounds uncertainty of a CE.

- Spatial Detection Resolution (R_s): the finest granularity of spatial bounds uncertainty of a CE.

Monochromatic Algorithm



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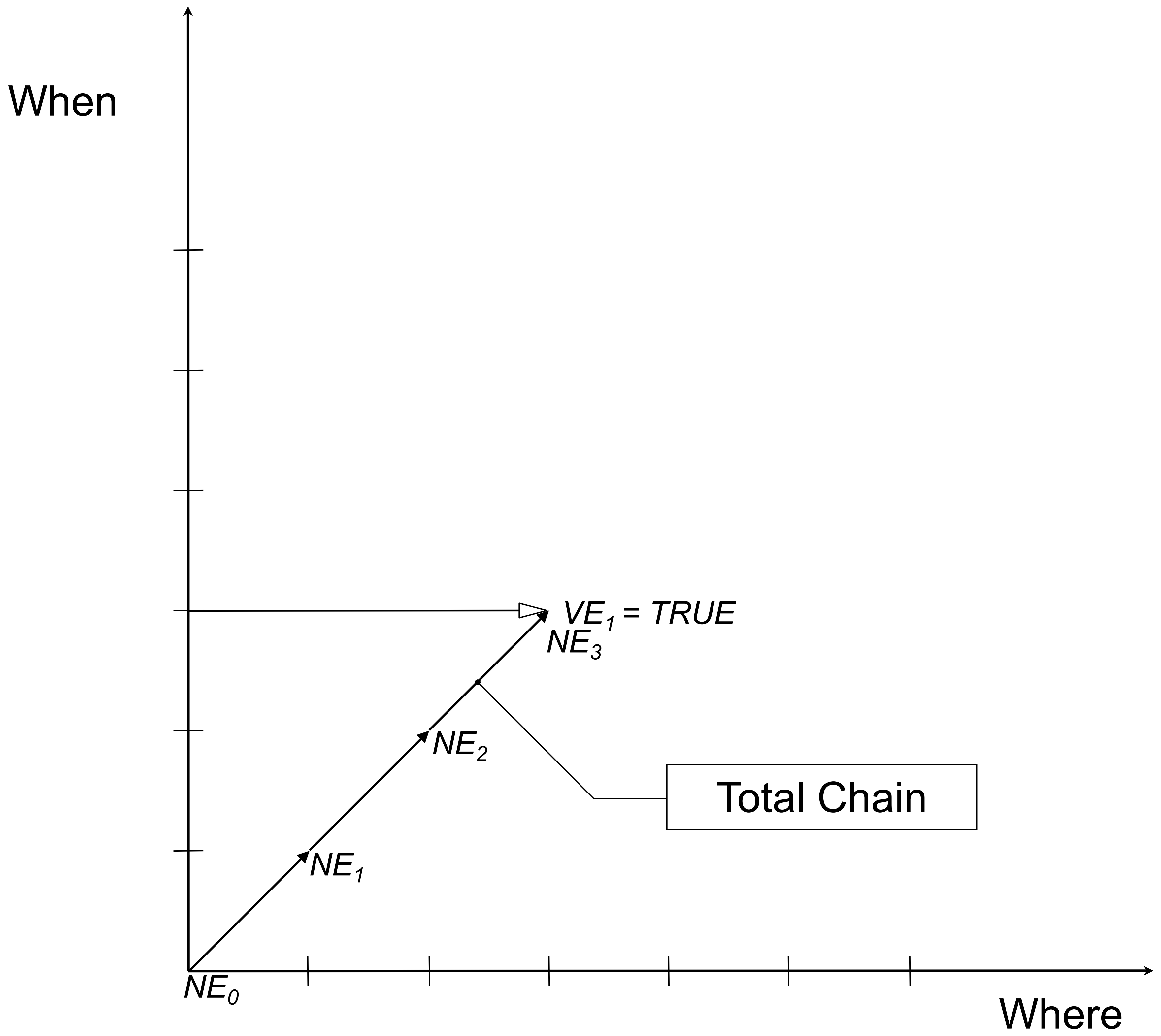

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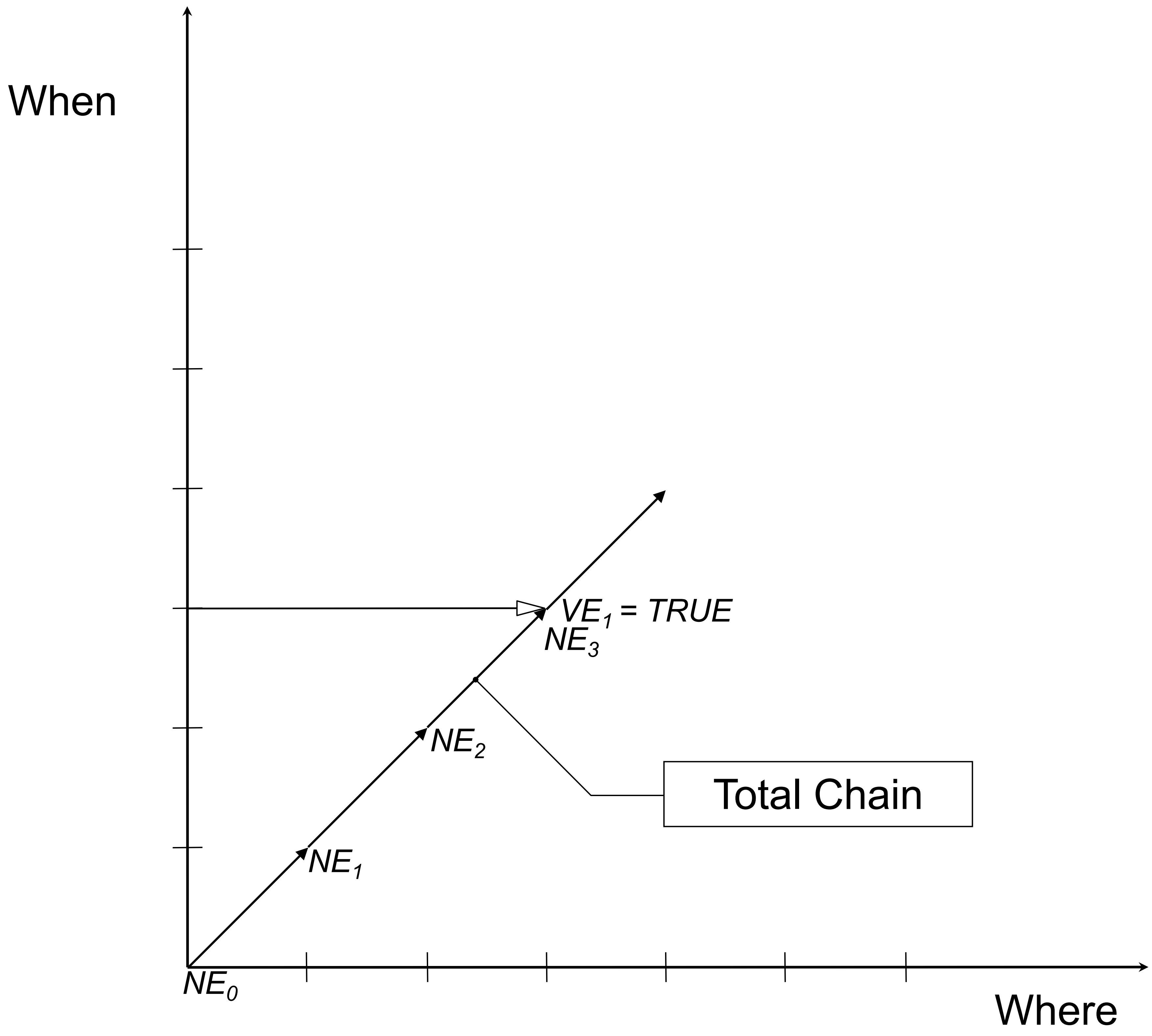

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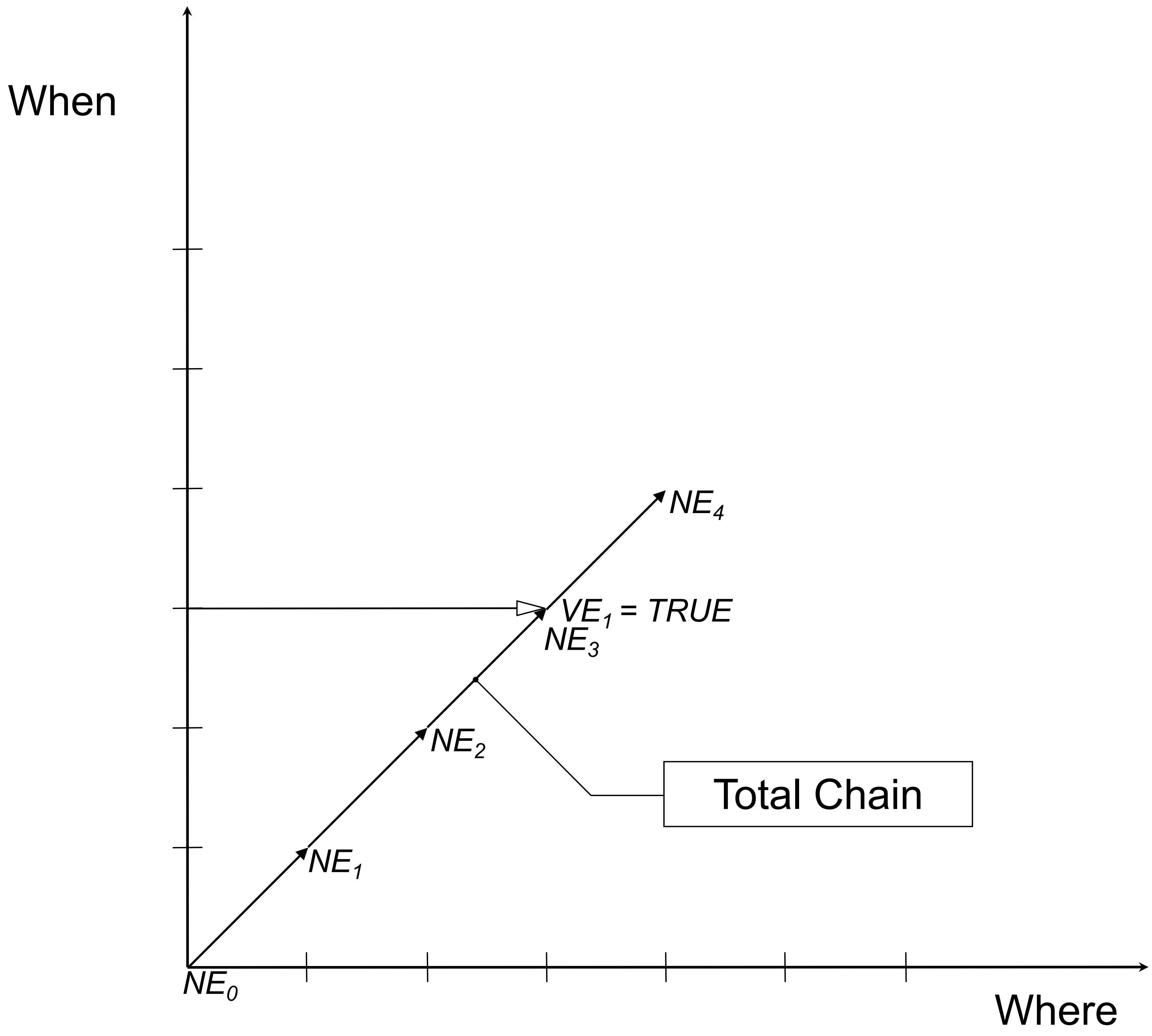

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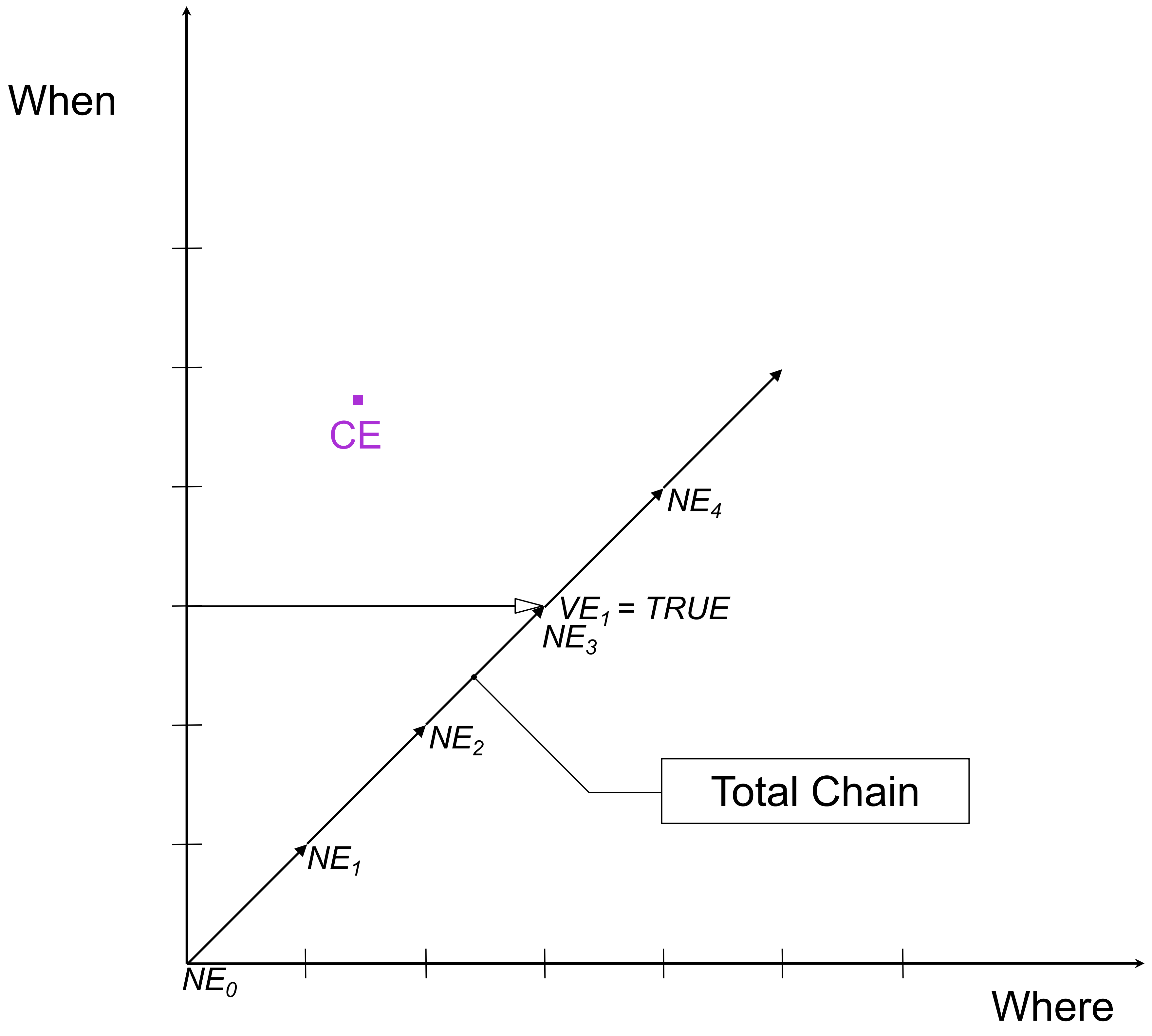

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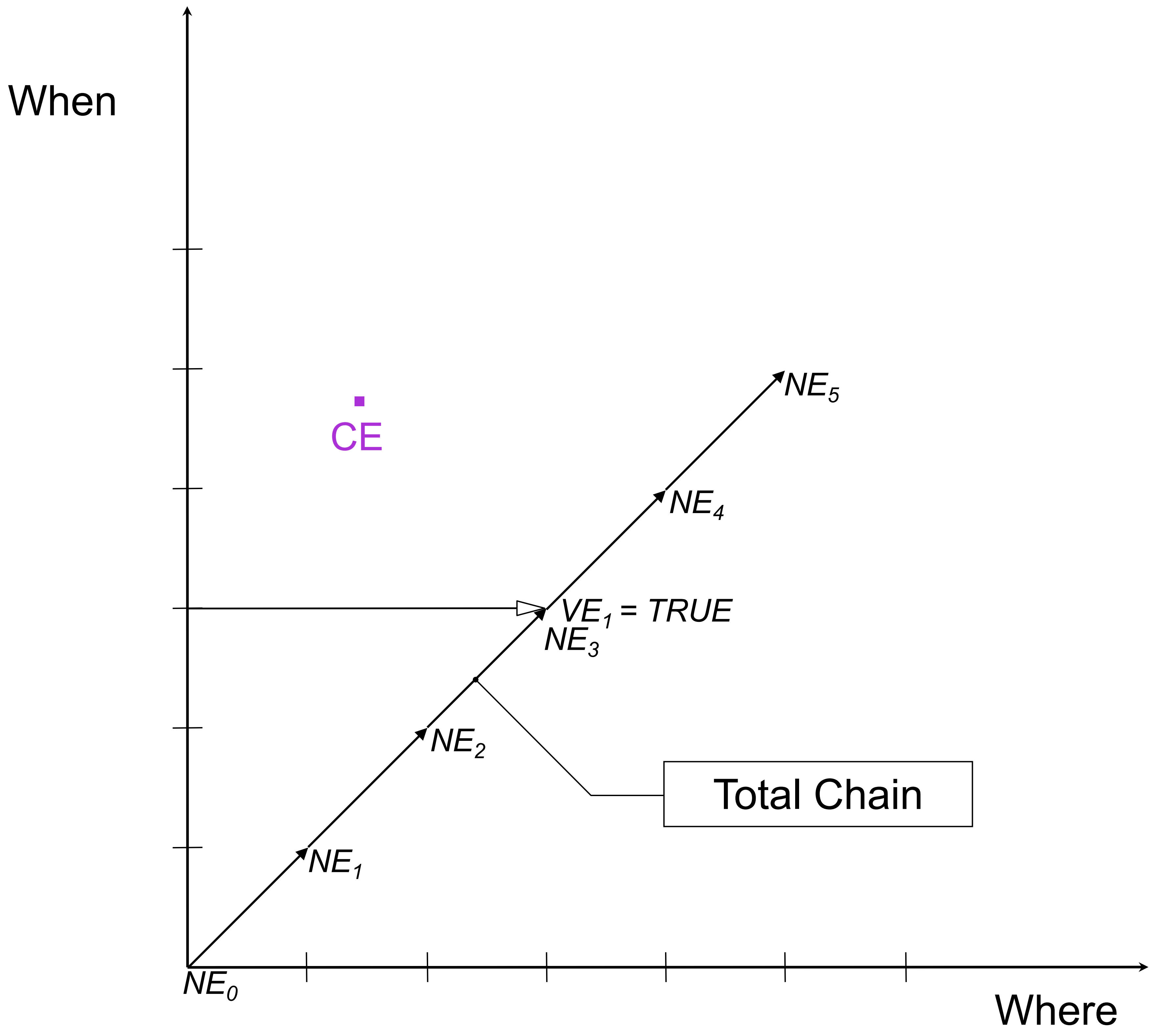

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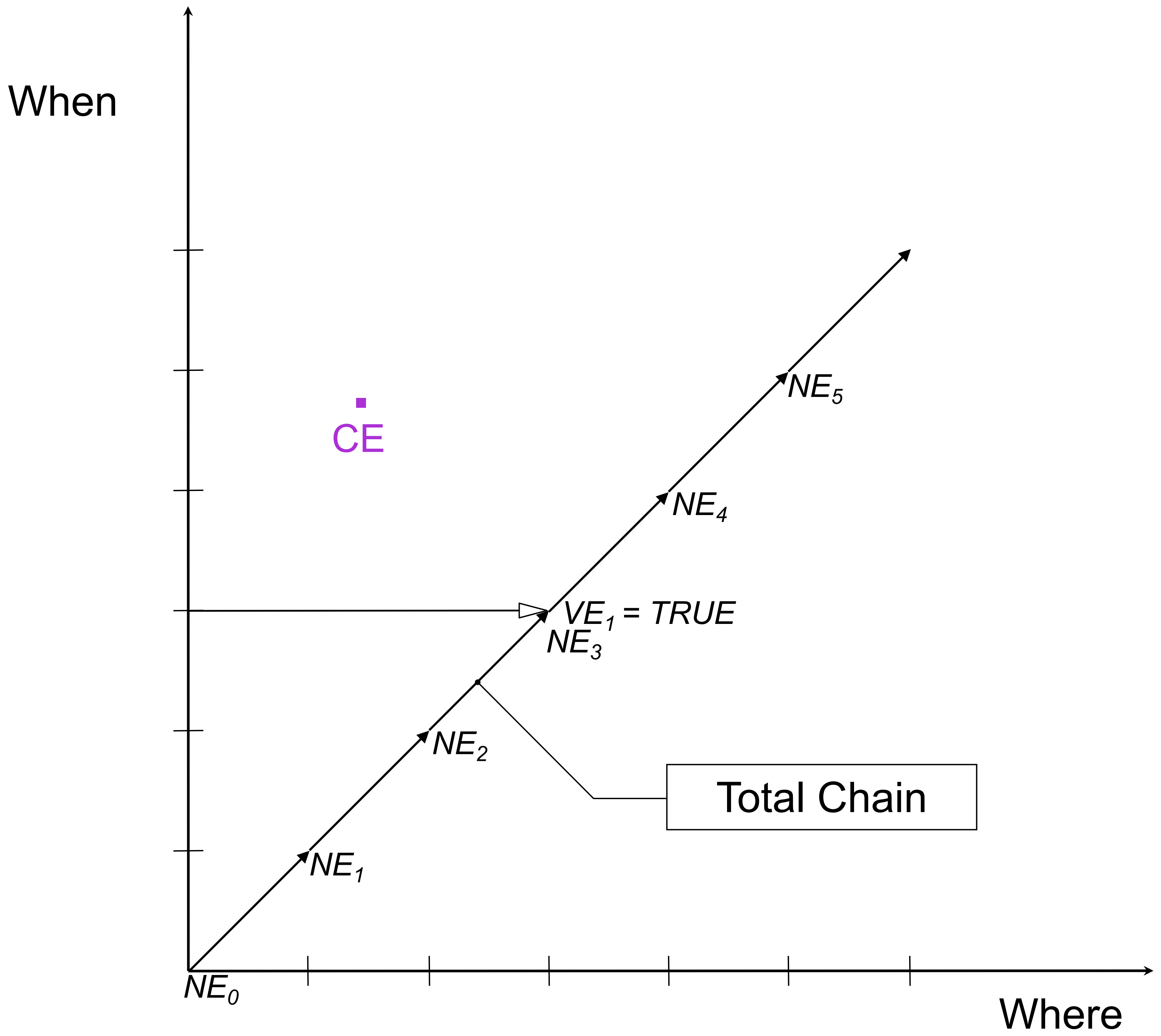

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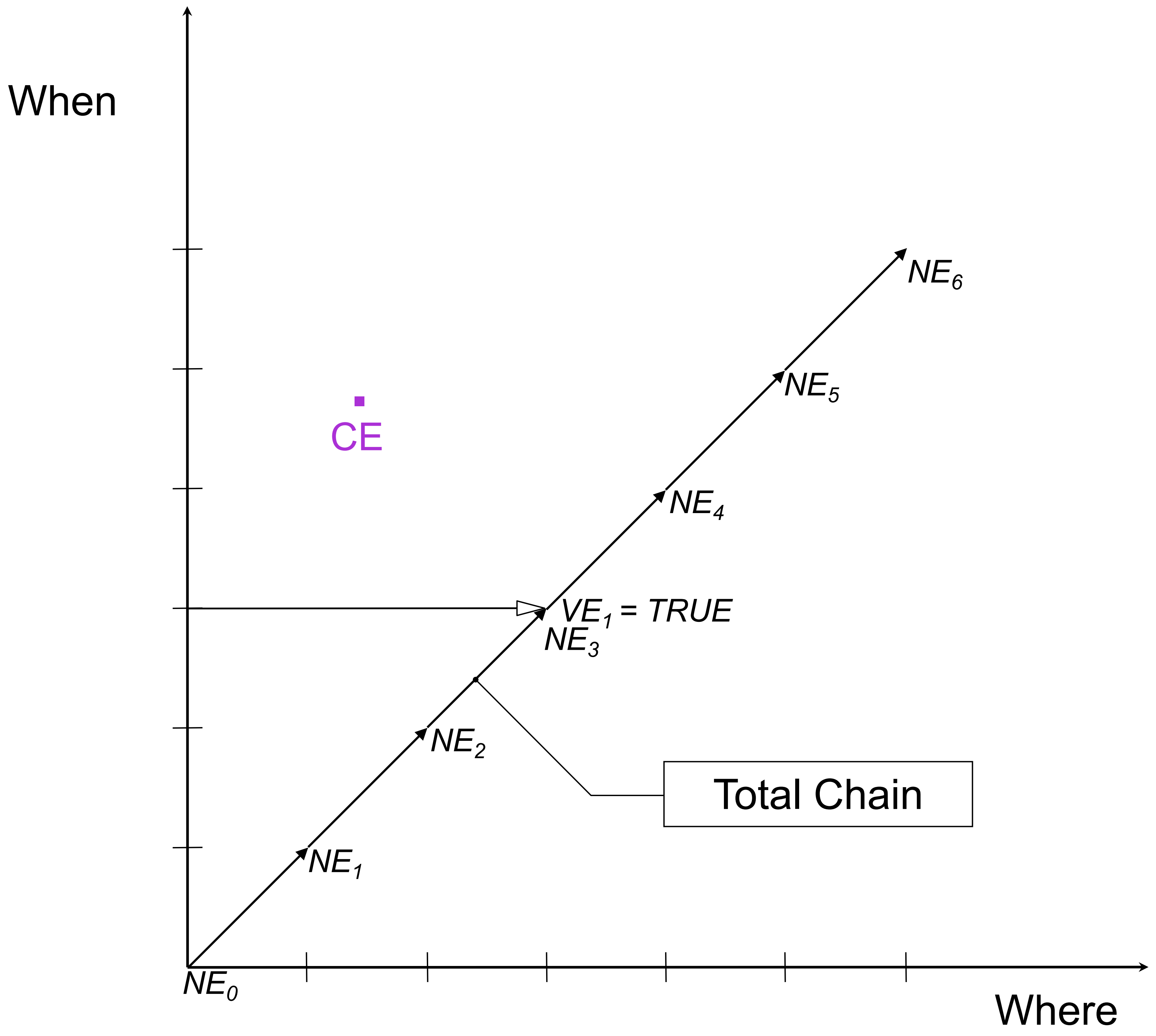

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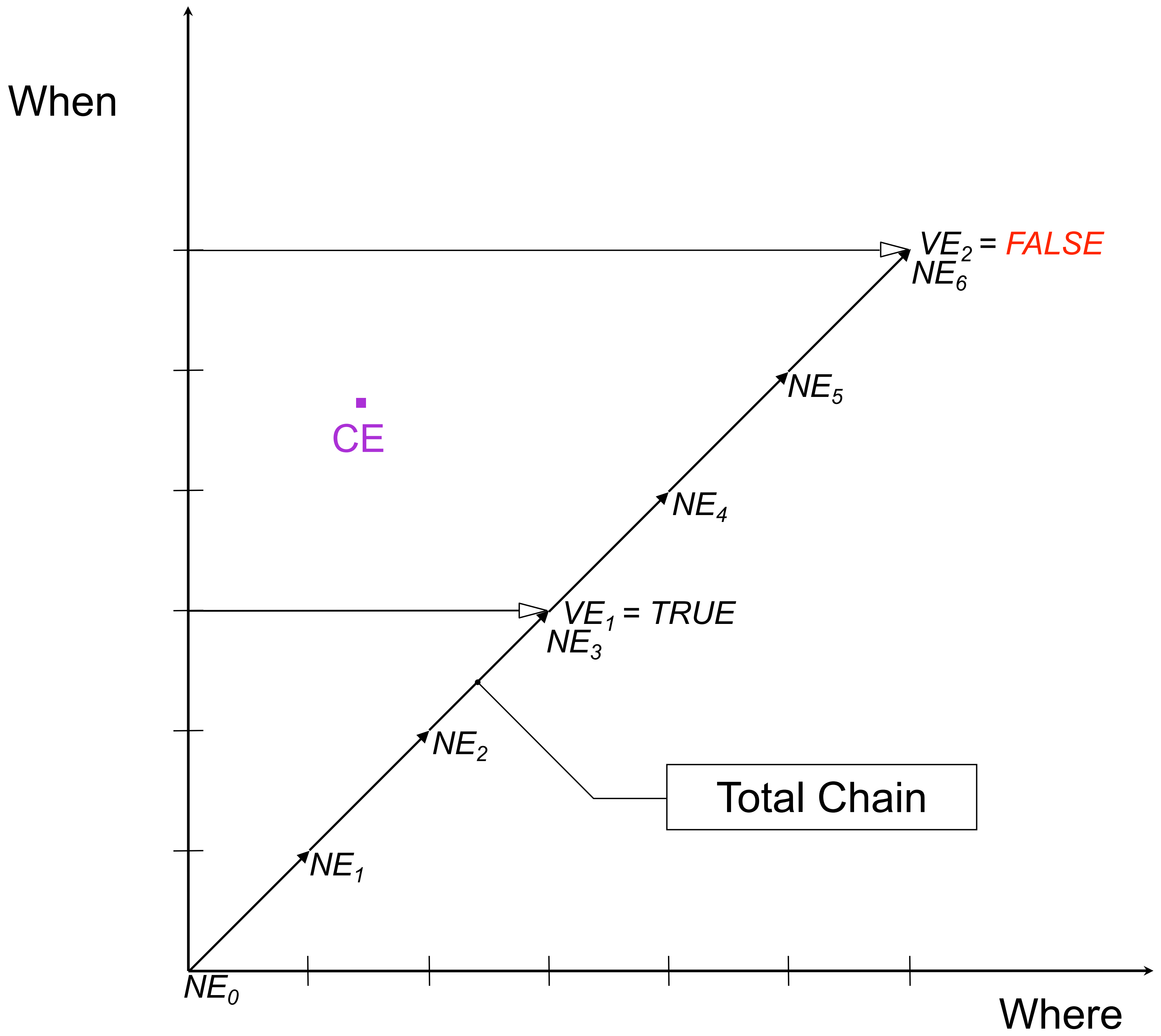

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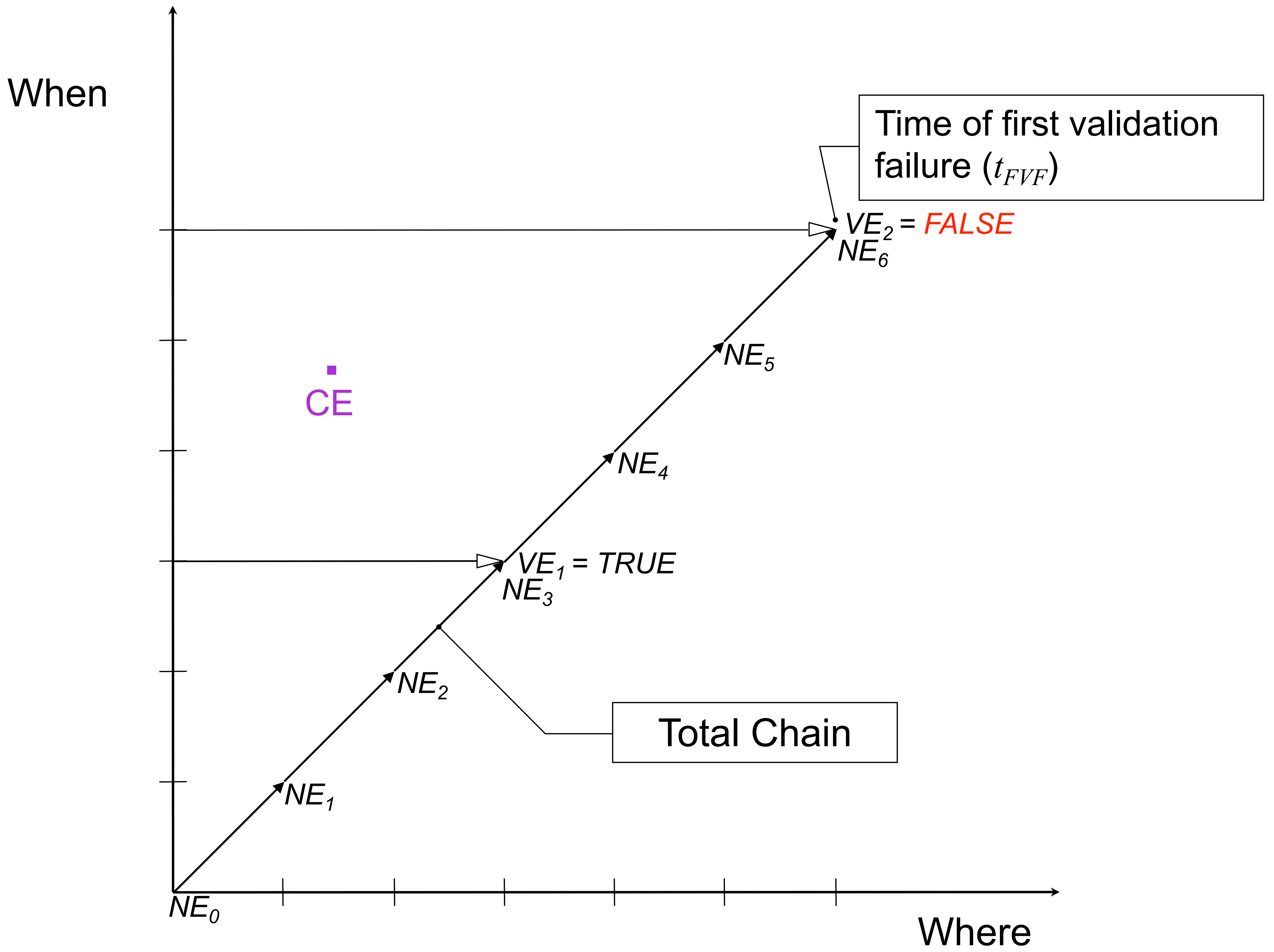

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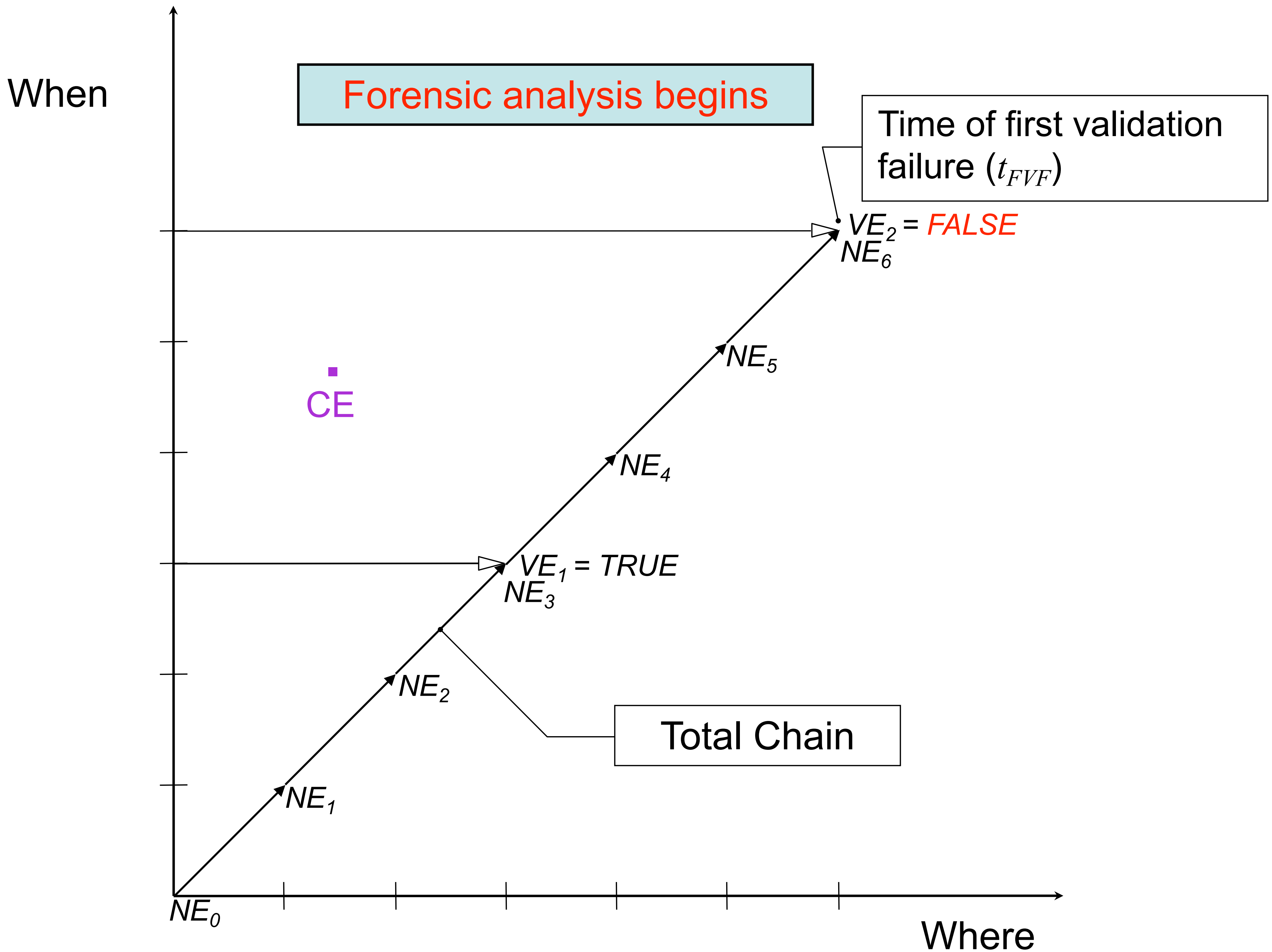

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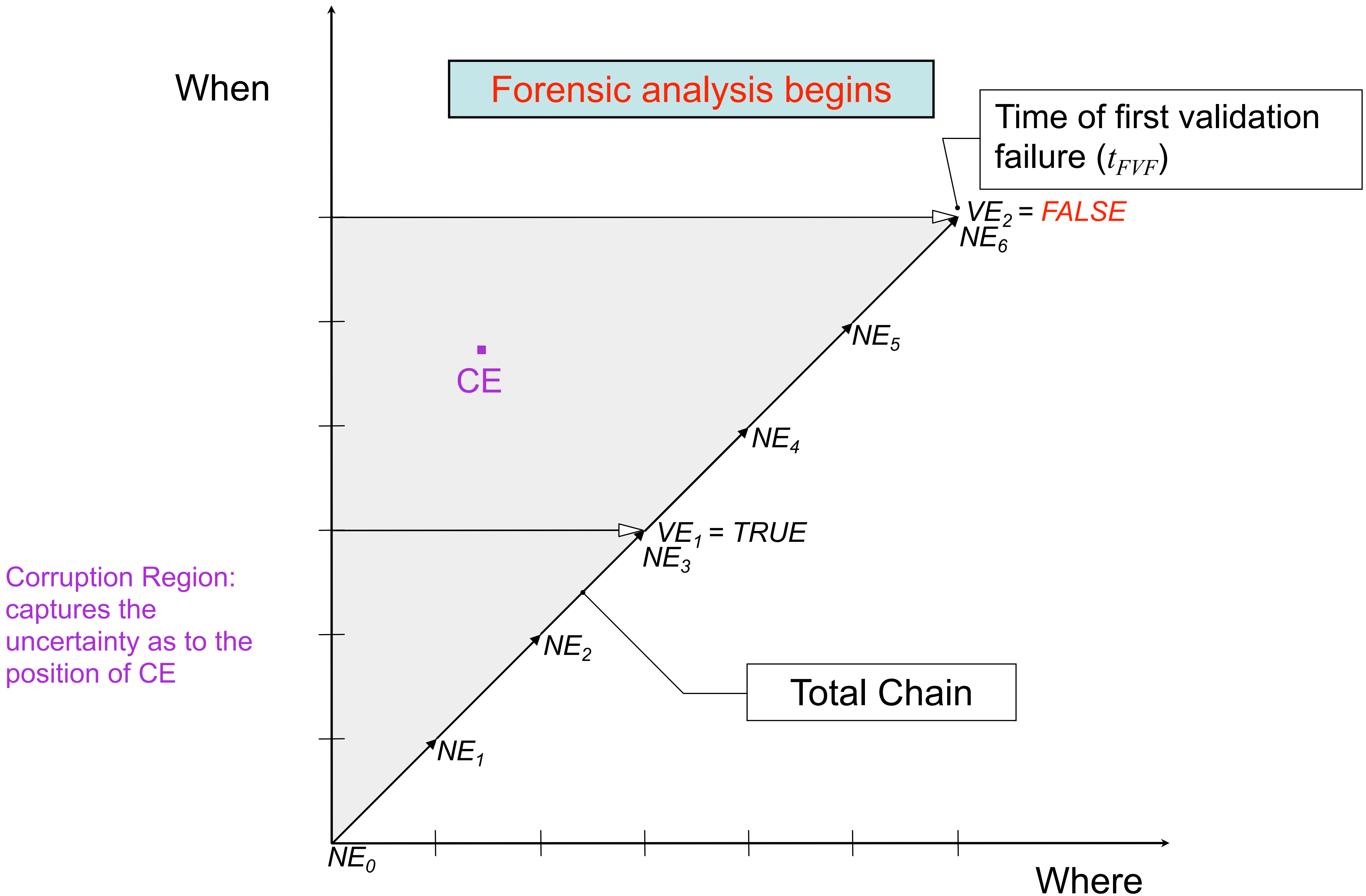

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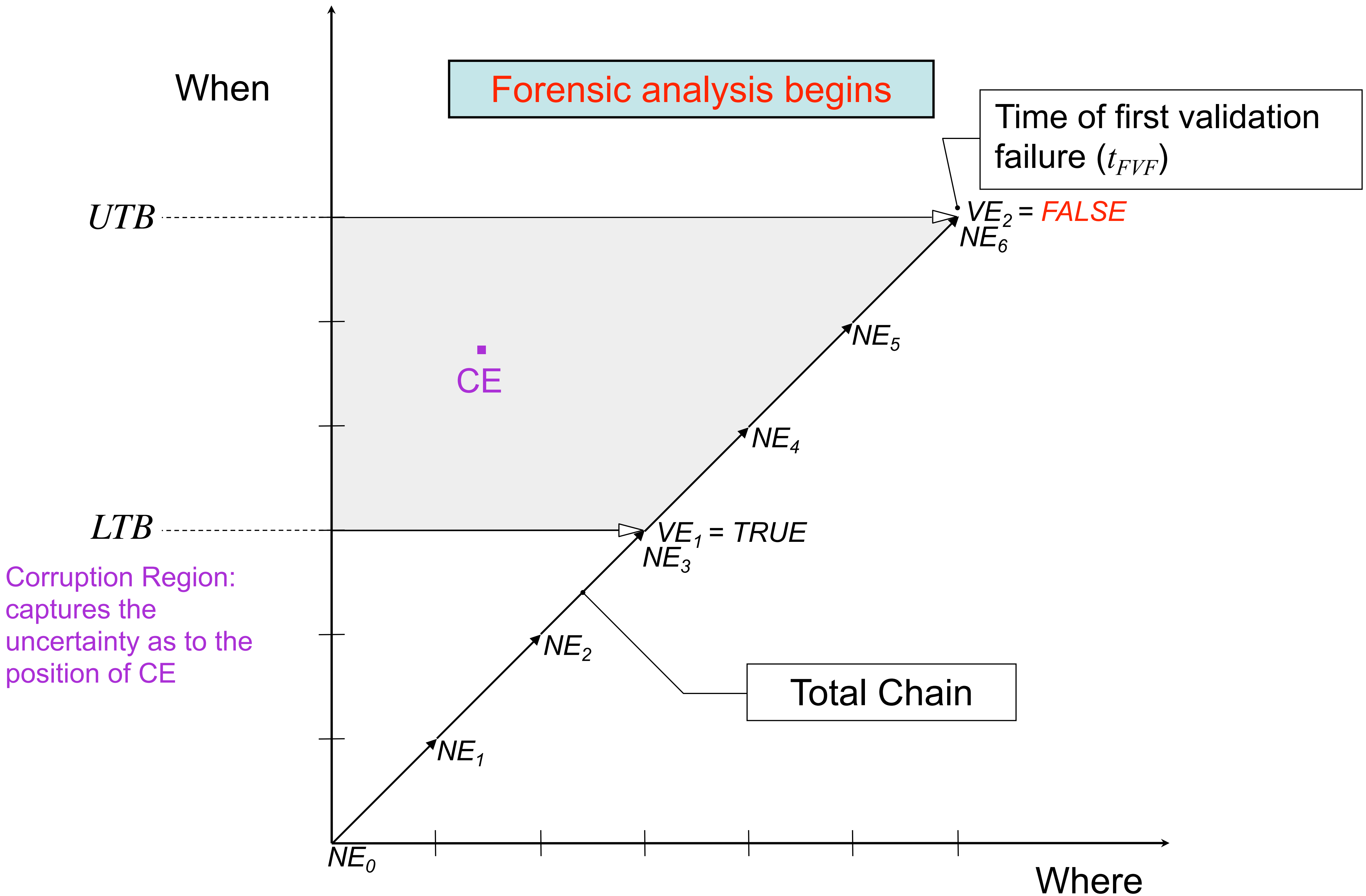

