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Understanding the Concepts Behind Ethics in Designing Cyber-Physical Systems

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Introduction

- Cyber-Physical Systems (CPS) are increasingly deployed in **critical domains**, such as healthcare and industrial systems.
- These systems often **process sensitive data and make decisions that directly affect humans**.

Introduction

- CPS design should consider not only functional requirements, but also **ethics-based requirements**, e.g., **Privacy, Security, and Transparency.**

- Existing approaches provide limited guidance on the **design techniques needed to implement them in CPS.**

How can ethics-based requirements be systematically incorporated into CPS design?

Ethical Shortcomings

- **(W1) Privacy.** CPS may expose sensitive data when protection mechanisms and legal constraints are not explicitly considered.
- **(W2) Security.** Widespread CPS data streams increase exposure to cyberattacks, requiring security measures to evolve over time
- **(W3) Transparency.** Users often lack clear information about what data are collected, how they are used, and which safeguards apply.

Research Methodology

- **RQ:** What design techniques have been proposed and/or applied to address Privacy, Security, and Transparency requirements in the design of CPS?

DESIGN OR DEVELOP* OR MANAGE* OR ARCHITECT*	AND	”CYBER-PHYSICAL SYSTEMS” OR “CYBER PHYSICAL”	AND	“NON-FUNCTIONAL REQUIREMENT”	AND	PRIVACY OR SECURITY OR TRANSPARENCY

Development Stage

Domain

Specific Ethics-based Concerns

Research Methodology

- **RQ:** What design techniques have been proposed and/or applied to address Privacy, Security, and Transparency requirements in the design of CPS?

Inclusion Criteria		Exclusion Criteria	
I1	The paper is written in English.	**E1**	The paper was published before 2020.
I2	The paper has been peer-reviewed.	**E2**	The paper is a duplicate or a shorter version of an already included work.
I3	The paper specifies design techniques on ethics in the context of CPS.	**E3**	The paper is outside the scope of the study

16 papers

Extracting Design Concepts

16 selected papers

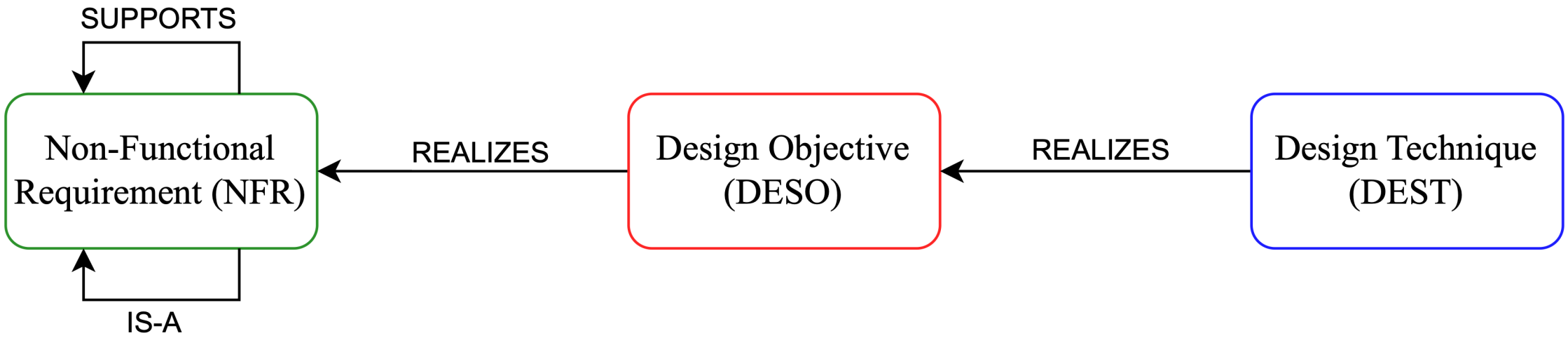
Extract design-oriented concepts

Code by ethical requirement

Group by semantic similarity

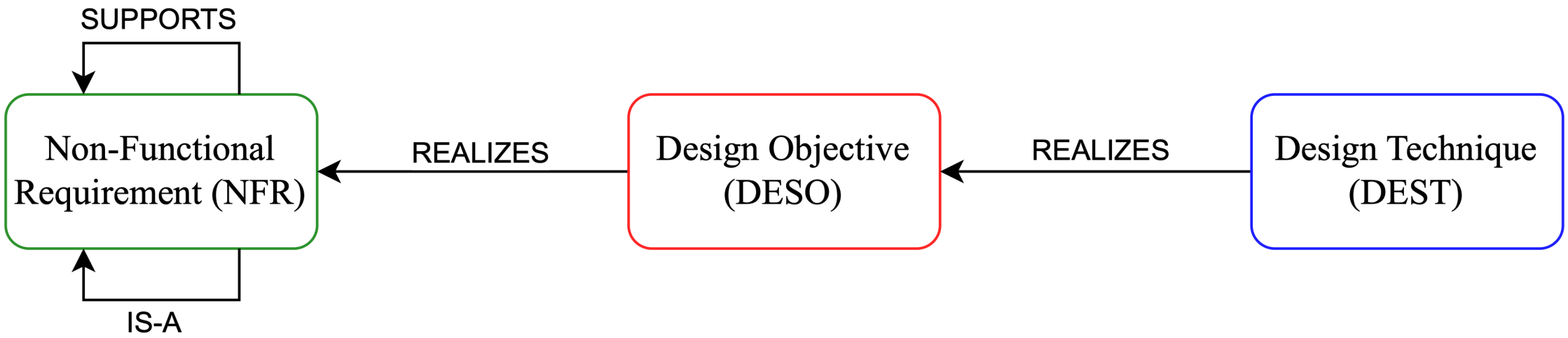
Identify recurring design strategies

Knowledge Base



NFR describes the target of a software system, e.g., privacy;
DESO represents the goals to realize the target, e.g., data protection;
DEST is concrete architectural or implementation-level solutions used to address the design objective, e.g., encryption.

Knowledge Base



RELIZES indicates that a DESO addresses a NFR, or that a DEST implements a DESO
SUPPORTS links complementary NFRs that reinforce one another without implying subclassing, thereby enhancing the parent concept's effectiveness.
IS-A denotes hierarchical specialization among NFRs

