On unreasonable ineffectiveness of security engineering:

the case of adverse selection of trust certificates

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Outline

Problem: All protocols are insecure

Background: Notion of trust

Analysis: Trust dynamics

Method: Learning trust concepts

Conclusion: Security is an elephant

Outline

Problem: All protocols are insecure

- The life cycle of security
- Adverse selection
- Problem of trust

Background: Notion of trust

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The Unreasonable Effectiveness of Mathematics in Natural Sciences

E. Wigner (1960)

- Why is nature made in the measure of our mind?

The Unreasonable **In**effectiveness of Engineering in Security

- Why are we not becoming more secure from more security technologies?

The Unreasonable Ineffectiveness of Engineering in Security

Why?

Failures are first-class citizens

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Bull's protocol

- *Isabelle:* secure for $E(k,m;n)$
- *Ryan & Schneider:* not for $E(k,m;n) = n \oplus H_k(m)$

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- *IETF MSec WG:* secure (7 drafts), verified (3 times)
- *Cathy & Dusko:* GDoI_PoP attack

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MQV

- *NSA:* "MQV is critical for national security of US"
- *Krawczyk:* MQV insecure

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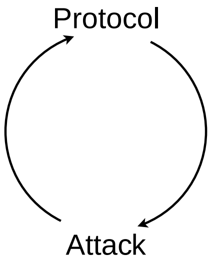
- *NSA:* "MQV is critical for national security of US"
- *Krawczyk:* MQV insecure, HMQV proven secure
- *Menezes:* HMQV insecure

Security is an adversarial process



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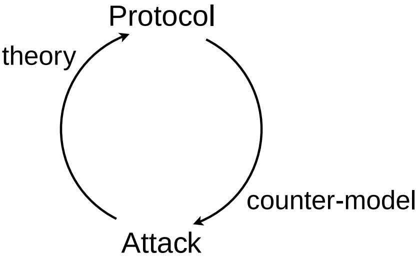

Adverse selection

	TRUSTE-certified	uncertified
honest	94.6%	97.5%
malicious	5.4%	2.5 %

Table: Trustworthyness of TRUSTE [Edelman 2007]

Adverse selection

Google		
	sponsored	organic
top	4.44%	2.73%
top 3	5.33%	2.93 %
top 10	5.89%	2.74 %
top 50	5.93%	3.04 %

Table: Malicious search engine placements [Edelman 2007]

Adverse selection

Yahoo!		
	sponsored	organic
top	6.35%	0.00%
top 3	5.72%	0.35 %
top 10	5.14%	1.47 %
top 50	5.40%	1.55 %

Table: Malicious search engine placements [Edelman 2007]

Adverse selection

Ask		
	sponsored	organic
top	7.99%	3.23%
top 3	7.99%	3.24 %
top 10	8.31%	2.94 %
top 50	8.20%	3.12 %

Table: Malicious search engine placements [Edelman 2007]

Adverse selection

"Pillars of the society" phenomenon

- social hubs are more often corrupt
- the rich are more often thieves
- ...

Problem of trust

- Why does adverse selection happen?
- Can it be eliminated? Limited?
- Can we hedge against it?
- Is there a rational trust policy?

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What is trust?

Alice trusts that Bob will act according to protocol Φ.

What is trust?

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Examples

- shopping: Bob will deliver goods
- marketing: Bob will pay for goods
- access control: Bob will not abuse resources
- key infrastructure: Bob's keys are not compromised

Modeling trust

Trust relation $u \xrightarrow[r]{\Phi} j$

- u: trustor
- j: trustee
- Φ: entrusted concept (protocol, task, property)
- r: trust rating

Views of Trust

Local: trust logics

$u \xrightarrow{\Phi} j$ means that

- u requires Φ
- j guarantees Φ

Views of Trust

Global: trust networks

$u \xrightarrow[r]{d} v \xrightarrow[s]{d} w \xrightarrow[t]{b} k$ means that

- u has a delegation certificate for v
- v has a delegation certificate for w
- w has a binding certificate for the key k

Views of Trust

Global: trust networks

$u \xrightarrow[r]{d} v \xrightarrow[s]{d} w \xrightarrow[t]{b} k$ means that

- u has a delegation certificate for v
- v has a delegation certificate for w
- w has a binding certificate for the key k
- thus u can use the key k
  - even compute its trust rating rst
- although they had no direct contact

