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On the Foundations of Trust in networks of Humans and Computers*

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***joint work with Jeannette Wing, Tiffany Hyun-Jin Kim and Adrian Perrig**

Outline

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1. ***What are Trustworthy Systems?***
   - *(in)security axioms*

2. ***Interactive Trust Protocols on Trustworthy Systems***
   - *necessary conditions: value, asymmetry, safety*

3. ***Role of Collateral in Interactive Trust Protocols***
   - *advantages of social ("street-level") collateral*

4. ***An Example: Street-Level Semantics for Attribute Authentication***
   - *semantics and visualization*

5. ***Summary and Future Research***
   - *why trust? why interactive protocols? why street-level?*
   - *systems, deception and scams, machine learning, trust networks*

(In)Security Axioms

1. There will always (> 15 years) be

- **bugs/features & human "errors" that will lead to security vulnerabilities**
- **adversaries (e.g., malware, insiders) willing and able to exploit them**

	'60s	'70s	'80s	'90s	'00s	'10s
Example Technology Feature	TSS	PC, Servers LANs	email, IP connectivity	WWW, mobility	physical systems, smart phones	social networks
New Adversary	opportunistic user	man-in-the -middle attacks	viruses, worms, outsiders -> insiders	large-scale DDoS, untraceable attacks	infrastructure attacks, phone malware	network deception, large-scale scams

(In)Security Axioms

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2. There will always be rapid innovation in IT, and it will always lead to low-assurance systems

- **frequent updates of system configurations**
  => perennially out-of-date assurances
  (e.g., "*high assurance* is always available when you no longer need it")
- **systems comprising components of diverse provenance**
  => non-uniform assurances and more attack surfaces
  (e.g., "lemon" apps always will drive high-assurance apps out of the market)

(In)Security Axioms

1. There will always (> 15 years) be
   - bugs/features & human "errors" that will lead to security vulnerabilities
   - adversaries (e.g., malware, insiders) willing and able to exploit them in the Internet

2. There will always be rapid innovation in IT, **and it will always lead to low-assurance systems**

   => frequent updates of system configurations

   => perennially out-of-date assurances

   (e.g., "*high assurance is always* available when you no longer need it")

   ⇒ systems comprising components of diverse provenance

   ⇒ non-uniform assurances ("toxic"components?) & more attack surfaces

   (e.g., "lemons" always will drive high-assurance apps out of the market)

3. There will always be
   - large, complex systems whose security is *not fully* understood by most users

"in software, only [module] giants survive…." [Lampson, ICSE, 1999]

"security is fractal: every part is as complex as the whole" [Lampson, CACM 2009]

What are Trustworthy Systems, then?

Systems with Demonstrable Security Properties
despite
Axiomatic Insecurity of their Commodity Computing Platforms

- **properties that hold *in the presence of an Adversary; e.g.,***
  - ***malware***
  - ***malicious insiders***

Interactive Trust Protocols

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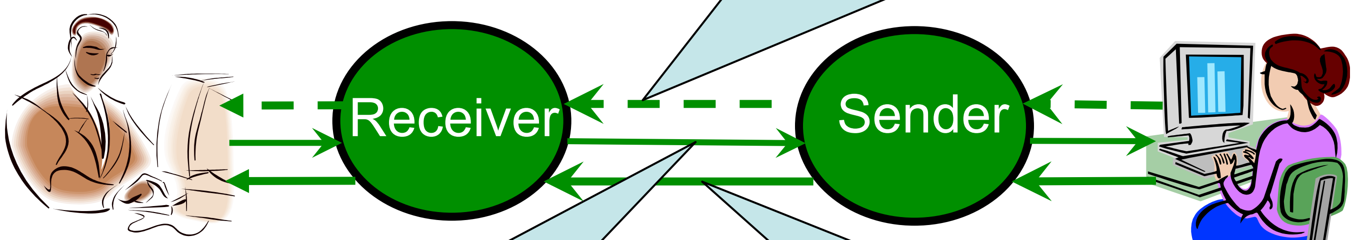
Specification: **Take Action** (e.g., “invest, click, send PII/acct, send problem”) **=> Receive Service**

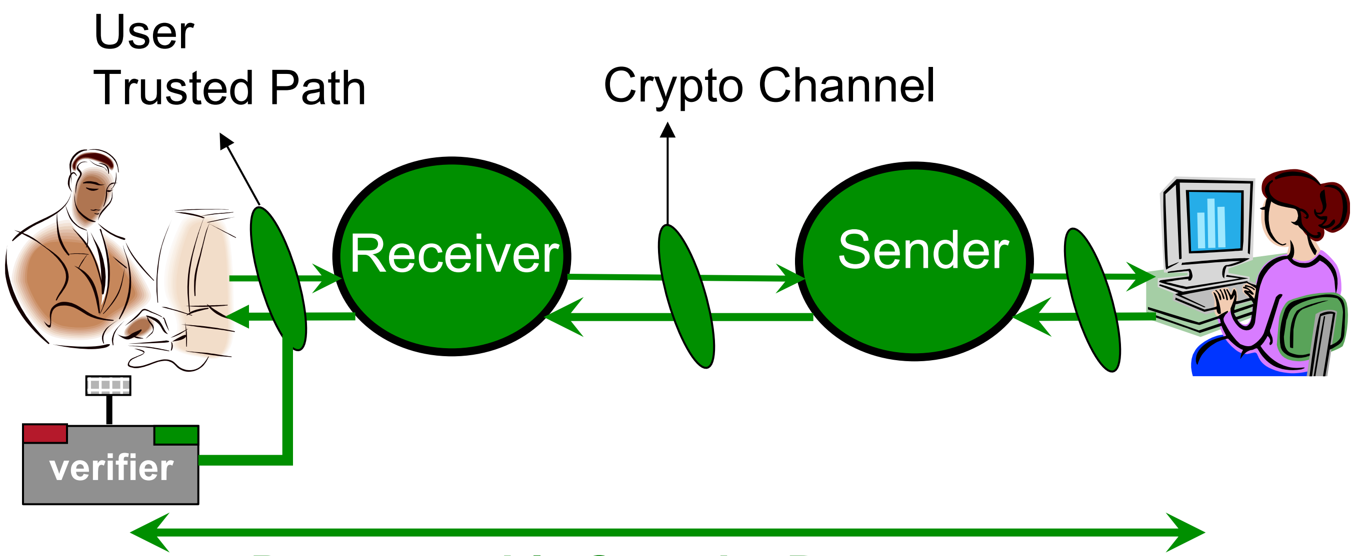


Either **Takes Specified Action** or **Rejects**

Provides Specified Service

?