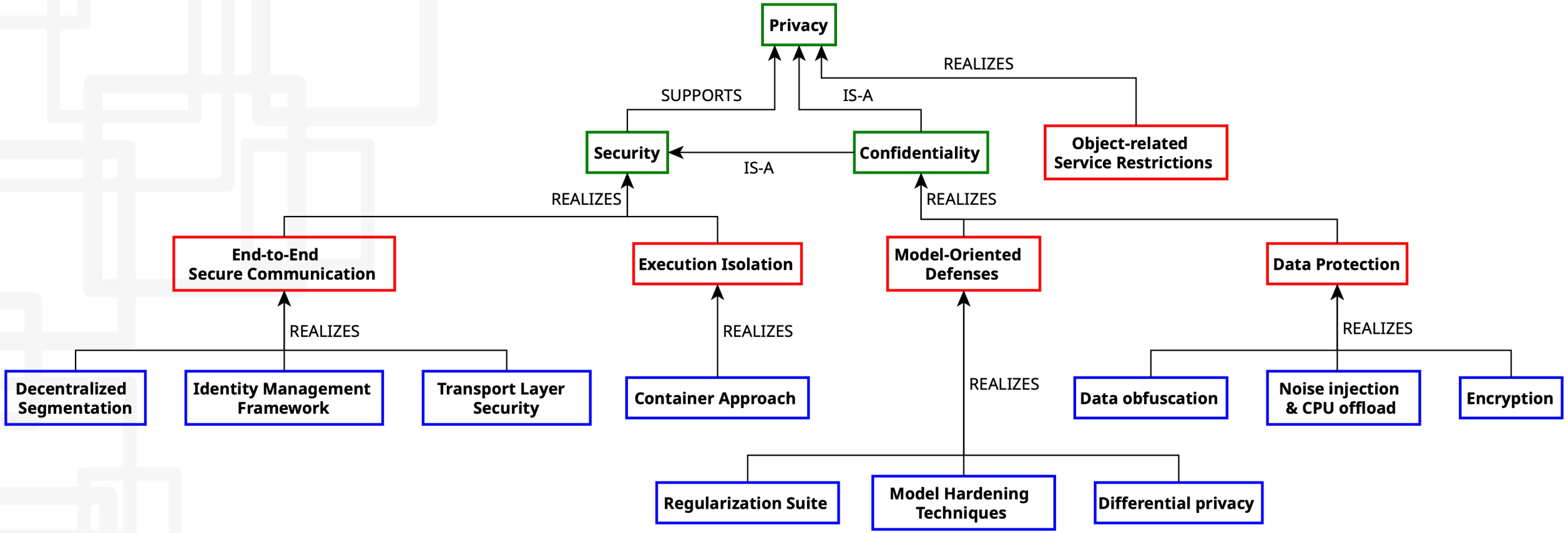
DeTe4CPES Design Approach

DEsign TEchniques for Cyber-Physical Ethical Systems (DeTe4CPES)

- Supports CPS design with Privacy, Security, and Transparency.
- Organizes knowledge extracted from the literature into knowledge graphs.
- Maps Design Objectives to corresponding Design Techniques.
- DeTe4CPES is publicly available.

Replication Package

Privacy



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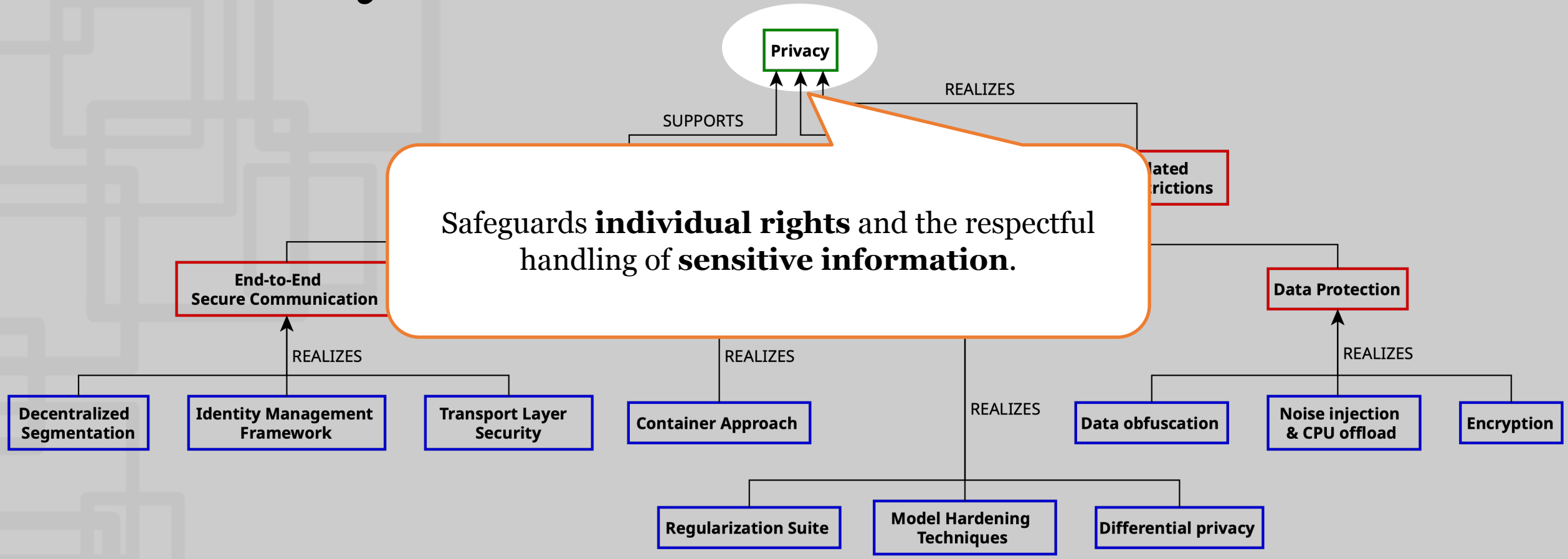
Privacy



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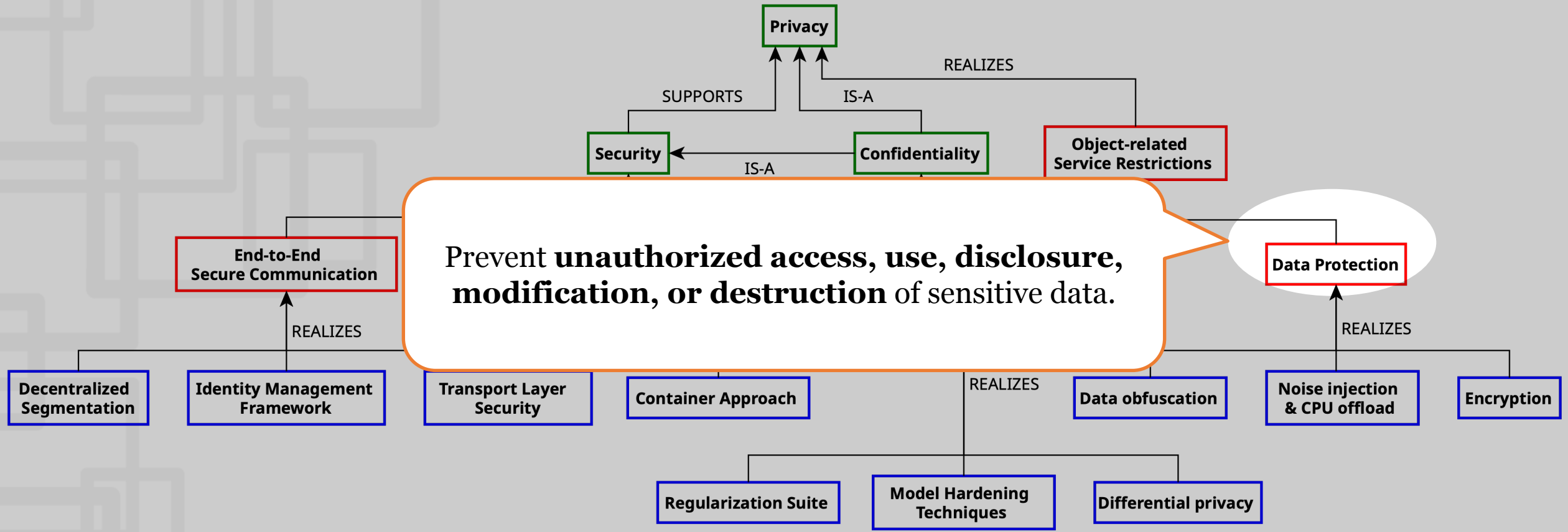
Privacy