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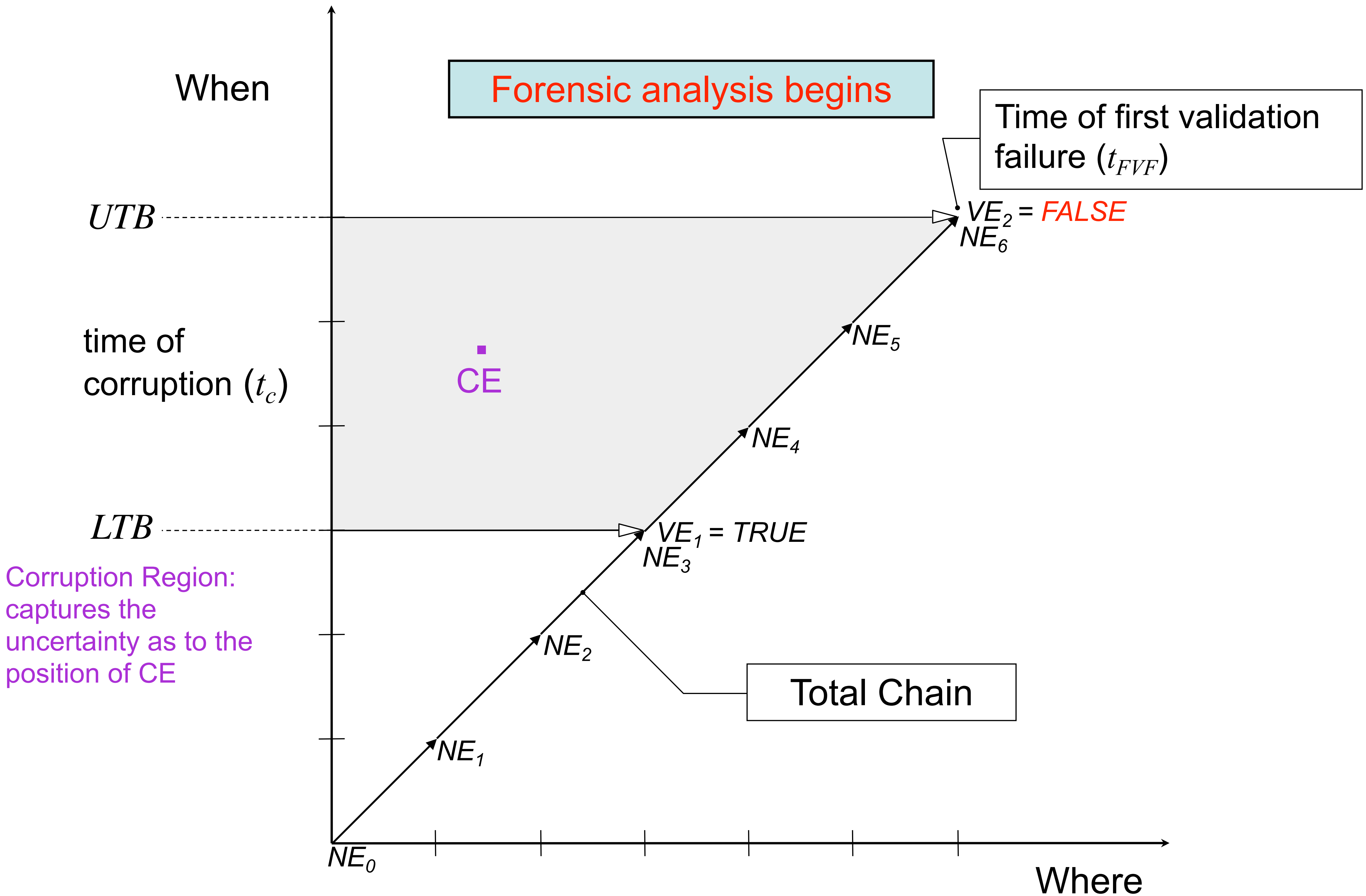

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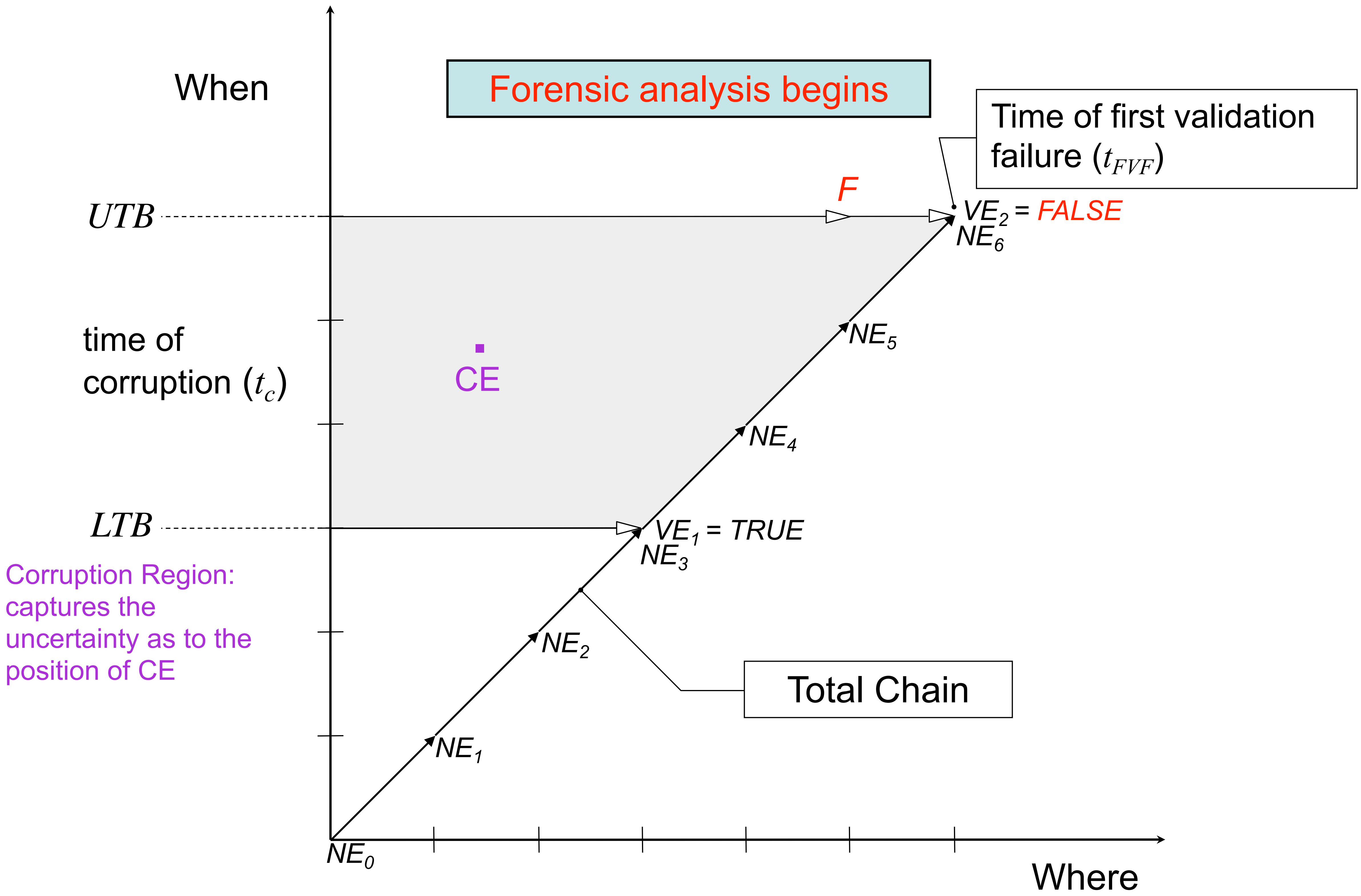

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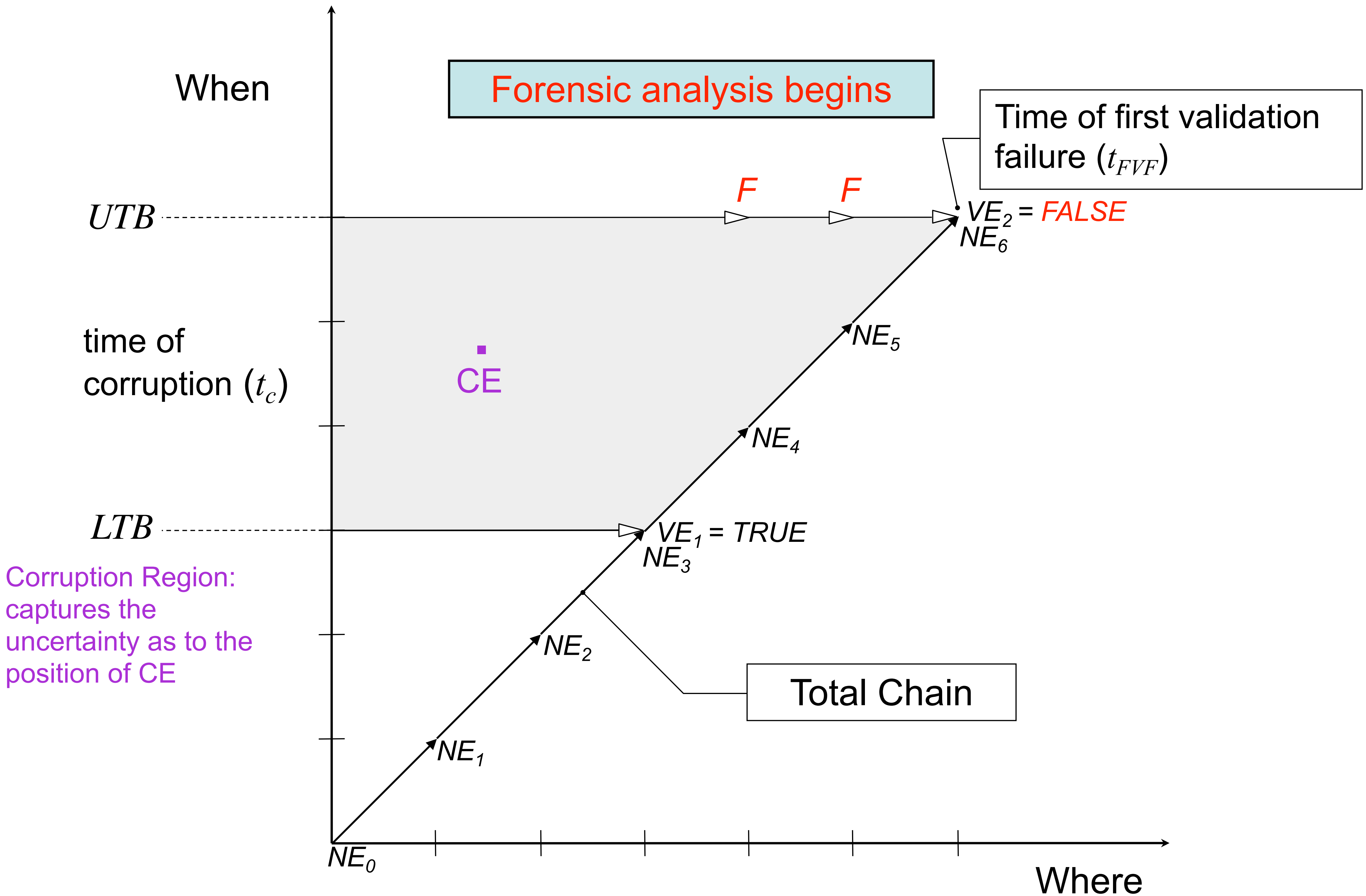

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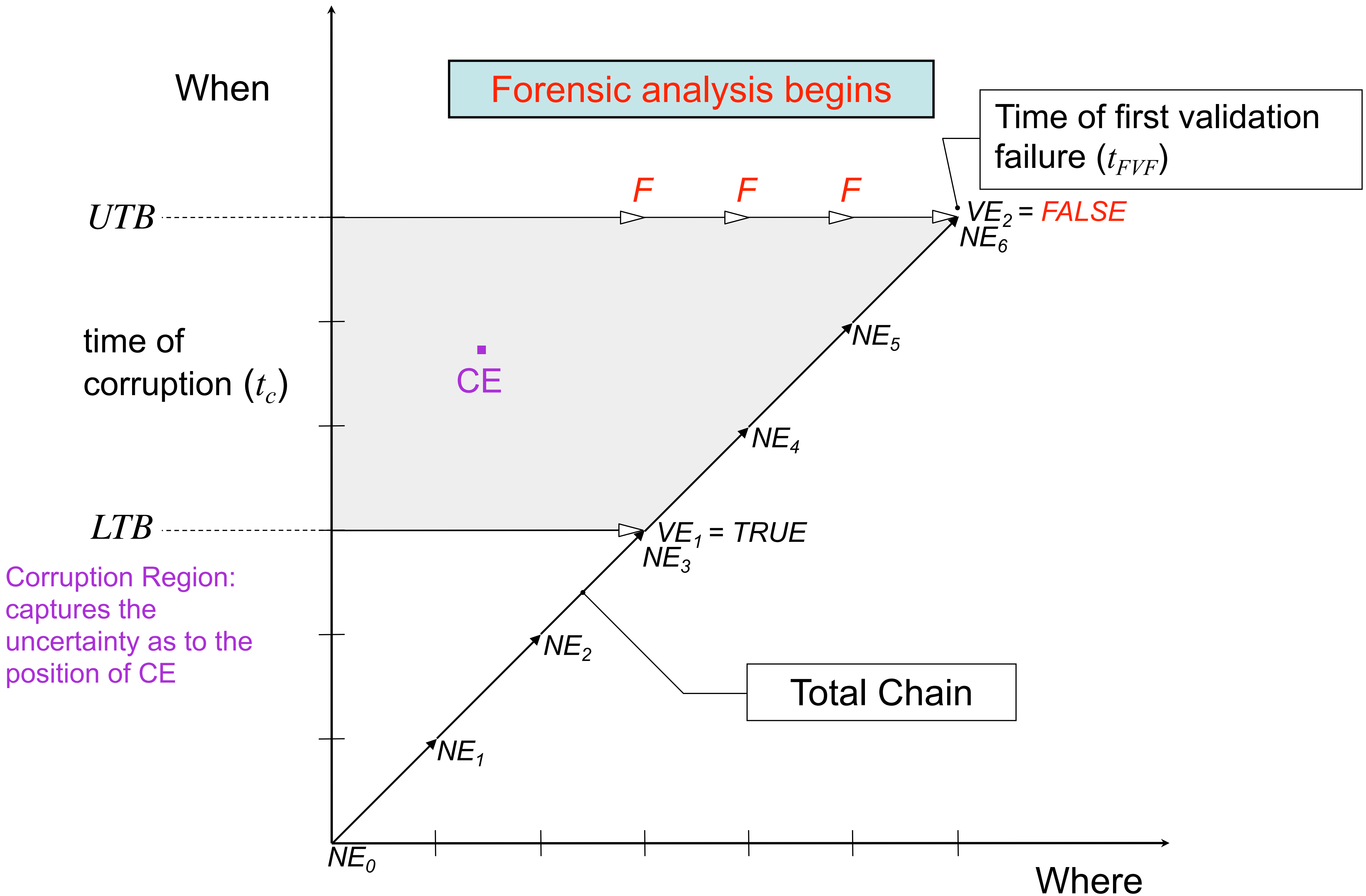

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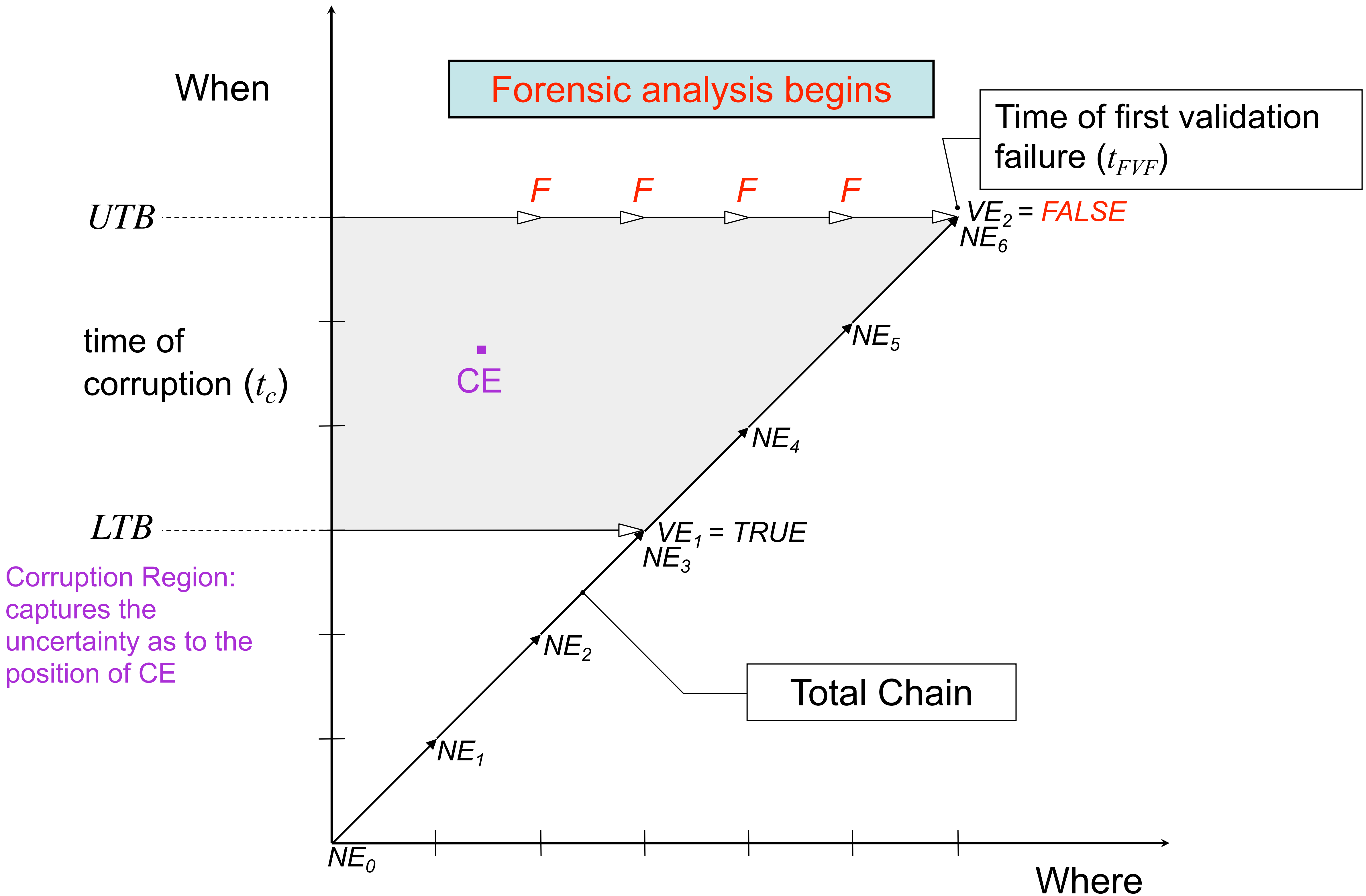

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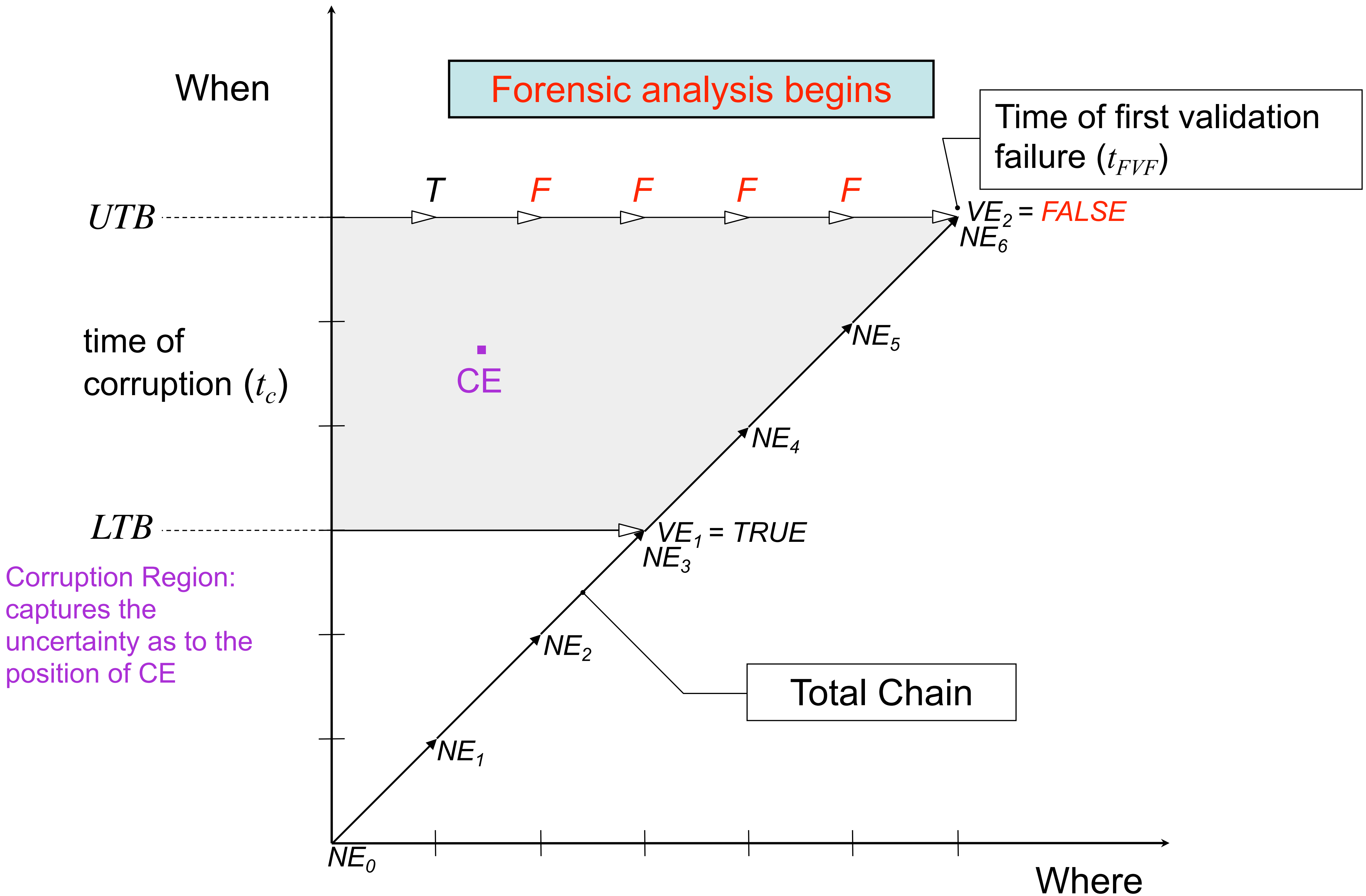

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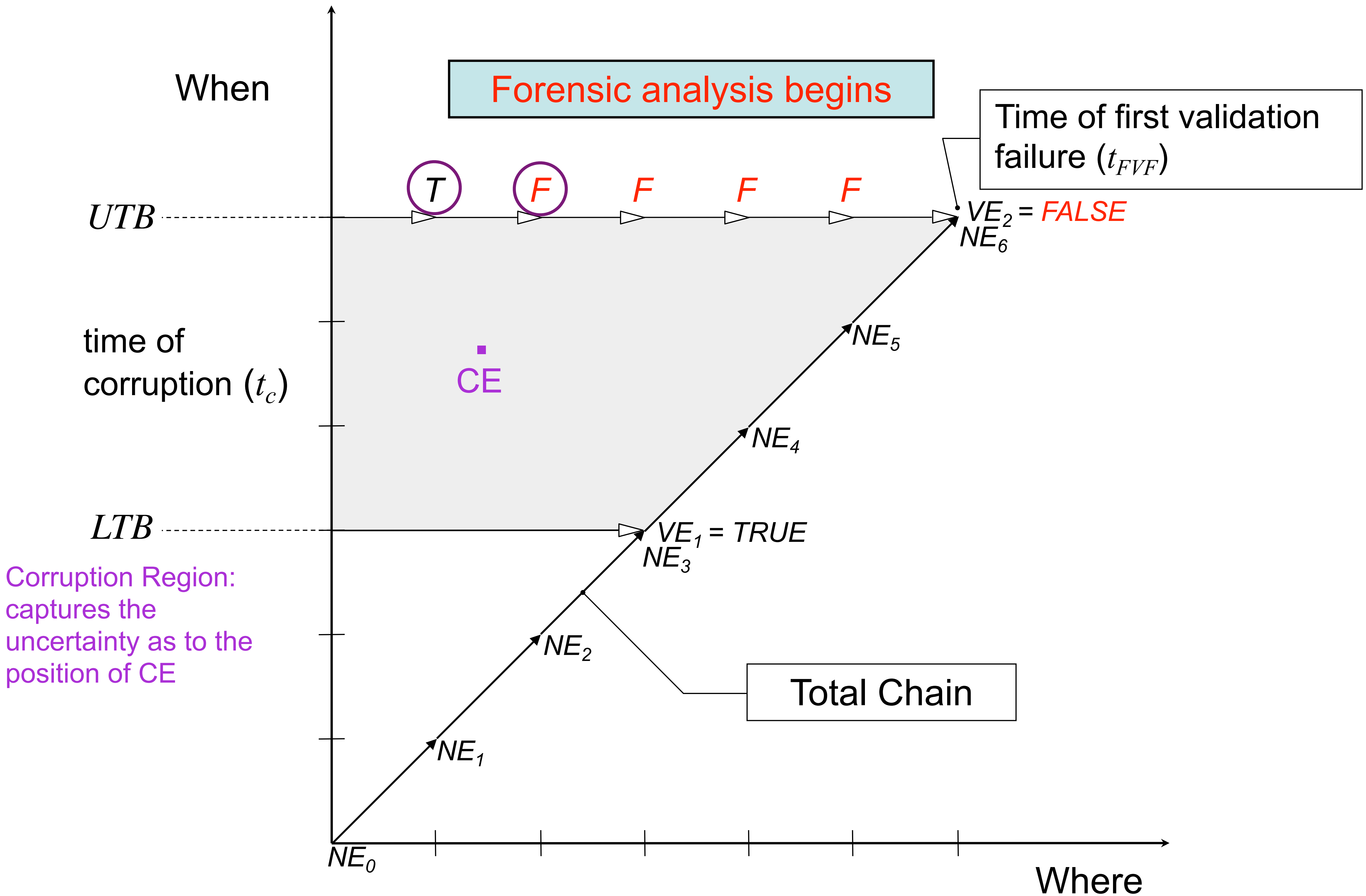

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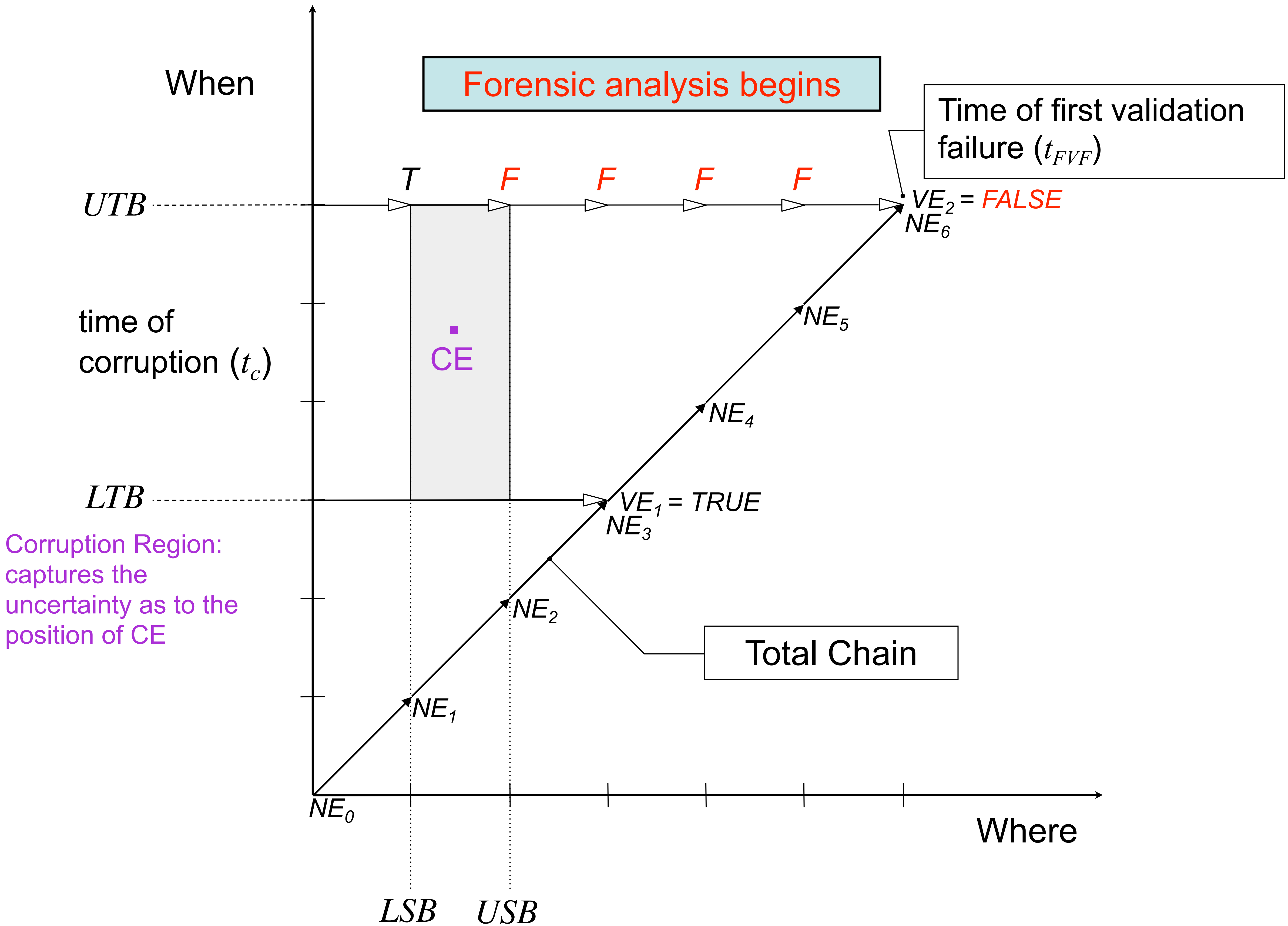

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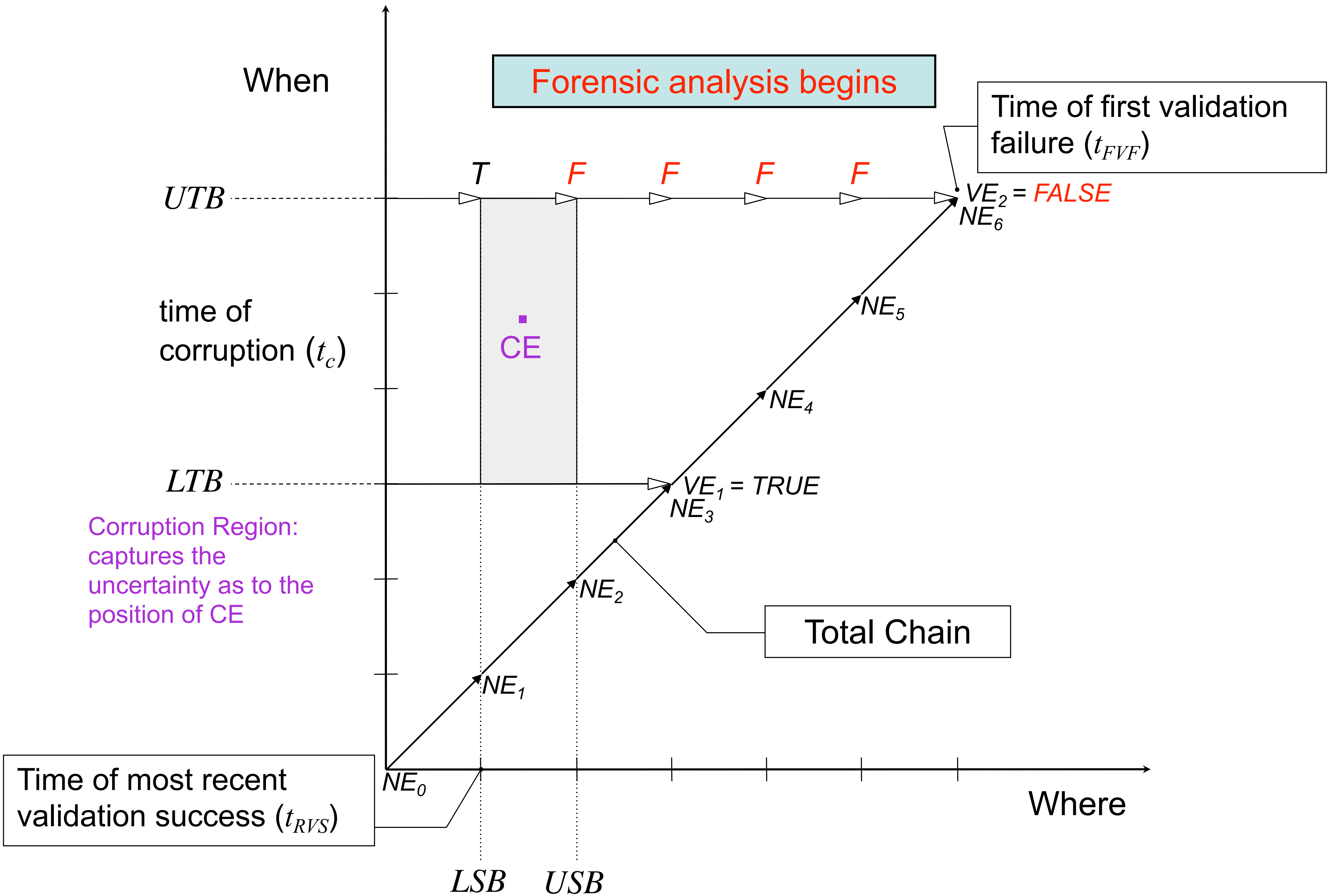

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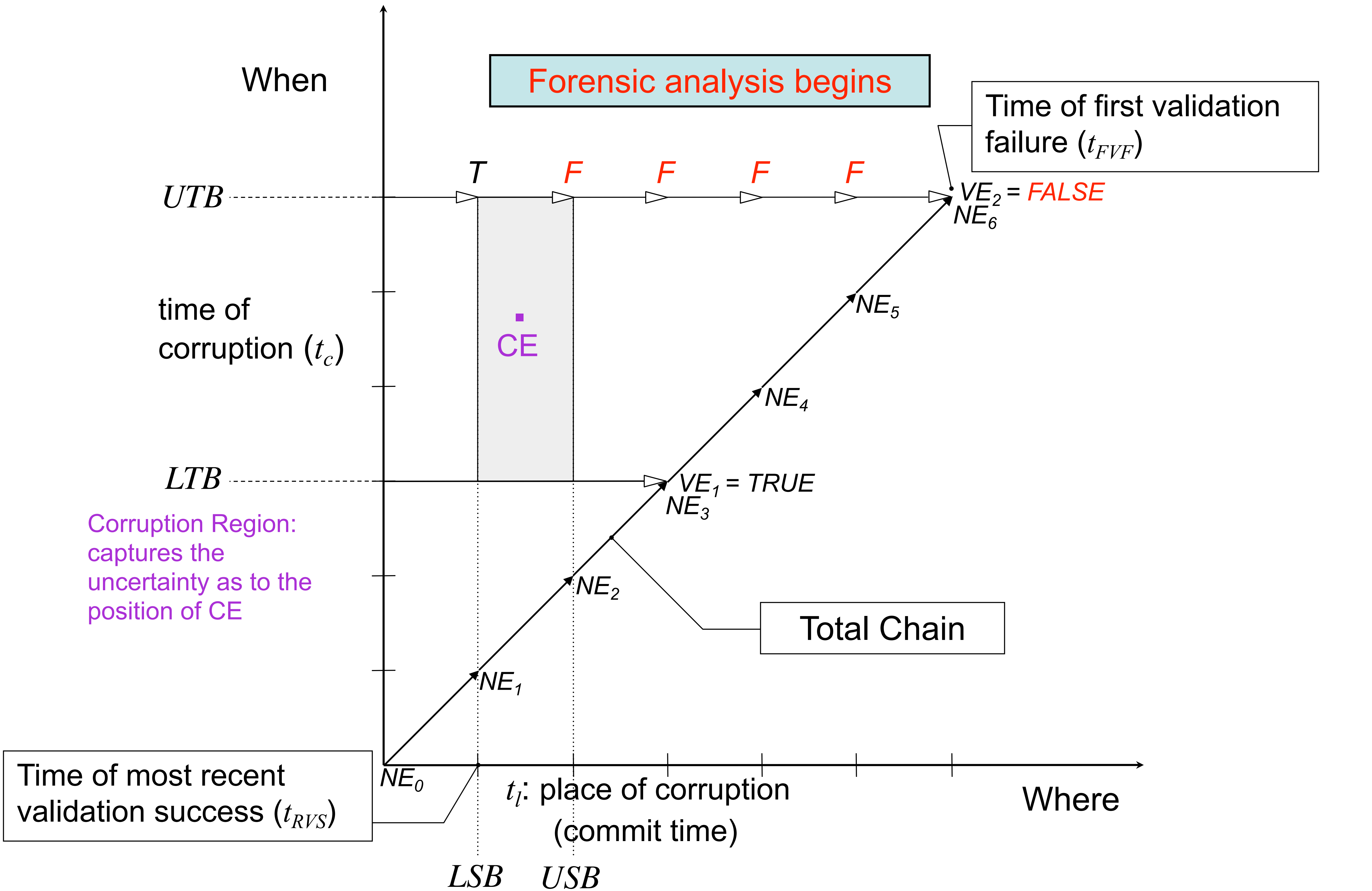
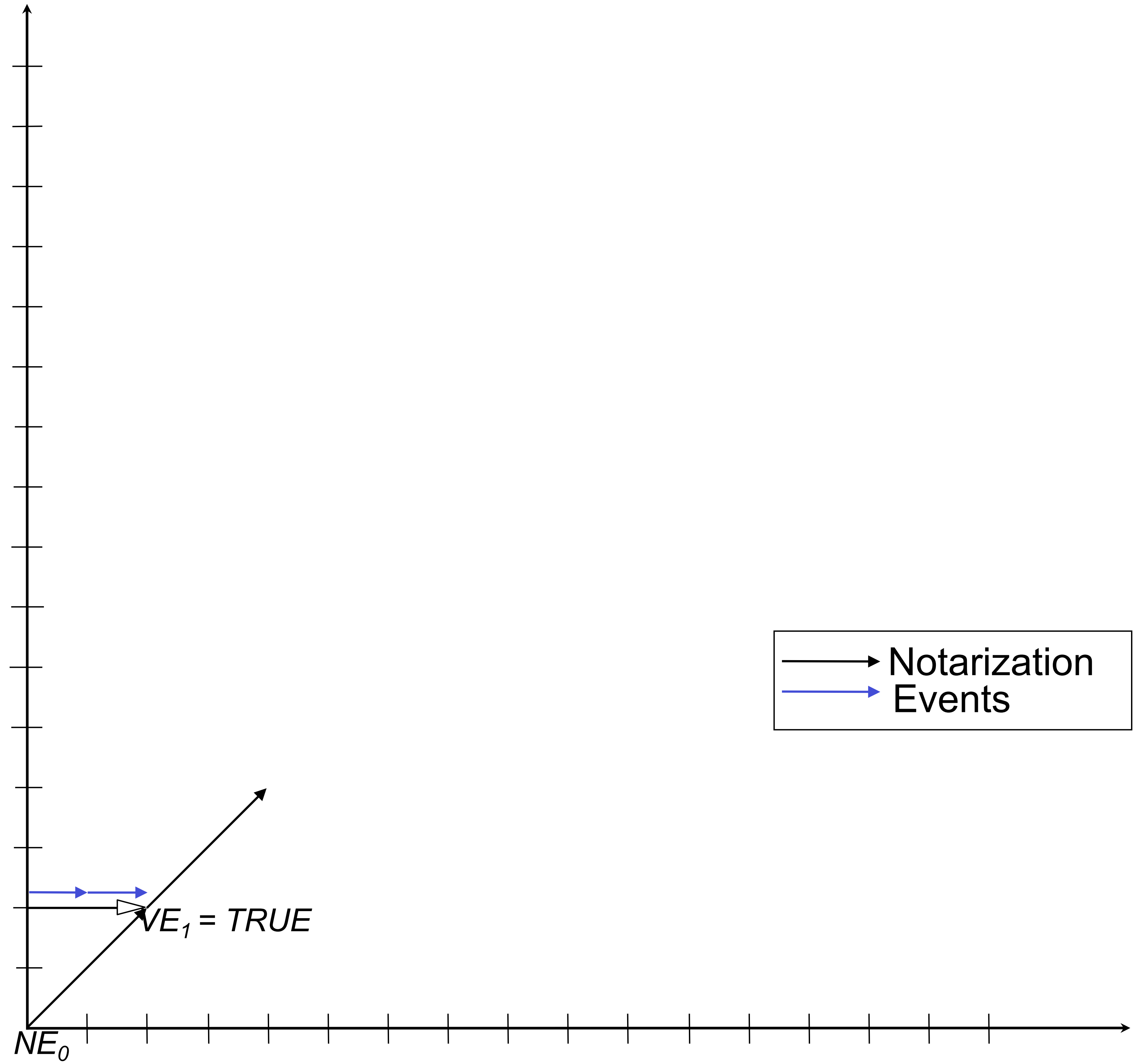


The a3D Algorithm

When

R_s = 1 day
N = 2
I_N = 2 days
V = 1
I_V = 2 days



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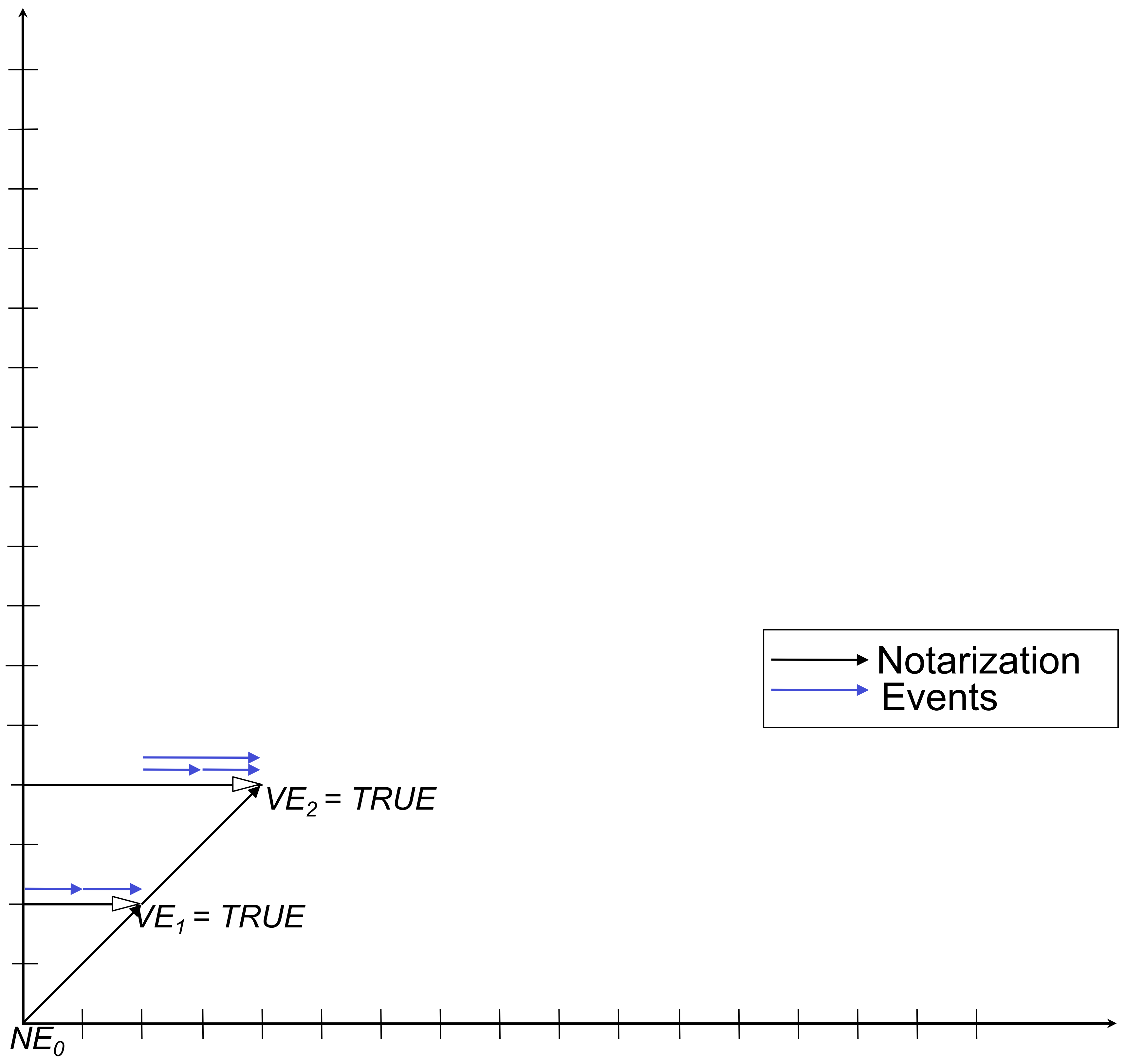