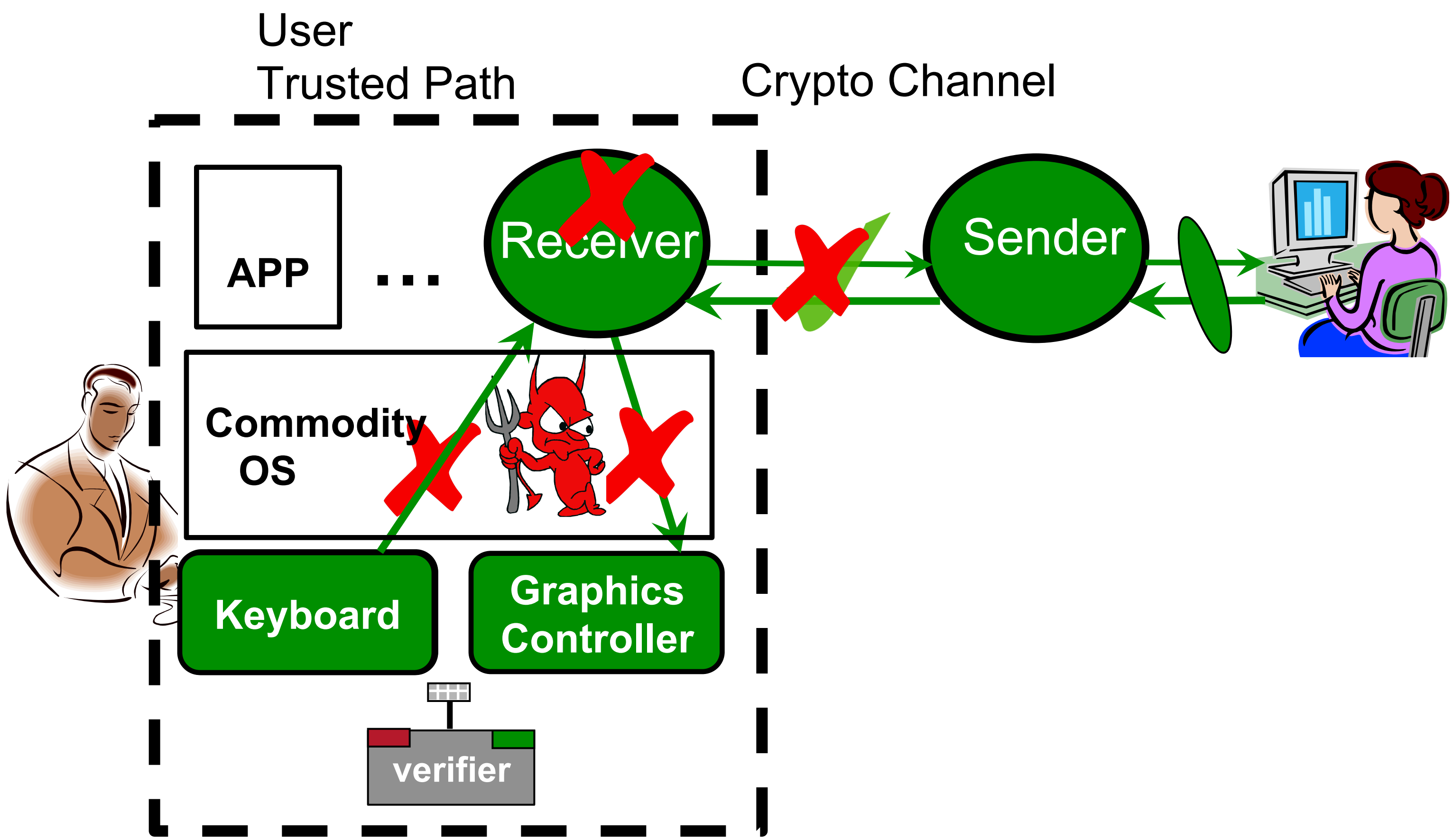
Am I talking to the Sender?



Demonstrable Security Property:

User-Verifiable End-to-End Trusted Path

Am I talking to the Sender?



Mouse Click: Accept {Sender, PK_{Sender}}?

Sources of Malware Today …

- ***Non-Uniform Assurances*:**
  e.g., unpatched systems -> exploits based on buffer overflows, XSS, etc.

