



CISPA

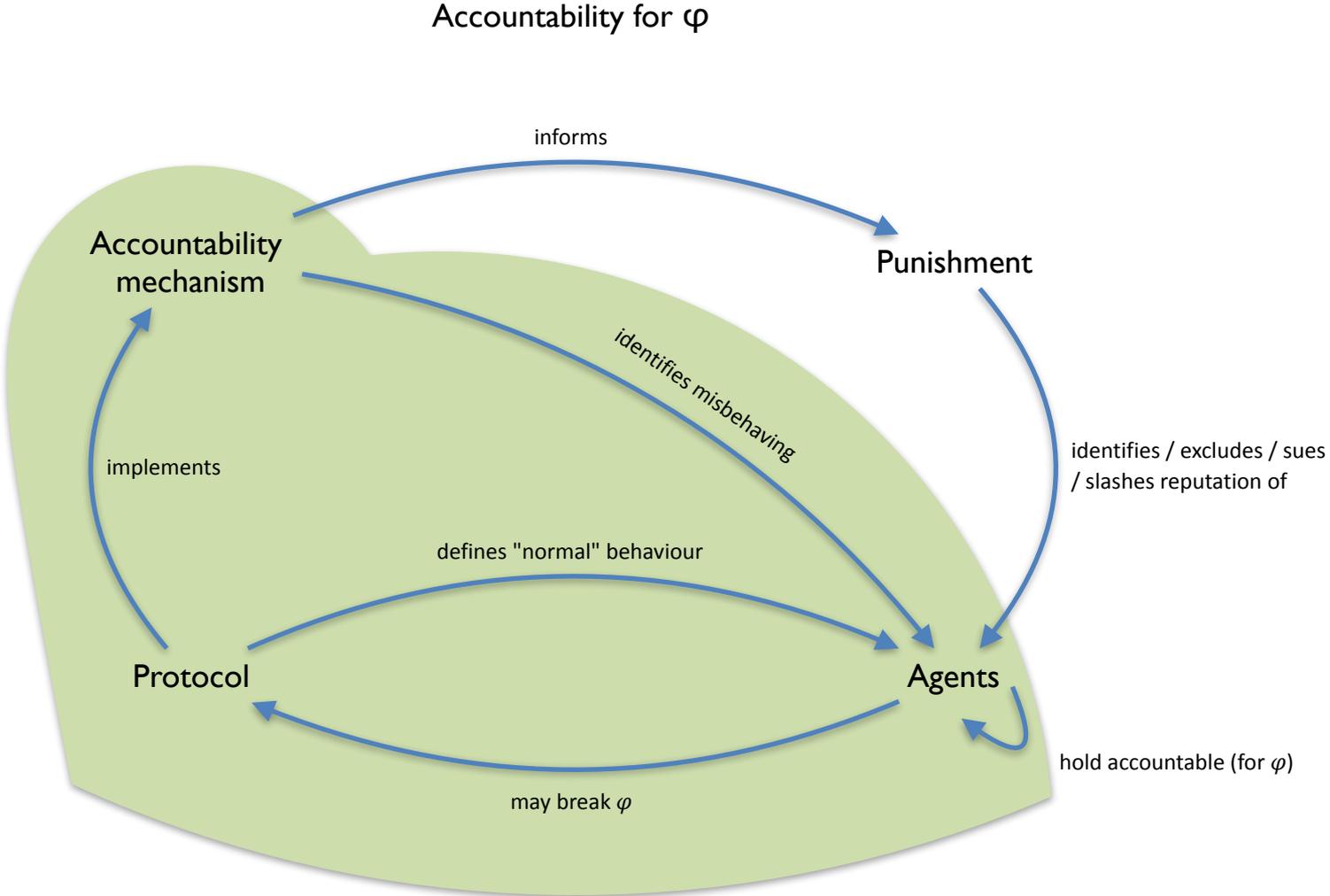
HELMHOLTZ CENTER FOR
INFORMATION SECURITY

Automated Verification of Accountability in Security Protocols

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Part I: What we talk about when we talk about accountability



$\neg \text{honest}(A, B, C)$

$\text{honest}(A) \Rightarrow \text{accountability for } \varphi$

$\text{honest}(A, B, C) \Rightarrow \varphi$

Why is it so hard?

soundness: $\text{verdict}(t) \subseteq \text{corrupted}(t)$

completeness: $\text{verdict}(t) \supseteq \text{corrupted}(t)$

(can imitate protocol)

$\text{verdict}(t) = \{A \mid t|_A \text{ observably different from spec}\}$

(e.g., PeerReview)

no complete view in the internet :(

$\text{verdict}(t) = \{A \mid A \text{ performed action outside spec causing } \neg\varphi\}$

Out-of-spec *action* causing $\neg\varphi$ does not mean the out-of-spec *process* is a cause.

