Privacy Policy Specification and Enforcement: Philosophy and Law meets Computer Science

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CMU Privacy Research Meeting
November 23, 2010

Problem Statement

Question: Is an organization's processes and practices compliant with privacy regulations and internal policies?

- Examples of organizations
  - Hospitals, financial institutions, universities, and other organizations that collect and use personal information
- Examples of privacy regulations
  - Health Insurance Portability and Accountability Act (HIPAA), Gramm-Leach-Bliley Act (GLBA), SB 1386

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Goal: Develop methods and tools to aid organizations in compliance activities

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Observation: Real privacy laws are complex.

- Long, dense — HIPAA Privacy Rule has 84 operational clauses for transmissions on $\sim$30 pages
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Desiderata: Interactive tools for enforcement and analysis

- "Are actions by Hospital Y's employees compliant with HIPAA?"
- "Does GLBA permit Bank X to disclose Bob's info to Charlie?"

Our Results

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3. Automated policy monitoring with minimal human input for enforcement of HIPAA, GLBA.

   (with D. Garg, L. Jia)

Outline

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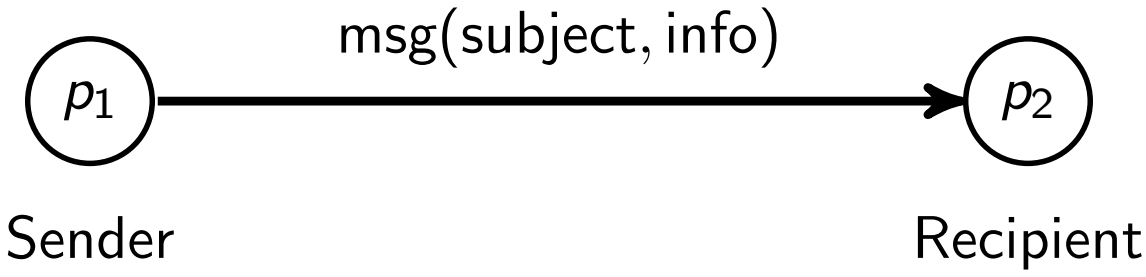
Transmission of protected information



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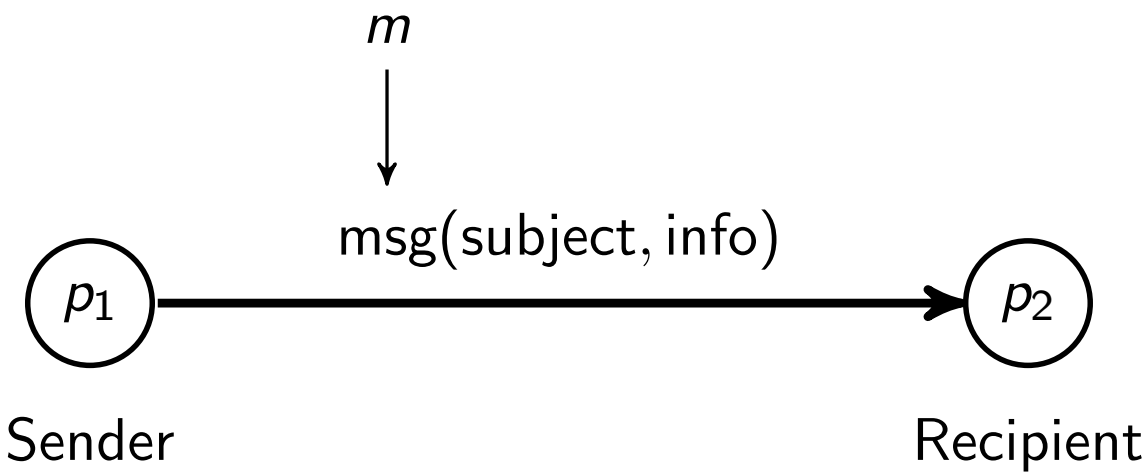