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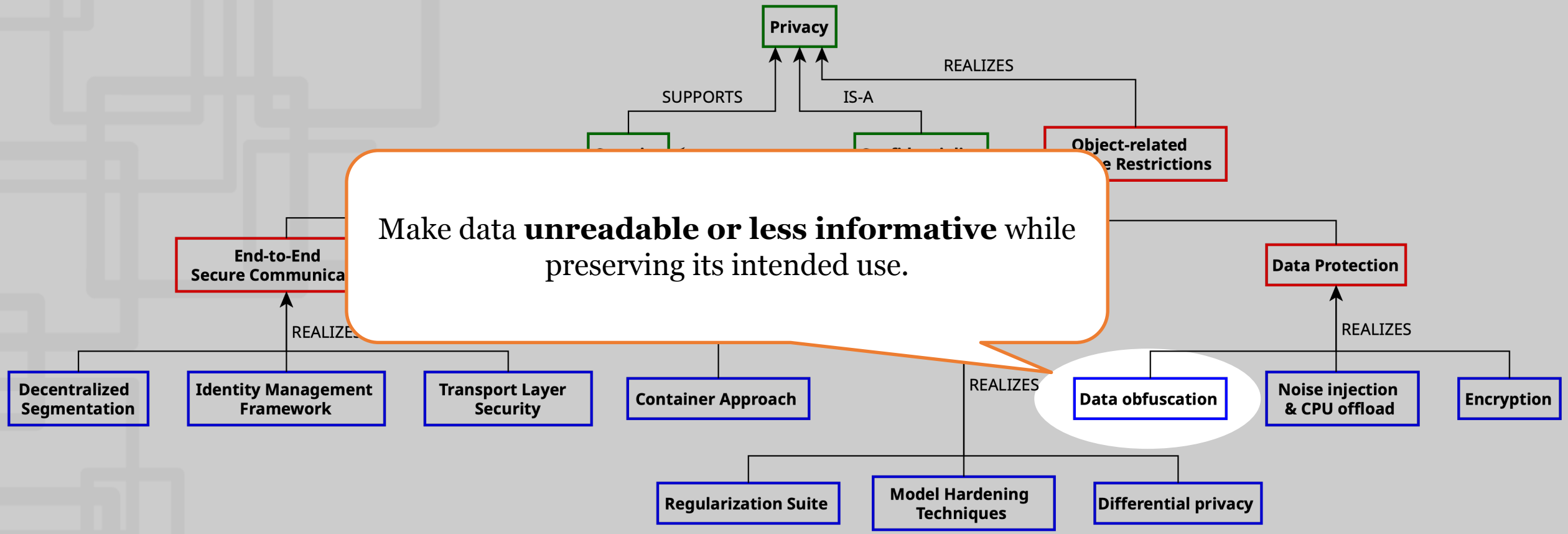

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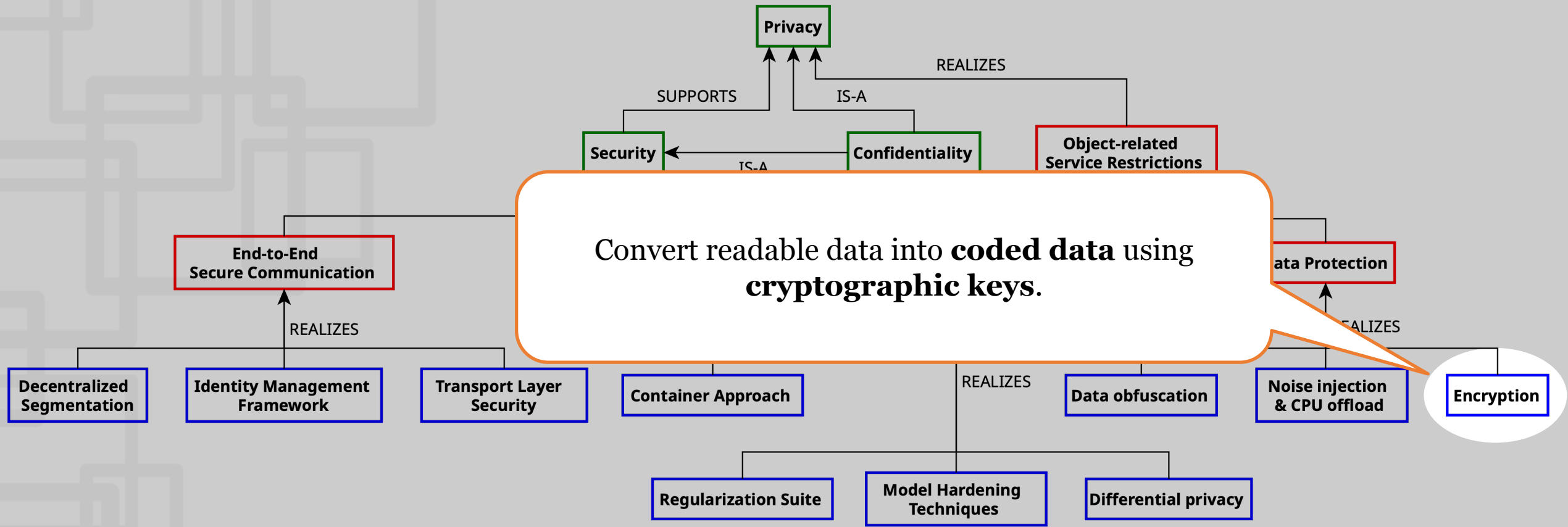
Privacy



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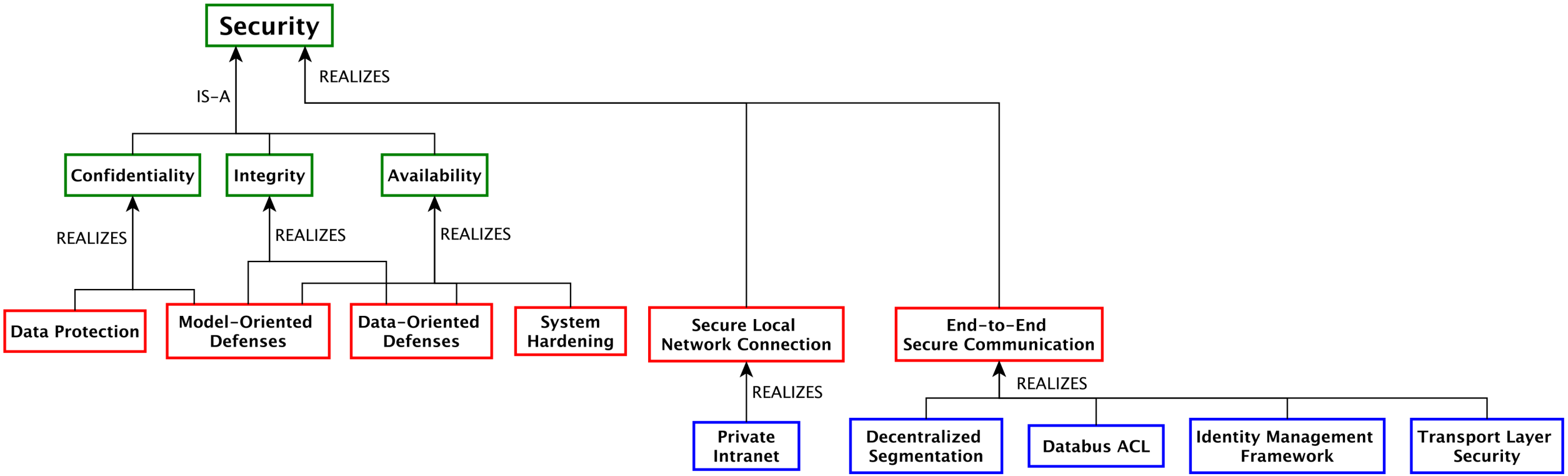
Security