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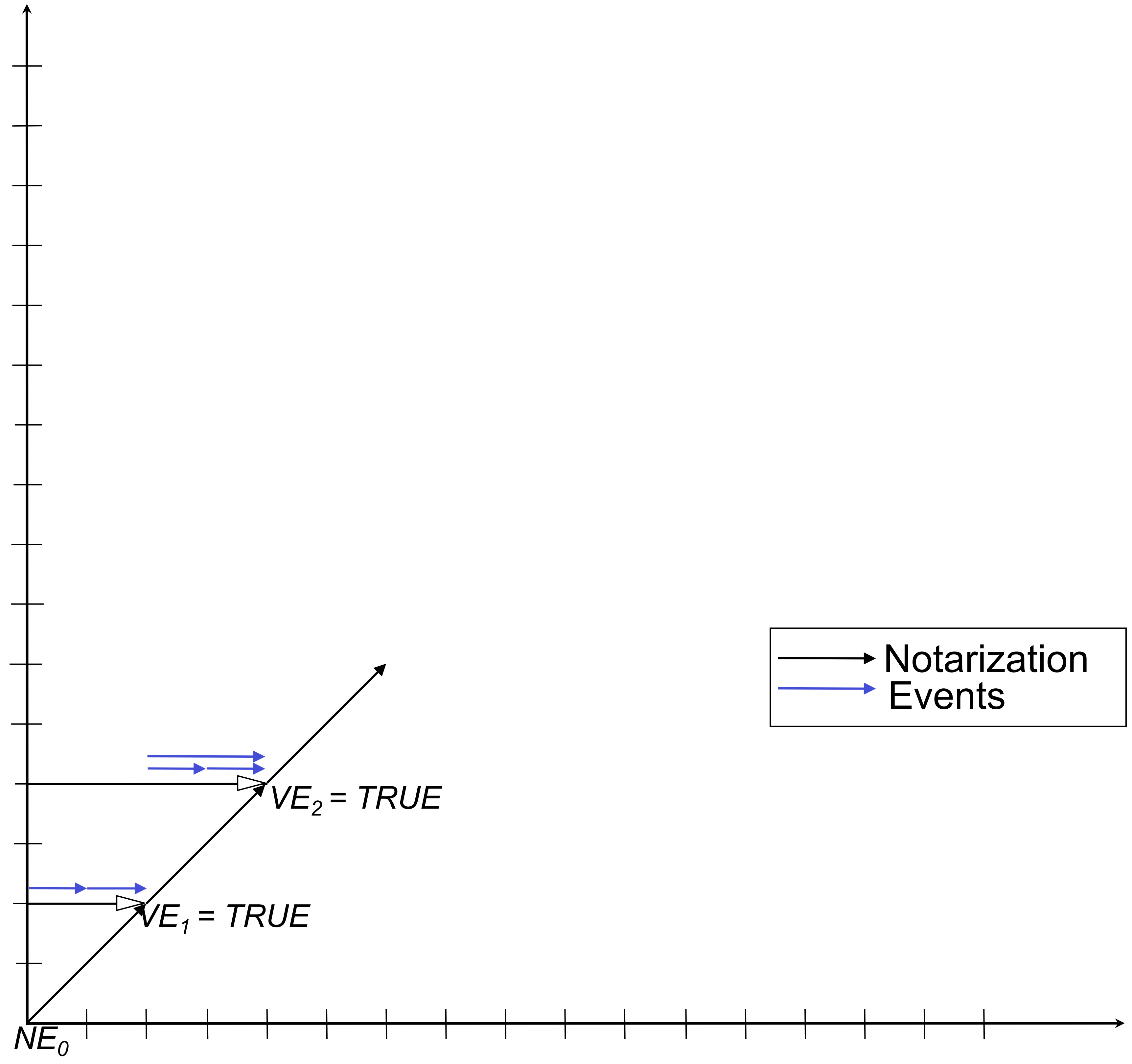

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When

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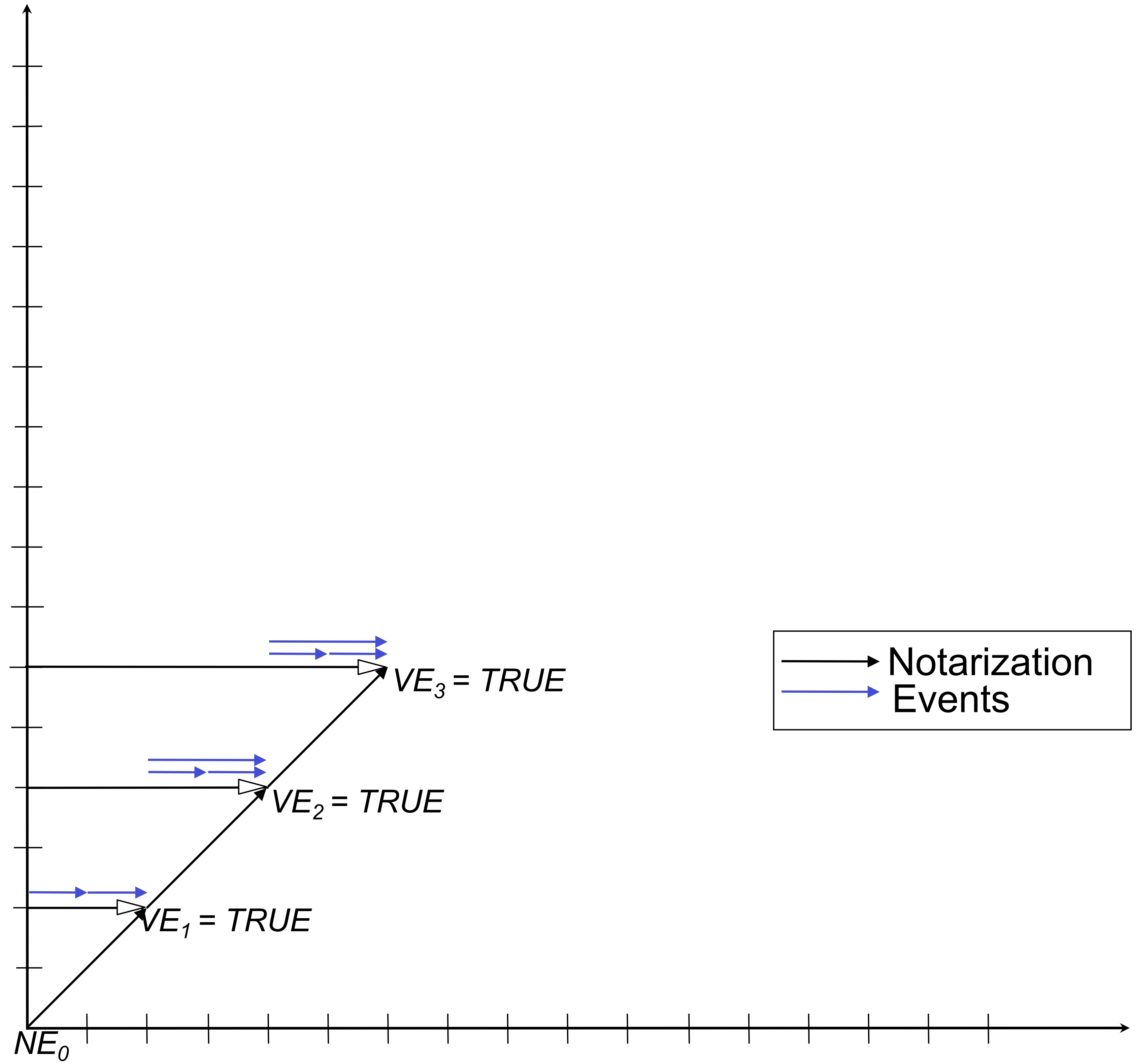
I_V = 2 days



The a3D Algorithm

When

R_s = 1 day
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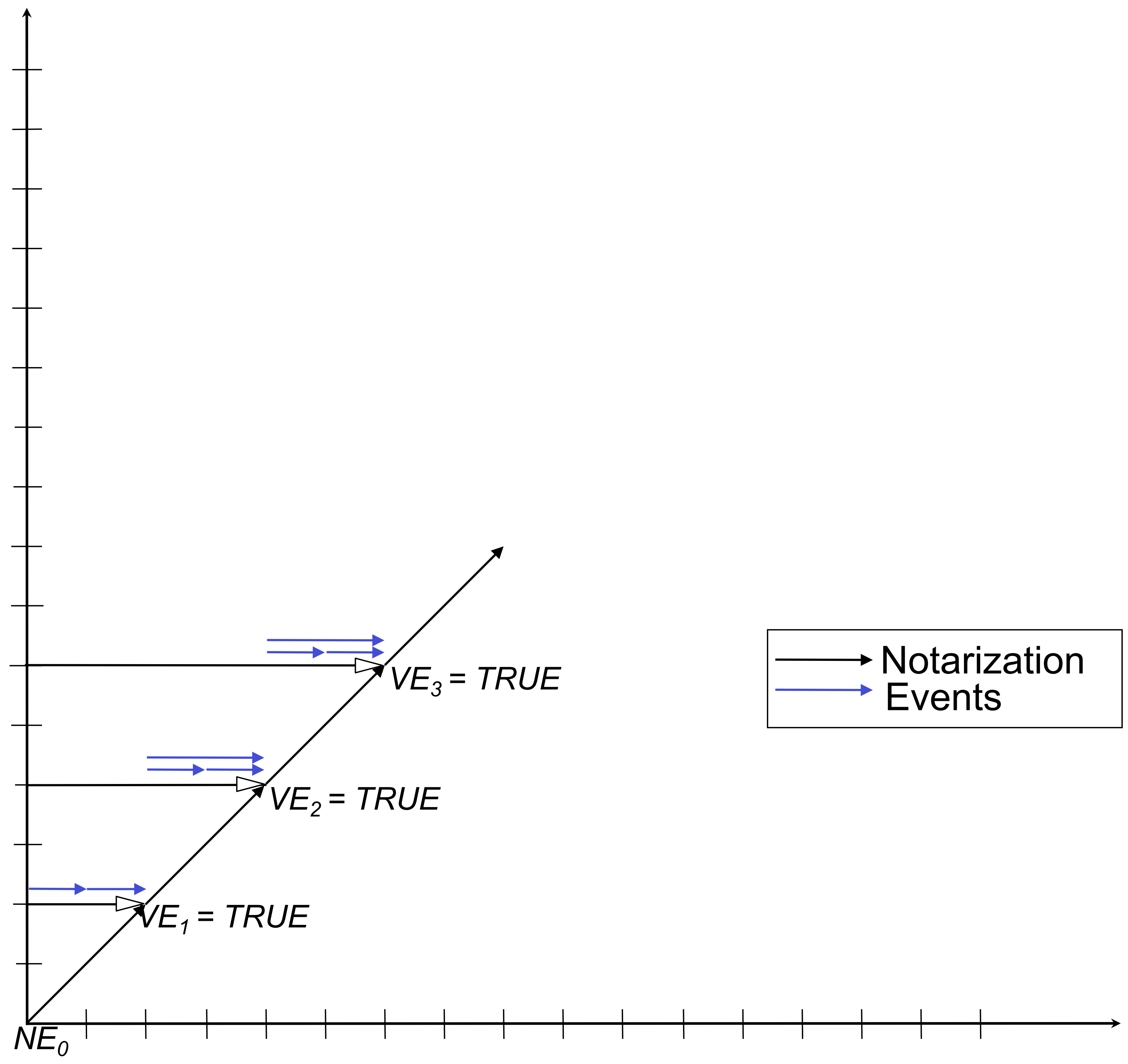

The a3D Algorithm

When

R_s = 1 day
N = 2
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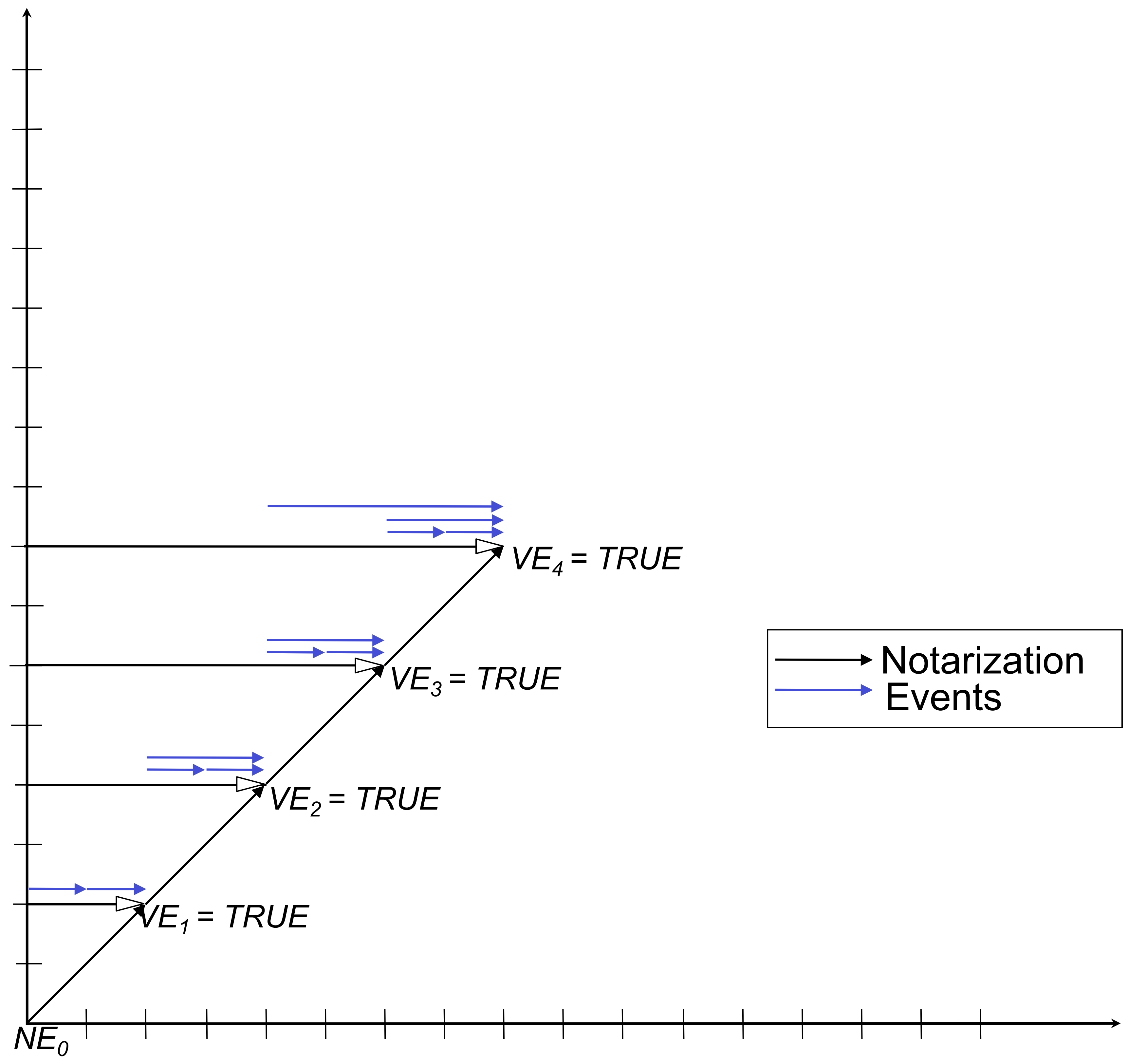
V = 1
I_V = 2 days



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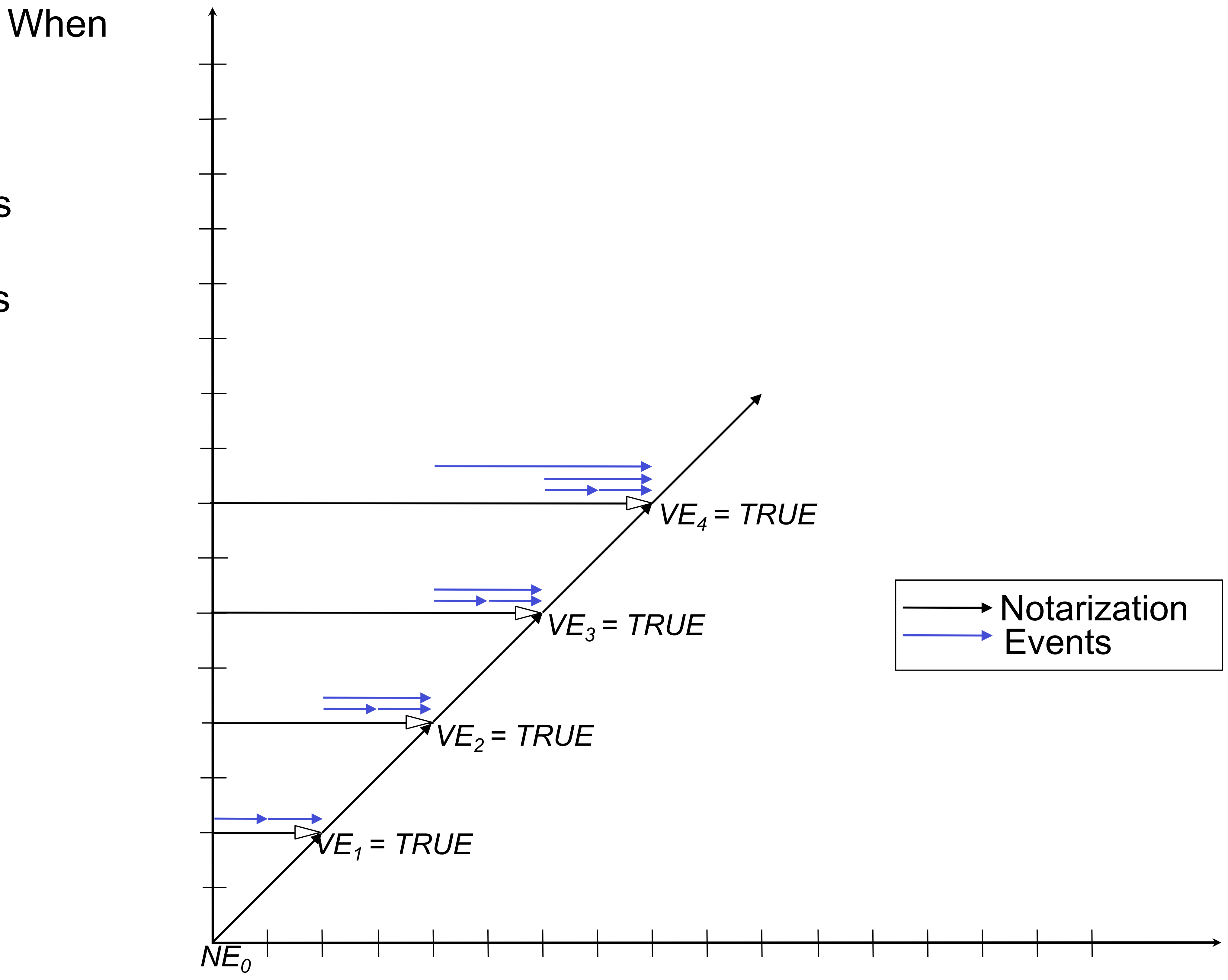

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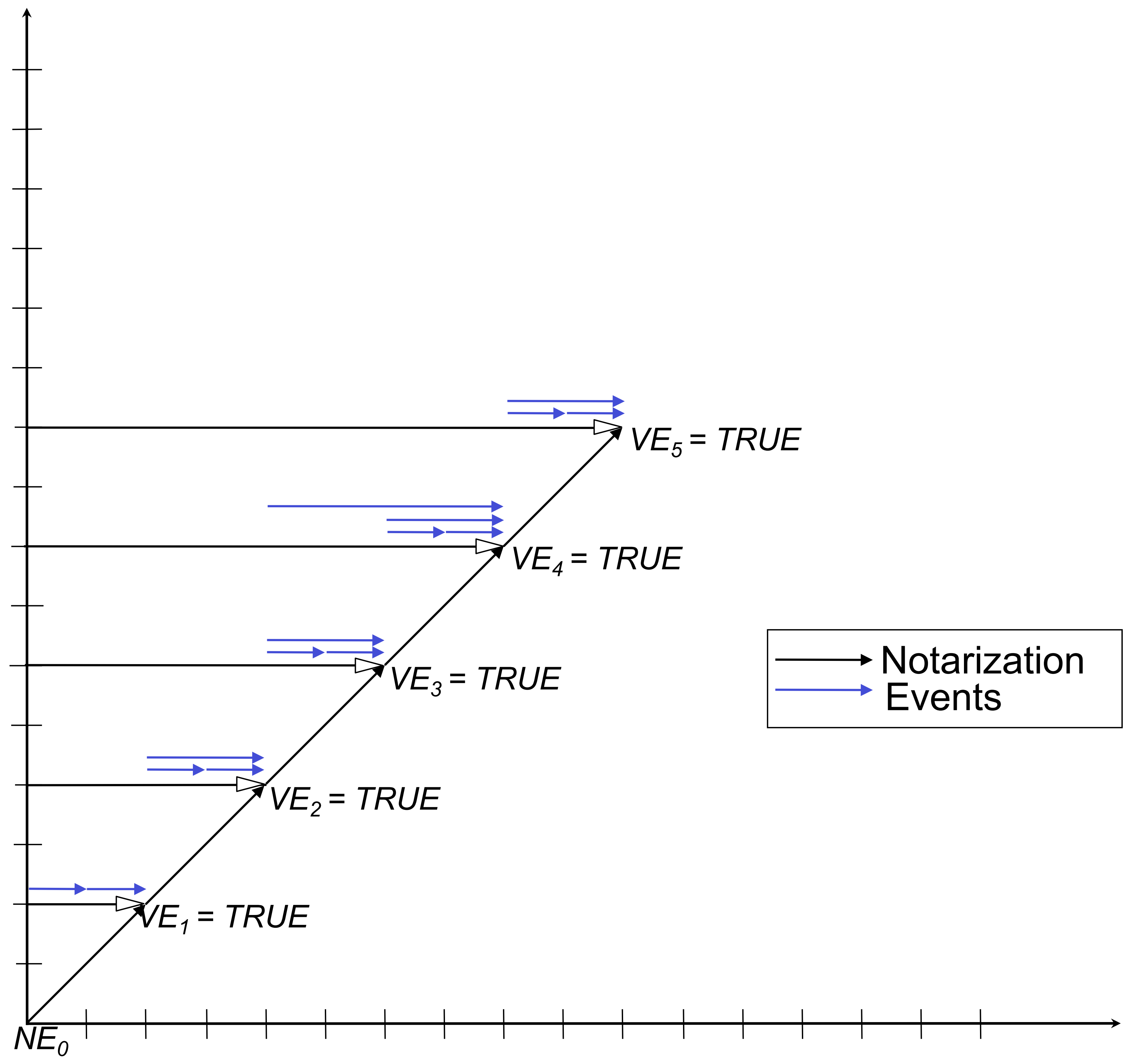
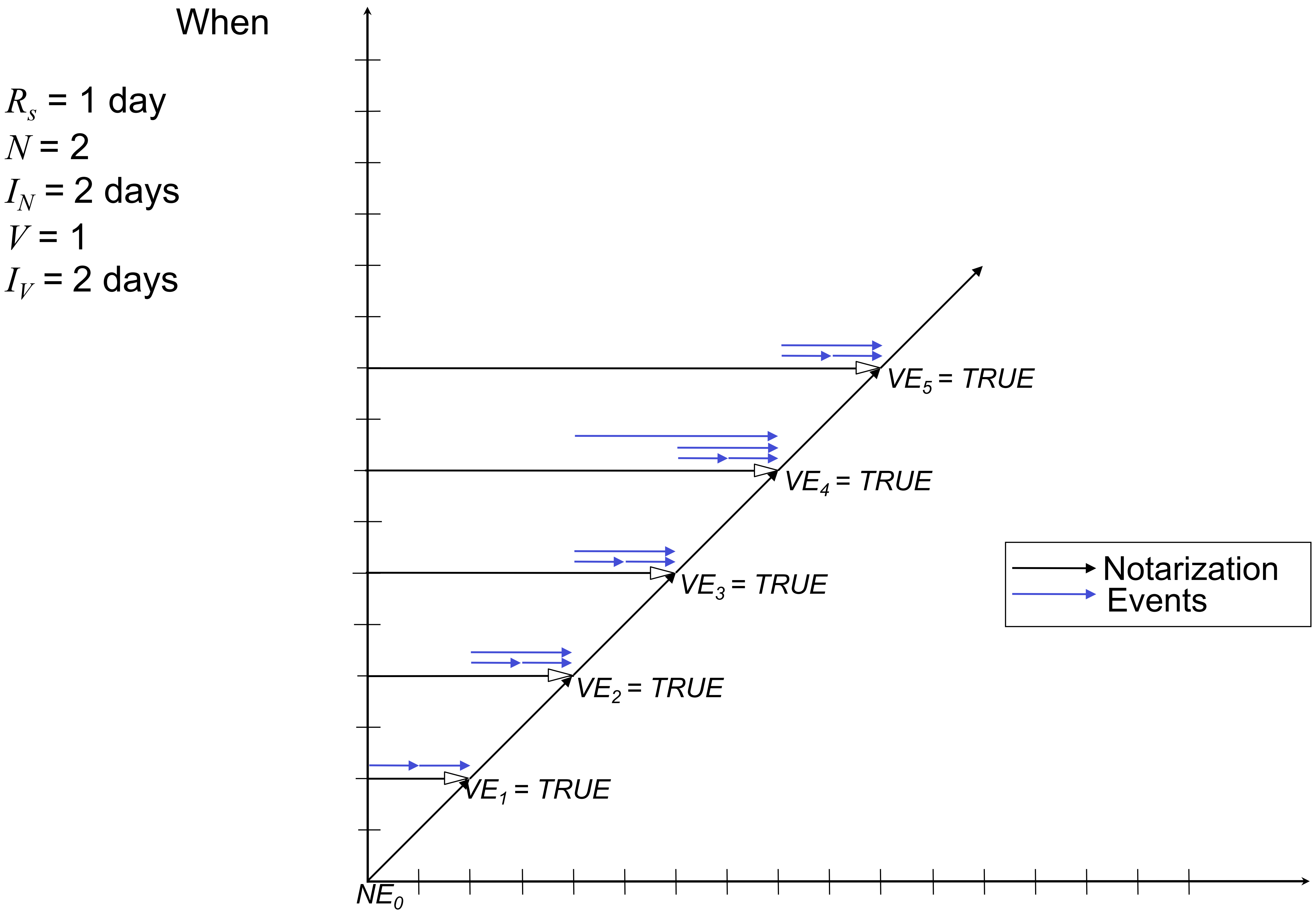


The a3D Algorithm



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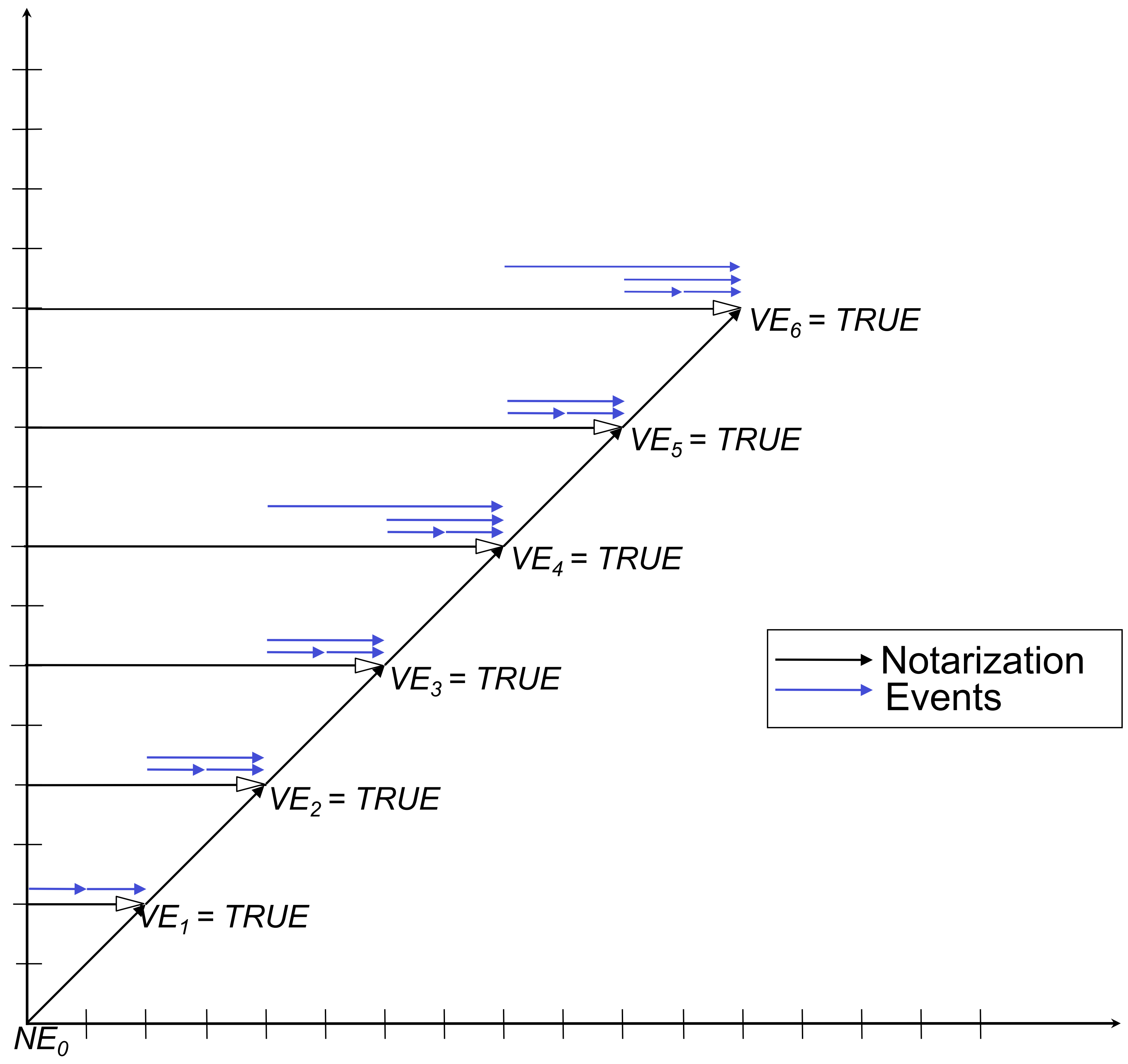

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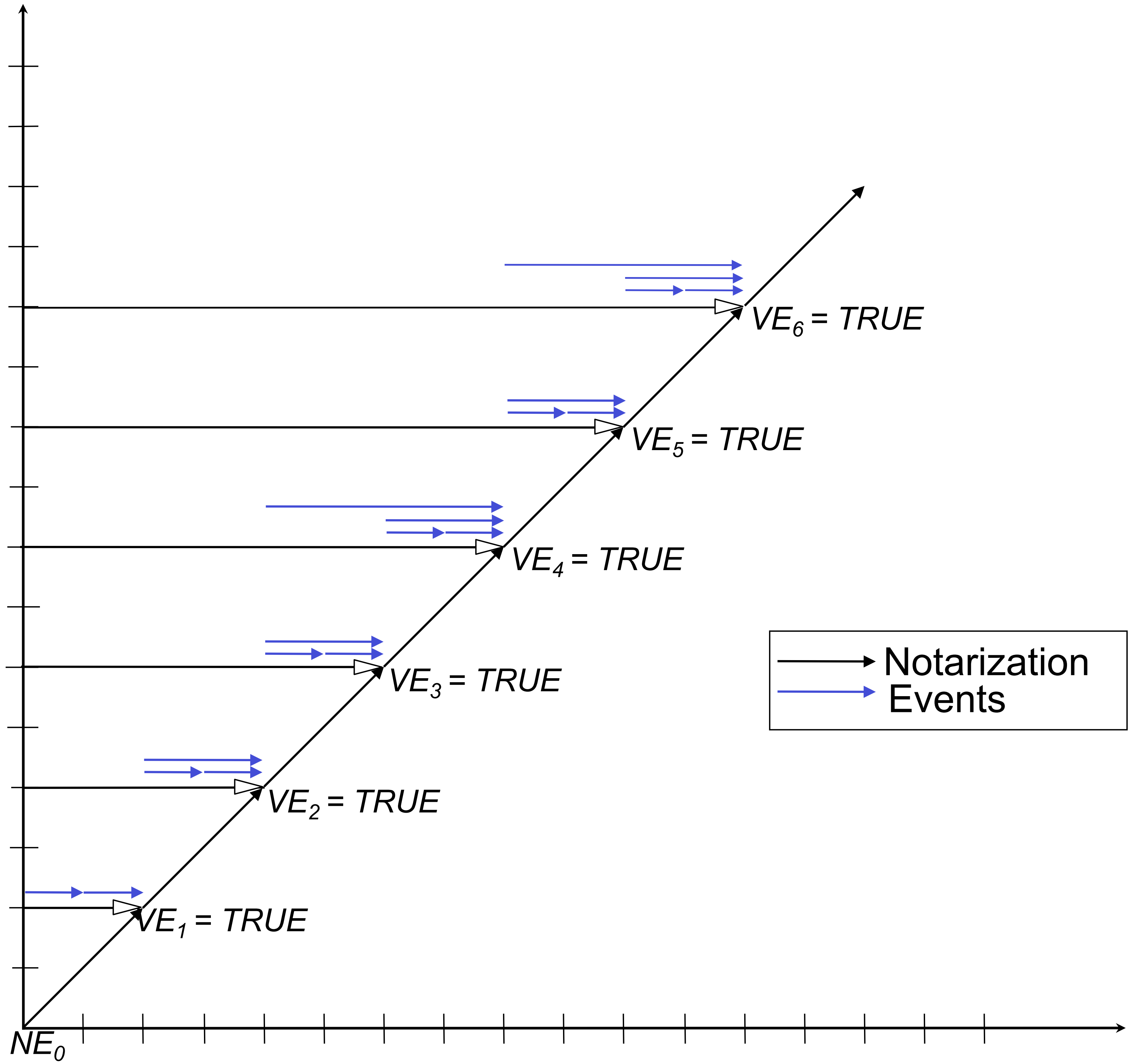

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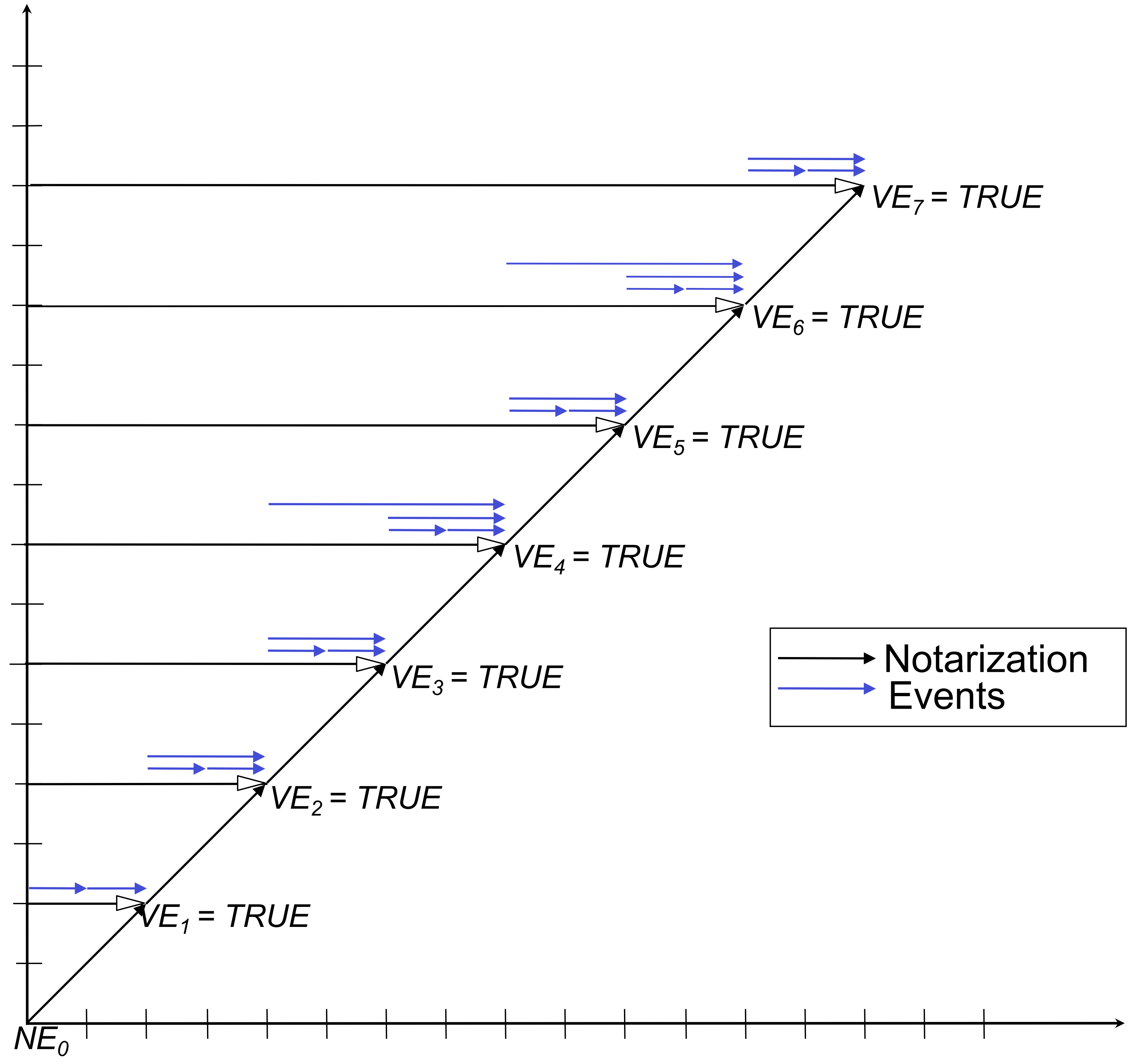

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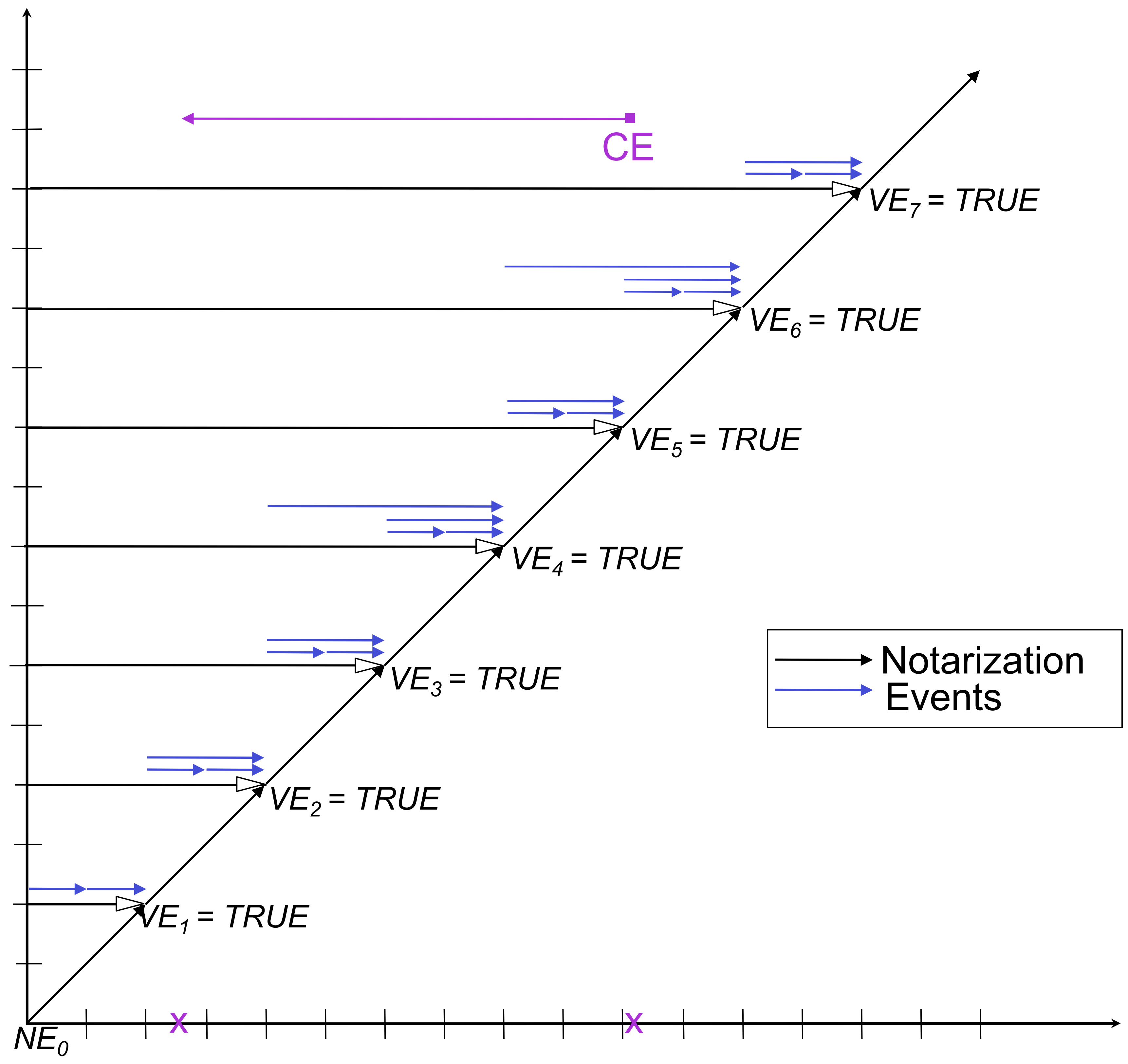

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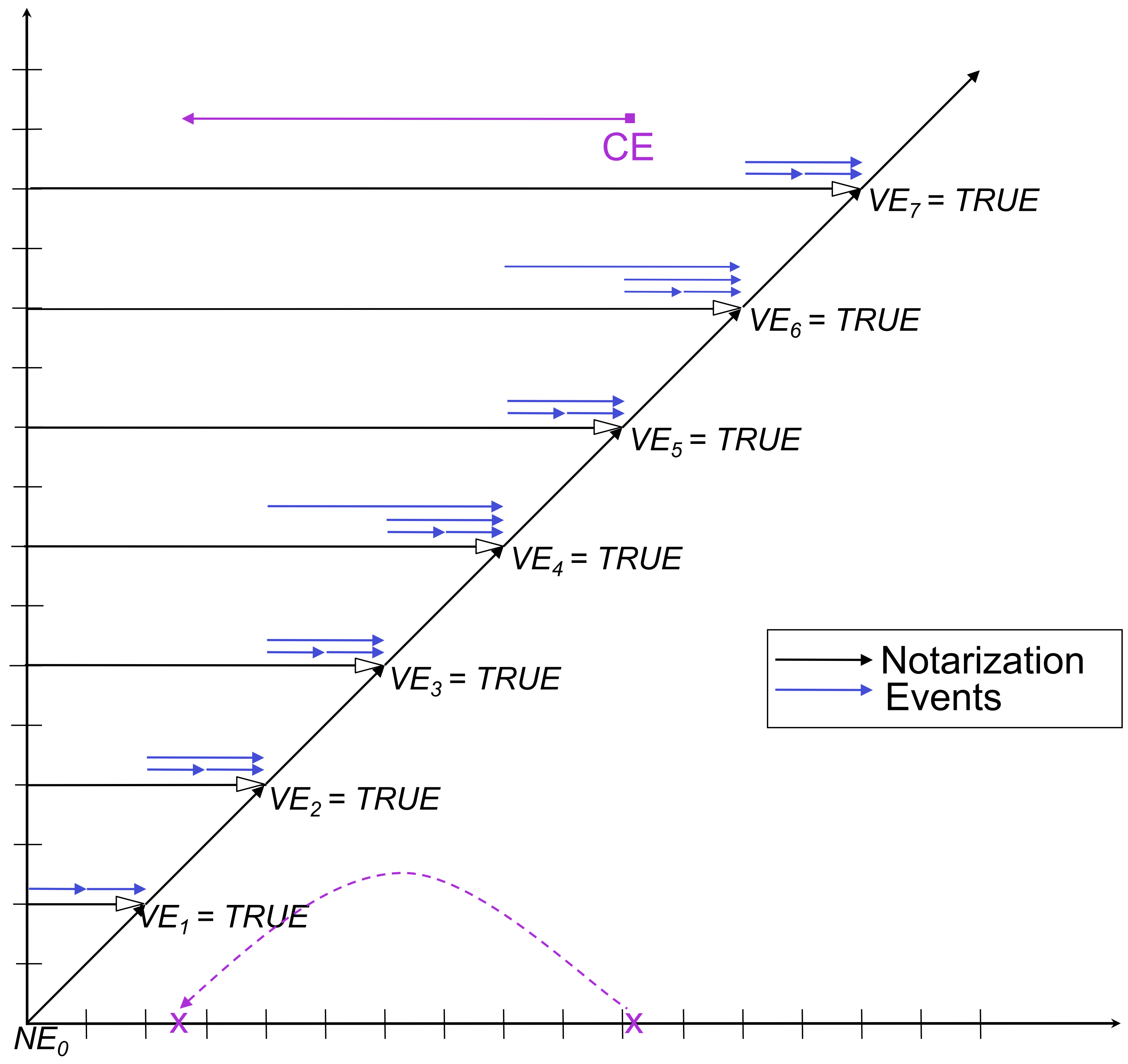

