A Game-Theoretic Approach for Security Control Selection

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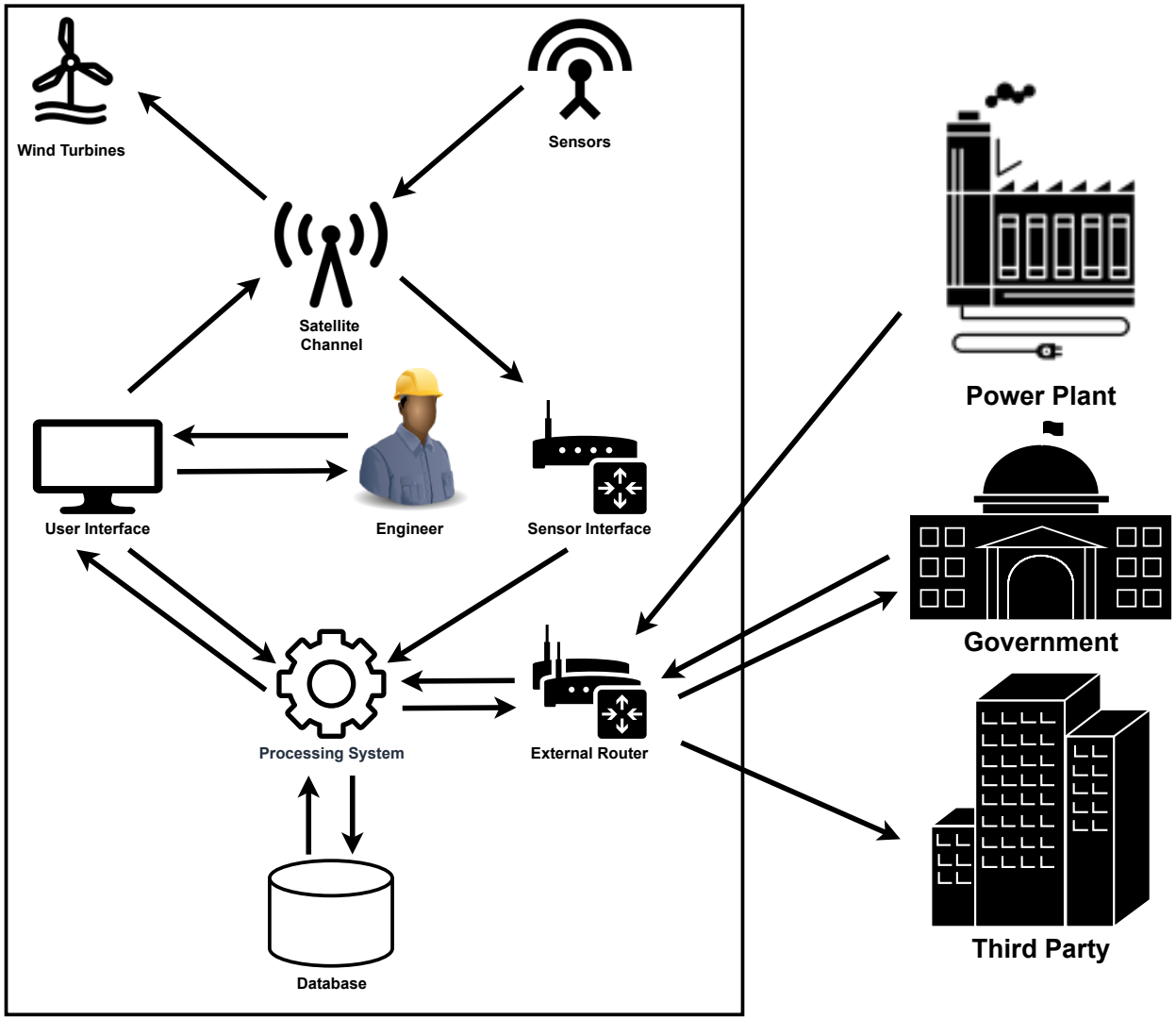
Story