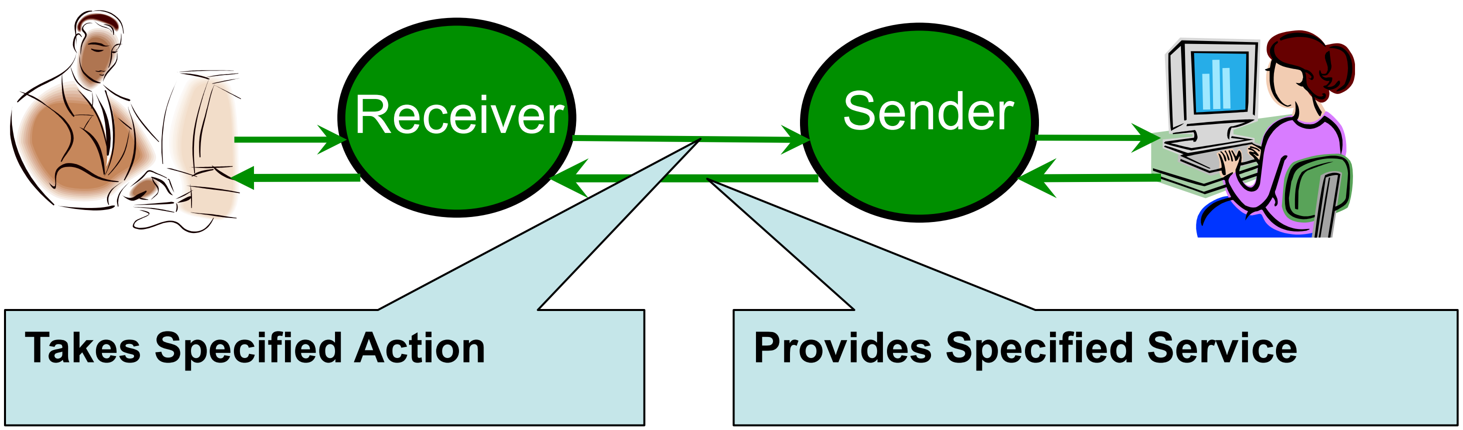
- ***Features*:**
  e.g., USB Drives, Network Drives; AutoRun/AutoPlay

- ***Large Software Systems*:**
  e.g., Microsoft Office (e.g., .ppt, .doc, .xls), Adobe .pdf … viral file infection

- ***Human Errors***
  e.g., social engineering, scams, deception
  via e-mail, P2P sharing, social networks

Most of Today's Problems will not Disappear any Time Soon

Value



Honest **or** ***Trustworthy*** **(TW) Behavior**

= compliance with the protocol specifications

- ***Both parties are TW => Both are <u>better off</u>*** **after session**
  Value to Receiver = $\mathbf{Tw_R > 0}$ and Value to Sender = $\mathbf{Tw_S > 0}$

- **Future sessions (Rational Receiver Takes Action again)**

Asymmetry

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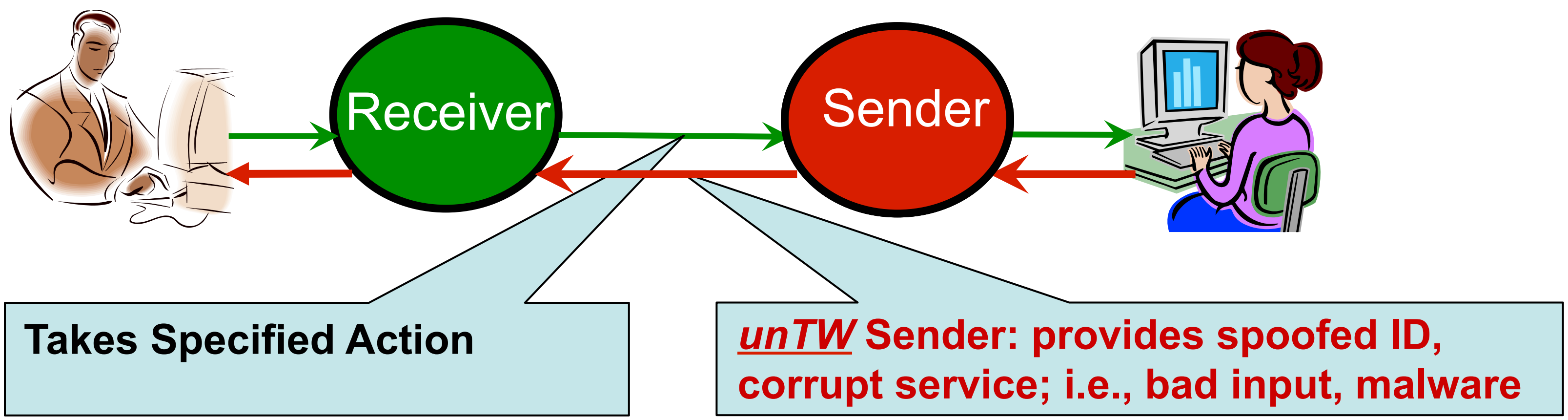


- ***unTW*** **Sender is** ***<u>better off</u>*** ***than TW Sender*** **and** ***TW*** **Receiver is** ***<u>worse off</u>*** **after session**

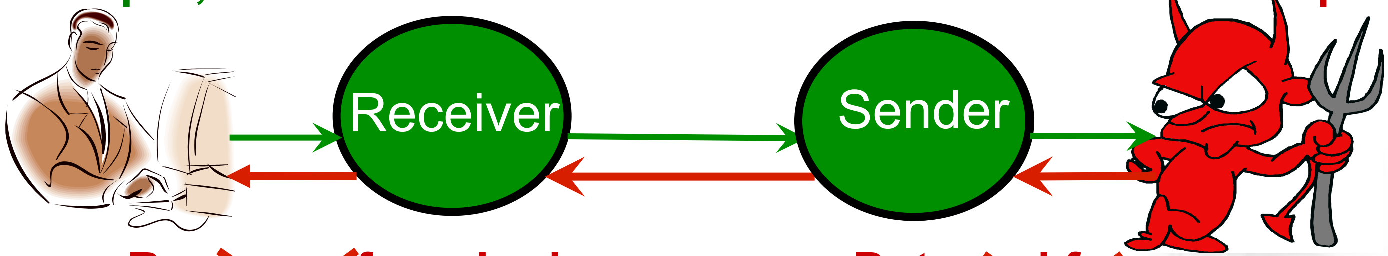
  $Gain_S = unTw_S - Tw_S > 0$ and $Loss_R > 0$

- ***unTW*** **Sender => No future sessions (Rational Receiver will "Reject")**

Asymmetry persists

Isolation ~~from~~ Sender:
bad input, malware discovered

Trustworthiness Evidence (past)
never sends a bad input, malware



Recovery from bad input, malware

Deterred from sending a bad input, malware

	Machine? ✓	**Human?**	
	Correct System & Machine Code	Correct System & User Behavior	**TWness Evidence**
	——	Punishment	**Deterrence**

Completeness: Behavioral-Trust Primitives

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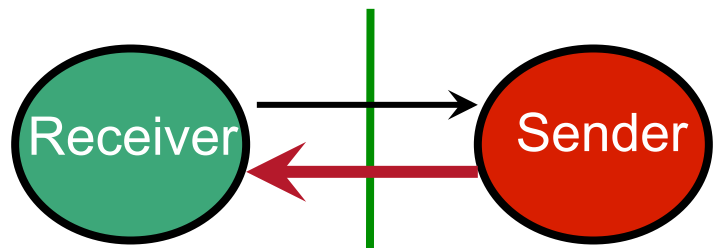

Behavioral Trust:

- Beliefs in Sender's trustworthiness =>
- Preferences/Aversions
- Risk =>
- Betrayal =>

Primitives be Supported in Human and Computer Networks ?