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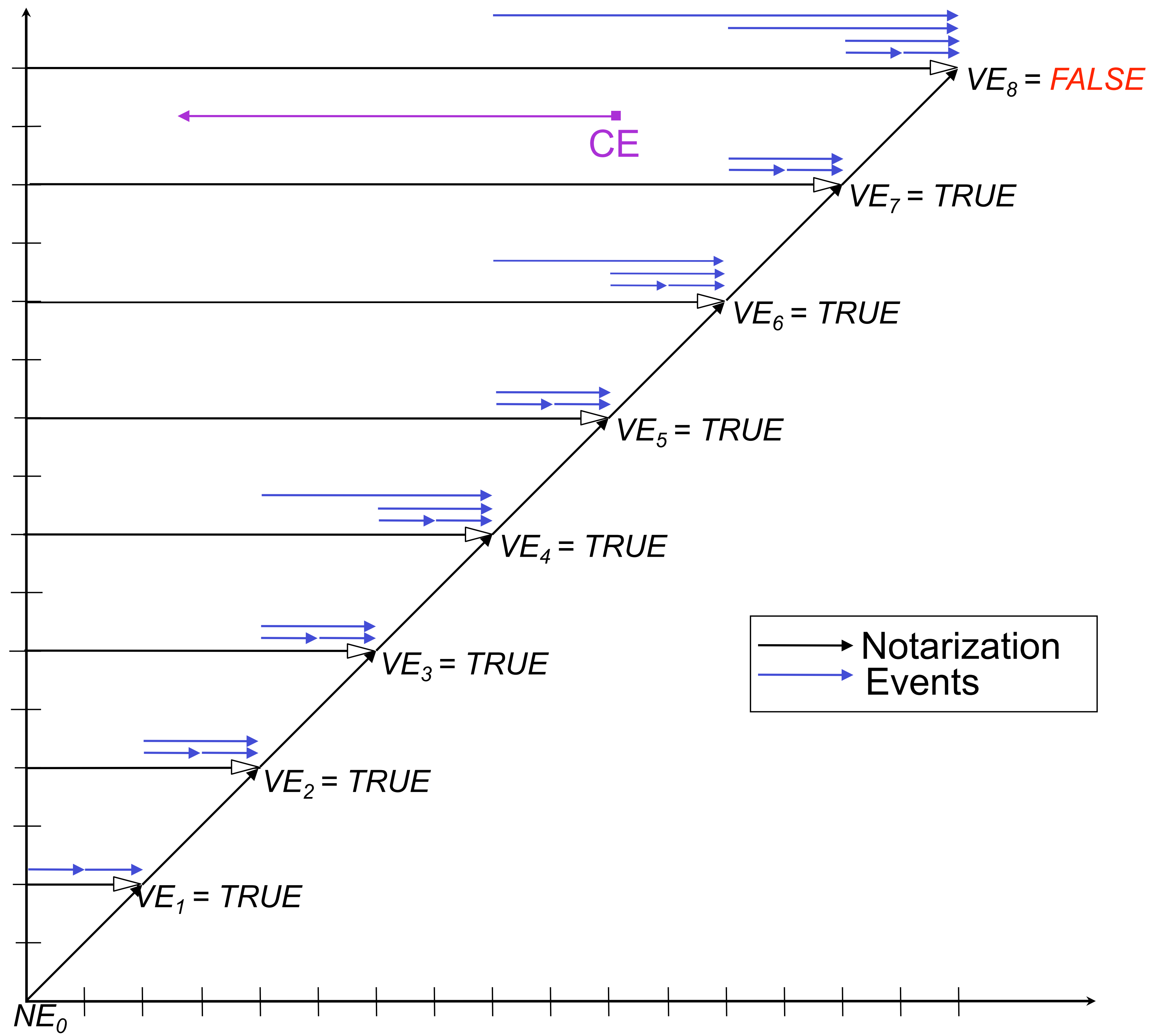

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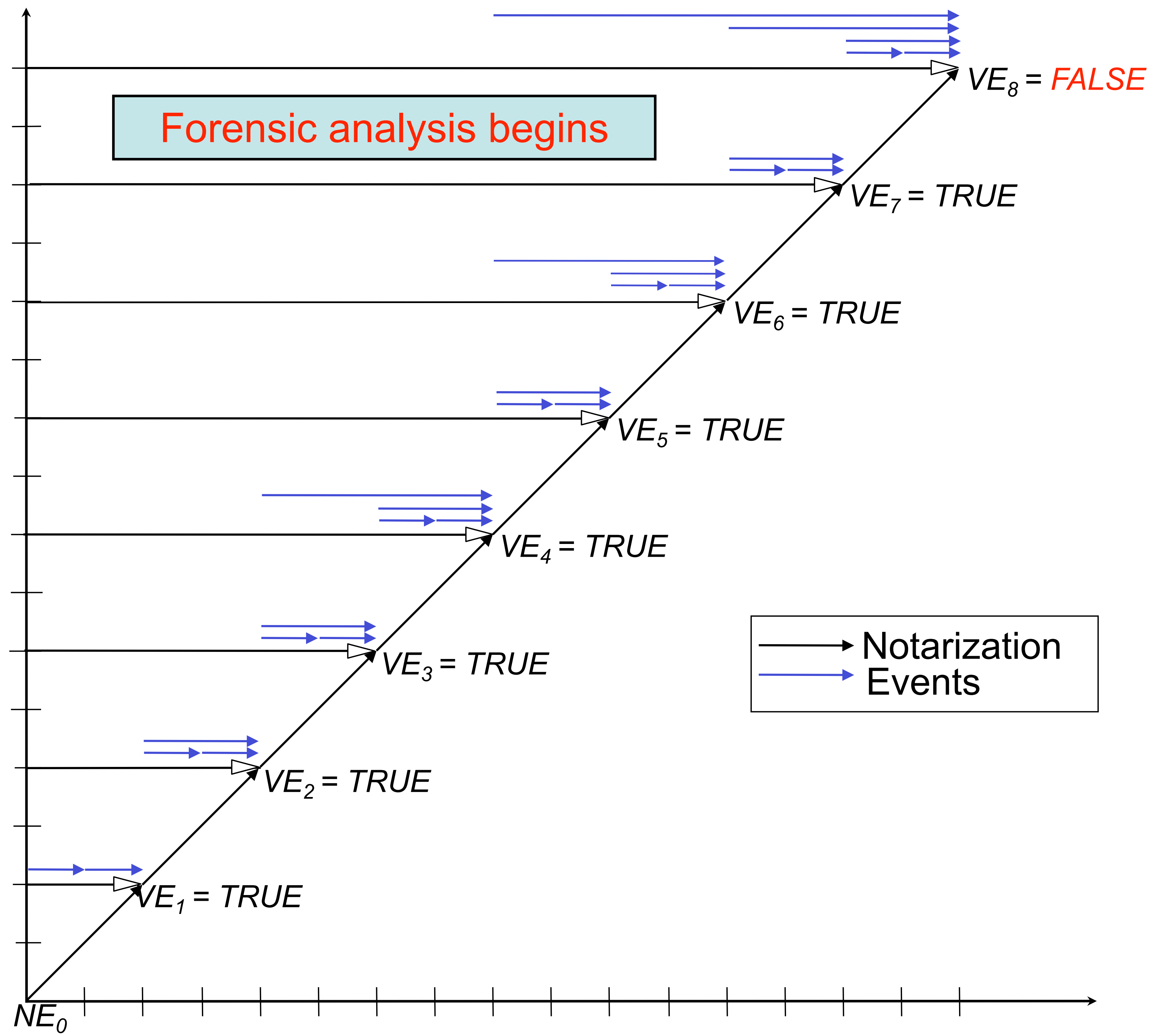

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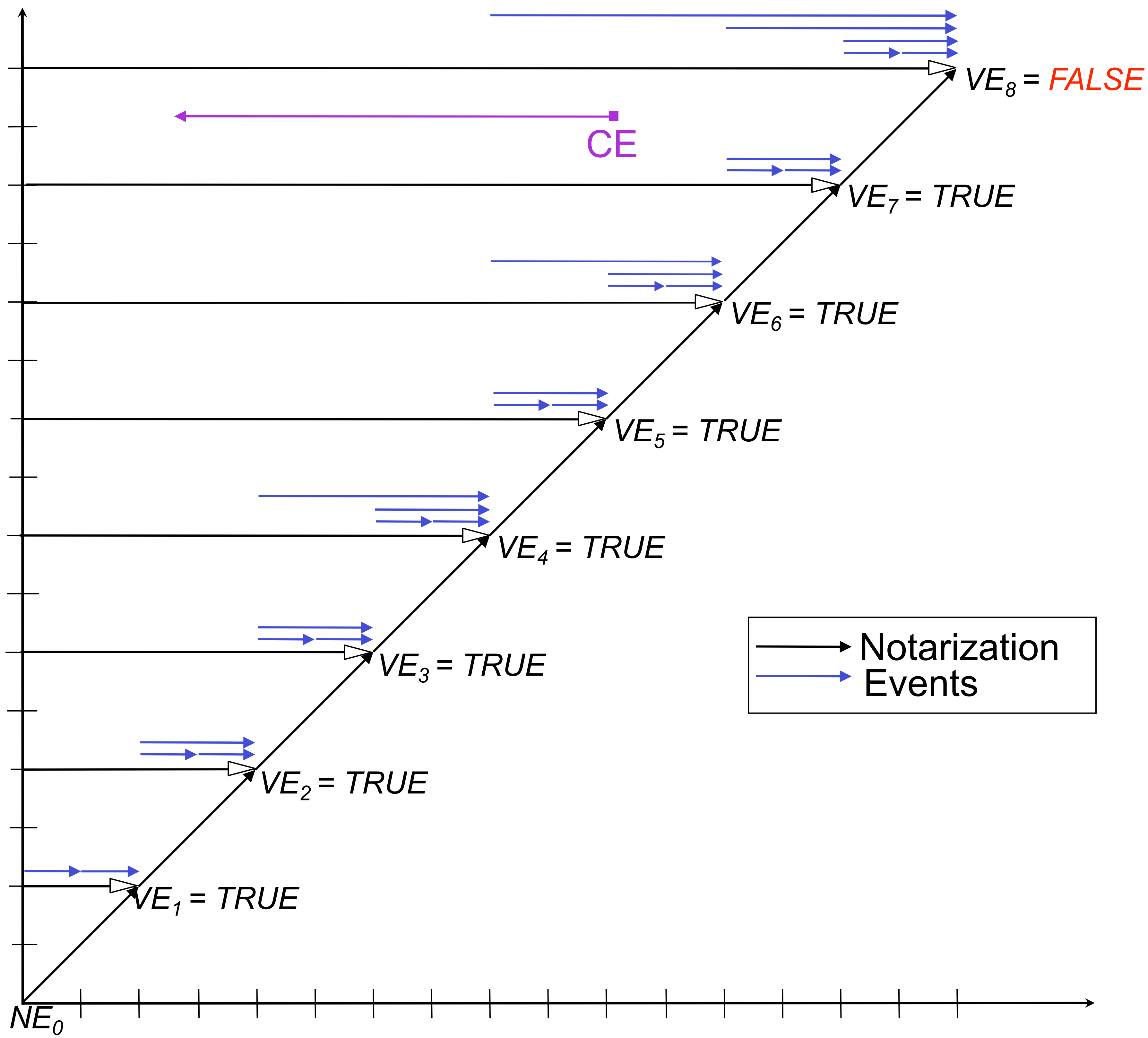

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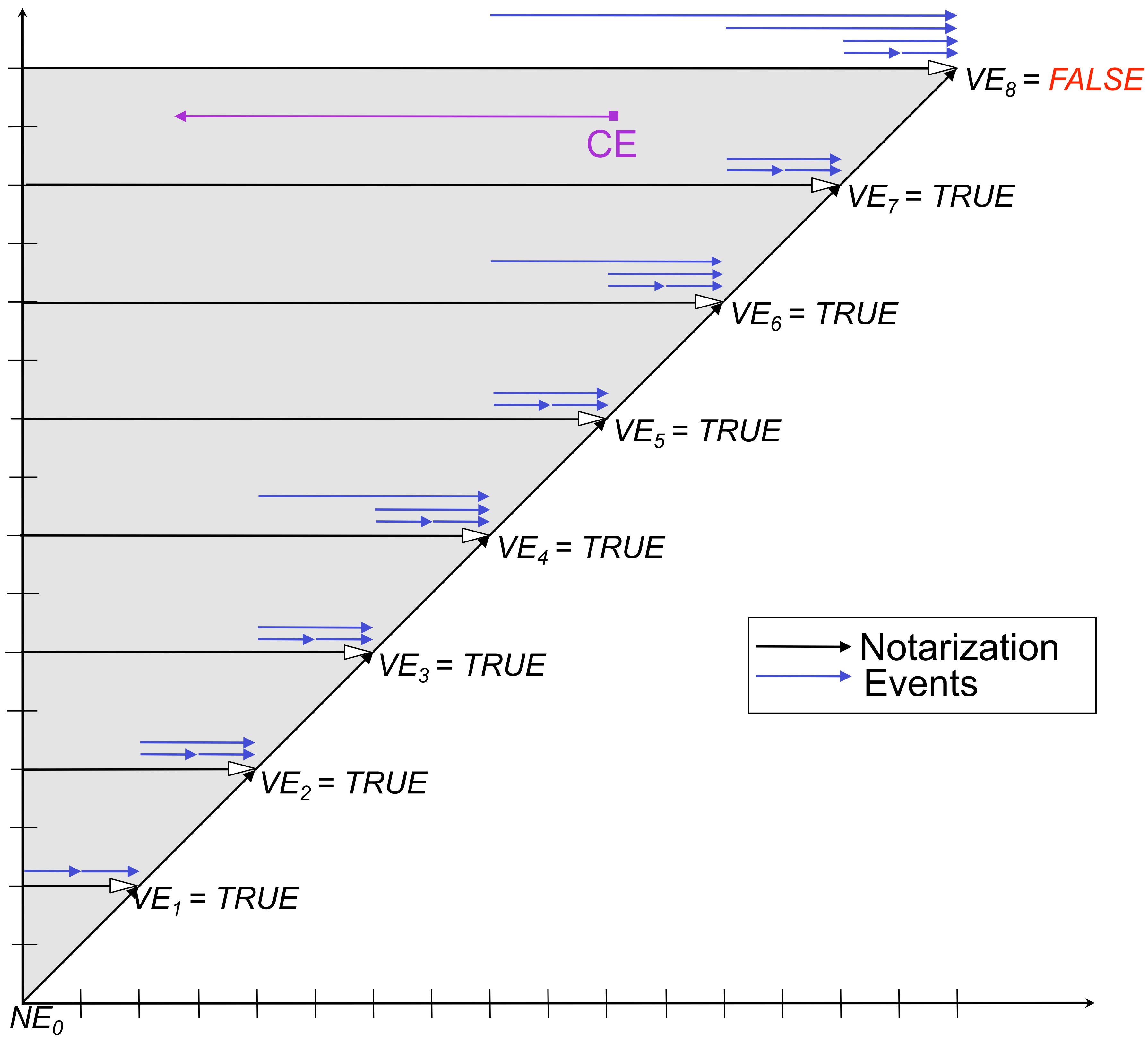

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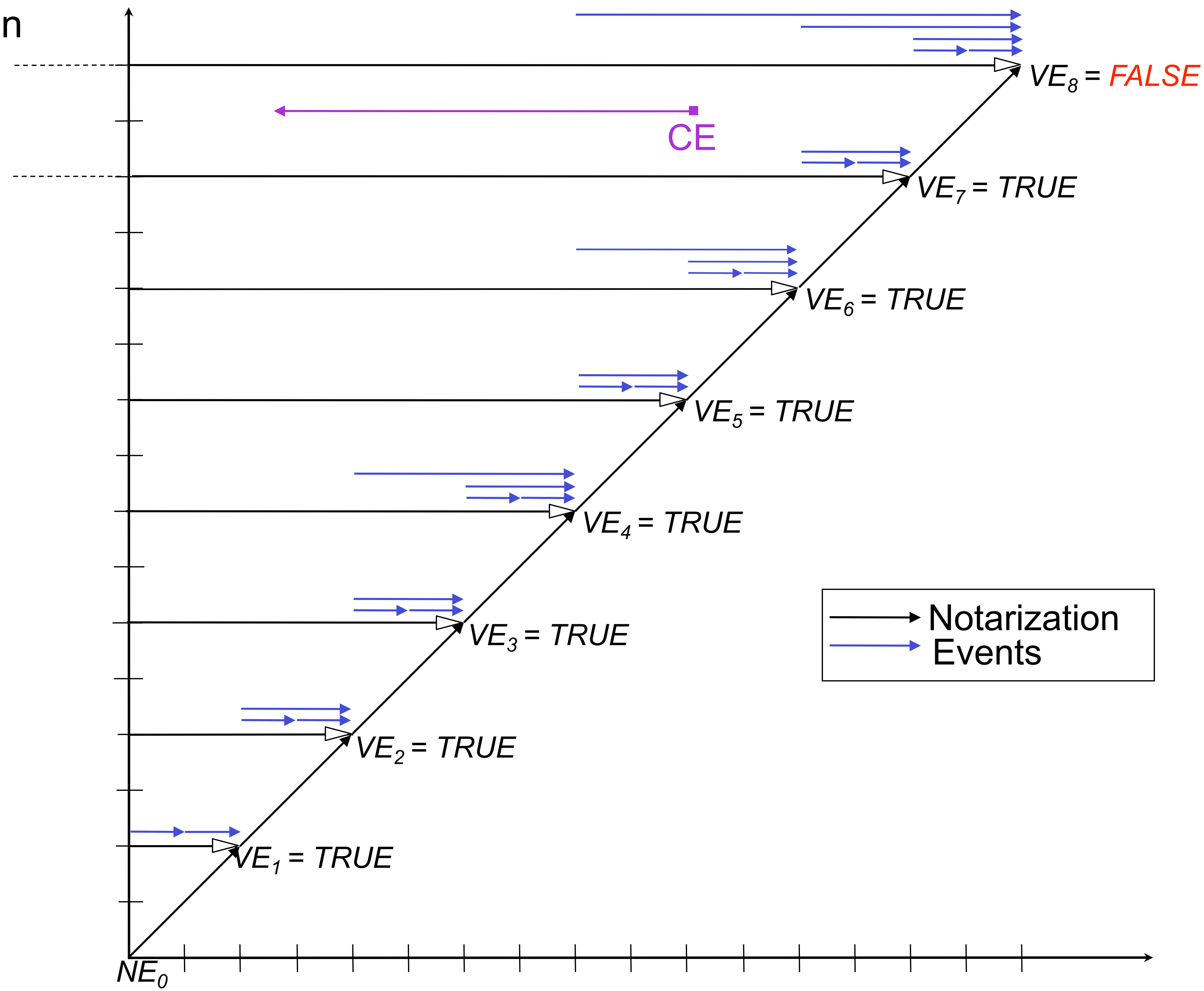

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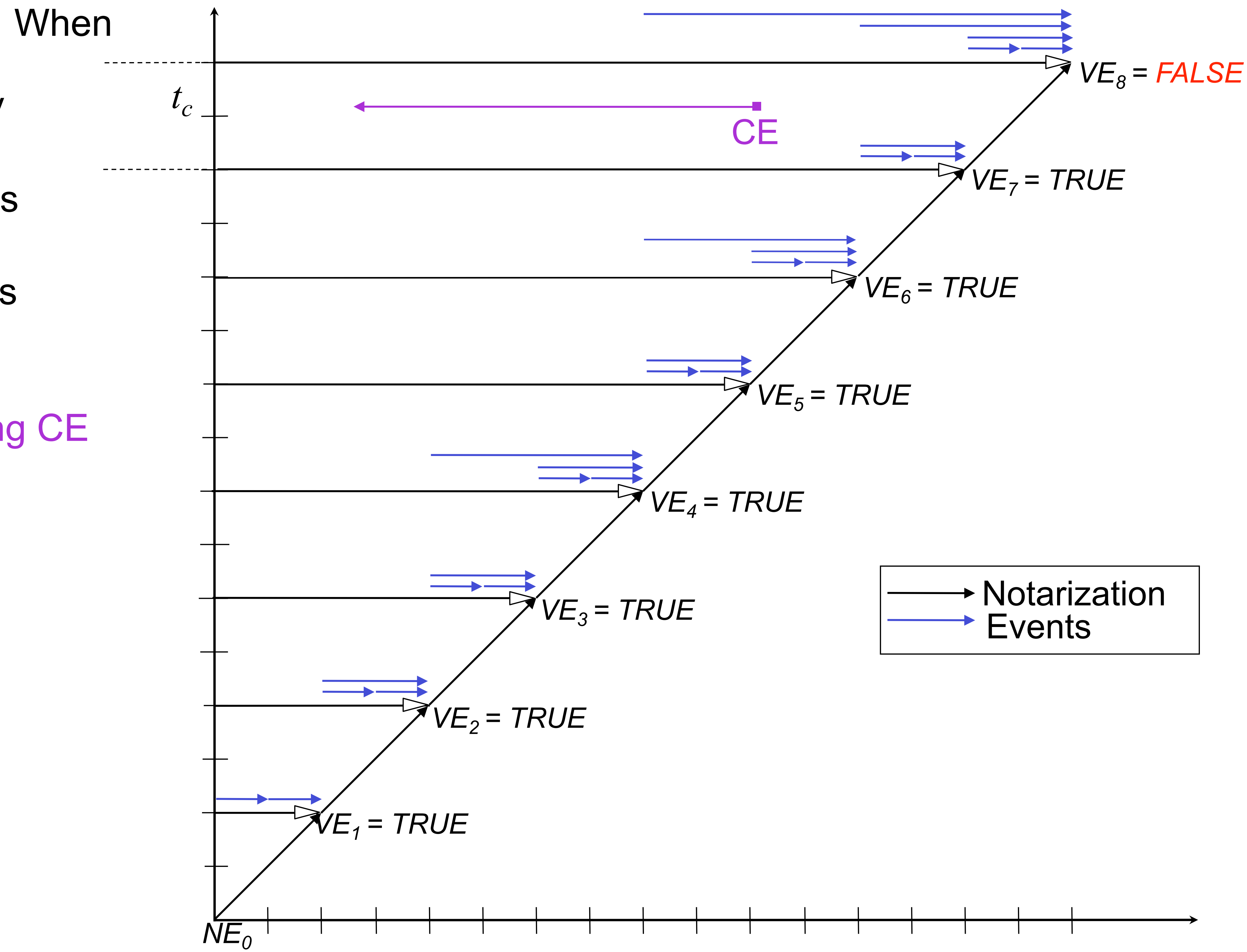

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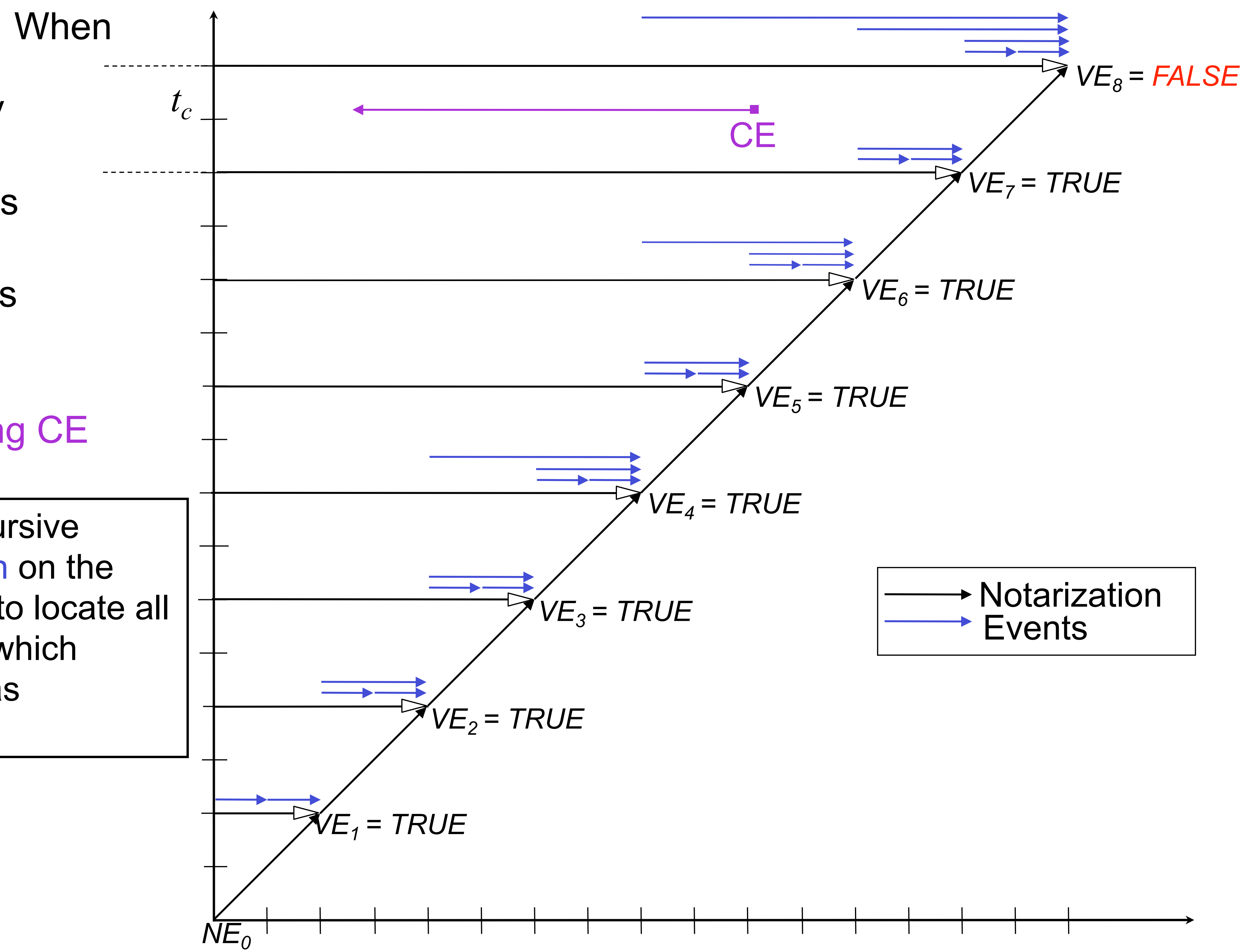

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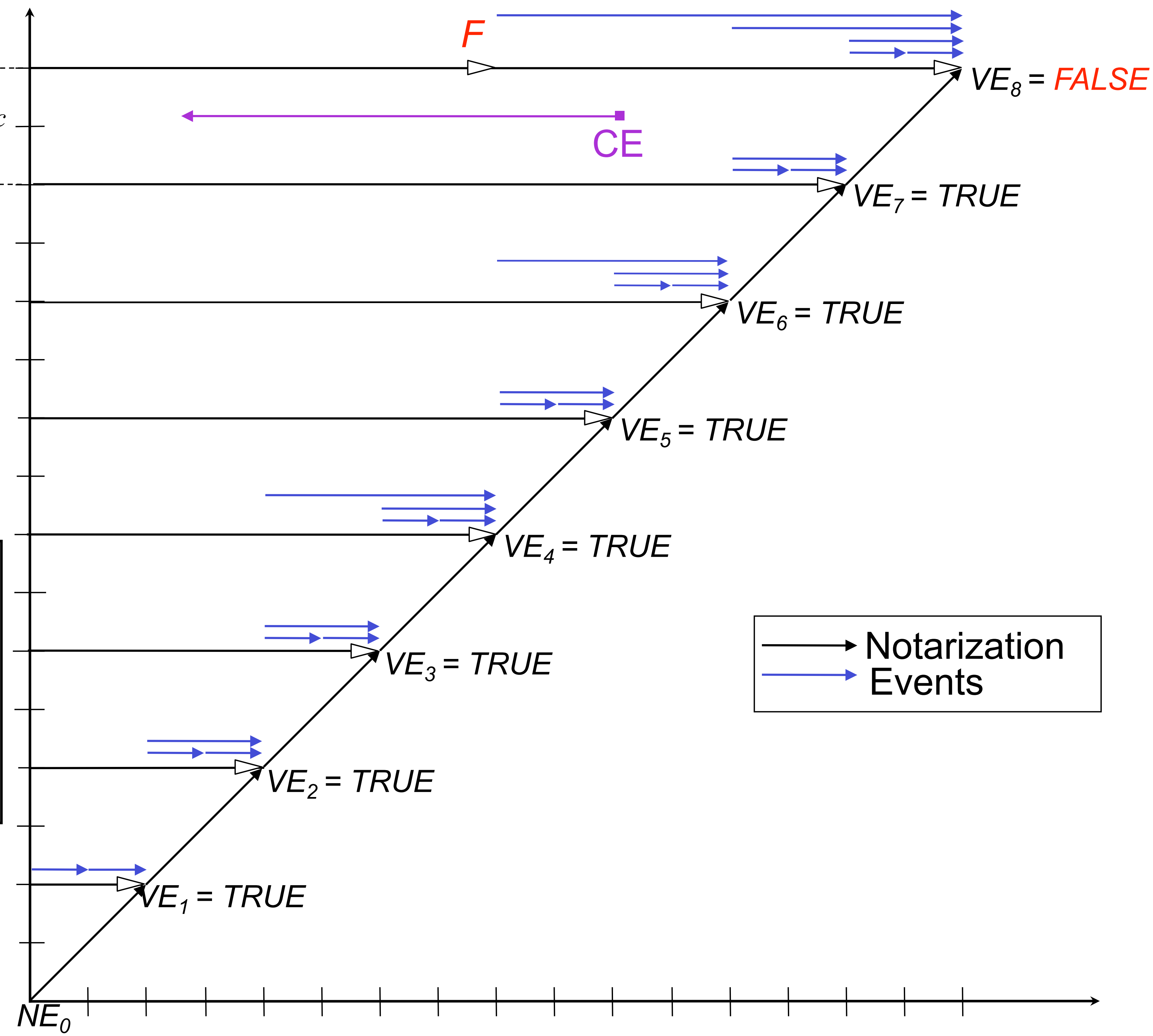

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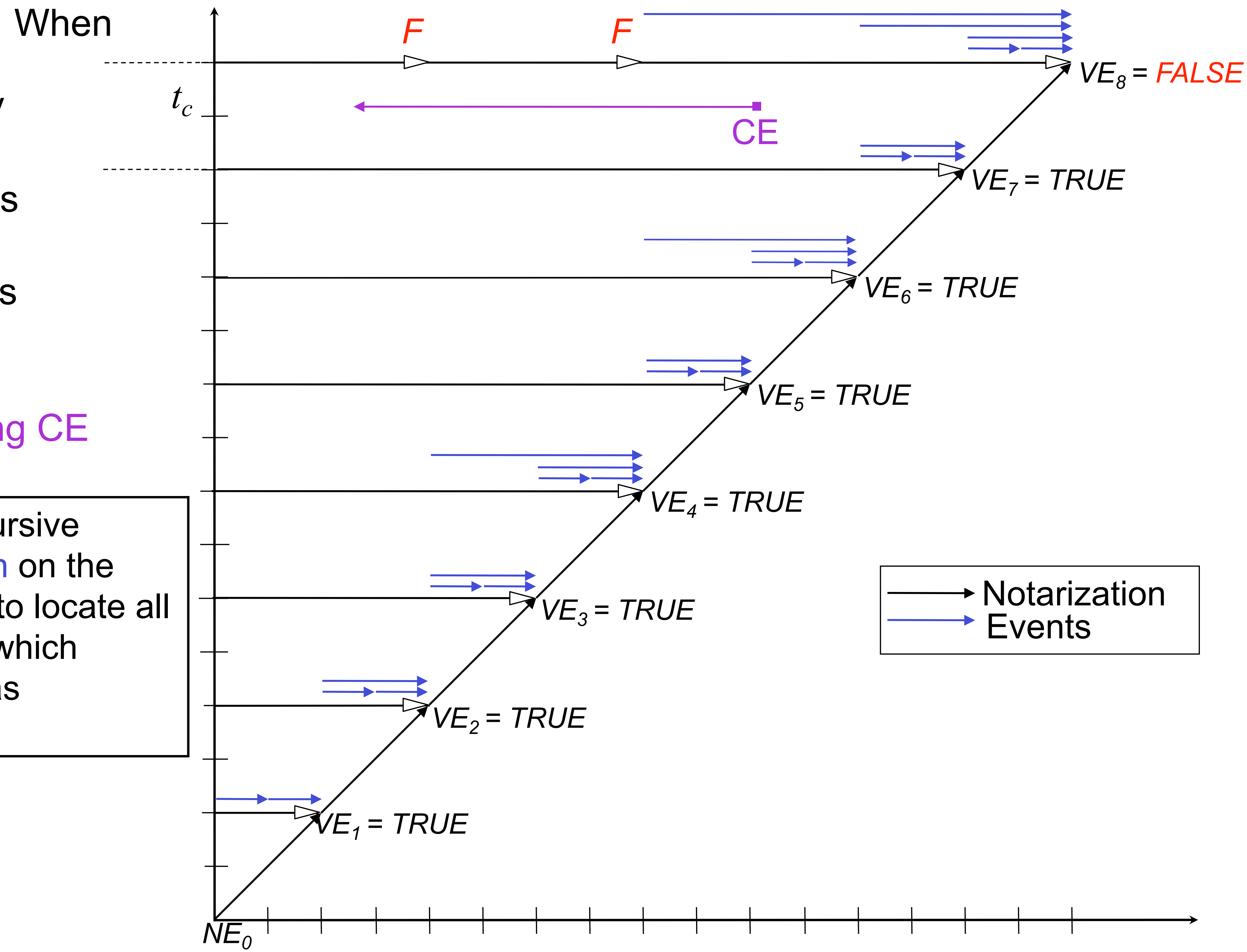

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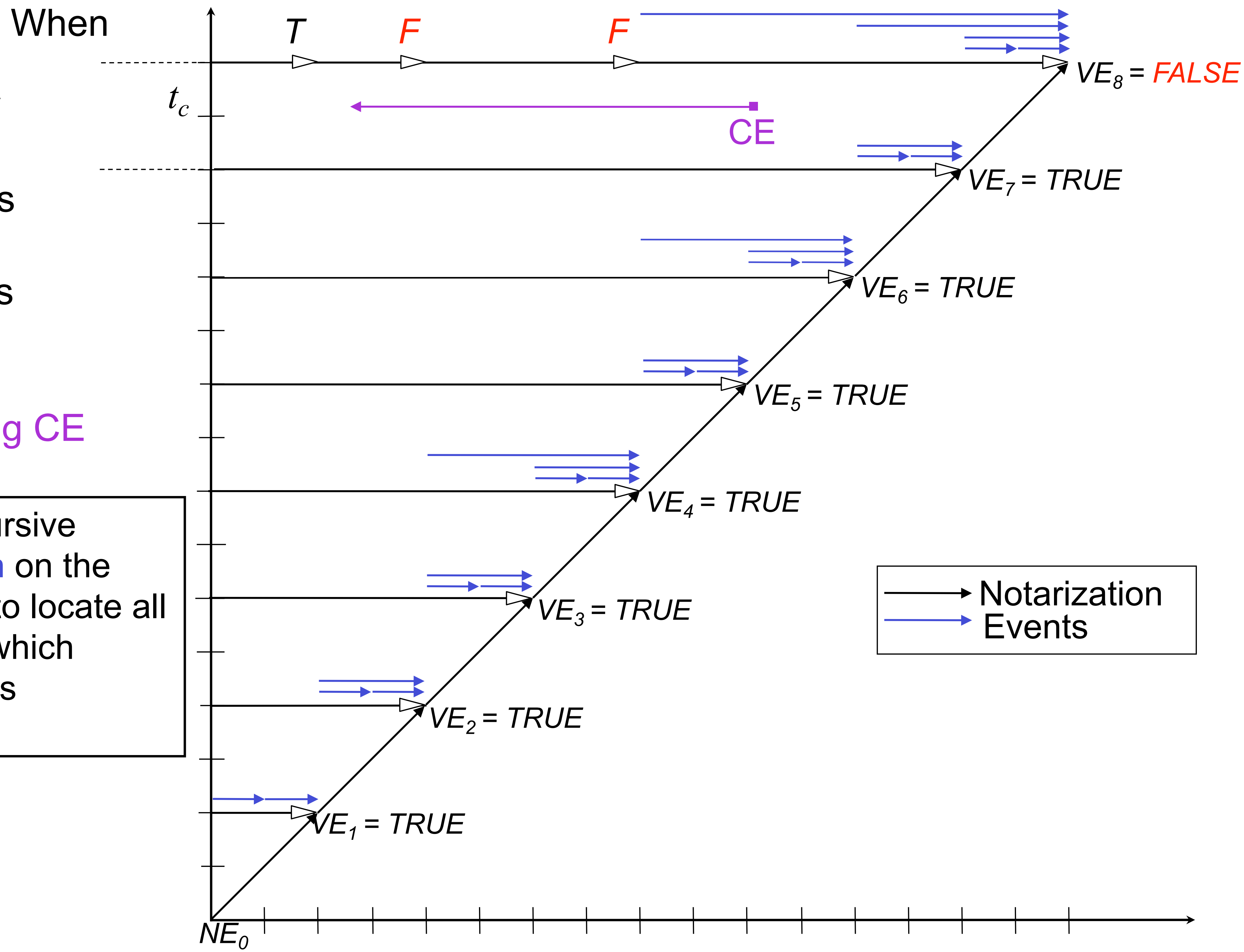

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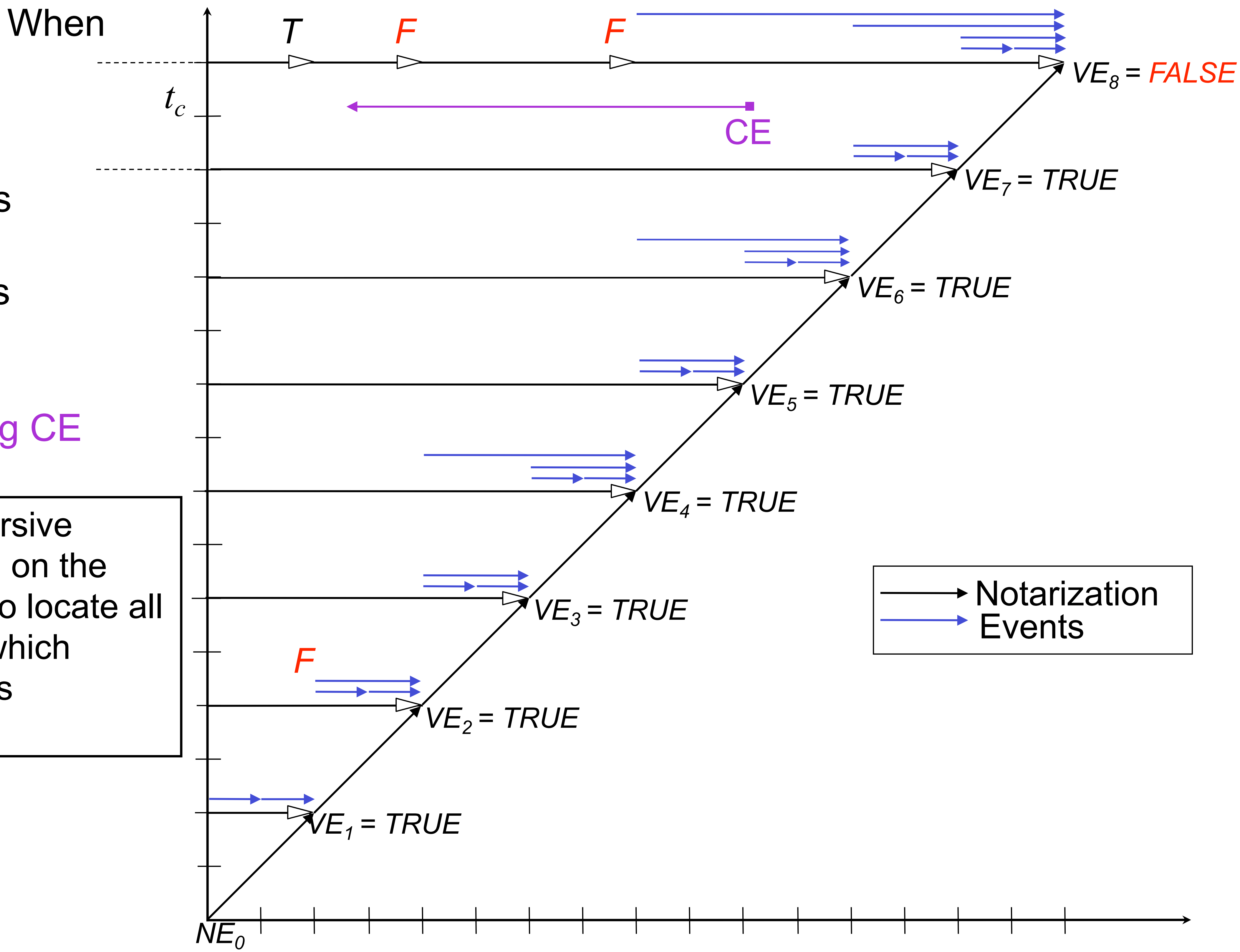

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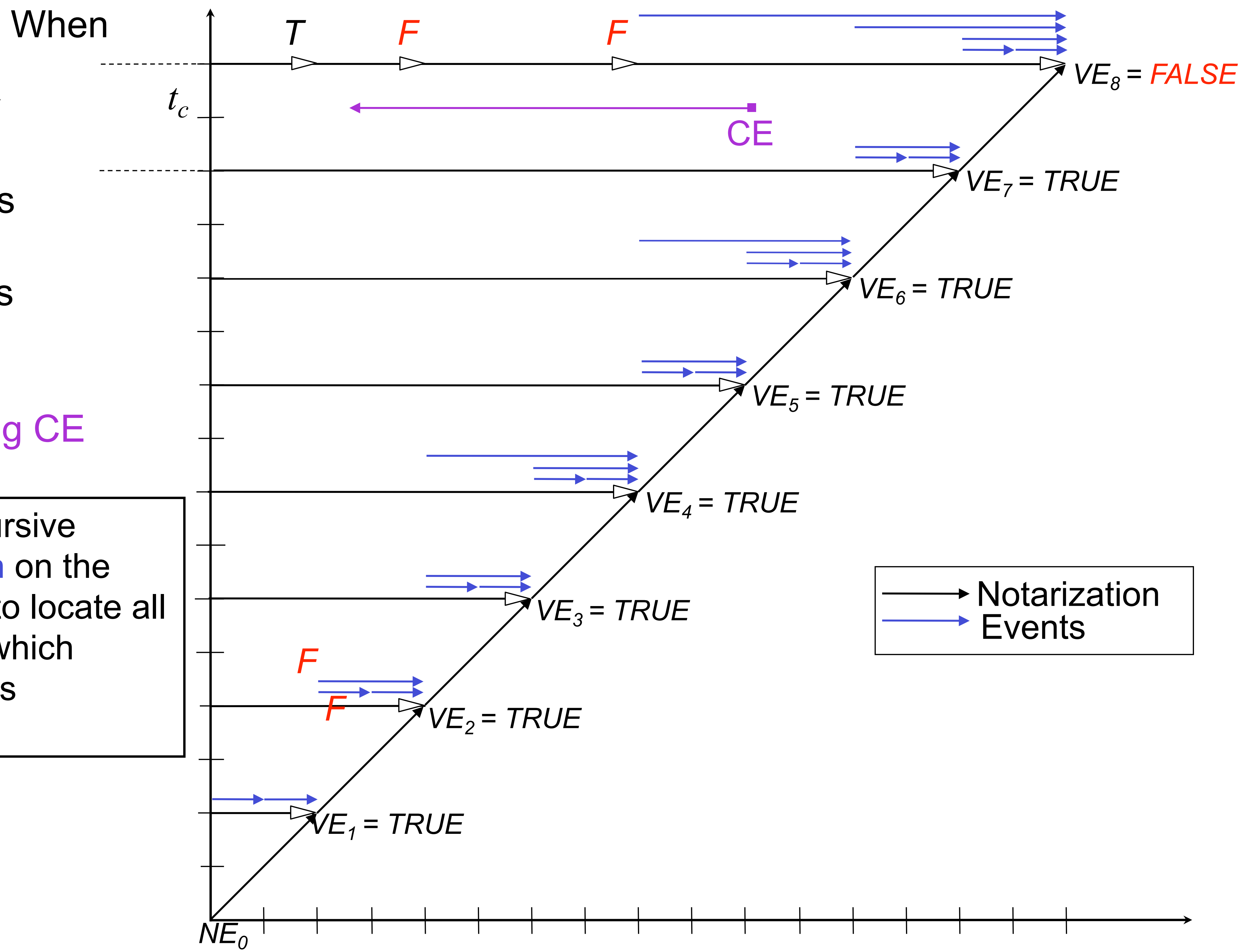