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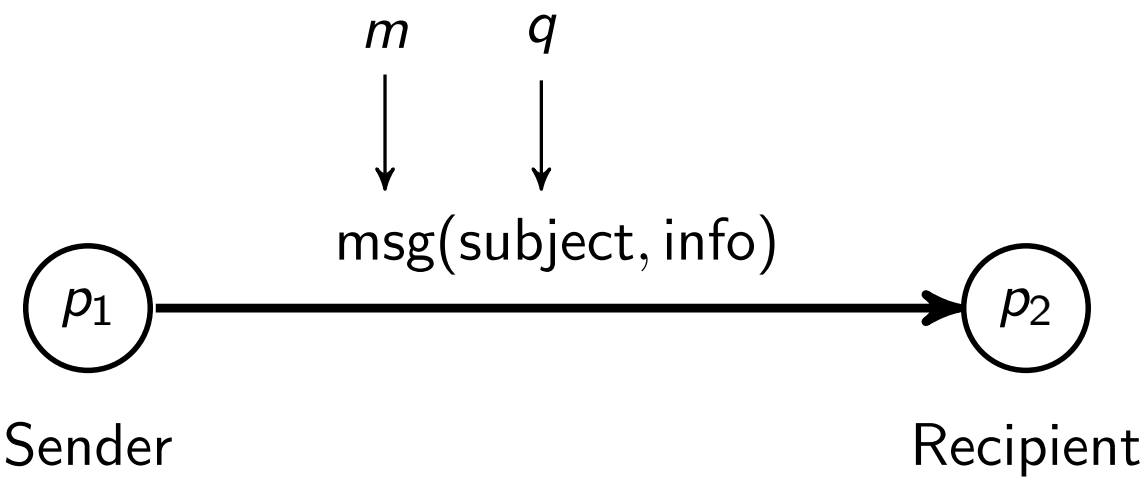

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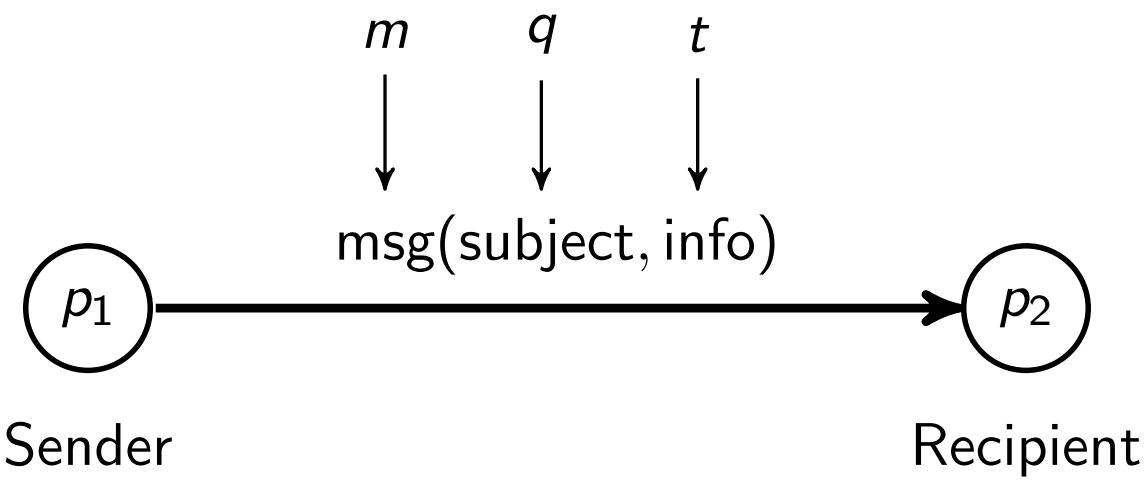

