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Universally Composable Firewall Architectures using Trusted Hardware

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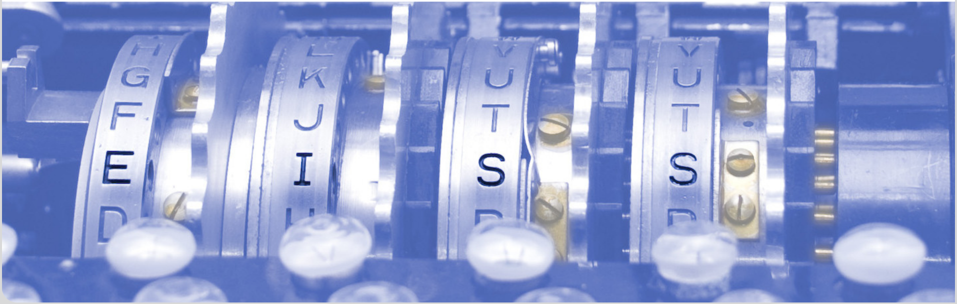
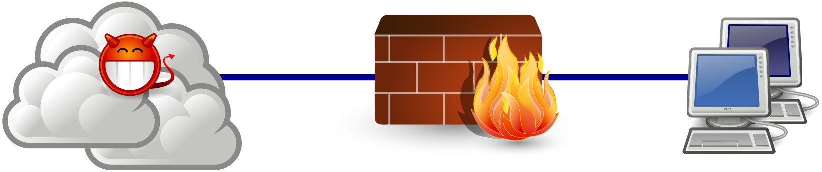


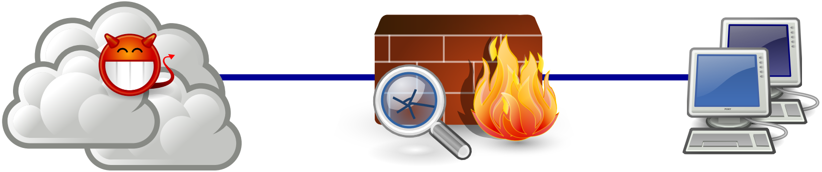
Outline

1. Malicious Firewalls
   - Concatenation of Packet Filters
   - Actively Malicious Firewalls
   - Trusted Hardware
   - Quorum Decisions
2. Analysis in the UC Framework
   - The Universal Composability Framework
   - Proving the Security of Our Approach

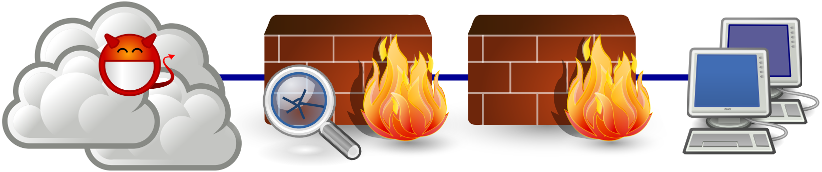
Firewalls



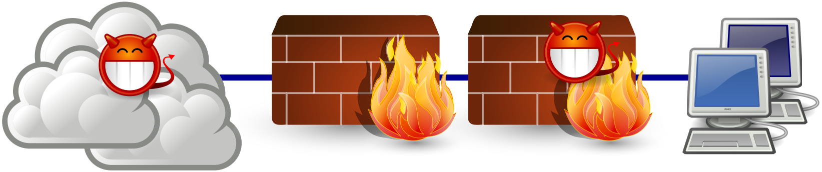
Are Firewalls Really Secure?



Just Use Two!