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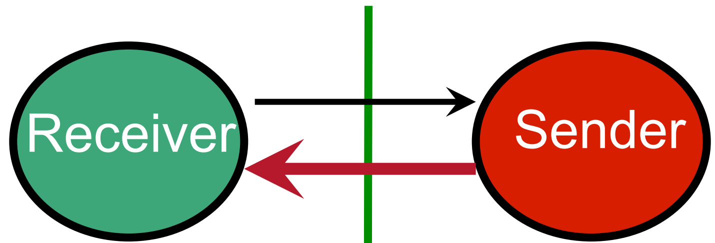
Completeness: Behavioral-Trust Primitives



Behavioral Trust:

Networking (e-commerce) Practice

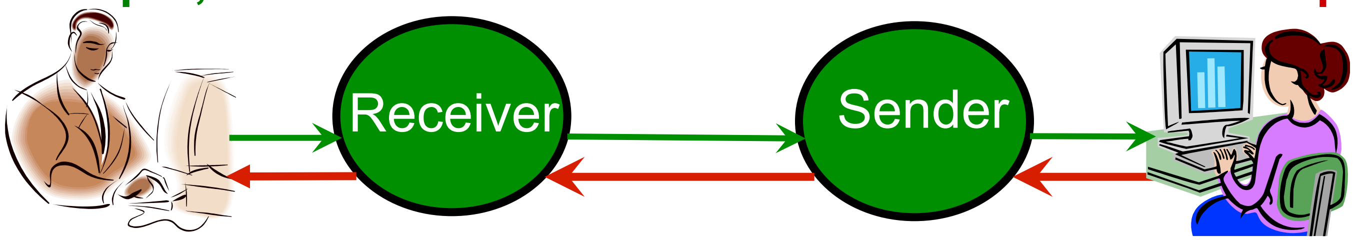
- **Beliefs in Sender's trustworthiness** => ***Trustworthiness evidence*** **=> *Correctness***
- **Preferences/Aversions**
- **Risk** => ***recovery*** from **Sender non-compliance**
- **Betrayal** => **deterrence =>"punishment"=>*Accountability***

we need: <= <=

Asymmetry persists

Isolation from Sender:
bad input, malware discovered

Trustworthiness Evidence (past)
never sends a bad input, malware



Recovery from bad input, malware

Deterred from sending a bad input, malware

*0% Isolation **and** 0%Trustworthiness <u>Evidence</u> **and** 0% Recovery **and** 0% Deterrence => 100% **Trust***

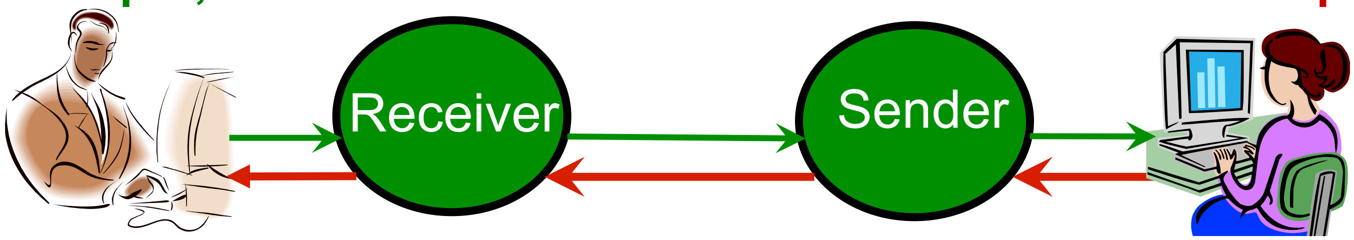
Is it *<u>ever</u>* Safe to Trust the Sender?