Wind Turbines
Sensors
Satellite Channel
User Interface
Engineer
Sensor Interface
Processing System
External Router
Database
Power Plant
Government
Third Party

Story (Continued) — Security Control Catalogues

ITSG-33

NIST SP 800-53

AC-7	**Unsuccessful Logon Attempts**
AC-7(1)	AUTOMATIC ACCOUNT LOCK
AC-7(2)	PURGE OR WIPE MOBILE DEVICE
AC-7(3)	BIOMETRIC ATTEMPT LIMITING
AC-7(4)	USE OF ALTERNATE AUTHENTICATION FACTOR
AC-8	**System Use Notification**
AC-9	**Previous Logon Notification**
AC-9(1)	UNSUCCESSFUL LOGONS
AC-9(2)	SUCCESSFUL AND UNSUCCESSFUL LOGONS
AC-9(3)	NOTIFICATION OF ACCOUNT CHANGES
AC-9(4)	ADDITIONAL LOGON INFORMATION
AC-10	**Concurrent Session Control**
AC-11	**Device Lock**
AC-11(1)	PATTERN-HIDING DISPLAYS
AC-12	**Session Termination**
AC-12(1)	USER-INITIATED LOGOUTS
AC-12(2)	TERMINATION MESSAGE
AC-12(3)	TIMEOUT WARNING MESSAGE
AC-13	Supervision and Review-Access Control
AC-14	**Permitted Actions without Identification or Authentication**
AC-14(1)	NECESSARY USES
AC-15	Automated Marking
AC-16	**Security and Privacy Attributes**

Story (Continued) — Main Takeaways

Key Challenges

Each System is unique and has different security needs

Threats vary greatly from system to system, and their environment (*Example:* Military vs. Manufacturing)

Many security controls exist in a given control catalogue

Not every control can be selected (dependencies, cost)

Story (Continued) — Main Takeaways

Key Challenges

Each System is unique and has different security needs

Threats vary greatly from system to system, and their environment (*Example:* Military vs. Manufacturing)

Many security controls exist in a given control catalogue

Not every control can be selected (dependencies, cost)

There is a human element to control selection!

Proposed Solution

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To develop an approach that will assist with control selection while accounting for the challenges mentioned above.

To focus on the human-centric nature of this problem.

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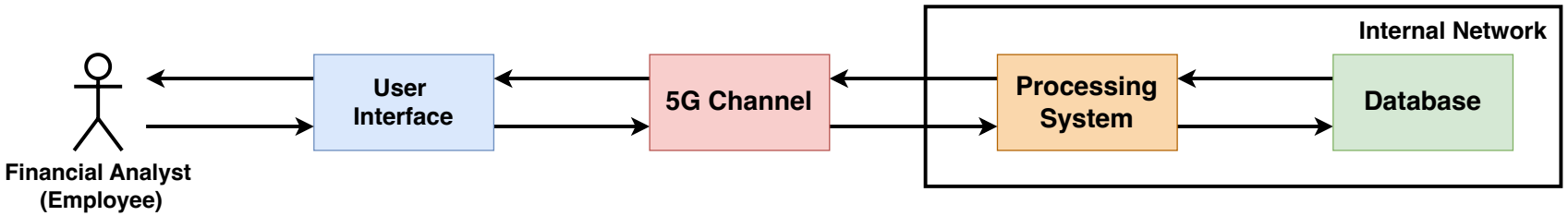
To focus on the human-centric nature of this problem.

Game theory is perfect for this!

Illustrative Example – *Firebird*



Step 1: Identify Applicable Atomic Controls

Goal

Identify a list of applicable security controls (*atomic controls*) for a given system from a security control catalogue (common practice).