(Counterexample: A is buggy CA. Emits slightly malformed certificate, which is used in attack, but malformedness is irrelevant. Had A followed the spec, same attack would have happened.)

This work

$\text{verdict}(t) = \{A \mid \text{Had } A \text{ followed spec, then } \varphi\}$

- Event(s) A caused $\neg\varphi$ iff
 - A and $\neg\varphi$, in fact, happened.
 - In any counterfactual where A happens, $\neg\varphi$ happens.
 - A is subset-minimal.
- "Umbrella" caused "not wet", as
 - I had an umbrella and did not get wet.
 - As long as I have my umbrella, I cannot get wet.
 - Without the umbrella, I could get wet.

- Event(s) A caused $\neg\varphi$ iff
 - A and $\neg\varphi$, in fact, happened.
 - In any counterfactual where A happens, $\neg\varphi$ happens.
 - A is subset-minimal.
- Output all sets of parties S , s.t.
 - $t \models \neg\varphi$ and $\text{corrupted}(t) \supseteq S$
 - there is related t' s.t. $t' \models \neg\varphi$ and $\text{corrupt}(t')=S$,
 - S is subset-minimal.



Part II: Accountability in terms of trace properties

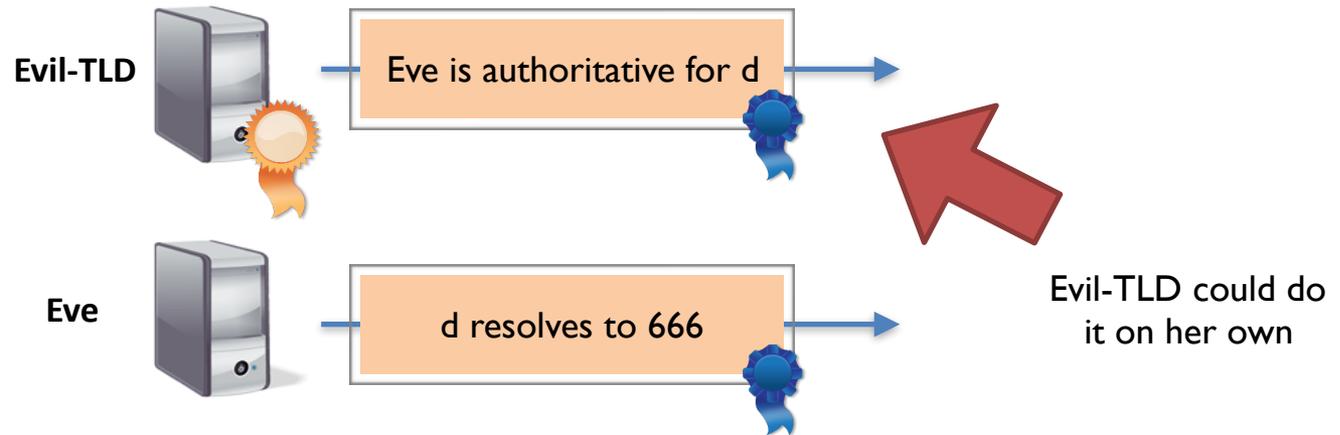
Case 1: weakest possible relation

- Consider t' is related to t iff $\text{corrupt}(t') \subseteq \text{corrupt}(t)$
- Idea: verdict function defined as

$$\text{verdict}(t) = \begin{cases} V_1 & \text{if } \omega_1(t) \\ \vdots & \\ V_n & \text{if } \omega_n(t) \end{cases}$$

- cases are **exhaustive** and **exclusive**, and for each i :
- **sufficiency**: Agents in V_i can produce violating trace
- **verifiability**: $V_i = \emptyset \iff \varphi$
- **minimality**: can't do with less than $S \in V_i$
- **uniqueness**: whenever ω_i is observed, parties in V_i are corrupted
- **completeness**: (omitted)