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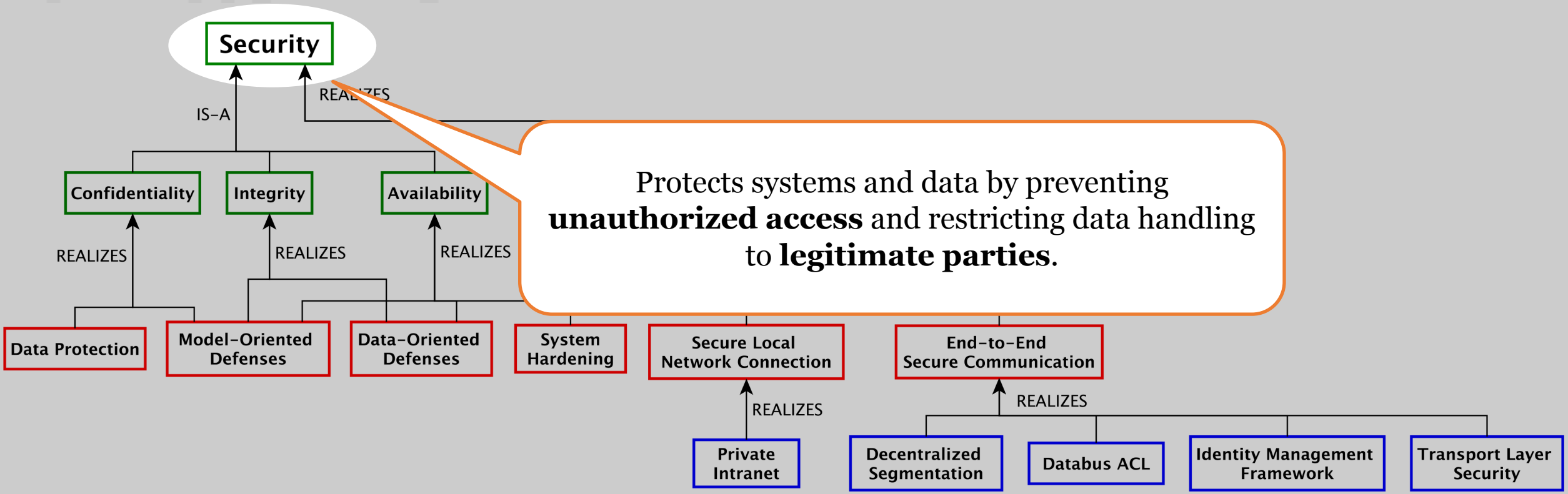

Protects systems and data by preventing **unauthorized access** and restricting data handling to **legitimate parties**.

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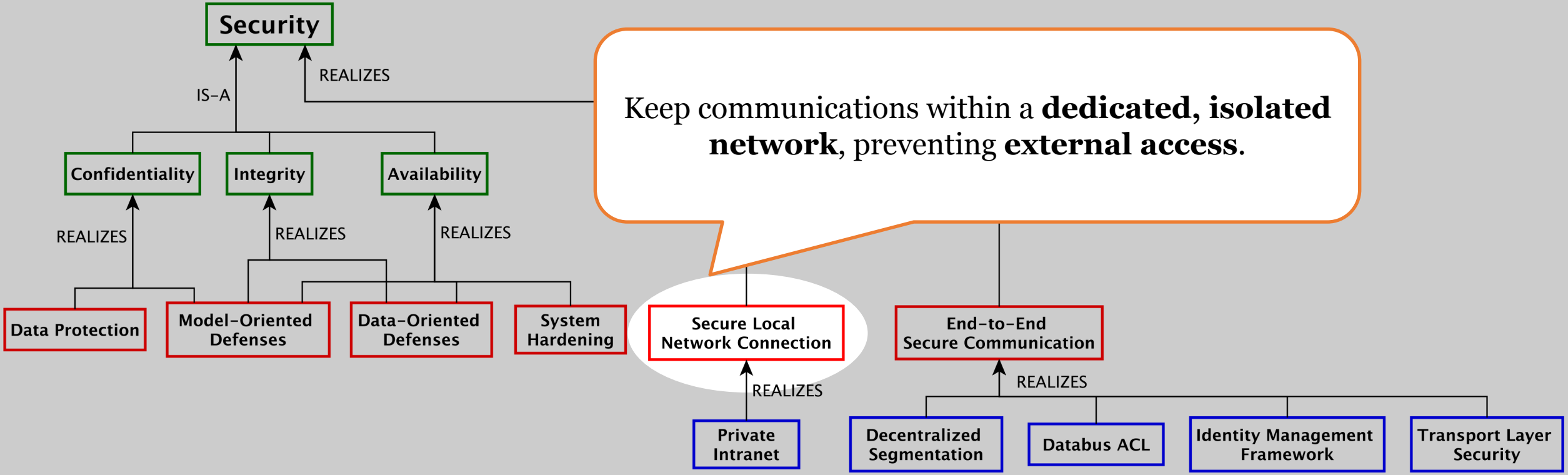
Security



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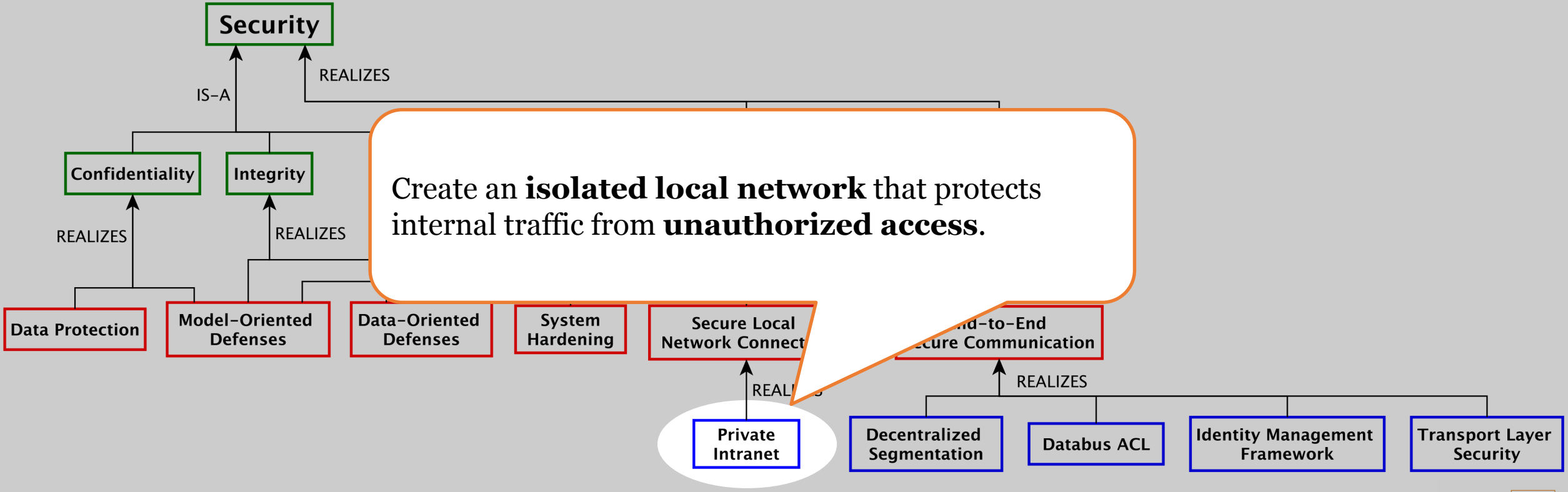

Create an **isolated local network** that protects internal traffic from **unauthorized access**.