Network dynamics

Networks are built upon networks:

- session keys upon long term keys
- strong secrets upon weak secrets
- crypto channels upon physical or social channels

Network dynamics

Networks are built upon networks:

- session keys upon long term keys
- strong secrets upon weak secrets
- crypto channels upon physical or social channels
- secure interactions upon trust
- trust upon secure interactions

Outline

Problem: All protocols are insecure

Background: Notion of trust

Analysis: Trust dynamics

- Trust dynamics
- Trust distribution
- Interpretation
- Recommender dynamics
- Trust authority

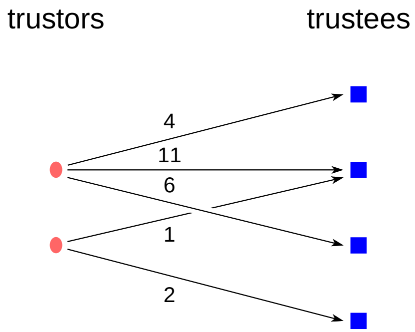
Method: Learning trust concepts

Trust dynamics

For a moment, we assume that the entrusted property Φ is fixed, and analyze dynamics of trust rating

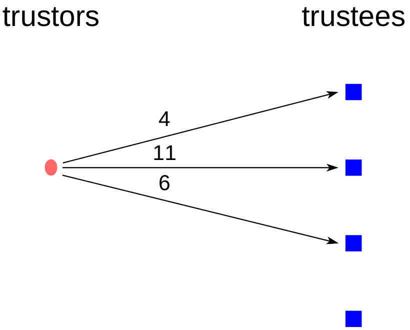
$$u \underset{r}{\longrightarrow} k$$

Trust rating matrix



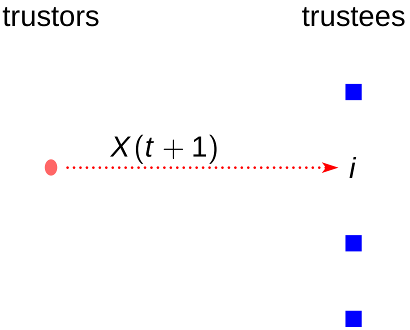
τ^1	4	11	6	0
τ^2	0	1	0	2

Private trust dynamics



$\tau(t)$	4	11	6	0

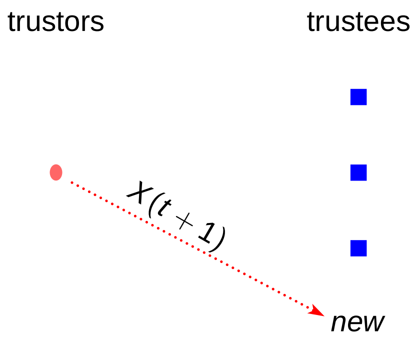
Private trust dynamics



$$\mathrm{Prob}\Big(X(t+1)=i\Big) = C(t)\tau_i(t)$$

(where $C(t) = \frac{1-\alpha}{\sum_{i\in J}\tau_i(t)}$)

Private trust dynamics



$$\mathrm{Prob}\Big(X(t+1) = new\Big) \quad = \quad \alpha$$

Private trust dynamics

Trust updating process

$$\tau_i(t+1) = \begin{cases} \tau_i(t) & \text{if } i \neq X(t+1) \\ 0 & \text{if } i = X\text{, not satisfactory} \\ 1 & \text{if } i = X\text{, satisfactory, new} \\ 1 + \tau_i(t) & \text{if } i = X\text{, satisfactory, not new} \end{cases}$$

Trust distribution

Task

Estimate

$$w_\ell(t) = \#\{i \in \mathrm{J} \mid \tau_i(t) = \ell\}$$

Trust distribution

$$
\begin{aligned}
w_1(t+1) - w_1(t) &= J \cdot \mathrm{Prob}\big(X(t+1) = i \mid i \text{ new}\big) \cdot \gamma_\perp \\
&\quad - w_1(t) \cdot \mathrm{Prob}\big(X(t+1) = i \mid \tau_i(t) = 1\big) \\
&= J\alpha\gamma_\perp - w_1(t)C(t)
\end{aligned}
$$