Yes, if *Trustworthy Behavior* is in *<u>Rational</u>* Sender's *interest*

Safety

Isolation ~~from~~ Sender:
bad input, malware discovered

Trustworthiness Evidence (past)
never sends a bad input, malware



~~Recovery~~ from bad input, malware

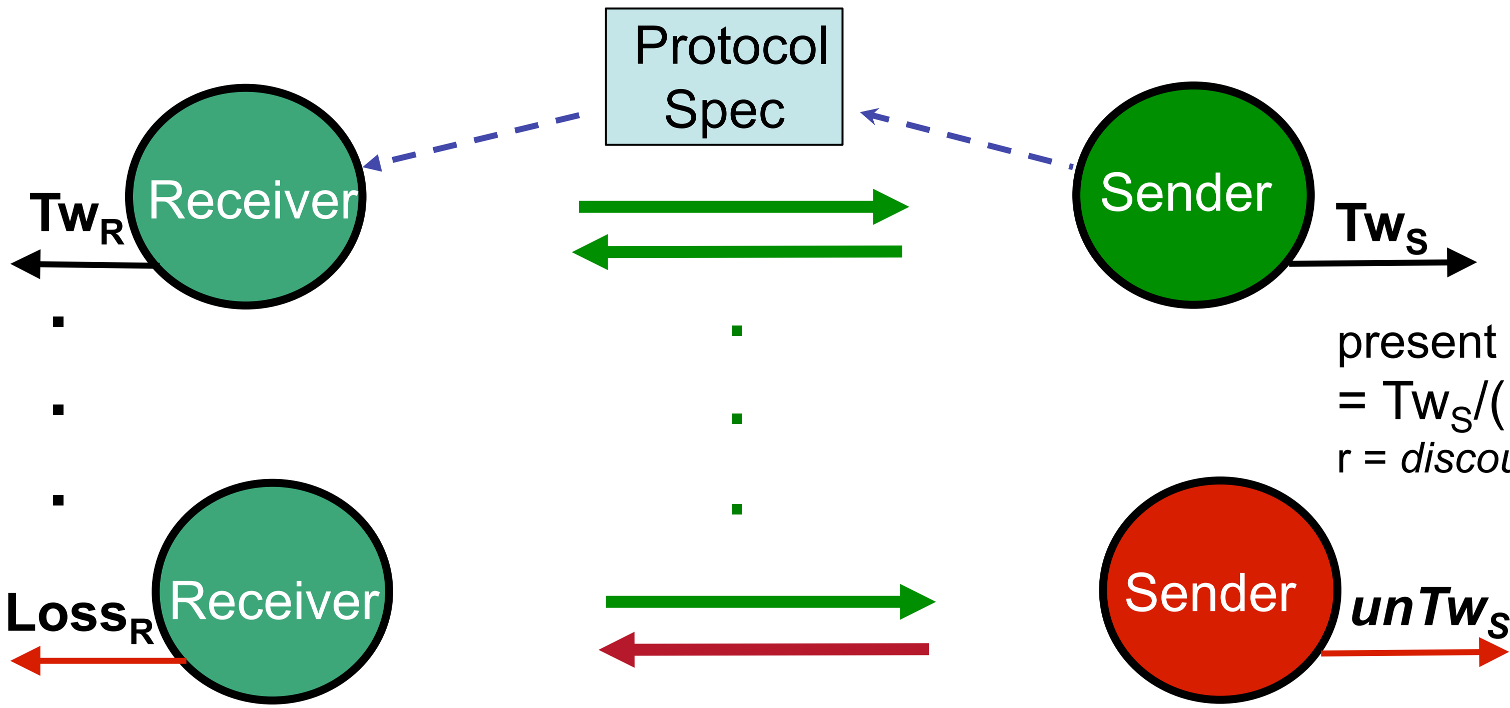
Deterred from sending a bad input, malware

Trust (Belief in *Rational* Sender's *Trustworthy Behavior*)
=> Sender's Present Value of all *Future Sessions* > $unTw_S$

<=>

Sender's discount rate = $r < Tw_S / Gain_S$

Safety



present value of session t
$= Tw_S/(1+r)^t$, t = 0, 1, 2…
r = *discount rate*

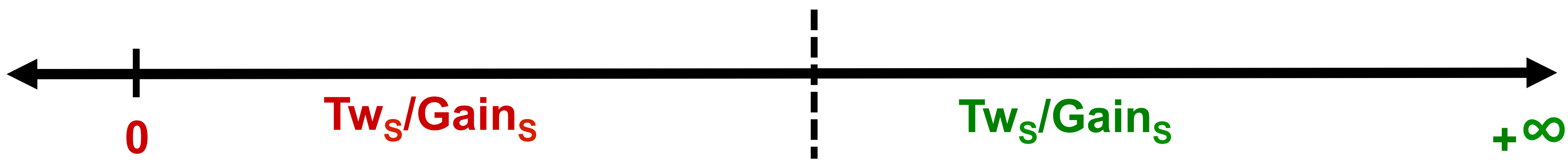
Present Value of all Future Sessions
$= Tw_S + Tw_S/(1+r) + Tw_S/(1+r)^2 + Tw_S/(1+r)^3 + \ldots = \mathbf{Tw_S(1+r)/r > unTw_S}$

- Trust: $r < Tw_S/(unTw_S - Tw_S) = Tw_S/Gain_S$

- no Trust: $r \geq Tw_S/Gain_S$

Safety

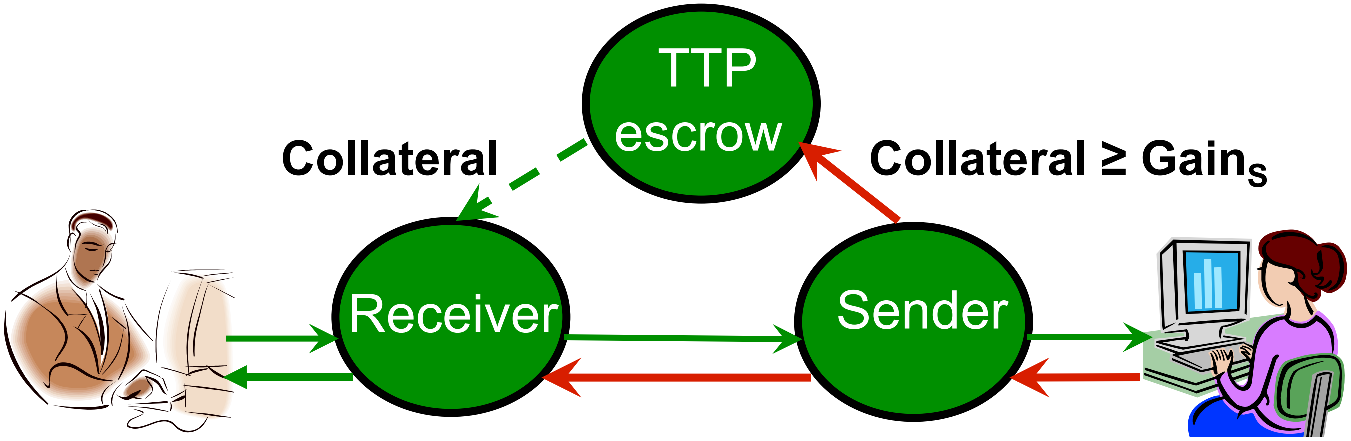
Problem:
r ?