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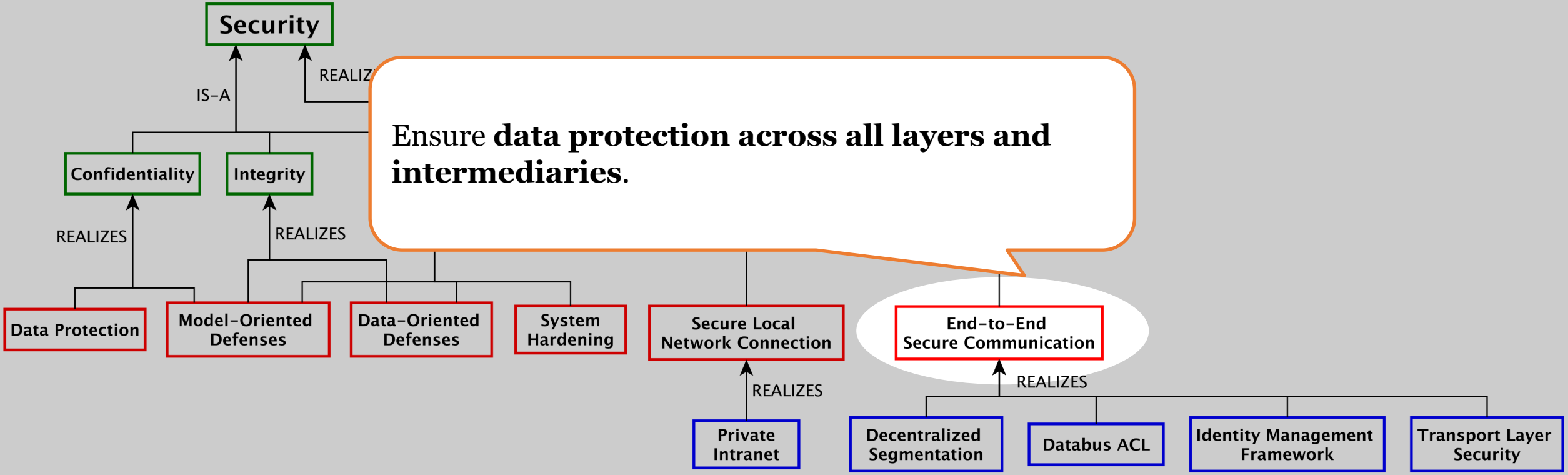

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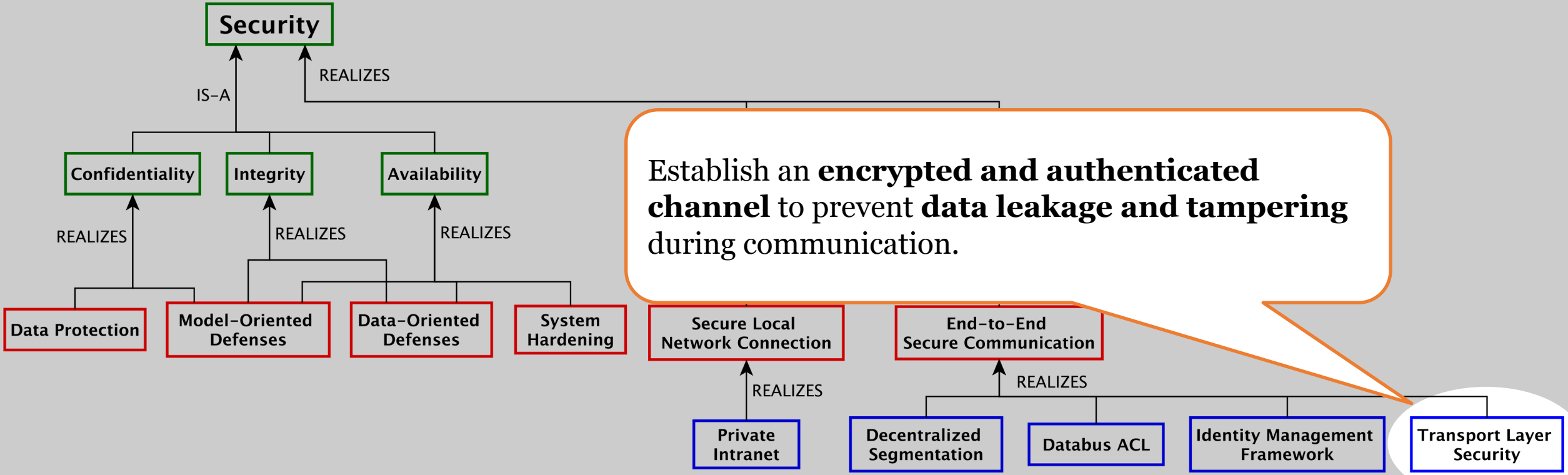