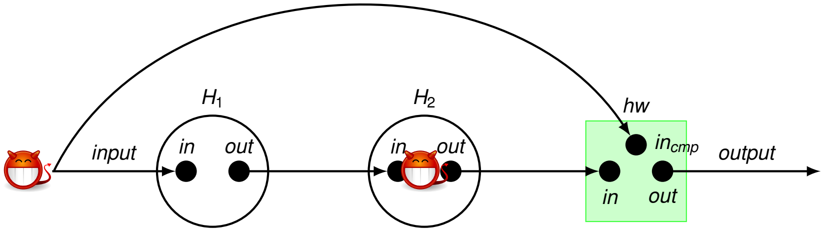
This Doesn't Work



Trusted Hardware

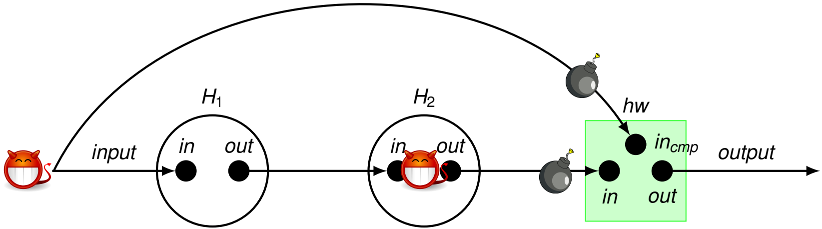
Our idea:

- Use a piece of trusted hardware
- Very simple functionality
- Not programmable, maybe even sealed
- Checks if “what goes in also comes out”

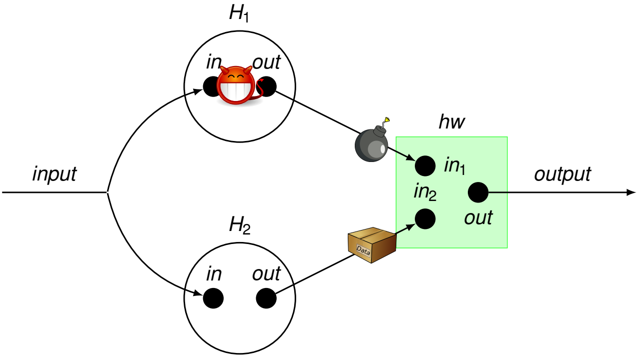


Trusted Hardware

This doesn't work either: The compromised firewall could send “evil packets” with clever timing:



What about this approach?



Research Challenge

Rigorously analyse the security of this approach.

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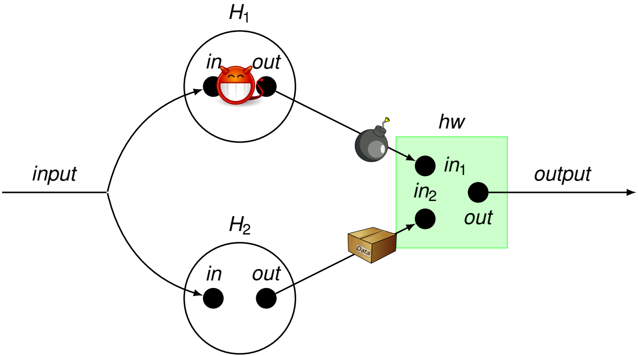

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Rigorously analyse the security of this approach.

The Universal Composability Framework

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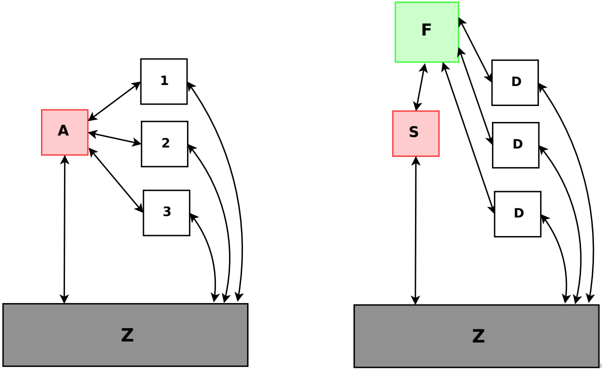
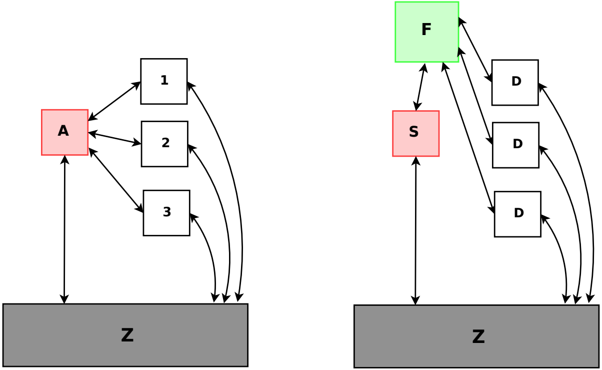
- Formal framework for the security of cryptographic protocols.
- Compare the concrete protocol with an “idealised” version.
- Simulation-based approach.