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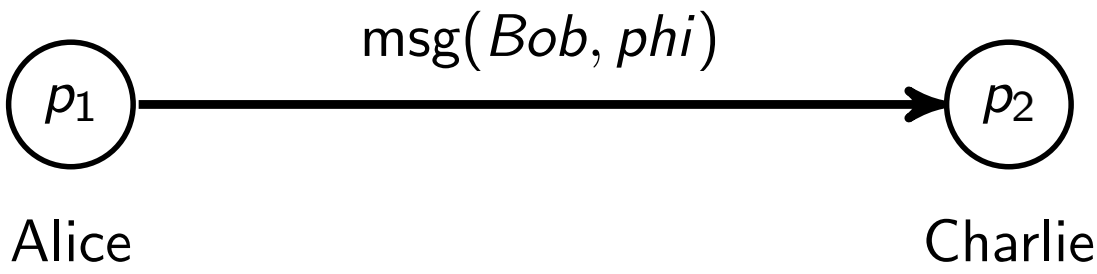

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Positive norms, φ_i^+: Transmission *may occur* if condition is satisfied.

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A transmission is lawful if and only if it satisfies at least one of the law's positive norms and all of the law's negative norms.

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Exceptions to negative norms:

"A covered entity must obtain an authorization for any use or disclosure of psychotherapy notes, except [...]."

Conclusion: Satisfy either the core or one of the exceptions.

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Structure of HIPAA and GLBA privacy laws

Health Insurance Portability and Accountability Act:

- Primarily positive norms
  - 56 positive norms, 7 negative norms, and 19 exceptions
  - Negative norms for patient consent or opt-out opportunity (§§164.508 and 164.510)
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Gramm-Leach-Bliley Act:

- Primarily negative norms
  - 5 negative norms and 10 exceptions
  - Negative norms require notices and opt-out opportunities (§§6802 and 6803)
- Allow all transmissions not explicitly denied

Important property of formalization:

- Traceability: Each clause in the law corresponds to one norm in formalization (roughly)

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HIPAA §164.506(c)(2)

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Principals' beliefs and professional judgement

HIPAA §164.512(f)(4)

"A covered entity may disclose protected health information about an individual who has died to a law enforcement official for the purpose of alerting law enforcement if the covered entity has a suspicion that the death may have resulted from criminal conduct."

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Conclusion: Borrow operators from temporal logic.

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$$
\begin{aligned}
\overline{\varphi_{\texttt{6802b1}}} \triangleq\ & \mathit{activerole}(p_1, \mathit{institution}) \wedge \\
& (t \in_{\mathcal{T}} \mathit{npi}) \wedge \\
& \neg \mathit{activerole}(p_2, \mathit{affiliate}(p_1)) \wedge \\
& \mathit{belongstorole}(q, \mathit{consumer}(p_1)) \\
& \supset \\
& \downarrow x.\ \Diamond\!\!\!\!-(\downarrow y.\ (x - y \geq 14) \wedge \\
& \qquad \exists m'.\ \mathit{send}(p_1, q, m') \wedge \\
& \qquad\quad \mathit{is\text{-}notice\text{-}of\text{-}potential} \\
& \qquad\quad\ \mathit{\text{-}disclosure}(m', p_1, p_2, (q, t), u))
\end{aligned}
$$

Syntax of the Policy Logic

Objective predicates	p_O		
Subjective predicates	p_S		
Objective atoms	P_O	$::=$	$p_O(t_1, \ldots, t_n)$
Subjective atoms	P_S	$::=$	$p_S(t_1, \ldots, t_n)$
Formulas	α, β	$::=$	$P_O \mid P_S \mid \top \mid \bot \mid$
			$\alpha_1 \wedge \alpha_2 \mid \alpha_1 \vee \alpha_2 \mid \neg\alpha \mid$
			$\forall\vec{x}.(c \supset \alpha) \mid \exists\vec{x}.(c \wedge \alpha) \mid$
			$\downarrow x.\alpha \mid \alpha\, \mathcal{S}\, \beta \mid \alpha\, \mathcal{U}\, \beta \mid \boxminus\alpha \mid \Box\, \alpha$
Restrictions	c	$::=$	$P_O \mid \top \mid \bot \mid c_1 \wedge c_2 \mid c_1 \vee c_2 \mid$
			$\exists x.c$

