Tragedy of the Anticommons in Digital Right Management of Medical Records

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- Security and Privacy of EHRs
- Digital Right Management Solution
- Tragedy of Anticommons
- Game-Theoretic Models
  - Non-cooperative Game Model
  - Cooperative Game Model
- Conclusions and Future Work

Motivation

- Modern healthcare communication architectures tend to be open and interconnected.
  - Electronic Health Record (EHR) system can reduce cost of the healthcare system and provide timely access to information.
  - Decentralized accesses of patient data are allowed for family doctors, medical specialists and even non-medical care providers.



Office of the Information and
Privacy Commissioner of Alberta

NEWS RELEASE

July 8, 2009

Commissioner urges vigilance in wake of computer virus outbreak at Alberta Health Services

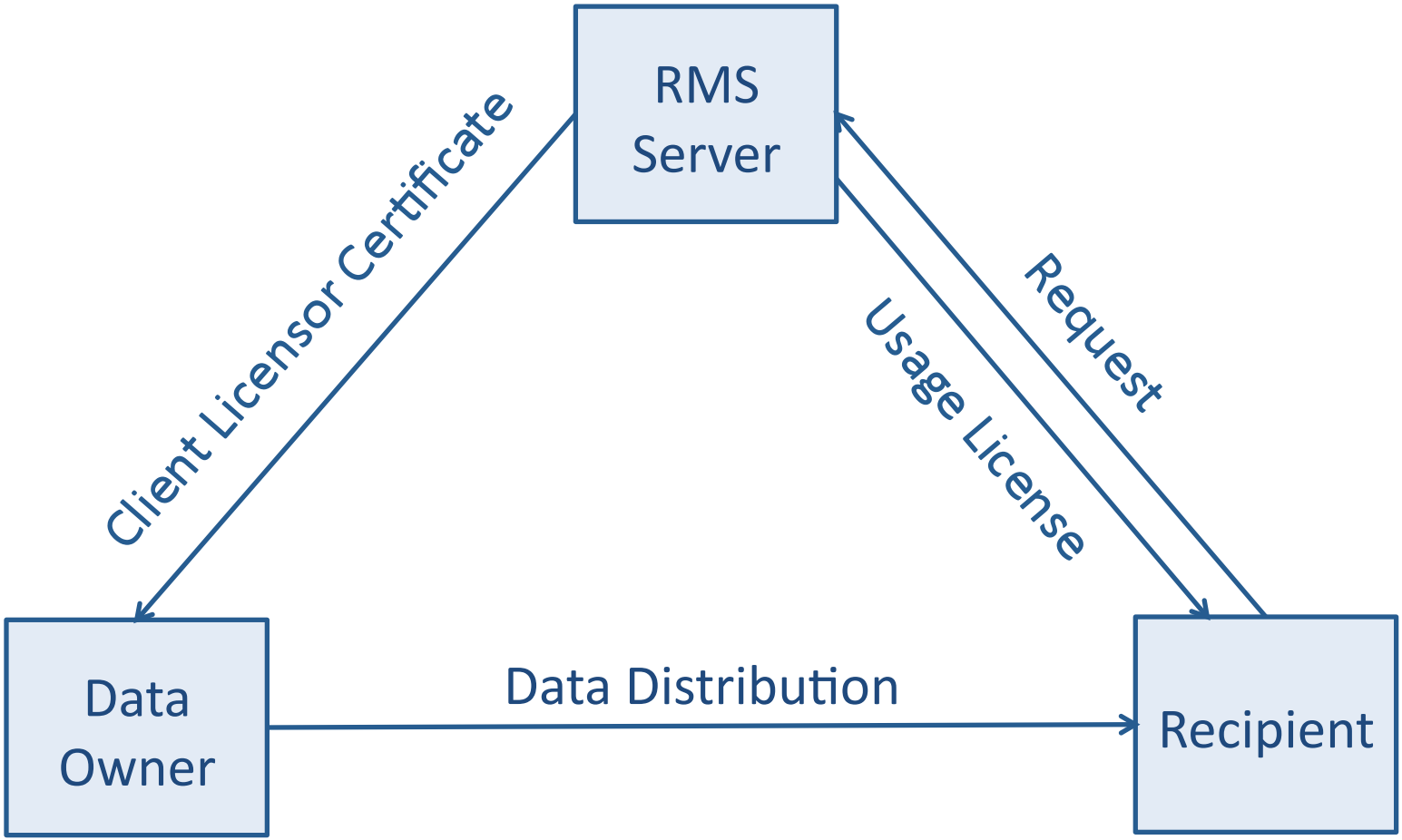
The Office of the Information and Privacy Commissioner has been notified by Alberta Health Services that a virus was present on the Alberta Health Services network in Edmonton. The virus impacted the network and Netcare, Alberta s electronic health record, before it was discovered and removed.