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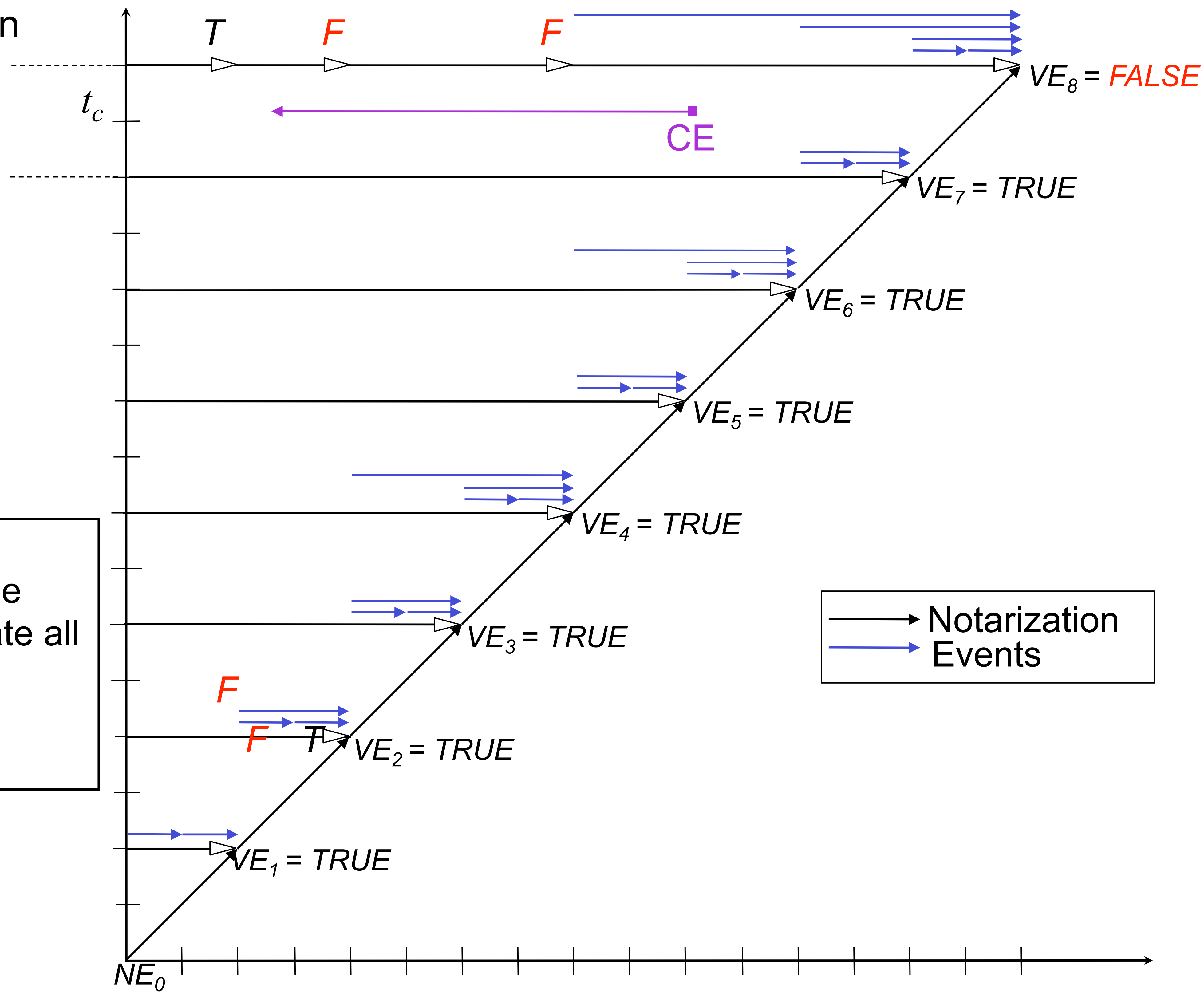

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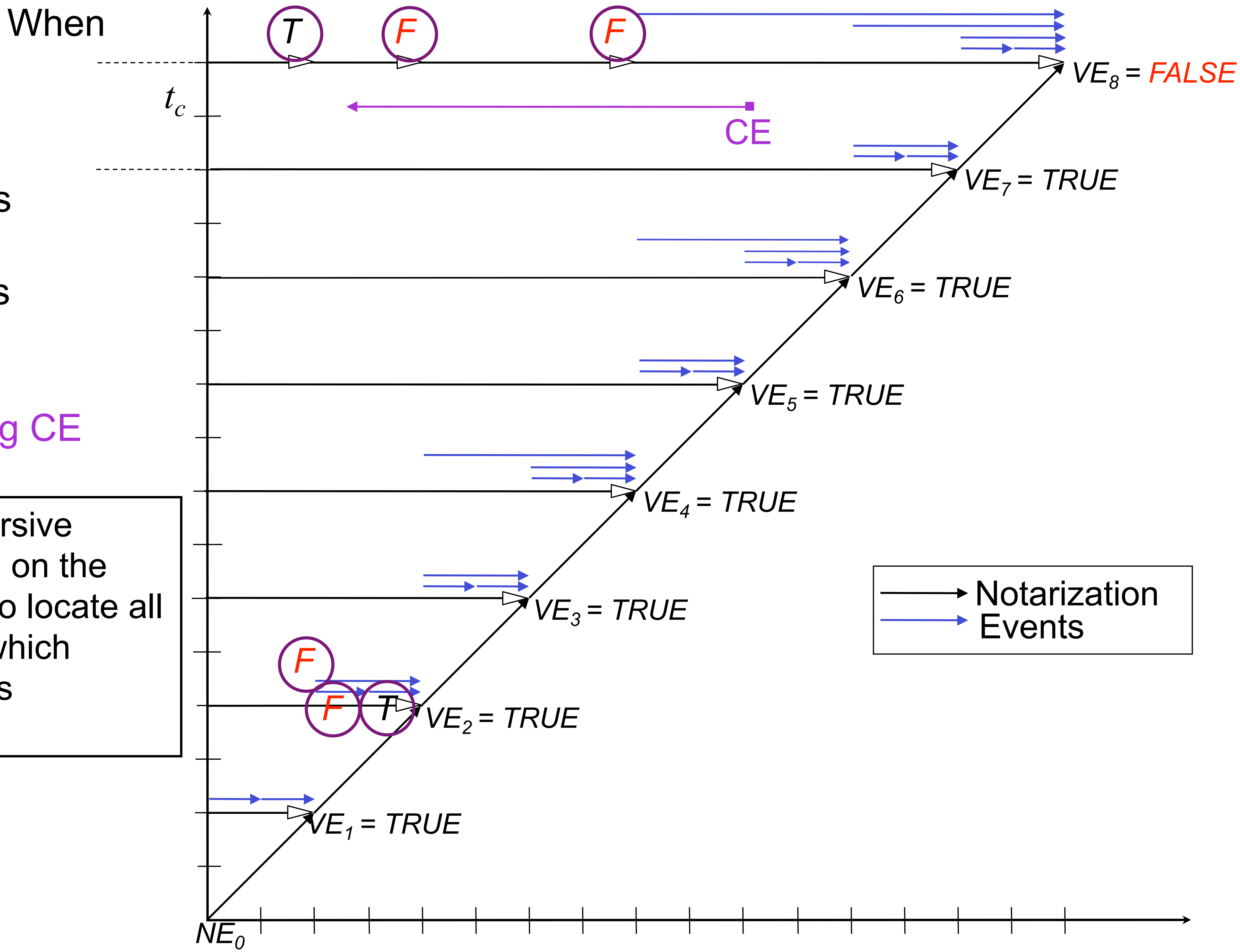

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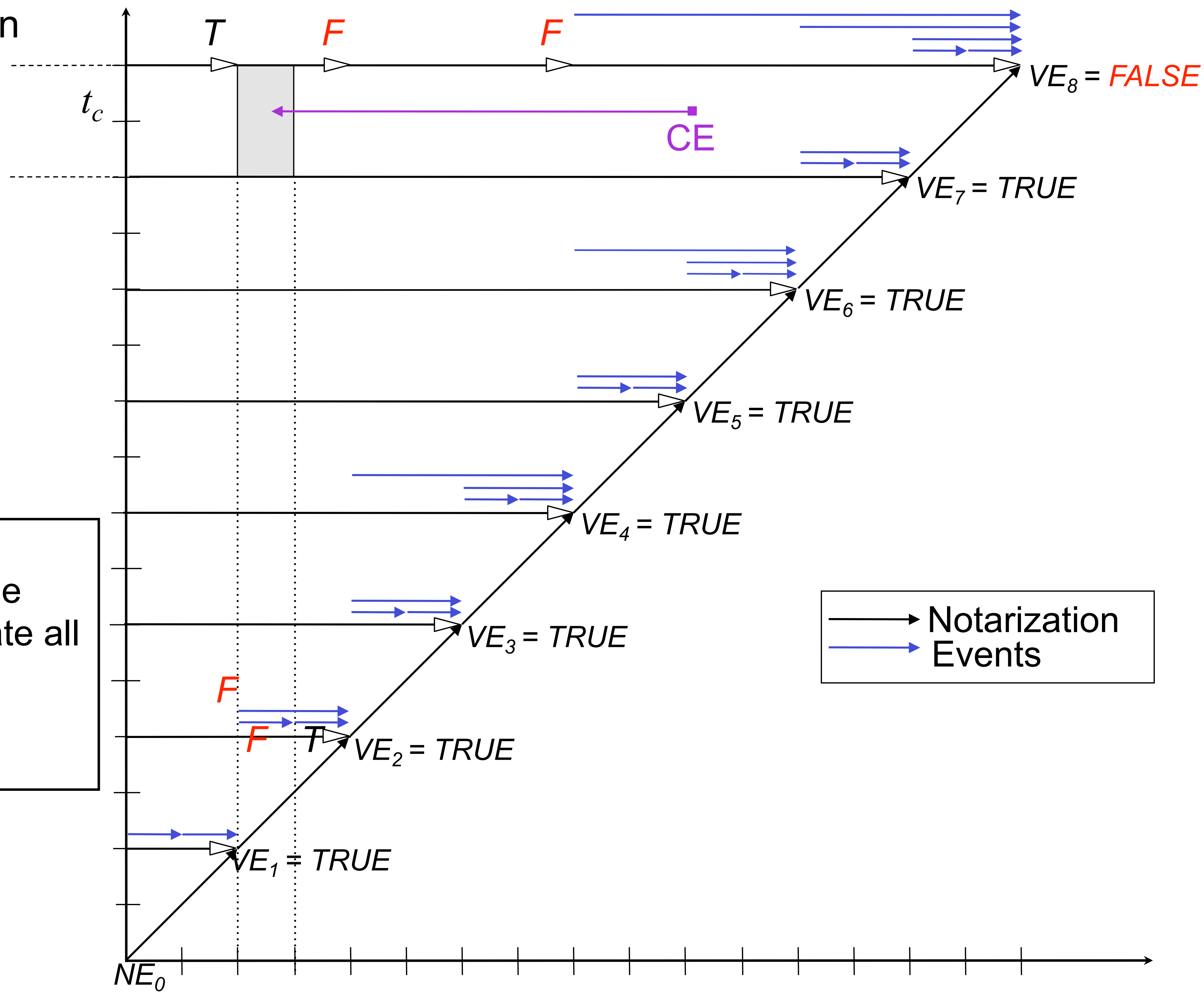

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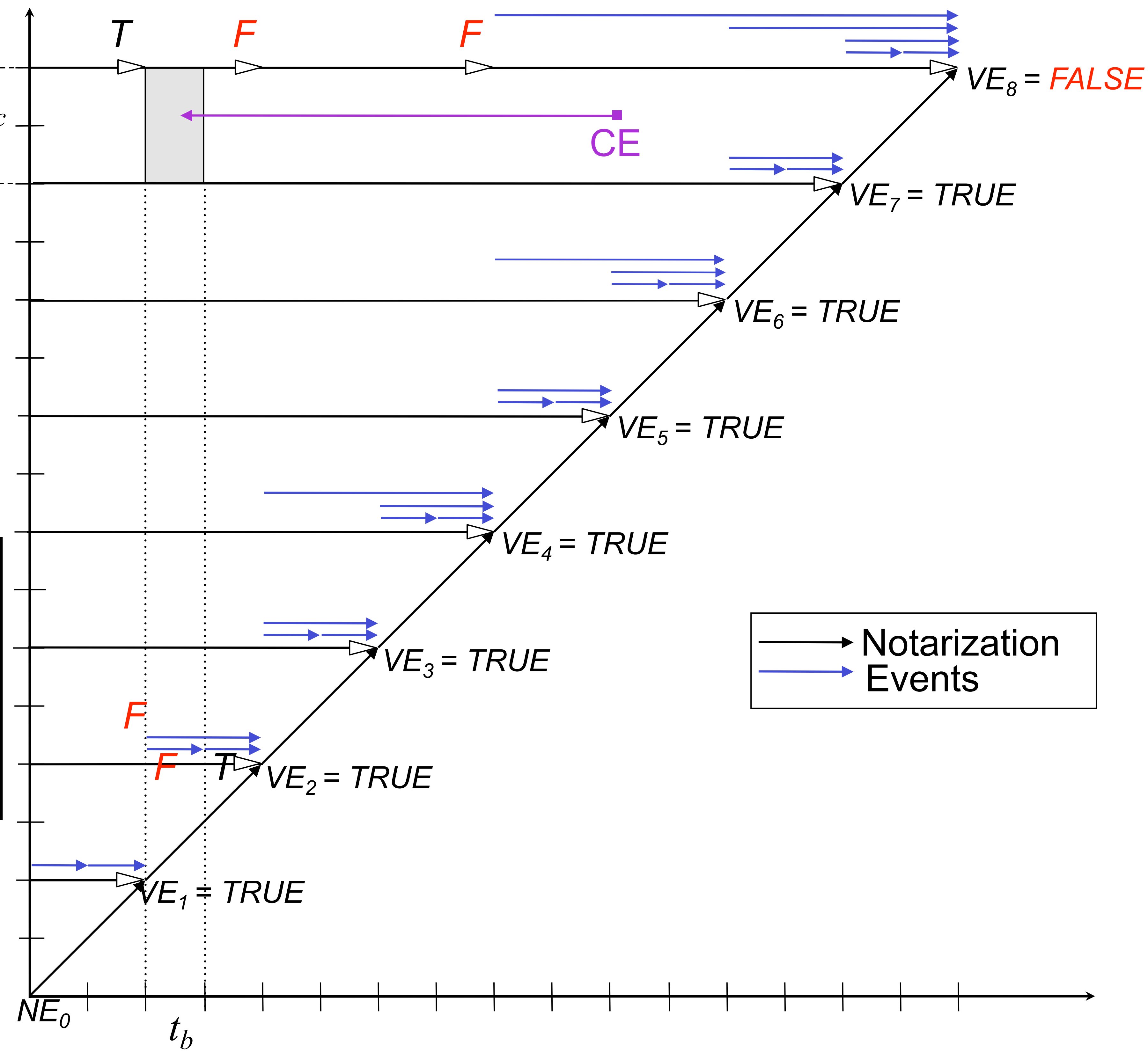

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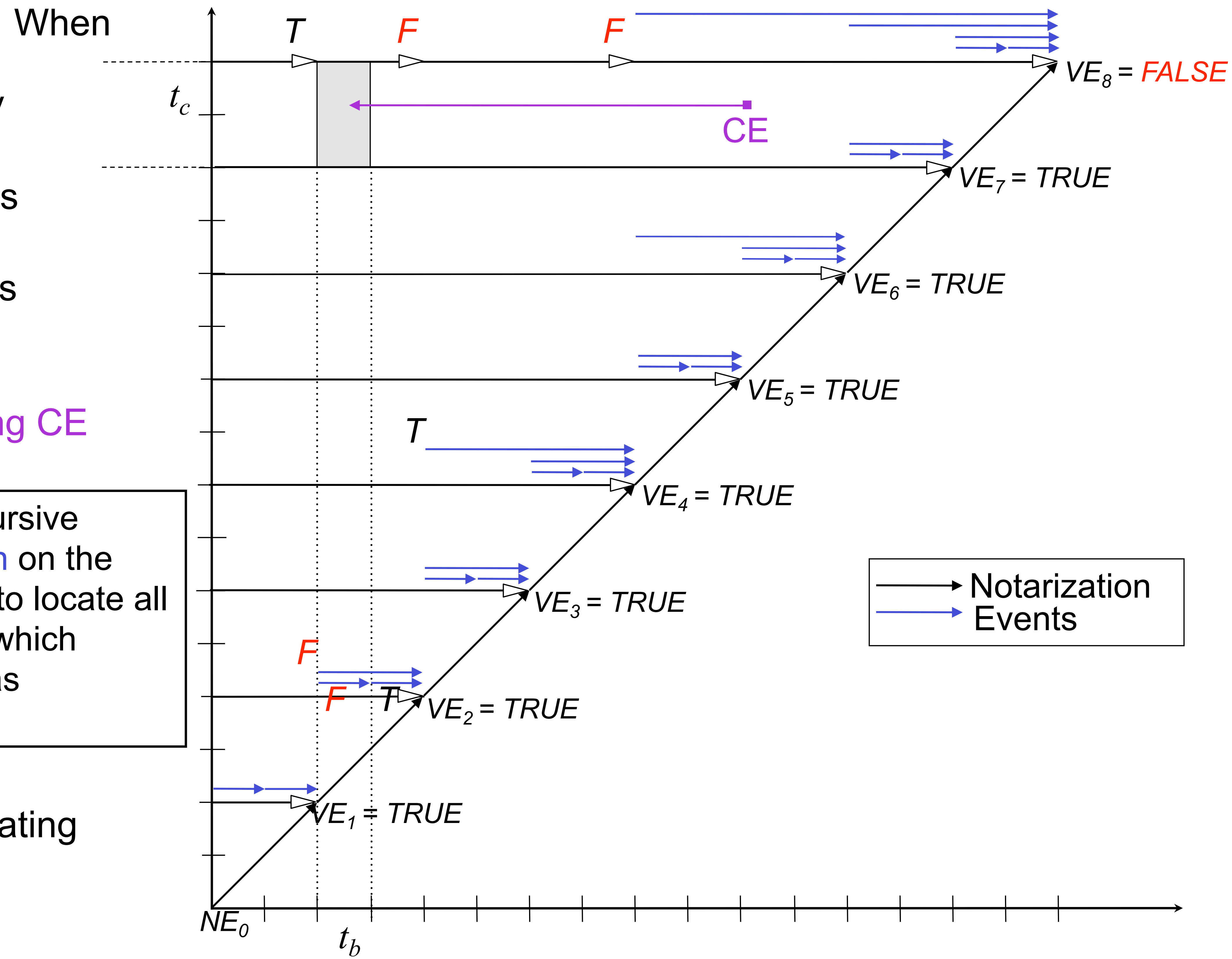

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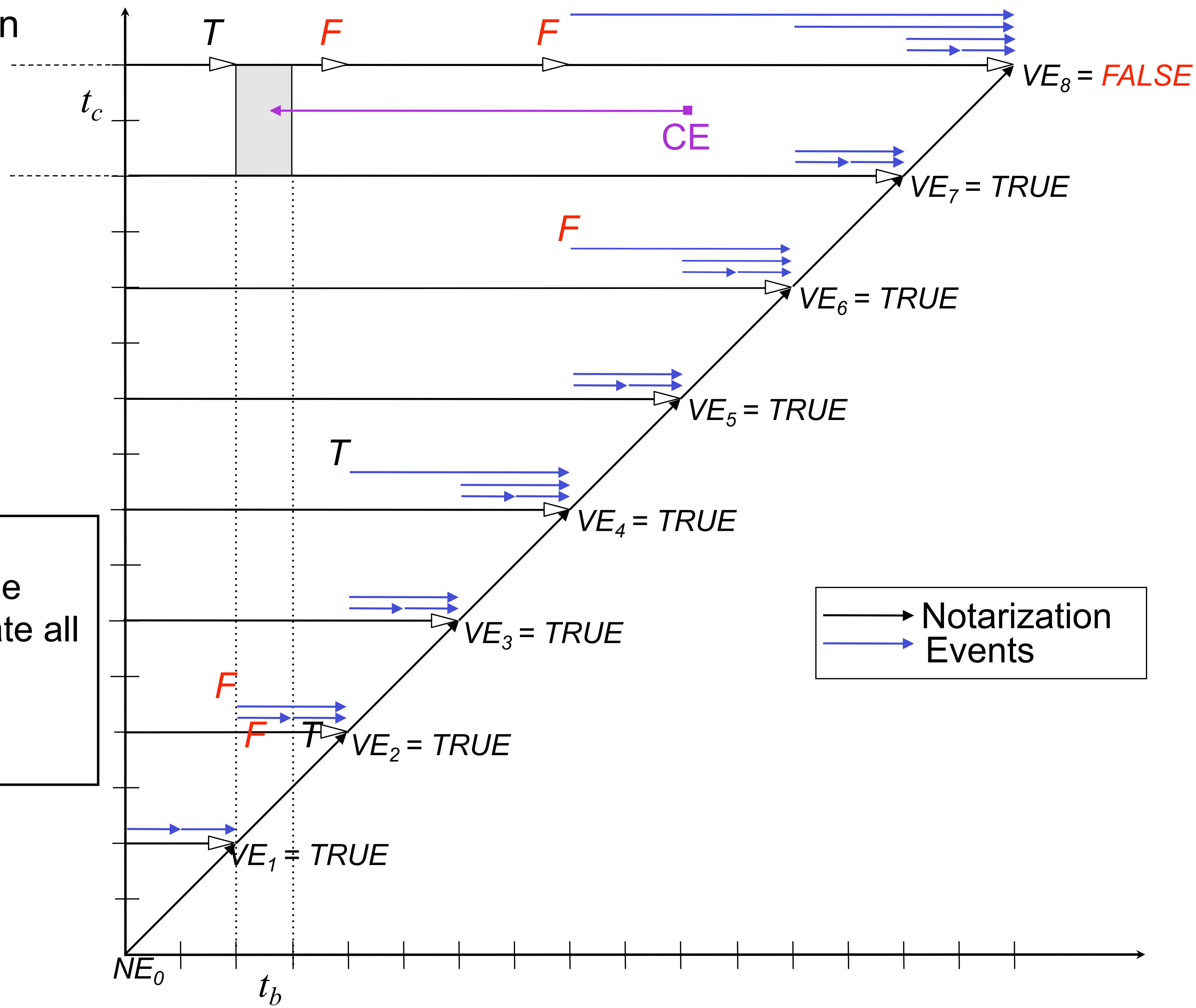

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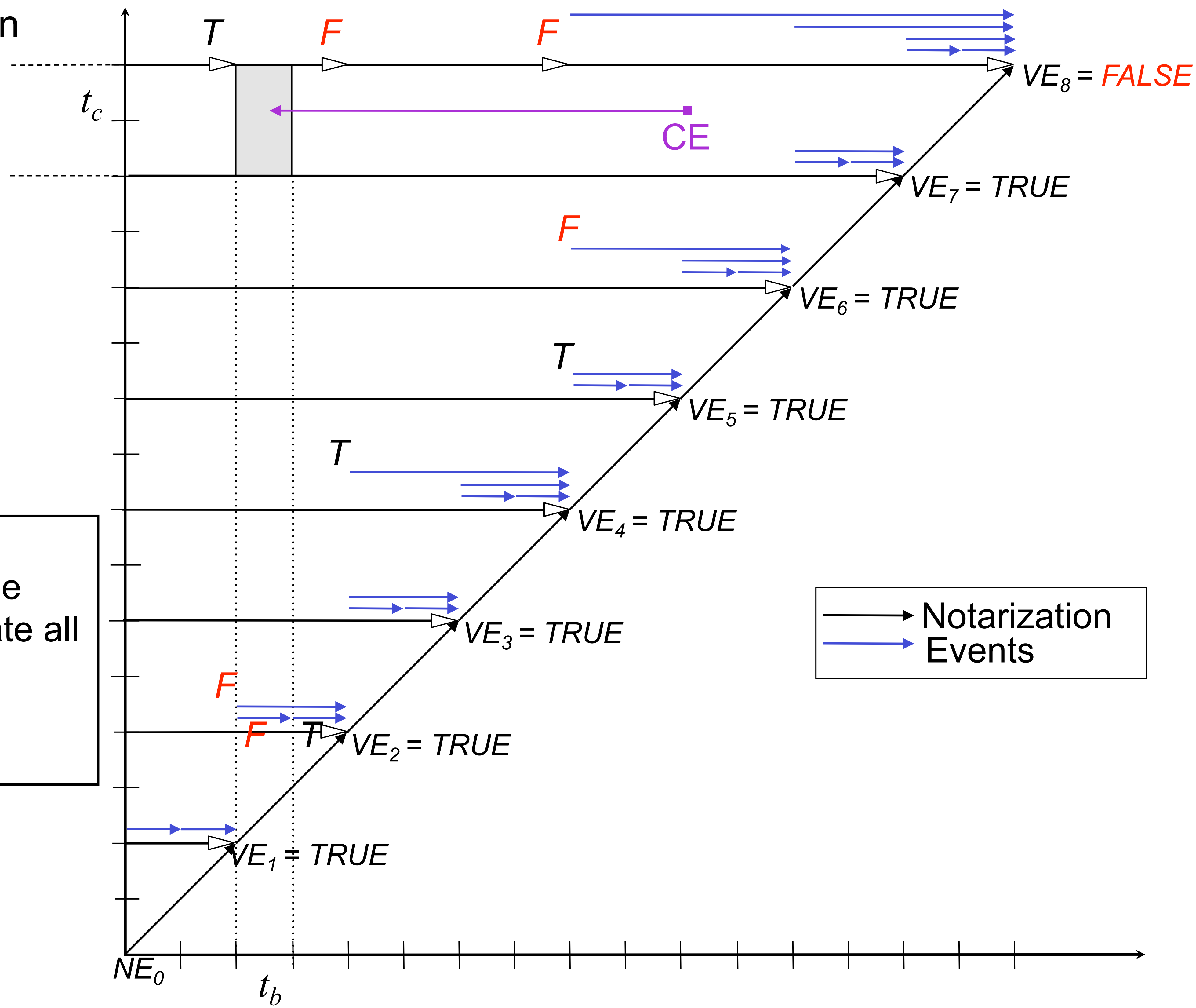

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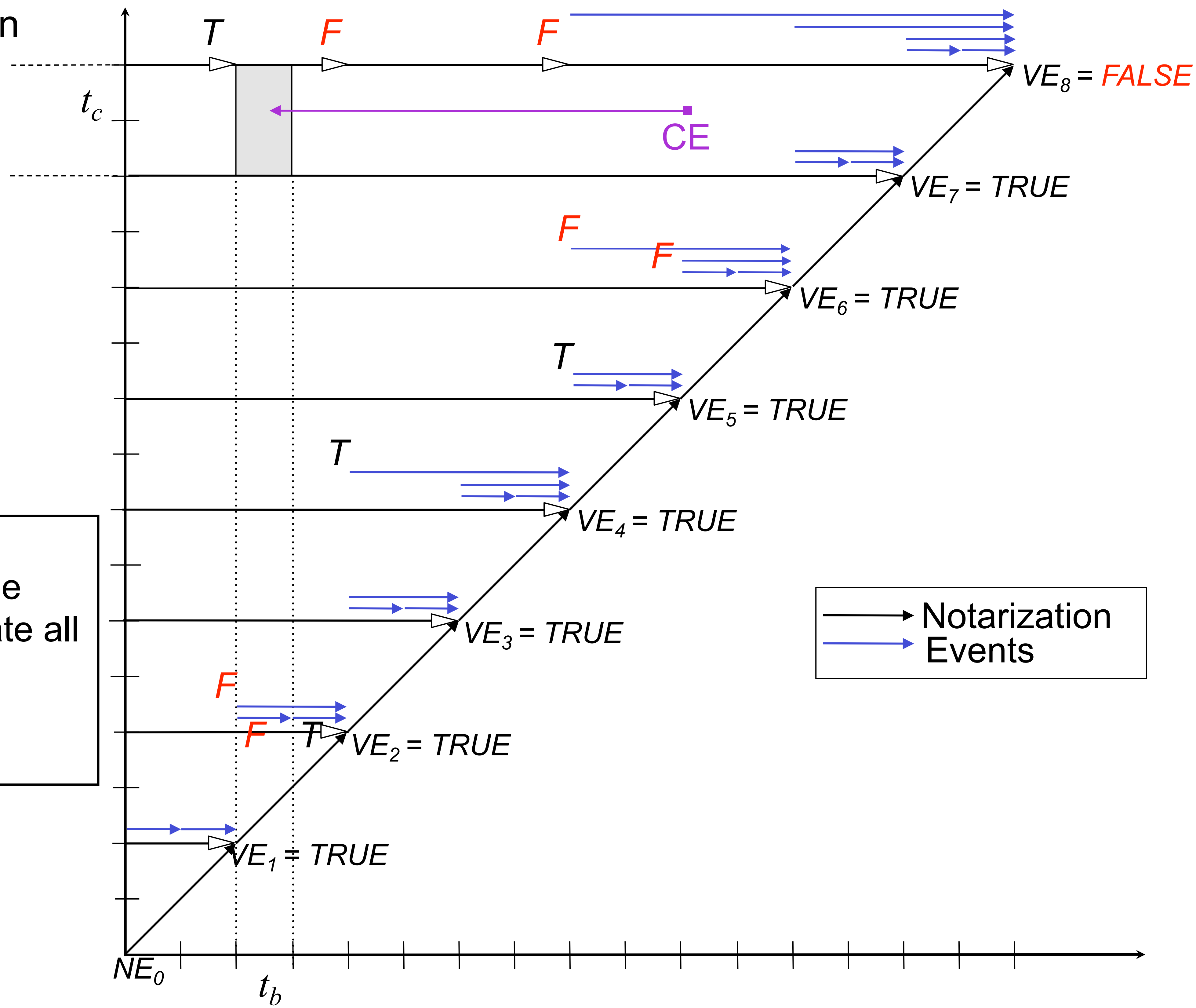

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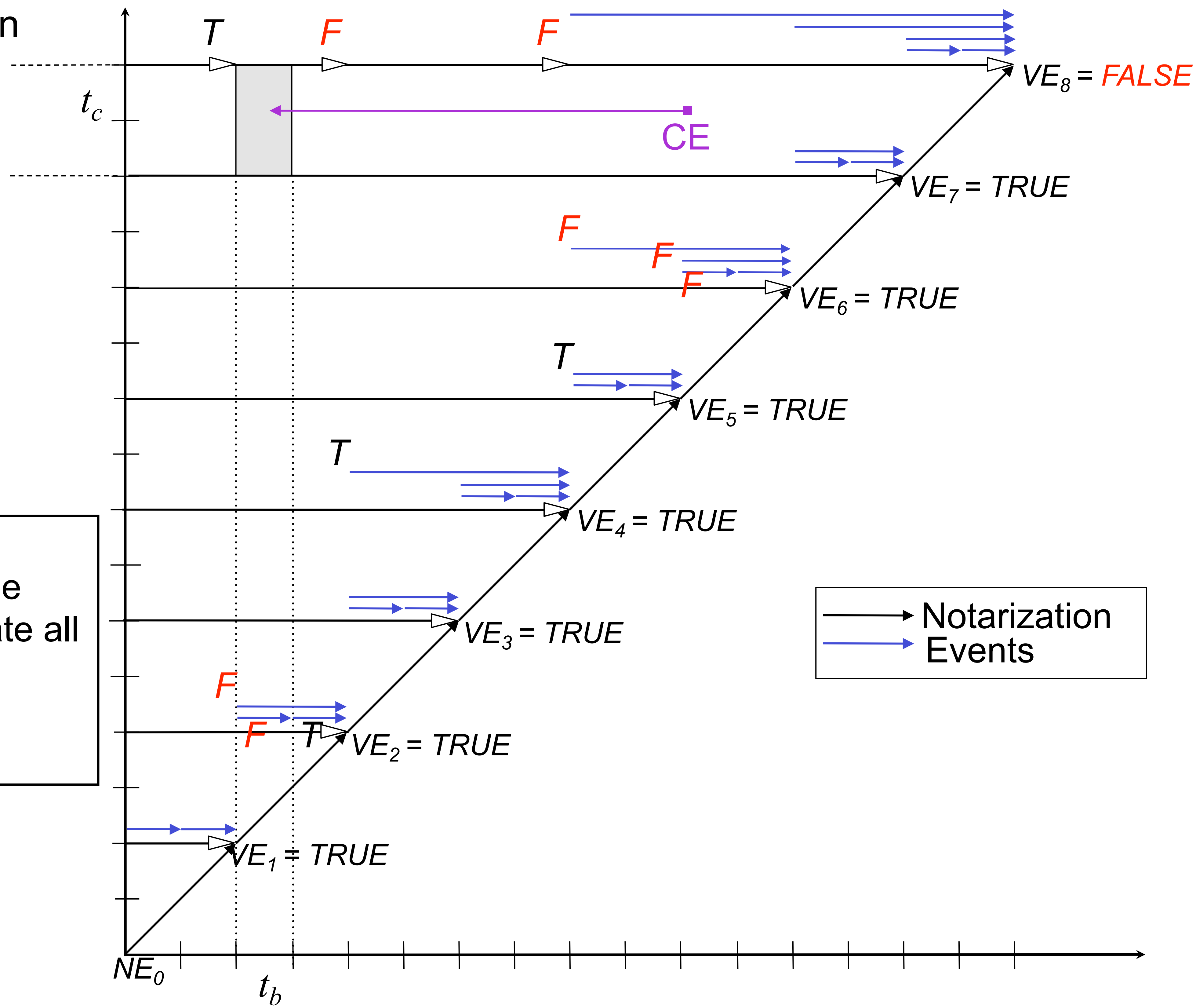

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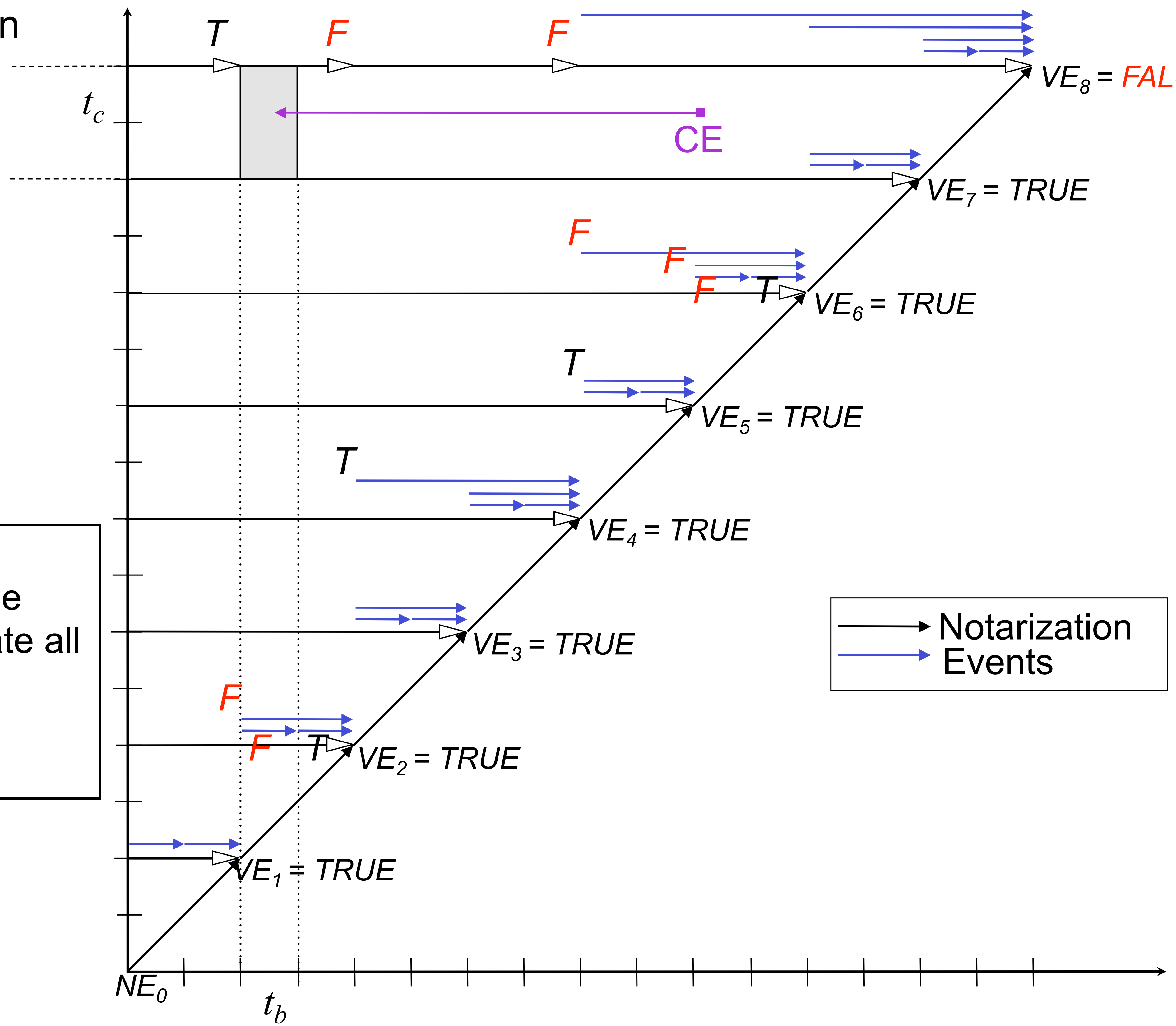

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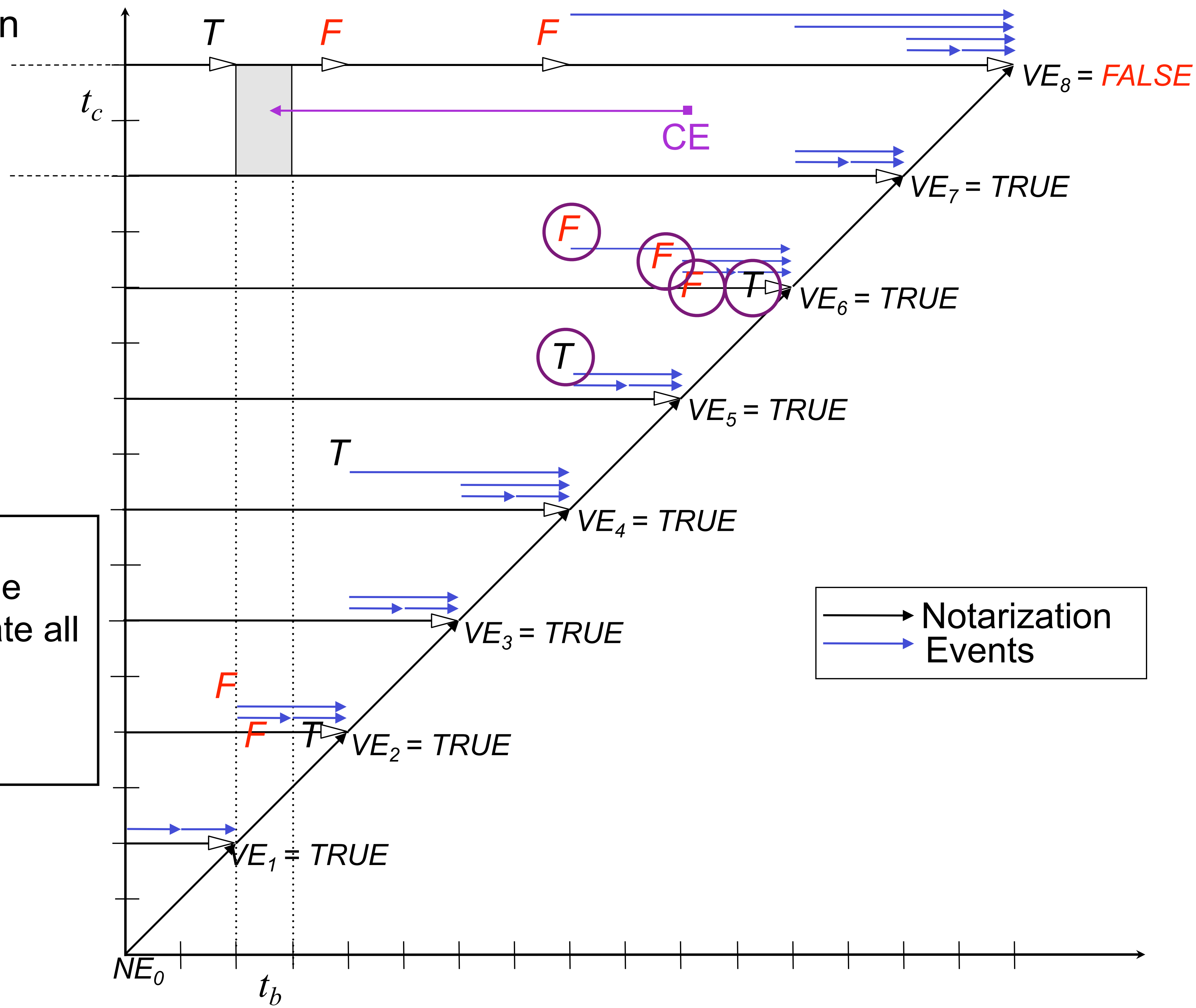

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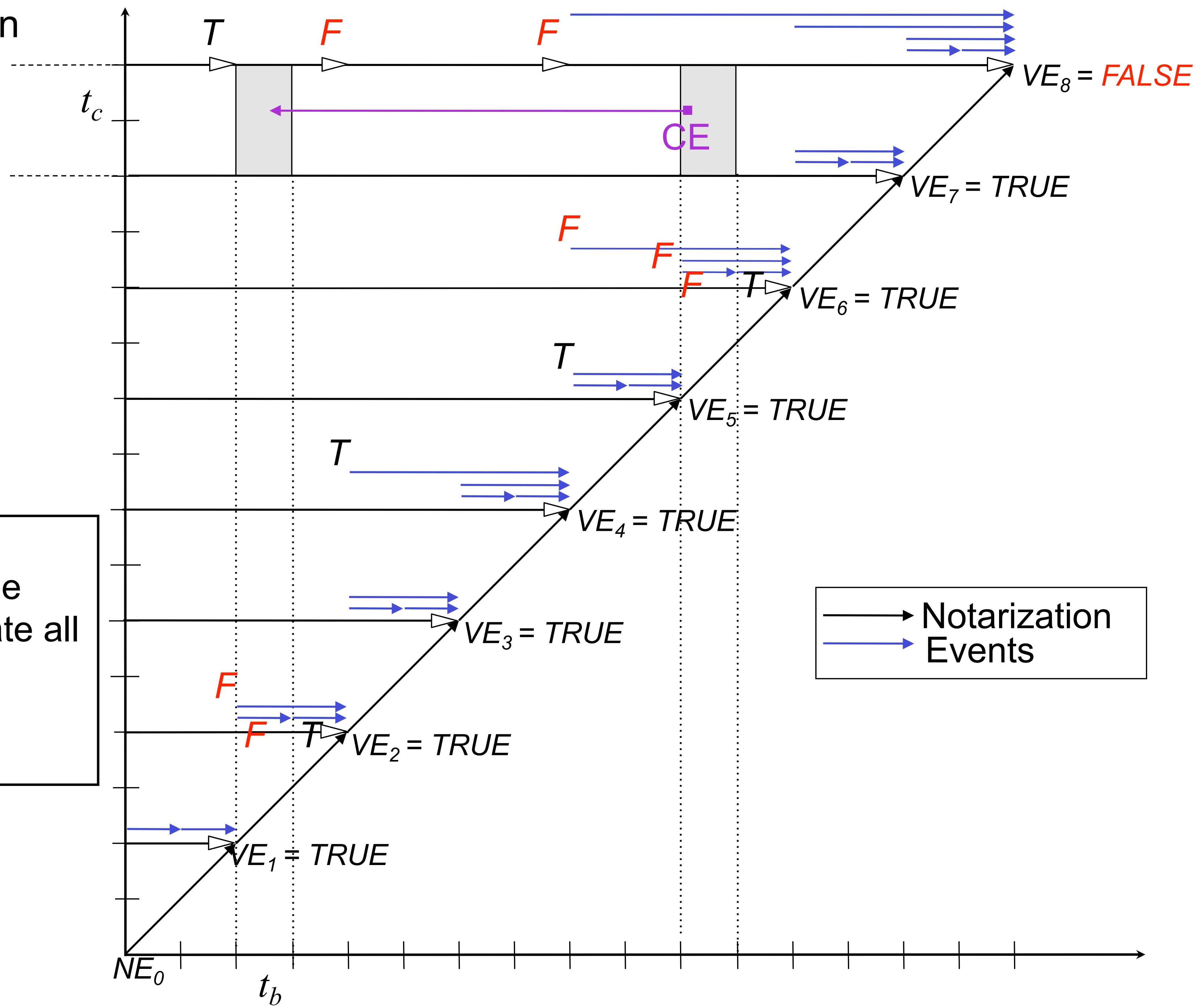

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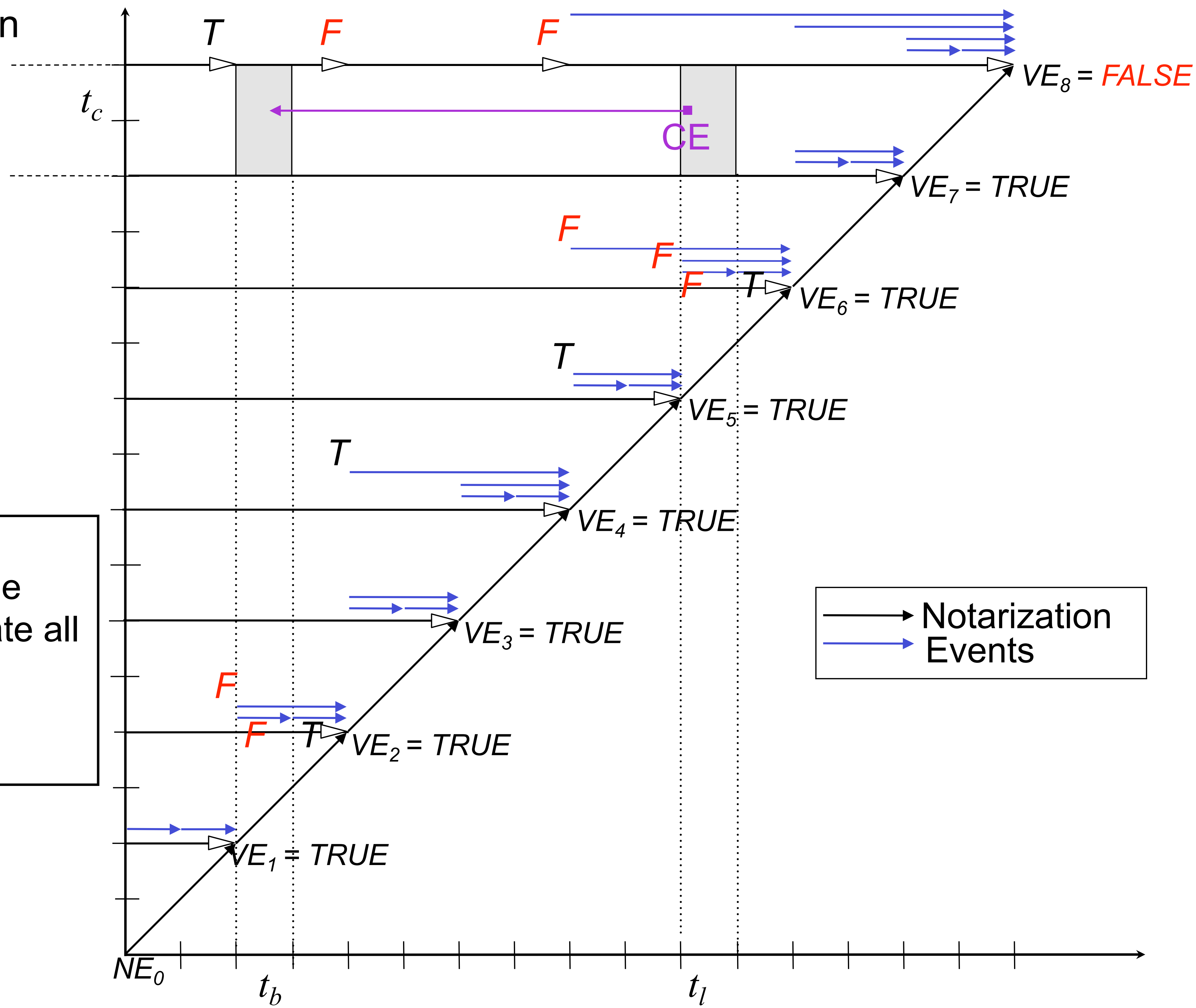