Case 2: arbitrary relation

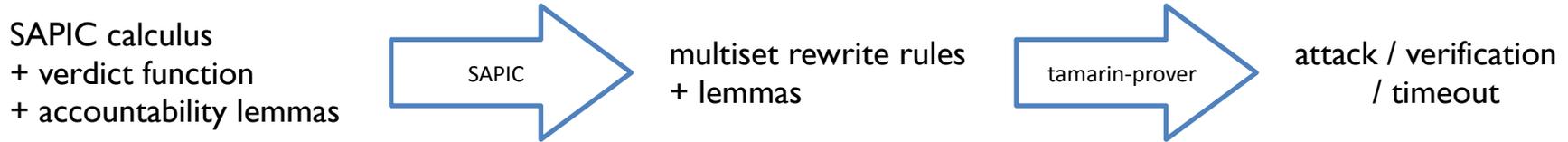


- "But that's not what happened" -> relation r between t and t'
- idea for translation: cases are liftings R of relation r
- combination of 11 different conditions, including lifting condition:

$$verdict(t) = \begin{cases} V_1 & \text{if } \omega_1(t) \\ V_2 & \text{if } \omega_2(t) \\ V_3 & \text{if } \omega_3(t) \end{cases} \quad \begin{matrix} \curvearrowright \\ R \end{matrix}$$



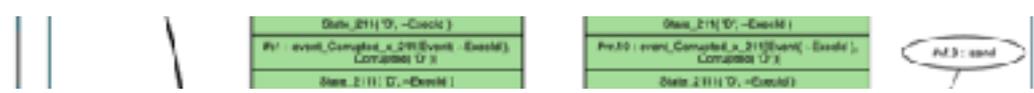
Part III: Implementation



- ✓ weakest possible relation
- ✓ arbitrary relation (lifting lemma offset to user)
- ✓ control-flow relation:

- ▶ two-trace lemma: for all t, t' , if t in related ω_i and ω_j , control-flow is the same
- ▶ translate process so it can run "twice", producing two traces in sequence