Trust distribution

$$
\begin{aligned}
w_\ell(t+1) - w_\ell(t) &= w_{\ell-1}(t) \cdot \mathrm{Prob}\Big(X(t+1) = i \mid \tau_i(t) = \ell - 1\Big) \cdot \gamma_{\ell-1} \\
&\quad - w_\ell(t) \cdot \mathrm{Prob}\Big(X(t+1) = i \mid \tau_i(t) = \ell\Big) \\
&= w_{\ell-1}(t) C(t) (\ell - 1) \gamma_{\ell-1} - w_\ell(t) C(t) \ell
\end{aligned}
$$

Trust distribution

The system

$$\begin{aligned}\Delta_t w_1(t) &= J\alpha\gamma_\perp - C(t)w_1(t)\\ \Delta_t w_\ell(t) &= w_{\ell-1}(t)C(t)(\ell-1)\gamma_{\ell-1} - w_\ell(t)C(t)\ell\end{aligned}$$

Trust distribution

. . . divided by J becomes

$$\begin{aligned}\Delta_t v_1(t) &= \alpha\gamma_\perp - C(t)v_1(t)\\ \Delta_t v_\ell(t) &= v_{\ell-1}(t)C(t)(\ell-1)\gamma_{\ell-1} - v_\ell(t)C(t)\ell\end{aligned}$$

where $v_\ell(t) = \frac{w_\ell(t)}{J} = \mathrm{Prob}(i \in \mathrm{J} \mid \tau_i(t) = \ell)$
form a stochastic process $v : \mathbb{N} \longrightarrow \mathcal{D}\mathrm{R}$

Trust distribution

...and since $v : \mathbb{N} \longrightarrow \mathcal{D}\mathrm{R}$ is a martingale, it extends to $v : \mathbb{R} \longrightarrow \mathcal{D}\mathrm{R}$ and the system becomes

$$\frac{dv_1}{dt} = \alpha\gamma_\perp - \frac{c}{t} v_1$$

$$\frac{dv_\ell}{dt} = \frac{\gamma_{\ell-1} c(\ell-1) v_{\ell-1} - c\ell v_\ell}{t}$$

where $C(t) \approx \frac{c}{t}$, for $c = \frac{1-\alpha}{1+\alpha\gamma_\perp}$ (see Appendix)

Trust distribution

The steady state of $v : \mathbb{R} \longrightarrow \mathcal{D}\mathrm{R}$ will be in the form $v_\ell(t) = t \cdot \upsilon_\ell$, where

$$\begin{aligned} \upsilon_1 &= \alpha\gamma_\perp - c\upsilon_1 \\ \upsilon_\ell &= \gamma_{\ell-1} c(\ell - 1)\upsilon_{\ell-1} - c\ell\upsilon_\ell \end{aligned}$$

Trust distribution

The steady state of $v : \mathbb{R} \longrightarrow \mathcal{D}R$ will be in the form $v_\ell(t) = t \cdot \upsilon_\ell$, where

$$\begin{aligned} \upsilon_1 &= \frac{\alpha\gamma_\perp}{c+1} \\ \upsilon_\ell &= \frac{(\ell-1)\gamma_{\ell-1}c}{\ell c+1}\,\upsilon_{\ell-1} \end{aligned}$$

Trust distribution

...which expands into

$$
\begin{aligned}
\upsilon_2 &= \frac{\alpha\gamma_\perp}{c+1}\cdot\frac{\gamma_1 c}{2c+1}\\
\upsilon_3 &= \frac{\alpha\gamma_\perp}{c+1}\cdot\frac{\gamma_1 c}{2c+1}\cdot\frac{2\gamma_2 c}{3c+1}\\
&\vdots\\
\upsilon_n &= \alpha\gamma_\perp\left(\prod_{\ell=1}^{n-1}\gamma_\ell\right)c^{n-1}\cdot\frac{(n-1)!}{\prod_{k=1}^{n}(kc+1)}\\
&= \frac{\alpha\gamma_\perp G_{n-1}}{c}\cdot\frac{(n-1)!}{\prod_{k=1}^{n}\left(k+\frac{1}{c}\right)}\\
&= \frac{\alpha\gamma_\perp G_{n-1}}{c}\cdot\frac{\Gamma(n)\Gamma\left(1+\frac{1}{c}\right)}{\Gamma\left(n+1+\frac{1}{c}\right)}\\
&= \frac{\alpha\gamma_\perp G_{n-1}}{c}\cdot B\left(n,1+\frac{1}{c}\right)
\end{aligned}
$$

