Universal Composability is Robust Compilation

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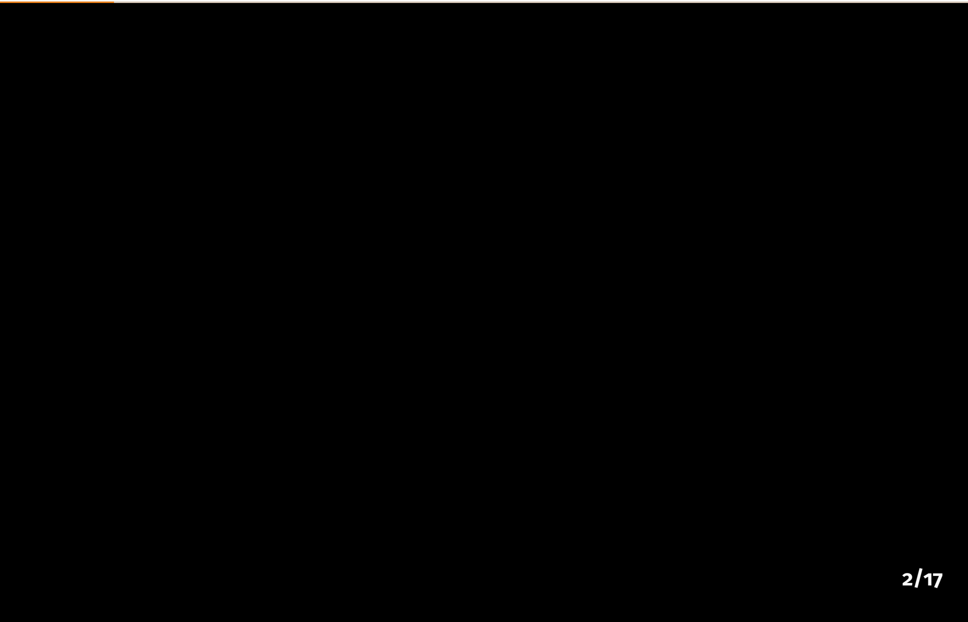
3 Carnegie Mellon University

4 WISCONSIN UNIVERSITY OF WISCONSIN–MADISON

DISCLAIMER

pl != crypto

A Magic Trick



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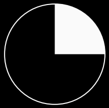

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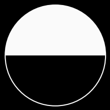

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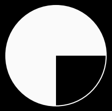

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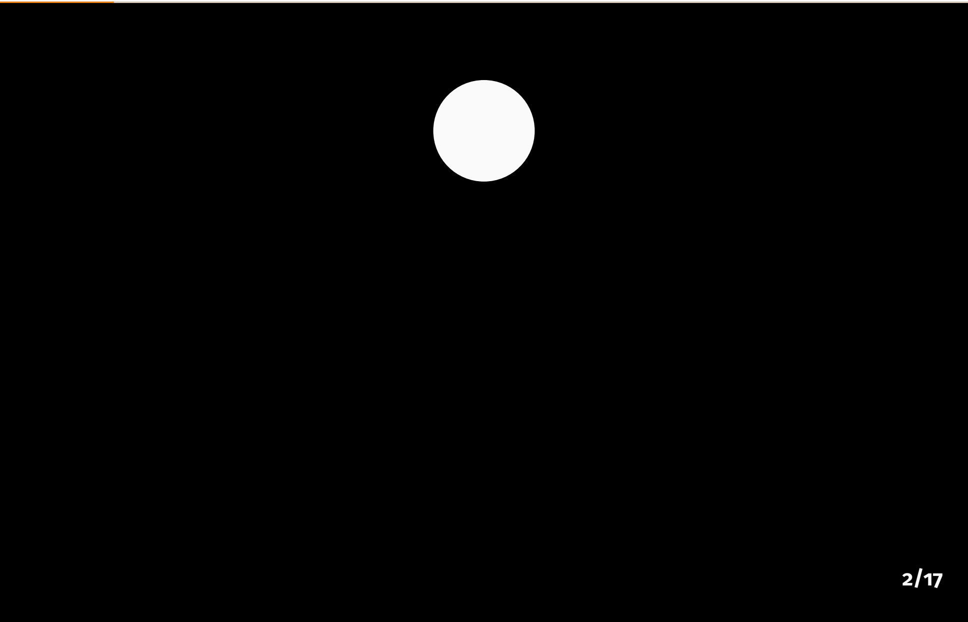