The virus is a new variant of a Trojan horse program called coreflood and is designed to steal data from an infected computer and send it to a server controlled by a hacker. Coreflood captures passwords and data the user of the computer accesses. The virus was active from May 15 to 29 before it was detected and removed.

- Security and privacy are major concerns of EHRs.

[http://www.oipc.ab.ca]

Digital Rights Management (DRM) is applied to protect EHRs.



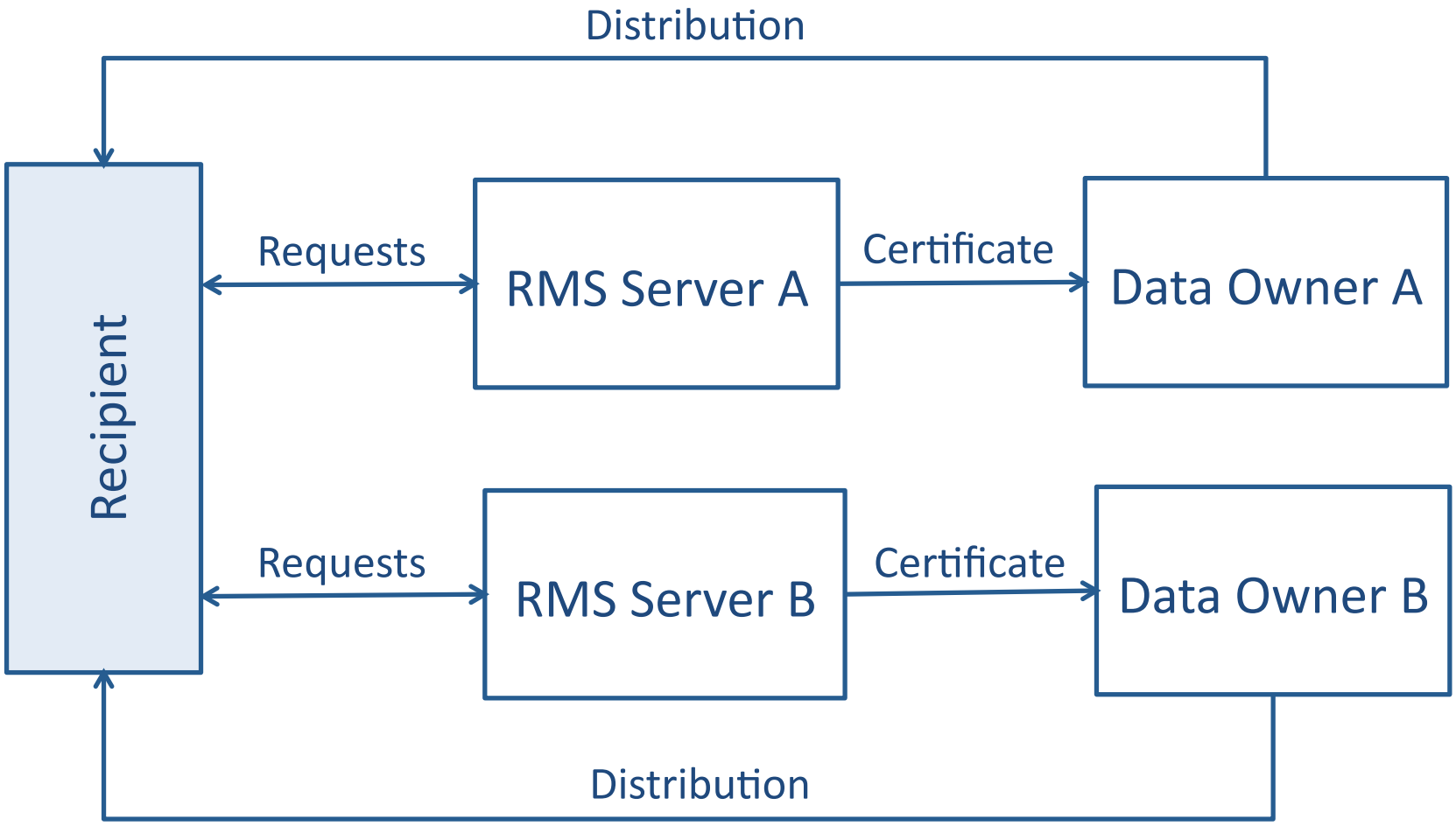
- Owners can control the distribution and use of information.