Trust distribution

The solution

$$\upsilon_1 = \frac{\alpha\gamma_\perp}{c+1}$$

$$\upsilon_n = \frac{\alpha\gamma_\perp G_{n-1}}{c} B\left(n, 1+\frac{1}{c}\right)$$

$$\stackrel{n\to\infty}{\longrightarrow} \frac{\alpha\gamma_\perp G}{c} n^{-\left(1+\frac{1}{c}\right)}$$

where

$$G = \prod_{\ell=1}^{\infty} \gamma_\ell > 0 \text{ follows from}$$

$$\frac{1}{e^{s_\ell}} \leq \gamma_\ell \leq 1 \text{ for some}$$

$$\sum_{\ell=1}^{\infty} s_\ell < \infty$$

Trust distribution

Theorem

The described process of trust building leads, in the long run, to the power law distribution of the number of trusteess with the trust rating n

$$w_n \approx \frac{\alpha\gamma_\perp GJ}{c} n^{-\left(1+\frac{1}{c}\right)}$$

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provided that the incidence of dishonest principals who act honestly long enough to accumulate a high trust rating — is low enough (so that $\gamma_\ell \stackrel{\ell\to\infty}{\longrightarrow} 1$ fast enough)

What does this mean?

Some things have a fixed scale

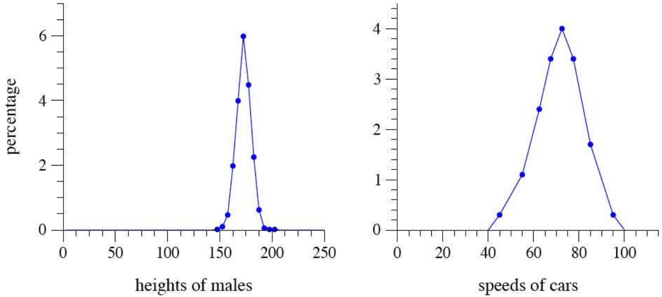

Figure: Normal distribution $f(x) = ae^{-bx^2}$

What does this mean?

Many social phenomena are scale-free

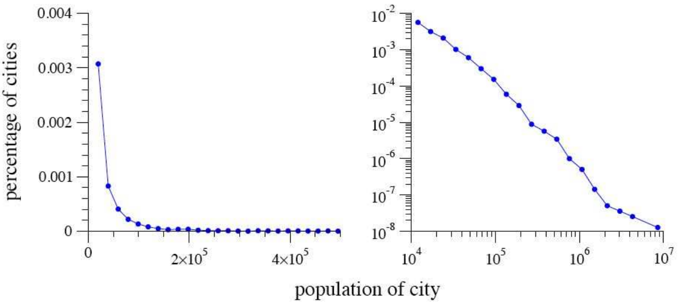

Figure: Power law $w(x) = ax^{-(1+b)}$

Dynamics → robustness → fragility

Dynamics of scale-free distributions

V. Pareto: "The rich get richer"

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Robustness of scale free distributions

The market is stabilized by the hubs of wealth.

Dynamics → robustness → fragility

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Robustness of scale free distributions

The market is stabilized by the hubs of wealth.

Fragility of scale free distributions

Theft is easier when there are very rich people.

Policy guidance

Change dynamics

Modify the process of accumulation to assure a less fragile distribution of trust.

Policy guidance

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Modify the process of accumulation to assure a less fragile distribution of trust, wealth, evolutionary fitness. . . .

Policy guidance??

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Moral

Simple social processes lead to complex policy problems.

Private vs public trust

But we only talked about private trust vectors.

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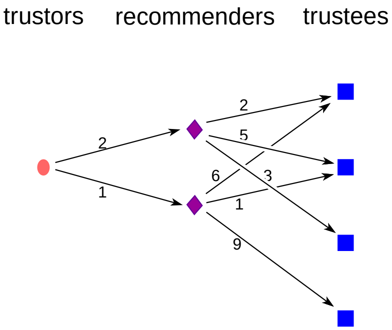
Why is private trust accumulation a social process?