- **$Tw_S/Gain_S$ -> 0 => no Trust**
  - $Gain_S >> Tw_S => unTw_S/Tw_S >> 2$
  => few future sessions if any => no trust
  e.g., possible **scams, insider attacks**

- **$Tw_S/Gain_S$ -> + ∞ => Trust**
  - $Gain_S$ **-> 0**
  => *rational* Sender has **no incentive to be untrustworthy**

Role of Collateral: $Gain_S$ -> 0



*(-) **Non-starter**: Sender has to post Collateral (for **all** Receivers)*

*(-) **Trusted Third Party:** a bootstrapping challenge*

*(+) **Deterrence**: rational Sender has no incentive to be unTW*

*(+/-) **Acceptability**: $Loss_R$ ≤ Collateral => Receiver can recover*

unacceptability: Receiver's $Loss_R$ > Collateral => Receiver could not recover
=> Protocol would not start

Role of Social ("Street-level") Collateral

+ Social Collateral: a Sender-Receiver Social Relation exists

e.g., friend, relative, classmate, co-worker, boss, co-conspirator…

=> (high) present value of future cooperation/sessions

=> Trust protocol always starts

+ A Trusted Third Party is unnecessary

Deterrence Hypothesis*: Loss of Social Relations (i.e., loss of social collateral) deters more than the Law*

- some support in Hu *et al.*, CACM, vol. 64, no. 6, 2011]

+ Deterrence:

- *Sender's* ***loss of social collateral*** *reduces* ***asymmetry*** *of Trust protocol*

+ Acceptability:

- *the greater Receiver's* ***exposure*** *to* ***Loss,*** *the higher* ***Social Collateral***

Street-Level Semantics for Attribute Authentication

e.g., attributes:

- ***Identity***
- ***Certificates***
- ***Address/Location***
- ***Social Connections***
- ***Reputation/Credentials***

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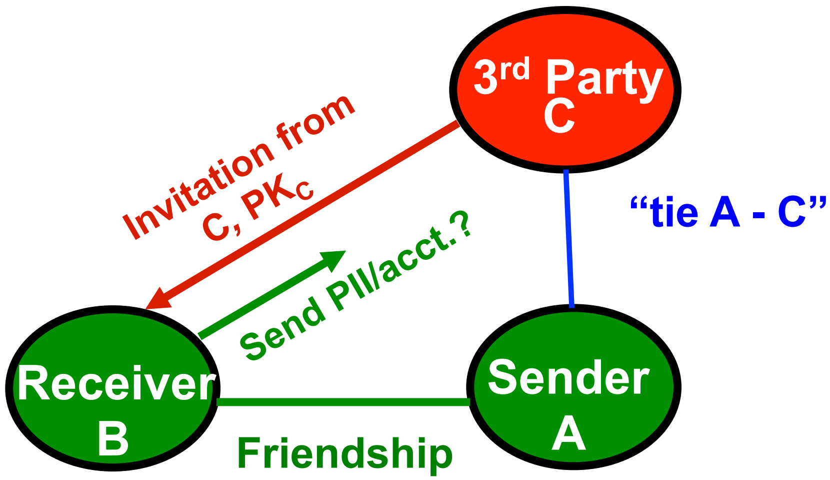
Accepting an Attribute



SC(A) @ B = social collateral of A at B

Friendship: a social relation

- *built-in* social collateral
- "street-level" punishment/sanction = *loss of future value*

Accepting an Attribute

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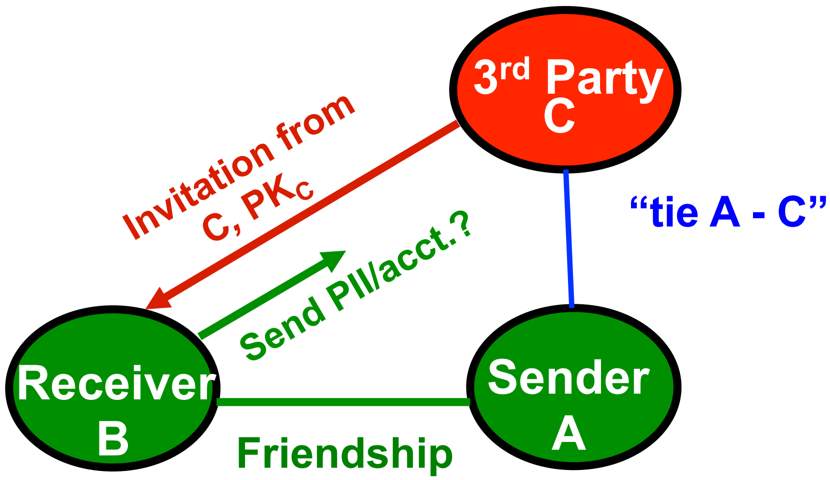

SC(A) @ B

SC(C) @ A = assigned value by B to {tie A-C}^{SK_A} based on tie evidence and strength necessary for attribute auth; e.g., C, PK_C

Attribute Authenticity* => *evidence of tie to Sender

=> *strength of tie (social distance) to Sender*

(communication frequency, recency, reciprocity, length, common acquaintance)

=>" street-level" punishment of 3rd party C (e.g., spoofed ID, false certificate)