[Petkovic et al. 2007]



Who owns the data?

Data ownership is fragmented.



Tragedy of the Anticommons: Competing right holders foreclose each other from productive use of a share of resources, which results in *underutilization* of resources.



- Multiple ownership of different pieces of a patient's medical history makes it difficult to assemble a complete record.
- The complete record has a greater value than sum of its parts.
- The barrier is not just technological but also economic.

From Commons to Anticommons

Tragedy of the Anticommons

Tragedy of the Commons



Self Labour Cattle Land Air Quality Environ





[Hardin 1968, Heller 1998, Fennell 2009, Hall 2010]

Tragedy of Commons: Prisoner's Dilemma

(G_1)

	C	D
C	2 , 2	0 , 3
D	3 , 0	1 , 1

- Both players are maximizers.
- NE in pure strategies (D, D) vs. Optimal team solution (C, C)
- Loss of efficiency:

$$\text{Price of Anarchy (PoA)} = \frac{\text{Social Welfare under NE}}{\text{Optimal Social Welfare}} = \frac{1+1}{2+2} = 50\%$$

Tragedy of Anticommons: Game of Chicken

(G_2)

	S	D
S	5 , 5	1 , 7
D	7 , 1	0 , 0

- Both players are maximizers: choose between S (Swerve) or D (Drive Ahead)
- NE in pure strategies (S, D), (D, S) vs. Optimal team solution (S, S)
- Loss of efficiency:

$$\text{Price of Anarchy (PoA)} = \frac{\text{Social Welfare under NE}}{\text{Optimal Social Welfare}} = \frac{7+1}{5+5} = 80\%$$

Non-Cooperative Game Model

- Consider two players P1 and P2.
- Each player decides the level of access granted to its users.
- $\lambda_i \ni [0,1]$, $i = 1, 2$, are decision variables:
  - $\lambda_i = 1$: Access is denied.
  - $\lambda_i = 0$: Access is fully granted.
  - $1\text{-}\lambda_i$ is the access level.
- $c \ni [0,1]$ is a unit cost on the granted access.
- p is a charge of access fee.

$$U_i(\lambda_1, \lambda_2) = p + (2\text{-}\lambda_1\text{-}\lambda_2)\lambda_i - c\,(1\text{-}\lambda_i),\ i = 1, 2,$$

The value of information is proportional to total accesses granted.

Nash Equilibrium vs. Team Optimal Solution

$$U_i(\lambda_1, \lambda_2) = p + (2\text{-}\lambda_1\text{-}\lambda_2)\,\lambda_i - c\,(1\text{-}\lambda_i),\ i = 1, 2,$$

- A unique NE is $\lambda_1 = \lambda_2 = (2+c)/3$.
- Worst case is $\lambda_1 = \lambda_2 = 1$ when $c = 1$, i.e., accesses are all denied.