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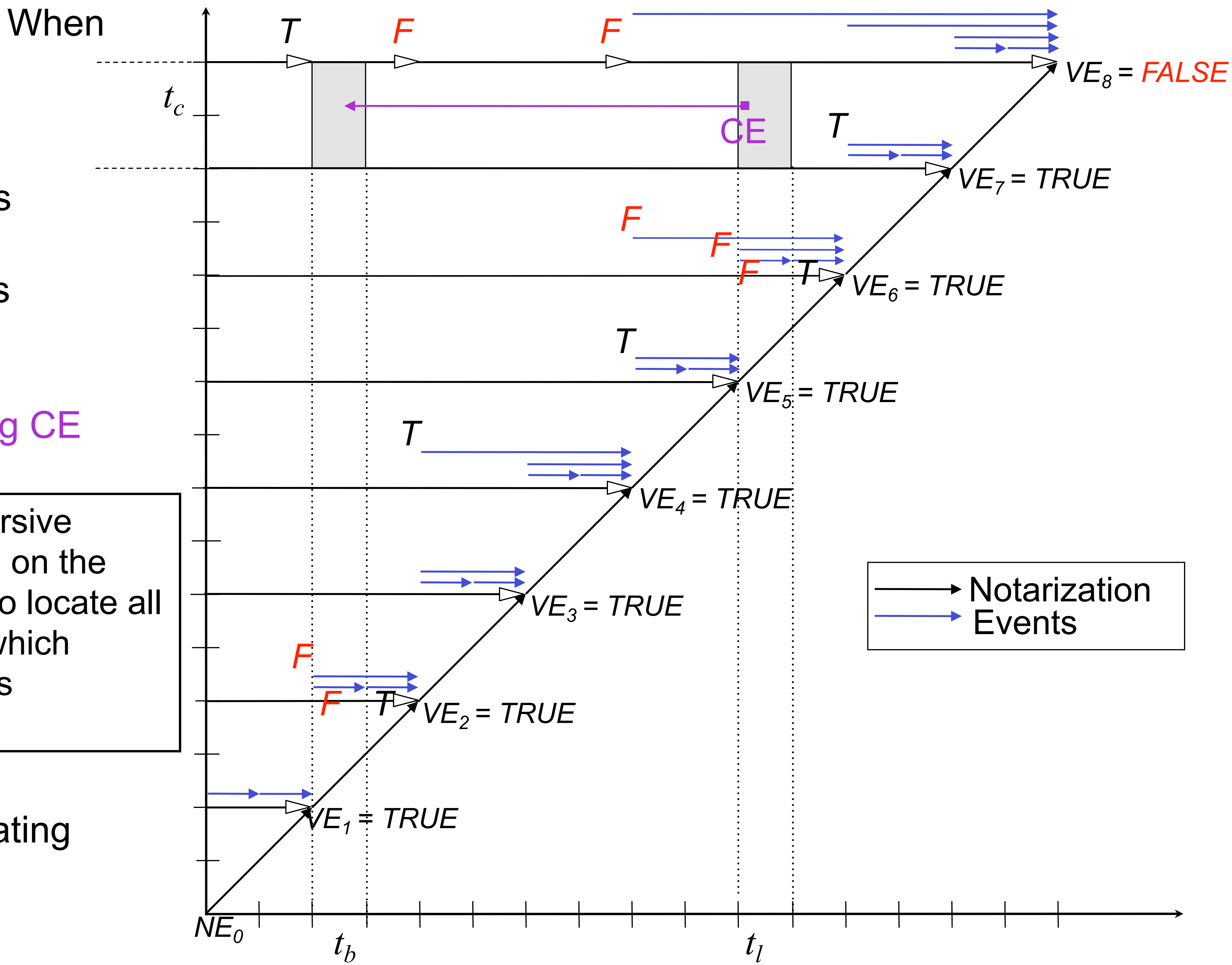

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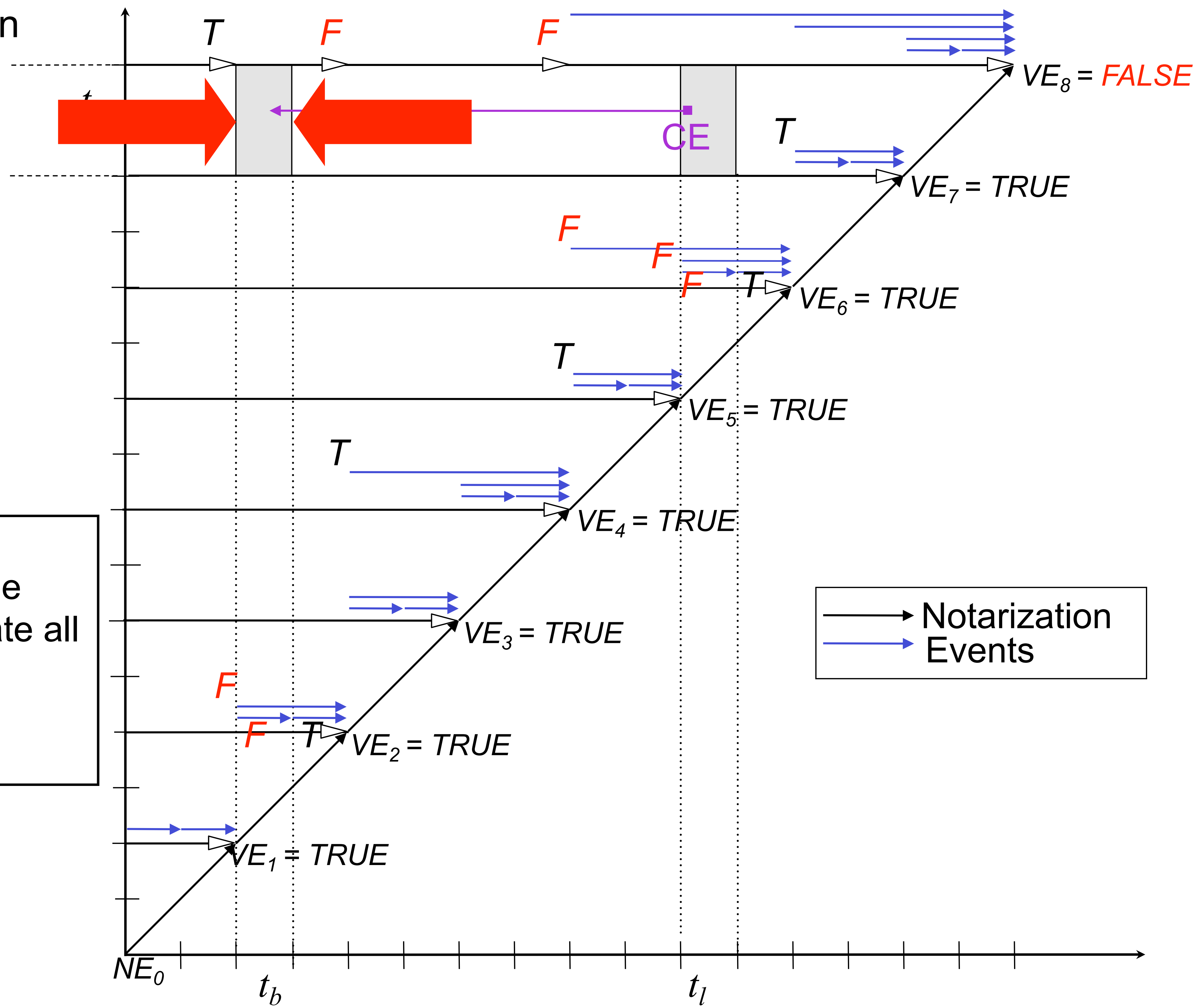

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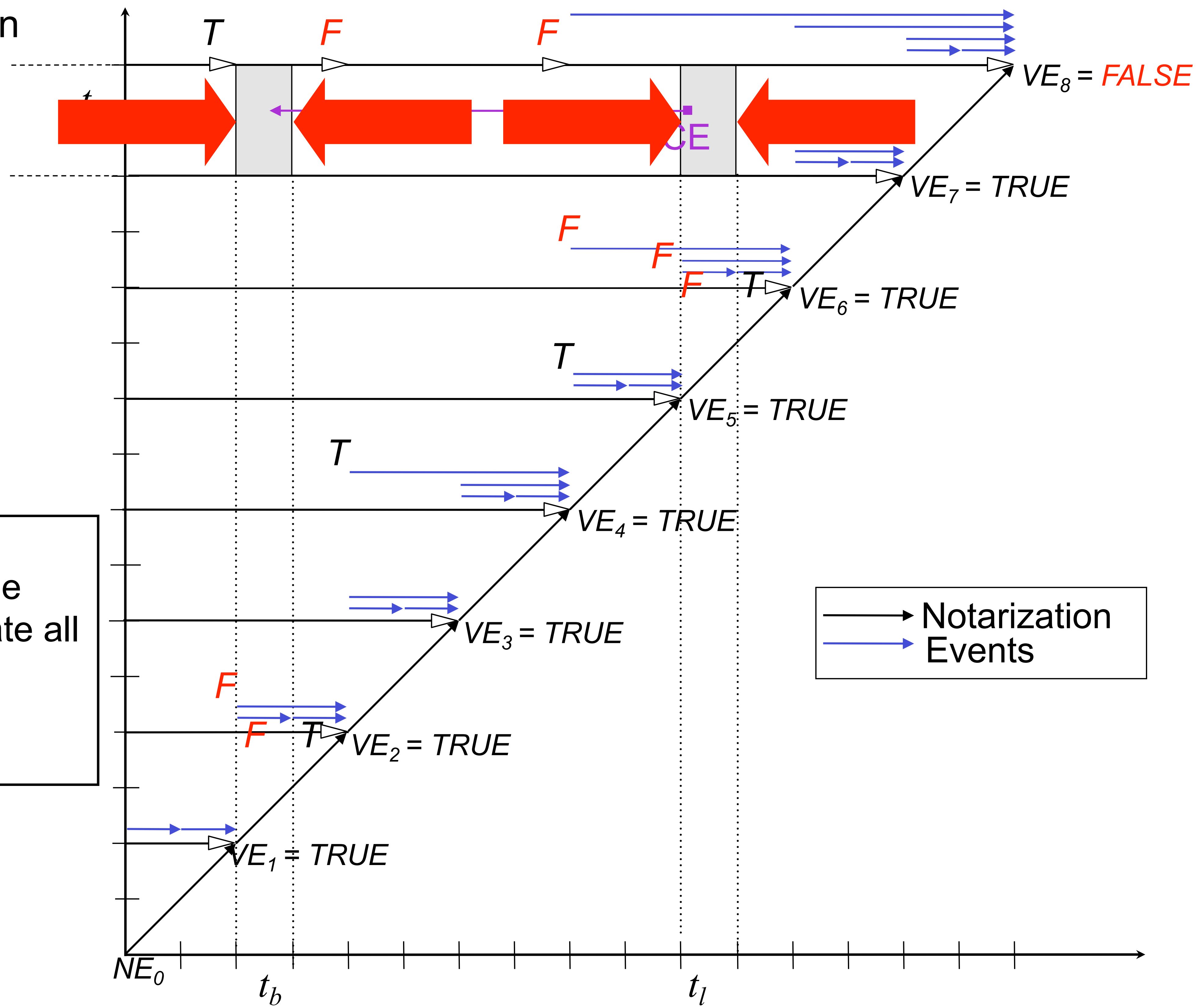
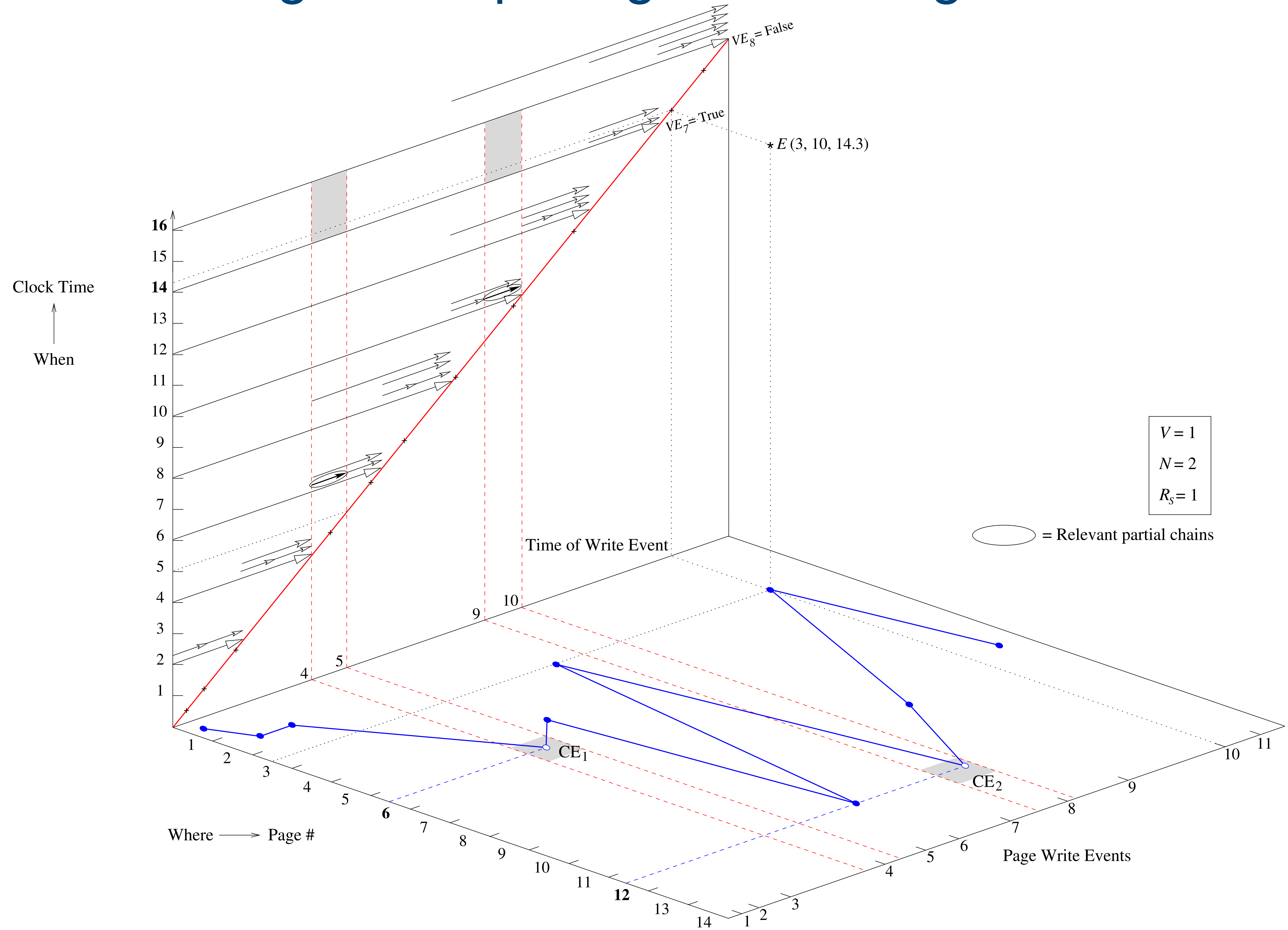


Comparison of Forensic Algorithms

	Partitioning		
	Commit-Time-Based	**Page-Based**	**Attribute-Based**
Tables Affected	Any number	Any number	One or several of those containing the designated attribute
R_s	Time interval	Time interval	Time interval
R_d	N/A	N/A	Number of subsets of domain values
Segment	One of the contiguous *periods* induced by R_s, starting from a particular anchor. Contiguous periods form a chronologically ordered partition.	One of the contiguous *periods* induced by R_s, starting from a particular anchor. Contiguous periods form a chronologically ordered partition.	One of the contiguous *periods* induced by R_s, starting from a particular anchor. Contiguous periods form a chronologically ordered partition.
Granule	Encompasses all tuples with *commit times* within the associated segment (one granule has tuples from many transactions committing in that segment).	Encompasses all tuples whose *physical location* is in a page mentioned within the associated segment.	Encompasses all tuples with *commit times* within the associated segment (one granule has tuples from many transactions committing in that segment).
Hashing order	Transactions hashed in order of increasing *commit time*.	Granules hashed in chronological *order of* "page write" *event* of the page. Granules not hashed in order of page number.	Transactions hashed in order of increasing *commit time*.
Segment Completion Event	When the last *tuple* in the granule associated with that segment commits	When the last *page* write event in the segment occurs.	When the last *tuple* in the granule associated with that segment commits
Notarization Factor (N)	Specified by DBA	Specified by DBA	Specified by DBA
Validation Factor (V)	Specified by DBA	Specified by DBA	Specified by DBA
I_N	$N \times R_s$	$N \times R_s$	$N \times R_s$
I_V	$V \times I_N$	$V \times I_N$	$V \times I_N$
Notarization	Occurs *as soon as* N granules are hashed.	Occurs *as soon as* N granules are hashed.	Occurs *as soon as* N granules are hashed.
Validation	Occurs as soon as V notarizations have occurred.	Occurs as soon as V notarizations have occurred.	Occurs as soon as V notarizations have occurred.

The Correlated Page-Based Corruption Diagram Depicting the a3D Algorithm



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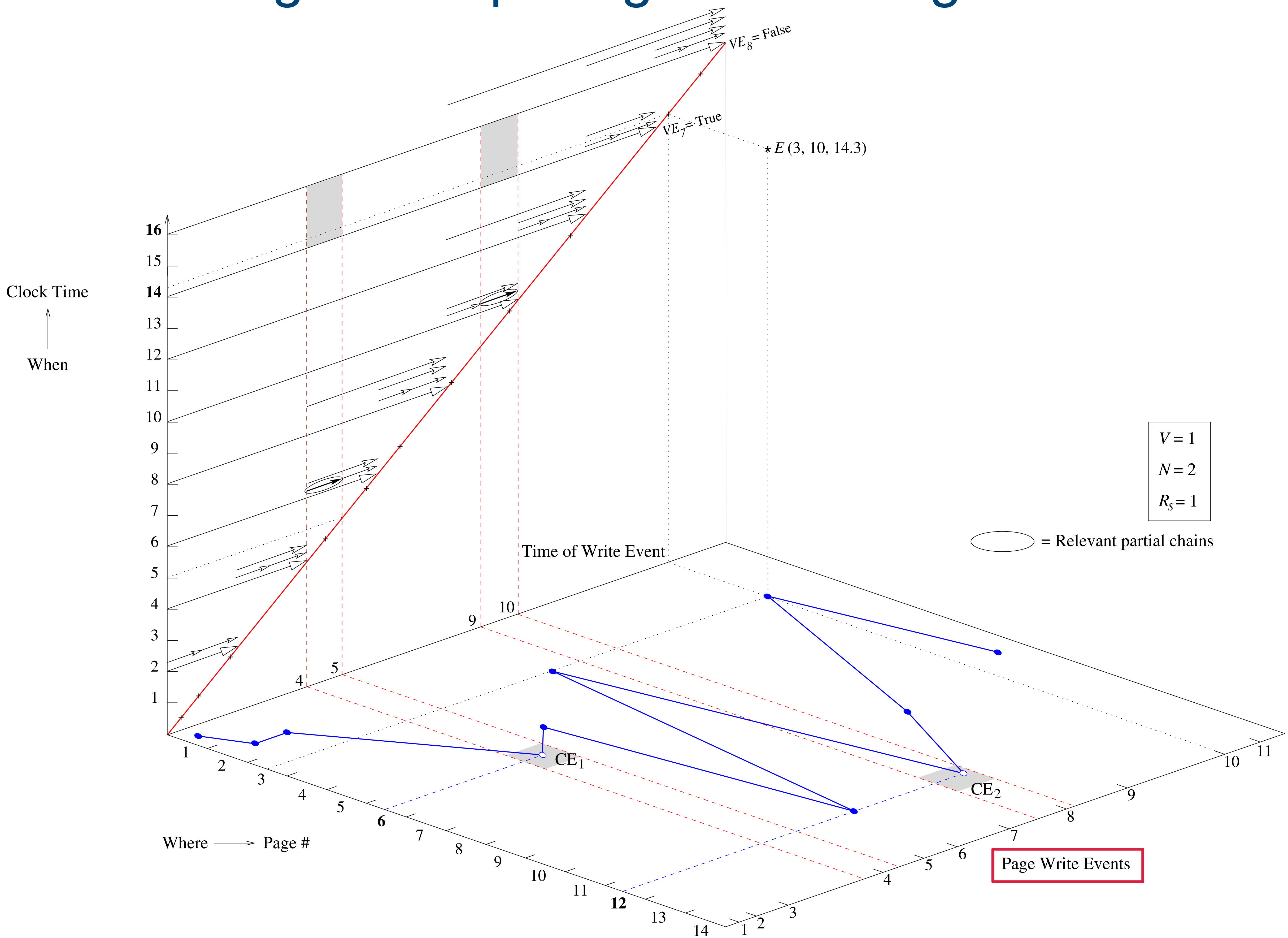

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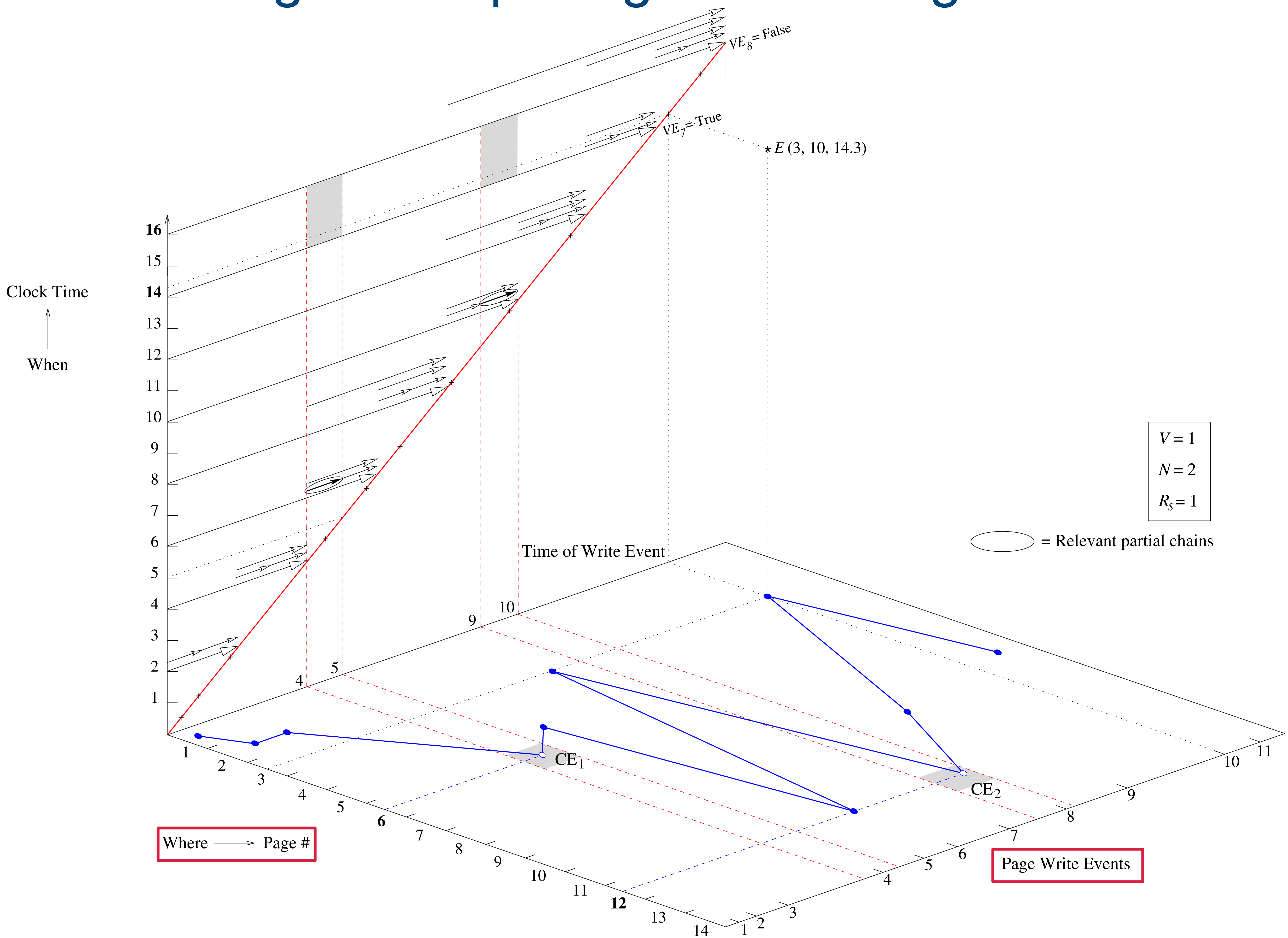

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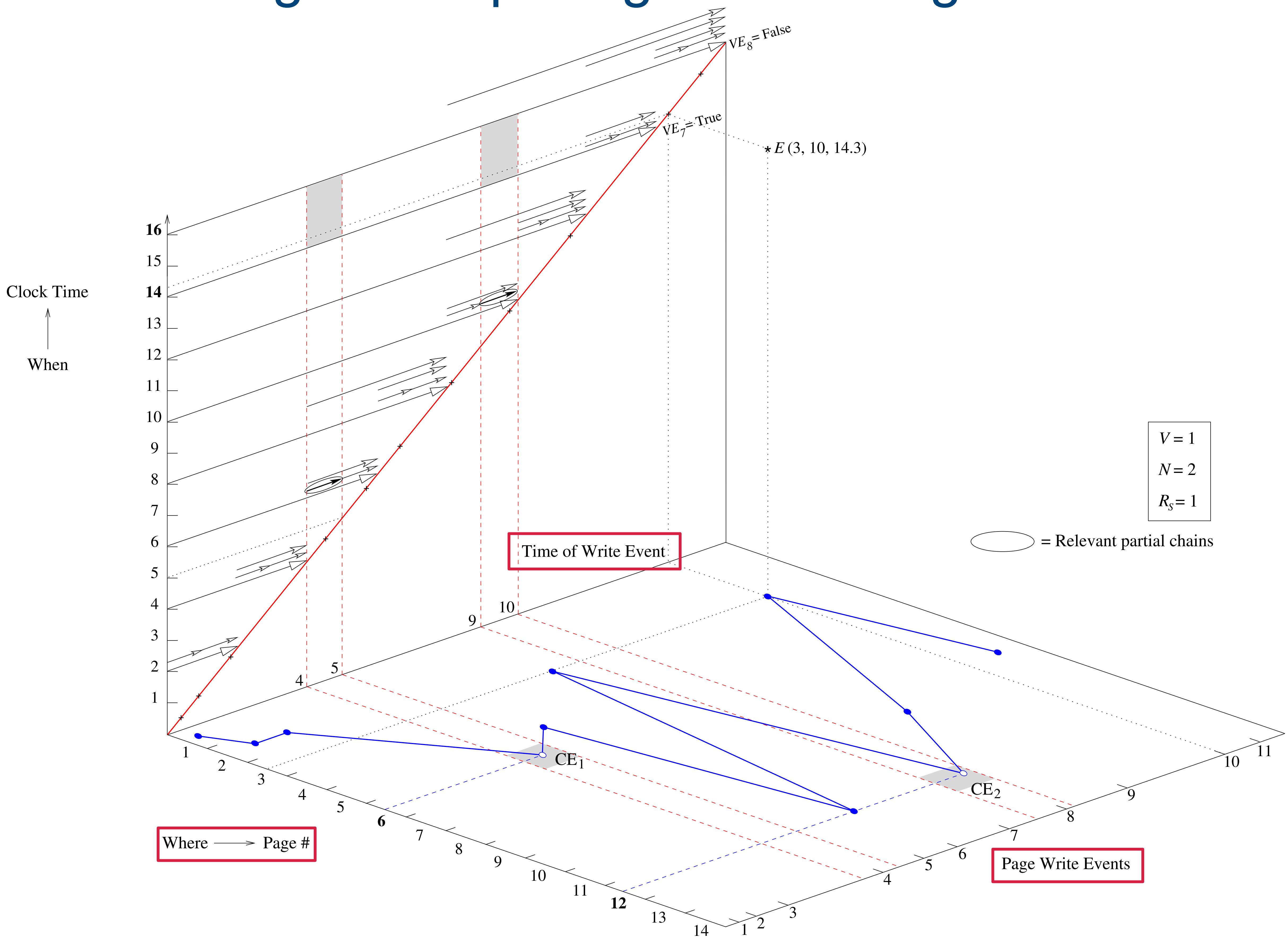

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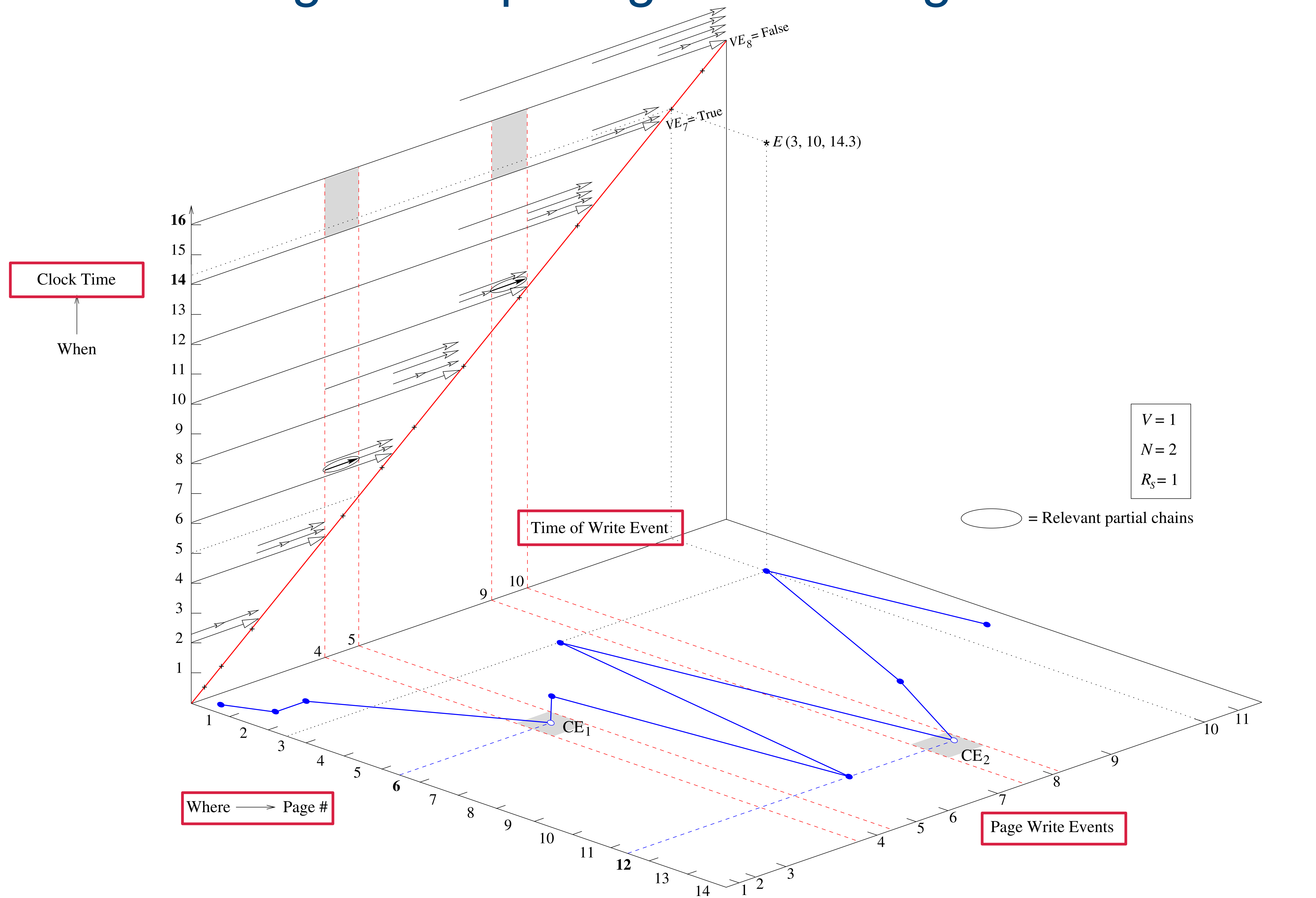

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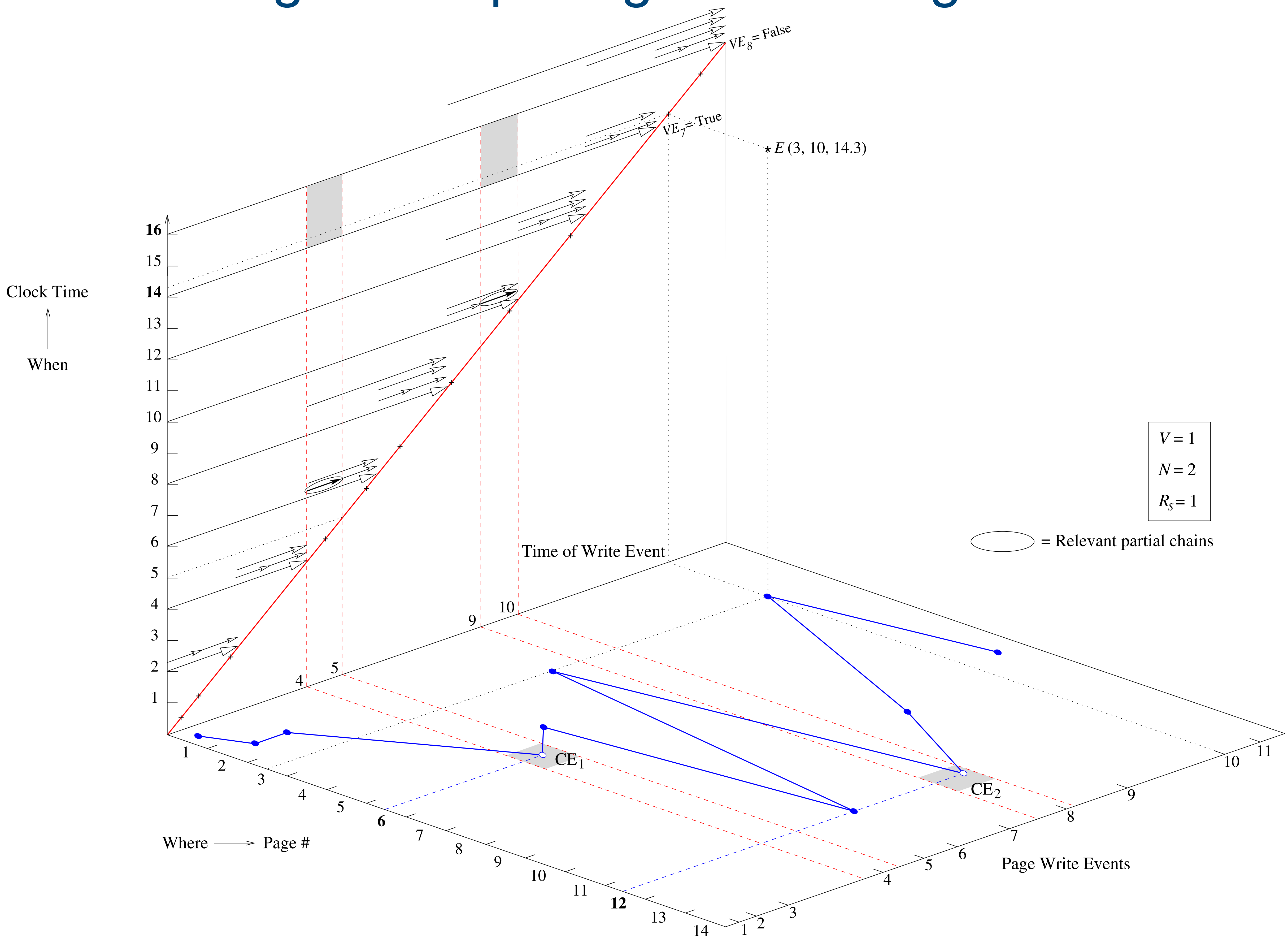

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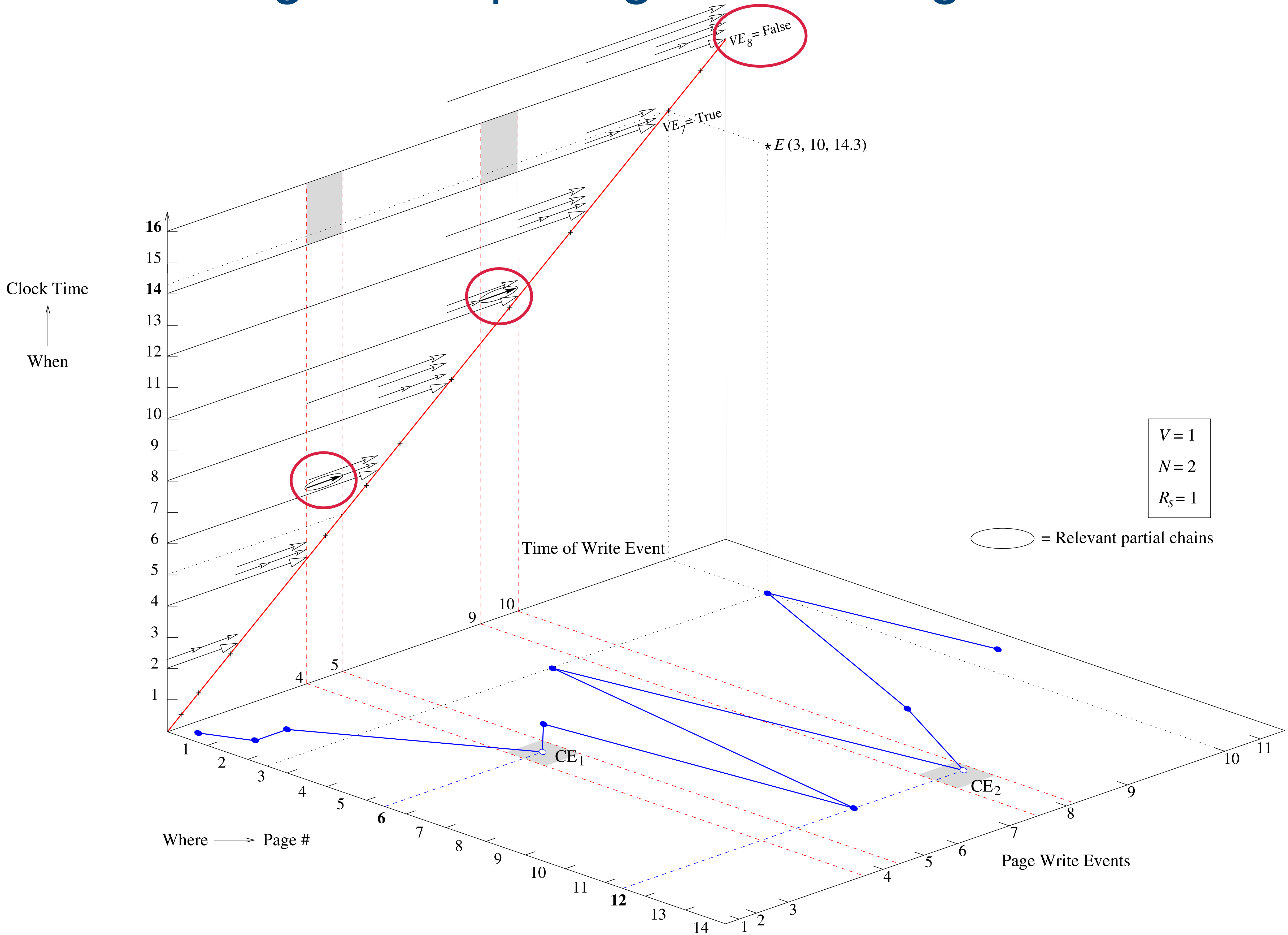

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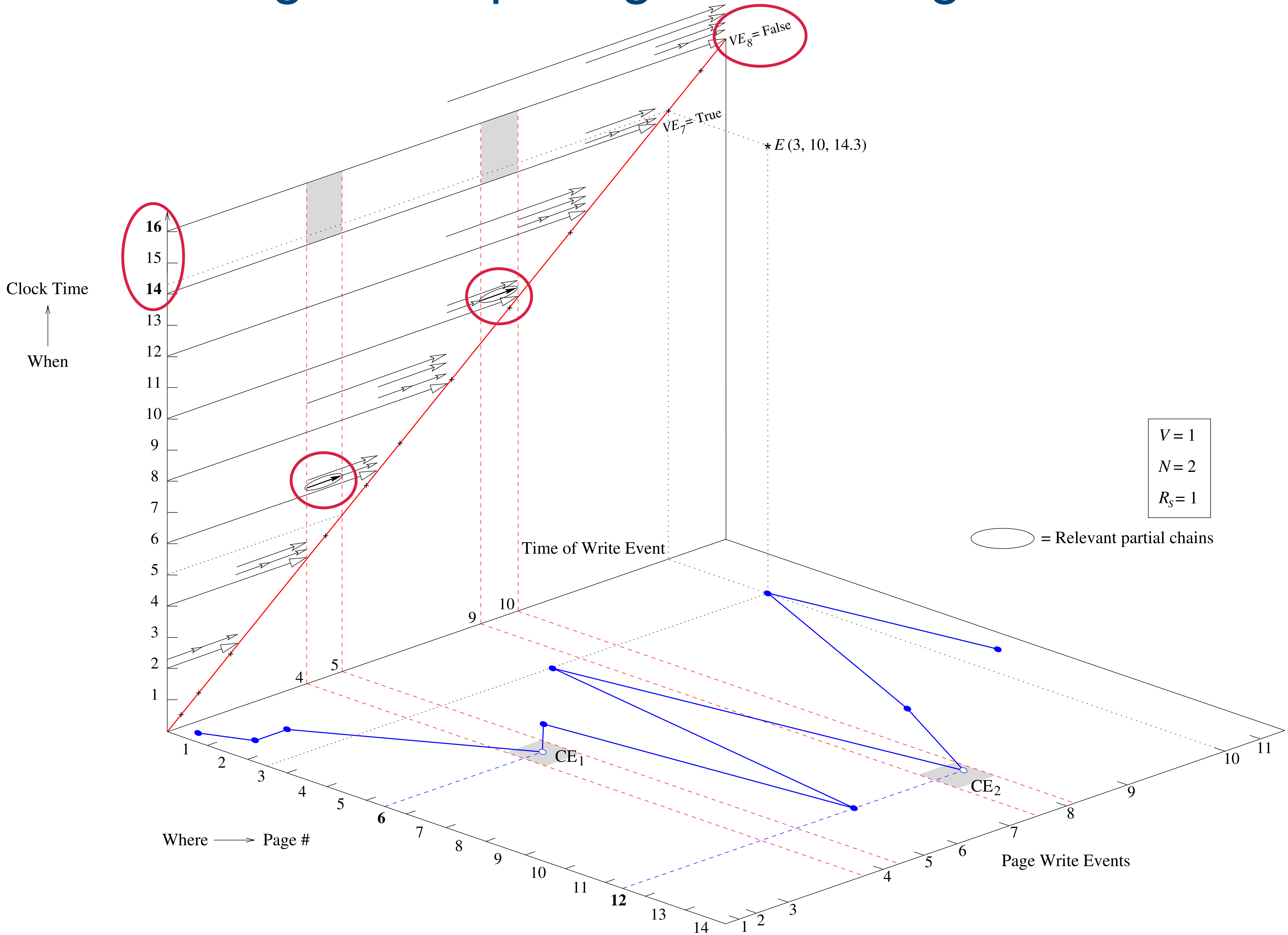