=> loss of endorsement by Sender => loss of value at Receiver

Accepting an Attribute

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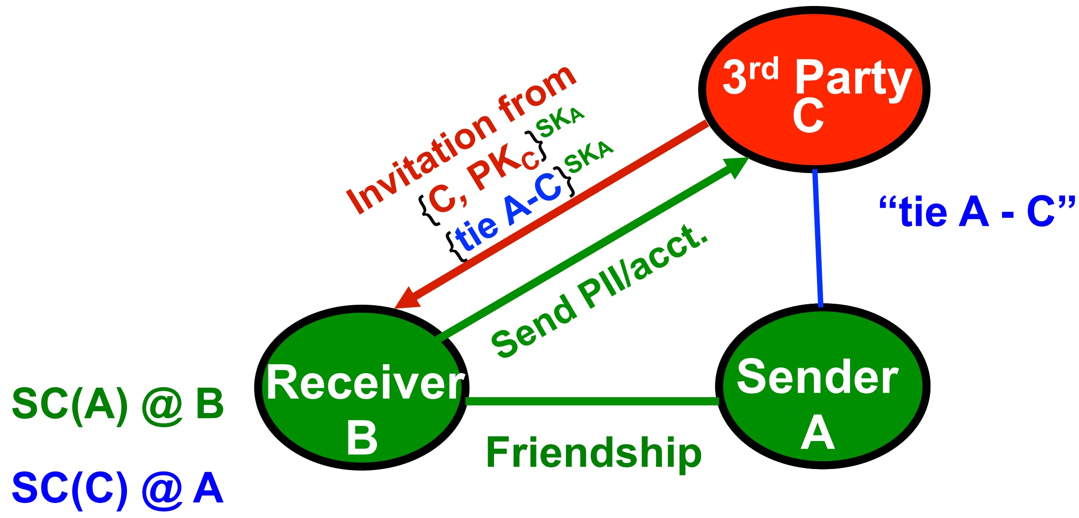
Example 1: Accepting a 3rd Party Attribute (Certificate) signed by a Friend



Deterrence: SC(A) @ B – SC(C) @ A ≥ P,
where **P ≥ 0** measures **friend A's** ***net loss of collateral*** if $\{C, PK_C\}^{SK_A}$ is **false**

Acceptability: SC(C) @ A ≥ T_{Bapp},
where T_{Bapp} measures loss incurred by **B**'s application if $\{C, PK_C\}^{SK_A}$ is **false**

B accepts A's authentication of $\{C, PK_C\}^{SK_A}$

Visualization of "Tie Strength" Evidence

Visualizing Tie Strength

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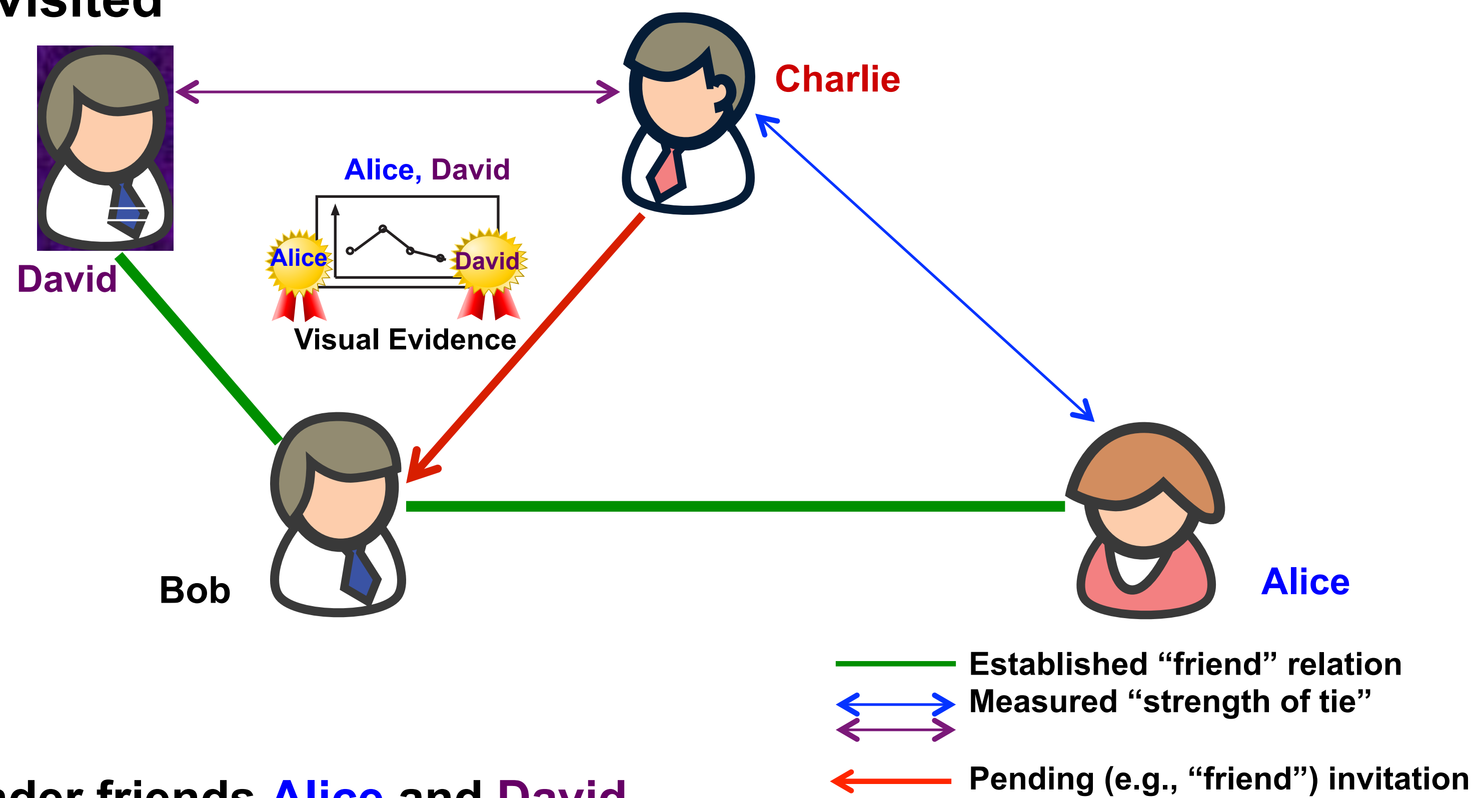
Example 2 Revisited



- Bob has Sender friends Alice and David
- Bob receives an "invitation" from 3rd Party Charlie
  - Charlie's "invitation" contains endorsed visual 'tie strength" evidence
- Bob accepts Charlie's "invitation" based on the social collateral it assigns to the "tie strength" between Alice and Charlie and David and Charlie

What Does Bob see?