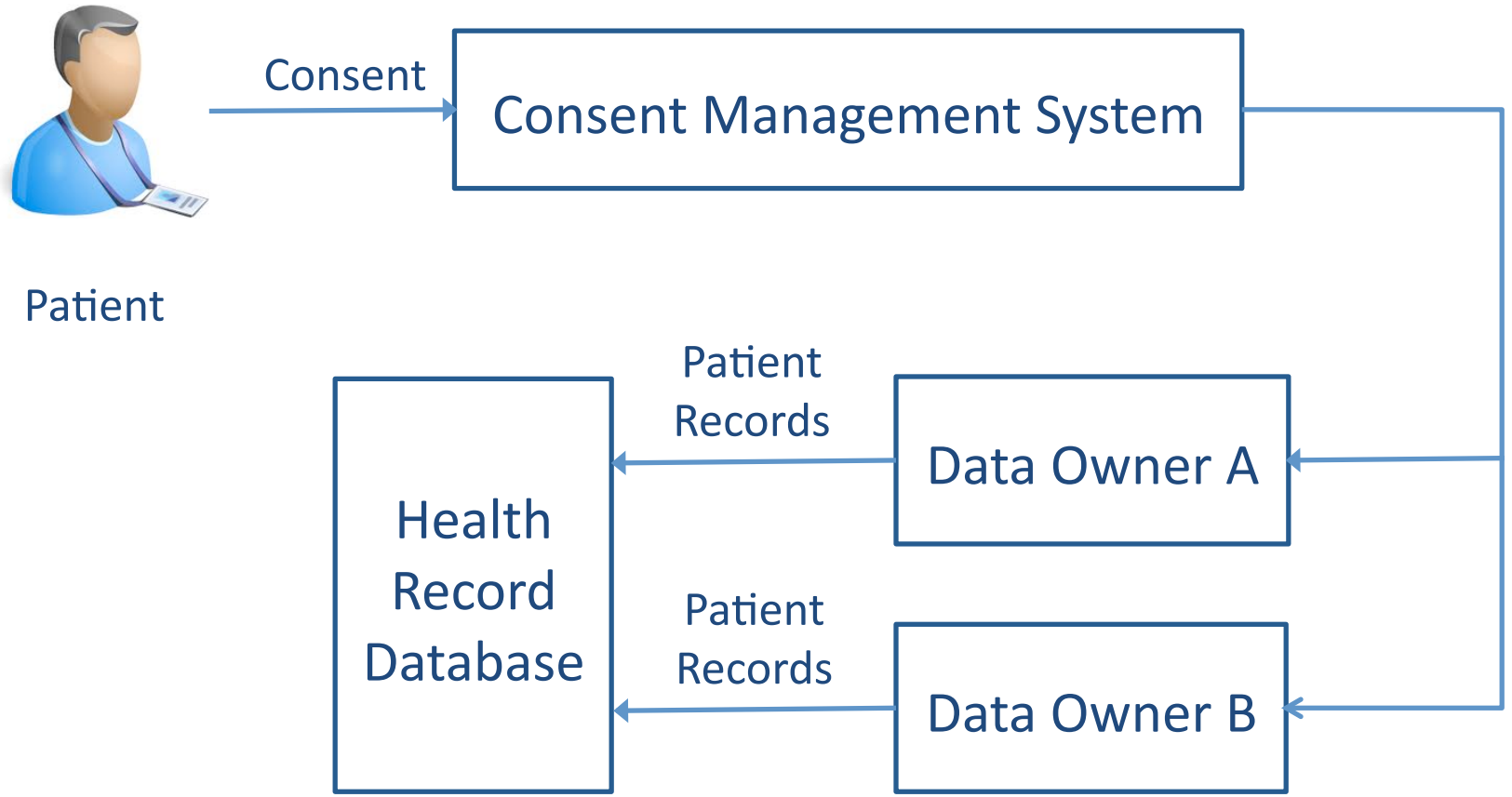
$$U(\lambda_1, \lambda_2) = U_1(\lambda_1, \lambda_2) + U_2(\lambda_1, \lambda_2)$$

- Team optimal solution is $\lambda_1 = \lambda_2 = (2+c)/4$.
- Worst case is $\lambda_1 = \lambda_2 = 3/4$ when $c = 1$, i.e., 1/4 accesses granted.