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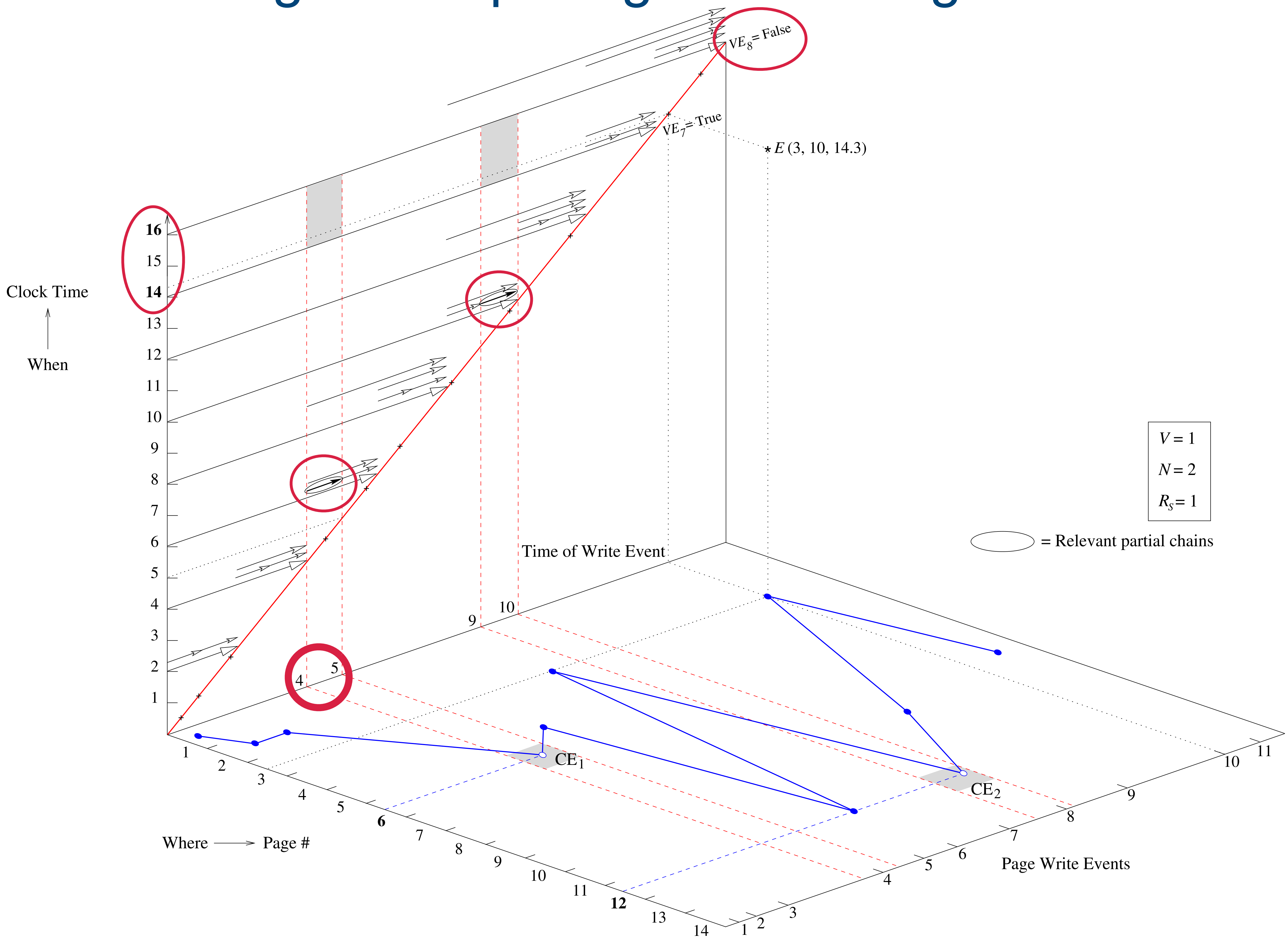

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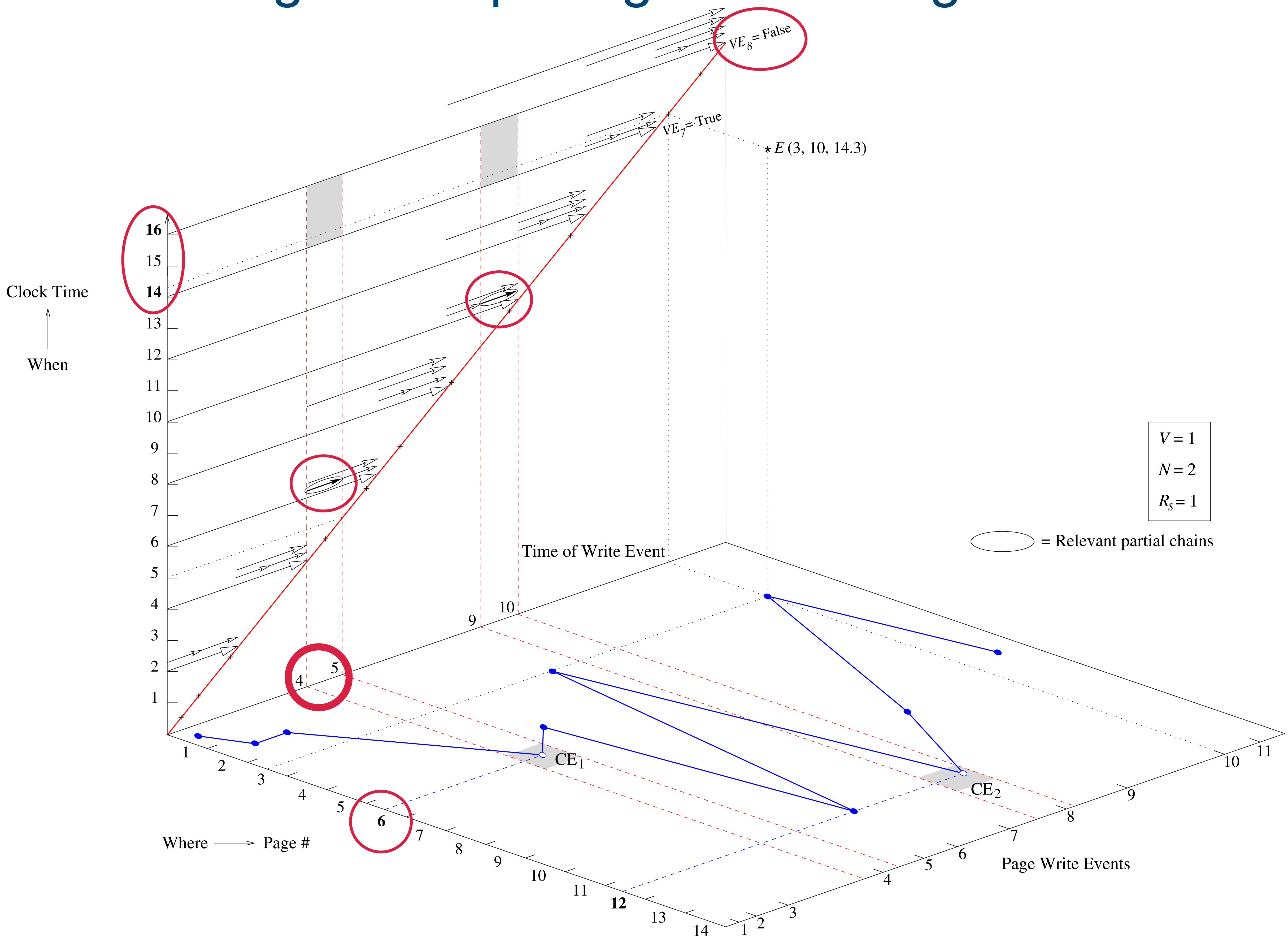
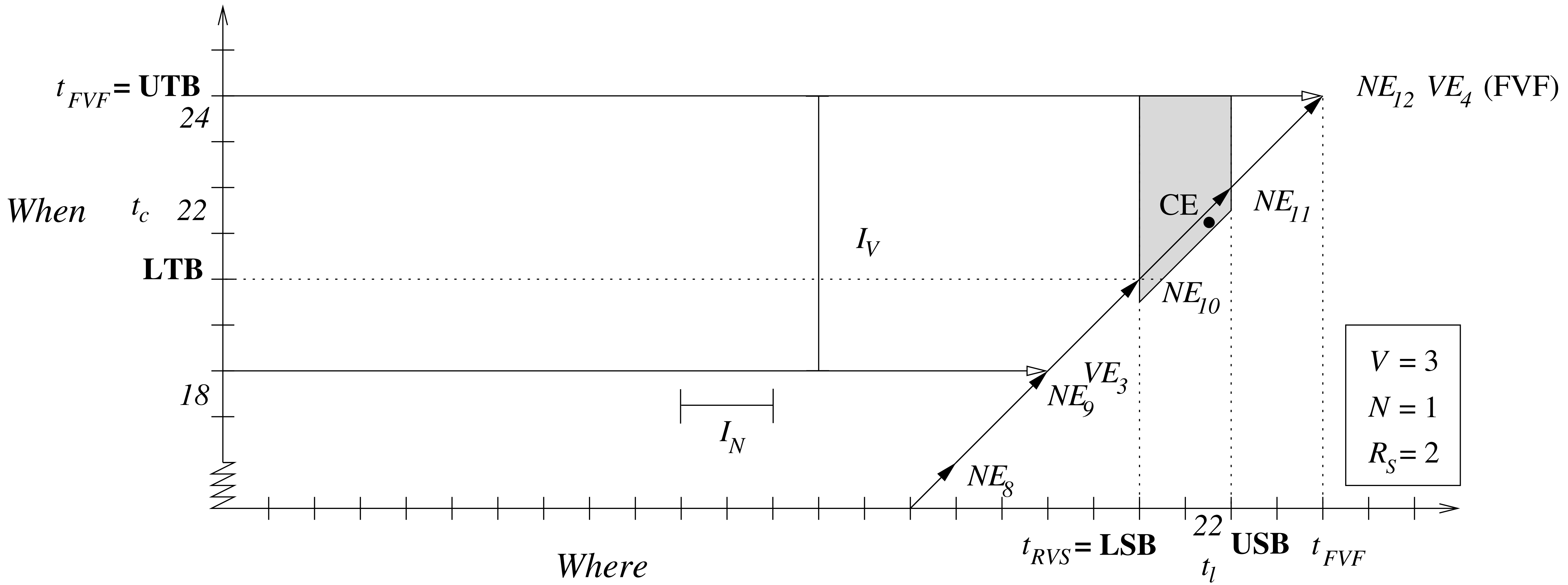


Outline

- Information Accountability
- Reference Architecture & Execution Phases
- Forensic Analysis
- Refinements
- Enterprise Considerations

Very Recent Corruptions



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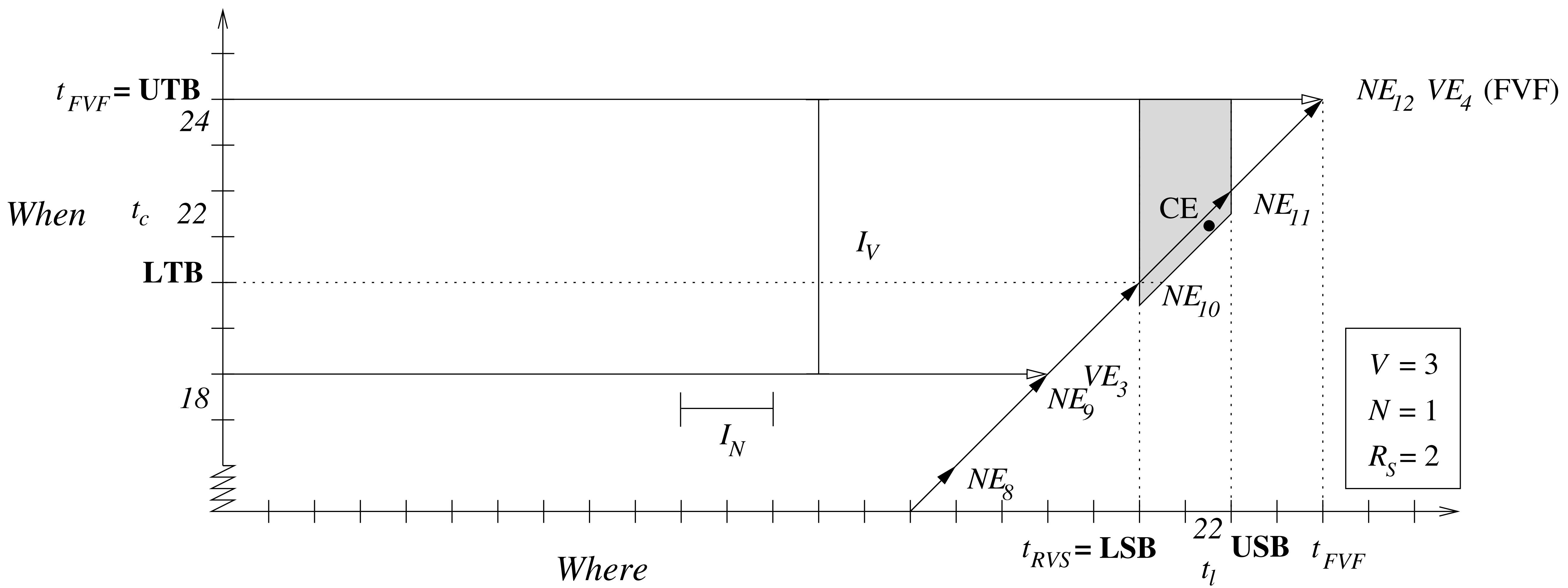

- In general $t_c > t_l$
- Exception: corruption affects currently executing transaction

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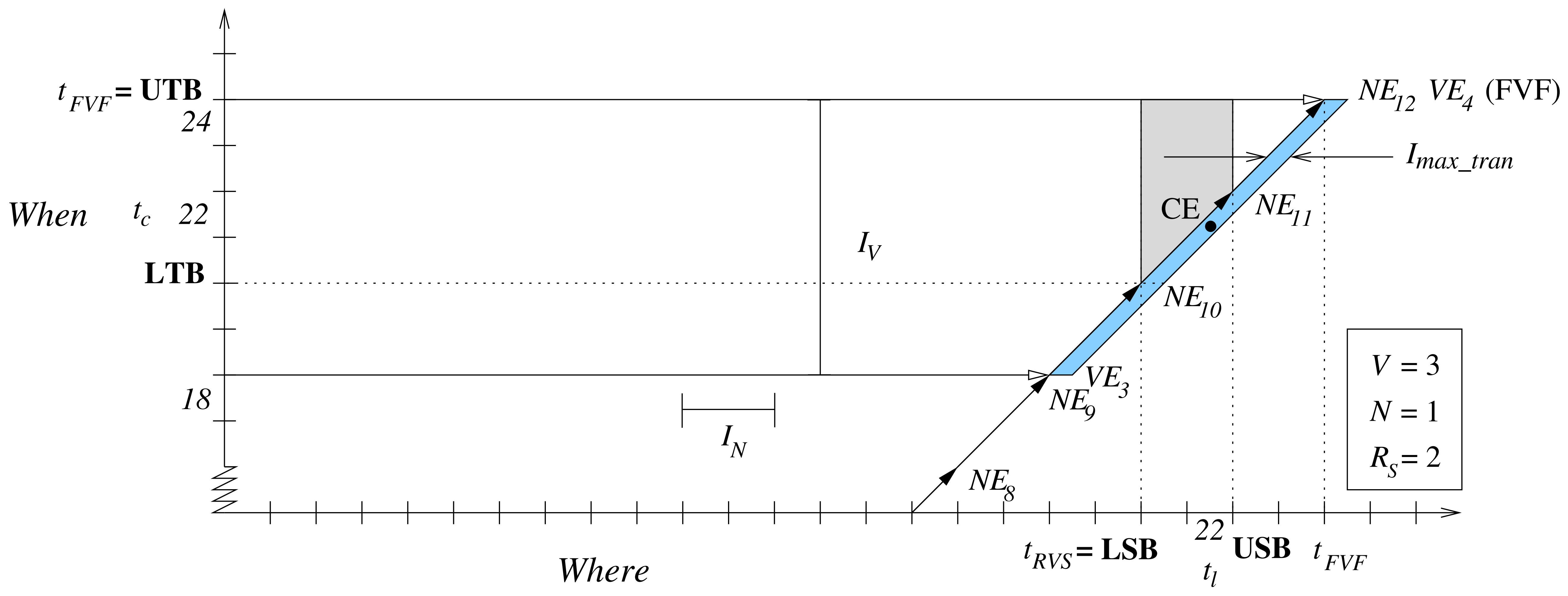

- In general $t_c > t_l$
- Exception: corruption affects currently executing transaction
- Introduce "envelope" of width I_{max_tran}

Very Recent Corruptions (2)

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- Different solution: Exploit the Regret Interval

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- The regret interval (I_R) is the minimum time interval before any adversary can reverse the change they made.

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- No introactive corruptions: $0 < I_N \leq I_V < I_R^* \leq I_R$

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- Shredding ensures information restriction.
  - Breaks semantics of information accountability
  - Reconcile shredding with tamper detection and forensic analysis?

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- Litigation holds “restore” info accountability.
- The capability to impose litigation holds prevents indiscriminate shredding and ensures accountability.

Outline

- Information Accountability
- Reference Architecture & Execution Phases
- Forensic Analysis
- Refinements
- Enterprise Considerations

Enterprise Architecture GUIs

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  - Chief Security Office (CSO)
  - Database Administrator (DBA)
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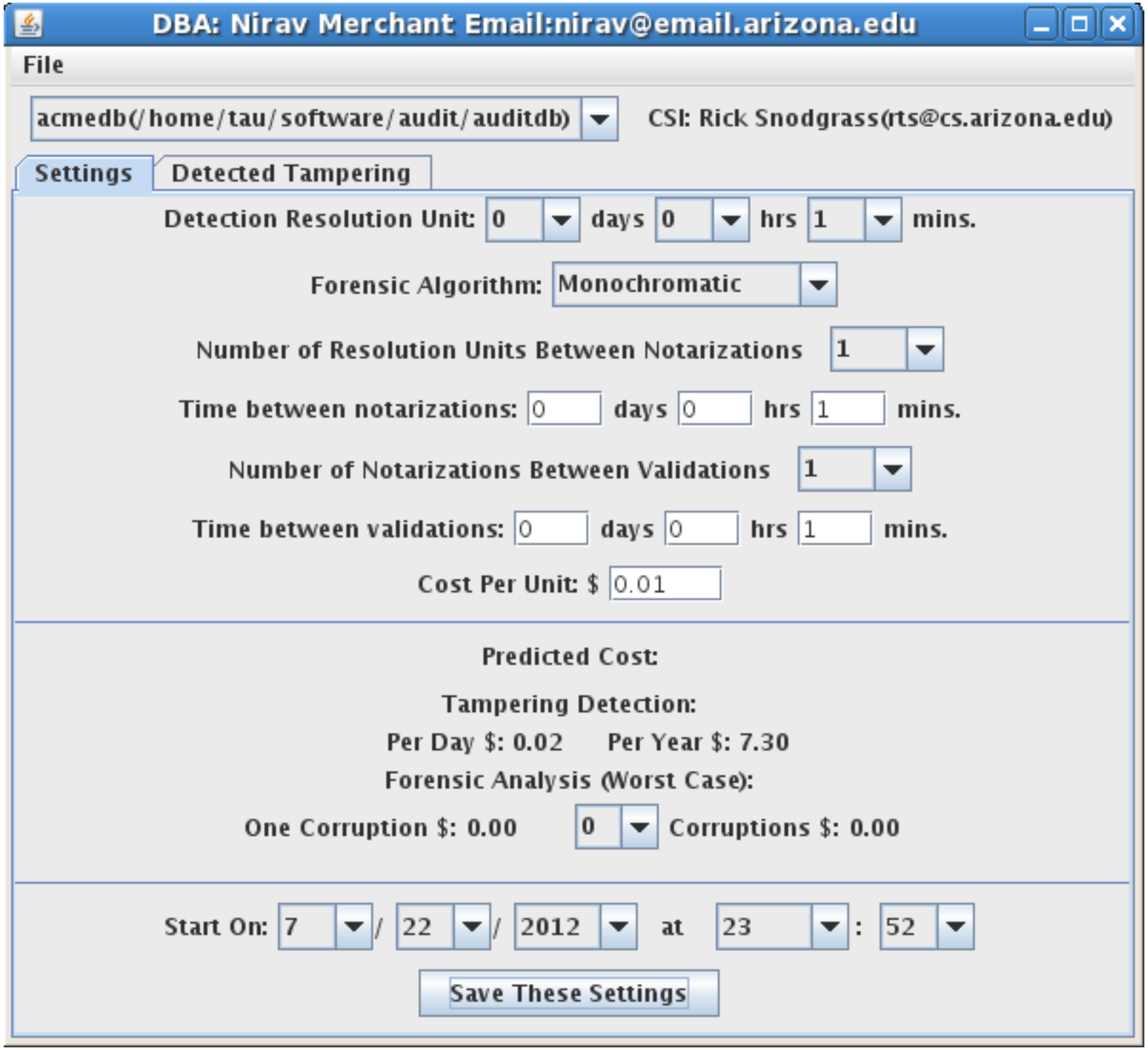
- Calculate the forensic cost for normal processing and forensic analysis

- Create corruption diagrams

DBA: Database-Specific Settings



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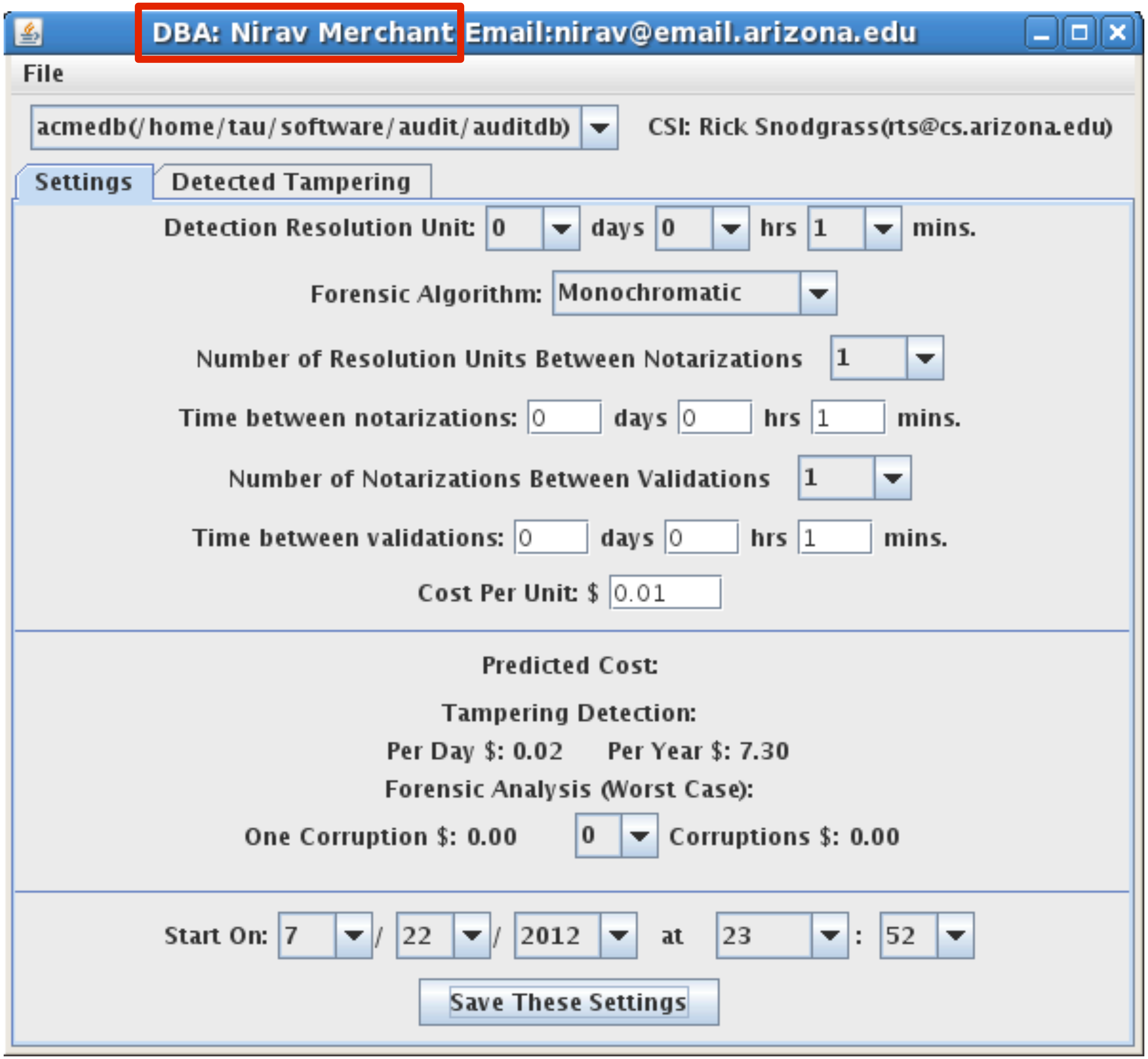

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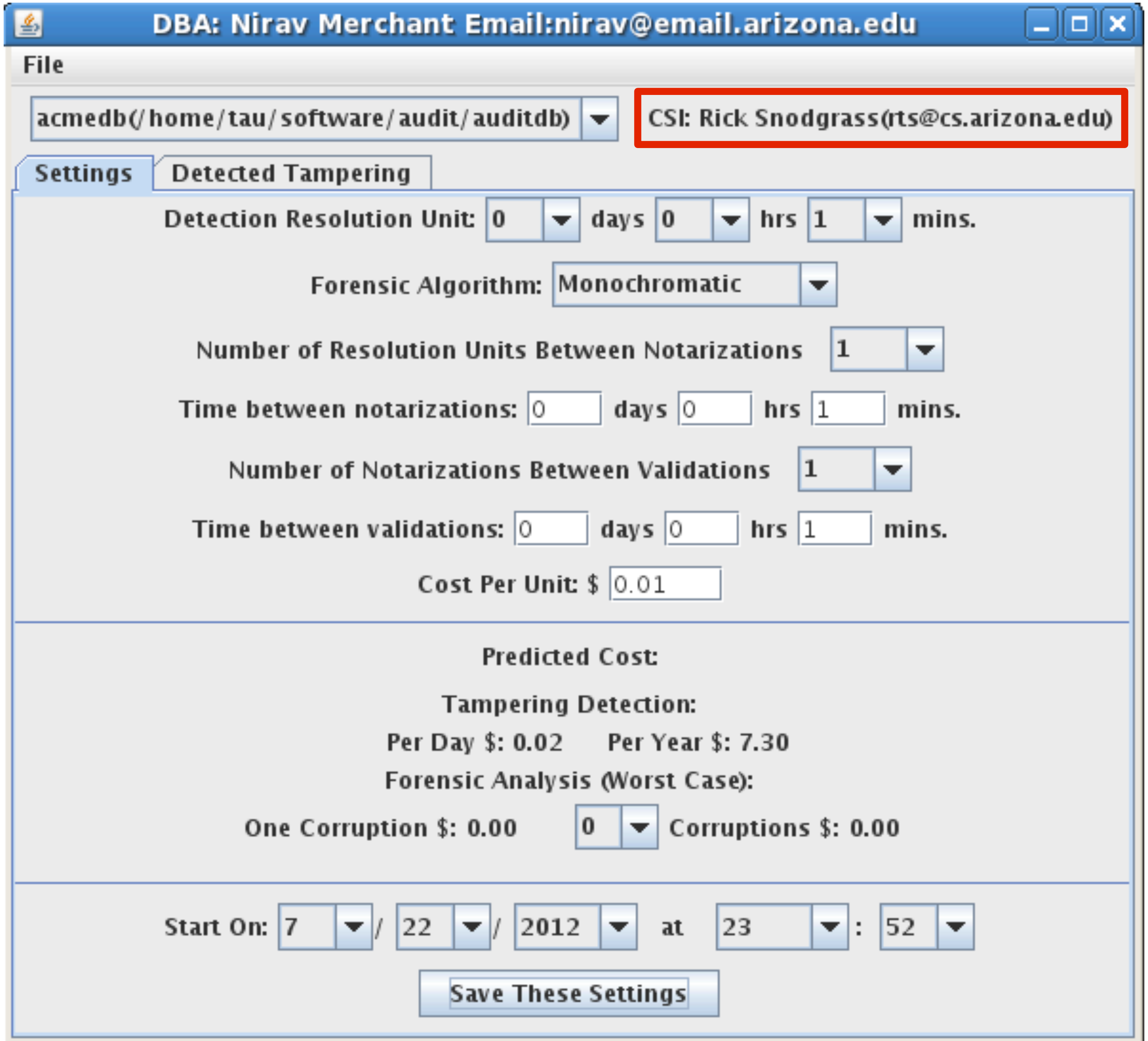

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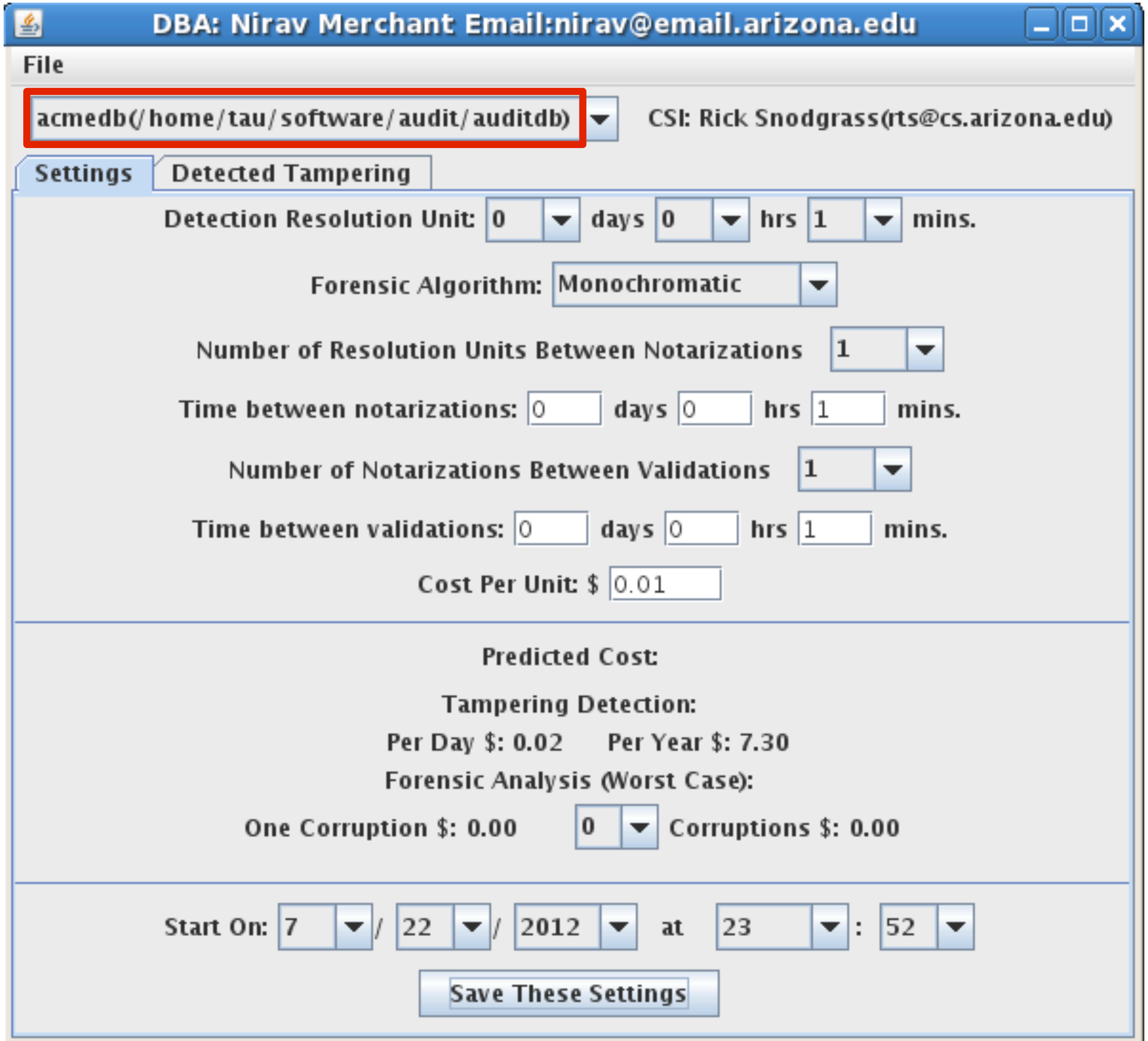

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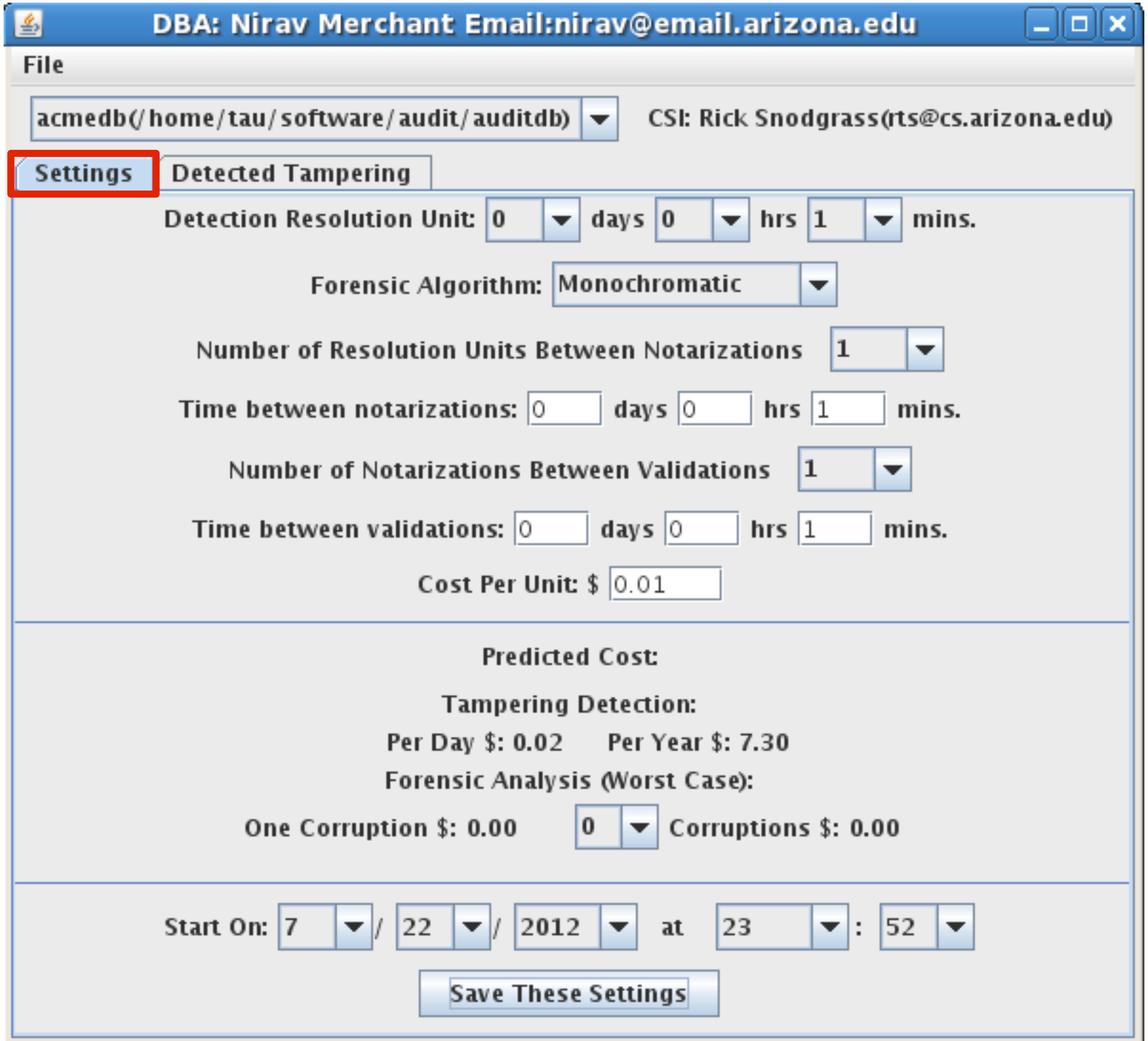

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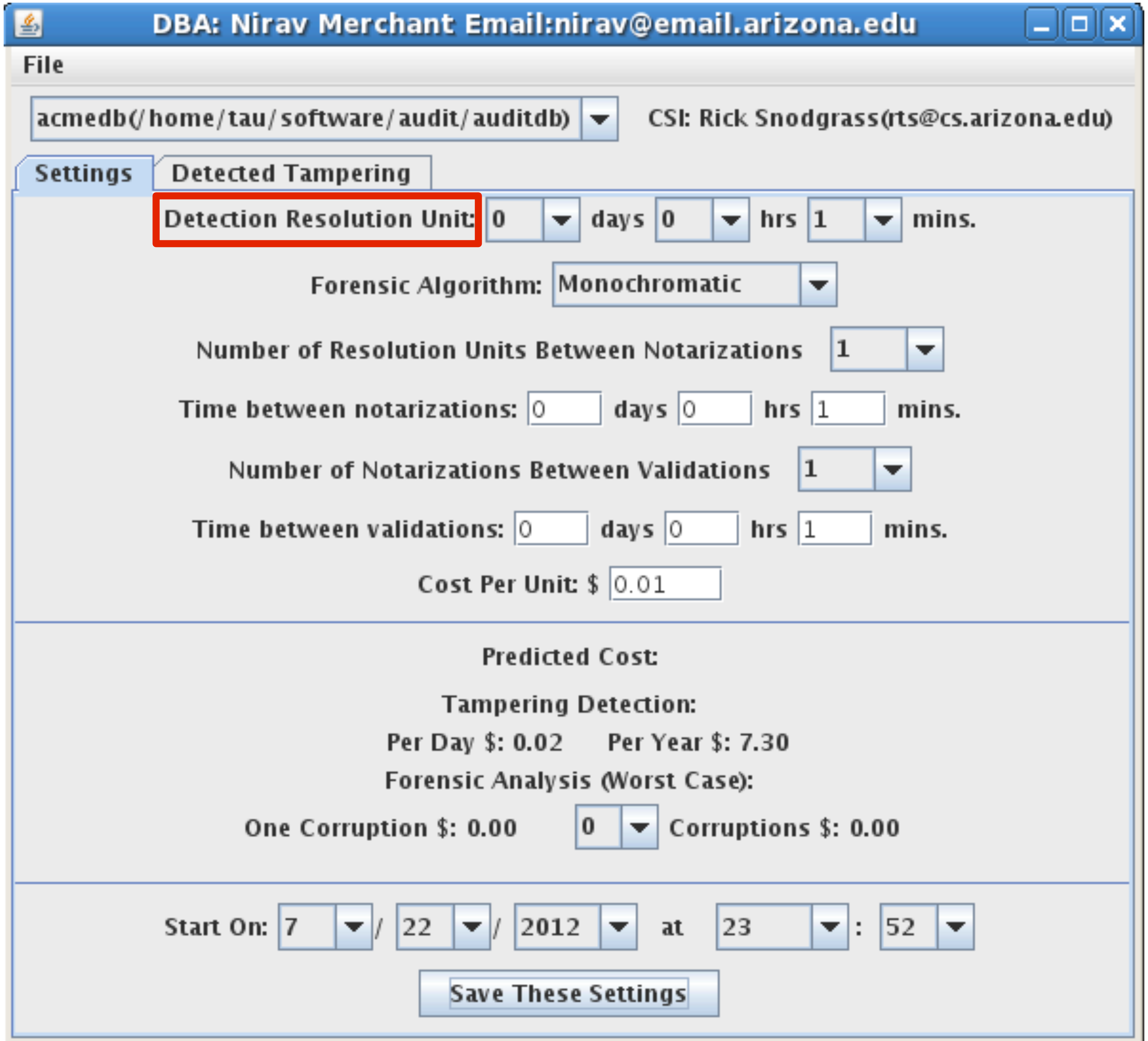

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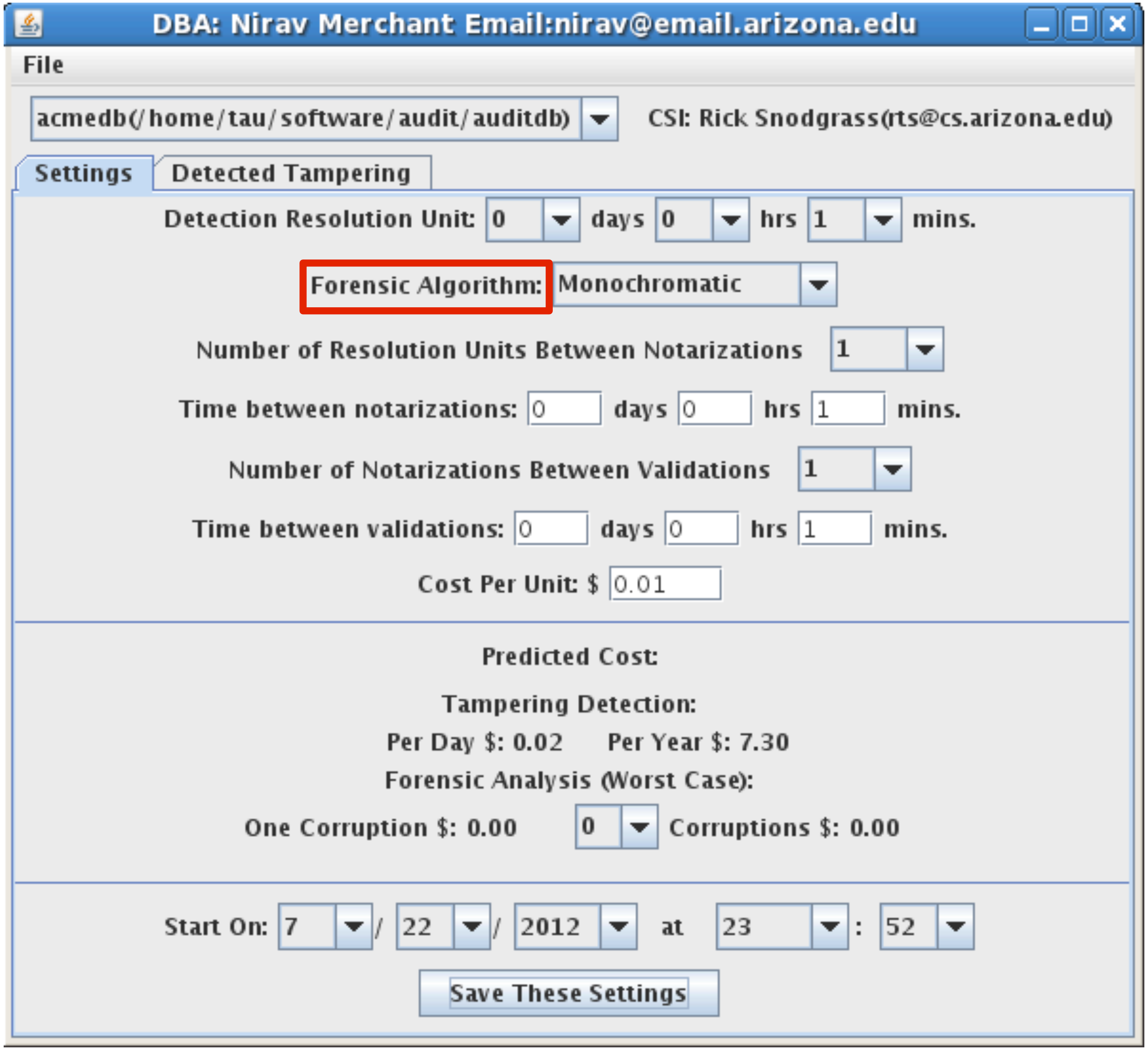

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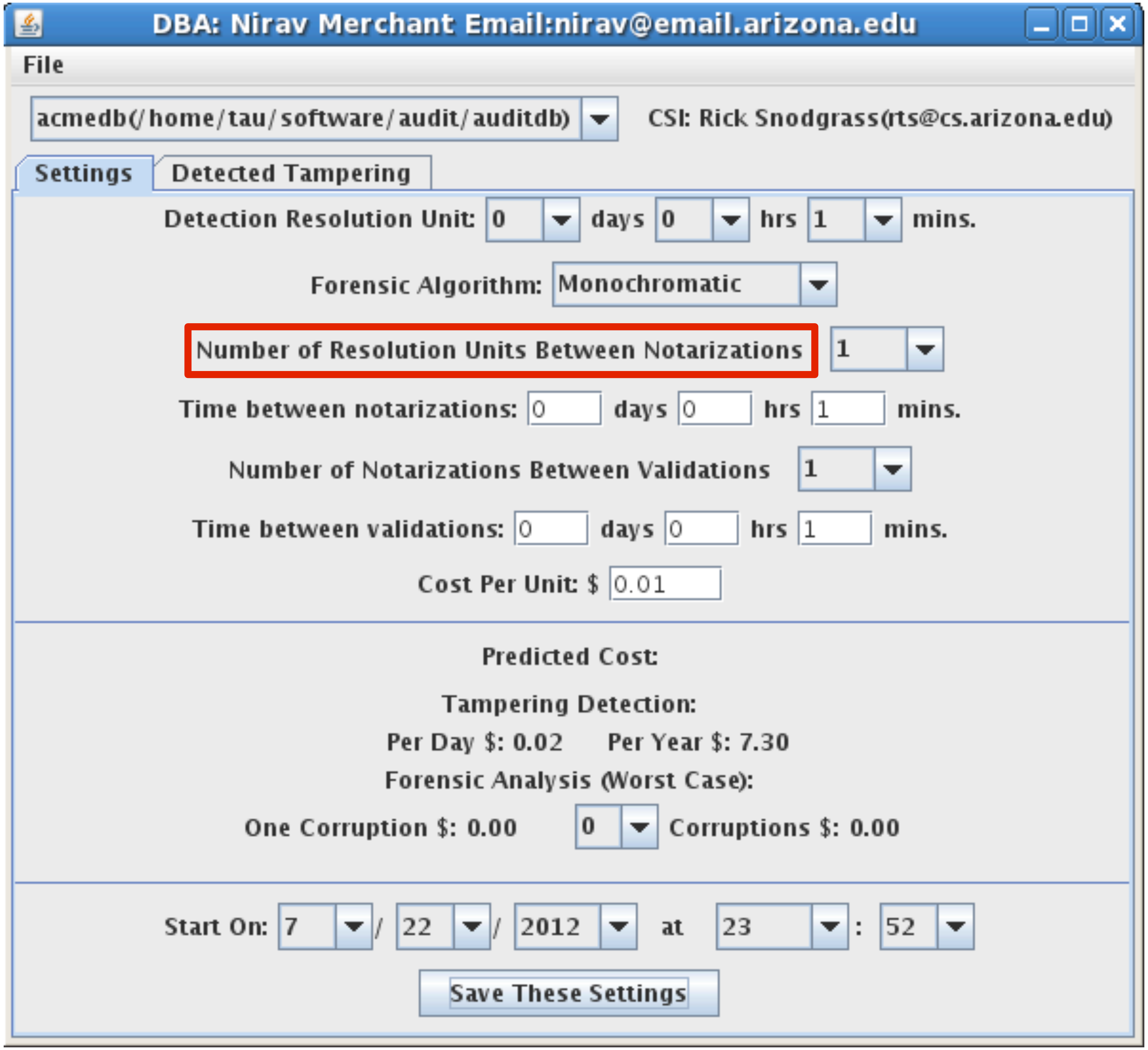