Required Inputs

Control Catalogue

Mandatory Controls

Threat Model

Step 1: Identify Applicable Atomic Controls – *Firebird*

Required Inputs

Control Catalogue: *ITSG-33*

Mandatory Controls: *SI-10: Input Validation*

Threat Model: **next slide**

Step 1: Identify Applicable Atomic Controls – *Firebird*

Table: Threat model and applicable atomic controls for *Firebird*

Assets	Threats	Security Objectives Violated	Applicable Atomic Controls
User Interface	▪ Commands received from unknown sources	▪ Confidentiality ▪ Integrity	▪ *AC-4: Information Flow Enforcement*
	▪ Improper/malicious commands entered	▪ Confidentiality ▪ Integrity	▪ *SI-10: Input Validation*
	▪ Employee freely accesses and changes features provided in the interface	▪ Confidentiality ▪ Integrity	▪ *AC-3: Access Enforcement* ▪ *AC-6: Least Privilege*
Database	▪ SQL injection from an improper analyst input changes or retrieves data	▪ Confidentiality ▪ Integrity	▪ *AC-4: Information Flow Enforcement* ▪ *SI-10: Input Validation*
	▪ Employee freely inspects data in the database	▪ Confidentiality	▪ *AC-6: Least Privilege*

Step 2: Assign Effectiveness to Atomic Controls

Goal

Assign an effectiveness to each atomic control gathered in **Step 1**.

Required Inputs

Threat Model

Atomic Controls (**Step 1**)

Step 2: Assign Effectiveness to Atomic Controls – *Firebird*

Table: Atomic payoff matrix for *Firebird*

	Database			*User Interface*		
	C	*I*	*A*	*C*	*I*	*A*
SI-10: Input Validation	Medium	Very High	None	Medium	High	None
AC-3: Access Enforcement	None	None	None	Medium	High	None
AC-4: Information Flow Enforcement	Medium	Medium	None	Medium	Low	None
AC-6: Least Privilege	High	None	None	Medium	Low	None

Step 2: Assign Effectiveness to Atomic Controls – *Firebird*

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	Database			*User Interface*		
	C	*I*	*A*	*C*	*I*	*A*
SI-10: Input Validation	Medium	Very High	None	Medium	High	None
AC-3: Access Enforcement	None	None	None	Medium	High	None
AC-4: Information Flow Enforcement	Medium	Medium	None	Medium	Low	None
AC-6: Least Privilege	High	None	None	Medium	Low	None

This is not the game matrix!

Step 3: Assign Cost to Atomic Controls

Goal

Assign a cost to each atomic control gathered in **Step 1**.

Required Inputs

Atomic Controls (**Step 1**)

Step 3: Assign Cost to Atomic Controls – *Firebird*

Table: Atomic control costs for *Firebird*

Control	**Cost**
SI-10: Input Validation	5
AC-3: Access Enforcement	6
AC-4: Information Flow Enforcement	4
AC-6: Least Privilege	3

Step 4: Specify and Generate Valid Control Combinations

Goal

Generate all valid security control combinations for the game using an algebraic specification.

Required Inputs

Mandatory controls

Effectiveness of atomic controls (**Step 2**)

Cost of atomic controls (**Step 3**)

Security Control Algebra

Definition

Security Control Algebra – A *security control algebra* is a commutative idempotent semiring $\mathscr{C} \stackrel{\text{def}}{=} (C, \oplus, \odot, 0, 1)$ where each element of the semiring $c \in C$ is a security control family.

C: Set of every possible security control family (possible combinations of controls)

$\oplus$: Operator denoting a choice of two security control families

$\odot$: Operator denoting a composition of two security control families

0: Non-implementable security control combination (one that does not exist). Identity with respect to $\oplus$.

1: Empty security control combination (no controls). Identity with respect to $\odot$.