Public trust process

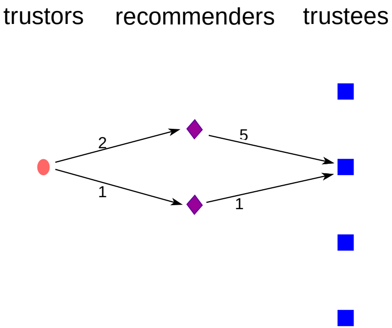
Using recommenders



2	A_1	2	5	3	0
1	A_2	6	1	0	9
σ	τ	10	11	6	9

Public trust process

Using recommenders



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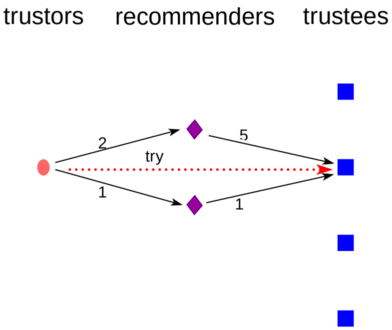

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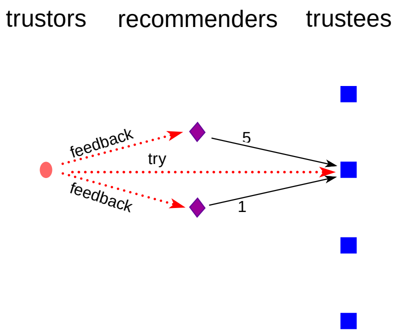

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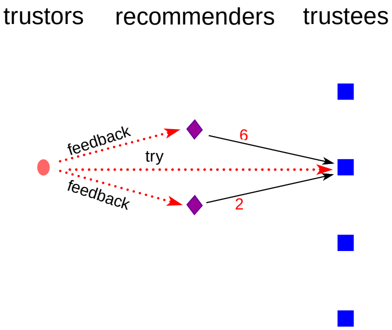

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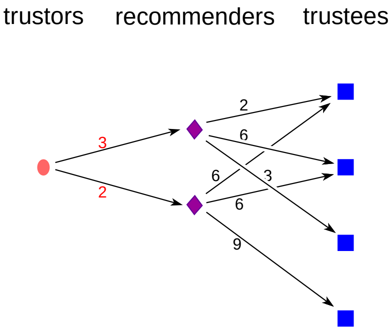

3	A_1	2	6	3	0
2	A_2	6	2	0	9
σ	τ	18	22	9	18

Trust authority distribution

Upshot

Recommenders' public trust vectors also obey the power law distribution.

Recommenders' reputations obey the power law distribution.

Trust authority distribution

Upshot

Recommenders' public trust vectors also obey the power law distribution.

Recommenders' reputations obey the power law distribution.

Consequence

Adverse selection

Outline

Problem: All protocols are insecure

Background: Notion of trust

Analysis: Trust dynamics

Method: Learning trust concepts

- Negative result
- Trust semantics

Conclusion: Security is an elephant

Fragility of trust networks

Corollary

The hubs attract attacks as soon as trust is

(a) public

(b) uniform

(c) abstract

Fragility of trust networks

Corollary

The hubs attract attacks as soon as trust is

(a) public
- ratings available to all

(b) uniform
- all certificates equally secure

(c) abstract
- "trust laundering" (*"Non olet."*)

Defending trust networks

Policy

Possible defense strategies are:

(a) non-public: private trust vectors
  - recommendations must be public

(b) non-uniform: higher security for higher trust
  - complicated; contradicts (a).

(c) non-abstract: retain trust concepts
  - "trust unlaundering": $u \xrightarrow[r]{\Phi} j$

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    - credit rating

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- "trust unlaundering": $u \xrightarrow[r]{\Phi} j$
  - record the actual feedback ($\sim$ "marked money")
  - credit rating
  - trust concept learning

Trust spaces

Definition

For the sets

- U of trustors, and
- J of trustees

we call

- a linear subspace of $\mathbb{R}^U$ — *trustor space*
- a linear subspace of $\mathbb{R}^J$ — *trustee space*

Trust communities

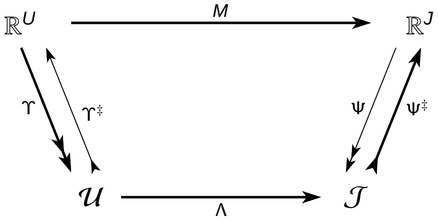
Definition

Let $M = (u \underset{r}{\longrightarrow} j)_{U \times J}$ be a trust matrix.