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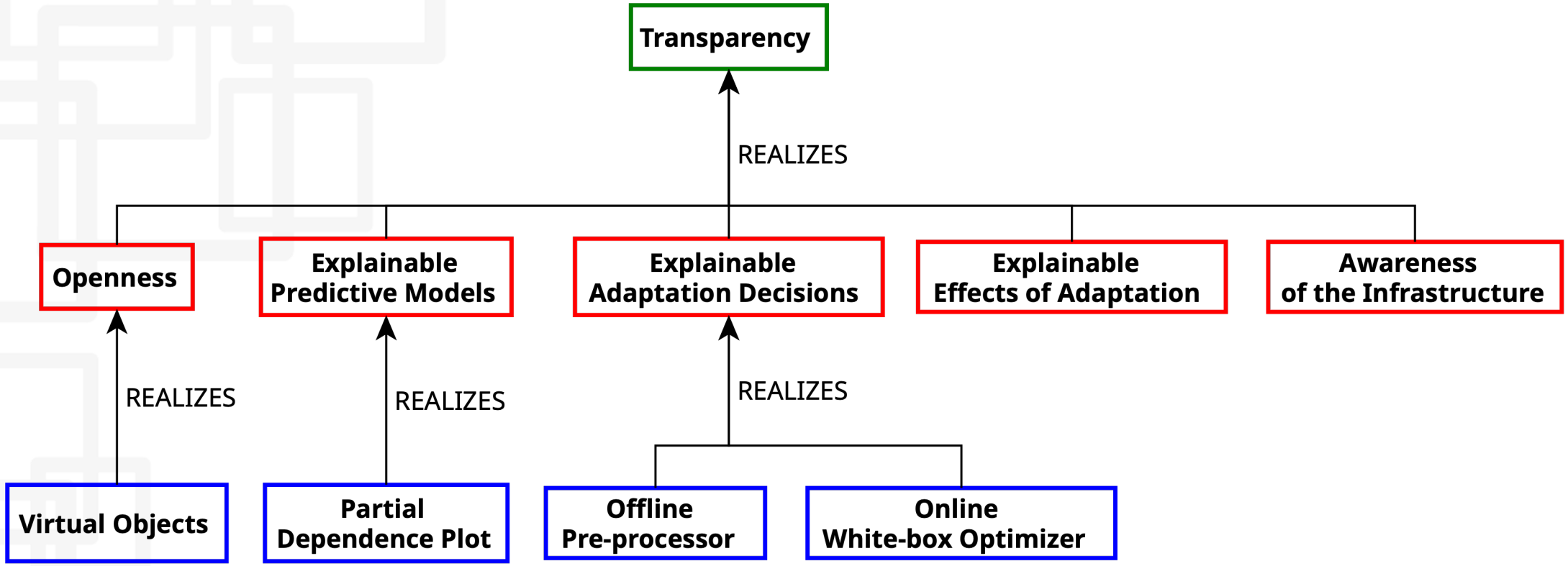
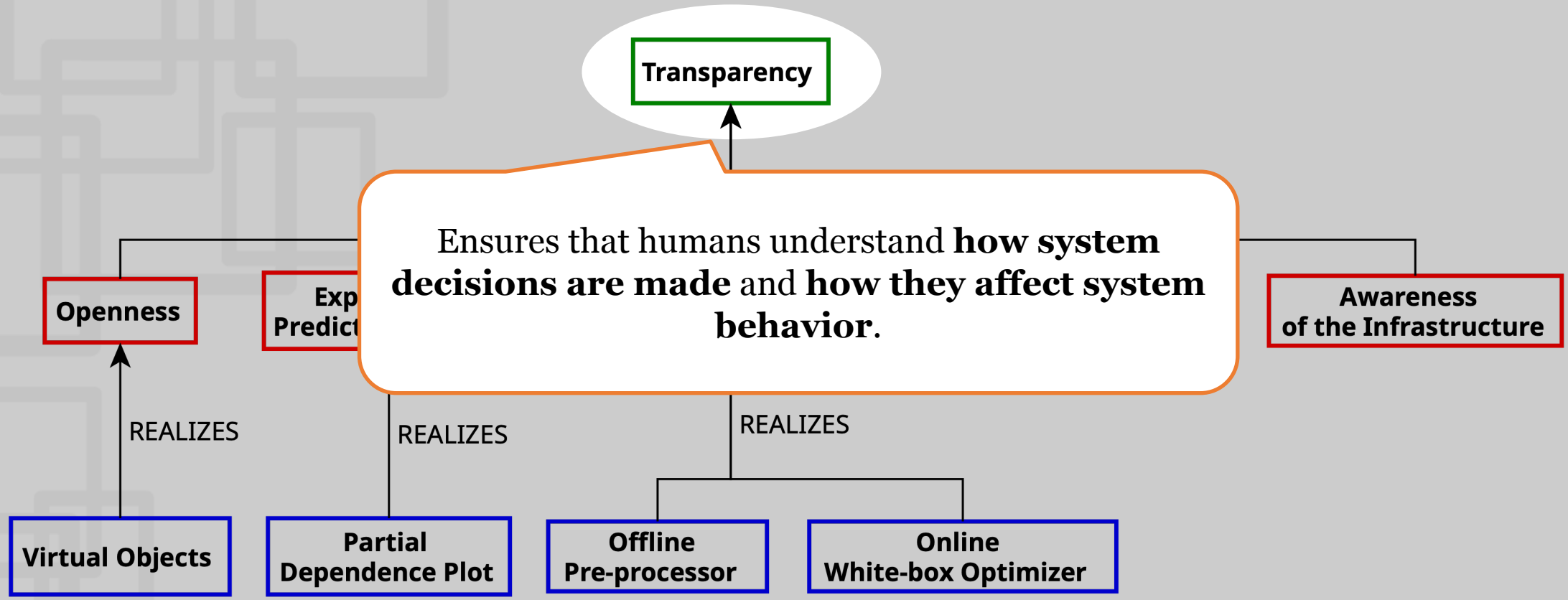
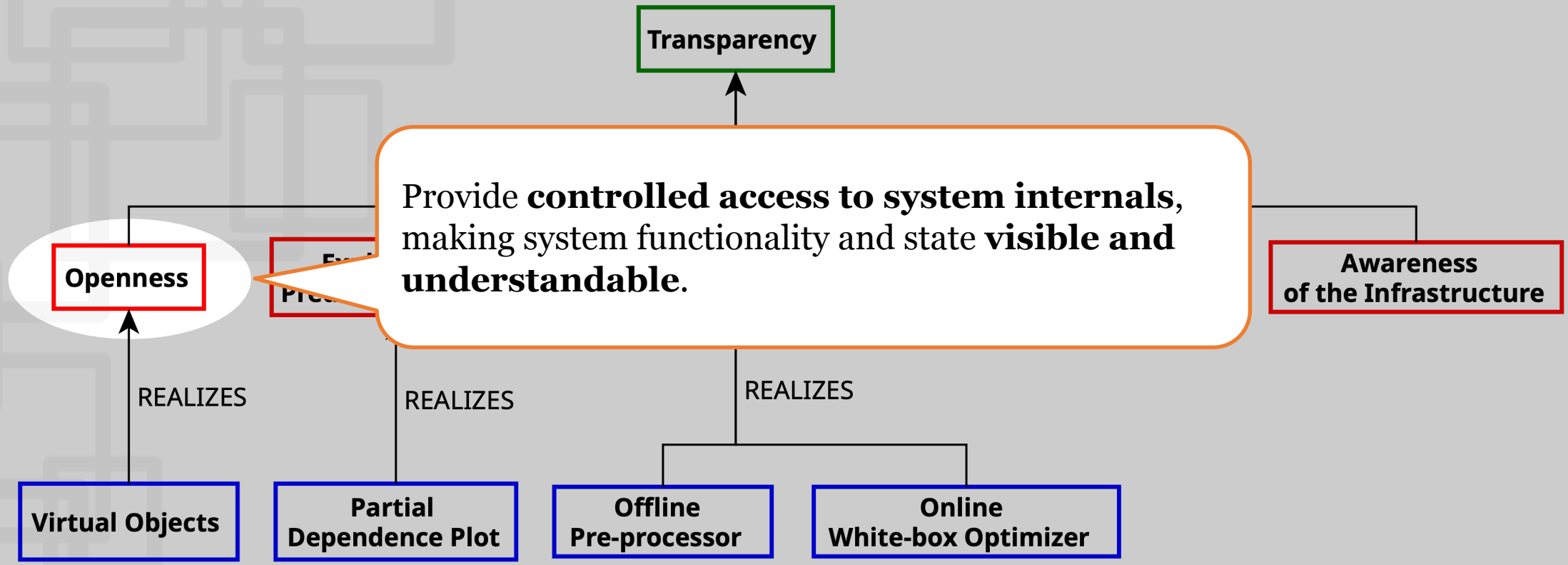
Transparency