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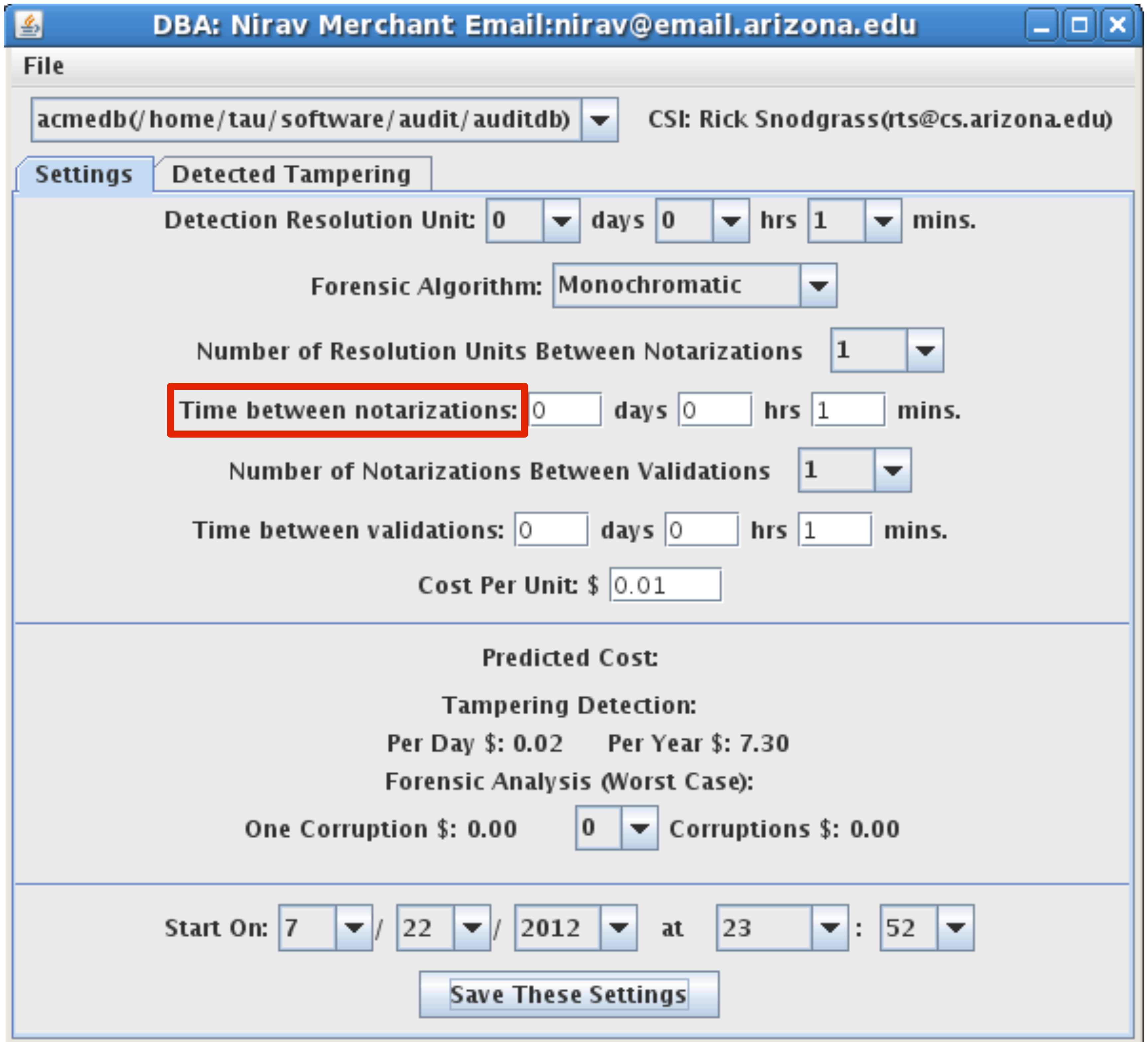

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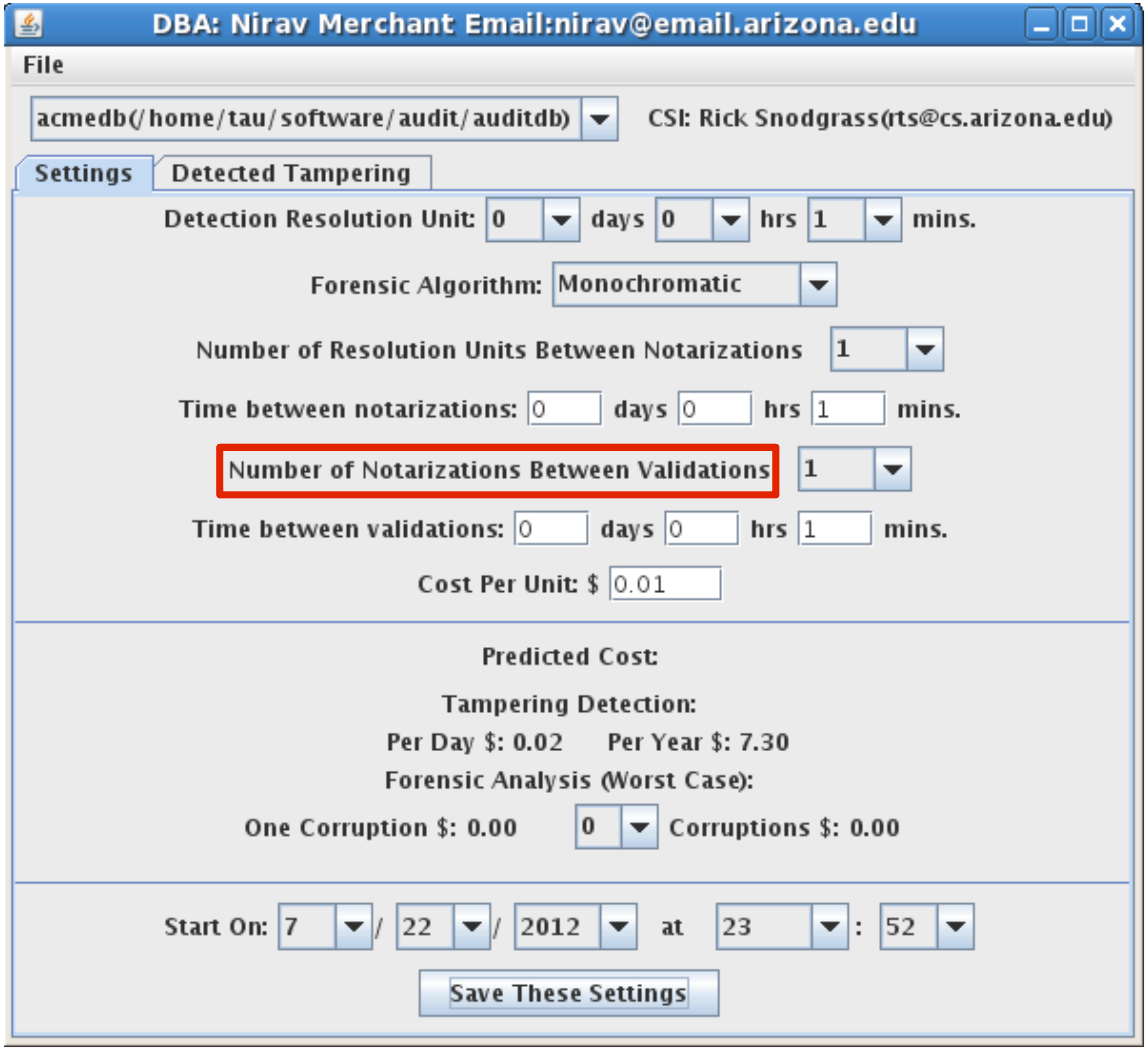

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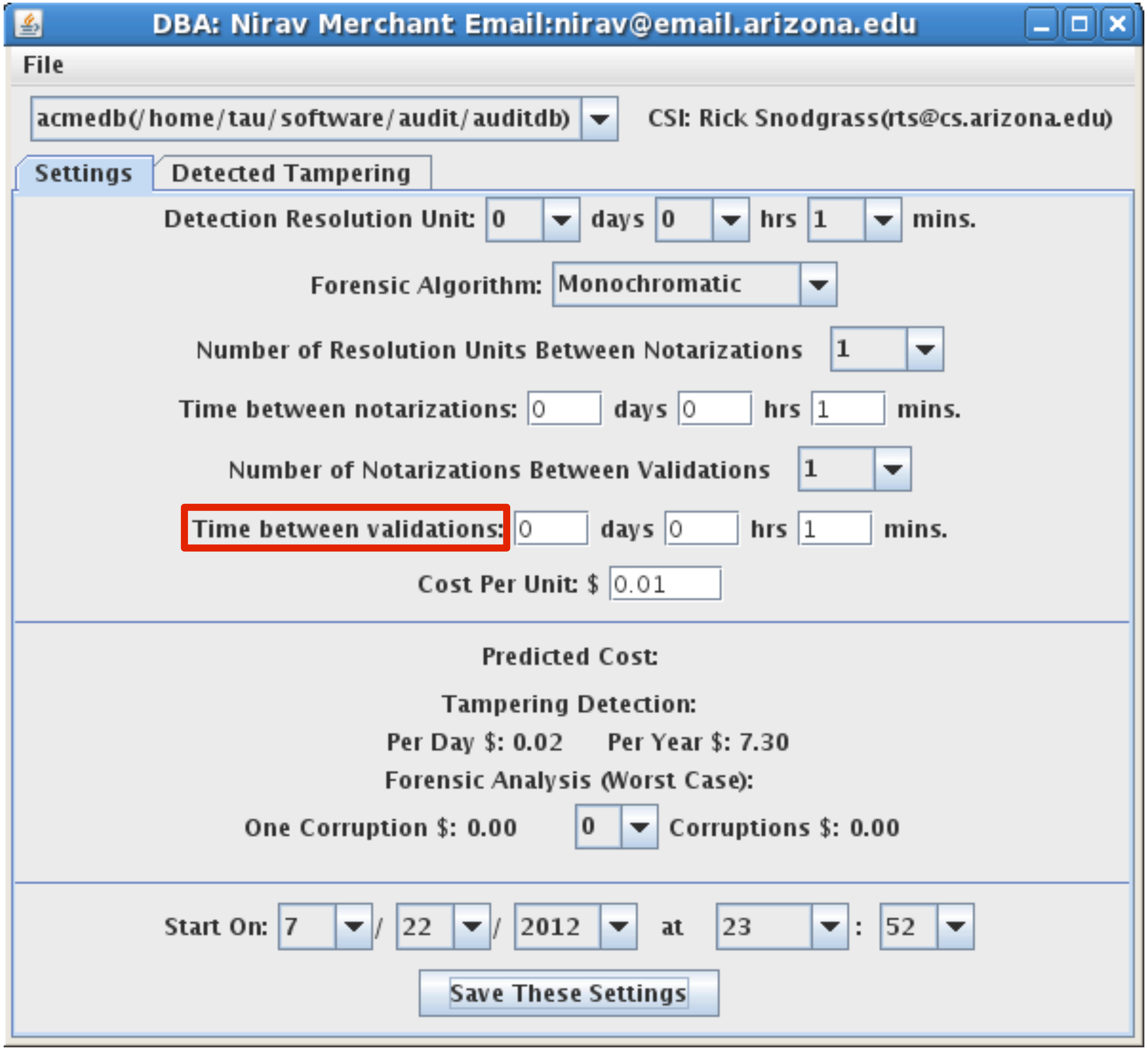

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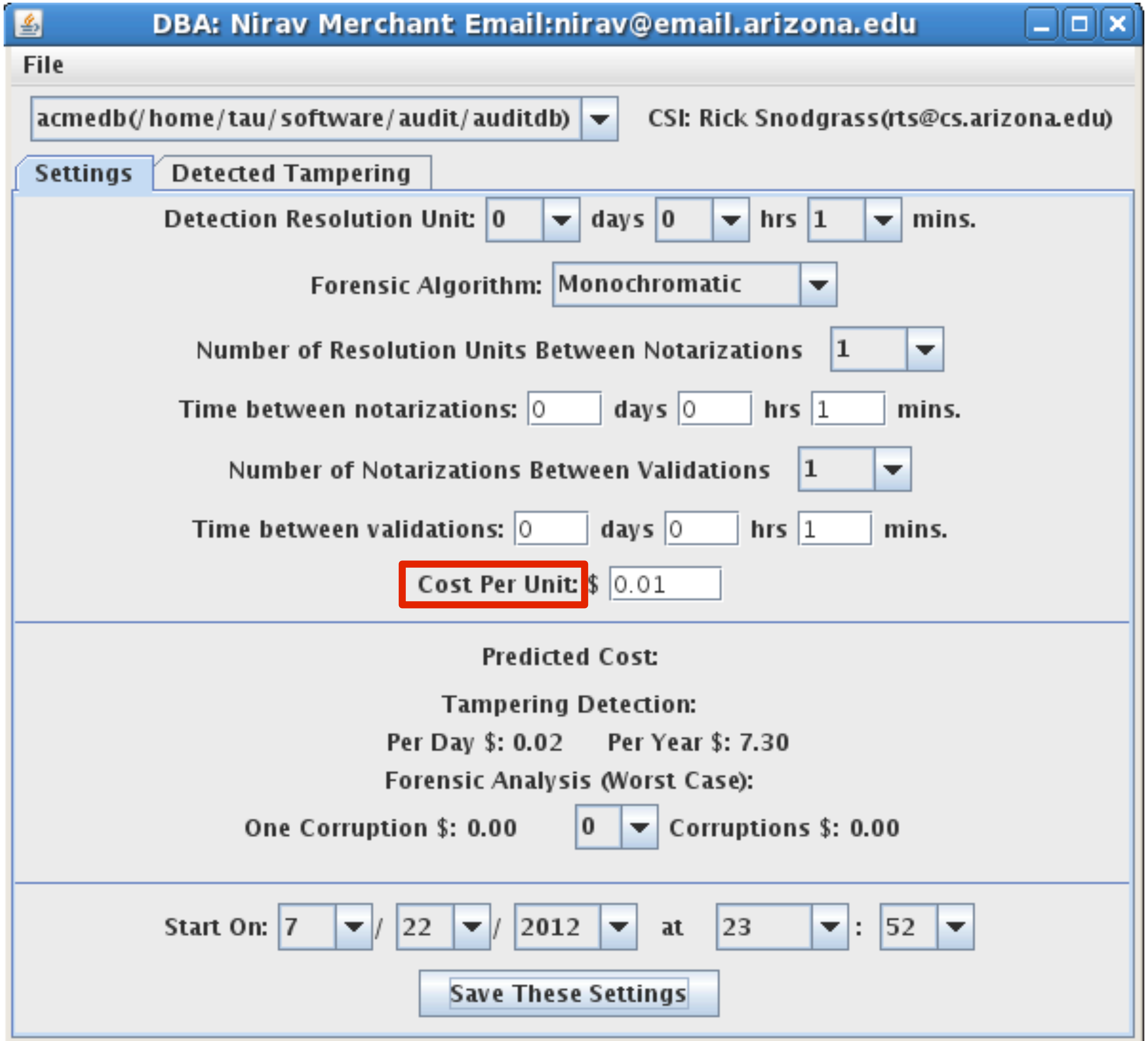

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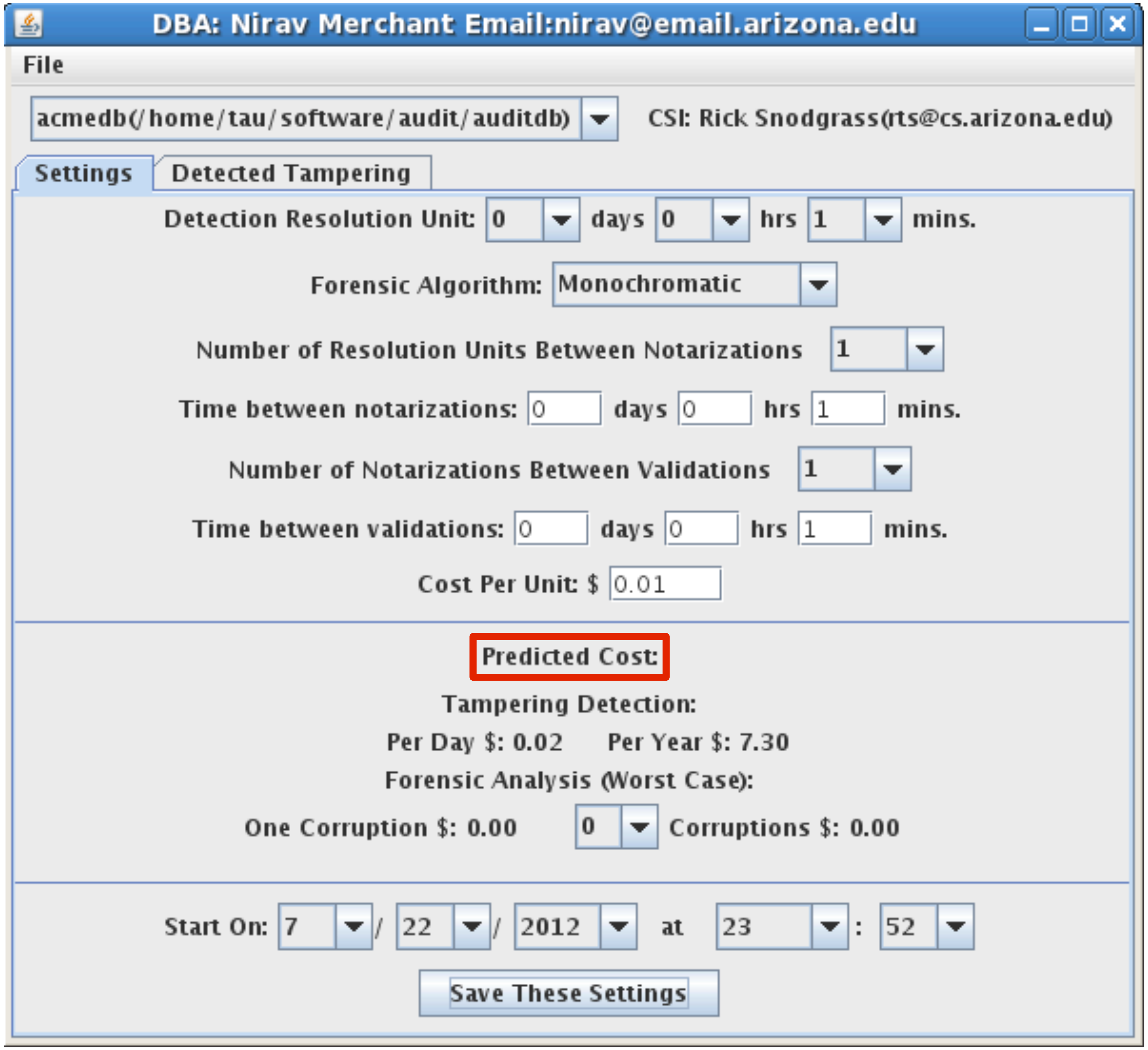

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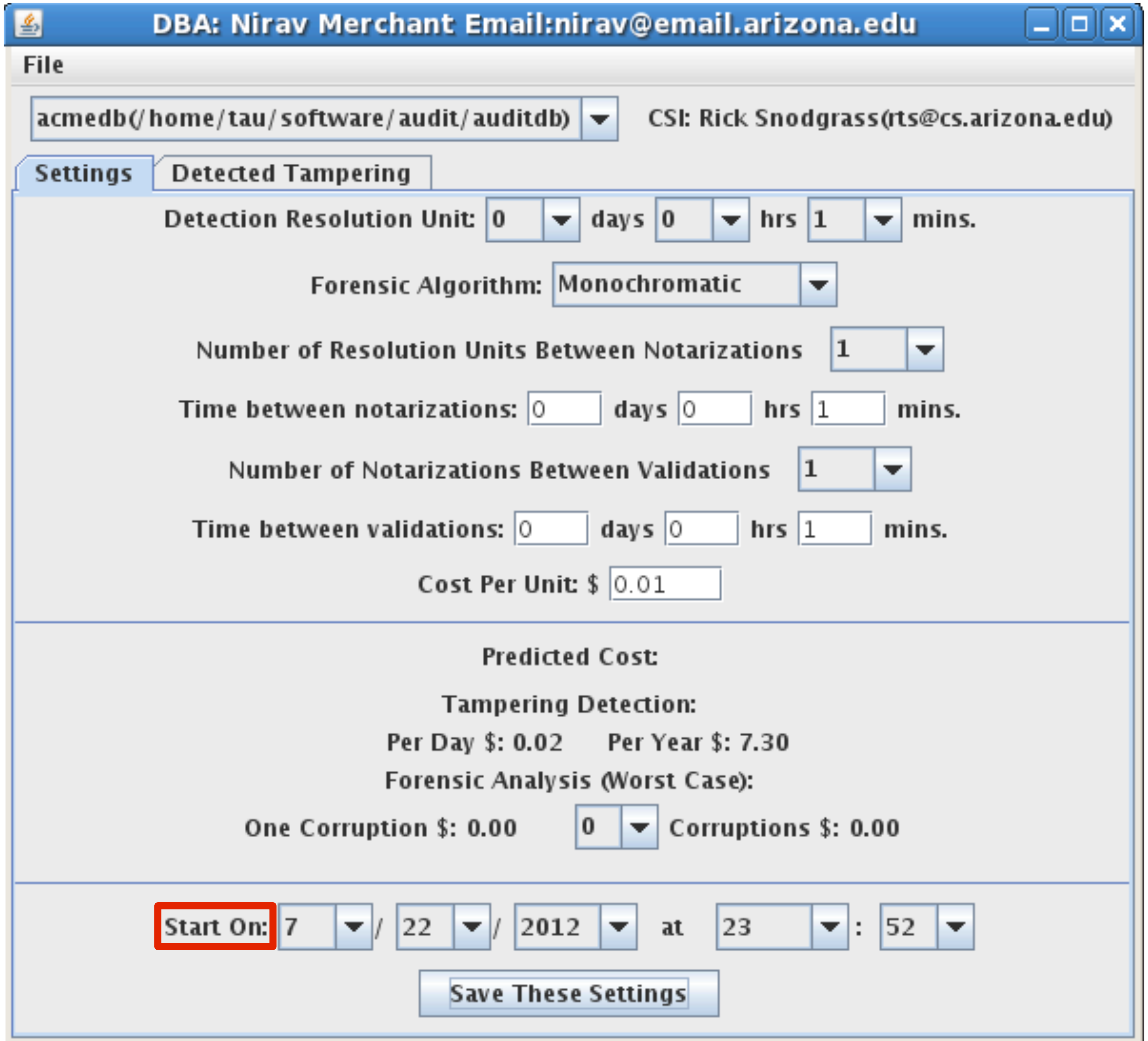
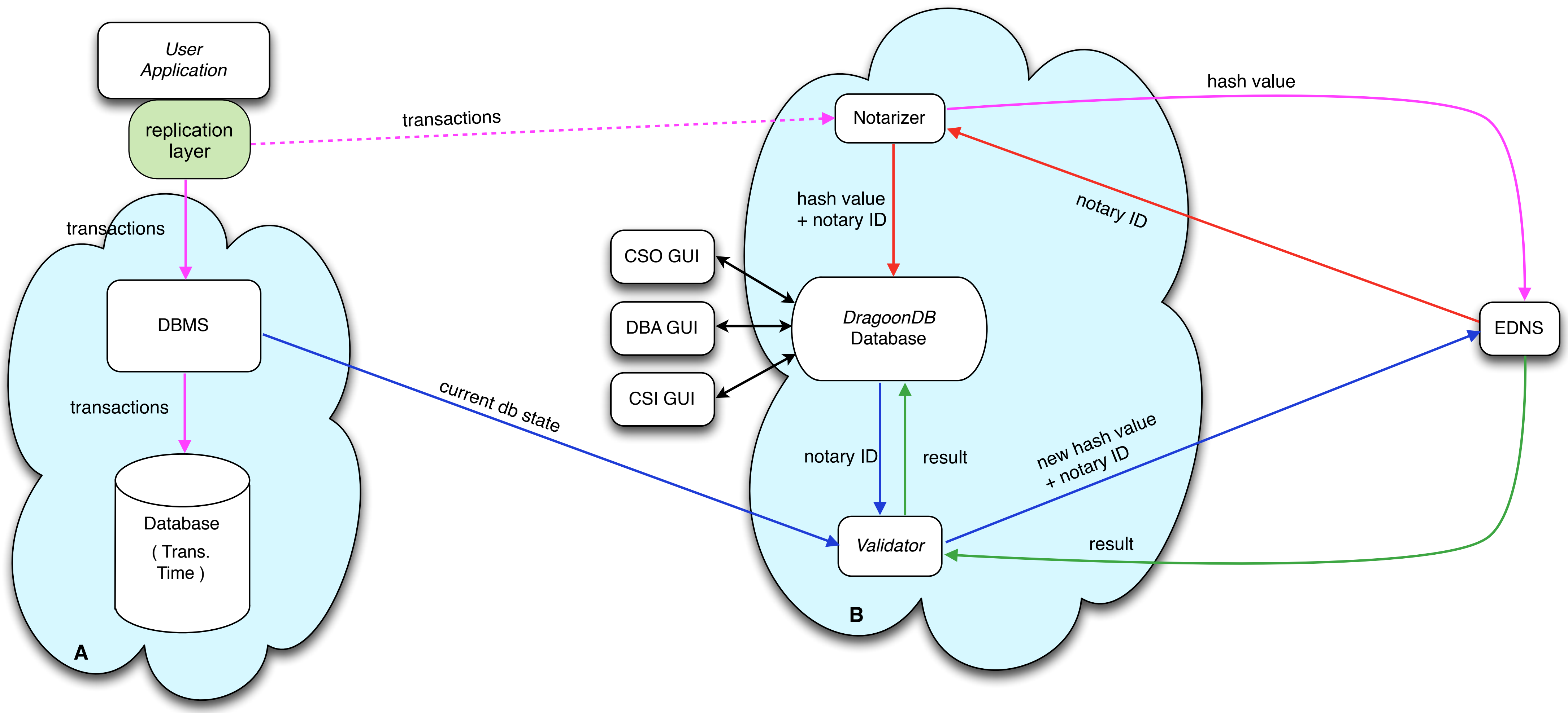


Information Accountability in the Cloud



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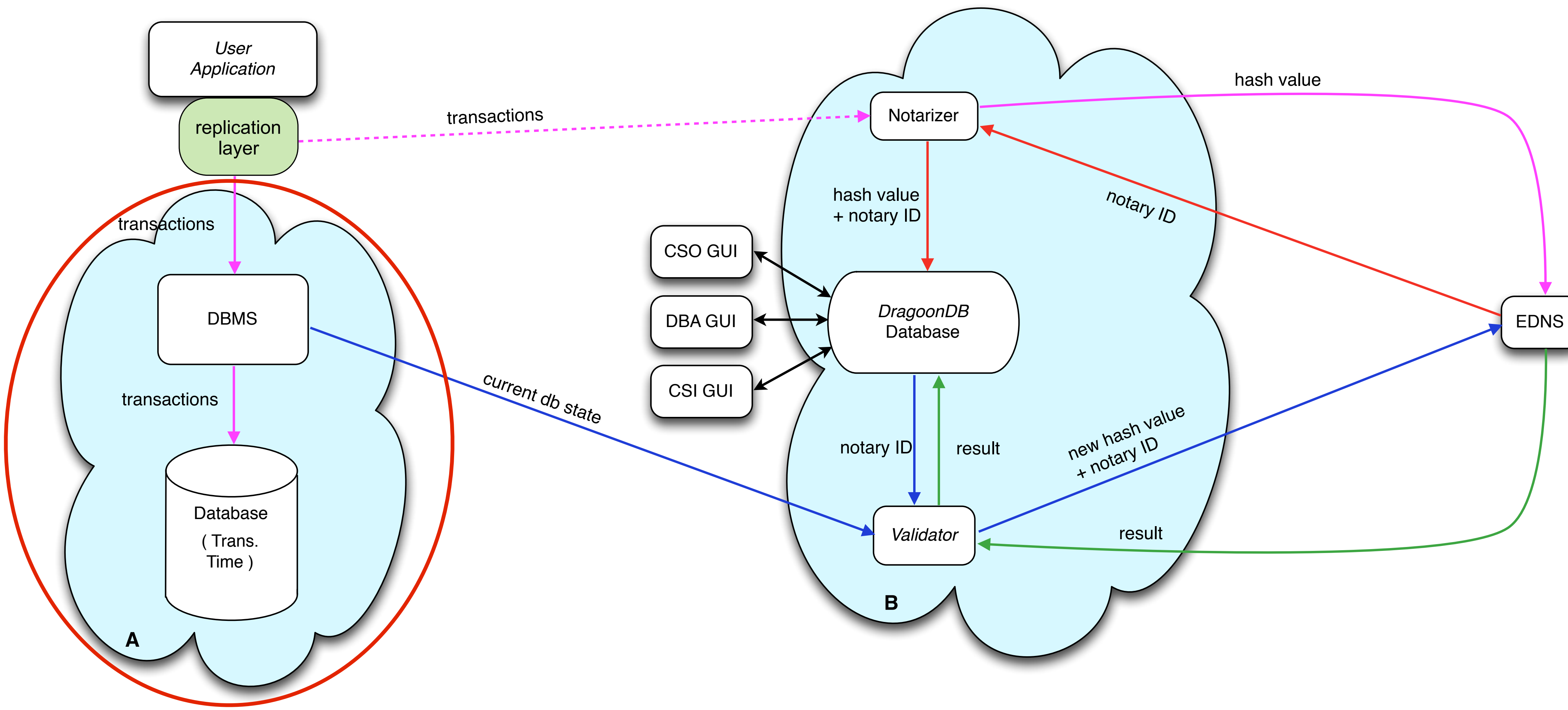

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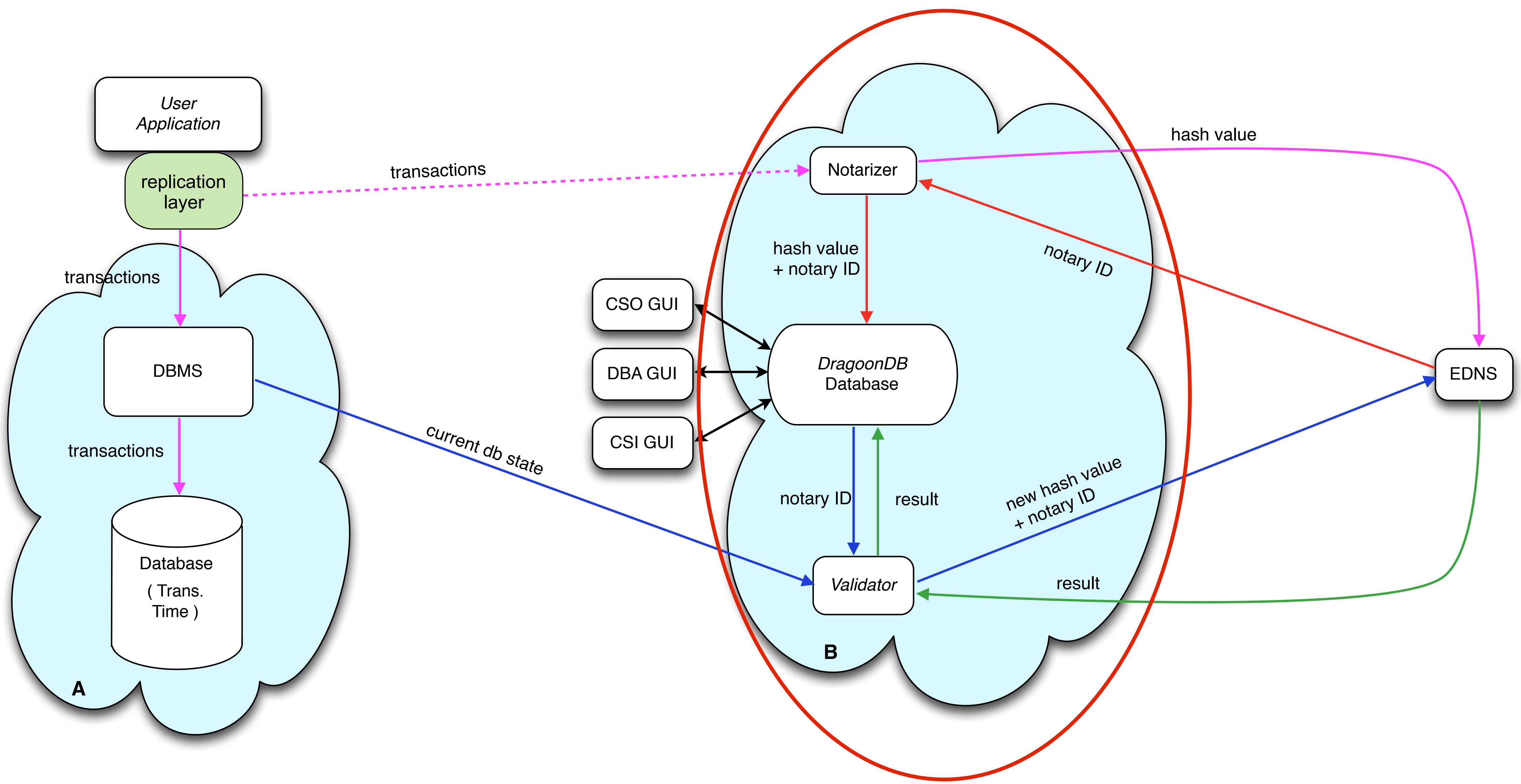

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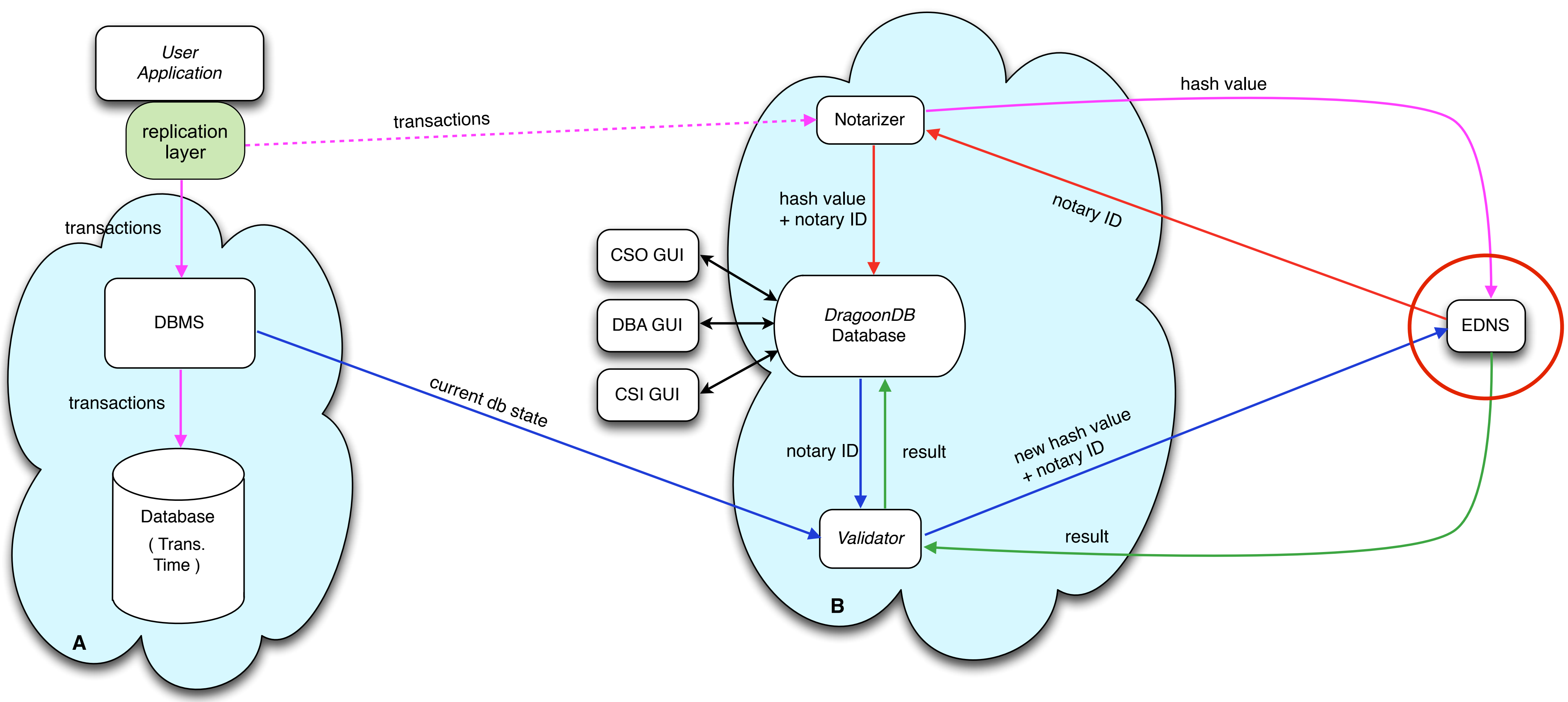

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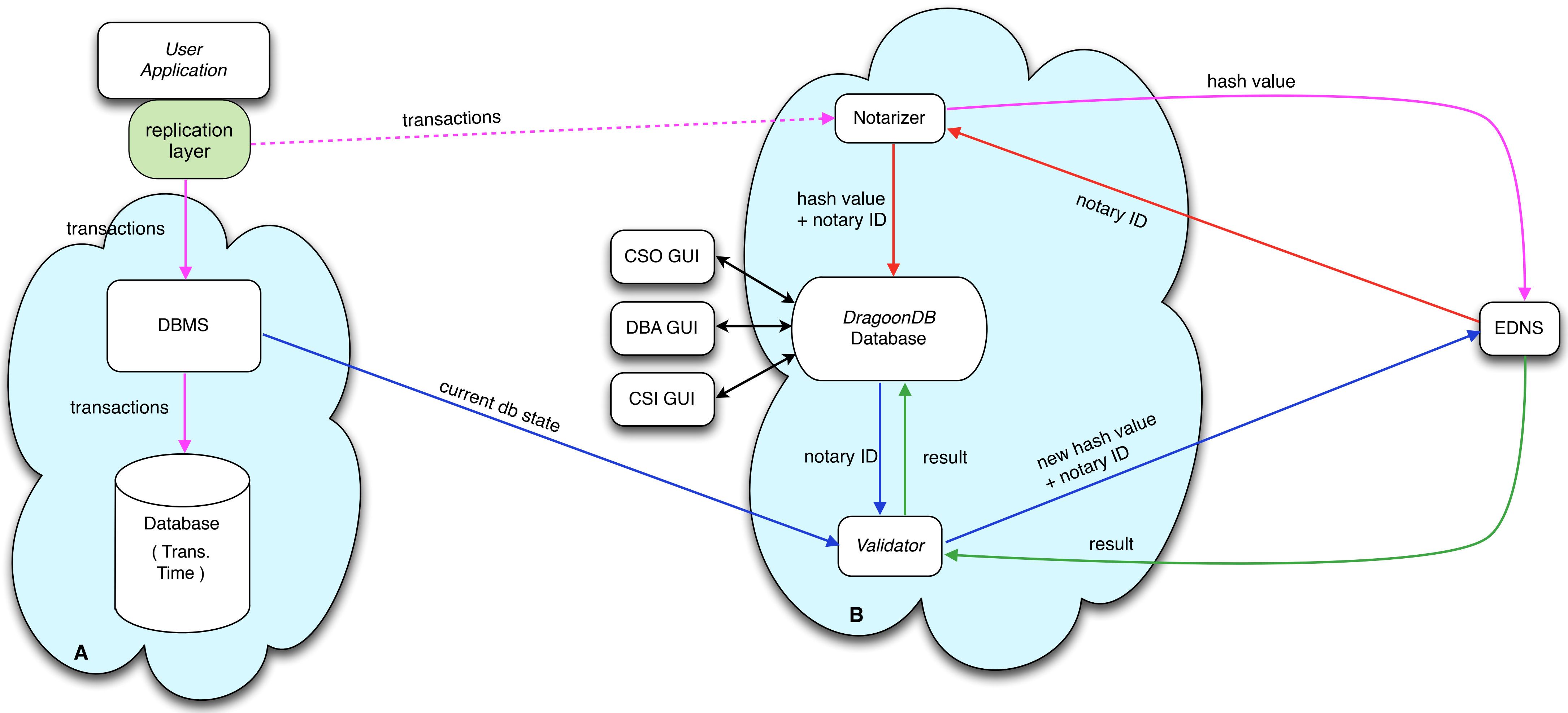

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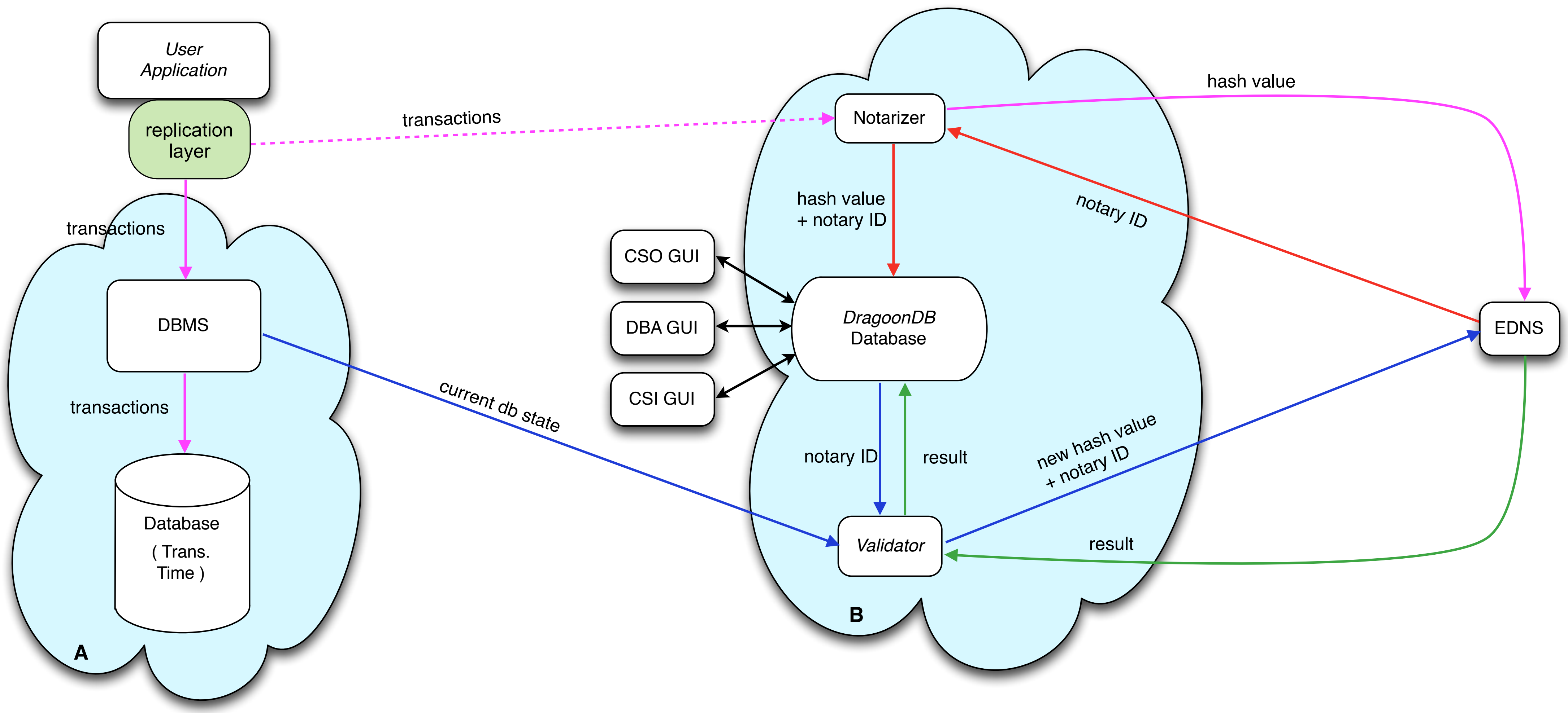

The new threat model may give rise to other temporal concepts.

Also holds for concurrency, replication, and distribution.

Summary

- Information Accountability
- Reference Architecture & Execution Phases
- Forensic Analysis
- Refinements
- Enterprise Considerations

Summary (2)

- Need to be able to capture history.
- Need to be able to revisit history.
- Need a trusted witness or at least consensus opinion to provide continuous assurance over time.

The Challenge

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As we have seen time arises naturally in many aspects of database information accountability (and in many guises).

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As we have seen time arises naturally in many aspects of database information accountability (and in many guises).

What is the deeper structure of the fundamental connection between temporal databases and information security?

Thank You!

Questions?