The Universal Composability Framework

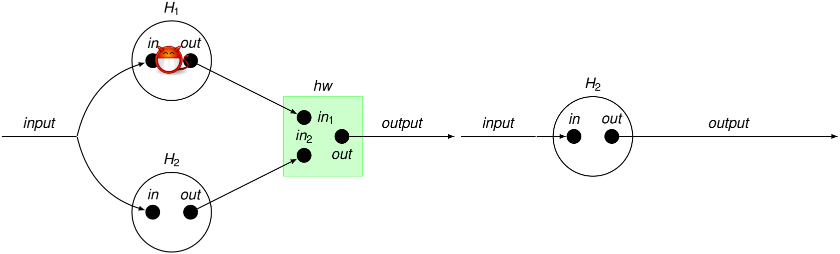
A protocol π securely realises an ideal functionality $\mathcal{F}$ if

$$\forall \mathcal{A} \exists \mathcal{S} \forall \mathcal{Z} : \text{REAL}_{\pi,\mathcal{A},\mathcal{Z}} \approx \text{IDEAL}_{\mathcal{F},\mathcal{S},\mathcal{Z}}$$



The Universal Composability Framework

With this approach we need not specify what a (uncompromised) firewall actually does!



Security Intuition

"As if the compromised firewall was not there."

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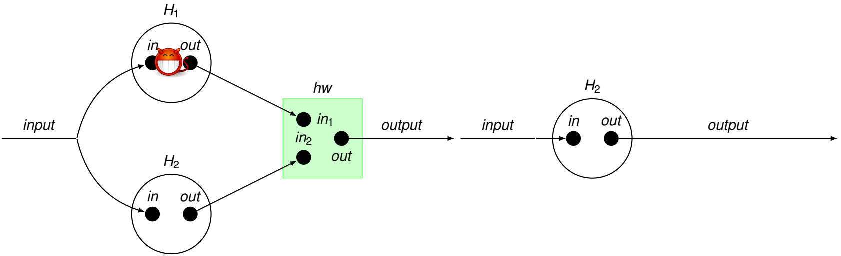

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Caveat Emptor

The Composition Theorem makes it possible to construct secure networks from smaller components:

Theorem (Composition Theorem [1])

Let ρ, ϕ, π be protocols such that ρ uses ϕ as subroutine and π UC-emulates ϕ. Then protocol $\rho^{\phi \rightarrow \pi}$ UC-emulates ρ.

Setup Assumptions

- No non-trivial protocols can be proven secure in the "bare" model [2].
- *Setup assumptions* alleviate this problem: Common Reference Strings [1], Public-Key Infrastructures [3], Tamper-Proof Hardware [4]

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Our Setup Assumption: A Trusted Packet Comparator

An idealised description of trusted hardware hw

Keep a local cache realised as an unordered list.

Upon receiving packet p on interface i:

- If there is another input interface $j \neq i$, and a corresponding entry (j, q) with $p \equiv q$ in the cache:
  - Remove (j, q) from the cache,
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- Otherwise, store (i, p) in the cache.

This is a much simpler functionality than that of a firewall!

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Security of Two Firewalls

The ideal functionality of two firewalls $\mathcal{F}_{\text{ideal}}$

- Upon receiving (input, p):
  - Ask the adversary if p should be delivered. If yes, let fw_k be the non-corrupted party; calculate $F_{\mathrm{fw}_k}(p, \mathrm{in}, s) = (p', i', s')$. Write p' to the output tape of hw, if $p' \neq \bot$ and $i' \neq \bot$. Else, do nothing. Save the new internal state s'.

This is not an absolute guarantee! We state what the adversary's capabilities "ideally" should be.