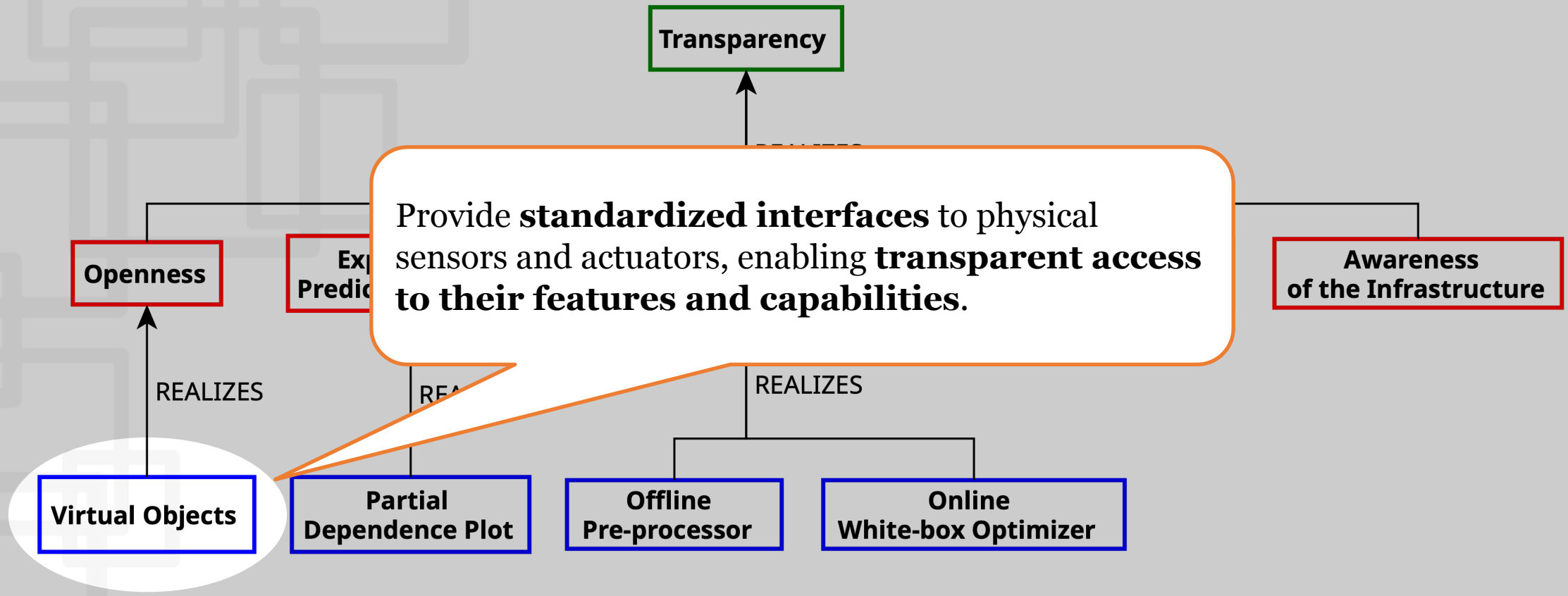
Transparency



Transparency



Transparency



Provide **standardized interfaces** to physical sensors and actuators, enabling **transparent access to their features and capabilities**.

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Patient Monitoring System

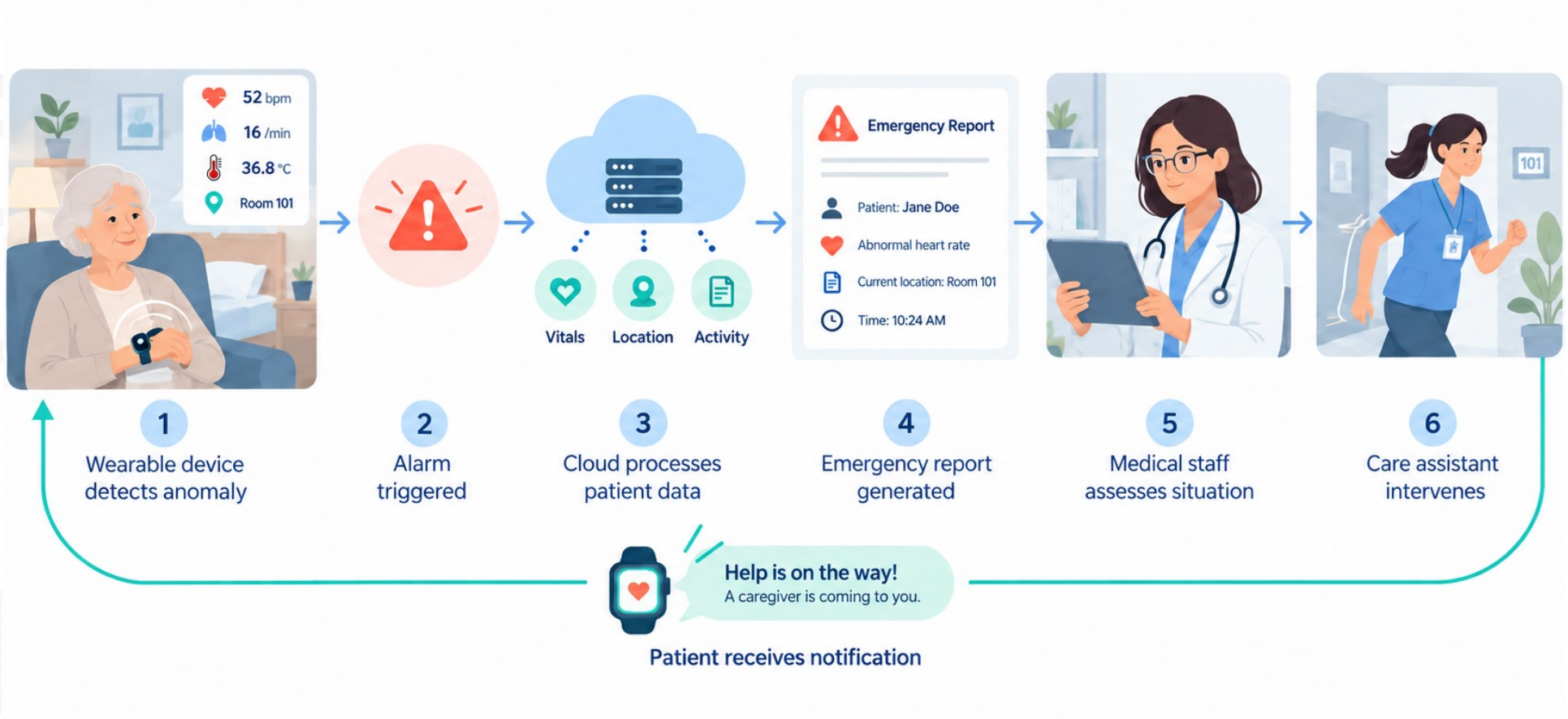
Context

- An assisted-living facility where patients are monitored through **wearable devices** collecting their location and vital parameters.
- The system involves a **cloud infrastructure**, the **head of medical staff**, and **care assistants**.

BPMN Representation

- The patient monitoring process is modeled using **Business Process Model and Notation (BPMN)** to represent its activities, events, and decisions.

Patient Monitoring System



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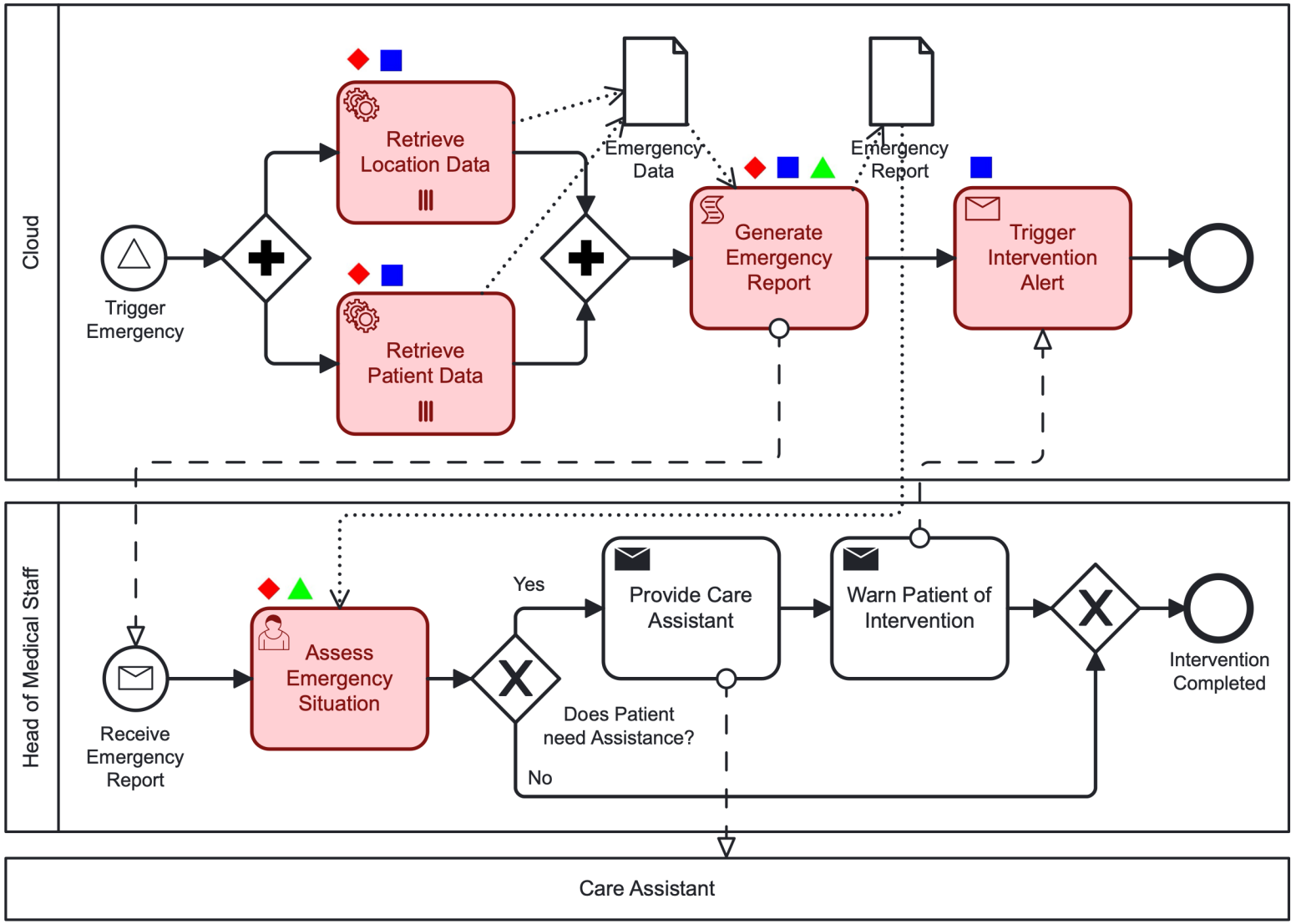
BPMN Diagram