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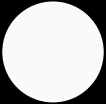
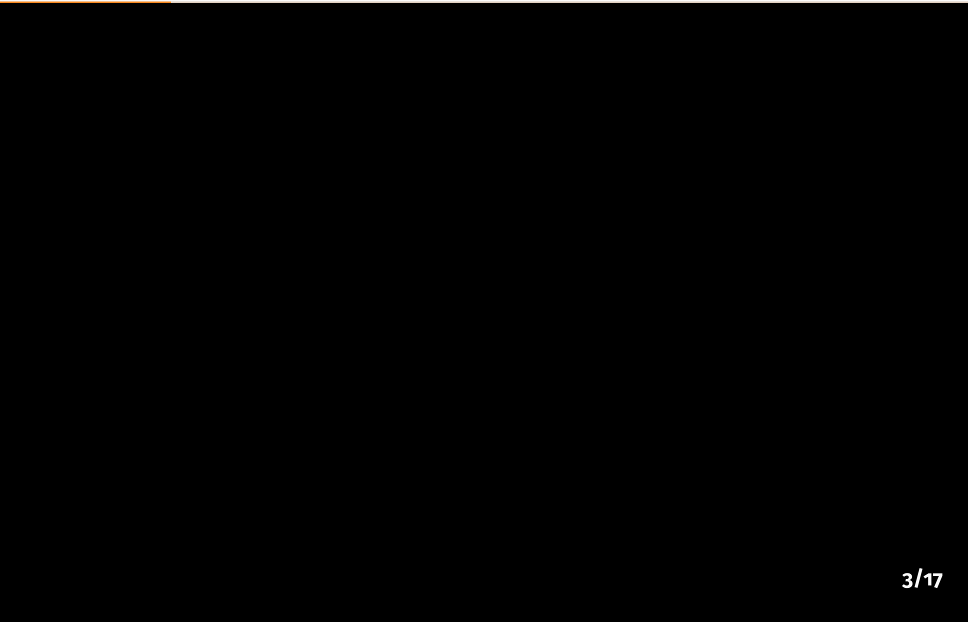


Spoiler: there are $0 + \epsilon$ hands raised

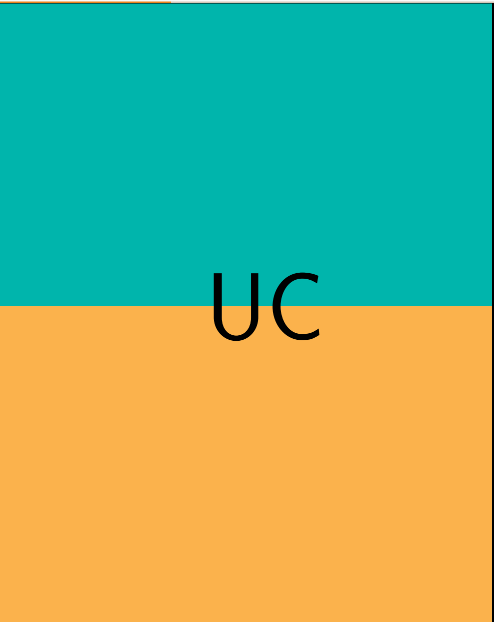
Motivation and the Journey



Motivation and the Journey

UC RC

Fields: UC



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This work: axiomatic formalisation, geared towards the newer theories SaUCy and iUC

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UC **Base Notions: ITMs** [4]

- protocols Π (using concrete crypto)

commitment for $b \in \{0,1\}$ *with SID sid:*

compute $G_{pk_b}(r)$ for random $r \in \{0,1\}^n$
set $y = G_{pk_b}(r)$ for $b = 0$, or $y = G_{pk_b}(r) \oplus \sigma$ for $b = 1$
send $(\texttt{Com}, sid, y)$ to the receiver

Upon receiving $(\texttt{Com}, sid, y)$ from P_i, P_j outputs $(\texttt{Receipt}, sid, cid, P_i, P_j)$

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- functionalities $\mathtt{F}$ (using abstract notions)

1. Upon receiving a value $(\texttt{Commit}, sid, P_i, P_j, b)$ from P_i, where $b \in \{0,1\}$, record the value b and send the message $(\texttt{Receipt}, sid, P_i, P_j)$ to P_j and $\mathcal{S}$. Ignore any subsequent $\texttt{Commit}$ messages.