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Solve State_211C "E", -ExecID > Pw #C )  
case in_c_corrupt_u_0_21  
Solve(Executer u ) #. )
```

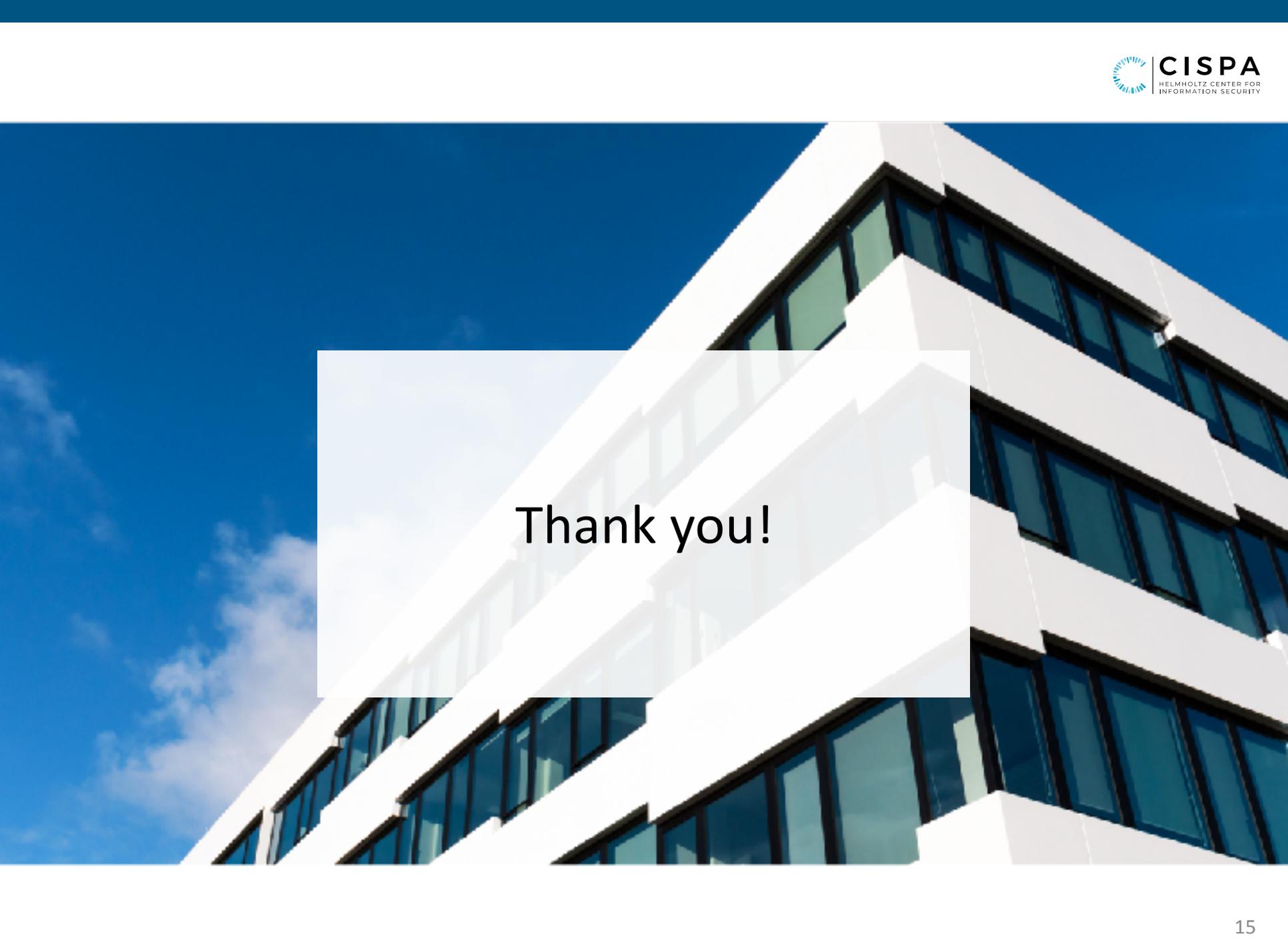


protocol	type	# lemmas generated	# helping lemmas	time
Certificate Transp.				
model by Bruni et al	✓, r_w	31	0	41s
extended model	✓, r_w	21	0	50s
OCSP Stapling				
trusted resp.	✓, r_w	7	3	945s
untrusted resp.	✗, r_w	7	3	12s
Centralized monitor				
faulty	✗, r_c	17	0	5s
fixed	✓, r_c	17	0	3s
replication	✓, r_c	17	0	7s
Accountable alg.				
modified-1	✓, r_c	27	1	5792s
modified-2	✓, r_c	27	1	2047s

(✓): verification (✗): attack (r_w): weak relation (r_c): control-flow r.

- Accountability is identifying misbehaving parties
- "misbehaving party" = "party whose deviation caused $\neg\varphi$ "
- This definition is practical and can be verified automatically

- **Ongoing work:**
 - integrate SAPIC calculus and translation in tamarin-prover
 - see development branch
 - support arbitrary number of parties
 - accountability in the decentralised setting
 - central adversary is not w.l.o.g.!
 - accountability in the cryptographic setting
 - trace properties: 👍 indistinguishability: 🤔



Thank you!

Why is it so hard?

soundness: $\text{verdict}(t) \subseteq \text{dishonest}(t)$

completeness: $\text{verdict}(t) \supseteq \text{dishonest}(t)$

(can imitate protocol)

$\text{verdict}(t) = \{P \mid t|_P \text{ observably different from spec}\}$

(e.g., PeerReview)

no complete view in the internet :(

$\text{verdict}(t) = \{P \mid \text{action by } P \text{ and outside spec caused } \neg\varphi\}$

If P followed spec, she might still cause $\neg\varphi$!

provocation

This work: $\{P \mid \text{Had } P \text{ followed spec, then } \varphi\}$

Case 1: weakest possible relation

- Consider t' is related to t iff $\text{corrupt}(t') \subseteq \text{corrupt}(t)$
- Idea: verdict function defined as

$$\text{verdict}(t) = \begin{cases} V_1 & \text{if } \omega_1(t) \\ \vdots & \\ V_n & \text{if } \omega_n(t) \end{cases}$$

- cases are **exhaustive** and **exclusive**
- **sufficiency**: $S \in V_i \Rightarrow \exists t. \text{corrupted}(t)=S \text{ and } \neg\varphi(t)$
- **verifiability**: $V_i = \emptyset \Leftrightarrow \varphi$
- **minimality**: can't do with less than $S \in V_i$
- **uniqueness**: whenever ω_i is observed, parties in V_i are corrupted
- **completeness**: (.. left out ..)

- Accountability via causation works and can be verified automatically
- **Ongoing work:**
 - integrate SAPIC calculus and translation in tamarin-prover
 - support arbitrary number of parties
- **Accountability in the decentralised setting (unpublished work)**
 - original definition in decentralised setting, parties deviate individually
 - provocation problem \rightarrow centralised setting is not w.l.o.g.!
 - optimality requirement: deviating parties exchange no more information than necessary. conjectured to be equal to centralised setting.