- Privacy
- Security
- Transparency

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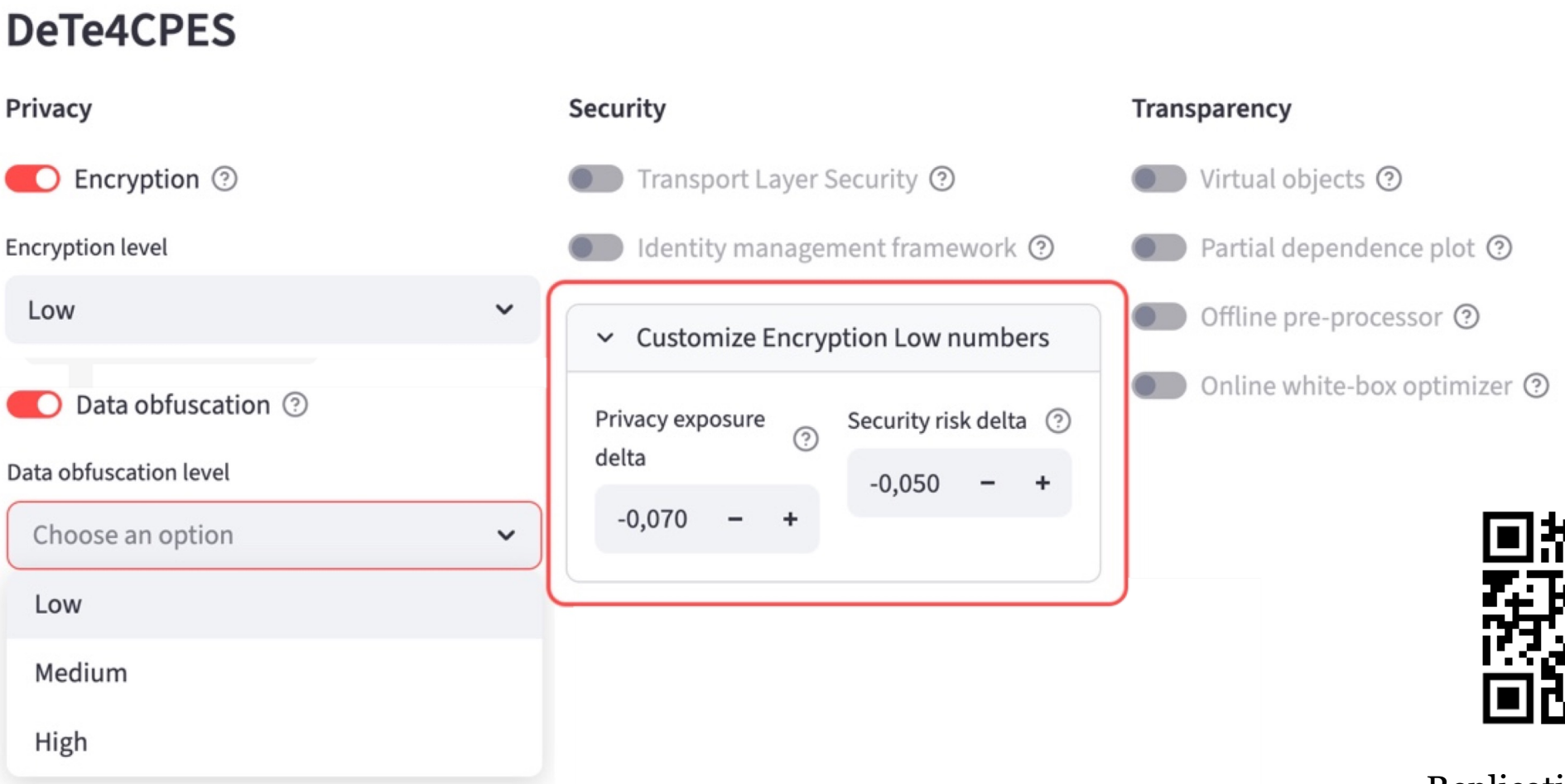
Mapping Shortcomings to BPMN

BPMN Activity	W1 Privacy	W2 Security	W3 Transparency
Retrieve Location Data	✓ Patient profiling without anonymization	✓ Data are sent over un-encrypted channels	–
Retrieve Patient Data	✓ Patient profiling without anonymization	✓ Data are sent over un-encrypted channels	–
Generate Emergency Report	✓ Use of personal and medical data	✓ The report could be manipulated	✓ Patient is unaware of which data is used
Trigger Intervention Alert	–	✓ An attacker could trigger the intervention alert	–
Assess Emergency Situation	✓ Access to personal and medical data	–	✓ Patient is unaware of emergency strategies

Addressing Ethical Shortcomings

Weakness	Design Objective (DESO)	Design Technique (DEST)
W1 Privacy	+ Data Protection	+ Encryption + Data Obfuscation
W2 Security	+ End-to-End Secure Communication + Secure Local Network Connection	+ Transport Layer Security + Private Intranet
W3 Transparency	+ Openness	+ Virtual Objects

Prototype Implementation



Replication Package

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Lessons Learned

- Ethics-related requirements require **intermediate design concepts**.
- Privacy, security, and transparency are **interdependent**.
- Suitable design techniques depend on the **application context**.
- Ethics-related limitations can be identified in concrete **system activities**.
- Quantitative indicators require **careful interpretation**.

Conclusion

Contributions

- Identification of **ethical shortcomings** in CPS design.
- **DeTe4CPES** — a conceptual approach for integrating ethics-based requirements into CPS design.
- Application of **DeTe4CPES** to a **patient monitoring use case**.
- Development of **a prototype tool** supporting automated analysis.

Future work

- Apply design techniques to **other CPS scenarios**.
- Automate **quantitative evaluation** through monitored metrics.

Thank you for your attention!

Questions?

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