Composable Long-Term Security with Rewinding

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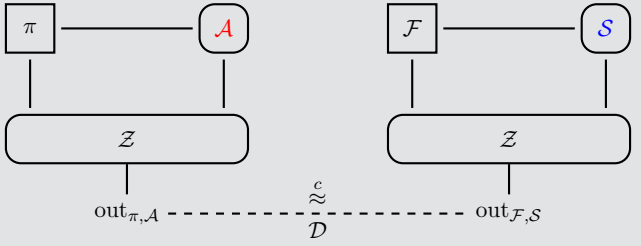
Computational UC in a nutshell [Can01; Can20]

Security experiment (Computional UC)

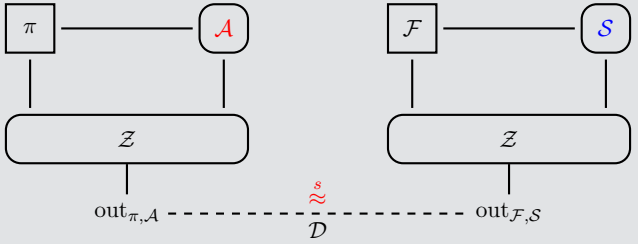
- **PPT** $\mathcal{A}$, $\mathcal{S}$, $\mathcal{Z}$ where $\mathcal{Z}$ outputs a **string** out.
- **PPT** distinguisher $\mathcal{D}$ gets out.



Statistical UC in a nutshell [Can01; Can20]

Security experiment (Statistical UC)

- **Unbounded** $\mathcal{A}$, $\mathcal{S}$, $\mathcal{Z}$ where $\mathcal{Z}$ outputs a **string** out.
- **Unbounded** distinguisher $\mathcal{D}$ gets out.



Long-Term UC in a nutshell [MU07]

Security experiment (Long-Term UC)

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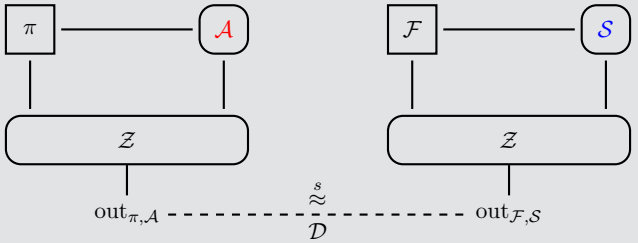

⇝ hardness assumptions hold *(only) during* protocol execution.

Long-Term UC commitments

Possibility results

$\mathcal{F}_{\text{Com}}$ from hardware assumptions (signature card [MU07], PUF+CRS [Mag+22]).

Impossibility result [MU07]

$\mathcal{F}_{\text{Com}}$ is impossible to realize in the CRS-hybrid model or any long-term revealing setup.

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- If CRS is not stat. hiding, $\mathcal{D}$ can extract.
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- ...but what about *rewinding*?

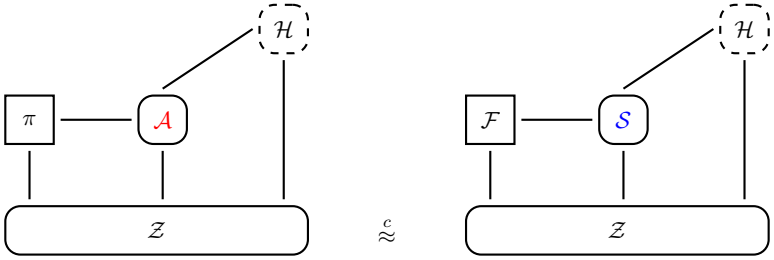
Our contribution

- New notion: **Long-term *rewinding* UC** (LTR-UC).
- New possibilities/protocols:
  - LTR-UC-secure $\mathcal{F}_{\mathsf{Com}}$ in the CRS-hybrid model (and commit-and-prove ZK).
  - One-sided LTR-UC-secure OT.
- New impossibilities: No full LTR-UC-secure OT from long-term revealing assumptions.
- New tools: **Pseudo-oracles** and their properties.

Angel-based UC security

Angel-based UC [PS04]

- Global entity, **helper** or **angel** $\mathcal{H}$ with "special power".
- E.g.: $\mathcal{H}$ brute-forces commitments under *judiciously chosen circumstances.*



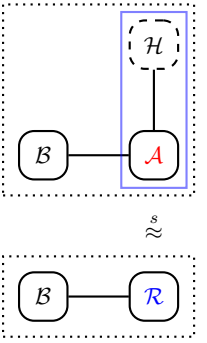
Rewinding-simulatable angels

[CLP10; Goy+15]

- $\mathcal{H}$ is a CCA commitment oracle:
  - $\mathcal{A}$ can run COM with $\mathcal{H}$.
  - $\mathcal{H}$ will brute-force extracts *accepting* commitments.
- $\mathcal{H}$ is **simulatable in PPT via rewinding** through $\mathcal{R}$.