Some form of coordination is needed.

A Coordinated Electronic Health Record System

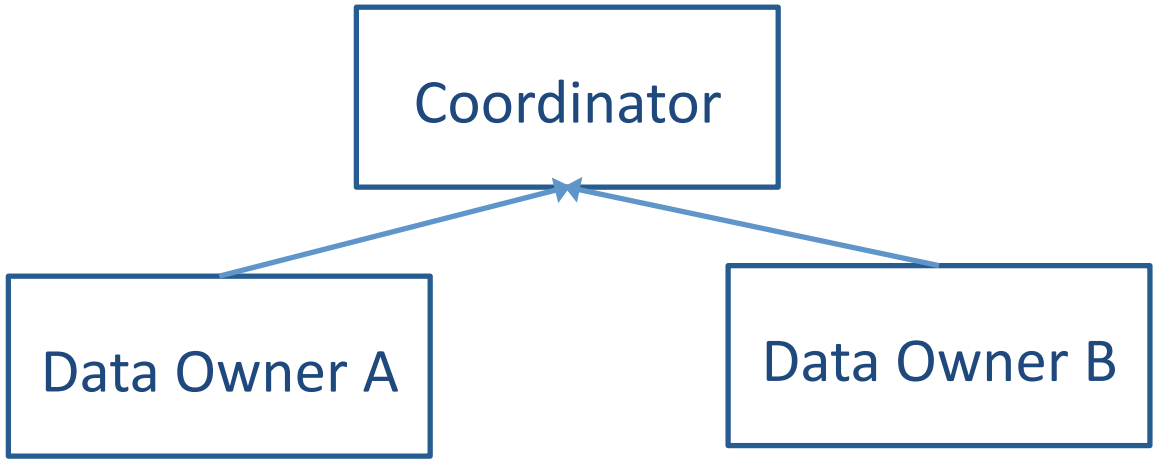


[Sheppard, Safavi-Naini, Jafari, 2009]



How to quantify the value of coordination?

Cooperative Game Model: Shapley Value



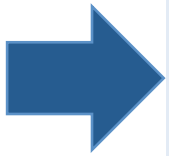
The characteristic function v is described by

- $v(\varnothing) = v(\{C\}) = 0$,
- $v(\{1\}) = v(\{2\}) = \frac{1}{4}(c\text{-}1)^2 + p$,
- $v(\{1, C\}) = v(\{2, C\}) = \frac{1}{4}(c\text{-}1)^2 + p$,
- $v(\{1, 2\}) = 2p$,
- $v(\{1, 2, C\}) = \frac{1}{4}(c\text{-}2)^2 + 2p$.

Value of Coordination

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- $v(\{1, 2, C\}) = \frac{1}{4}(c\text{-}2)^2 + 2p.$



Shapley Values

- $u_1 = 1/3 - c/3 + c^2/12 + p$
- $u_2 = 1/3 - c/3 + c^2/12 + p$
- $u_3 = 1/3 - c/3 + c^2/12$

- The coordination is least valuable when c = 1, which yields u_3 = 1/12.
- The coordination is most valuable when c = 0, which yields u_3 = 1/3.

Conclusions and Future Work

- The fractured ownership among medical service providers and insurers has created the tragedy of *anticommons* for DRM implementation.
- Multiple ownerships in DRM will lead to *underutilization* of HER resources even though security and privacy are guaranteed.
- The barrier is not just technical but also *economic*.
- Cooperative and non-cooperative game-theoretic models can be used to understand strategic behaviors of data owners and the value of coordination.
- Game-theoretic tools can provide a theoretical basis for implementation of DRM technologies, design of security policies and provision of incentive mechanisms.

Q. Zhu, C. Gunter and T. Başar, “Tragedy of Anticommons in Digital Right Management of Medical Records,” Technical Report, CSL-UIUC, 2012.

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