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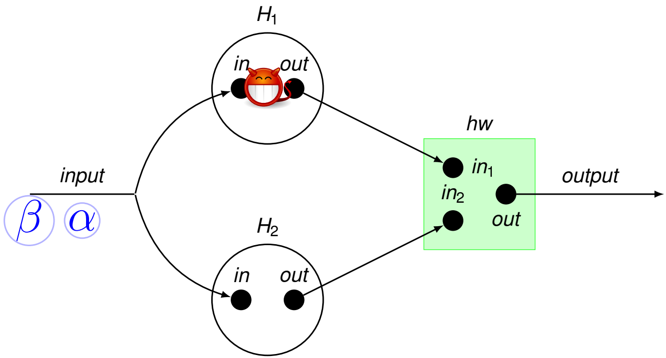

No!

The adversary can *re-order packets* at will!

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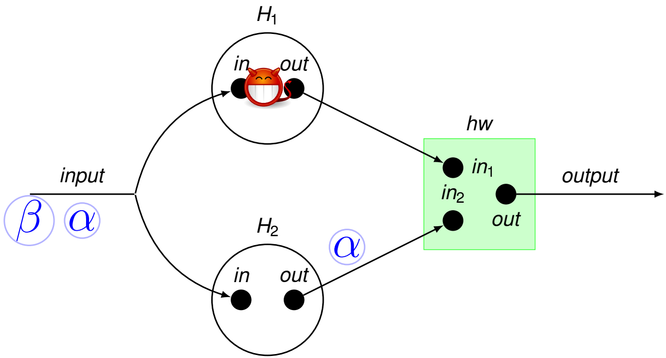

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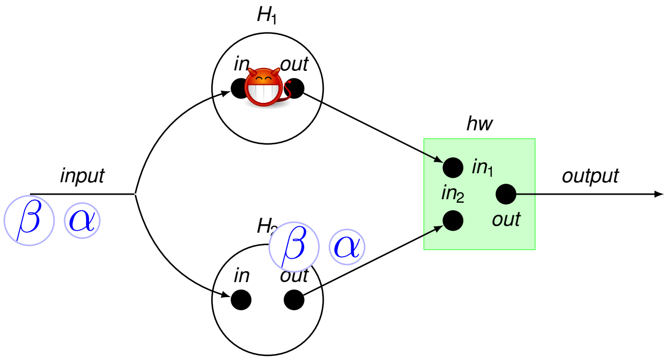

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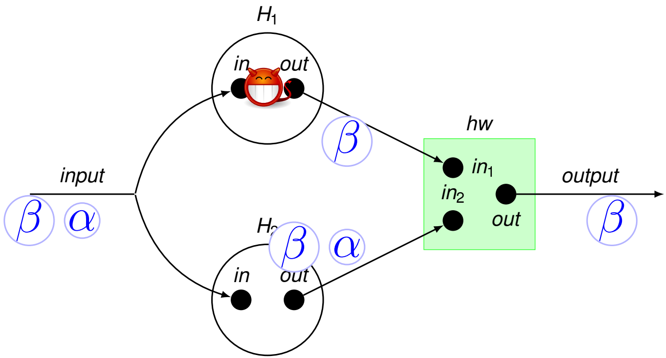

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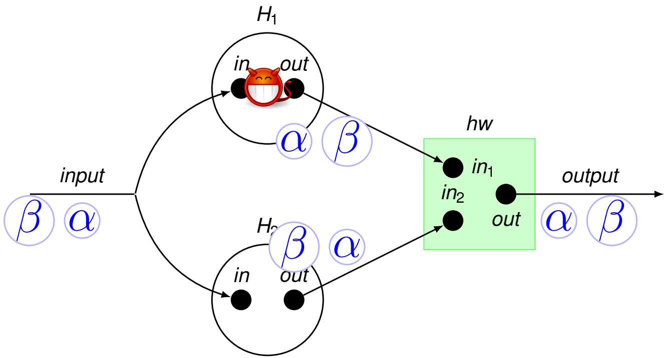

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The ideal functionality of the two-firewall approach

The ideal functionality of two firewalls with packet reordering $\mathcal{F}_{\text{ideal}_2}$

- Upon receiving (input, p): Let w.l.o.g fw_1 be the non-corrupted party; calculate $F_{\mathrm{fw}_1}(p, \mathrm{in}, s) = (p', i', s')$. If $p' \neq \bot$ and $i' \neq \bot$, save p' in an indexed memory structure m at the next free index. Save new internal state s'. Give p to the adversary.
- Upon receiving $(\text{deliver}, j)$ from the adversary: If $m[j]$ contains a valid packet, write $(\mathrm{out}, m[j])$ to the output tape of hw and clear $m[j]$; else do nothing.