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- attackers $\mathcal{A}$ & $\mathcal{S}$ (corrupting parties etc.)
- environments $\mathcal{Z}$ (objective witness)

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Perfect (!!) UC

$$
\begin{tikzcd}
 & 0/1 & & & & 0/1 & \\
 & Z \arrow[u, Rightarrow] \arrow[dl, leftrightarrow] \arrow[dr, leftrightarrow] & & \approx & & Z \arrow[u, Rightarrow] \arrow[dl, leftrightarrow] \arrow[dr, leftrightarrow] & \\
\Pi \arrow[rr, leftrightarrow] & & A & & \mathtt{F} \arrow[rr, leftrightarrow] & & \mathtt{S}
\end{tikzcd}
$$

$\leftrightarrow$ represent communication channels

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$$\Pi \vdash_{\mathrm{UC}} \mathtt{F} \stackrel{\text{def}}{=} \forall \text{poly } A, \exists \mathtt{S}, \forall Z.$$

$$\textsc{Exec}[Z, A, \Pi] \approx \textsc{Exec}[Z, \mathtt{S}, \mathtt{F}]$$

Perfect (!!) UC (computational UC in Künneman et al. CSF'24)

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UC Beneifts: Compositionality

- if $\Pi_1 \vdash_{\mathsf{UC}} \mathtt{F}_1$
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recall they are all ITMs

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Fields

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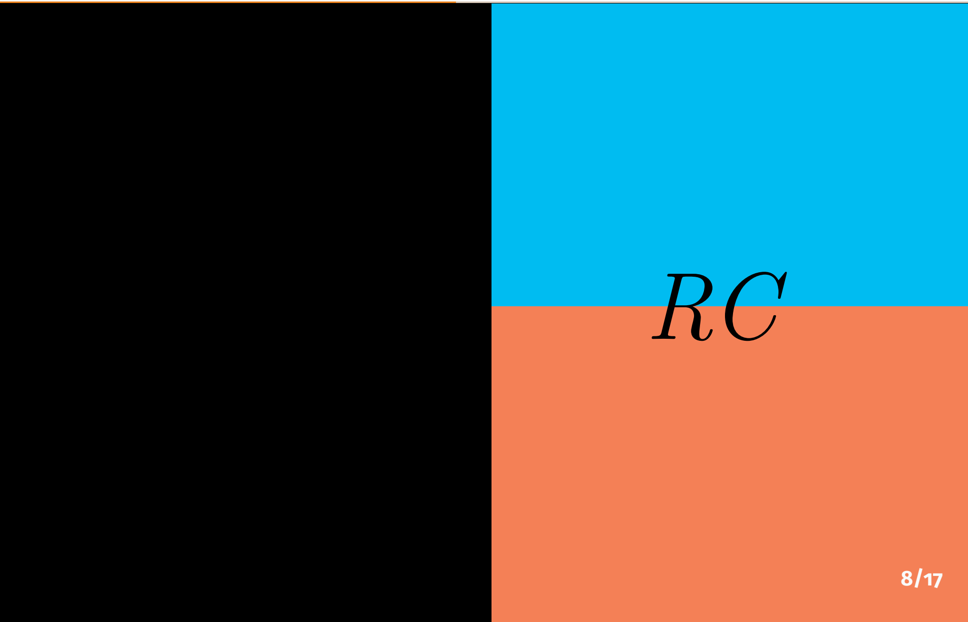
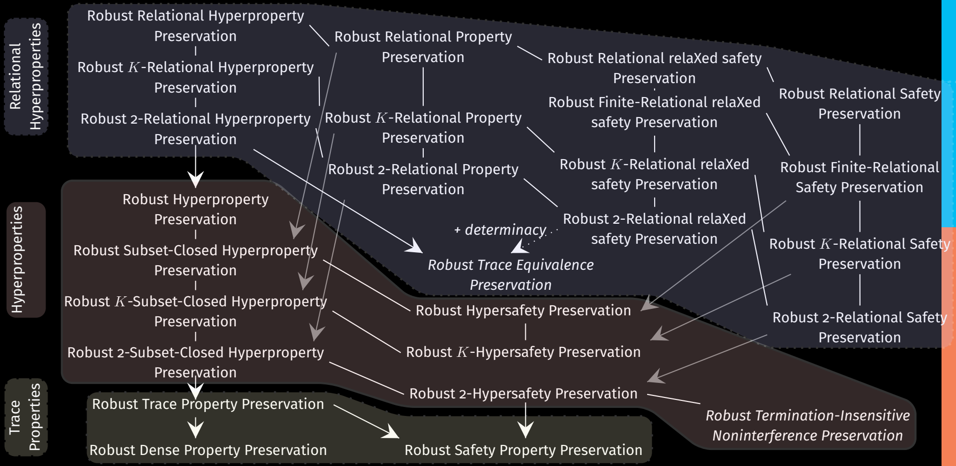