- Subjective predicates p_S model beliefs and purposes
- Restricted quantifiers $\forall\vec{x}.(c \supset \alpha)$, $\exists\vec{x}.(c \wedge \alpha)$
- Temporal operators $\downarrow x.\alpha$, $\alpha\, \mathcal{S}\, \beta$, $\alpha\, \mathcal{U}\, \beta$, $\boxminus\alpha$, $\Box\, \alpha$ ($\diamondminus\alpha$, $\Diamond\alpha$ defined)

Related Work on Privacy Policy Specification

- Logics and languages for specification of privacy policies
  - P3P [Cranor et al.], XACML [OASIS], EPAL [Backes et al.], requirements engineering [Breaux and Antón], LPU [Barth et al.], Privacy APIs [Gunter et al.], deontic logic [I. Lee et al.], SecPAL [Becker et al.], ...

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- Formal specification of privacy laws
  - LPU [Barth et al.]: Examples from HIPAA and GLBA
  - Datalog HIPAA [Lam et al.]: HIPAA §§164.502, 506, and 510
  - Privacy APIs [Gunter et al.]: HIPAA §164.506
  - Deontic logic [I. Lee et al.]: Examples from FDA CFR §610.40

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Properties of enforcement

Observations:

Enforcement by execution-time access control alone is insufficient.

- Purposes, beliefs, future obligations, etc. are not mechanically checkable at the time of access
- Cannot always demand human involvement at execution time (e.g., medical emergency)

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Human experts used only to resolve essential subjective predicates.

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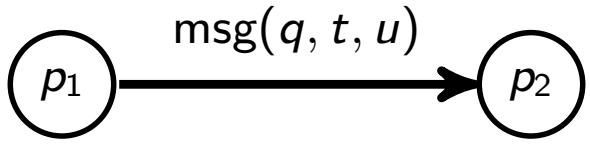

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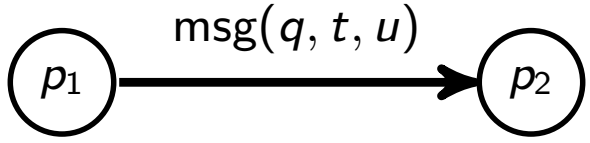

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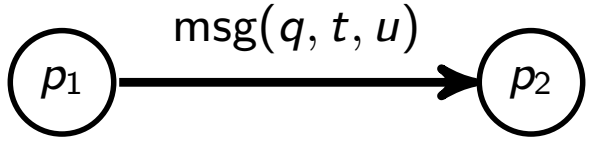

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  - Sound: Any extension of log satisfies residual policy iff it satisfies original policy
  - Minimal: Residual policy contains only those predicates whose truth cannot be determined from the current log (e.g., future obligations, subjective predicates)

Simpler Sublogic

$$
\begin{array}{lrcl}
\text{Formulas} & \varphi & ::= & P_O \mid P_S \mid \top \mid \bot \mid \varphi_1 \wedge \varphi_2 \mid \varphi_1 \vee \varphi_2 \mid \\
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- Policy logic with temporal operators translated into sublogic

Modeling Incomplete Audit Logs

- Structures L model audit logs with possibly *incomplete information*
- Map each atom to $\mathtt{tt}$ (true), $\mathtt{ff}$ (false), $\mathtt{uu}$ (unknown)

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  - Subjective incompleteness (log lacks subjective knowledge)
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  - Past incompleteness (log may miss relevant past states)

Modeling Incomplete Audit Logs

- Structures L model audit logs with possibly *incomplete information*
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- Log evolution modeled as a relation $L' \geq L$

$$(\rho_L(P) \in \{\mathtt{tt}, \mathtt{ff}\}) \Rightarrow (\rho_{L'}(P) = \rho_L(P))$$

Reduction Algorithm

$$\texttt{reduce}(L, P) \quad = \quad \begin{cases} \top & \text{if } \rho_L(P) = \texttt{tt} \\ \bot & \text{if } \rho_L(P) = \texttt{ff} \\ P & \text{if } \rho_L(P) = \texttt{uu} \end{cases}$$