This *explicitly* models the adversary's ability to schedule packets!

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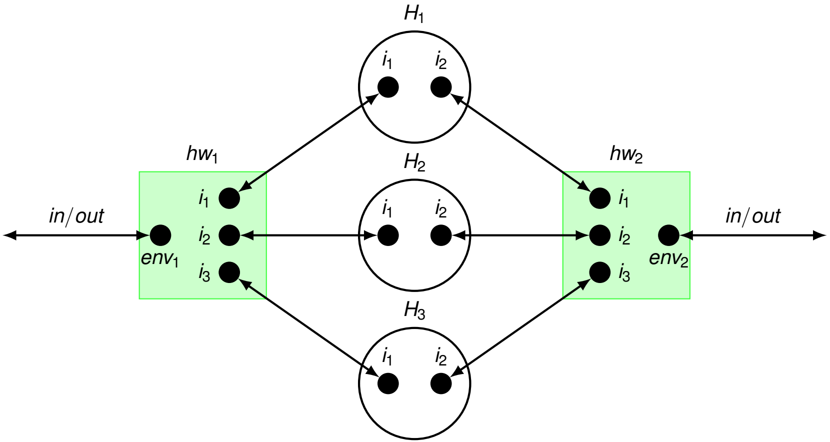
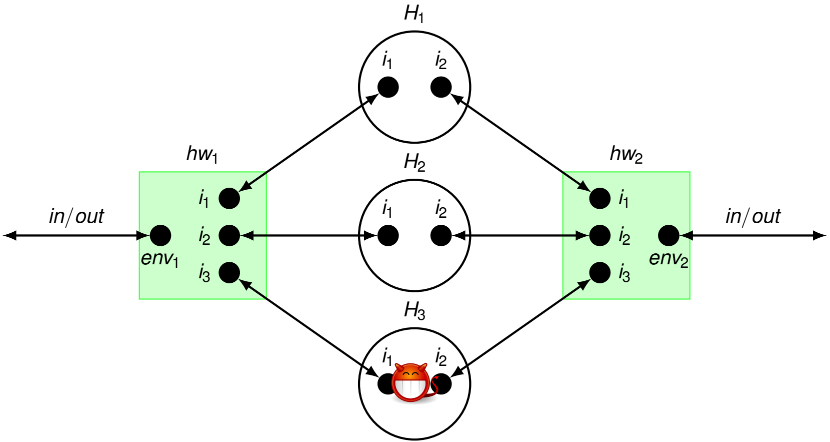
What About Availability?



Is this as secure as the 2-firewall approach?

Packet Duplication Attack



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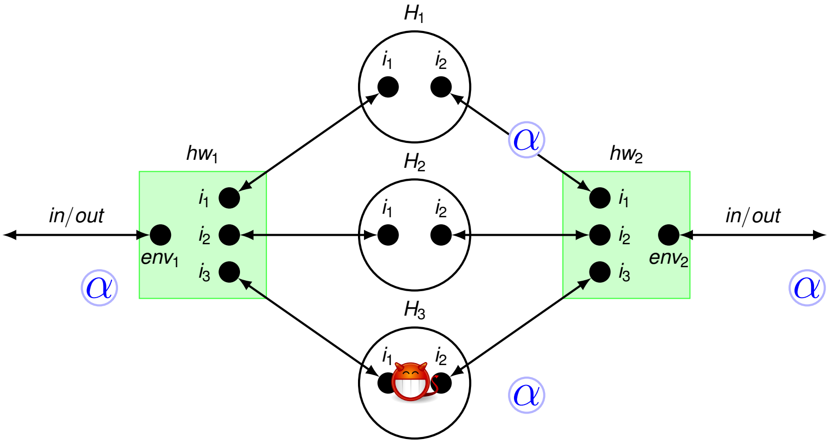