Robust Compilation [5]



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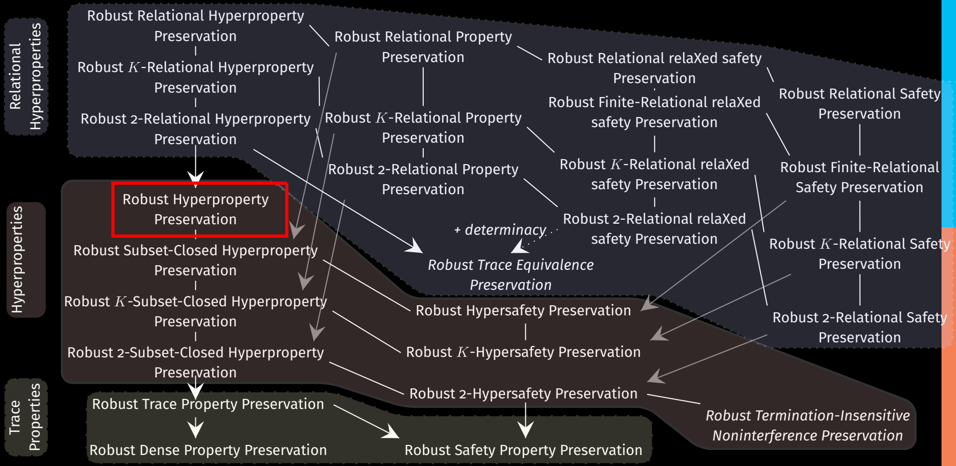

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Robust Hyperproperty Preservation: RHC

$$\llbracket P \rrbracket \overset{\bar{t}}{\underset{\rightsquigarrow}{\bowtie}} \mathbf{A} \iff P \overset{\bar{t}}{\underset{\rightsquigarrow}{\bowtie}} A$$

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$$\llbracket\cdot\rrbracket \vdash RHC \overset{\text{def}}{=} \forall P, \mathbf{A}.\ \exists A.\ \forall \overline{t}.$$
$$\mathbf{A} \bowtie \llbracket P \rrbracket \rightsquigarrow \overline{t} \iff A \bowtie P \rightsquigarrow \overline{t}$$

For any language S and $\mathbf{T}$

A Closer Look

$$\forall \text{poly } \mathsf{A}, \exists \mathsf{S}, \forall \mathsf{Z}.$$

$$\begin{tikzcd}[column sep=small]
 & 0/1 & & & & 0/1 & \\
 & \mathsf{Z} \arrow[u, Rightarrow] \arrow[dl, <->] \arrow[dr, <->] & & \approx & & \mathsf{Z} \arrow[u, Rightarrow] \arrow[dl, <->] \arrow[dr, <->] & \\
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$$\forall P, \mathbf{A}. \exists A. \forall \bar{t}.$$

$$\begin{tikzcd}
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\llbracket P \rrbracket & \bowtie & \mathbf{A} \arrow[r, Leftrightarrow] & P & \bowtie & A
\end{tikzcd}$$

Our (Isabelle'd) Connection

UC			RC
protocol	$\sqcap$	$[\![P]\!]$	compiled program
concrete attacker	A	$\mathbf{A}$	target context
ideal functionality	$\mathtt{F}$	P	source program
simulator	$\mathtt{S}$	A	source context
environment, output	Z, 0/1	$\overline{t}$, $\rightsquigarrow$	trace, semantics
communication	$\leftrightarrow$	$\bowtie$	linking
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human translation $\Pi \to \mathtt{F}$		$[\![\cdot]\!]$: $P \to \mathbf{P}$ compiler	

Why Should You Care?