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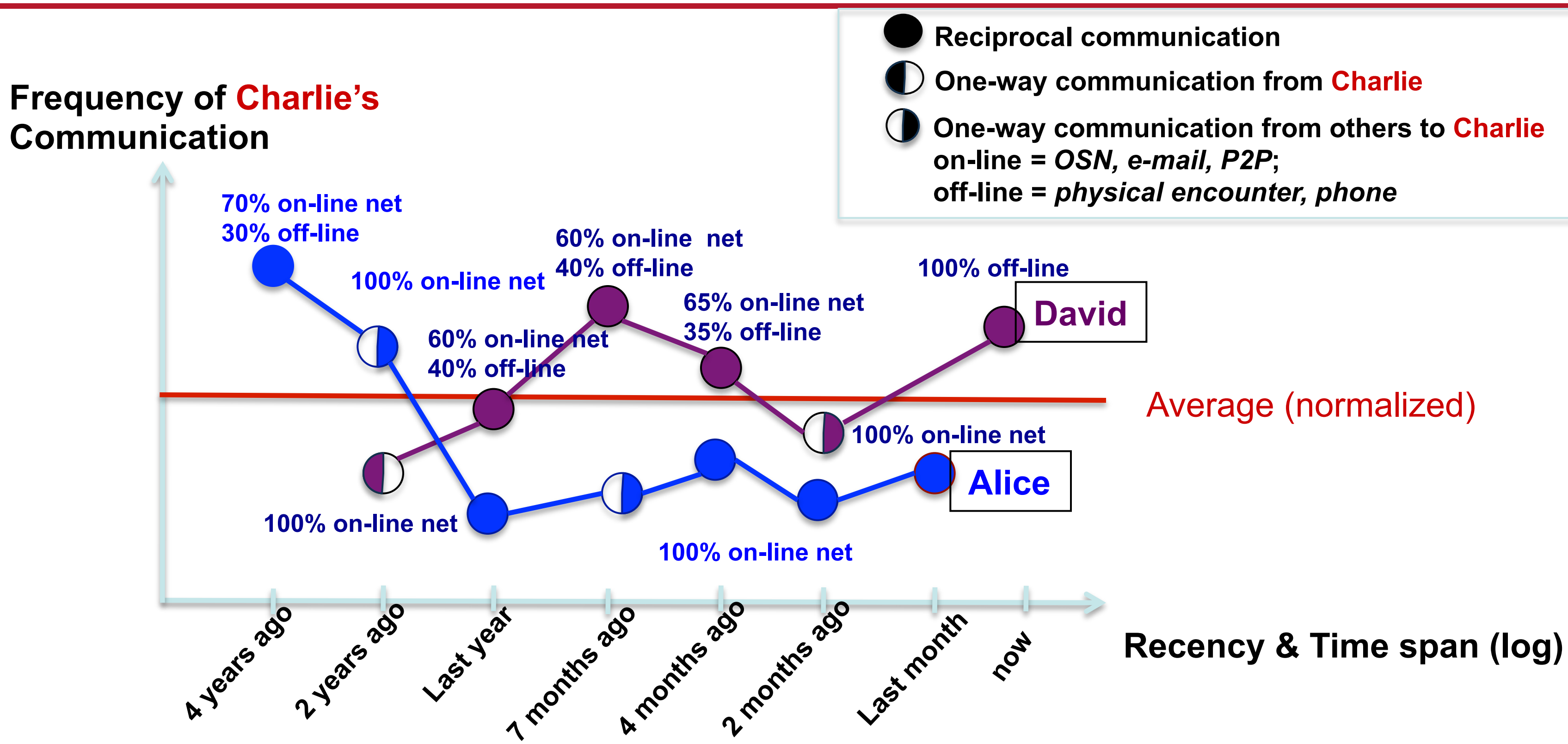

Visualized parameters:

- Frequency of communication (y axis)
- Length of relationship (x axis)
- Reciprocity of communication (circles)
- Selected mutual friends (individual graphs: Alice, David)
- Recency of interaction (leftmost points on x axis)

Usability: A Facebook Example

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- **Mechanical Turk-based user study result: 93 participants**
  - **84.9% understood "tie strength" on our graph**
  - **90.3% would *not* accept "invitations" below the average communication frequency**
  - **60.2% felt in control of their privacy in confirming "strength of ties"**
  - **82.8% mentioned that our authentication application was easy to use**
  - **88.2% indicated that our visual evidence was useful**
  - **83.8% indicated that they would use our application before accepting "invitations"**

Why Trust?

1. Trust Correlates with Wealth

- countries where people *trust more* have *higher GDP*
- measured trust: ***surveys*** (e.g., German Socio-Economic Panel, US General Social Survey, World Value Survey)

2. Network Interpretation

- *new* trust relations => larger pool of services, more cooperation, "network effect," increased competition, *productivity*, innovation, markets and ultimately *economic development/wealth*

3. *New Focus For Security Research*

- *past: most security researchers have been merchants of fear! We're good at it!*
- *future*: security infrastructures that promote *new* trust relations (and cooperation)

  Safety Analogy:
  air breaks in railcars (1896), automated railways signals and stops (1882)
  => safe increase in train speeds, railroad commerce, economic opportunities
- **goal: seek security mechanisms that create new value, not just prevent losses**

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Future Research

1. **Systems – Other roots of trust: software roots of trust**
   - **TPM are *not* useful for device controllers and power-challenged devices**
   - **explore security mechanisms *without* secrets**
   - **"simplify" provably complex (e.g., crypto) problems by using valid trust assumptions**

2. **Understand on-line deception and scams**
   - **initial work by Stajano and Wilson**
   - **interactive scams have trust-protocols w/ failed safety conditions**

3. **Explore machine learning techniques for scam detection**
   - **other areas than intrusion detection; e.g., advice to users**
   - **insider attacks explained**

4. **Trust Networks**
   - **explore social collateral and relations for deterrence and recovery**