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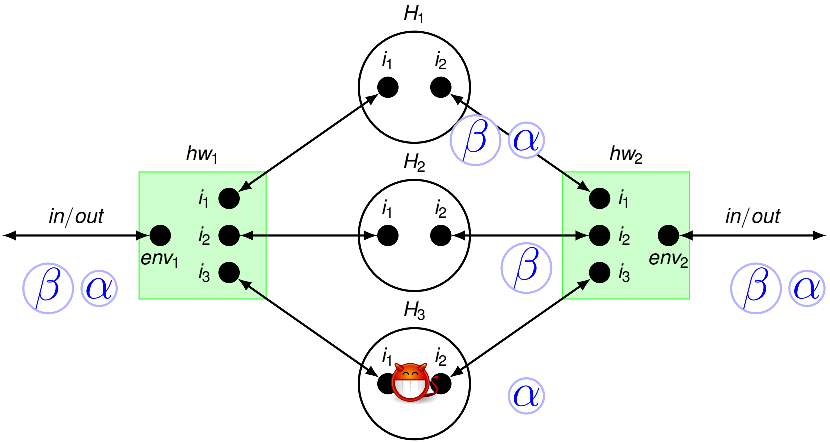

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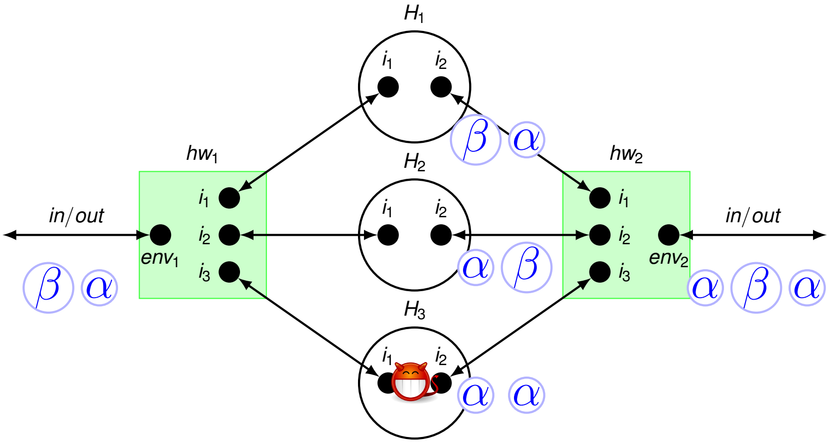

Fix: "Packet Accounting"

Keep a local cache for each incoming interface realised as an unordered list. Upon receiving packet p on interface i:

- Check if the cache of interface i contains an entry $-q$ with $p \equiv q$. If so, delete $-q$ and halt.
- Check if there exists an interface $j \neq i$ with an entry q with $p \equiv q$ in the cache of that interface:
  - Remove q from the cache,
  - output p,
  - add an entry $-p$ to the cache of all other interfaces k with $k \neq i$ and $k \neq j$.
- Otherwise, store p in the cache of interface i.

Conclusion

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- We investigated the idea of actively compromised firewalls.
- Goal: Combine several candidate implementations into one secure firewall.
- Serial concatenation does not work, even with trusted hardware.
- The quorum does work.
- Future Work: Model availability in UC, Bounded Queues.

References

- R. Canetti, "Universally composable security: a new paradigm for cryptographic protocols," in *Foundations of Computer Science, 2001. Proceedings. 42nd IEEE Symposium on*, oct. 2001.
- R. Canetti and M. Fischlin, "Universally composable commitments," in *Advances in Cryptology–Crypto 2001*. Springer, 2001, pp. 19–40.
- B. Barak, R. Canetti, J. B. Nielsen, and R. Pass, "Universally composable protocols with relaxed set-up assumptions," in *Foundations of Computer Science, 2004. Proceedings. 45th Annual IEEE Symposium on*. IEEE, 2004, pp. 186–195.
- J. Katz, "Universally composable multi-party computation using tamper-proof hardware," in *Advances in Cryptology – EUROCRYPT 2007*, ser. Lecture Notes in Computer Science, M. Naor, Ed. Springer Berlin Heidelberg, 2007, vol. 4515, pp. 115–128. [Online]. Available: http://dx.doi.org/10.1007/978-3-540-72540-4_7