Prove RHC via UC

(e.g., Viaduct …Acay et al PLDI'21)

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Admittedly, less explored,

(is there more?)

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Mechanise UC proofs with program analysis tools

(Deepsec, Cryptoverif, Squirrel, etc)

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as in computer-aided crypto

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- Fill the `missing lines` (4!)
- Wrap real and `ideal` processes with an environment proxy to regulate scheduling
- Add the missing `lines` for adaptive corruption (binding or hiding, not both)

What Will You Find in the (64 pp) Paper?

1. Axiomatised UC semantics

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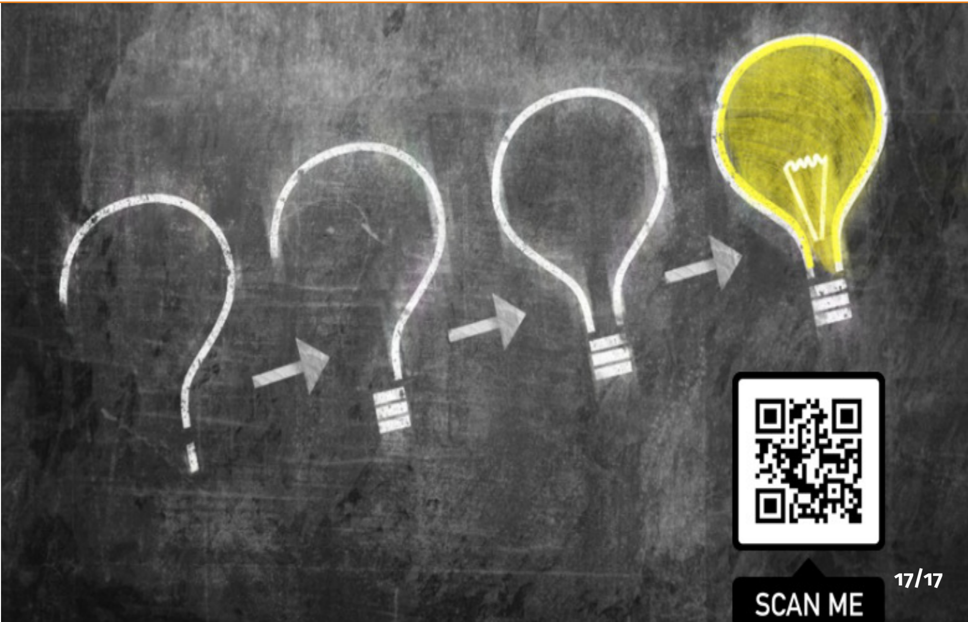
6. A lot of insights

What Will You Find in the (64 pp) Paper?

A security proof between ITMs is a UC proof,
a security proof between arbitrary languages is a RC one.

5. Mechanised UC proof for 1-bit commitment for static & adaptive corruption
6. A lot of insights

Questions?



The Full Abstraction (false) Conjecture

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\end{tikzcd}
$$

$$
\begin{array}{c}
[\![P_1]\!] \bowtie \mathbf{A} \Downarrow \\
\Updownarrow \\
[\![P_2]\!] \bowtie \mathbf{A} \Downarrow
\end{array}
\iff
\begin{array}{c}
P_1 \bowtie A \Downarrow \\
\Updownarrow \\
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\end{array}
$$

FAC is relational, RHC is propositional, like UC

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- if only there were a protocol definition language …(future work)

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- Linking
- Program FFI
- Attacker FFI
- Complete FFI

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- Just program-level linking in any PL
- Must follow 3 (obvious) axioms

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  thus, no need to do induction, just reason about the $source + simulator$ and $\mathbf{target}$ programs (with tools)