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$$\begin{aligned} \texttt{reduce}(L, \forall \vec{x}.(c \supset \varphi)) = \ & \text{let} \\ & \{\sigma_1, \ldots, \sigma_n\} \leftarrow \widehat{\texttt{sat}}(L, c) \\ & \{\vec{t_i} \leftarrow \sigma_i(\vec{x})\}_{i=1}^{n} \\ & S \leftarrow \{\vec{t_1}, \ldots, \vec{t_n}\} \\ & \{\psi_i \leftarrow \texttt{reduce}(L, \varphi[\vec{t_i}/\vec{x}])\}_{i=1}^{n} \\ & \psi' \leftarrow \forall \vec{x}.((c \wedge \vec{x} \notin S) \supset \varphi) \\ & \text{return} \\ & \quad \psi_1 \wedge \ldots \wedge \psi_n \wedge \psi' \end{aligned}$$

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- Structure L contains two message transmissions:
  - $\mathit{send}(A, B, M_1)$
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- Reduction yields $\texttt{reduce}(L, \varphi) = \psi$, where

$$
\begin{aligned}
\psi \quad = \quad & \mathit{is\_law\_official}(B) \wedge \\
& \mathit{is\_law\_official}(D) \wedge \\
& \forall p_1, p_2, m.\ ((\mathit{send}(p_1, p_2, m) \wedge \\
& \qquad (p_1, p_2, m) \notin \{(A, B, M_1), (C, D, M_2)\}) \\
& \qquad \supset \mathit{is\_law\_official}(p_2))
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$$

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  "Any violation of a safety property can be detected in the next reduction"

Theorem (Enforcement of safety properties)

Suppose φ is a safety property and L is complete up to time τ_0. Then, $\texttt{reduce}(L, \varphi) \rightarrow^* \bot$ if and only if there is a time $\tau \leq \tau_0$ at which φ has been violated.

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- 67 clauses are safety properties with subjective predicates
  - Simplify to conjunctions and disjunctions of subjective predicates through `reduce`

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  - Fully automated enforcement of 17 clauses from the HIPAA Privacy Rule; minimal human input for other 67.

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Thank you!

Semantics of the Sublogic

$L \models P$ iff $\rho_L(P) = \mathtt{tt}$

$L \models \top$

$L \models \varphi \wedge \psi$ iff $L \models \varphi$ and $L \models \psi$

$L \models \varphi \vee \psi$ iff $L \models \varphi$ or $L \models \psi$

$L \models \forall \vec{x}.(c \supset \varphi)$ iff for all $\vec{t}$ either $L \models \overline{c}[\vec{t}/\vec{x}]$ or $L \models \varphi[\vec{t}/\vec{x}]$

$L \models \exists \vec{x}.(c \wedge \varphi)$ iff there exists $\vec{t}$ such that $L \models c[\vec{t}/\vec{x}]$ and $L \models \varphi[\vec{t}/\vec{x}]$

Definition of $\widehat{sat}$

Assume: The function $\mathtt{sat}(L, P)$ computes all substitutions σ for variables in P such that $L \models P\sigma$, if certain argument positions in P are ground.

$$
\begin{array}{lcl}
\widehat{\mathtt{sat}}(L, p_O(t_1, \ldots, t_n)) & = & \mathtt{sat}(L, p_O(t_1, \ldots, t_n)) \\
\widehat{\mathtt{sat}}(L, \top) & = & \{\bullet\} \\
\widehat{\mathtt{sat}}(L, \bot) & = & \{\} \\
\widehat{\mathtt{sat}}(L, c_1 \wedge c_2) & = & \bigcup_{\sigma \in \widehat{\mathtt{sat}}(L, c_1)} \sigma + \widehat{\mathtt{sat}}(L, c_2\sigma) \\
\widehat{\mathtt{sat}}(L, c_1 \vee c_2) & = & \widehat{\mathtt{sat}}(L, c_1) \cup \widehat{\mathtt{sat}}(L, c_2) \\
\widehat{\mathtt{sat}}(L, \exists x.c) & = & \widehat{\mathtt{sat}}(L, c) \backslash \{x\} \qquad (x \text{ fresh})
\end{array}
$$