- A *trustor community* is an eigenspace of $M^{\ddagger}M$.
- A *trustee community* is an eigenspace of $MM^{\ddagger}$.

Spectral decomposition of trust matrix

M induces a bijection Λ between the communities



$$M = \sum_{\ell=1}^{d} \lambda_\ell |\Psi_\ell\rangle\langle\Upsilon_\ell|$$

Trust concepts

Definition

Let $M = (u \underset{r}{\longrightarrow} j)_{U \times J}$ be a trust matrix.

A *trust concept* is a pair $\Phi_\ell = \langle \Upsilon_\ell, \Psi_\ell \rangle$ where

- $\Upsilon_\ell \subseteq \mathbb{R}^U$ is a trustor community
- $\Psi_\ell \subseteq \mathbb{R}^J$ is a trustee community
- $\Lambda(\Upsilon_\ell) = \Psi_\ell$

Qualitative decomposition of trust

$$u \xrightarrow[r \;=\; \sum r_\ell]{\Phi \;=\; \sum r_\ell \Phi_\ell} j$$

where

$$r_\ell \quad = \quad \lambda_\ell \Psi_{j\ell} \Upsilon_{u\ell}$$

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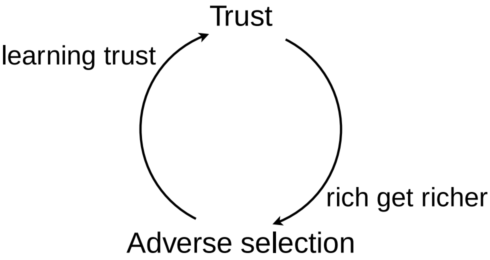
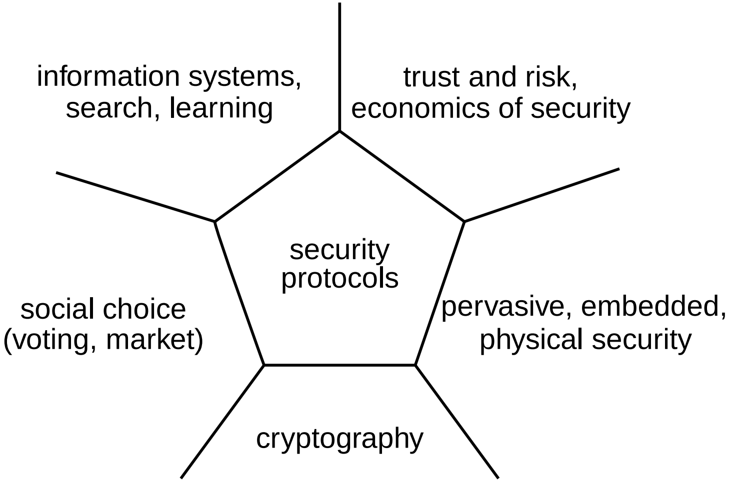
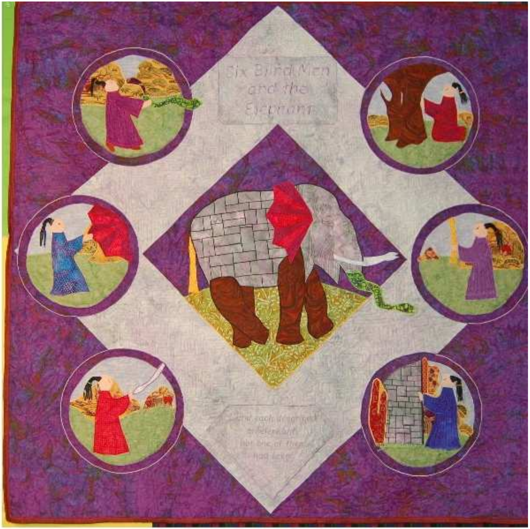
Security is an adversarial process



Security is a collaborative process



Security Engineering



Six Blind Men and the Elephant

Summary

- **Problem**: old
- **Background**: fragmented
- **Analysis**: dynamics
- **Method**: semantics (no simple policy)