Step 4: Specify and Generate Valid Control Combinations – *Firebird*

Denoting the security control family as F,

$$F \quad = \quad SI\text{-}10 \odot opt\left[AC\text{-}3, AC\text{-}4, AC\text{-}6\right] \qquad \text{such that} \qquad AC\text{-}3 \xrightarrow{F} AC\text{-}6$$

Step 4: Specify and Generate Valid Control Combinations – *Firebird*

$$
\begin{aligned}
F &= \mathit{SI\text{-}10} \odot \mathit{opt}\left[\mathit{AC\text{-}3}, \mathit{AC\text{-}4}, \mathit{AC\text{-}6}\right] \\
F &= \mathit{SI\text{-}10} \oplus \mathit{SI\text{-}10\ AC\text{-}3} \oplus \mathit{SI\text{-}10\ AC\text{-}4} \oplus \mathit{SI\text{-}10\ AC\text{-}6} \oplus \mathit{SI\text{-}10\ AC\text{-}3\ AC\text{-}4} \oplus \\
&\quad \mathit{SI\text{-}10\ AC\text{-}3\ AC\text{-}6} \oplus \mathit{SI\text{-}10\ AC\text{-}4\ AC\text{-}6} \oplus \mathit{SI\text{-}10\ AC\text{-}3\ AC\text{-}4\ AC\text{-}6}
\end{aligned}
$$

Step 4: Specify and Generate Valid Control Combinations – *Firebird*

Budget = 15

Table: Security control combination costs for *Firebird*

Security Control Combination	**Cost**
SI-10	5
SI-10 AC-4	9
SI-10 AC-6	8
SI-10 AC-3 AC-6	14
SI-10 AC-4 AC-6	12
SI-10 AC-3 AC-4 AC-6	18

***SI-10 AC-3 AC-4* does not respect dependencies, and therefore not present**

Step 5: Construct the Game Matrix

Goal

Generate the game matrix

Required Inputs

Valid control combinations (**Step 4**)

Effectiveness Definition

Definition (Effectiveness of a Security Control Combination)

$$
\begin{aligned}
Eff(1) &= 0 \\
Eff(a) &= E(a) \text{ if } a \text{ is atomic} \\
Eff(a \odot b) &= 1 - (1 - Eff(a))(1 - Eff(b))
\end{aligned}
$$

Step 5: Construct the Game Matrix – *Firebird*

Table: Game matrix for *Firebird*

	Database			*User Interface*		
	C	*I*	*A*	*C*	*I*	*A*
SI-10	0.5	0.9	0.0	0.5	0.8	0.0
SI-10 AC-4	0.75	0.95	0.0	0.75	0.84	0.0
SI-10 AC-6	0.9	0.9	0.0	0.75	0.84	0.0
SI-10 AC-3 AC-6	0.9	0.9	0.0	0.875	0.968	0.0
SI-10 AC-4 AC-6	0.95	0.95	0.0	0.875	0.872	0.0

This is a one-shot zero-sum game!

Step 6: Play the Game

Goal

Play the game based on expected attacker profiles.

Required Inputs

Game matrix (**Step 5**)

Attacker Profiles

Definition (Attacker Profile)

Ordered sets of security objectives expected to be targeted by an attacker.

Step 6: Play the Game – *Firebird*

Attacker Profile: attacker expected to equally target confidentiality of the interface and confidentiality of the database

	Database			*User Interface*		
	C	*I*	*A*	*C*	*I*	*A*
SI-10	0.5	0.9	0.0	0.5	0.8	0.0
SI-10 AC-4	0.75	0.95	0.0	0.75	0.84	0.0
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***SI-10 AC-4 AC-6* is the suggested strategy**

Step 6: Play the Game – *Firebird*

Attacker Profile: attacker expected to target (1) the confidentiality of the interface followed by (2) the integrity of the interface

	Database			*User Interface*		
	C	*I*	*A*	*C*	*I*	*A*
SI-10	0.5	0.9	0.0	0.5	0.8	0.0
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***SI-10 AC-3 AC-6* is the suggested strategy**

Discussion and Conclusion

Capturing Human Elements in Control Selection

Viewing control selection as a game captures the opposing dynamics of the attacker and analyst.

Reduction of Assumptions

Practical applications of game theory typically require numerous assumptions.

Limitation: Numerous possible Control Combinations

With N optional controls, there are 2^N possible combinations for the game.

Thank You

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