Robust rewinding

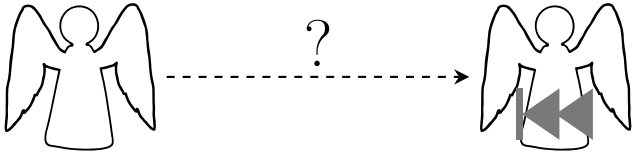
- UC simulation is straightline $\rightsquigarrow$ use $\mathcal{H}$
- Security reductions $\rightsquigarrow$ use $\mathcal{R}$.
- k-robust rewinding: Exempt k-round "left side" from being rewound.



$\langle \mathcal{B}, \mathcal{A}^{\mathcal{H}} \rangle \overset{s}{\approx} \langle \mathcal{B}, \mathcal{R} \rangle$

Rewinding-based angels/oracles?

- LTR-UC also based on a CCA commitment oracle $\mathcal{H}$.
- But what is an "angel/oracle that rewinds"?



Pseudo-Oracles

Oracle/ITM

Stateful $\mathcal{O}$ gets message from $\mathcal{A}$, returns output.

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Stateful $\mathcal{O}$ gets message and **view of** $\mathcal{A}$, returns output.

Properties of pseudo-oracles

Black-box

$\mathcal{O}$ only uses $\mathcal{A}$ black-box (instead of view($\mathcal{A}$)).

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k-robust pseudo-PPT ($\widehat{=}$ rewinding simulatable)

For any k-round $\mathcal{B}$:

$$\exists \text{PPT } \mathcal{R}: \quad \langle \mathcal{B}, \mathcal{A}^{\mathcal{O}} \rangle \overset{s}{\approx} \langle \mathcal{B}, \mathcal{R} \rangle$$

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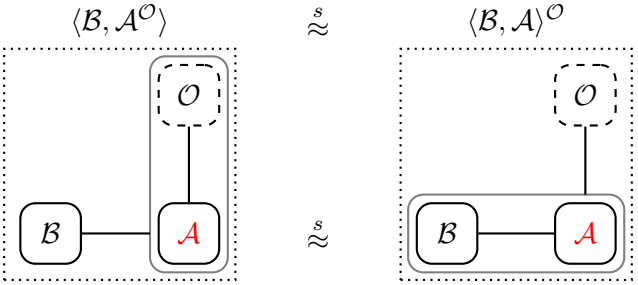
k-robust composition-order invariant

For any k-round $\mathcal{B}$:

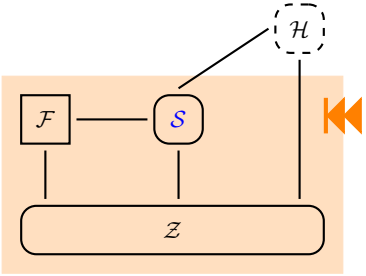
$$\langle \mathcal{B}, \mathcal{A}^{\mathcal{O}} \rangle \overset{s}{\approx} \langle \mathcal{B}, \mathcal{A} \rangle^{\mathcal{O}}$$

Composition-order invariance (COI)



Why is LTR-UC meaningful at all?

- LTR-UC angel $\mathcal{H}$ **rewinds environment and ideal functionalities!**
- What remains of the ideal guarantees of $\mathcal{F}$?



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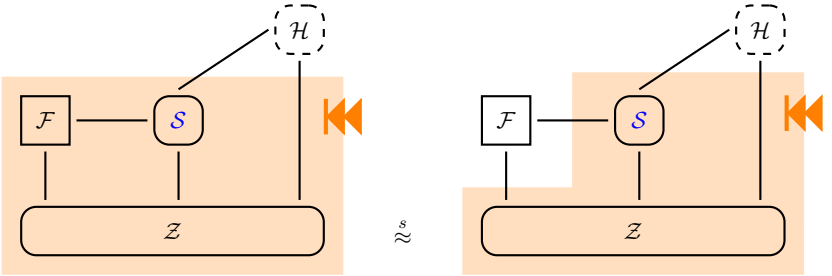
- What remains of the ideal guarantees of $\mathcal{F}$?
- **k-robust COI** $\implies$ meaningful for k-round functionalities.



Conclusion

- LTR-UC brings rewinding-based simulation to UC.
  - New possibilities: Com, ZK, one-sided-secure OT *from CRS*
  - Old impossibilities: (fully secure) OT from long-term revealing assumptions.
- Pseudo-Oracles $\neq$ Oracles: Basic properties need non-trivial proofs.

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Thank you!

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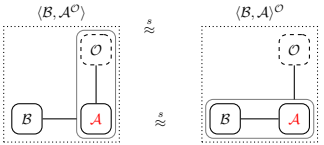
COI for our CCA-Com $\mathcal{O}$



Core difference to [CLP10; Goy+15]:

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- This work: COI via **reduction** to hardness assumption.

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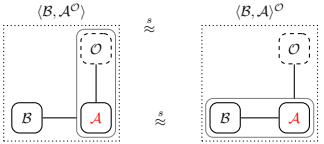

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Proof idea (based on [PRS02] rewinding schedule):

- Given same randomness, **main thread** execution is **identical, unless** different committed values extracted (during look-ahead).
- Reduce different extracted values to **binding break** of COM.

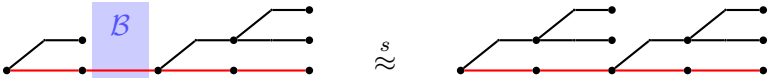

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Image sources

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